Global Impacts of Land Degradation

July 2006
Final version

Overseas Development Group
University of East Anglia
Norwich UK

Table of Contents

Preface

This paper is a scientific and technical review of the state of current knowledge of the global impacts of land degradation. The study was commissioned by the Scientific, Technical and Advisory Panel (STAP) of the Global Environment Facility (GEF) to support the development of the 'pilot' phase of the new GEF focal area of Land Degradation in GEF-3 (2002-2006), looking towards more evidence-based implementation based upon good science in GEF-4 (2006-2010).

The terms of reference for this study are to provide GEF-STAP with:

a) A typology of global impacts of land degradation, including synergistic effects, based upon the current accepted incremental principles of GEF - this is to include biophysical impacts only, but indications as to how purely domestic impacts may impinge on global development impacts and trade-offs
b) An account of current state of knowledge of each of these impacts, with a box with a case example of each (wherever possible)
c) An analysis of the degree of certainty in the evidence
d) A gap analysis of where and what scientific inputs are needed, including some assessment of principles that would be needed to carry forward an evidence-based scientific agenda on land degradation control. Initially, these principles would include an integrated agro-ecosystem approach and employment of the precautionary principle.

It was further envisioned that the substantive part of the study will be approximately 25 pages with Annexes as necessary, fully referenced with up-to-date recent evidence from the scientific literature.

A preliminary draft and PowerPoint presentation were submitted at the Inter-Agency Technical Meeting in Washington DC on 3 April 2006. The approach adopted by our Review Team was broadly accepted, but the Team was asked to extend the review to include some of the more immediate global human and developmental impacts on the grounds that these are effectively inseparable from the environmental impacts, that global impacts on the environment often work through failures in human development, and that interventions to mitigate impact will often have to target major development issues in order to achieve protection for the global environment. The Review Team accepted this challenge. However, this has inevitably made the study somewhat longer than originally planned.

The Review Team undertaking the research and writing of this study consists of Dr John McDonagh, Professor Michael Stocking and Dr Yuelai Lu.

Overseas Development Group
University of East Anglia

Norwich, 31st July 2006

1. Introduction

This scientific and technical review is to assist the Global Environment Facility in identifying global impacts of land degradation with the view to implementing new projects in GEF-4 that have verifiable scientific validity and priority status in terms of the scale and seriousness of the impact.

The GEF definition of land degradation (LD) sets the thematic boundaries of this review. It is:

> "…any form of deterioration of the natural potential of land that affects ecosystem integrity either in terms of reducing its sustainable ecological productivity or in terms of its native biological richness and maintenance of resilience." (GEF 1999).

This is a broad definition, notably including deforestation, but only implicitly stressing LD's linkage to ecosystem goods and services. The definition is, therefore, largely bound in ecological concepts of ecosystem integrity, productivity, species richness and ecological resilience. There is some controversy as to what these concepts entail and how they are linked to notions of social resilience (see Adger et al., 2005; Cumming et al., 2005). Most of this scientific review, therefore, deals with global *environmental* impacts. However, Section 4 uses the Millennium Development Goals as a framework to present the main socio-economic impacts that are of greatest current concern and reflects on the "added value" this framework brings to the analysis.

This review is also designed to accord with GEF principles in terms of restricting itself to *global* impacts and activities that may be taken as *incremental*. There has been widespread discussion within and outside the GEF on how these principles may be encompassed in the LD focal area and its Operational Program 15 (Sustainable land management – SLM; GEF 2003a). SLM especially is usually seen as a 'domestic' concern and one for which national governments have primary responsibility. LD similarly is usually tackled as a local land problem with very particular and specific technologies that need to be assessed for their local relevance (Gisladottir and Stocking 2005). Nevertheless, a good body of evidence is being assembled to show, either through linkages or through the importance of the process of LD itself, that LD is indeed a global impact concern. This review has followed the guidance in Gustafson (2005) on how to justify the global nature of LD impact and its ability to meet the principles of incrementality.

Determining the global significance of LD is an inexact process, based to date on a weak scientific and technical background. However, unsustainable land use practices are some of the most common and widespread drivers of many "global environmental problems such as loss of topsoil, loss of biodiversity, increased carbon emission and loss of carbon sequestration potential" (Gustafson 2005, p.24). Clearer global relevance is where LD processes cross national boundaries, as in downstream sedimentation, flooding and pollution. However, Gustafson concludes that, "in reality, most land degradation that entails soil erosion, loss of vegetative cover, or degradation of waterways will meet the global significance test under GEF's definition."

Articulated slightly differently, an impact is clearly global when it affects a process or component of the environment that is global in its extent or importance, such as the atmosphere or a unique plant community. But an impact can also achieve global status due to the frequency at which it occurs and/or the total area affected. Most LD impacts would classify as global for these latter reasons.

Currently, there are no internationally-agreed means to measure or assess the global impact of LD or the global benefit of SLM. Currently, on-the-ground investments in sustainable agriculture (such as improved tillage systems and windbreaks), sustainable rangeland management (such as indigenous plants for restoration) and sustainable forest management (such as multiple use tree species) are all considered as GEF-eligible, especially if strategically and in scientific terms they:

- reflect the impact of LD on ecosystem health
- reflect the linkage between poverty and LD
- incorporate cross-sectoral approaches to land management that integrate ecological, economic and social dimensions of LD
- envision early intervention in areas vulnerable to LD (i.e. preventative)
- promote synergies with focal areas that are widely understood to be global, such as biodiversity and climate change.

In this review, we aim to assist the process of identifying the global impacts and determining what is incrementally eligible. Existing frameworks are weak at measuring global environmental benefits, and baseline information is needed from which progress can be measured (GEF, 2005a). Further, while the global impacts are known to exist, they are often over-looked, under-reported or poorly researched. Therefore, through scientific criteria for understanding the scale, type, degree of impact and widespread nature of the processes, we intend this study to provide further means to justify inclusion of LD as a global concern. Our typology of impacts in the next section uses these criteria expressing the magnitude of the impact of LD on global processes, systems and extent.

2. Typology of Global Impacts of Land Degradation

Global impacts of land degradation can be classified in several ways, by the environmental system affected; by impact on ecosystem service; by type of LD process; by production system/eco-region impacted on or by type of management practice that causes the degradation. These are elaborated below with an explanation of why they have or have not been included in the typology used in this review:

i) By impact on **global systems**. This takes as its main focus components (and constituent sub-components) of the global environment such as climate, biodiversity, human development indictors, around which there is particular interest and concern. GEF OP15 emphasises these and it is logical to make them part of the typology used in this review.

ii) By impact on **ecosystem services**. The Millennium Ecosystem Assessment (MA) uses an ecosystem functions/services framework and defines land degradation as any land related phenomenon that causes "… any decline in these services over an extended period…" (MA, 2005a). Section 3.5 of this review uses the ecosystem service framework to examine human impacts of LD.

iii) By **land-related process or phenomena**, including processes that are clearly degradation such as erosion and deforestation but also processes that are part of normal soil function but that can increase with LD e.g. CO_2 emission. Many studies that aim to quantify LD and its impacts focus on these processes so, for practical reasons, this should be part of the typology. In the sense that many of these processes and phenomena are so widely spread across continents, there is also a good case for allowing this category to be a measure of how global is the impact.

iv) By **production systems**. GEF OP15 uses a production systems framework (rain-fed, irrigated agricultural land; rangelands & pasture; woodlands & forests) to analyze impacts of land degradation on ecosystem structure and function. For those drivers and impacts that are related to land use this is a logical approach for classifying LD. The MA (2005a) also uses a similar but not identical systems classification (forest, cultivated, mountain, urban, coastal, fresh water etc.). An impact felt across a whole production system is likely to be global in nature.

v) By **type of management practice causing LD** such as over-grazing, vegetation clearance for agriculture, "poor" land management practices (e.g. inappropriate tillage, over-intensive cropping etc.). Most LD assessments include a useful discussion of these management-related drivers. It is, however, important to acknowledge that other types of LD drivers exist that are either wholly natural (e.g. natural variability in wind, rainfall patterns) or where the link with human activity is indirect and/or uncertain (e.g. climate change may lead to management changes that cause LD). The global scope of many these practices also suggests that this approach is a good way to identify the global nature of the impact.

In summary, the main level of analysis will be the environmental components and sub-components impacted by LD (including human development impacts in section 4). Where possible, important LD processes and phenomena will be considered as well as their relative significance in different production systems and eco-regions. The extent of the impact and the sensitivity of the environmental component affected by this impact will be discussed. Available information on the current state, future trends, options for mitigation of and/or adaptation to the different impacts will be included and gaps in our knowledge will be identified.

3. Environmental Impacts of Land Degradation

3.1 Climate Change

This is the global impact linkage that has received most attention, both in terms of its presumed seriousness and in the scope and breadth of scientific enquiry that has addressed it. LD contributes to climate change through two main processes: production of green-house gases (GHGs) and direct contributions of dust to the atmosphere. There are also important feed-back loops operating between climate change, land, vegetation and LD, particularly in drylands, where climate warming and droughts may promote desertification, further soil erosion, dust storms and changes in albedo. These complex processes will be considered in this section.

3.1.1 Climate: atmospheric GHGs

The two gases of most interest are carbon dioxide (CO_2) and methane (CH_4), thought to contribute 60% and 15% of the anthropogenic greenhouse effect respectively (IPCC 2001). Though recent research suggests methane production from natural vegetation might be more significant than previously thought (Keppler et al., 2006) and de-vegetation might decrease this, the most significant and documented LD-

GHG linkages concern carbon dioxide. CO_2 is released when vegetation is cleared and burned and when soil organic matter is mineralized. There is much interest also in the climate change mitigation potential of the reverse of this process, carbon sequestration, in both vegetation (forests particularly) and soil.

Box 1. Facts and figures for carbon

- The IPCC estimates fossil fuel emissions from 1980-1990 and 1990-1999 were approximately 5.4 and 6.3 Pg C yr^{-1} respectively (IPCC, 2001).
- The rate of atmospheric C increase was 3.2 ± 0.1 Pg C yr^{-1} during 1990 to 1999: less than total emissions as much is absorbed by oceans and terrestrial ecosystems (IPCC, 2001).
- Total land-use change activities were responsible for emissions of 2.0-2.2 Pg C yr^{-1} in the 1980s and 1990s (Houghton, 2005).
- Tropical deforestation has released 1-2 Pg C yr-1 (Houghton, 2005).

Note : 1 Pg = 1 petagram = 10^{15}g = 1 billion tonnes = 1 gigatonne

Global terrestrial carbon stocks amount to between 2,221 Pg C and 2,477 Pg C, depending on which estimate is used (see Box 1 for unit clarification). Of this, 1,567 Pg C are held in the soil and 657 Pg C are held in plants (IPCC 2001). These are substantial amounts when compared to the atmospheric carbon pool, which is about 760 Pg C (Lal, 2003). There is great variation in soil carbon stock in different biomes in terms of total amount and distribution above and below ground. In crop land up to 98% of carbon is stored in soil. Drylands generally do not store large amounts of carbon in vegetation, but because of their extent (over 40% of the earth's surface), they have large carbon storage potential (Table 1; White and Nackoney, 2003; FAO, 2004).

Table 1. Estimates of Dryland Carbon Reserves in Petagrammes (Pg)

	Biotic	Soil organic	Soil inorganic	Total	Share of global (%)
Hyper-arid and arid	17	13	732	862	28
Semiarid and dry sub-humid	66	318	184	568	18
Total in drylands	83	431	916	1430	46
Global totals	576	1583	946	3104	
Share of global (%)	14	27	97		

(Source: MA 2005a)

In forests, about half of the total forest carbon is stored in living biomass and dead wood, and half in the litter and soil (Table 2). Vital as a carbon sink, forest ecosystems store 335-365 Pg of carbon in their biomass alone with the total C storage in the biomass, dead wood, litter and soil of forest systems exceeding total atmospheric carbon (FAO, 2006; MA, 2005a).

Table 2. Carbon stock in forests 2005 (tonnes ha^{-1})

Region	Living biomass	Dead wood	Litter	Soil	Total
Africa	95.8	7.6	2.1	55.3	160.8
Asia	57.0	6.9	2.9	66.1	132.9
Europe	43.9	14.0	6.1	112.9	176.9
North and Central America	60.1	9.0	14.8	36.6	120.6
South America	110.0	9.2	4.2	71.1	194.6
Oceania	55.0	7.4	9.5	101.2	173.1
World	71.5	9.7	6.3	73.5	161.1

(Source: FAO, 2006)

3.1.1.1 Deforestation: atmospheric GHGs

Deforestation and forest degradation (see Box 2 for definitions) result in increased GHG emissions. These processes also often catalyze other LD processes such as erosion and leaching (GEF, 2003a).

Box 2. Forest-related definitions

Deforestation refers the direct human-induced conversion of forested land to non-forested land, which mainly involves the reduction in the area of forest land (Lanly, 2003).

Forest degradation refers to a decrease in the quality and/or condition, this being related to one or a number of different forest ecosystem components (vegetation layer, fauna, soil, ...), to the interactions between these components, and more generally to its functioning (Lanly, 2003).

Deforestation: the conversion of forest to another land use *or* the long-term reduction of the tree canopy cover below the minimum 10 % threshold (FAO, 2001).

Forest Degradation: Changes within the forest which negatively affect the structure or function of the stand or site, and thereby lower the capacity to supply products and/or services (FAO, 2001)

Current status of deforestation and forest degradation

According to the most recent global forest resource assessment by FAO, total forest area in 2005 was estimated to be 3,952 billion ha or 30 % of total land area (FAO 2006).

The net average change in forest area in the period 1990–2005 is estimated at -8.4 million hectares per year, (-8.9 in the period 1990–2000, -7.3 in 2000-2005). Africa and South America suffered the largest net loss of forests from 1990 to 2005, about 4.3 and 4.0 million hectares per year respectively (Table 3). Africa accounts for over 50 % of net recent global deforestation (last five years), although the continent hosts only 16 % of the world's forests so the continent tends to figure prominently in assessments that aim to identify degradation hotspots/priority areas for conservation (e.g. Myers et al., 2000).

Table 3. Deforestation and forest degradation (1990-2005)

Region	Annual change in area of forest (1000 ha)	Annual change in area of primary forest (1000 ha)
Africa	-4263	-270
Asia	-194	-1510
Europe	805	956
North & Central America	-329	-545
Oceania	-417	82
South America	-3952	-3297
World	-8351	-5848

(Source: FAO, 2006)

Deforestation and carbon dioxide emission

CO_2 emission is the major global environmental impact of deforestation and forest degradation, particularly in humid tropics (Achard et al., 2002; Houghton, 2003; Fearnside and Laurance, 2004; Moutinho and Schwartzman, 2005). Any of the carbon stores can be affected (i.e. the living biomass, dead wood, litter, soil) and some studies have attempted to estimate these (e.g. FAO, 2006; Table 4).

Table 4. Trends in carbon stocks in forest biomass 1990–2005

Region	Carbon in living biomass (Gt)		
	1990	2000	2005
Africa	65.8	62.2	60.8
Asia	41.1	35.6	32.6
Europe	42.0	43.1	43.9
North and Central America	41.0	41.9	42.4
South America	97.7	94.2	91.5
Oceania	11.6	11.4	11.4
World	299.2	288.6	282.7

(Source: FAO, 2006)

Tropical deforestation has released in the order of 1-2 Pg C year^{-1} (15-35 % of annual fossil fuel emissions) during the 1990s (Houghton, 2005). Conversion of forests to agricultural land is the major driver of deforestation. Houghton (2003) estimated that global long-term flux of carbon from changes in land use (1850–2000) released 156 PgC to the atmosphere, about 60% of it from the tropics. Average annual emissions from land-use change activities during the 1980s and 1990s were 2.0 and 2.2 Pg C yr^{-1}, respectively, dominated by releases of carbon from deforestation in tropical areas (Table 5).

Table 5. Average annual flux of carbon to the atmosphere from land use changes (Pg C)

Region	1850–2000	1980–1989	1990–1999
Tropics	98	1.93 ± 0.6	2.20 ± 0.6
Non-tropics	58	0.06 ± 0.5	−0.02 ± 0.5*
Global total	156	1.99 ± 0.8	2.18 ± 0.8

*Negative values indicate an accumulation of carbon on land. (Source: Houghton, 2003)

Forests hold much higher carbon than other types of ecosystems. Conversion to other forms of land use releases differing proportions of carbon from the original vegetation and soil to the atmosphere (Table 6). Clearing the land for agriculture releases most of the above ground carbon. Other types of management such as logging and forest degradation due to over-exploitation impact predominantly on the above ground carbon leaving below ground stocks relatively intact.

Table 6. Percent of initial carbon stocks lost to the atmosphere when tropical forests are converted to different kinds of land use*.

Land Use	Carbon lost to the atmosphere expressed as % of initial carbon stocks	
	Vegetation	Soil (to 1m depth)
Cultivated land	90-100	25
Pasture	90-100	12
Degraded croplands and pastures	60-90	12-25
Shifting cultivation	60	10
Degraded forests	25-50	<10
Logging	10-50	<10
Plantations**	30-50	<10
Extractive reserves	0	0

*The loss of carbon may occur within 1 year, with burning, or over 100 years or more, with some wood products. **Managed plantations hold on average a third to a half as much carbon as an undisturbed forest as it is repeatedly harvested. (Source: Houghton, 2005)

There is considerable variation in these types of estimate. Guo and Gifford (2002) analysed the data of land use change and soil carbon stocks from 74 publications. The result indicates that soil C stocks decline after land use change from pasture to plantation (-10%), native forest to plantation (-13%), native forest to crop (-42%), and pasture to crop (-59%). Soil carbon stock increases after land use change from native forest to pasture (+8%), crop to pasture (+19%), crop to plantation (+18%), and crop to secondary forest (+53%).

Palm et al. (2005) estimated the above ground carbon stock under different land use types in Indonesia (Figure 1) and generally much higher proportions of the original carbon were estimated to be lost when forest was converted to other uses. When primary forest is transformed into logged forest, carbon stock decreases from 306 to 93 t C ha^{-1}; if primary forest is transformed into cropland, the above ground carbon stock will be decreased to 2 t C ha^{-1}.

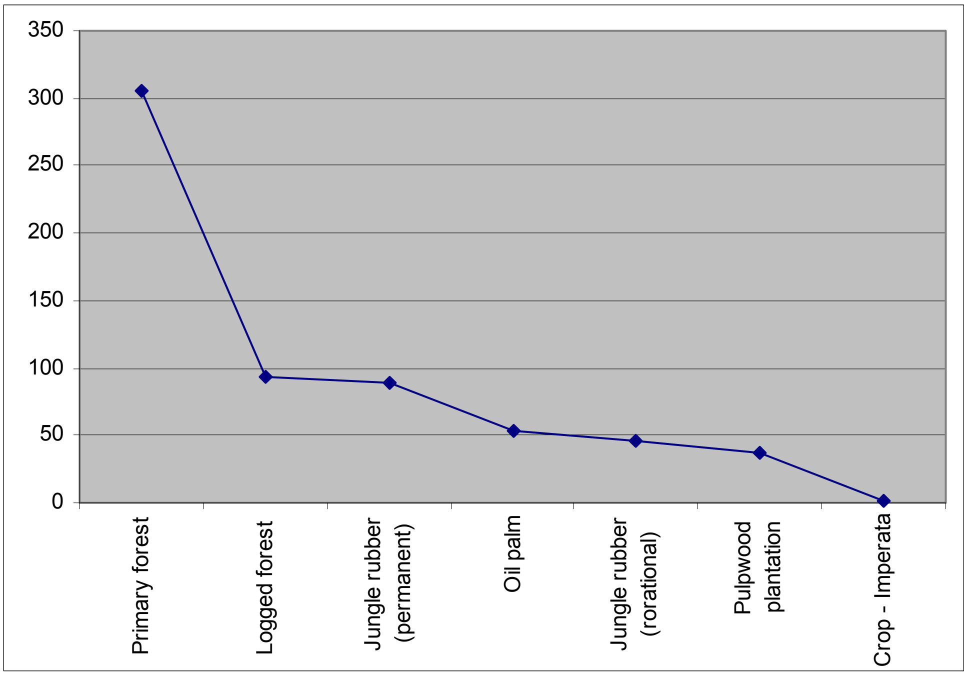

Figure 1. Time-averaged carbon stock under different land use (t C/ha), Indonesia (Based on the data of Palm et al. 2005, the above ground carbon loss or sequestration potential of a land use system is determined by the average carbon stored in that land use system during its rotation)

Other GHGs
Current emissions of greenhouse gases from deforestation amount to about 27 % of the enhanced greenhouse effect estimated to result from all anthropogenic emissions of greenhouse gases. In addition to CO_2 emission, other greenhouse gases, such as CH_4 and N_2O, are emitted as a result of the conversion of forests to agricultural lands (Table 7).

Table 7. Relative contribution of deforestation to the anthropogenic greenhouse effect in 2000 relative to pre-industrial times

Greenhouse gases	Contribution to the enhanced greenhouse effect (%)	Deforestation as percent of total emissions	Deforestation as percent of the enhanced greenhouse effect
CO_2	58	26	15
CH_4	21	48	10
NO_2	6	33	2
HFC's & HCFC's	15	0	0
Total	100		27

(Source: Houghton, 2005)

3.1.1.2 Soil organic matter mineralization: GHG concentrations

A number of attempts have been made to estimate global soil carbon stock using soils maps and relevant soil information taken from representative soil profiles, the results of these estimates vary widely from 1220 to 2200 Pg (Table 8). Although fraught with uncertainty, with both methods and definitions varying between studies, these figures still provide an overview of the magnitude of soil carbon stocks in terrestrial systems and their potential role in climate change.

Table 8. Estimates of global soil carbon stocks

Study	Global soil C stock (Pg to a depth of 1m)
Post et al. (1982)	1400
Buringh (1984)	1427
Sombroek et al. (1993)	1220
Eswaran et al. (1993)	1576
Batjes (1996)	1462 – 1548

(source: Milne et al., 2006)

Above and below ground stocks differ substantially with agro-ecological zone (Table 9)

Table 9. Global carbon stocks in vegetation and soil carbon pools down to a depth of 1 m.

Biome	Area(10^9 ha)	Global Carbon Stocks (Gt C)		
		Vegetation	Soil	Total
Tropical forests	1.76	212	216	428
Temperate forests	1.04	59	100	159
Boreal forests	1.37	88	471	559
Tropical savannas	2.25	66	264	330
Temperate grasslands	1.25	9	295	304
Deserts and Semi-deserts	4.55	8	191	199
Tundra	0.95	6	121	127
Wetland	0.35	15	225	240
Croplands	1.60	3	128	131
Total	15.12	466	2011	2477

(Source: IPCC, 2000)

The consensus today suggests that the soil organic carbon pool is around 1,550 Pg, far greater in size than the atmospheric carbon pool at 760 Pg (Lal 2003, IPCC 2001), and important as it is sensitive to disturbance. Though estimates cannot be precise, Lal and Bruce (1999) estimate that agriculture may have caused the loss of as much as 55 Pg C from soil since settled agriculture began. The processes leading to CO_2 emission have been well studied. In natural undisturbed climax systems a dynamic equilibrium is usually present between soil organic matter (SOM) breakdown and replenishment through litter fall, plant root die off and decomposition. Once land is opened for agriculture this equilibrium is disturbed, SOM breakdown exceeds replenishment and there is a net loss of CO_2 from the soil (Nye and Greenland, 1960). Once under agriculture, soil disturbance, tillage etc. will promote further SOM decomposition as physically protected organic matter is exposed and the accessibility of the microbial organisms to their organic substrates increases. Most of the contribution to atmospheric CO_2 made by the soil is associated with this conversion of land over to agriculture. These processes only become degradation when unsustainable practices such as over-intensive cropping, biomass burning, inadequate organic matter replenishment etc. cause SOM to decline to levels that affect the productivity of the soil.

In addition to carbon dioxide, agriculture is also the major source of Methane and Nitrous Oxides. Table 10 below summarises the contribution of agriculture to GHG emissions high-lighting those effects that can be viewed as consequences of land degradation.

Table 10 Agriculture's contribution to global greenhouse gas and other emissions. Sources considered to be forms of land degradation are emboldened.

Gas	Carbon dioxide	Methane	Nitrous oxide	Nitric oxides	Ammonia
Main effects	Climate change	Climate change	Climate change	Acidification	Acidification Eutrophication
Agricultural source (estimated % contribution to total global emissions)	**Land use change, especially deforestation**	Ruminants (15)	Livestock (including manure applied to farmland) (17)	**Biomass burning (13)**	Livestock (including manure applied to farmland (44)
		Rice production (11)	Mineral fertilizers (8)	Manure and Mineral fertilizers (2)	Mineral fertilizers (17)
		Biomass burning (7)	**Biomass burning (3)**		**Biomass burning (11)**
Agricultural emissions as % of total anthropogenic sources	15	49	66	27	93

(Source: FAO, 2003)

GHGs emission from grassland

Grasslands and their management deserve brief consideration here as, although some widespread practices may not fall within a definition of LD, e.g. annual burning, they can certainly cause substantial GHG emissions and lead quite rapidly to LD and further impacts. White et al. (2000) defined grassland as terrestrial ecosystems dominated by herbaceous and shrub vegetation and maintained by fire, grazing, drought and/or freezing temperatures. So not only non-woody grasslands but also savannas, woodlands, shrub-lands, and tundra are included. The estimated area of grassland range from approximately 41 to 56 million km^2, or 31 to 43 % of the earth's surface, White et al. (2000) estimated total grassland area is 52.5 million km^2, about 41% of earth's surface.

Grasslands are mostly found in dryland areas, 57% are found in the aridity zone from hyper-arid to dry sub-humid, the other 23% in the humid zone, 20% in cold zone

(White et al., 2000). Box 3 illustrates how grassland management can play an important role in global carbon cycle and soil organic carbon stocks.

Box 3. Carbon storage in grassland- some basic information

- Grasslands store approximately 34 % of the global stock of carbon in terrestrial ecosystems.
- Unlike tropical forests, where vegetation is the primary source of carbon storage, most of the grassland carbon stocks are in the soil.
- Cultivation and urbanization of grasslands, and other modifications of grasslands through desertification and livestock grazing can be a significant source of carbon emissions.
- Biomass burning, especially from tropical savannas, contributes over 40 % of gross global carbon dioxide emissions.
- Some exotic grassland plant species may decrease total carbon storage because they have less extensive below-ground root networks for storing organic matter than native grassland plants.

Source: White et al, (2000).

Conversion of grassland to arable land (and vice versa) can lead to a significant decline in soil organic carbon stocks, 25-43% in one study in US prairie land (Potter et al., 1999). Other North American studies have shown similar losses (e.g. Liebig et al., 2005). The magnitude and rate of SOC loss from cropland is influenced by climate, soil texture, C inputs, degree of soil disturbance, erosion, and SOC status prior to cultivation.

Fire in grasslands can release a significant amount of GHGs and aerosols. Burning transfers up to 90 % of the aboveground carbon and nitrogen pools in some grasslands, and 3 % of the total nitrogen pool to 10 cm in the soil, into the atmosphere as CO_2, CO, CH_4, N_2O, NO_X, and particulates (IPCC 2000). Biomass burning in savanna contributes up to 42 % of the total global CO_2 emissions from biomass burning (Table 11). Van de Werf et al. (2003) estimated that the sum of carbon emissions from tropical fires and fuel wood use was 2.6 Pg C yr^{-1}. An additional flux of 1.2 Pg C yr^{-1} was released indirectly, as a result of decomposition of vegetation killed by fire but not combusted. The sum of direct and indirect carbon losses from fires represented 9% of tropical and subtropical net primary production (NPP).

Table 11. Global Estimates of Annual Amounts of Biomass Burning

	Biomass burned (Tg dry matter yr^{-1})	Carbon released (Tg Cyr^{-1})
Savannas	3690	1660
Agricultural waste	2020	910
Tropical forests	1260	570
Fuel wood	1430	640
Temperate and boreal forests	280	130
Charcoal	20	30
World Total	8700	3940

(Source: White et al., 2000)

3.1.1.3 Soil erosion: GHG concentrations

Lal and Bruce (1999) estimated that erosion displaces about 0.5 Gt of soil C yr^{-1}, of which about a fifth enters the atmospheric CO_2 pool (Lal and Bruce, 1999). Lal revised these estimates upwards more recently (2003: 437) suggesting that the amount of soil displaced is far greater and that the total emitted as CO_2 could be as high as 0.8-1.2 PgC yr^{-1}. These figures are equivalent to about a third of the annual increase in CO_2, and are comparable to the C emission from tropical deforestation. If accurate, and this is an area where it is difficult to be precise, erosion control is an even more important strategy than the IPCC suggests (IPCC, 2000, see Box 4).

Box 4. Effects of soil erosion on global carbon budget

- 1094 million ha (Mha) land is affected by water erosion, of which 751 Mha is severely affected (total useable land area = approx. 9,000 million ha).
- 549 Mha land is affected by wind erosion, of which 296 Mha is severely affected.
- A combination of mineralization and C export by erosion causes a severe depletion of the soil organic carbon (SOC) pool on eroded compared with un-eroded or slightly eroded soils.
- The SOC redistributed over the landscape or deposited in depressional sites may be prone to mineralization
- Gross erosion by water may be 75 billion Mg, of which 15-20 billion Mg are transported by the rivers and eventually into the ocean.
- The amount of total C displaced by erosion on the earth, assuming a delivery ratio of 10% and SOC content of 2-3%, may be 4.0-6.0 Pg yr^{-1}.
- With 20% emission due to mineralization of the displaced C, erosion-induced emission may be 0.8-1.2 Pg C yr^{-1} on the earth.
- The accuracy of these estimates has been questioned (e.g. Oost et al, 2005). Some research even suggests that 0.6 to 1.5 Gt C yr^{-1} may be sequestered globally through deposition in terrestrial environments (Stallard, 1998).
- The main uncertainty here perhaps is the fate of carbon in eroded sediment which is not well understood.
- However, soil erosion reduces productivity which in turn reduces the flux of carbon from the atmosphere to biomass and from biomass to the soil.

Source: Oldeman (1994); Lal (2003).

The recent MA desertification synthesis estimates that 300 million tonnes of carbon are lost to the atmosphere from drylands due to desertification each year (4% of total global emissions from all sources. MA, 2005a)

3.1.1.4 Soil carbon sequestration: GHG concentrations

Lal and Bruce (1999) believe that up to 40 Pg of the C they estimate has been lost due to the conversion of land to agriculture since settled agriculture began might be recoverable though the adoption of management practices that promote the sequestration of C in the soil. The FAO (2001: 61) suggests 23-44 Pg C in agricultural soils over the next 50 years might be possible. These estimates agree well with each other and are also comparable to the global sequestration potential of forests, estimated at 60-87 Pg C (ibid.).

A number of soil management practices have the potential sequester carbon and so reduce its accumulation in the atmosphere (Batjes, 2001; Smith 2002; FAO 2004). They generally rely on increasing organic additions to the soil and/or reducing carbon losses, often by reducing the extent or rate of decomposition. As SOM is closely linked to soil quality, nutrient supply and productivity many of these practices have the potential to increase farm income. However, these measures vary greatly in terms of their effectiveness, technical feasibility (particularly in the south) and resource demands.

The effect of soil management practice on carbon sequestration varies with many factors such as soil texture, cropping systems, time, location and climate/soil feedbacks:

Soil texture

Jarecki and Lal (2005) analysed soil samples obtained from two long-term experiments in Ohio. No-till increased SOC and N pools in the 0 to 5 cm layer in silt loam soil but had no effect in clay soil. The historic loss of the SOC pool for 0 to 30 cm depth under agricultural land-use was 25 to 35% in silt loam and 19 to 25% in the clayey soil.

Cropping system

West and Post (2002) used a global database of 67 long-term agricultural experiments, consisting of 276 paired treatments, to quantify potential soil C sequestration rates for different crops in response to decreasing tillage intensity or enhancing rotation complexity. On average, a change from conventional tillage (CT) to no-till (NT) can sequester 57 ± 14 g C m^{-2} yr^{-1}, but wheat-fallow systems may not result in SOC accumulation with a change from CT to NT. Enhancing rotation complexity can sequester an average 20 ±12g C m^{-2} yr^{-1}, but change from continuous corn to corn-soybean may not result in a significant accumulation of SOC.

Time

Smith (2004) indicated that soil carbon sequestration could meet at most about one-third of the current yearly increase in atmospheric CO_2-carbon, but the duration of the effect would be limited, with significant impacts lasting only 20-50 years. However, if atmospheric CO_2 concentrations are to be stabilized at reasonable levels (450-650 ppm), drastic reductions in carbon emissions will be required over the next 20-30 years. Given this, carbon sequestration should form a central role in any portfolio of measures to reduce atmospheric CO_2 concentrations over this crucial period, while new energy technologies are developed and implemented.

Geographical location

Betts (2000) argued that the net climatic consequence of some soil management measure could be reduced if it is implemented in the wrong geographical location. For example if afforestation were to be implemented at high latitude, particularly in areas with significant snow cover, the warming effect of decreased albedo could offset the cooling effect of carbon sequestration. On the other hand, Betts also noted that increasing the area of tropical forests can cool the local environment by enhancing transpiration, adding to the greenhouse gas benefit of afforestation.

Climate/soil feedbacks

Increases in CO_2 and rising temperatures associated with climate change may affect soil organic carbon storage and turn-over rates and hence influence soil structure and a range of other soil and land properties. These feedback processes are not yet fully understood but recent studies have provided sufficient clarification in some areas to demonstrate that some feedbacks may be very important (Box 5).

Box 5. Evidence for feed-backs between land degradation and climate

- Giardina and Ryan (2000) suggested that soil organic carbon decomposition rates are not sensitive to temperature fluctuations, that increased temperature alone will not increase soil organic matter decomposition rates. Some recent research has questioned this, however. Knorr et al. (2005) developed a three-pool model to analyse published data sets including those from Giardina and Ryan's earlier study. These findings suggested that non-labile SOC is more sensitive to temperature than labile SOC, implying that the long-term positive feedback of soil decomposition in a warming world may be even stronger than currently thought (Powlson, 2005). Jones et al. (2005) used two different models (HadCM3LC and RothC) to simulate the changes in global soil carbon stocks decreasing under climate warming. They concluded that that the projection of a positive feedback between climate and carbon cycle is robust, but the magnitude of the feedback is very uncertain and dependent on the structure of the soil carbon model.

- Melillo et al. (2002) conducted some decade long soil warming experiments in a mid-latitude forest and found that the acceleration of soil organic matter decay and carbon dioxide fluxes to the atmosphere in response to soil warming was small and short-lived, they claimed because of the limited size of the labile soil carbon pool in forest systems. They believe, in contrast to Knorr et al. (2005) that it is indeed the more labile SOC that is subject to accelerated decomposition as temperature increases. Melillo et al. predict that the largest potential increases are in those systems where large labile pools exist such as high latitudes with scrubby or grassland vegetation on organic often waterlogged soils. It does seem likely that in these systems the combination of warming and drying are more likely to lead to large increases in decomposition rates and CO_2 emission.

- Another potentially very important but uncertain feedback loop between climate change and soil carbon storage at high latitudes is the thawing of (permanently) frozen soils. However, out imperfect understanding of the complexity of carbon and methane fluxes involved, means that the overall response of Arctic soils to global warming is still unclear (Stokstad, 2004).

- Agren and Bosatta (2002) question some of the incubation methodologies commonly used in these studies and argue that turnover times of soil organic matter are more sensitive to temperature changes under artificial incubation conditions than when they are estimated from soils at their native temperatures.

3.1.2 Climate: temperature and precipitation

3.1.2.1 Deforestation: temperature and precipitation

Deforestation and conversion of land to pasture or cropland can impact on other atmospheric components leading to consequences for the local, regional and global climate. Generally, surface albedo increases with vegetation removal, aerodynamic roughness is reduced leading to less mechanical mixing of the atmosphere in the boundary layer, there is less evapo-transpiration leading to lower atmospheric moisture concentrations and there is an increase in the ratio of convective sensible heat transfers to latent heat transfers[1] from the surface to the atmosphere (Berbet and Costa, 2003; Betts, 2000; Lawton et al., 2001; Marland et al., 2003; WMO, 2005). In one study changes in forest cover in the Amazon basin were shown to affect the flux of moisture to the atmosphere, regional convection, and hence regional rainfall. These changes in forest cover have consequences far beyond the Amazon basin with recent work by Lawton et al. (2001) showing clearly that deforestation in Central America has negatively impacted rainfall in adjoining regions.

It is commonly claimed that forest has an important role in stabilizing landscapes, protecting land from soil erosion and regulating hydrological cycles (MA, 2005a). Recent work challenges the conventional wisdom that links large-scale flooding to deforestation (FAO and CIFOR, 2005). Though forests can play a role in minimising runoff that causes localised flooding there is no evidence that a loss of trees significantly contributes to severe widespread flooding. Even at the local level, the report notes, the flood-reducing effects of forests are heavily dependent on soil depth and structure, and saturation levels, not exclusively on the presence of the trees – the undergrowth and forest litter tend also to check erosion. Where land-use effects on flooding were observable it was only in relatively small basins. Thus the land degradation and soil erosion that are often associated with the loss of forest cover are not necessarily the result of the forest removal itself, but of the poor land-use practices (overgrazing, litter removal, destruction of the organic matter, clean weeding, Box 3) implemented after forest removal.

3.1.2.2 Land degradation: temperature and precipitation

Land degradation can also significantly affect climate due to land surface changes that impact on surface energy budgets (e.g. by increasing albedo) or affect surface evapo-transpiration, (Marland et al., 2003; WMO, 2005).

Figure 2 illustrates the mechanisms by which land degradation can affect the temperature and precipitation elements of climate (MA, 2005a).

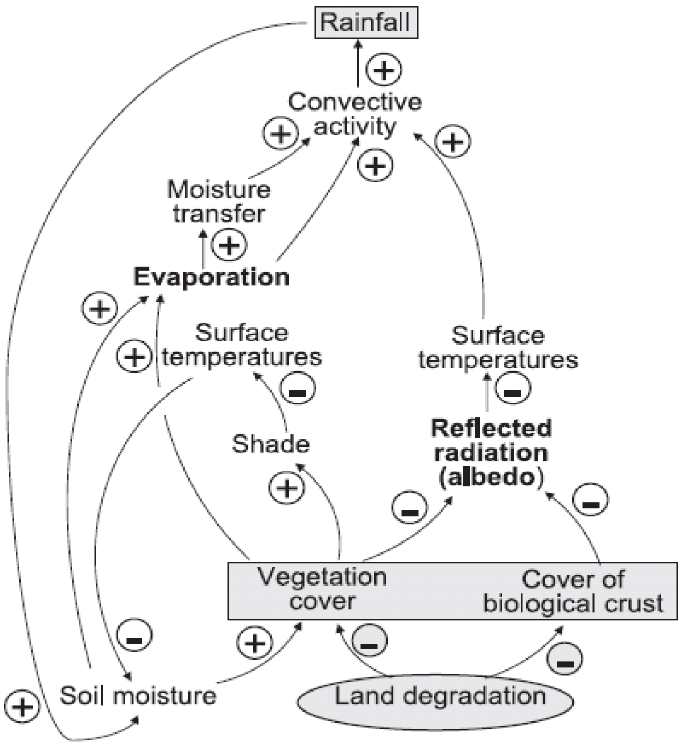

Figure 2. Land degradation and climate regulating process (MA, 2005a)

Pielke et al. (2002) reviewed published research on regional and global climatic impacts of land-use change mediated through effects on the surface-energy budget and on the carbon cycle. They argued that the surface-energy budget effects may be the more important.

3.1.2.3 Dust storms

Dust storms have always existed as natural phenomena but their increased frequency and severity is one of the manifestations of land degradation, particularly in the world's drylands. In this report our interest is in the extent to which human activities, particularly land use and management, are contributing to these increases.

Source of dust and frequency of storms

Through analysing TOMS (Total Ozone Mapping Spectrometer) data, both Washington et al. (2003) and Prospero et al. (2002) have identified the dominant sources of atmospheric dust as North Africa, the Arabian Peninsula, Central Asia, China, Australia, North America, and South Africa. A number of sources are associated with areas where human impacts are well documented, e.g., the Caspian and Aral Seas, Tigris-Euphrates River Basin, south-western North America, and the loess lands in China. However, the largest and most active sources are located in truly remote areas where there is little or no human activity (e.g. Lake Chad Basin which is the most intense dust source in the world).

Goudie and Middleton (1992) analysed long-term meteorological records for a large number of areas (the Great Plains of the USA, the USSR, Morocco, the Arabian Gulf, Australia, the Sahel-Sudan zone of Africa, China, Mongolia and Mexico) and concluded that there is no single global trend in dust-storm frequency. Some areas show clear upward trends, others the reverse or a more cyclical pattern.

Contribution of human activities to dust storms

Prospero et al. (2002) concluded that though efforts to assess the consequences of human activity on large-scale dust mobilization have not yet been successful, these are important phenomena that need to be looked at in a systematic and quantitative way. In many cases it is evident that natural climatic components (precipitation totals, snow cover, and wind strength) determine the frequency of dust events in any one year. It can therefore be argued that there are indirect impacts of LD on dust storms mediated through its impacts on climate (discussed above). There is some evidence for a more direct link between LD and dust storms, though this is less conclusive. Natsagdorj et al. (2003) analysed Mongolian dust storms from 1937–1999 and found that that the annual number of dusty days was about 15 in the 1960s and about 50 in the 1980s, a greater than three-fold increase. However, the number of dusty days has been decreasing since 1990, a decrease not mirrored by a decrease in LD. Though it is likely that both human activities (causing LD) and annual precipitation change contribute to the trend, it is difficult to disentangle the two. In a different study Tegen and Fung (1995) calculated that disturbed sources (i.e. degraded lands) contributed 30–50% of the total atmospheric dust loading of Saharan dust over the Atlantic Ocean. These disturbed sources include natural soils known to have been affected by the Saharan/Sahelian boundary shift (i.e. desertification), cultivation, deforestation, and wind erosion. In more recent research, Tegen et al. (2004) investigated the relative importance of climate and land use in determining global soil dust emission through calibrating a dust-resource model with emission indices derived from dust-storm observations. The results show that dust from agricultural areas contribute <10% of the global dust load. However, simulations of future changes in dust emission under different climate and land use scenarios suggested that dust emission will be increasingly influenced by anthropogenically-induced changes in climate and natural vegetation. The research also indicates that dust storm frequency from agricultural sites is significantly greater than those from non-agricultural sites.

Engelstaedter et al. (2003) assessed the degree to which dust emissions are controlled by vegetation cover and geomorphic setting using dust storm frequency (DSF) data from over 2400 meteorological stations worldwide. Results indicate that DSF is highest in desert/bare ground and shrub-land regions, and comparatively low in grassland regions. Average DSF is inversely correlated with leaf area index and net primary productivity underlining the importance of vegetation and its loss as a driver of dust storm formation.

Due to different definitions and measurement methodologies for dust storms in different countries, comparing the frequency of dust-storms and associated dusty days in the countries even along the route of the same storms is difficult, as are attempts to clarify the links between dust storms and human activities (Chung et al., 2005). This is one area where there is a need for greater standardization of methodology if our ability to quantify regional and global level impacts is to improve.

Environmental impacts of dust storms
The transportation of dust from one area to another can have a number of impacts (Goudie and Middleton, 2001):

- Climatic effects including absorption and scattering of solar radiation affecting air temperatures; influence on marine primary productivity; promotion of ocean cooling; modification of rainfall amounts through effects on convectional activity and cloud formation;
- Influence the nutrient dynamics and biogeochemical cycling of both terrestrial and oceanic ecosystems: e.g. by supplying nutrients to ocean surface waters and the seabed, transporting disease spores etc.
- Additions of dust to land surfaces may affect soil formation and soil characteristics (e.g. soil texture variation with the distance from the source of the dust);
- Contribution of sediments to the oceans.

Harrison (2004) reports that mineral dust is an important component of the atmospheric aerosol loading, with 1-2 Pg of dust eroded by the wind into the atmosphere every year. Atmospheric dust affects regional climates by altering the balance of incoming and outgoing radiation, influencing cloud properties and affecting some atmospheric chemical processes. The net climatic impact could be large, but it is currently very unclear whether dust will produce warmer or colder conditions at a regional scale, and unclear how regional changes will affect the global climate.

Rosenfeld et al. (2001) found that dust inhibits precipitation. The detrimental impact of dust on rainfall is smaller than that caused by smoke from biomass burning or anthropogenic air pollution, but the abundance of desert dust in the atmosphere renders it important. Reduced precipitation can lead to drier soil which raises more dust, thus providing a possible feedback loop to further decrease precipitation. Land use changes that expose the topsoil can also initiate such positive feedback processes. Goudie and Middleton (2001) demonstrated variations in dust deposition rate with distance from source to deposition site: as would be expected deposition rates fall with increasing distance from source site. The estimated annual rate of Saharan dust deposition varies from 200 g m^{-2} in SW Niger to 36 in SE Mediterranean and 0.2g m^{-2} in French Alps.

Jickells et al. (2005) describes the potential “iron fertilization” role of dust that could promote phytoplankton growth over vast areas of the ocean. Aeolian dust transport, mainly from the great deserts of the world, is the dominant external input of iron to the surface of the open ocean. Dust production, transport, and deposition to the oceans again depend on climatic factors, particularly atmospheric structure, which regulates uplift and wind speed and precipitation, which influence removal. Changing terrestrial land uses to create carbon sinks to help mitigate global change may reduce dust fluxes to the ocean and thereby reduce primary productivity, offsetting gains in terrestrial carbon storage.

In conclusion there are indications that dust storms have relatively minor but increasing impacts in a number of globally important areas including climate and ocean productivity. It is very difficult to quantify these effects, however, and very few studies have done this convincingly.

3.2 Biodiversity

3.2.1 Above ground biodiversity

The Global Species Assessment (IUCN, 2004) states that habitat destruction and degradation is the major threat faced by globally threatened birds and amphibians, affecting 86% and 88% of threatened species (1,045 and 1641 species respectively), and 86% (652 species) of the 760 threatened mammals for which data are available. This is because the majority of these species occur in tropical forests, where the most serious habitat loss is taking place. Tropical forests are also particularly rich in biodiversity, covering less than 10% of the Earth's land area yet harbouring between 50% and 90% of Earth's terrestrial species (MA, 2005a). On average, 5% of the world's native tree species are threatened (12% in North and Central America, 7% in Africa, 6% in South America, 4% in Asia, 3% in Oceania, and 2% in Europe) (FAO, 2006).

One of the indicators of forest degradation is the decline in primary forests (i.e. forests of native species, in which there are no clearly visible indications of human activity and ecological processes are not significantly disturbed). Primary forests generally have higher levels of biodiversity than other forest types.

Of the 1,045 globally threatened birds affected by habitat destruction, selective logging or tree-cutting and general deforestation affect some 30%, firewood collection and the harvesting of non-woody vegetation affect 15% and conversion to tree plantations some 10%. Overall, 60% of globally threatened birds are impacted upon by forestry activities (IUCN, 2004).

Figure 3 shows the extent of impacts of different drivers to global biodiversity change, and their current trends (MA, 2005a). Many of these drivers are commonly manifested in different types of LD: Habitat change (deforestation), over-exploitation (unsustainable land-use) and pollution (non-point source pollution from agricultural land). LD can also impact on biodiversity indirectly through its contribution to climate change (see above).

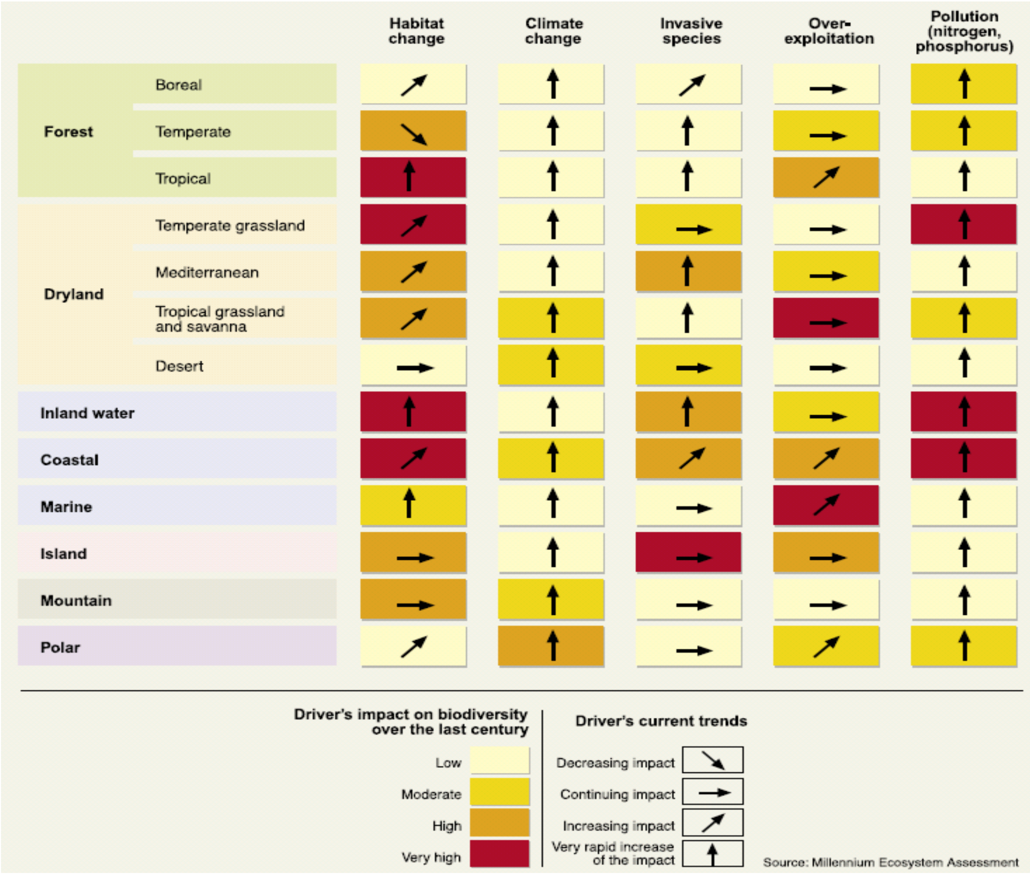

Figure 3. Impacts and current trends of drivers of biodiversity loss (MA, 2005a)

In addition to the drivers detailed in Figure 3, The UNCBD (2004) identifies several more specific management practices leading to LD and creating major pressures impacting on dryland biodiversity e.g. burning the land, soil management, over-harvesting. The UNCBD highlights the impacts of agricultural intensification on biodiversity and Box 6 summarises the different forms this impact can take. The MA, UNCBD, The Global Species Assessment (IUCN, 2004) and other analyses (e.g. Sala et al., 2000), all agree that land-use change is the driver with perhaps the largest effect on biodiversity in terrestrial ecosystems, affecting all groups above and below ground. Whilst land-use change and LD are not the same thing, they will always occur together when forest is converted to farmland and it is this loss and or degradation of the forest resource that impacts most significantly on biodiversity, though other factors do also (Box 6).

Box 6. Ways in which the expansion and intensification of agricultural land-use can lead to loss of biodiversity

– Loss, modification, and fragmentation of habitats, which may be caused by deforestation, erosion, overgrazing, and silting of low-lands
– Intensification of agriculture, which is often accompanied by farm and field consolidation, reduction of field margin, clearance and levelling of adjacent watershed, expansion in the use of modern varieties, great use of pesticides
– Pollution and disturbance, which includes application of agro-chemicals, discharge of industrial waste, and fertilizer leaching to water system causing eutrophication and therefore decrease in aquatic biodiversity

Source: FAO 2003; Foley et al., 2005

3.2.2 Below ground biodiversity

Land degradation is directly linked with the UNCBD thematic programmes, *dry and sub-humid lands biodiversity* and *soil biodiversity initiativ*e under the *agricultural biodiversity* programme (UNCBD, 2004). Soils contain more uncharacterized biodiversity than any of the rest of the terrestrial biosphere (Fitter, 2005) with perhaps only 10% of protozoa and 5% of mite species having been taxonomically described (Brussaard et al., 1997; Adams and Wall, 2000). Table 12 shows the number of species presently described of selected soil biota that have been better studied.

Table 12. Total number of described species of various soil organisms

Size Class Organism	Number of Species Described
Microorganisms	
Bacteria and archea	3,200
Fungi	ca.35,000
Microfauna	
Protozoa	1,500
Nematodes	5,000
Mesofauna	
Mites (Acari)	ca. 30,000
Springtails (Collembola)	6,500
Diplura	659
Symphyla	160
Pauropoda	500
Enchytraeids	>600
Macrofauna	
Root herbivorous insects	ca. 40,000
Millipedes (Diplopoda)	10,000
Isopods	2,500
Termites (Isoptera)	2,000
Ants (Formicidae)	8,800
Earthworms (Oligochaeta)	3,627

(Source: Francaviglia, 2003)

Biodiversity of any kind has intrinsic value and this should be respected. However, the functional roles of soil faunal and microbial groups in soil and ecosystem health are increasingly acknowledged and it is perhaps of more immediate concern if these are compromised (Bardgett and Cook, 1998; Francaviglia, 2003; Swift et al., 2004; Jones and Bradford, 2001; Bignell et al., 2005). A number of these roles are linked, directly or indirectly, to the health and function of ecosystems and/or global systems or processes e.g. organic matter decomposition, gas exchange and carbon sequestration (Table 13). For the purposes of this report, unless the soil biodiversity impact reduces the productive potential of the soil then it is not considered as it falls outside our working definition of land degradation.

Table 13. Essential functions performed by the different soil biota groups

Functions	Organisms involved
Maintenance of soil structure	Bioturbating invertebrates and plant roots, mycorrhizae and some other micro-organisms
Regulation of soil hydrological processes	Most bioturbating invertebrates and plant roots
Gas exchanges and carbon sequestration	Mostly micro-organisms and plant roots, some C protected in large compact biogenic invertebrate aggregates
Soil detoxification	Mostly micro-organisms
Nutrient cycling	Mostly micro-organisms and plant roots, some soil and litter feeding invertebrates
Decomposition of organic matter	Various saprophytic and litter feeding invertebrates (detritivores), fungi, bacteria, actinomycetes and other micro-organisms
Suppression of pests, parasites and diseases	Plants, mycorrhizae and other fungi, nematodes, bacteria and various other micro-organisms, collembola, earthworms, various predators
Sources of food and medicines	Plant roots, various insects (crickets, beetle larvae, ants, termites), earthworms, vertebrates, micro-organisms and their by-products
Symbiotic and asymbiotic relationships with plants and their roots	Rhizobia, mycorrhizae, actinomycetes, diazotrophic bacteria and various other rhizosphere micro-organisms, ants
Plant growth control (positive and negative)	Direct effects: plant roots, rhizobia, mycorrhizae, actinomycetes, pathogens, phytoparasitic nematodes, rhizophagous insects, plant growth promoting rhizosphere micro-organisms, bio-control agents Indirect effects: most soil biota

(Source: FAO, http://www.fao.org/ag/agl/agll/soilbiod/soilbtxt.stm#function)

Land-use change: impacts on soil biodiversity

The composition of soil microbial populations is quite dynamic and can change relatively quickly in response to changes in the soil environment such as moisture levels, aeration, presence of organic substrates etc. Many land management practices, some of which are viewed as direct promoters of LD (e.g. vegetation burning, excessive soil tillage, soil erosion) and some that are not, will cause these changes but we should also consider whether particular types of soil biodiversity change constitute LD in their own right. A functional focus is helpful here – where the impact on soil organisms has a negative effect on the function of the soil then this is clearly a form of degradation and there are some examples where this type of impact has been documented e.g. the impact of heavy metals in sewage sludge applied to UK agricultural land (see Box 7). The loss of a species of soil organism is only likely to affect a function if that species is the only species (or one of very few) that carries it out. Thus functions such as nitrogen fixation, nitrification etc. are likely to be sensitive indicators of biodiversity loss in soils.

Other functions such as the different steps in organic matter decomposition can be carried out by many different species of micro-organism so the functional significance of losing some of these species may not be significant.

Box 7. Sewage sludge, heavy metals and soil biodiversity.
Application of sewage sludge to agricultural soil is widespread in the UK and regarded as useful practice to improve physical characteristics and provide nutrients to growing crops. However, the contamination with heavy metals from sludge (particularly from industrial areas) often restricts its application.

Effective nitrogen fixation in a legume generally requires the presence of a very specific species of Rhizobia bacteria and if this species is absent or lost e.g. due to contamination of the soil with heavy metals in sewage sludge, then nitrogen fixation will not take place. Obbard and Jones (2001) studied the adverse effects of heavy metal on symbiotic N_2 fixation rates and found that the effects vary with different species and planting regime. Experiments on broad bean and pea indicated a significant, but minor-inhibitory metal-related effect on the rate of N_2 fixation compared to untreated soils and soils amended with a relatively uncontaminated sludge; the effects were apparent with white clover grown in inter-specific competition with ryegrass under mixed sward conditions, compared to white clover grown in pure sward.

Whilst some studies have found there to be measurable soil biodiversity impacts from specific management practices (e.g. vegetation removal, intensification: Bardgett and Cook, 1998) rather few have looked specifically at the impact of soil erosion and other forms of LD on functional groups of soil biodiversity. Rather, recent focus of soil biodiversity work has been on trying to understand what these groupings are, (Swift, 2001; Bunning and Jiménez, 2003) and how they might best be classified (Swift, 2001; Black et al., 2003; Ekschmitt et al., 2003)

Harris (2003) reported an approach for using measurements of the soil microbial community as an indicator of degradation and the success of remedial efforts to reverse it. Groffman and Bohlen (1999) studied the linkages between soil, sediment biodiversity and ecosystem function but there are great difficulties in this type of work with isolating and describing the organisms that live in these habitats and studying their activities under realistic conditions.

3.2.3 Agricultural biodiversity

Land degradation is also closely linked with GEF's Strategic Priority (SP-2) in biodiversity to mainstream biodiversity in agriculture, its thematic focus on agricultural biodiversity and its Operational Program 13 *Conservation and Sustainable Use of Biodiversity Important to Agriculture* (GEF, 2002). Farmers have long been the custodians of the genetic wealth present in the species, varieties and land races they use (McNeeley 2005). They have also guarded a rich and varied local knowledge on how to manage biodiversity through production landscapes. This understanding of the interlinkages between biodiversity and land management developed into a conceptual framework of 'agrodiversity' which informed one of the first of GEF's projects on agricultural biodiversity, called 'People, Land Management and Environmental Change (PLEC, 1996-2002)'

The agrodiversity framework specifically intersects interests in biodiversity conservation and sustainable use with farmers' management of soils and land resources (Figure 4). This occurs, for example, in the management of resource endowments ('organisational diversity': Leach et al., 1999), the local knowledge of soil management ('management diversity': Gyasi et al., 2004) and the employment of biological forms of soil conservation ('agro-bio-diversity': Thrupp, 2004). Land degradation is, therefore, a key variable in the protection and management of PLEC's broad conceptualisation of agricultural biodiversity.

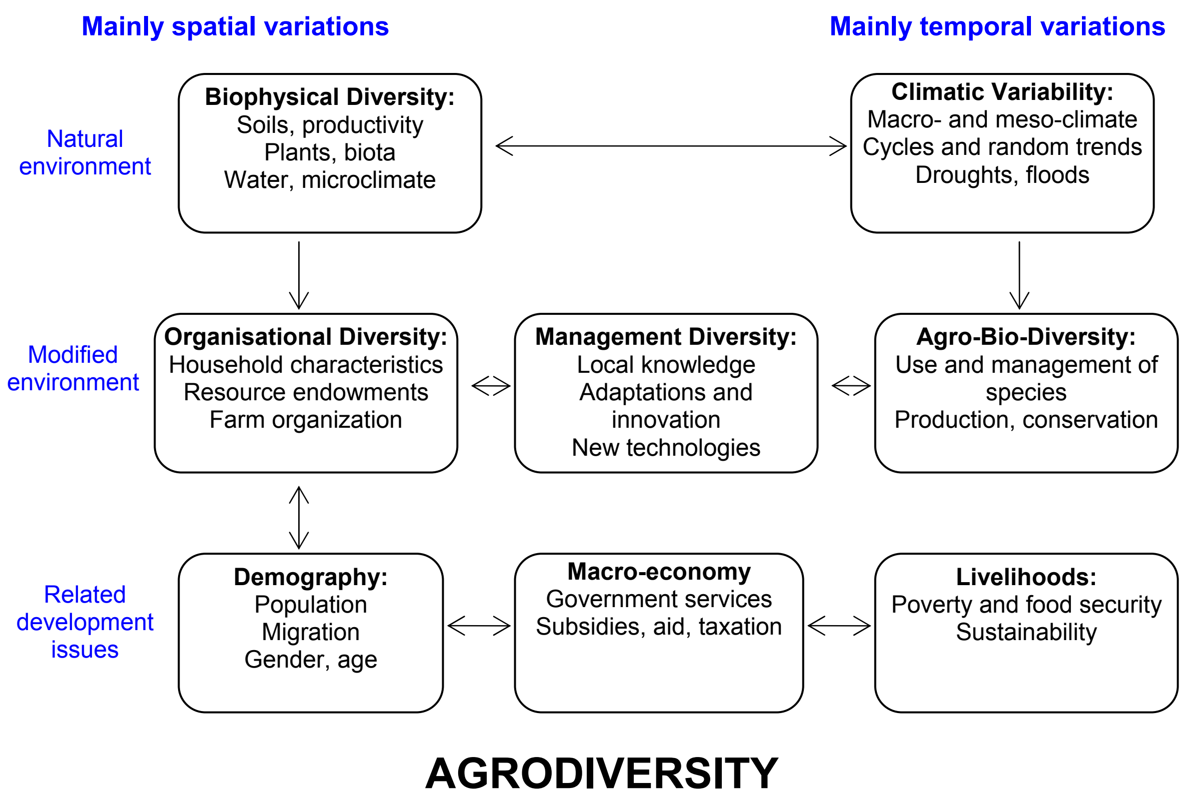

Figure 4. The ‘agrodiversity’ conceptual framework linking agricultural biodiversity across scales and time (Source: Brookfield and Stocking, 1999)

To illustrate, one GEF project found 55 wild species of vegetable and 70 upland rice varieties cultivated in one small area of highland Yunnan in China and 54 varieties of yam in Sekusua-Onson in Ghana (Brookfield et al., 2002). Underwriting this biodiversity of both domesticated and wild species is the continuing quality of the land resource base, especially the intrinsic fertility of the soil and the local systems of soil management. Conversely, continuing loss of biodiversity concerns land users who draw upon a range of varieties and species of plants and animals for their livelihoods and well-being. Two principal processes are cited in the scientific literature whereby land degradation impacts agricultural biodiversity. Directly, a declining land resource base affects the range of choices of plants that land users may grow. Indicators of biodiversity condition are well accepted as measures of sustainable land management (Dumanski 1997; Dudley et al 2005). Indirectly, declining environmental conditions impact on the ecological provisioning services of land and make it more difficult for land users to provide for food, fuel and fibre (MA 2005a).

The concept of ‘ecoagriculture’ is based upon the link between biodiversity and sustainable land management (McNeeley and Scherr 2003). Though primarily advocated for its benefits for natural biodiversity, it equally has benefits for biodiversity in hedgerows, agroforestry and complex intercropping systems (see Box 8). The developmental benefits are also promoted in increased productivity and efficiency of agricultural systems. The converse also applies: as land degrades and soil quality declines, the ability of the land to support a range and variety of plants and animals commensurately declines (Pacini et al., 2003).

Box 8. Ecoagriculture strategies for land and resource management

Ecoagriculture *increases wildlife habitat* in non-farmed patches in agricultural landscapes, creating mosaics of wild and cultivated land uses, by:

- Creating new protected areas that also directly benefit local farming communities (by increasing the flow of wild or cultivated products, enhancing locally valued environmental services, or increasing agricultural sustainability)
- Establishing habitat networks and corridors in “in between” spaces that are compatible with farming (such as hedgerows or windbreaks)
- Raising the productivity of existing farmland to prevent or reverse conversion of wild lands, along with explicit measures to protect or restore the biodiversity value of uncultivated lands.
-

Ecoagriculture *enhances the habitat quality* of productive farmlands, by:

- Reducing agricultural pollution through new methods of nutrient and pest management, and farm and waterway filters
- Modifying the management of soil, water, and natural vegetation to enhance habitat quality
- Modifying the mix and configuration of agricultural species to mimic the structure and function of natural vegetation.

Source: McNeeley (2005).

3.3 International Waters

International waters are defined as “the oceans, large marine ecosystems, enclosed or semi-enclosed seas and estuaries, as well as rivers, lakes, groundwater systems, and wetlands with trans-boundary drainage basins or common borders. The water-related ecosystems associated with these waters are considered integral parts of the systems.” (Belausteguigoitia, 2004).

GESAMP (2001) recognised three ways in which land and international waters are linked:

- through the ecological interdependence of the marine and terrestrial environments, which are linked by complex atmospheric, geological, chemical and biological interactions;
- the social and economic interdependence of human activities on particular ecological linkages; and
- the trans-boundary nature of coastal and marine environmental problems, necessitating international cooperation in setting common objectives and in implementing compatible policies and programmes.

Land and water ecosystems affect each in a numbers of ways, summarised in Table 14. Many of the land to sea fluxes can result from LD.

Table 14. Fluxes from Land to Sea and from Sea to Land, Differentiating between Natural and Anthropogenic Factors

Factor	Land to Sea	Sea to Land
Natural	- river discharge - groundwater - sediment - nutrients and minerals - humics and organics - storm debris - earthquake debris - volcanic debris	- energy and debris from hurricanes - cold water and nutrients from upwelling - wave action - salt and salt aerosols - sand - nutrients through carcasses, guano
Anthropogenic	- sediment (increase from land use and decrease from dams) - nutrients and organic matter from agriculture and sewage - coliform bacteria - herbicides and pesticides - heavy metals - oil and chemicals	- oil and chemical spills - chronic input of oil and chemicals - sewage from ships - ballast water containing exotic organisms - debris from ships - brackish infiltrations of groundwater reservoirs by water extraction - pharmaceuticals

(Source: MA, 2005a)

3.3.1 International waters: global status and trends

The Global International Water Survey (GIWA) which was partly funded by GEF was carried out in 66 sub-regions of the world from 1999 to 2004 (Hempel and Daler, 2004). One of the main findings regarding trans-boundary water pollution was that suspended solids, which have increased mainly as a result of deforestation and agricultural practices, severely affect coral reefs, sea grasses and riverine habitats in one fifth of the GIWA regions/sub-systems.

The GIWA report projected that by 2020, the environmental impacts of pollution are predicted to increase in severity in over three-quarters of GIWA regions/sub-systems, making this the most negative future outlook for any of the GIWA concerns (UNEP 2006). The Millennium Ecosystem Assessment on costal ecosystem made similar projections for changes in coastal ecosystems with eutrophication and pollution, both common consequences of LD, of particular concern (Table 15).

Table 15. Projections of trends and areas of rapid change in coastal ecosystems

Trends in costal ecosystems related to land based activities	Certainty
Large increases in rates of eutrophication and prevalence of hypoxic or dead zones as levels of nutrient inputs and wastes rise as ocean waters warm.	High
Since nutrient production through agricultural waste and human sewage are expected to increase in the future and since wetland loss will likely occur at current or higher rates, eutrophication will undoubtedly increase worldwide.	Medium
Pollutant levels are expected to increase in the near future, despite effective controls on some substances in some areas.	High
Some geographic areas of the world are expected to show particularly high rates of change and loss of certain ecosystem services, e.g. Southeast Asia.	High
Toxin loadings, pathogens, and alien species invasions will further stress coastal ecosystems and may impede natural recovery and managed restoration; human well-being will suffer as a consequence unless significant improvements to coastal management are systematically made across wide regions of the globe	High

(Source: MA, 2005a)

3.3.2 Source of pollutants

The input of nutrients (particularly nitrogen and phosphorous) to both surface and groundwater from land-based activities is increasing globally and has led to eutrophication of coastal and near-shore waters and degradation of freshwater. Agricultural activities are increasingly important significant sources of pollution in water ecosystems, particularly in developing countries (FAO, 2003) (Boxes 9 & 10).

While it is difficult to isolate the contribution of agricultural activities from domestic and industrial inputs, a study in the UK showed that half of the P contribution to surface waters in the UK was from agriculture (fertilizer and livestock, Table 16).

Box 9 Eutrophication of Lake Victoria
Lake Victoria (area 68,800 sq km) shares its coast with three countries (Kenya, Tanzania and Uganda) and its catchment with five countries (Kenya, Tanzania, Uganda, Burundi and Rwanda). It is drained by a number of large and small rivers and streams (Twong'o et al 2002). Forest clearance in the catchments and on the lake margins, eroded soil and non-point source pollution from the land contribute to the environmental changes experienced by the lake over the last 40 years. Over-fishing, species introductions, industrial pollution are other important drivers of these changes that together seriously threaten the ecosystem function and overall diversity of the lake (Odada et al, 2004; Verschuren et al 2002). Twong'o et al (2002) identified three main instances of catchment degradation affecting the Lake, the first of which is land degradation.

Significant problems are caused in the lake by eutrophication and low dissolved oxygen levels caused by nutrient pollution. Scheren et al (2000) reported that 94% of the nitrogen and 90% of phosphorous input into the lake input originates from atmospheric deposition and land runoff. exacerbated by forest burning and exploitation of land for agriculture. With the current trend of population growth, further degradation of the Lake Victoria ecosystem can be countered only if land management strategies that severely restrict nutrient input to the lake and its tributaries are implemented on a multinational, basin-wide scale.

Table 16. Nutrient loads to Lake Victoria

Sources	Scheren et al (2000)		Twong'o et al (2002)	
	Total nitrogen (%)	Total phosphorus (%)	Total nitrogen (%)	Total phosphorus (%)
Catchments/agricultural	22.0	55.2	31.8	17.8
Atmosphere deposition	71.6	35.8	65.7	76.1
Industry			0.3	1.1
Municipal domestic	6.4	9.0	2.3	5.1

Box 10. Ocean Pollution from Land-based Sources - *East China Sea, China*
The environment of the East China Sea (ECS) faces by huge stresses from anthropogenic activities and population growth in the Yangtze River drainage basin and coastal areas. The main pollutants are inorganic nitrogen, phosphate, oil hydrocarbons, organic matter and heavy metals. Nutrients are the dominant pollutant of the Yangtze River estuary and the adjacent ECS. Nutrients cause eutrophication of the coastal ocean and the estuarine area and very often lead to "red tides". In the past two decades, the geographical extent and severity of the nutrient pollution has steadily increased. Fertilizers used in agriculture are the major source of nutrients, and this use has increased significantly over the past 20 years.
Atmosphere deposition is another source of pollution in this area and, whilst estimating this process with any precision is difficult, all assessments indicate that the amount is significant. (Li D and Daler D, 2004)

Also in the UK agriculture is by far the highest contributor of diffuse sources of nitrogen contributing an estimated 70% of the total input to inland surface waters (DEFRA, 2002; Table 17). The recent GIWA in the Black Sea also showed that agricultural contributes 35% of total eutrophication, while urbanization, energy production and transport contribute 35%, 20% and 10% respectively (Borysova et al., 2005)

Table 17 Major Phosphorus Inputs to Surface Waters in the UK

Sources	Proportion
Livestock	34%
Human and household waste	24%
Fertiliser	16%
Detergents	10%
Background source	9%
Industry	7%

(Source: DEFRA, 2002)

Non-point pollution caused by agricultural activities damages a number of different components of the environment as well as human health. In the UK, again where some studies have been done. the total external cost of agriculture has been estimated at £2.34 billion yr^{-1}. Significant costs arise from contamination of drinking water with pesticides (£120 million per year), nitrate (£16 m), *Cryptosporidium* (£23 m) and phosphate and soil (£55 m)(Table 18). Studies with this level of break-down and quantification are rare but, where they exist can be very revealing.

Table 18. The annual total external costs of UK agriculture, 1996

Cost Category	UK (£ million)
1. Damage to Natural Capital: Water	
1a. Pesticides in sources of drinking water	120
1b. Nitrate in sources of drinking water	16
1c. Phosphate and soil in sources of drinking water	55
1d. Zoonoses (esp. *Cryptosporidium*) in sources of drinking water	23
1e. Eutrophication and pollution incidents	6
1f. Monitoring and advice on pesticides and nutrients	11
2. Damage to Natural Capital: Air	
2a Emissions of methane	280
2b Emissions of ammonia	48
2c Emissions of nitrous oxide	738
2d Emissions of carbon dioxide	47
3. Damage to Natural Capital: Soil	
3a Off-site damage caused by erosion	14
3b Organic matter and carbon dioxide losses from soils	82
4. Damage to Natural Capital: Biodiversity and Landscape	
4a Biodiversity/wildlife losses (habitats and species)	25
4b Hedgerows and dry-stone walls	99
4c Bee colony losses	2
4d Agricultural biodiversity	+
5. Damage to Human Health: Pesticides	
5a Acute effects	1
5b Chronic effects	+
6. Damage to Human Health: Nitrate	0
7. Damage to Human Health: Micro-organisms and Other Disease Agents	
7a Bacterial and viral outbreaks in food	169
7b Antibiotic resistance	+
7c BSE and new variant CJD	607
TOTAL	£2343

(Source: Pretty et al., 2000)

The increased contamination of soil and water environments is of particular concern in developing countries where environmental regulation, public awareness and extension services are weak (Hartemink, 2002; Naidu, 1998). For example, China is rapidly moving towards the situation, common in many developed countries, where agriculture has become the main source of water pollution. Non-point pollution from crop and livestock production is one of the critical factors causing Chinese agriculture to be unsustainable. A recent research shows that there are already seven provinces (primarily in the coastal region) where there is a high risk to human and environmental health from crop related non-point pollution, and a further seven provinces where the risks are at a more moderate level. By 2010 the number of provinces at high risk level could rise to 15 given current trends. Over use and inappropriate use of agro-chemicals is a major contributor to the contamination of soil and water (NPP Taskforce, 2004). Since the early 1990s, fertilizer consumption in developing countries has surpassed developed countries and continues to increase (Figure 5), particularly in Asia, less so in Africa.

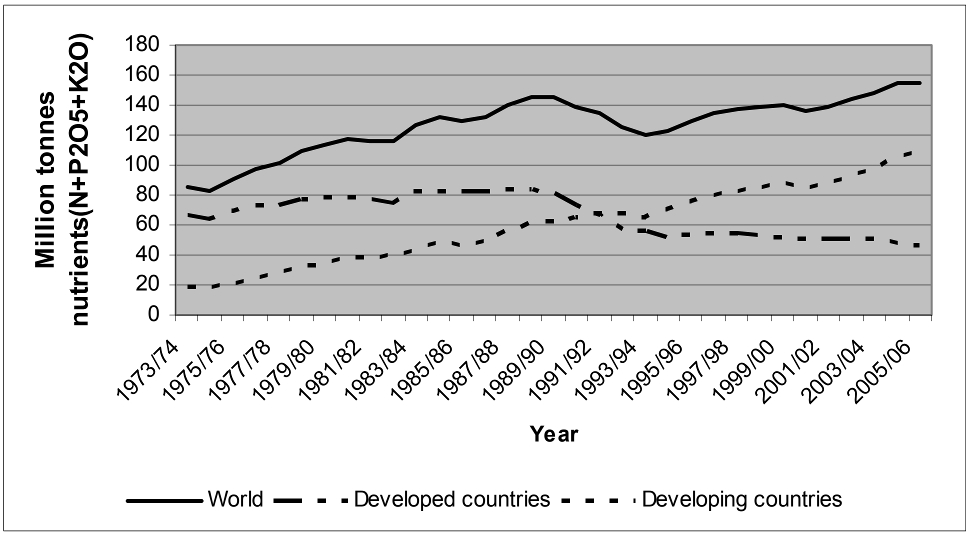

Figure 5. Total fertilizer nutrient consumption (Data source: IFA, 2006)

3.3.3 Land ocean links through atmospheric deposition

Already referred to above in section 3.1.2.3. Jickells, et al. (2005) recently outlined the issues regarding iron cycling and global climate change and the further research needs. These are summarised here:

- Iron is an essential nutrient for all organisms;
- For marine phytoplankton, physiological iron requirements must be met from within the water column;
- Iron supply is a limiting factor for phytoplankton growth over vast areas of the oceans;
- The dominant external input of iron to the surface of the open ocean is aeolian dust transport, mainly from the great deserts of the world;
- Reduction in Fe limitation increases primary production and hence CO_2 uptake
- The dust supply from the North African and Asian deserts directly affects the tropical North Atlantic and temperate North Pacific, respectively;
- There is uncertainty in our understanding of these processes with future priorities including: (i) dust deposition processes, (ii) aerosol iron bioavailability, and (iii) the impact of iron on marine nitrogen fixation and trace gas emissions.

The MA (2005a) on coastal ecosystem assessment identified three categories of direct drivers to coastal ecosystem change which included habitat loss or conversion, habitat degradation, and overexploitation. Land degradation, including deforestation, soil erosion and agricultural runoff, directly contribute to the coastal ecosystem changes.

3.4 Persistent Organic Pollutants (POPs)

3.4.1 POPs and GEF

The Stockholm Convention on Persistent Organic Pollutants (POPs) is an internationally binding treaty directed at the sound management of hazardous chemicals, especially those which are known to be spread throughout the world as a result of past use. The Convention was initiated in 2001 and entered into force on 17 May 2004.

By definition, POPs are highly toxic and highly persistent in the environment, can evaporate and travel long distances through air and through water, and are readily bio-accumulative. The Stockholm Convention currently target 12 chemicals (the dirty dozen) and these include:

- nine organochlorine pesticides (aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex and toxaphene);
- two industrial chemicals (hexachlorobenzene and polychlorinated biphenyls, or PCBs); and
- two groups of chemicals referred to as unintentional byproducts (polychlorinated dioxins and polychlorinated furans, also known as dioxins and furans).

In response to the Stockholm Convention which is aimed at protecting human health and the environment from POPs, the GEF Assembly, at its meeting in Beijing in October 2002, designated POPs as one of GEF's six focal areas, making POPs a major focus of GEF assistance. In 2003, the GEF council adopted its operational program on persistent organic pollutant (OP14). The OP14 refers POPs include pesticides, industrial chemicals or unwanted by-products of industrial processes or combustion (GEF, 2003b).

3.4.2 Source and distribution of POPs

The major sources of POPs in agricultural land are from pesticide application to vegetation and soil and atmospheric transport and deposition of pesticide residues. The major pathways through which the pesticides leave soil are volatilisation to the atmosphere, leaching to the subsoil and ground water, runoff to water systems and uptake by plant and animals (Gevao and Jones, 2002).

POPs-containing pesticides are also used for non-agricultural purposes, for example, DDT was commonly used for malaria control in many developing countries (Bouwman, 2003; Diaz-Barriga et al. 2003).

Pesticides can move in the environment three-dimensionally in different media (air, water, sediments, animals). The processes involved in pesiticide transportation include emission, wash-off, degradation, sorption, adsorption, volatilization, leaching, runoff, deposition, plant and animal uptake (Gavrilescu, 2005). POPs can be emitted to the atmosphere via various routes: transferring to the air flow during the treatment of agricultural crops; evaporating from treated surfaces of plants and soils; and wind erosion (Galiulin et al., 2002). POPs can be atmospherically transported thousands of miles, for example from mid- and low-latitude sources to the Arctic troposphere (Bard, 1999). Bard (1999) showed that the top Arctic predators such as seals and polar bears have surprisingly high levels of POPs contamination. POPs can reach the Arctic mainly through global distillation, the volatilization of pesticides from temperate and tropical zones, followed by atmospheric transport northward, and re-deposition of organic pollutants in colder regions.

Appropriate land management can reduce surface runoff and soil erosion, and therefore reduce the move of POPs from soil to water bodies. Removing these organopollutants from the soil in an ecologically responsible, safe, and cost-effective way is a challenge to land management.

Soil organic matter plays an important role in the control of the fate of POPs in the environment. Wilcke and Amelung (2000) found that the easily measured soil organic carbon concentrations may be used to predict polycyclic aromatic hydrocarbon concentrations in native grassland soils of the prairie.

3.4.3 Bioremediation of POPs

There are different technologies available to remediate soils and groundwater contaminated with POPs. These technologies vary from destructive techniques such as incineration and electro-chemical oxidation, sequestration techniques such as engineered landfills and deep well injection, to bioremediation based on the activities of microbial and phytoremediation using various plants to treat the contaminants. Compared with traditional incineration methods, bioremediation and phytoremediation technologies are more cost effective and environmentally sound (SENES Consultants Limited, 2002)

In addition to POPs, soil micro-organisms are also essential for the bioremediation for other chemical and organic pollutants (Knox et al 1999). Maintaining the diversity of organisms in soils is therefore imperative for the continued and improved effectiveness of bioremediation; and active organisms in the soil will also improve other soil properties such as decomposing organic waste, soil formation and nutrient cycling**.** Capturing the full benefits provided by soil organism will make the bioremediation process more cost-effective, and this perhaps is start point for the synergies between LD control and POPs intervention.

3.5 LD and ecosystem services

In the previous sections of this report we have looked at the impacts of LD on the components and subcomponents of the environment, particularly those covered by the GEF focal areas, e.g. climate (change), biodiversity and international water bodies. Most published work on LD impacts also focuses on specific impacts though precisely quantifying these and attributing them to LD is not always straightforward. This approach does not always reveal or give appropriate emphasis to the links, feedbacks and trade-offs between land degradation, other processes and different environmental components in the same way that ecosystem based frameworks can.

In this section we try to look at LD using the ecosystem service framework, an approach used in the Millennium Ecosystem Assessment (MA 2003) that focuses on the benefits people obtain from ecosystems. These benefits include goods (such as food) and services (such as waste assimilation) (Costanza et al, 1997; de Groot et al, 2002; MA, 2003). The question "What constitutes a global impact?" must still be asked. The view that there is something intrinsic about all ecosystems, from that existing in a small puddle to a large tract of rainforest, that elevates their value to a global level, is not really tenable. We apply here the same principles as those outlined in the introduction to this study: where the impact is on an ecosystem that is very clearly global in extent or importance, this is a global impact. Similarly, the cumulative effect of many smaller impacts on important ecosystem services might also be considered to be global.

3.5.1 Ecosystem services and the MA Framework

Ecosystem services have been identified and categorised in different ways. de Groot et al (2002) identified 23 ecosystem services and categorised them by function into regulation, production, habitat, and information services. The Millennium Assessment (MA) categories were somewhat different: provisioning, supporting, regulating and cultural services (Table 19). *Provisioning services* refer to the products obtained from ecosystems; *Regulating services* are the benefits obtained from the regulation of ecosystem processes; *Cultural services* include non-material benefits people obtain from ecosystems such as cognitive development, reflection, recreation, and aesthetic experiences; *Supporting services* are those necessary for the production of all other ecosystem services. Supporting services differ from provisioning, regulating, and cultural services in that their impacts on people are often indirect or occur over a relatively long time period, whereas changes in the other categories have relatively direct and short-term impacts on people.

Many of these services are interlinked (primary production, photosynthesis, nutrient cycling, and water cycling, for example, all involve different aspects of the same biological processes).

Table 19. Ecosystem services under different categories

Provisioning Services	Regulating Services	Cultural services	Supporting Services
• Food • Fiber • Fuel • Genetic resources • Biochemicals, natural medicines, and pharmaceuticals • Ornamental resources • Freshwater	• Air quality regulation • Climate regulation • Water regulation • Erosion regulation • Water purification and waste treatment • Disease regulation • Pest regulation • Pollination • Natural hazard regulation	• Cultural diversity • Spiritual and religious values • Knowledge systems (traditional and formal) • Educational values • Inspiration • Aesthetic values • Social relations • Sense of place • Cultural heritage values • Recreation and ecotourism	• Soil formation and retention • Production of atmospheric oxygen • Primary Production • Nutrient cycling • Water cycling • Provisioning of habitat

Distribution of ecosystem system services

Ecosystem services are distributed unevenly at different spatial and temporal scales, and their value will also often differ according to stakeholder (Table 20 & 21, Newcome et al, 2005; Rodriguez et al, 2006). An important part of determining the impact of LD on ecosystem services is understanding the scale at which the service is accessed and who the beneficiaries are.

Table 20. Distribution of ecosystem services with generalised indication of beneficiaries

Distributional pattern	Dimensions		
Spatial distribution	Local	Regional/national	Global
Temporal distribution	Short-term	Long-term	
Beneficiary stakeholders	Private individuals	Commercial enterprise	Public bodies

Source: Adapted from Newcome et al, 2005

Table 21. some selected ecosystem services and their distributions

Services	Local	Regional	Global
Livestock/food	x	x	
Plant/food	x	x	
Forest products			
- timber	x	x	x
- fuelwood/charcoal	x	x	
- non-timber forest products	x	x	
Genetic resources			
- traditional medicine	x		
- pharmaceuticals	x	x	x
- research	x	x	x
Flood and water yield regulation	x	x	
water quality improvements	x	x	
Erosion control	x	x	
Pollination	x	x	
Nutrient cycling	x	x	x
Carbon Sequestration	x	x	x
Habitats and species diversity	x	x	x
Aesthetic value	x	x	x
Recreation and tourism	x	x	x
Traditional/cultural knowledge & traditions	x	x	x

Source: Adapted from Newcome et al, 2005

Tradeoffs between ecosystem services

Although categorised into different groups, ecosystem services are inherently linked, and the relationships between them may be highly non-linear. Trade-offs may occur when the desire is to optimize one or more services (often local and short-term) and this leads to reductions or losses in others (often global and long-term; Foley et al. 2005; Rodriguez et al, 2006).

The MA Framework

The MA Framework is designed to address changes in ecosystem services and their implications for human well-being. It integrates the drivers of ecosystem change, the status of ecosystem services and human wellbeing into a single framework with ecosystem service as its cornerstone Figure 6.

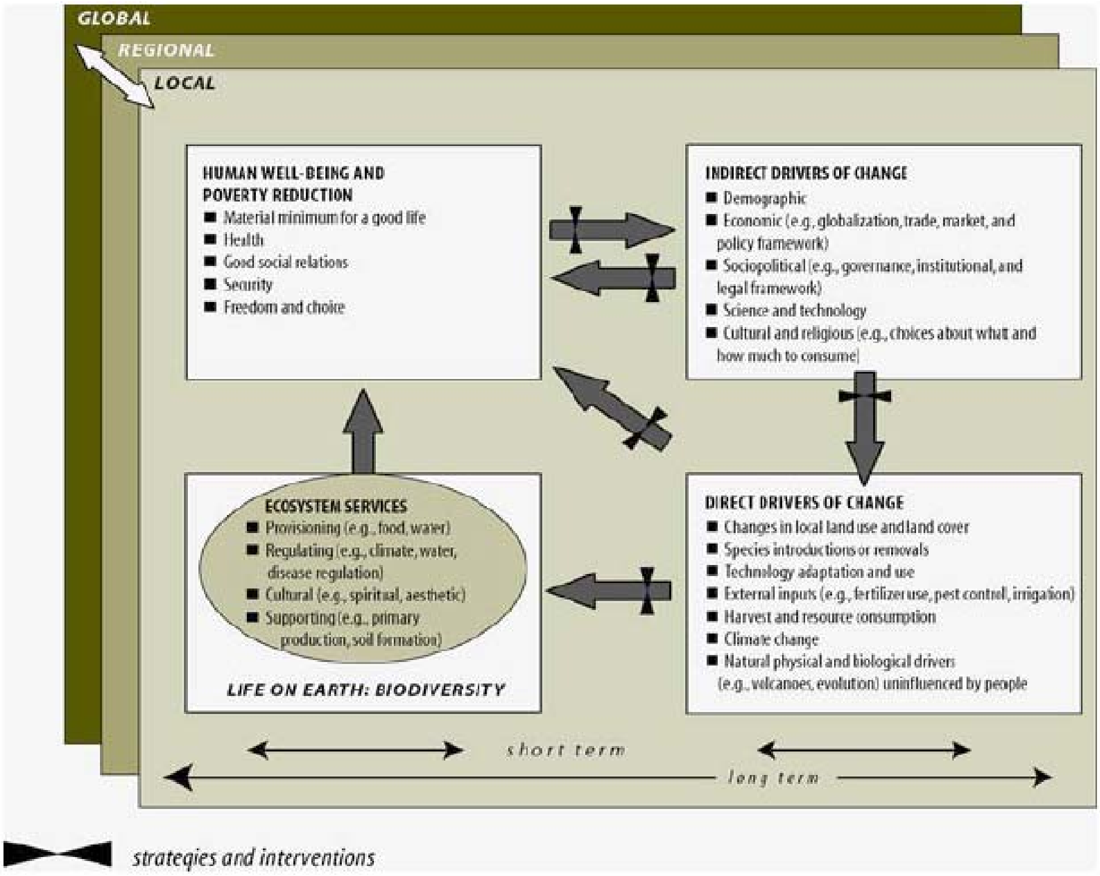

Figure 6. The MA framework (MA, 2003)

3.5.2 LD impacts on ecosystem services

As with impacts in other areas mental issues, LD impacts the ecosystems services through different processes. LD in a particular form may have strong impacts on some services, but week impacts on other services:

Provisioning services

Seeking provisioning services from ecosystems is perhaps the most common and important direct driving force leads to land use change which often either deteriorate the resource base or brings about negative externalities (Foley et al 2005). Therefore, LD may impact on ecosystem's provisioning services through either land use conversion and or inappropriate land management practices.

Land use conversion from one system to another may dramatically increase a particular provisioning service, mostly food, but often at the cost of reducing other services. For example, a study in Sumatra, Indonesia estimated that, when forest is converted into continuous cassava, above ground carbon storage decreases from 306 to 2 t/ha and above plant species (an indicator of biodiversity) from 120 to 15 per standard plot. The trade-off is that this conversion could create 98-104 person-day/ha/yr employment opportunity at the rate of return to labour at 1.78 \$/person-day (Tomich et al, 2005). In this example the trade-off between local/global and short-term/longer term is evident. Although perhaps not immediate, there will eventually be an impact of LD on the local short-term services of most interest to the resource user i.e. crop production and income generation.

Soil erosion and nutrient depletion caused (directly) by inappropriate land management are often the main causes of decline in ecosystem's provisioning services. There is a wide range of methods for quantifying these impacts (e.g. Lal, 1998; Lal et al, 2003; Sanchez, 2002; Tenberg et al, 1998) but the results obtained are often not comparable and this makes it difficult to upscale locally observed results to regional and global level (Lal, 1998).

Regulation services

The regulation services of ecosystem can be impaired by de-vegetation and vegetation degradation, deterioration of soil structure, loss of soil organic matter and organisms, and soil contamination.

Vegetation cover, forests in particular, plays an important role in the global carbon cycle and consequently in regulating the global climate system. The impact of deforestation and forest degradation on climate regulation is discussed in section 3.1.1. Another important impact of deforestation on climate regulation is the change in land surface reflection and water vapour flux, leading to changes in the regional and global temperature and precipitation regime (section 3.1.2).

Water regulation is regarded as another important service of forest and other natural vegetation. Recent reviews of the global evidence, however, shows that flooding is more often associated with inappropriate land use practices rather than deforestation per se (section 3.1.2.1).

As discussed above in section 3.1 soils play a key role in climate regulation, water supply and water purification. Soils represent a major terrestrial stock of carbon and changes in these carbon stocks (both increases and decreases) can be of global significance and may either mitigate or worsen climate change. SOC is vital for ecosystem functions, having a major influence on soil structure, water-holding capacity, cation exchange capacity, and the ability of the soil to form complexes with metal ions and to store nutrients. Appropriate management of soils to increase SOC levels can therefore increase provisioning and other regulating services of the ecosystem (section 3.1.1.4).

Regulating services also contribute to provisioning services, e.g., by reducing soil erosion and providing micro-climatic conditions beneficial to crop production. On a global scale, climate is in part regulated by ecosystems, including land cover, soil organisms, and phytoplankton (Falkowski et al. 2000).

Cultural services

The impact of LD on ecosystem cultural services are more complicated and less easy to measure than some other impacts. Cultural services, mostly intangible, emerge from individual or collective perceptions, and thus are highly dependent on local biophysical and cultural context and can change over time. A change in farming systems, local values, loss of indigenous knowledge are examples of such changes.

Cultural services are often valued and/or accessed in the context of local knowledge systems which may have been developed over thousands of years and are quite often locally specific. For example, the GEF supported project PLEC revealed that it is smallholder farmers, predominantly in the tropics, who have safeguarded and conserved more biological diversity and more economically important species than all protected areas combined. Skilled in using the natural diversity of the environment –

for cultivating crops, managing the soil, water and vegetation, and maintaining their livelihoods in difficult circumstances – they have a wealth of knowledge and skills. Their systems of land use and practices are highly dynamic, drawing on local knowledge, extensive experience and experimentation. In these systems, biodiversity is better protected, land degradation is better controlled, and food security and livelihoods are enhanced (Brookfield et al, 2002; Kaihura and Stocking, 2003). Investigating the cultural service impact of land degradation needs to take account of the diversity knowledge, skills, cultivation norms and organisational arrangement when they exist, as these mediate the impact of land degradation and cultural service provision.

Box 11 details the globally Important Ingenious Agricultural Heritage Systems (GIAHS) project currently being implemented by FAO with a clear focus on cultural values, many of which might be impacted on by LD.

Supporting services

By definition, supporting services are essential for the supplying of all other services, but less directly useable by people. However land degradation impacts on all other ecosystem services through its impacts on these supporting services. Compared with the impacts on other services, the impacts of LD on supporting services can be measured more directly as many supporting services are closely associated with the intrinsic biophysical properties of the ecosystem.

Land degradation in the form of water- and wind-driven soil erosion changes soil structure and can have a negative impact on the cycling of nutrients, particularly those that are soluble or in some other way mobile e.g. nitrogen. This impact is one of decreasing the provisioning services. Most forms of tillage promote soil organic matter decomposition and those practices that lead to soil compaction or surface sealing can reduce soil water infiltration and the ability of the land to play a role in regulating the water cycle. Deforestation and expansion of intensive agriculture often impacts negatively on the regulating and cultural services of ecosystems through the degradation of natural habitats.

3.5.3 Ecosystem integrity

The GEF OP15 used the term "ecosystem integrity" in defining land degradation and the objective:

> … any form of deterioration of the natural potential of land that affects ecosystem integrity. The objective (of OP15) is to mitigate the causes and negative impacts of land degradation on the structure and functional integrity of ecosystems …..

So, ecosystem integrity is used here as both a bench mark for measuring the impact of land degradation, and a target to achieve through sustainable land management. However, it is not wholly clear what the term ecosystem integrity means in the context of land degradation and sustainable land management.

Existing definitions of ecosystem integrity, though used in different contexts, reflect the capability of a system to support services of value to humans (Box 12). When considering the measurement of LD impacts on ecosystem integrity the following are important:

- the ability to maintain services provision: this will include the components and processes through which the ecosystem services are generated. For example adequate soil organic matter improves the formation of water stable aggregate and therefore improves soil water holding capacity and water regulation services
- the rate of service flow: over-use of service may lead to the decline in system's ability to maintain services. For example continued cultivation may lead to soil nutrient deflation and therefore reduce soil's provisioning service
- the interactions among the services and links between different ecosystems, this helps to understand/manage trade-offs, regional integration (up-stream down-stream) and sectoral cooperation (land and water).

Box 12. Ecosystem integrity definitions

– integrity reflects the ability of ecosystems to sustain services to humans and the identification of those services can best emerge from multi-sector partnerships, in which all stakeholders seek agreement on the uses to which an ecosystem will be put, recognizing the linkages with other ecosystems (De Leo and Levin, 1997)

– the maintenance of the community structure and function characteristic of a particular locale deemed satisfactory to society (Cairns, 1977)

– the capability of supporting and maintaining a balanced, integrated, adaptive, community of organisms having species composition, diversity, and functional organisation comparable to that of natural habitats of the region (Karr and Dudley, 1981)

– it is much more useful to characterize in detail the functional and structural aspects of ecosystems to provide a conceptual framework for assessing the impact of human activity on biological systems and to identify practical consequences stemming from this framework (Noss, 1995)

3.5.4 Ecosystem services and Human wellbeing

The well-being of each individual, weather poor or rich, depends on clean water, clean air, fertile soils and other services provided by natural systems (Table 20). However, the natural assets and the services they provide are especially important for the poor. Several recent global assessments/studies have revealed the importance of natural assets and ecosystem services to people living in poverty, and the importance of environmental investment in alleviating world poverty generally (Hamilton, 2005; Newcome et al. 2005; UNDP, 2005; WRI, 2005), the key messages from these studies can be summarised as follows:

- Poor households rely heavily on environmental assets as a source of wealth from which to generate income and improve their livelihoods (Table 22)
- Environmental assets also are an essential source of wealth for developing-country economies (Table 23)
- The environmental assets of poor households are under severe and increasing stress, reducing their livelihood opportunities and ability to escape poverty
- Poor farmers may be aware of the value of ecosystem services, but may be prevented from taking action to conserve them because of more immediate economic pressures, or do not own the titles to land they cultivate.

Table 22. Number of people dependent on various ecosystem services

Dependent on forests in some way	1.6 billion
• Smallholder farmers who grow farm trees or manage remnant forests for subsistence and income	500 million to 1 billion
• Indigenous people wholly dependent on forests	$60 million
Poor dependent on agriculture in Sub-Saharan Africa	>500 million
Rural poor who keep livestock	600 million
• Landless rural poor who keep livestock	150 million
Fishers and fish-farmers in the Lower Mekong River basin	40 million

Source: WRI, 2005

Table 23. Estimation of the composition of per capita wealth, 2000

Income group	Overall wealth per capita ($ in 2000)	Environmental wealth as % of total wealth
Low income	7,532	26
Middle income	27,616	13
High income (OECD)	439,063	2
World	95,860	4

Source: Hamilton et al, 2005

More details about land degradation impacts on human development are discussed in Chapter 4.

3.5.5 Ecosystem services vs global environmental concerns

In the context of understanding the global impacts of land degradation the ecosystem service (ES) and the impacts approach used in the other sections of this report both provide useful, sometimes over-lapping information. The ES framework stimulates a more systematic consideration of issues of the scale at which services are accessed and affected by LD. It also requires the user to engage with the complexity of ecosystems: a challenge but does highlight the importance of linkages and trade-offs between environmental components and options for their management. This approach is valuable as most conventional impact studies (on which this review relies) tend to be more focussed and reductionist in nature generating only partial insights into the diversity of relationships between different environmental components and processes, people and the services they require.

The overlap and complementary between the two approaches are summarised in the following table.

Table 24. Comparison of two approaches in LD impact study

Characteristic	Eco-system service approach	Individual impact approach
Scale	More sophisticated consideration of scale	Focus on global scale impacts
Holistic	Comprehensive, including tangible and intangible aspects	Focus on global environmental concerns, less direct focus on linkages, trade-offs etc.
Measurability and data availability	Many indicators are difficult to measure, particularly cultural services. Available data scant in many areas	Most of indicators are measurable or routinely measured
Relevance to GEF incremental cost assessment	Perhaps less relevant to incremental cost assessment as precise quantification generally difficult	Perhaps allows easier measurement of incremental costs

Table 25. Summary of ecosystem services and global impacts

Service type	Climate change	Biodiversity	International water	POPs	Human wellbeing
Provisioning	GHGs emission from crop production	Biodiversity loss due to land use change and expansion of intensive agriculture	Non-point pollution from crop/livestock production	Application of agrichemicals	Food security, varied diet, income, availability of safe drinking water, clean air etc.
Regulating	Land use change leads to changes in land surface albedo and roughness; carbon storage in vegetation and soil; frequency and extent of dust storms	Pollination and seed dispersal	Soil erosion and sedimentation	Micro-organism activities and bioremediation,	Diseases control; deforestation
Cultural		Indigenous farming systems and management knowledge maintain habitat and species diversity	Holy hills/trees are protected for water regulation		Knowledge and skills; landscapes beauty; spiritual inspiration;
Supporting	Photosynthesis; global nutrient cycling	Soil formation to support above ground and underground biodiversity	Dust storms and ocean fertilization	Bioremediation	Supporting other ecosystem services

4 Human Impacts of Land Degradation

LD impacts directly and indirectly in many ways on people's livelihoods, their vulnerability and food security. A comprehensive review of all the linkages, particularly the indirect ones in all their variety and complexity, is not possible in this report. A useful overview is possible, however, by looking at LD impacts in each of the areas covered by the Millennium Development Goals (MDGs) as most of these address the key social and economic development concerns of the global community.

4.1 Evolution of Land Degradation as an International Development Agenda

The first international effort on tackling land degradation was the Stockholm UN Conference on Human Environment in 1972. There have been a number of key milestones since, charted in Annex 1, as LD/ desertification have become prominent on the international agenda. This increase in prominence has been driven by several factors: (i) increasing pressure on land resources by people; (ii) the perceived acceleration of land degradation and its global impacts (environmental and socio-economic); (iii) the recognition that in many areas where there is concern about hunger and food security these issues are quite closely linked to LD; (iv) the recognition that LD control is rather difficult and examples of clear successes difficult to find.

The United Nations Convention to Combat Desertification (UNCCD) in 1994 was an important milestone promising a coordinated and institutionalised effort from the international community in combating land degradation. However, implementation of the UNCDD in its early days was constrained by several factors including both financial resources and political will (Bassett and Talafre, 2003) and it has only relatively recently engaged with some of the important socio-economic aspects of LD. The Johannesburg World Summit on Sustainable Development (WSSD) in 2002 was another milestone, reaffirming the political support of the international community for the UNCCD and designating GEF as the funding agency for the its implementation. A more explicit recognition of the linkage between LD and the MDGs may also help with implementation of the UNCCD though it remains a challenge to clearly identify and quantify the impacts of LD and the benefits of its control at national and global levels.

4.2 Millennium Development Goals (MDGs)

4.2.1 Overview

The Millennium Development Goals were adopted at the UN Millennium Summit in September 2000 and have provided a framework to help guide the actions and activities of nations and the international development community since. Ensuring environmental sustainability is one of the eight goals, but land degradation was not explicitly included as an indicator in the MDG framework. However, recent progress reports and needs assessments for MDGs and other global efforts such as the MA have recognised that land degradation and soil fertility are key development indicators in many areas due to their close relationship with food security, poverty reduction, health, and environmental sustainability (Box 13).

Box 13. Linking land degradation and MDGs - perspectives of international communities

<u>GEF and MDGs</u>
Land degradation has triggered large-scale population movements, disrupted economic development prospects, aggravated regional conflicts, and threatened the lives and livelihoods of people living under its shadow. The GEF sees the path to ending poverty and hunger as one that must involve sound environmental management and sustainable development practices *(GEF, 2005b)*

<u>MA and MDGs</u>
The loss of services derived from ecosystems is a significant barrier to the achievement of the Millennium Development Goals of reducing poverty, hunger, and disease; the problem of degradation of drylands, a process known as desertification, is acknowledged as a cause as well as a consequence of poverty *(MA, 2005b)*

<u>Role of Agriculture in MDGs</u>
Agriculture plays a crucial role in addressing the needs of a growing global population and is inextricably linked to poverty eradication, especially in developing countries. Enhancing the role of women at all levels and in all aspects of rural development, agriculture, nutrition and food security is imperative *(WSSD, 2000)*

<u>World Bank and MDGs</u>
The sustainable management of land resources will help achieve Goal I by increasing the incomes of the poor and reducing threats to food production in vulnerable areas. Land degradation also contributes to biodiversity loss as habitats are reduced, and to climate change (*World Bank, 2002)*

<u>UNEP and MDGs</u>
Land degradation and desertification are without question among the central issues facing the international community if we are to meet the Millennium Development Goals and achieve a just, healthier and more stable world *(Klaus Toepfer, 2005)*

4.2.2 The distribution of land degradation and the poor

The World Bank estimates that 1.4 billion people worldwide inhabit fragile lands, of whom 1.3 billion are in developing countries (World Bank, 2003). Irrespective of the scale of the analysis there is often a strong association between the distribution of poor people reliant on agriculture and the location of fragile environments, i.e. the poorer people in a community, region or country are likely to be farming the steeper land, the drier less fertile soils or those areas remote from the settlements where forest still exists to be cut down (World Bank, 2003; Table 26). Fragile environments are often more susceptible to LD and poorer people are often relatively less able to practice sustainable land management leading to feedback loops (and the risk of a downward spiral) linking poverty, food security and LD.

Table 26. Environmental fragility in developing countries

Characteristics	Number of people (million)	Share of population on fragile land (%)
Aridity	518	40
Slope	216	17
Poor soil	430	33
Forest	130	10
Total	1,294	100

Adapted from World Bank, 2003

Sub-Sahara Africa has the highest proportion of population living on fragile land (Figure 7) but the extent of the vulnerability of this region goes beyond this. The FAO has attempted to map the global distributions of soil degradation, population pressure (growth rate) and food insecurity (FAO, 1996; 2005). Sub-Sahara Africa and south Asia are revealed as the areas where the highest intensity of all three phenomena occur.

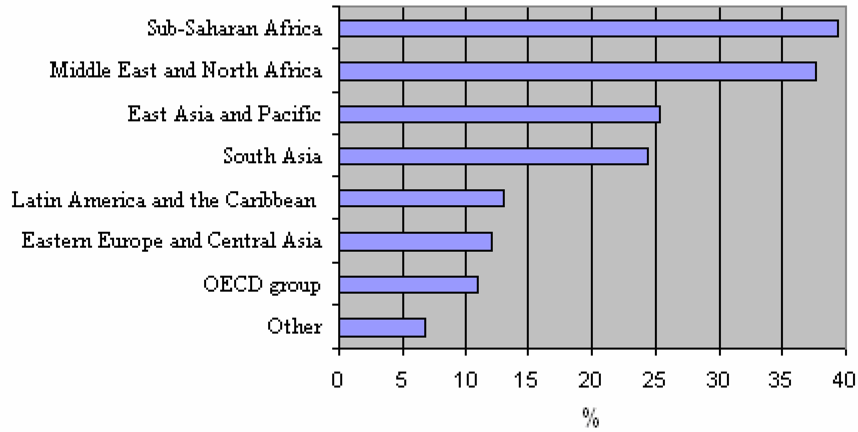

Figure 7. Regional distribution of people living on fragile land (Source: World Bank, 2003)

4.2.3 Land degradation, food security & poverty

LD and agricultural productivity

Food security is influenced by food production, but also its distribution and accessibility. Some current estimates suggest that the global impact of LD on food security is not significant. Wiebe (2003) claimed land degradation (focussed on soil erosion) at a global scale causes annual productivity declines in the order of only 0.4 % for the major crops. However, other (often national level) studies show LD can threaten the food security of poor people in fragile environments, particularly those whose livelihoods rely largely on agricultural activities (Scherr, 1999; Sanchez, 2002).

These apparent contradictions suggest productivity impact might be highly site-specific and some work has indeed shown that the sensitivity and resilience exhibited by a soil are strong determinants of the impact of degradation on productivity (Stocking, 2003; Figure 8). This type of soil specific information can be a very useful guide to management, helping the land-user prioritise management activities and better appreciate when and where investment in conservation might be cost effective. Only a few of this type of study have been conducted, however and there is also a real lack of any synthesis extrapolating from this type of site and soil specific information to national and global level food security.

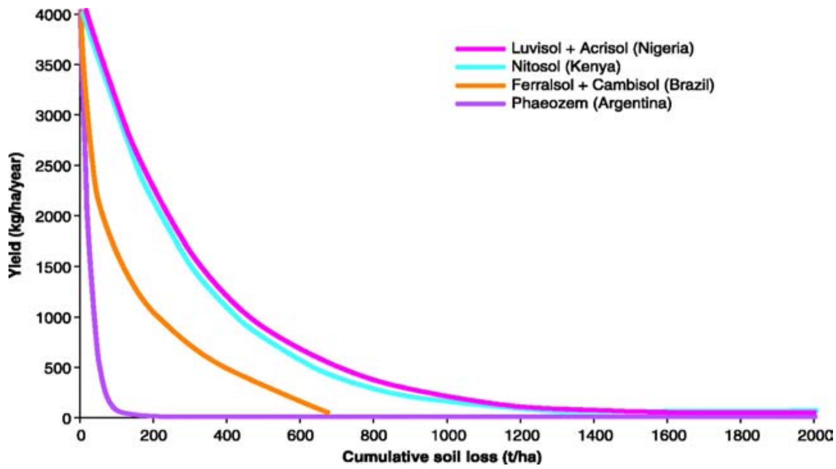

Figure 8. Erosion-yield relationships for a selection of tropical soils

Wiebe (2003) also believes that the real impact of land degradation on food production has been masked by yield growth due to greater use of technology and inputs over the last few decades, drivers expected to be less important in the future. Thus future impacts of LD on productivity and food security could be more severe making it more important to understand these linkages better now. It may also be that it is those areas already suffering most from food insecurity are likely to suffer the greatest impacts from future LD. Biggelaar et al., (2003) evaluated the global impact of soil erosion on productivity (crop yield) by using a large dataset of 179 plot-level studies on soil erosion-productivity from 37 countries. They found that with same amounts of erosion, yield declines were two to six times higher in Africa, Asia, Australia and Latin America than in North America and Europe. In those continents where average yields are already low future yield declines are expected to be more rapid than other continents suffering similar erosion rates.

LD and GDP

About 70 per cent of poor people in developing countries live in rural areas and depend directly or indirectly on agriculture for their livelihoods (WEHAB Working Group, 2002). The relationship between the GDP of a nation and its dependence on agriculture is negative and quite strong (Figure 9). The FAO calculates that the world's average GDP per capita was $5,752 in 2002, and the average contribution of agricultural to national GDP was 4%. For those nations with a per capita GDP less than half of the world average, the average agricultural share in total GDP was 25% (FAO, 2004). This strong reliance of poor countries and the poor within countries on agriculture and other natural resources based activities is supported by other studies (e.g. Hamilton et al., 2005). In a recent Tanzania study it was found that though the average percentage of rural household income derived from agriculture was already quite high at almost 50%, this figure rose to almost 70% for the poorest income quartile (Ellis, 2003). These findings emphasise the relatively high sensitivity of the poor to LD and other forms of natural resource degradation.

The impact of LD on GDP is difficult to quantify precisely and few studies have tried to do this. In one analysis, undertaken in seven developing countries in Africa, Asia, and Latin America, Berry et al., (2003) estimated that the problems of sustainable land management cut 3-7 % from agricultural GDP.

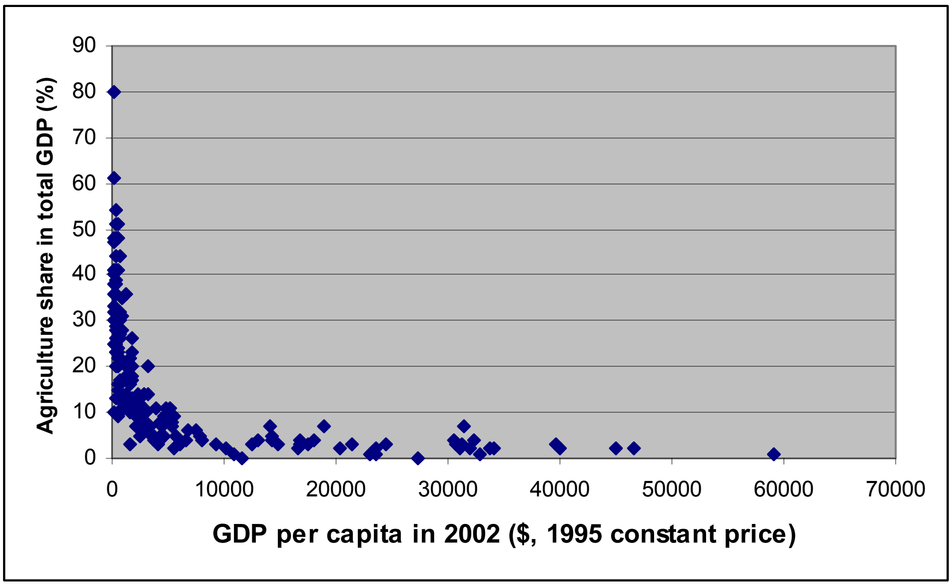

Figure 9. GDP per capita and the share of agriculture in total GDP in 2002 (based on FAO , 2004)

LD and ecosystem services

Wong et al. (2005) examined the linkage between poverty and ecosystem services in seven African countries including Kenya, Mali, Mauritania, Mozambique, Rwanda, Tanzania, and Uganda. It is interesting to note that LD (in its different forms) was the most common factor constraining ecosystem's food and fibre provision functions in this study.

4.2.4 Land degradation, gender and education

Food production, fuel wood collection, soil and water conservation are all areas influenced directly or indirectly by LD and area for which women and girls often take or are given responsibility.

In rural Rajasthan, India, approximately 50 person-hours per month are required for households gathering fuel-wood; in Malawi women, assisted by young girls, spend between 4 hr and 15 hr per week collecting fire wood (depending on the distance to woodland: Laxmi et al., 2003; Rehfuess et al., 2006). Possible consequences of the significant and increasing time requirement for this activity are girls missing days at school or dropping out altogether. For adult women there might be reduced time for child-care, other work duties or leisure. Any strategy that improves the access of rural people to alternative cooking fuel options promises multiple benefits: reduced pressure on forest/vegetation, decreased LD, reduced negative impact on women and girls of the type outlined above etc. (Rehfuess et al., 2006).

Tenge et al. (2004) found that in the West Usambara highlands of Tanzania soil conservation was adopted by 57% of the female-headed households but only 38% of the male-headed households. This suggests that it is particularly important to ensure that women have access and the means to use SWC information but also that improvements in land rights for women are likely to benefit conservation of this resource.

4.2.5 Land degradation and human health

Long-term good health relies on continued stability and functioning of ecosystem (Collins, 2001; MA 2005c). Many of the possible impacts of LD on human health are indirect, mediated through its impacts on climate, biodiversity, hydrological systems, agriculture etc. The recent MA synthesis on ecosystems and human health is perhaps the most comprehensive assessment on the linkage between human health and ecosystem services (MA 2005c). Table 27 summarises the potential impact of land degradation on the infectious diseases extracted from the MA Health report.

Table 27. Infectious diseases and land degradation linkages.

Disease	Emergence Mechanism	Anthropogenic Drivers	Geographical Distribution	Sensitivity to LD	Confidence Level[1]
Malaria	niche invasion; vector expansion	deforestation; water projects	Tropical	+ + + +	+ + +
Chagas disease	habitat alteration	deforestation; urban sprawl and encroachment	Americas	+ +	+ + +
Leishmaniasis	host transfer; habitat alteration	deforestation; agricultural development tropical	Americas; Europe and Middle East	+ + + +	+ + +
Meningitis	habitat alteration; dust storms	desertification	Saharan Africa	+ +	+ +
Rabies	biodiversity loss, altered host selection	deforestation and mining	Tropical	+ +	+ +
Trypanosomia sis	habitat alteration	deforestation	Africa	+ + +	+ +
Guanarito; Junin; Machupo	biodiversity loss; reservoir expansion	monoculture in agriculture after deforestation	South America	+ +	+ + +
Nipah/Hendra viruses	niche invasion	industrial food production; deforestation; climate abnormalities	Australia; Southeast Asia	+ +	+ +

(source: Adapted from MA 2006 (Health Synthesis)). The key to the health impact table:
[1] + = low confidence ; + + = moderate; + + + = high; + + + + = very high.

Dust particles have been shown to cause a wide range of respiratory disorders including chronic bronchitis and lower respiratory illness. A recent MA (2005a) report quoted the research of Molesworth et al. (2003) indicated that dust storms have also been implicated in changes in the spatial and temporal dynamics of meningococcal meningitis epidemics in Saharan Africa. Key factors that have been identified as determinants of areas at risk of epidemic meningitis are land cover and absolute humidity.

4.2.6 Summary: towards better integration of land degradation into the MDGs

The above sections discussed the links between LD and some of the MDGs. LD has direct or indirect links to all of the goals and these are summarised in Table 28.

Table 28. LD and MDGs linkages

MDGs	LD linkages
G 1: Eradicate extreme poverty and hunger	LD induced productivity decline and loss of biodiversity may lead to food insecurity, malnutrition, and increased vulnerability to adverse shocks.
G 2: Achieve universal primary education	Children spending more time on fuel & water collection and food production as land and vegetation degrades.
G 3: Promote gender equality and empower women	The impact of LD on women can be disproportionately high. Women often manage land more sustainably yet have fewer rights and access.
G 4: Reduce child mortality	Malnutrition, food shortage and degraded ecosystems increase the risk of child mortality.
G5: Improve maternal health	Indirect impacts: see G3
G6: Combat HIV/AIDS, malaria and other diseases	Disturbance to ecosystems, water ways and water movement etc. can influence disease transmission pathways; Malnutrition is a serious danger for people living with HIV/AIDS, see G1
G7: Ensure environmental sustainability	LD links to CC, BD, IW, POPs. LD is directly linked to deforestation which is included in the current MDGs framework as an indicator.
G8. Develop a global partnership for development	LD impacts have local, national and global dimensions. Many aspects of LD might be better managed/controlled by global partnerships.

Some recent assessments indicate LD could be better integrated into the current MDG framework. The MDGs needs assessment conducted by the Millennium Project in five pilot countries (Bangladesh, Cambodia, Ghana, Tanzania and Uganda) indicated that, in these countries, the promotion of soil and water conservation and the improvement of soil fertility are the priorities for intervention (Millennium Project, 2004). Similarly the recent World Resource report recommended that the importance of soil fertility and the threat of land degradation to the world's poor are so great that soil fertility and the status of land degradation should be included in the MDG framework (WRI, 2005). This view is also shared by DFID (2005) which argues that the MDGs do not adequately show that poor people suffer most from effects of environmental degradation.

5. Knowledge gaps

Table 29 summarises the main gaps in our knowledge of the impacts of land degradation.

Table 29 Research needs on global environmental impacts of land degradation

Impact	Know with some certainty	Likely but less certain	Need to know
LD on CC	• are an important carbon pool in the global carbon cycle; • Land use change, deforestation in particular, is critical in the global carbon cycle; • Soil management changes can sequester carbon from atmosphere; • Agricultural land use is a major source of CH_4 and N_2O emission	• Land surface change (e.g. albedo, roughness) play an important role in regional and global climate change • The extent to which human activities accelerate the occurrence of sandstorms • The extent to which biomass burning contributes to climate change • The contribution of changes in soil management to carbon sequestration	• The effect of climate change on land degradation trends in different regions/systems • The impact of the changing climate on soil as carbon sink or source • Potential of new LD control technologies for SC sequestration • More on the nature and significance of land/LD/climate feedbacks and their significance • The fate of carbon in eroded soil
LD on BD	• Deforestation (natural forests in particular) leads to loss of habitat and species; • Land use change and management, including fragmentation and burning , leads to loss of habitat and biodiversity; • Non-point pollution from crop production damages aquatic habitats and biodiversity	• Methods (indicators) for measuring the impact of LD on BD	• Impact of biodiversity loss combined with climate change on land degradation • Impact of LD on below ground biodiversity and the impact of this on soil function
LD on IW	• Agricultural land use activities are a major source of pollution of international waters • Land use and land cover change alters the global hydrological cycle	• Atmospheric deposition of soil dust damages coral reefs • The impacts of land degradation isolated from other land-based activities • The pathways by which LD impacts on IW	• Integrated strategies for land and water management • The role of land degradation in the land-ocean-atmosphere linkage
LD on POPs	• Soil is a major pool of POPs • Soil organic matter content and microbial population are important factors in determining the fate of POPs • POPs can be transported through soil erosion and runoff as part of the LD process	• Conditions where soils release or sequester POPs • The extent to which biomass burning produces POPs	• Synergies for soil management and prevention of POPs damage
LD on ecosystem	•	• Ways of measuring the impacts of LD on ecosystem integrity	• The ecosystem services at global level • Strategies for restoration

integrity			of degraded ecosystems • A monitoring and evaluation framework for LD impacts on ecosystem integrity

Land degradation impact pathways
Our knowledge about the nature of impact pathways is limited. Air and water are the major media through which impacts of land degradation are transferred from local to global, for example atmospheric deposition, coastal sedimentation. For some impacts, food chains are also an important pathway, for example the transfer of POPs. Apart from environmental pathways, the impact of land degradation can also be globalised through social pathways. For example rural-urban and trans-boundary migration which transfer the impact of land degradation to other places.

Land degradation and climate change
Much research has been conducted on soil carbon dynamics in recent decades. Mostly for purposes of soil fertility management and quality assessment. These field-observed data, some of them gained from long-term field experiments, are used to demonstrate the contribution of land-use change to atmospheric carbon and the role of land as a carbon sink. There is a lack of frameworks and systematic methods linking field evidence to climatic impacts at different scales.

Emission of other GHGs (e.g. CH_4, N_2O) in the context of LD and CC linkage is still poorly understood and under-researched. Particularly as some carbon sequestration practices risk having their benefits offset by increased N_2O emission.

The impact of land degradation on climate change goes beyond GHG emission. Recent research suggests that land surface change (deforestation in particularly) might have an effect on climate change similar in order to the effect of GHGs. Other research suggests that land-based carbon sequestration practices such as afforestation may reduce the dust supply to atmosphere and then reduce the nutrient deposition in the ocean, so reducing marine biomass production. This may offset the carbon sequestration effects of land based activities. Establishment of vegetation may change the land surface albedo and therefore offset the cooling effect of carbon sequestration of vegetation establishment. There is a need for an all-encompassing framework that can capture all these factors in order to make balanced assessments of the climatic impact of land degradation.

Land degradation and biodiversity
Further research is needed to explore the links between LD and biodiversity in different systems. Some research has highlighted the possible relationship between soil biodiversity and sediment biodiversity. Other research also highlighted the importance of land-water transition areas in land and water biodiversity linkage. But our knowledge of these areas is poor.

Another area which needs further research is the land-ocean linkages (this is also related to international waters) e.g. the desert dust from Africa may have negative effects on coral reefs in Caribbean.

Land degradation and international water
The land-water transition zones, including coastal zone and offshore transboundary waters are the areas need particularly attention. The ecosystem functions and their role in land-water (international) linkage, though important, are under researched. These zones are also important in linking soil biodiversity and sediment biodiversity.

LD and POPs

Land contamination is an important issue in developed countries and is an increasingly common form of LD in developing countries. Though this is traditionally treated as a local problem, the global environmental impact of land contamination is still an under researched area.

Land degradation and sand storms
There is increasing concern about the increased frequency and scale of dust storms, particularly in northeast Asia. For example, ADB and GEF are working with northeast Asian countries on dust storm prevention. There is also growing evidence that dust storms can play an important role in climate change and land-ocean linkages. However, our knowledge is limited on the contribution of human activities to dust storms and the global impacts of interventions aimed to control dust storms.

6. Conclusions and Recommendations

6.1 Summary of impacts

Table 30 summarises our best estimate of the sensitivity of the major global environmental components and processes to land degradation. The clearest linkage is between land degradation and the climate. Carbon pools in soil and above ground vegetation, particularly forest, are large and quite easily influenced by a number of management practices and forms of LD. Estimates of historical contributions of agriculture to atmospheric CO_2, the amounts and rates of carbon lost as a consequence of deforestation and/or conversion of land to agriculture and other soil-vegetation-atmosphere carbon fluxes all suggest that LD has had a significant impact, through raising atmospheric CO_2 concentrations, on climate and future impacts are likely.

The potential impact of deforestation on above-ground biodiversity is large and well documented. Impacts of other forms of LD on biodiversity are less clear with affects on below ground biodiversity likely to be the most significant. There are large gaps in our knowledge here. Variability in the sensitivity of different soils and ecosystems and the biodiversity they contain to LD mean large numbers of quite focussed studies are required to assemble an aggregate estimate of the global impact.

With international waters it is the coastal areas that are most susceptible, particularly to pollution-related impacts as a consequence of LD. There is evidence of global impacts as large stretches of coast can be affected and impacts can extend to reef and other aquatic ecosystems. There is growing interest in the impact/importance of land-derived dust deposits to ocean systems but again this is an area where there is considerable uncertainty.

The contamination of water, ecosystems, food-chains etc. by pesticides applied to or accumulating in soil is the clearest impact linking land and land degradation with persistent organic pollutants. Erosion, and some other forms of LD will contribute to this contamination but other processes, not considered as LD can do this also e.g. normal drainage of water through the soil, the accumulation of soil-derived POPs by growing plants destined for food or feed etc.

Most of the direct impacts of LD on human development would normally be considered not to be global as they occur and have usually to be managed within particular countries. There are countless indirect impacts, however, on the global environment. Any impact on a community that reduces their food supply, their health status, education, wealth etc. will also reduce their ability to manage their environment sustainably, to engage with concerns around global public goods such as biodiversity and a stable climate.

Table 30. Matrix of impacts of land degradation on the global environment.

LD Process	Variables	Climate change	Bio-diversity	International waters	POPs	MDGs	
						Food security	Human health
Land use change (Deforestation, landscape fragmentation,)	Albedo	++					
	Evapotranspiration	++			++		
	Roughness	++					
	Vegetation cover	++		+		+	+
	Vegetation composition	++	+++	+		+	+
	Habitat loss/degradation		+++			++	+++
	Carbon loss from vegetation removal	+++					
	Land use conversion	+++				++	+++
Biomass burning "Land clearing, crop residue burning,)	Aeolian dust emission	++					+++
	GHGs emission	+++					
	POPs emission				+++		++
Dust storms	Absorbing/deflecting incoming radiation	++	++	++	++		
	Nutrient cycle and deposition	+	++	++	++		
	Air pollution						++
Decline in SOC	GHG emission from soil	+++					
	Microbial activities		++		++	+++	
	Soil nutrient availability		++	++		+++	
	Soil structure					+++	
Land contamination	Agro-chemical load in soil		++	+++	+++	+++	
	in surface runoff		++	+++	+++		++
	in sediments		++	+++	+++		++
	in groundwater		+		+++		++
	in food chain		++	++	+++		++
	in atmosphere		++	++	+++		++
Irrigation	Biomass production	++				+++	
	Waterlogging	+				+++	
	Salinization					+++	
	Surface water extraction			++		+++	
	Groundwater depletion		++	++		+++	
Soil erosion	Soil redistribution	++	+++	+++	++		
	Biomass production	++				+++	
Habitation change (mining, road construction)	Land surface disturbance			++			++
	Landscape fragmentation		+++				

* + represents the sensitivity to LD process, where + = light; ++ = medium; +++ = strong

6.2 Concluding points

Throughout the writing of this review we have looked at direct and indirect global impacts of LD. The concentration of GHGs in the atmosphere is straightforward to view in global terms as the direct impact on this is the same everywhere. The indirect impacts are much more variable, however: the consequences of rising GHG concentration for climate, climate change on biophysical and socio-economic systems around the world etc.

Most of the other impacts discussed here, direct and indirect, vary greatly across the globe. For example, the impacts of LD on biodiversity, international waters, human health etc. depend greatly on location and the ability of local systems and/or communities to cope, on their sensitivity and resilience. Where studies have focused on resilience and sensitivity of the systems or system components the impact analysis is often then able to cope with the variability encountered and arrive at more precise quantifications of individual impacts and their cumulative effect. This approach is recommended in future attempts to address the “gaps” identified in Table 29.

This review has shown that some impacts are global because the impacts are on truly global processes such as climate, others are global because they affect global public goods or because they occur sufficiently frequently and/or at sub- and supra-national scales to be of global concern. Practically every impact discussed can have indirect global impacts and we would recommend that GEF take this view also.

Though it is usually possible to say whether there are likely to be incremental impacts/benefits of LD/its control and that they are likely to be significant or not it is difficult to be more precise than this in most cases with the available data.

However, despite the uncertainties and gaps the evidence is there for mainstreaming land degradation concerns into local and national development planning. Mainstreaming at the global level is also required. The MDG framework is a good example of a prominent, globally adopted tool for target-setting and strategic development planning that marginalizes LD issues.

References

Achard F, Eva H D, Stibig H J, Mayaux P, Gallego J, Richards T and Malingreau J P, 2002, Determination of deforestation rates of the world's humid tropical forests. Science 297(5583): 999–1002.

Adams G A and Wall D H, 2000, Biodiversity above and below the surface of soils and sediments: linkages and implications for global change. BioScience 50(12):1043–1048.

Adger W N, Hughes T P, Folke C, Carpenter S R, and Rockström J, 2005, Social-ecological resilience to coastal disasters. Science 309(5737): 1036-1039.

Agren G I and Bosatta E, 2002, Reconciling differences in predictions of temperature response of soil organic matter. Soil Biology & Biochemistry 34: 129-132.

Bard S M, 1999, Global transport of anthropogenic contaminants and the consequences for the Arctic marine ecosystem. Marine Pollution Bulletin 38(5): 356-379.

Bardgett R D and Cook R, 1998, Functional aspects of soil animal diversity in agricultural grasslands. Applied Soil Ecology 10(3): 263-276.

Bassett C and Talafre J, 2003, Implementing UNCCD: towards a recipe for success. Review of European Community and International Law, 12(2):133-139.

Batjes N H, 1996, Total carbon and nitrogen in the soils of the world. European Journal of Soil Science 47 (2): 151-163.

Batjes N H, 2001, Options for increasing carbon sequestration in West African soils: an exploratory study with special focus on Senegal. Land Degradation and Development 12: 131-142.

Belausteguigoitia J C, 2004, Causal chain analysis and root causes: the GIWA approach. Ambio 33(1–2): 7-12.

Berbet M L C and Costa M H, 2003, Climate change after tropical deforestation: seasonal variability of surface albedo and its effects on precipitation change. Journal of Climate16: 2099-2104.

Berry L, Olson J and Campbell D, 2003, Assessing the extent, cost and impact of land degradation at the national level: findings and lessons learned from seven pilot case studies. Report commissioned by the Global Mechanism with the support of the World Bank.

Betts R A, 2000, Offset of the potential carbon sink from boreal forestation by decreases in surface albedo. Nature 408:187-190.

Biggelaar C, Lal R, Wiebe K and Breneman V, 2003, The global impact of soil erosion on productivity I: absolute and relative erosion-induced yield losses, Advances in Agronomy 81:1-48.

Bignell D E, Tondoh J, Dibog L, Pin Huang S, Moreira F, Nwaga D, Pashanasi B, Guimarães Pereira E, Susilo F-X and Swift M J, 2005, Below ground biodiversity assessment – developing a key functional group approach in best-bet alternatives to slash and burn. In: Palm C A, Vosti S A, Sanchez P A and Ericksen P J (eds) Slash-and-Burn Agriculture: The Search for Alternatives, Columbia University Press, pp119-142.

Black H I J, Hornung M, Bruneau P M C, Gordon J E, Hopkins J J, Weighell A J and Williams D L, 2003, Soil biodiversity indicators for agricultural land: nature conservation perspectives. In: Francaviglia R (Ed), Agricultural Impacts on Soil Erosion and Soil Biodiversity: Developing Indicators for Policy Analysis. Proceedings from an OECD Expert Meeting - Rome, Italy, March 2003, pp517-530.

Borysova O, Kondakov A, Paleari S, Rautalahti-Miettinen E, Stolberg F and Daler D, 2005, Eutrophication in the Black Sea region: impact assessment and causal chain analysis. University of Kalmar, Kalmar, Sweden.

Bouwman H, 2003, POPs in Southern Africa, The Handbook of Environmental Chemistry - Persistent Organic Pollutants Vol O: 297-320.

Brookfield H and Stocking M, 1999, Agrodiversity: definition, description and design. *Global Environmental Change* 9(2): 77-80.

Brookfield H, Padoch C, Parsons H and Stocking M 2002, Cultivating Biodiversity. ITDG Publishing, London.

Brussaard L, Behan-Pelletier V M, Bignell D E, Brown V K, Didden W, Folgarait P, Fragoso C, Wall-Freckman D, Gupta V V S R, Hattori T, Hawksworth D L, Klopatek C, Lavelle P, Malloch D W, Rusek J, Söderström B, Tiedje J M and Virginia R A, 1997, Biodiversity and ecosystem functioning in soil. Ambio 26: 563-570.

Bunning S and Jiménez J J, 2003, Indicators and assessment of soil biodiversity/soil ecosystem functioning for farmers and governments. In: Francaviglia R (eds), Agricultural impacts on soil erosion and soil biodiversity: developing indicators for policy analysis. Proceedings from an OECD Expert Meeting - Rome, Italy, March 2003, pp121-141.

Buringh P, 1984, Organic carbon in soils of the world. In: Woodwell G M (eds), The role of terrestrial vegetation in the global carbon cycle. measurement by remote sensing, SCOPE 23. John Wiley, New York. pp. 91-109.

Cairns J, 1977, Quantification of biological integrity. In: Ballentine R K and Guarraia L J (eds), The integrity of water, U.S. Environmental Protection Agency, Office of Water and Hazardous Materials, Washington, DC. pp. 171-187.

Chung Y S, Kim H S, Park K H, Dulam J and Gao T, 2005, Observations of dust-storms in China, Mongolia and associated dust falls in Korea in spring 2003. Water, Air, and Soil Pollution: Focus 5:15–35.

Collins A E, 2001, Land degradation, health ecology and development. Land Degradation and Development 12(3):237-250.

Costanza R, d'Arge R, Groot R. de Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neil RV, Paruelo J, Raskin RG, Sutton P and Belt M Van Den, 1997, The value of the world's ecosystem services and natural capital. Nature 387:253–260.

Cumming G S, Barnes G, Perz S, Schmink M, Sieving K E, Southworth J, Binford M, Holt R D, Stickler C and Van Holt T, 2005, An exploratory framework for the empirical measurement of resilience. Ecosystems 8(8): 975-987.

De Leo G and Levin S, 1997, The multifaceted aspects of ecosystem integrity, Conservation Ecology [online] 1(1)3, http://www.consecol.org/vol1/iss1/art3 (accessed on 2o June 2006)

DEFRA, 2002, The government's strategic review of diffuse water pollution from agriculture in England: agriculture and water: a diffuse pollution review, Department for Environment, Food and Rural Affairs, London.

de Groot R S, Wilson M A and Boumans R M J, 2002, A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics 41(3): 393-408.

DFID, 2005, Environmental Sustainability Factsheet, Policy Division Info series. Ref No: PD Info 048, Department for International Development, London.

Diaz-Barriga F, Borja-Aburto V, Waliszewski S and Yanez L, 2003, DDT in Mexico. The Handbook of Environmental Chemistry - Persistent Organic Pollutants Vol O: 371-388.

Dudley N, Baldock D, Nasi R and Stolton S, 2005, Measuring biodiversity and sustainable management in forests and agricultural landscapes. Philosophical Transactions of the Royal Society of London B 360: 457-470.

Dumanski J, 1997, Criteria and indicators for land quality and sustainable land management. ITC Journal 3-4: 216-222.

Ekschmitt K, Stierhof T, Dauber J, Kreimes K, Wolters V, 2003, On the quality of soil biodiversity indicators: abiotic and biotic parameters as predictors of soil faunal richness at different spatial scales. Agriculture, Ecosystems and Environment 98: 273–283.

Ellis, F and Mdoe, N, 2003, Livelihoods and rural poverty reduction in Tanzania. World Development 31(8):1367–1384.

Engelstaedter S, Kohfeld K E, Tegen I and Harrison S P, 2003, Controls of dust emissions by vegetation and topographic depressions: an evaluation using dust storm frequency data. Geophysical Research Letters, 30(6):1294.

Eswaren H, Vandenberg E and Reich P, 1993, Organic-carbon in soils of the world. Soil Science Society of America Journal 57(1):192-194.

Falkowski P (and other 16 co-authors), 2000, The Global Carbon Cycle: A Test of our Knowledge of Earth as a System. Science 290: 291-296.

FAO and CIFOR, 2005, Forests and floods: drowning in fiction or thriving on facts? RAP Publication 2005/03, Forest Perspectives 2, Published by CIFOR, Bogor and FAO, Rome.

FAO, 1996, World food summit technical background document: technical atlas. http://www.fao.org/wfs/index_en.htm (accessed on 2 May 2006)

FAO, 2001, Global forest resources assessment 2000, FAO Forestry Paper 140, FAO, Rome.

FAO, 2003, World agriculture: towards 2015/2030 - An FAO perspective, FAO, Rome.

FAO, 2004, Carbon sequestration in dryland soils, World Soils Resources Reports 102, FAO, Rome.

FAO, 2005, FAO Statistical Yearbook 2004, FAO, Rome.

FAO, 2006, Global forest resources assessment 2005, FAO Forestry Paper 147, FAO, Rome.

Fearnside P M and Laurance W F, 2004, Tropical deforestation and greenhouse gas emissions. Ecological Applications 14:982-986.

Fidelis Kaihura and Michael Stocking (eds), 2003, Agricultural biodiversity in smallholder farms of East Africa, United Nations University Press, Tokyo.

Fitter A H, 2005, Darkness visible: reflections on underground ecology. Journal of Ecology 93 (2): 231-243.

Foley J A (and 18 co-authors), 2005, Global Consequences of Land Use. Science 309(5734):570-574.

Francaviglia R (ed), 2003, Agricultural Impacts on Soil Erosion and Soil Biodiversity: Developing Indicators for Policy Analysis, Proceedings from an OECD Expert Meeting Rome, Italy, March 2003.

Galiulin R V, Bashkin V N and Galiulina R A, 2002, Behavior of persistent organic pollutants in the air-plant-soil system. Water, Air, and Soil Pollution 137: 179–191.

Gavrilescu M, 2005, Fate of pesticides in the environment and its bioremediation, Engineering in Life Sciences 5(6): 497 – 526.

GEF, 1999, Clarifying linkages between land degradation and the GEF focal areas: an action plan for enhancing GEF support (GEF/C.14/4), Global Environment Facility, Washington DC.

GEF, 2002, Conservation and sustainable use of biodiversity important to agriculture. Operational Program 13, Global Environment Facility, Washington DC.

GEF, 2003a, Sustainable land management. Operational Program 15. Global Environment Facility, Washington DC

GEF, 2003b, Persistent organic pollutants. Operational Program 14. Global Environment Facility, Washington DC

GEF, 2005a, Additional information to support the GEF strategy to enhance engagement with the private sector (GEF/C.27/Inf.7), Global Environment Facility, Washington DC.

GEF, 2005b, Achieving the Millennium Development Goal - A GEF progress report, Global Environment Facility, Washington DC

GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection) and Advisory Committee on Protection of the Sea. 2001. Protecting the oceans from land-based activities - land-based sources and activities affecting the quality and uses of the marine, coastal and associated freshwater environment. Rep. Stud. GESAMP No. 71, 162 pp.

Gevao B and Jones K C, 2002, Pesticides and persistent organic pollutants. In: Haygarth P M and Jarvis S C (eds), Agriculture, Hydrology and Water Quality, CAB International, pp83-106.

Giardina C, and Ryan M, 2000, Evidence that decomposition rates of organic carbon in mineral soil do not vary with temperature. Nature 404: 858-861.

Gisladottir G, Stocking M, 2005, Land degradation control and the global environmental benefits. Land Degradation and Development 16: 99-112.

Goudie A S and Middleton N J, 1992, The changing frequency of dust storms through time, Climatic Change 20: 197-225.

Goudie A S and Middleton N J, 2001, Saharan dust storms: nature and consequences. Earth-Science Reviews 56 : 179–204.

Groffman P M and Bohlen P J, 1999, Soil and sediment biodiversity. Bioscience 49(2):139-148.

Guo L B and Gifford R M, 2002, Soil carbon stocks and land use change: a meta analysis. Global Change Biology 8:345-360.

Gustafson R C, 2005, Land degradation and the GEF: a guide to developing project proposals and accessing project funding from the Global Environment Facility for sustainable land management. United Nations Environment Programme, Nairobi and the Global Environment Facility, Washington DC.

Gyasi E A, Kranjac-Berisavljevic G, Blay E and Oduro W, 2004, Managing agrodiversity the traditional way: lessons from West Africa in sustainable use of biodiversity and related natural resources. UNU Press, Tokyo.

Hamilton K, Ruta G, Bolt K, Markandya A, Pedroso-Galinato S, Silva P, Saeed Ordoubadi M, Lange G M and Tajibaeva L, 2005, Where is the wealth of nations? Measuring capital for the 21st century, World Bank, Washington DC.

Harris J A, 2003, Measurements of the soil microbial community for estimating the success of restoration. European Journal of Soil Science 54:801–808.

Harrison S, 2004, Dust, land-use and climate change, Global Change News Letter No. 58:3-4.

Hartemink A E 2002. Soil science in tropical and temperate regions - some differences and similarities. Advances in Agronomy 77:269-292.

Hempel G and Daler D, 2004, Why a global international waters assessment (GIWA)? Ambio 33(1–2):2-7.

Houghton R A, 2003, Revised estimates of the annual net flux of carbon to the atmosphere from changes in land use and land management 1850–2000. Tellus 55B:378–390.

Houghton R A, 2005, Tropical deforestation as a source of greenhouse gas emissions. In: Moutinho P and Schwartzman S (eds), 2005, Tropical Deforestation and Climate Change, Instituto de Pesquisa Ambiental da Amazônia, Belém, Pará, Brazil, pp13-21.

IFA, 2006, (IFA) Total fertilizer nutrient consumption - Million tonnes nutrients, N + P_2O_5 + K_2O. http://www.fertilizer.org/ifa/statistics/indicators/tablen.asp (accessed on 20 June 2006).

IPCC, 2000, Land use, land-use change, and forestry - a special report of the intergovernmental panel on climate change, Cambridge University Press.

IPCC, 2001, Climate change 2001: the scientific basis, Cambridge University Press.

IUCN, 2004, 2004 IUCN red list of threatened species: a global species assessment. IUCN, Gland, Switzerland and Cambridge, UK.

Jarecki M K and Lal R, 2005, Soil organic carbon sequestration rates in two long-term no-till experiments in Ohio. Soil Science 170(4):280-291.

Jickells T D, An Z S, Andersen K K, Baker A R, Bergametti G, Brooks N, Cao J J, Boyd P W, Duce R A, Hunter K A, Kawahata H, Kubilay N, LaRoche J, Liss P S, Mahowald N, Prospero J M, Ridgwell A J, Tegen I and Torres R, 2005, Global iron connections between desert dust, ocean biogeochemistry, and climate. Science 308(5718): 67 – 71.

Jones C, McConnell C, Coleman K, Cox P, Falloon P, Jenkinson Dand Powlson D, 2005, Global climate change and soil carbon stocks: predictions from two contrasting models for the turnover of organic carbon in soil. Global Change Biology 11: 154–166.

Jones T H and Bradford M A, 2001, Assessing the functional implications of soil biodiversity in ecosystems. Ecological Research16(5):845-858.

Kaihura F and Stocking M A, 2003, Agricultural biodiversity in smallholder farms of East Africa, Tokyo/New York/Paris: United Nations University Press.

Karr J R and Dudley D R 1981, Ecological perspective on water quality goals. Environmental Management 5: 55-68.

Keppler F, Hamilton J T G, Braß M and Röckmann T, 2006, Methane emissions from terrestrial plants under aerobic conditions. Nature 439: 187-191.

Klaus Toepfer, 2005, Speech at high-level segment of the UNCCD COP 7, Nairobi, October 2005. http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=456&ArticleID=5013&l=en (accessed on 2 May 2006).

Knorr W, Prentice I C, House J I, and Holland E A, 2005, Long-term sensitivity of soil carbon turnover to warming. Nature 433:298–302.

Knox A S, Gamerdinger A P, Adriano D C, Kolka R K and Kaplan D I, 1999, Sources and practices contributing to soil contamination. In: Adriano D C, Bollag J M, Frankenberger, Jr W T and Sims R C (Eds) Bioremediation of Contaminated Soils, No. 37, Ch. 4

Lal R, 1998, Soil erosion impact on agronomic productivity and environment quality. Critical Reviews in Plant Sciences 17(4):319-464.

Lal R, 2003, Soil erosion and the global carbon budget, Environment International 29(4):437-50

Lal R, den Biggelaar D and Wiebe K D, 2003. Measuring on-site and off-site effects of soil erosion on productivity and environment quality. In: Francaviglia R (ed) Agricultural impacts on soil erosion and soilo biodiversity: developing indicators for policy analysis, Proceedings from an OECD Expert Meeting, Rome, Italy.

Lal, R and Bruce J P, 1999, The potential of world cropland soils to sequester C and mitigate the greenhouse effect. Environmental Science & Policy 2(2): 177-185.

Lanly J P, 2003, Deforestation and forest degradation factors, Paper to World Forestry Congress XII, Quebec City, Canada. http://www.fao.org/DOCREP/ARTICLE/WFC/XII/MS12A-E.HTM (accessed on 2 May 2006).

Lawton R O, Nair U S, Pielke R A, and Welch R M, 2001, Climatic impact of tropical lowland deforestation on nearby montane cloud forests. Science 294:584-587.

Laxmi V, Parikh J, Karmakar S and Dabrase P, 2003, Household energy, women's hardship and health impacts in rural Rajasthan, India: need for sustainable energy solutions. Energy for Sustainable Development 7(1):50-68.

Leach M, Mearns R and Scoones I, 1999, Environmental entitlements: dynamics and institutions in community-based natural resource management. World Development 27: 225-247.

Li D and Daler D, 2004, Ocean pollution from land-based sources: East China Sea, China. Ambio 33:107-113.

Liebig M A , Morgan J A, Reeder J D, Ellert B H, Gollany H T and Schuman G E, 2005, Greenhouse gas contributions and mitigation potential of agricultural practices in northwestern USA and western Canada. Soil & Tillage Research 83:25–52.

MA, 2003, Millennium Ecosystem Assessment: Ecosystems and Human Well-being -- A framework for assessment. World Resources Institute, Washington DC.

MA, 2005a, Ecosystems and human well-being: current state and trends, Millennium Ecosystem Assessment. World Resources Institute, Washington DC.

MA, 2005b, Living beyond our mean: natural assets and human wellbeing, Statement from the Board, Millennium Ecosystem Assessment. World Resources Institute Washington DC.

MA, 2005c, Ecosystems and human well-being: Health synthesis, Millennium Ecosystem Assessment. WHO, Geneva.

Marland G (and 18 co-authors), 2003, The climatic impacts of land surface change and carbon management, and the implications for climate-change mitigation policy. Climate Policy 3:149–157.

McNeeley J and Scherr S, 2003, Ecoagriculture: strategies to feed the world and save wild biodiversity. Island Press, Washington DC

McNeeley J, 2005, Mainstreaming agrobiodiversity. In: Peterson C and Huntley B (eds.) Mainstreaming biodiversity in production landscapes. GEF Working Paper 20, Global Environment Facility, Washington DC, pp.36-50.

Melillo J M, Steudler P A, Aber J D, Newkirk K, Lux H, Bowles F P, Catricala C, Magill A, Ahrens T and Morrisseau S, 2002, Soil warming and carbon-cycle feedbacks to the climate system. Science 298 :2173-2176.

Millennium Project, 2004, Millennium development goals needs assessments: country case studies of Bangladesh, Cambodia, Ghana, Tanzania and Uganda. Millennium Project , New York.

Milne E, Easter M, Cerri C E, Paustian K and Williams S (Eds), 2006, Assessment of soil organic carbon stocks and change at national scale. Technical report of the Global Environment Facility co-financed project No.GFL-2740-02-438.

Molesworth A M, Cuevas L E, Connor S J, Morse A P and Thomson M C, 2003, Environmental risk and meningitis epidemics in Africa. Emerging Infectious Diseases 9(10):1287–1293.

Moutinho P and Schwartzman S (eds), 2005, Tropical deforestation and climate change, Instituto de Pesquisa Ambiental da Amazônia, Belém, Pará, Brazil.

Myers N, Mittermeier R A, Mittermeier C G, da Fonseca G A, Kent J, 2000, Biodiversity hotspots for conservation priorities. Nature 403: 853-858.

Naidu R, 1998, Contaminants and the soil environment - Preface. Geoderma 84:1–2.

Natsagdorj L, Jugder D, Chung Y S, 2003, Analysis of dust storms observed in Mongolia during 1937–1999. Atmospheric Environment 37:1401–1411.

Newcome J, Provins A, Johns H, Ozdemiroglu E, Ghazoul J, Burgess D and Turner K, 2005, The Economic, Social and Ecological Value of Ecosystem Services: A Literature Review. Report prepared for the Department for Environment, Food and Rural Affairs (Defra) by Economics for the Environment Consultancy (EFTEC), London.

Noss R, 1995, Maintaining ecological integrity in representative reserve networks. Discussion paper. World Wildlife Fund Canada/World Wildlife United States, January 1995. Cited from: De Leo, G. and Levin, S,. 1997. The multifaceted aspects of ecosystem integrity, Conservation Ecology [online] 1(1)3, http://www.consecol.org/vol1/iss1/art3 (accessed on 20 June 2006)

NPP Taskforce, 2004, Policy recommendations to reduce non-point pollution from crop production in China, Report submitted to China Council for International Cooperation on Environment and Development. http://www.harbour.sfu.ca/dlam/04nonpoint.htm (accessed on 20 June 2006)

Nye, P H and Greenland D J, 1960, The soil under shifting cultivation. Commonwealth Agricultural Bureau, Farnham Royal, Bucks, United Kingdom.

Obbard J P and Jones K C, 2001, Measurement of symbiotic nitrogen-fixation in leguminous host-plants grown in heavy metal-contaminated soils amended with sewage sludge. Environmental Pollution 111:311-320.

Odada E O, Olago D O, Kulindwa K, Ntiba M and Wandiga S, 2004, Mitigation of environmental problems in Lake Victoria, East Africa: causal chain and policy options analyses. Ambio 33(1–2):13-23.

Oldeman L, 1994, The global extent of soil degradation. In: Greenland D and Szabolcs I (eds), Soil Resilience and Sustainable Land Use, Wallingford, UK, pp99-118.

Oost K Van, Govers G, Quine T A, Heckrath G, Olesen J E, Gryze S D and Merckx R, 2005, Landscape-scale modelling of carbon cycling under the impact of soil redistribution: the role of tillage erosion. Global Biogeochemical Cycles 19-B4014, doi:10.1029/2005GB002471.

Pacini, C., Wossink, A., Giesen, G., Vazzana, C. and Huirne, R. 2003. Evaluation of sustainability of organic, integrated and conventional farming systems: A farm and field-scale analysis. Agriculture, Ecosystems and Environment 95: 273-288.

Palm C A, Noordwijk M van, Woomer P L, Alegre J C, Arévalo L, Castilla C E, Cordeiro D G, Hairiah K, Kotto-Same J, Moukam A, Parton W J, Ricse A, Rodrigues V and Sitompul S M, 2005, Carbon Losses and sequestration after land use change in the humid tropics. In: Palm C A, Vosti S A, Sanchez P A, and Ericksen P J (eds), Slash-and-Burn Agriculture: The Search for Alternatives, Columbia University Press, pp41-63.

Pielke R A, Marland G, Betts R A, Chase T N, Eastman J L, Niles J O, Niyogi D D S and Running S W, 2002, The influence of land-use change and landscape dynamics on the climate system: relevance to climate-change policy beyond the radiative effect of greenhouse gases. Philosophical Transactions of the Royal Society of London Series A-Mathematical Physical and Engineering Sciences 360 (1797): 1705-1719.

Post W M, Emanuel W R, Zinke P J and Stangenberger A G, 1982, Soil carbon pools and world life zones. Nature 298:156-159.

Potter K N, Torbert H A ,Johnson H B and Tischler C R, 2000, Carbon storage after long-term grass establishment on degraded soils. Soil Science 164: 718-725.

Powlson D, 2005, Will soil amplify climate change? Nature 433:204–205.

Pretty J N, Brett C, Gee D, Hine R E, Mason C F, Morison J I L, Raven H, Rayment M D, Bijl G van der, 2000, An assessment of the total external costs of UK agriculture. Agricultural Systems 65 (2):113-136.

Prospero J M, Ginoux P, Torres O, Nicholson S E and Gill T E, 2002, Environmental characterization of global sources of atmospheric soil dust identified with the Nimbus 7 total ozone mapping spectrometer (TOMS) absorbing aerosol product. Reviews of Geophysics 40(1):1002, doi:10.1029/2000RG000095.

Rehfuess E, Mehta S, and Prüss-Üstün A, 2006, Assessing household solid fuel use: multiple implications for the Millennium Development Goals. Environmental Health Perspectives 114(3): 373–378.

Rosenfeld D, Rudich Y and Lahav R, 2001, Desert dust suppressing precipitation: a possible desertification feedback loop. PNAS 98(11): 5975-5980.

Rodríguez J P, Beard T D Jr, Bennett E M, Cumming G S, Cork S, Agard J, Dobson A P and Peterson G D, 2006 Trade-offs across space, time, and ecosystem services. Ecology and Society **11**(1): 28. [online] http://www.ecologyandsociety.org/vol11/iss1/art28 (accessed on 20 June 2006)

Sala O E, Chapin F S , Armesto J J , Berlow E, Bloomfield J, Dirzo R, Huber-Sanwald E, Huenneke L F, Jackson R B, Kinzig A, Leemans R, Lodge D M, Mooney H A, Oesterheld M, Poff N L, Sykes M T, Walker B H, Walker M, Wall D H, 2000, Global biodiversity scenarios for the year 2100. Science 287(5459):1770-1174.

Sanchez P A, 2002, Soil fertility and hunger in Africa. Science 295: 2019 – 2020.

Scheer S J, 1999, Soil degradation: a threat to developing-country food security by 2020? Food, Agriculture, and the Environment Discussion Paper 27. International Food Policy Research Institute, Washington, DC.

Scheren P A G M, Zanting H A and Lemmens A M C, 2000, Estimation of water pollution sources in Lake Victoria, East Africa: application and elaboration of the rapid assessment methodology. Journal of Environmental Management 58: 235–248

SENES Consultants Limited, 2002, Technical guidelines for environmentally sound management of persistent organic pollutant wastes. Report prepared for: Secretariat of the Basel Convention United Nations Office at Geneva.

Smith P, 2002, Effects of cultivation practice on carbon storage in arable soils and grassland. In: Petersen S O and Olesen J E (eds), Greenhouse gas inventories for agriculture in the Nordic countries, DIAS Report Plant Production no. 81, DIAS, Tjele, Denmark: 64-69.

Smith P, 2004, Soils as carbon sinks: the global context. Soil Use and Management 20(2):212-218.

Sombroek W G, Nachtergaele F O and Hebel A, 1993, Amounts, dynamics and sequestering of carbon in tropical and sub-tropical soils. Ambio 22 (7): 417-426

Stallard R F, 1998, Terrestrial sedimentation and the carbon cycle: coupling weathering and erosion to carbon burial. Global Biogeochemical Cycles 12 (2): 231-257.

Stocking M, 2003, Tropical soils and food security: The next 50 years. Science 302:1356-1359.

Stokstad E, 2004, Defrosting the carbon freezer of the North. Science 304:10618-1620.

Swift M J, Izac A-M N, Noordwijk M van, 2004, Biodiversity and ecosystem services in agricultural landscapes - are we asking the right questions? Agriculture, Ecosystems and Environment 104:113–134.

Swift, M, 2001, Soil biodiversity principles, expert review for the UNEP BPSP initiative on Managaing Agricultural Resources for Biodiversity Conservation: A Guide to Best Practices. http://www.unep.org/bpsp/Agrobiodiversity/agrobiodiversity%20thematic/soilbiodiv.pdf (accessed on 2 May 2006)

Tegen I and Fung I, 1995, Contribution to the atmospheric mineral aerosol load from land surface modification. Journal of Geophysical Research 100(D9):18,707–18,726.

Tegen I, Werner M, Harrison S P and Kohfeld K E, 2004, Relative importance of climate and land use in determining present and future global soil dust emission, Geophysical Research Letters 31:L05105, doi:10.1029/2003GL019216.

Tenberg A, Veiga D M, Dechen S C F and Stocking M. 1998, Modelling the impact of erosion on soil productivity: A comparative evaluation of approaches on data from southern Brazil. Experimental Agriculture 34:55-71.

Tenge A J, Graaff J D and Hella J P, 2004, Social and economic factors affecting the adoption of soil and water conservation in West Usambara highlands. Tanzania, Land Degradation and Development 15: 99–114.

Thrupp, L.A. 2004. The importance of biodiversity in agro-ecosystems. Journal of Crop Improvement 12: 315-337.

Tomich T P (and 14 co-authors), 2005, Balancing agricultural development and environmental objectives. In: Palm C A, Vosti S A, Sanchez P A, and Ericksen P J (eds), Slash-and-Burn Agriculture: The Search for Alternatives, Columbia University Press, pp415-440.

Twong'o T K, Sikoyo G M and Wakhungu, J W (eds.) A cross-border survey of aquatic-resources management in East Africa, African Centre for Technology Studies (ACTS) (http://www.acts.or.ke/pages/publications/TBNRM%20%20Status%20and%20Trends%20Chpt2.pdf) (Accessed on 2 May)

UNCBD, 2004, Thematic programmes - dry and sub-humid lands biodiversity. http://www.biodiv.org/programmes/areas/dryland/default.asp (accessed on 2 May 2006).

UNEP, 2006, Challenges to international waters – regional assessments in a global perspective. United Nations Environment Programme, Nairobi, Kenya.

van der Werf, G. R., J. T. Randerson, J. Collatz, and L. Giglio, 2003, Carbon emissions from fires in tropical and subtropical ecosystems. Global Change Biology 9: 547–562.

Verschuren D, Johnson T C, Kling H J, Edgington D N, Leavitt P R, Brown ET, Talbot M R and Hecky R E, 2002, History and timing of human impact on Lake Victoria, East Africa. Proc. Roy. Soc. London B 269: 289-294.

Washington R, Todd M, Middleton N J, and Goudie A S, 2003, Dust-storm source areas determined by the total ozone monitoring spectrometer and surface observations. Annals of the Association of American Geographers 93 (2): 297-313.

WEHAB Working Group, 2002, A framework for action on agriculture, background paper for World Summit for Sustainable Development, Johannesburg.

West T O and Post W M, 2002, Soil organic carbon sequestration rates by tillage and crop rotation: a global data analysis, Soil Sci. Soc. Am. J. 66:1930–1946.

White R and Nackoney J, 2003, Drylands, people, and ecosystem goods and services: A web-based geospatial analysis, http://forests.wri.org/pubs_content.cfm?PubID=3813 (accessed on 2 May 2006).

White R, Murray S and Rohweder M, 2000, Pilot analysis of global ecosystems grassland ecosystems. World Resources Institute, Washington DC.

Wiebe K, 2003, Linking land quality, agricultural productivity and food security. Agricultural Economic Report, No 83, USDA, Washington DC.

Wilcke W and Amelung W, 2000, Persistent organic pollutants in native grassland soils along a climosequence in North America. Soil Science Society of America Journal 64:2140-2148.

WMO, 2005, Climate change and land degradation, WNO-No 989, Gevena.

Wong C, Roy M and Duraiappah A K, 2005, Connecting poverty & ecosystem services: a series of seven country scoping studies. UNEP, Nairobi, Kenya.

World Bank, 2002, The environment and the Millennium Development Goals, World Bank Working Paper No. 2476, Washington DC.

World Bank, 2003, World development report 2003: sustainable development in a dynamic world, World Bank, Washington, DC.

WRI, 2005, World Resources 2005 - The wealth of the poor: managing ecosystems to fight poverty. World Resources Institute, Washington DC.

WSSD, 2000, Report of the world summit on sustainable development, A/CONF199/20. United Nations, New York.

Annex 1. The evolution of LD on the International Development Agenda

Table A1. Evolution of LD as an International Development Agenda

Dates	Events	Consensuses and Efforts
1972	UN Conference on the Human Environment, Stockholm	Natural resources… including land… must be safeguarded … (*Declaration principle 2*); the necessary machinery for the international acquisition of knowledge and transfer of experience on soil capabilities, degradation, conservation and restoration should be strengthened (*Declaration recommendation 15)*
1977	UN Conference on Desertification (UNCOD)	Held in Nairobi, Kenya: Desertification addressed as a worldwide problem for the first time and a Plan of Action to Combat Desertification (PACD) adopted
1987	Our Common Future (Brundtland Report)	Definition of Sustainable Development: Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs
1990	Global Assessment of Human-induced Soil Degradation (GLASOD)	Committed by UNEP and implemented by ISRIC, the GLASOD project (1987-1990) produced a world map of human-induced soil degradation. Status of soil degradation was mapped within loosely defined physiographic units (polygons), based on expert judgement. Despite its short-comings, this remains the only database to define the status of human-induced soil degradation at the global scale.
1992	UN Conference on Environment and Development– Earth Summit	Held in Rio de Janeiro, Brazil, the Earth Summit and Agenda 21 call on the UN General Assembly to set up an inter-governmental committee to prepare a legally binding instrument that addresses the problem of desertification
1992	Agenda 21	An outcome of the Earth Summit, is a 40 chapter action blueprint on specific issues relating to sustainable development. Chapter 12 is dedicated to the problem of desertification.
1994	United Nations Convention to Combat Desertification (UNCCD)	Adopted in Paris, the Convention is the first international treaty to address the issues of poverty and environmental degradation in rural areas, particularly in Africa. June 17 becomes the world day to combat desertification
1997	The World Atlas of Desertification	Produced by UNEP the Atlas summarises the state of scientific knowledge on the drylands of the globe. It clearly shows that desertiflcation is one of the world's most pressing environmental problems, and that it is a truly global issue.
2000	UN Millennium Declaration	Reaffirmed support for the principles of sustainable development, including those set out in Agenda 21 (*para 22*). To press for the full implementation of the Convention on Biological Diversity and the Convention to Combat Desertification in those Countries Experiencing Serious Drought and/or Desertification, particularly in Africa (*para 23*)
2002	World Summit on Sustainable Development (WSSD)	Reaffirmed the role of land degradation control in poverty reduction: Combat desertification and mitigate the effects of drought and floods through…. as one of the tools for poverty eradication; …address causes of desertification and land degradation in order to maintain

		and restore land, and to address poverty resulting from land degradation. Called on the Global Environment Facility (GEF) to designate land degradation as a focal area, and making GEF a financial mechanism of the UNCCD (*Report of the WSSD, A/CONF.199/20)*
2002	Global Environmental facility 2nd Assembly	Held in Beijing, land degradation was adopted as one of GEF's focal areas: OP15 with the title of Sustainable Land Management is dedicated to the new focal area.
2005	World Summit 2005	Reaffirmed the support to combating land degradation as set out in WSSD 2002 *(2005 World Summit Outcome, A/RES/60/1).*
2005	Millennium Ecosystem Assessment (MA)	Launched by U.N. Secretary- General Kofi Annan in June 2001 and was completed in March 2005, the MA aimed to provide decision makers and the public scientific information concerning the consequences of ecosystem change for human well-being and options for responding to those changes. The synthesis report of the MA with title of Ecosystems and Human Well-being: Desertification Synthesis integrates findings of the MA related to current state and future trends of desertification and its impacts on ecosystems and human well-being.
2006	International Year of Desert and Desertification (IYDD)	Declared by UN General Assembly, the International Year of Deserts and Desertification (IYDD). The IYDD is aimed to support the implementation of Agenda 21, the Plan of Implementation of the World Summit on Sustainable Development, and raise public awareness (Resolution adopted by the General Assembly, A/RES/58/211)
On-going	Millennium Development Goals (MDGs)	Adopted in 2000 in the UN Millennium Declaration, the MDGs set out time-bound and quantified targets for addressing extreme poverty for all the nations in the world. It targets all the important aspects of poverty - income, hunger, disease, shelter, gender equality, education, environmental sustainability and international aid. Land degradation was not included as a indicator in the beginning, but recent reviews and assessments recognised the importance to address land degradation and soil fertility because its close link to poverty and food security.
On-going	Land Degradation Assessment in Drylands (LADA)	The LADA project aims to assess causes, status and impact of land degradation in drylands in order to improve decision making for sustainable development in drylands at local, national, sub-regional and global levels.

(sources: based on the information on relevant web-sites)

---

[1] **Sensible heat transfer:** movement of heat from one place to another as a consequence of conduction or convection or both**; latent heat transfer:** heat added or removed during a change of state of a substance i.e. solid, to a liquid to a gas or vice versa, the temperature remaining constant