OECD Environment Working Papers No. 93

The Economic Feedbacks of Loss of Biodiversity and Ecosystems Services

Anil Markandya

https://dx.doi.org/10.1787/5jrqgv610fg6-en

OECD

Unclassified **ENV/WKP(2015)14**

Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development **10-Nov-2015**

English - Or. English

ENVIRONMENT DIRECTORATE

ENV/WKP(2015)14
Unclassified

THE ECONOMIC FEEDBACKS OF LOSS OF BIODIVERSITY AND ECOSYSTEMS SERVICES - ENVIRONMENT WORKING PAPER No. 93

By Anil Markandya from the Basque Center for Climate Change, Bilbao, Spain

OECD Working Papers should not be reported as representing the official views of the OECD or of its member countries. The opinions expressed and arguments employed are those of the author.

Authorised for publication by Simon Upton, Director, Environment Directorate.

Keywords: biodiversity, ecosystem services, MSA.

JEL classification: Q22, Q57, D55, O44.

OECD Environment working papers are available at www.oecd.org/environment/workingpapers.htm

JT03386049

Complete document available on OLIS in its original format

English - Or. English

OECD ENVIRONMENT WORKING PAPERS

OECD Working Papers should not be reported as representing the official views of the OECD or of its member countries. The opinions expressed and arguments employed are those of the author(s).

OECD Working Papers describe preliminary results or research in progress by the author(s) and are published to stimulate discussion on a broad range of issues on which the OECD works.

This series is designed to make available to a wider readership selected studies on environmental issues prepared for use within the OECD. Authorship is usually collective, but principal author(s) are named. The papers are generally available only in their original language -English or French- with a summary in the other language.

Comments on OECD Working Papers are welcomed, and may be sent to:

OECD Environment Directorate
2, rue André Pascal, 75775 PARIS CEDEX 16, France
or by e-mail to env.contact@oecd.org

OECD Environment Working Papers are published on
www.oecd.org/environment/workingpapers.htm

ABSTRACT

The topic of biodiversity loss has been the subject of a vast and growing scientific and economic literature. Species are estimated to be going extinct at rates 100 to 1000 times faster than in geological times. Globally, terrestrial biodiversity is projected to decrease by a further 10% by 2050. As with biodiversity, the planet has also experienced major losses in the services derived from ecosystems. During the last century, for example, the planet has lost 50% of its wetlands, 40% of its forests and 35% of its mangroves. Around 60% of global ecosystem services have been degraded in just 50 years. While there is a large and growing literature on the values associated with the services that ecosystems provide, much less has been done in analysing the causality in the other direction – i.e. in assessing the linkages from changes in ecosystem services to the functioning of the economy.

This report contributes to an effort to identify environmental pressures under different structural and environmental policy assumptions and the associated damages that will result under different economic scenarios to 2050. Based on these it aims, *inter alia,* to examine how the environmental pressures may affect economic growth paths. This report contributes to that goal by looking at the consequences of the loss of biodiversity and ecosystem services. It does so by reviewing the main findings in the literature and key issues involved in the valuation of biodiversity and ecosystems services, as well as key issues involved in linking loss of biodiversity and ecosystems services to economic activity. The report finishes by identifying the main opportunities and obstacles in including biodiversity and eco-system services into a dynamic general equilibrium framework.

Keywords: biodiversity, ecosystem services, MSA.

JEL classification: Q22, Q57, D55, O44.

RÉSUMÉ

La perte de biodiversité fait l’objet d’un riche corpus d’ouvrages scientifiques et économiques, qui ne cesse de s’étoffer. On estime que le rythme d’extinction des espèces est aujourd’hui 100 à 1 000 fois supérieur à celui des époques géologiques. À l’échelle mondiale, la biodiversité terrestre devrait, selon les projections, reculer encore de 10 % d’ici 2050. Comme pour la biodiversité, la planète enregistre également d’importantes pertes au niveau des services dérivés des écosystèmes. Au cours du dernier siècle, par exemple, elle a perdu 50 % de ses zones humides, 40 % de ses forêts et 35 % de ses mangroves. Environ 60 % des services écosystémiques mondiaux se sont dégradés en 50 ans à peine. S’il existe un nombre imposant et croissant de travaux publiés sur les valeurs associées aux services fournis par les écosystèmes, l'analyse des relations de cause à effet dans l'autre direction, c'est-à-dire à l'évaluation des conséquences des changements intervenant dans les services écosystémiques sur le fonctionnement de l’économie, a beaucoup moins retenu l’attention.

Le présent rapport s’inscrit dans un effort visant à identifier les pressions environnementales sur la base de différentes hypothèses relatives aux politiques structurelles et environnementales, ainsi que les dommages attendus d’ici 2050 selon différents scénarios économiques. Il s’agit notamment d’analyser comment ces pressions sont susceptibles de peser sur les trajectoires de croissance économique. Ce rapport contribue à cette analyse en s’intéressant aux conséquences des pertes de biodiversité et de services écosystémiques. Pour ce faire, il passe en revue les principaux constats présentés dans la littérature, les difficultés fondamentales posées par l’évaluation de la biodiversité et des services écosystémiques, ainsi que les grands problèmes liés à la détermination des liens entre, d’une part, la biodiversité et les services écosystémiques et, d’autre part, l’activité économique. Pour terminer, le rapport repère les principales possibilités et difficultés d’intégration de la biodiversité et des services écosystémiques dans un cadre d’équilibre général dynamique.

Mots clés : biodiversité, services écosystémiques, AME.

Classification JEL: Q22, Q57, D55, O44.

TABLE OF CONTENTS

Tables

Figures

1. Introduction

In October 2013 the OECD launched a study on the Cost of Inaction and Resource Scarcity: Consequences for Long Term Economic Growth (CIRCLE). The main purpose was to identify environmental pressures under different structural and environmental policy assumptions and the associated damages that will result under different economic scenarios by 2050. Based on this it aims, *inter alia*, to examine how the environmental pressures may affect economic growth paths. This report contributes to that goal by looking at the consequences of the loss of biodiversity and ecosystem services. According to the terms of reference it has the following objectives:

a. Review the main findings in the literature and key issues involved in the **valuation of biodiversity and ecosystems services**.

b. Review the literature and key issues involved in **linking loss of biodiversity and ecosystems services to economic activity**. This will include a discussion of analytical frameworks (and if relevant, modelling approaches) that have been used in literature to examine aggregate economic effects (via valuation and/or a production function approach).

c. Discus the main **opportunities and obstacles in including biodiversity and ecosystem services into a dynamic general equilibrium framework**.

The report is structured according to these three themes. **Section 1** provides a review of the literature on the values of biodiversity and ecosystem services, noting what has been achieved so far and what gaps remain. It starts by defining the terms more clearly and then focuses on the monetisation of the values of ecosystem services as that is the metric used in the economic modelling to which we seek to link these services. **Section 2** looks at the studies that have valued the loss of biodiversity and ecosystem functions as a result of economic growth. This has been done, however, in a framework that has not always taken account of the possible impacts of environmental losses on the rate of growth of an economy. Links between ecosystems and economic growth go in two directions: growth may cause a decline in the services derived from the ecosystems and this decline may, in turn, affect the rate of economic growth. The latter linkage has proved to be the more elusive, but there is some material on both directions of causality, and **Section 3** covers the research carried out and models developed related to these. Finally, **Section 4** discusses the potential for using the existing literature and tools on economic valuation and modelling of ecosystems in the context of the CIRCLE project. It also identifies some next steps and further work to be undertaken to integrate ecosystems into the economic models that are currently used for long-term planning.

Some of this proposed research will take time and it is therefore necessary also to look at complementary approaches where the roles of ecosystems are not fully integrated into the dynamic integrated assessment models, but are assessed in modules outside the main assessment framework and their impacts are incorporated via soft links so that the consequences of ecosystem loss on the functioning of the economic structure, on GDP and on growth are not evaluated in one model, but estimated in a separate module and fed back into the model.

2. The Valuation of Biodiversity and Ecosystem Services[1]

2.1 Biodiversity and Ecosystem Services

The term biodiversity is used here as defined by the Convention on Biological Diversity as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part. This includes diversity within species, between species and of ecosystems". The same reference source defines an ecosystem as "a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit", [2] and ecosystem services are the benefits people obtain from ecosystems. The focus of much of the literature has been on the nature of these services and their value which are discussed in this paper. Before doing so, however, it is important to consider both concepts and the link between them.

The topic of biodiversity loss has been the subject of a vast and growing scientific and economic literature. Species are estimated to be going extinct at rates 100 to 1000 times faster than in geological times (Pimm et al. 1995, Chivian and Bernstein 2008). Moreover the rate of extinction is accelerating as habitats get smaller and smaller (Pimm and Raven, 2000). Globally, terrestrial biodiversity (measured as *mean species abundance* – or MSA – an indicator of the intactness of a natural ecosystem) is projected to decrease by a further 10% by 2050 (OECD, 2012).

There is some evidence that these extinctions are associated with economic and social losses. For example, between 1981 and 2006, 47% of cancer drugs and 34% of all "small molecule new chemical entities" (NCE) for all disease categories were natural products or derived directly from them (Newman and Cragg, 2007). In some countries such as Asia and Africa, 80% of the population relies on traditional medicine (including herbal medicine) for primary health care.[3] As extinctions continue, the availability of some of these medicines is likely to be reduced and new drug developments may be curtailed (Nunes and van Den Berg, 2001).

Yet, while we have a number of pieces of evidence of this nature, and there are numerous studies that look at the value of biodiversity in specific geographical contexts, no one has estimated the global value of biodiversity loss as such.[4] This is because the links between biodiversity and biological systems and the economic and social values that they support are extremely complex. Even the measurement of biodiversity is challenging, with a multi-dimensional metric being regarded as appropriate (Purvis and Hector, 2000; Mace et al., 2003) but with further work being considered necessary to define the appropriate combination.

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

1. The first part of this section draws on Markandya and Chiabai, 2011.

2. http://www.cbd.int/convention/articles/default.shtml?a=cbd-02

3. "Traditional Medicine", World Health Organization web site.

4. For a brief review see ten Brink (ed.) 2011, Chapter 5.4.

Table 1. Ecosystem Services

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

Source: MEA, 2005

These services are provided by a range of different ecosystems where different habitats can be found. An ecosystem where several habitats are present is referred to as a biome. The literature contains ten broad categories (listed in Table 2), for which values of the services described in Table 1 have been estimated. It should be noted that not all studies work with these categories of biomes and some services (e.g. pollination) cut across the biome classification.

Before looking into detail at the values of services provided by the ecosystems or biomes, two general points are worth noting. First, one finds that, as with biodiversity, the planet has experienced major losses in the services derived from these ecosystems. During the last century, for example, the planet lost 50% of its wetlands, 40% of its forests and 35% of its mangroves. Around 60% of global ecosystem services have been degraded in just 50 years (ten Brink, 2011).

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

Table 2. Major Biomes Used in the Ecosystem Valuation Literature

Biome (marine/aquatic?)	Biome (terrestrial?)
Marine (Open Oceans)	Freshwater (Rivers/Lakes)
Coral Reefs	Tropical Forests
Coastal Systems	Temperate Forests
Coastal Wetlands	Woodlands
Inland Wetlands	Grasslands

Source: De Groot et al., 2012.
Note: Coastal systems include estuaries, continental shelf areas and sea grass but not wetlands such as tidal marshes, mangroves and salt water wetlands.

In short, the current state of knowledge on the links between biodiversity and ecosystem services is still a topic of research and while some clear lines are emerging, they are not strong enough to allow formal modelling to be carried out at a level that would produce credible estimates of the global value of biodiversity. The latter therefore remains a topic for research.[5] At the same time, some efforts have been made to recognise that at least a part of the difference in the productivity of an ecosystem may depend on how much biodiversity it contains and, furthermore, this link between productivity and ecosystem diversity can be captured quantitatively using the concept of *mean species abundance* (MSA). The use of MSA in deriving the stock value of a biome is discussed below.

2.2 Average Values for Ecosystem Services

A large number of studies have been undertaken to value the flow of services as listed in Table 1, from the biomes listed in Table 2. Much of this work has been summarised in "The Economics of Ecosystems and Biodiversity " (TEEB) study (TEEB Synthesis report, 2010), which was launched by the G8+5 Ministers of the Environment in 2007 to draw attention to the global economic benefits of biodiversity and the costs of biodiversity and ecosystem loss. A more comprehensive set of background papers and sectoral and country studies have been undertaken since (Russi et al., 2013; McVittie and Hussain, 2013; TEEB, 2013).[6] A good reference to the economic valuation of ecosystems that was undertaken as part of the TEEB exercise is ten Brink (2011). One particular study undertaken as part of TEEB that is particularly relevant to this exercise is discussed further below (Hussain et al., 2011).

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

6. The full list of studies is available at http://www.teebweb.org/our-publications/all-publications/

A recent survey that collects and summarises the findings of many of these studies is De Groot et al., 2012 (see Table 3).[7] They identified more than 1 600 studies over the period 1960 to 2008, and extracted 655 data points that could be used to calculate the flow of services in terms of international dollars per hectare per year.[8] Studies in different currencies were converted into US dollars using *purchasing power parity* (PPP) exchange rates and account was taken of the inflation between the year of the study and the standardised year, which was 2007.

Table 3 provides the main results that emerge from this literature review. The results show a significant value from the different biomes, ranging from a high of USD 352,249/ha/yr for coral reefs to a low of USD491/ha/yr for marine areas. In terms of services, the main categories they use are regulating, followed by cultural, provisioning and habitat. Within the regulating services, ecosystems provide an important source of waste treatment and erosion prevention.

The methods used to elicit these estimates cover the whole range of valuation techniques used in environmental economics. Perhaps more than most environmental valuation studies, the main method used in this set is direct market valuations, notably direct market pricing. Table 4 summarises the share of different techniques in the set of valuation studies. Direct market valuation methods include market pricing, payment for environmental services and factor income/production function methods. They are mostly deployed for provisioning service valuation but are also frequently used for habitat and cultural services. Cost Based Methods include: avoided cost, restoration cost, and replacement cost. They are mostly used for the valuation of regulating services. The revealed preference methods consist of hedonic pricing and travel cost based assessments, and are used exclusively for valuing cultural services. Finally, stated preference methods consist of contingent valuation, conjoint choice and group valuation and are used for valuing habitat and cultural services.

The categories given in Table 3 cover a wide range of services with different methods of elicitation of values. Some economists might question whether the services valued using stated preferences or indirect valuation methods of revealed preferences are as ‘real’ as those obtained using market methods. While this cannot be established absolutely, the predominant evidence is that non-market methods for valuation, when used with care and following the best techniques available, do provide credible numbers that can be compared to those obtained from market methods. Indeed, where both methods have been used to value the same services, the numbers generally turn out to be comparable (Pearce et al., 2006).[9]

While the work summarised in Tables 3 and 4 is impressive, there are a number of aspects of this body of literature that make its use in the context of economy-wide modelling problematic. First, it is not really possible to take the average values given in the table and use them as single figures that apply to all services provided by a given biome. For example, most models work with countries and regions and one could calculate the areas in hectares that are coastal wetlands, inland wetlands, tropical forests etc. The average values per hectare, however, cannot be applied to other areas or regions without some consideration of local factors, such as population density, the degree of development of the region etc., because these factors can lead to major differences in values. One can see this by looking at the extent of variation around the mean in the studies summarised in Table 3. Table 5 provides this information and

7. A related study is Costanza (2014). It draws on the same literature but takes it a stage further to attempt a global value of the services of these ecosystems.

8. International or Geary-Khamis dollar is a unit of currency constructed to standardize money values by correcting money values across countries to the same purchasing power that the US dollar has at a point in time. This involved using PPP exchange rates as has been done in the Table cited.

9. Unfortunately, market methods cannot be used for some services (e.g. non-use aspects of cultural services), where such comparisons cannot be made and where other methods of verification (e.g. contributions to charities or other voluntary payments) have been made.

shows that the mean and median values are very different and there are many studies with values much lower than the mean (in some cases by an order of magnitude) and a number with values well above the mean. Thus, local factors need to be taken into account when incorporating ecosystem values into economic models. Such differences can be accounted for at various levels through a procedure referred to as benefit transfer. The simplest would be to take an individual estimate from a similar area in the country or from a similar country. A more sophisticated method would involve carrying out a meta-analysis in which the individual values are used to estimate a relationship giving the value per hectare as a function to environmental and socioeconomic variables. Such an approach has been widely evaluated (Lindjhem and Navrud 2008; Brander et al., 2008). While there can be significant errors of transfer, the method does allow one to get figures that are broadly of the right order of magnitude. Meta-analysis is discussed further in the section on 'Taking Local factors Into Account'.

Second, the coverage of ecosystem services is far from complete. Although Table 3 provides numbers under most categories, the items included do not pick up all the linkages between the service and the state of the biome. For example, the role of oceans in climate regulation is still being investigated and the studies from which current values have been derived are based only on a partial understanding of the underlying physical phenomena. The same applies to the value of genetic resources and genetic diversity in different biomes and to a number of other categories of services.

Third, the average values that have been attributed to some categories of services reflect developed country valuations which cannot easily be transferred to developing country situations. While this is not true for provisioning services or for services from biomes such as ocean systems, coral reefs and coastal systems, it is true for recreational and other cultural services. The consequence is that for these categories of services the transferability of the numbers to developing countries may be problematic (see below).

Table 3. Summary of Monetary Values for Each Service by Biome

(Int. $/Ha./Yr. 2007 Price level)

		Marine	Coral Reefs	Coastal Systems	Coastal Wetlands	Inland Wetlands	Rivers & Lakes	Tropical Forests	Temperate Forests	Woodlands	Grasslands
Provisioning Services Total		**102**	**55,724**	**2,396**	**2,998**	**1,659**	**1,914**	**1,828**	**671**	**253**	**1,305**
1	*Food*	93	667	2,384	1,111	614	106	200	299	52	1,192
2	*Water*				1,217	408	1,808	27	191		60
3	*Raw Materials*	8	21,528	12	358	425		84	181	170	53
4	*Genetic Resources*		33,048		10			13			
5	*Medicinal Resouces*				301	99		1,504			1
6	*Ornmental Resources*		472			114				32	
Regulating Services Total		**65**	**171,478**	**25,847**	**171,515**	**17,364**	**187**	**2,529**	**491**	**51**	**159**
7	*Air Quality Regulation*							12			
8	*Climate Regulation*	65	1,188	479	65	488		2,044	152	7	40
9	*Disturbance Moderation*		16,991		5,351	2,986		66			
10	*Water Flow Regulation*					5,606		342			
11	*Waste Treatment*		85		162,125	3,015	187	6	7		75
12	*Erosion Prevention*		153,214	25,368	3,929	2,607		15	5	13	44
13	*Nutrient Recycling*				45	1,713		3	93		
14	*Pollination*							30		31	
15	*Biological Control*					948		11	235		
Habitat Services Total		**5**	**16,210**	**375**	**17,138**	**2,455**		**39**	**862**	**1,277**	**1,214**
16	*Nursery Service*			194	10,648	1,287		16		1,273	
17	*Genetic Diversity*	5	16,210	180	6,490	1,168		23	862	3	1,214
Cultural Services Total		**319**	**108,837**	**300**	**2,193**	**4,203**	**2,166**	**867**	**990**	**7**	**193**
18	*Esthetic Information*		11,390			1,292					167
19	*Recreation*	319	96,302	256	21,930	2,211	2,166	867	989	7	26
20	*Inspiration*					700					
21	*Spiritual Experience*			21							
22	*Cognitive Development*		1,145	22					1		
	Total Economic Value	**491**	**352,249**	**28,918**	**193,844**	**25,681**	**4,267**	**5,263**	**3,014**	**1,588**	**2,871**

Source: De Groot et al., 2012.
Note: Coastal systems include estuaries, continent shelf areas and sea grasses but exclude wetlands like tidal marshes, mangroves and salt water wetlands.

The Millennium Ecosystem Assessment recommends not to iinclude habitat services in order to avoid double counting (as these values are already accounted for in other services, especially provisioning services). Furthermore, desert and polar regions were excluded from the analysis due to the low number of value data points. Cultivated land and urban areas were excluded because they are human-dominated systems. These excluded biomes do produce ecosystem services but there were insufficient primary valuation studies to allow a meaningful analysis.

Table 4. Methods Used to Value Ecosystem Services (%)

Ecosystem Services	Direct Market Values	Cost Based Methods	Revealed Preference	Stated Preference
Provisioning	84%	8%	0%	3%
Regulating	18%	66%	0%	5%
Habitat	32%	6%	0%	47%
Cultural	39%	0%	19%	36%

Source: Adapted from De Groot et al., 2012
Note: Percentages sum across the rows.

Table 5. Range of Values in Studies of Ecosystem Services (Int$/Ha./Yr. 2007 Price Levels)

Ecosystem	Mean	Median	Minimum/Mean (%)	Maximum/Mean (%)
Marine	491	135	17%	339%
Coral Reefs	352,915	197,900	10%	603%
Coastal Systems	28,917	26,760	90%	145%
Coastal Wetlands	193,845	12,163	0.2%	458%
Inland Wetlands	25,682	16,534	12%	409%
Rivers and Lakes	4,267	3,938	34%	182%
Tropical Forests	5,264	2,355	30%	396%
Temperate Forests	3,013	1,127	9%	545%
Woodlands	1,588	1,522	86%	138%
Grasslands	2,871	2,698	4%	207%

Source: Adapted from De Groot et al., 2012

2.3 Taking Local Factors into Account

Locally applicable values can be derived from the data of studies through the use of a procedure called benefit transfer, in which meta-analysis is a key method. This consists of estimating unit values of ecosystem services for a given site as a function of site characteristics as well as the socio-economic and geographical characteristics of the region or country and the method of estimation used. The estimation uses data from individual studies to construct the meta-level database from which a statistical estimation of the function is carried out.

Examples of meta-analytical functions that have been estimated in the literature include inland European wetlands (Brander et al., 2011); grasslands, global wetlands, mangroves and coral reefs (Hussain et al., 2011); recreational and passive forests services (Chiabai et al., 2009). In all cases but one (coral reefs), one of the explanatory variables is the level of per capita income, measured in PPP terms, so the value of a given class of ecosystem services rises with per capita income. The elasticity of unit ecosystem service values with respect to GDP varies considerably: from around 0.4 for European wetlands, to 0.6 for wetlands globally, to 0.7 for recreational services of forests, 0.9 for grasslands, 1.5 for mangroves and 3.5 for non-use or passive values of forests.[10] Other variables that emerge as significant include: the presence of similar ecosystems nearby, population concentrations within a local range of the biome (e.g. 50 km), concentration of economic activity in the same range, and method of estimation used.

Where meta-analytical functions are available, they can be used to provide some guidance values for services in other local areas, although a significant level of uncertainty remains with the estimates (Johnston et al., 2010 and 2014). Indeed, some research shows that the extent of the error in making a transfer of values using sophisticated meta-analysis can be quite large and the method is not always more accurate than a simpler transfer based on adjusting for differences in per capita GDP (Lindhjem and Navrud, 2006). Nevertheless, it is generally more reliable to use estimated functions that are based on as wide a data set as possible.

As far as incorporating these values into economic models is concerned, the margins of error should not prevent them from being included (there are after all similar errors in other aspects of socio-economic modelling). Ideally some spatial differentiation is desirable within a country but even a single value for some of the service could provide a useful complement to the economic components of the model. The more difficult question is how to link the changes in the values of services to changes in economic activity. Most of the studies provide an estimate of the service currently provided and the metric used is frequently either the total value of a system or the value per hectare. Economic growth can often change the functioning of the system. If it reduces the size, for example, of a wetland or a forest one could use the value per hectare and apply it to the area lost. The assumption in doing this is that the marginal and average values are equal: we do not know if this is the case and there is little evidence to guide us.[11]

Another difficulty arises when economic development does not consist of a loss of an area but a change in its quality. Forests, woodlands, grasslands may not disappear but may get degraded when roads are built or overexploited for pasture. The valuation then has to focus on how to value changes in quality, for which the literature is much thinner (although there are studies looking at specific impacts). From a modelling perspective, however, a metric of quality will be needed and this is not generally available.

2.4 Incorporating Biodiversity into the Ecosystem Valuation Framework

As noted in the introduction, an attempt has been made to incorporate biodiversity changes within the ecosystem approach. To do this, biodiversity is measured as "the remaining *mean species abundance* (MSA) of original species, relative to their abundance in pristine or primary vegetation, which are assumed not to be disturbed by human activities for a prolonged period" (Alkemade et al., 2009: p.375). The peculiarity of MSA is related to the fact that it is not built on actual observations in the study area, but on the relations between pressures or drivers and impacts on species abundance. For each pressure under consideration a meta-analysis is first carried out to put in relation the MSA values with a number of

10. In valuing mortality risks in different countries the OECD has recommended an elasticity of 0.8 (OECD, 2011) but that applies for that specific public good and cannot be transferred to other such goods.

11. Economic growth will also change the value attached to a given set of ecosystem services. Increases in value can be expected over time. These can be approximated based on the "income" elasticity of current values discussed in the previous sub-section.

drivers. The MSA values used in the meta-analysis are constructed from indicators taken from the literature, and specifically the abundance of different species (number of individuals per species, density or cover) registered in primary vegetation areas (natural or relatively untouched) and the abundance of species in disturbed environments. The MSA indicator as dependent variable in the meta-analysis is constructed by dividing the species numbers by the area.

MSA values are calculated for each of the above-mentioned drivers taking into account the cause-effect relationships for each driver as estimated in the meta-analysis. As ecosystem approaches use the area of land as the basis of calculating the value of services obtained, the MSA component of a geographical region is taken into account by multiplying the area by an MSA value normalized on a scale of zero to one with different normalization for different ecosystem services. For example, if an area is pristine and there has been no loss of biodiversity, its MSA value will be one. Whereas if it is managed in some way, the value will range from 0.5 to 0.7 depending on which service is being considered. An area that has become totally artificial and depleted of all species will have a value of zero (Braat and ten Brink, 2008: Chapter 5). Such “MSA adjusted areas” have been estimated for different biomes across the world and over time, going back to 1900 and even earlier by the biodiversity modelling work undertaken by the GLOBIO team in the Netherlands (Alkemade et al., 2009). Clearly there is the implicit assumption that one can make a linear trade-off between the measure of biodiversity in terms of MSA and land area. The authors provide some justification for this but also recognize that there is a major element of expert judgment involved in obtaining the MSA adjusted scales.

The MSA adjusted areas have been used to estimate the value of services from the worlds’ biomes at different points of time in the past and estimates have also been made of the likely loss of services by 2050 if no action is taken. In the Costs of Policy Inaction study, Braat and ten Brink (2008) estimate that monetary losses in 2050 will run at around one percent of GDP and cumulative losses from 2000 to 2050 will be around 7% of 2050 consumption. In a reworking of the data as well as a back-casting analysis, Markandya and Chiabai (2013) find that losses from 1900 to 2000 have been between 1.4 and 3.8% of GDP in 2000. For the period from 2000 to 2050 they get a range of losses of between 0.2 to 0.6 % of 2050 GDP. If, however, account is taken of the net value of agricultural output from the land conversions, then the net losses are much smaller in global terms although they can still be significant in some regions, particularly in Africa. The use of the GLOBIO model is discussed further in the next section.

3. Using Ecosystem Values in Economic Modelling

3.1 General Considerations

The purpose of valuing ecosystems is to provide a better guide to policies that affect their condition and use and to better recognise their role in ensuring sustained economic development. As noted, the links between ecosystems and economic performance go in two directions. First, economic activities have an impact on the services that these systems provide. These services have a value not dissimilar to the values provided by other goods and services, and changes in these values need to be taken into account in project and policy-related decisions. Second, a loss of ecosystems makes the functioning of the economic system less effective. The regulating services, in particular, contribute to transport, energy, agriculture, recreation and related sectors. As the economy grows, hopefully on a new low carbon pathway, the relative importance of these sectors and their links to the natural environment and to the ecosystems that underpin it will increase. These linkages need to be better understood, which requires integrating the ESS functions into traditional economic models. We turn to these modelling issues next, before returning to the broader question of mainstreaming ESS into economic decision-making.

3.2 Modelling Issues

In order to link ecosystem services to economic growth we need to include the former explicitly into dynamic models that track economic changes as a function of different policies. While there are several models that look at some aspects of the links between natural resources and economic growth (going back to the 1970s with *The Limits to Growth*), few of them include ecosystem services as an explicit component and that also link these ecosystem services to an economy-wide framework that can analyse economic growth. Hussain et al., (2011) identify ten modelling frameworks that look at ecosystems in a relatively comprehensive way.[12] Those models that do so in some form or other and for which a reasonable amount of information is available, are given in Table 6.[13] In selecting these, two of the ten models surveyed in Hussain et al. were excluded on the grounds that they did not provide enough detail on monetary valuations or on how they functioned (the International Futures (IF) simulator and ARIES); two more were excluded because they did not cover all the key sectors (IMPACT-Water and Ecopath fell in this category). The remaining six models are examined in more detail and discussed below.

Given the aims of the CIRCLE project, the four key questions to examine in respect of the different models are the following:

a. Does the model include ESS in both directions – i.e. the impact of economic changes on ESS and thereby on welfare as well as the impact of ESS changes on production possibilities for goods and services and thereby on growth?
b. Does the model take account of the inter-relationships between markets – i.e. does it have a general equilibrium structure –allowing for market imperfections such as unemployment, trade barriers etc.?
c. Does the model include a spatial dimension so that ecosystems impacts of growth can be taken into account depending on where they occur?
d. Is the coverage of ecosystems complete – i.e. are all biomes included in the system?

Each of the above models is evaluated with respect to these four questions.

12. These are GUMBO, the International Futures (IF) Simulator, IMAGE, Globio, IMPACT-Water, MIMES, InVEST, Ecopath and related modules, and the UK National Ecosystem Assessment UKNEA). The UKNEA is not really a model but more an approach. It is included because it offers some assessment of the effect of ESS on the economy.

13. There are several models that are variants of the GUMBO and GLOBIO-IMAGE models. A survey of these can be found in Hussain et al., 2011 and Costanza et al, 2007.

Table 6. Integrated Assessment Models that Incorporate Ecosystem Service Effects of Growth

Model	Ecosystems Covered	Economic Structure	Other	References
GUMBO-MIMES	11 biomes, ESS feed into production and welfare functions	Economic output based on capital, labour, knowledge. Links from ESS to Economic module	No spatial modelling. Economic module does not have a CGE structure. ESS valuation information is sketchy	Boumans et al., 2002. http://www.ebmtools.org/mimes.html
GLOBIO-IMAGE	ESS from biomes affected by socio-economic drivers	LEITAP, extended version of GTAP, used to model land use changes	Changes in land for agriculture affects different biomes. Spatially explicit.	Alkemade *et al*. (2009) http://www.globio.info/publications http://www.globio.info/
InVEST	Production functions linking LULC type to ESS	Economic production functions determine demand for land & ESS	Still developing. Coverage not global as yet. Spatial resolution is high. Not CGE.	http://www.naturalcapitalproject.org/InVEST.html
UK NEA	ESS from different biomes spatially disaggregated scale	Scenarios estimate changes in ESS	No economic modelling but ESS changes valued for some services	http://uknea.unep-wcmc.org/Resources/tabid/82/Default.aspx

Source: Adapted from Hussain et al., 2011

3.3 Causality from ESS Changes to Economic Functions

All the above models examine the implications of economic development growth on ESS in either physical or monetary terms. However, the only models that explicitly account for the impact of ESS changes on economic performance are the GUMBO-MIMES set. In those ESS services affect the measure of "natural capital", which in turns enters as an input to the production function for other goods and services.

The economic component of GUMBO draws together three groups of inputs – the production of ecosystem goods, the production of ecosystem services, and the economic production based on socio-economic stocks of social capital, knowledge, labour force and built capital. These feed in to the overall production of goods and services for satisfying human needs; waste is modelled as a negative feedback.

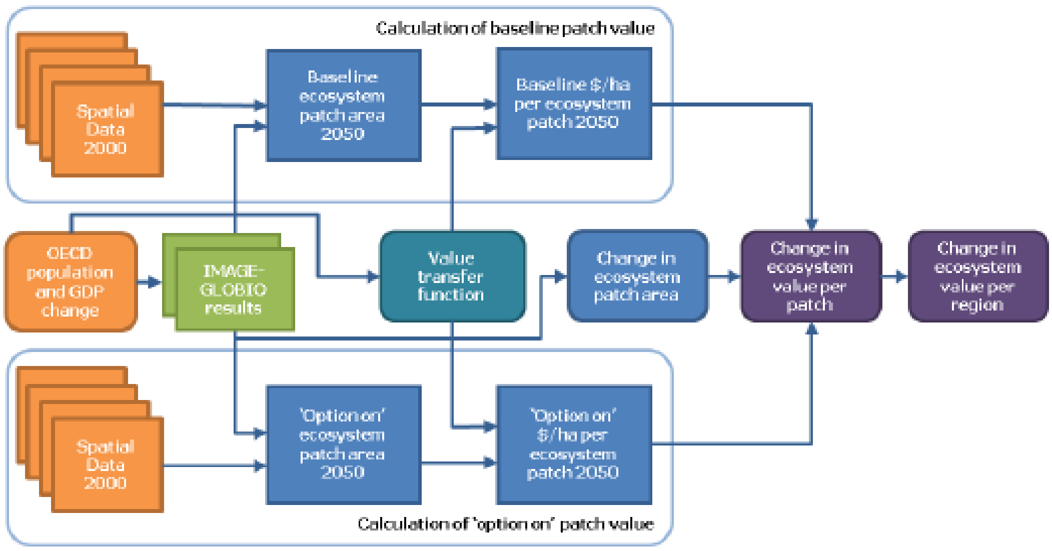
The total production is divided into personal consumption, and savings rates for the main capital stocks, including natural capital. A key feature of GUMBO is modelling dynamic processes including feedbacks among human technology, economic production and welfare, and ecosystem goods and services. These linkages make it possible to estimate the costs and benefits associated with specific changes, by calculating the marginal product of ecosystem services in both the production and welfare functions.

This positive aspect of GUMBO, however, is partly cancelled by the fact that the economic modelling is highly aggregated, with the output of all goods and services modelled as a single quantity, whose level is a function of different forms of capital, represented through a Cobb Douglas (Boumans et al., 2002). Feedbacks from a decline in ecosystem services on output need to be more disaggregated than that, with some goods and services, such as agriculture, energy, tourism, etc., more affected than others such as manufacturing. Nevertheless the attempt is in the right direction and apparently MIMES is making further refinements though it has not been possible to find anything on them.[14]

3.4 The use of a general equilibrium structure

The only model that has a link with a general equilibrium structure is the IMAGE-GLOBIO model, which consists of an economic module which examines different development scenarios. These scenarios give rise to changes in ESS in different locations, which are tracked through the IMAGE component of the model. Figure 1 below shows the linkages between the different parts of the modelling framework. The general equilibrium framework comes in when the consequences of different scenarios are worked out in terms of changes in demand for land, agricultural commodities, energy etc., and the model used is a version of the GTAP family (LEITAP). Note, however, that IMAGE-GLOBIO does not include ESS services in the economic modelling and nor does it value the ESS in monetary terms. The latter has been done in a preliminary fashion in the TEEB report by Hussain et al., 2011 and some of the results obtained are presented below.

Figure 1. The IMAGE-GLOBIO Model Structure



14. The website for MIMES directs us to on-going work archived at a Google Code site. Learn more about MIMES at www.uvm.edu/giee/mimes or www.afordablefutures.com/services/mimes. The first site cannot be found and the second does not provide any information on the economic modelling.

None of the other models have this feature. GUMBO-MIMES models include natural capital as an input into the production process but do not work with an interrelated market structure.

InVEST is a rich structure that, like IMAGE-GLOBIO, takes different scenarios and looks at their implications for ecosystem services. There is, however, no modelling of the scenarios in an economy-wide framework. The UK National Ecosystem Assessment (NEA) also works through the ecosystem implications of different scenarios, without examining how policies that represent the change from one scenario to another affect different markets.

3.5 Inclusion of a Spatial Dimension

The spatial dimension is incorporated into GLOBIO-IMAGE, InVEST and the UK NEA but not in GUMBO (although MIMES is working on developing that). The importance of including this aspect into the modelling is highlighted by the fact that the impacts of different scenarios on ecosystem functioning are found to vary considerably by location. This can be seen visually from the application of the IMAGE-GLOBIO model to compare changes in biomes from 2000 to 2050 under a number of different development scenarios. The scenarios considered are summarised in Table 7, which also indicates key features of the baseline and how each scenario differs from that baseline.[15]

The analysis then proceeds to evaluate the impacts of the different scenarios on biomes across the globe. The GLOBIO-IMAGE model has a spatial disaggregation at 0.5x0.5º grid cells (average 50mx50m). Almost all terrestrial cells classified in one of the biomes resulting in 2.3 million “patches”. The CGE model with scenarios gives changes in MSA adjusted areas of grassland, tropical forest and temperate forests. It does not provide changes for other biomes, such as marine areas. The resulting alterations in the MSA areas as a result of the move from the Baseline to Scenario 1 (higher agricultural productivity) can be seen from a comparison of Figures 2 and 3. Even at the level of a global map one can see significant shifts in values, and if one works at a more detailed level, there will be even more variations to be observed.

Table 7. Scenarios Analysed Using the GLOBIO-IMAGE Model

Scenario	Baseline	Change to Baseline
1. Agricultural Productivity	0.64% growth p.a. in yields	Investment leads to 40% increase in crop and 20% in livestock productivity
2. Reducing Post-Harvest Losses in forestry	Current losses around 30%	Losses decline by half to 15%
3.Better forest management	Current rates of logging continue	Reduced impact logging and increase in forest plantations
4. Protected Areas	Level of PAs = 14% of land area maintained	Increase of PAs to (a) 20% and (b) 50% of each region
5. Reduced Deforestation	Current trends continue	All dense forests protected from

15. Some of the scenarios could be compared with respect to the baseline in terms of costs and benefits. These were scenarios 1-4. The results show that both the agricultural productivity and the forestry scenarios have very high benefit cost ratios. The ratio for protected areas is much lower.

		agricultural expansion
6. Stricter Climate Regime	Biofuel in 2050 modest (=0.5 Mn. Km^2)	GHG Conc. Limited to 450 ppm with 4 Mn.Km^2 bioenergy area
7. Dietary Changes	Livestock doubles with population	(a) Willett diet with low meat or (b) no meat at all by 2050
8. Agricultural Trade	Current trade regime in force	Non-Tariff Barriers and subsidies removed so full trade liberalization by 2020

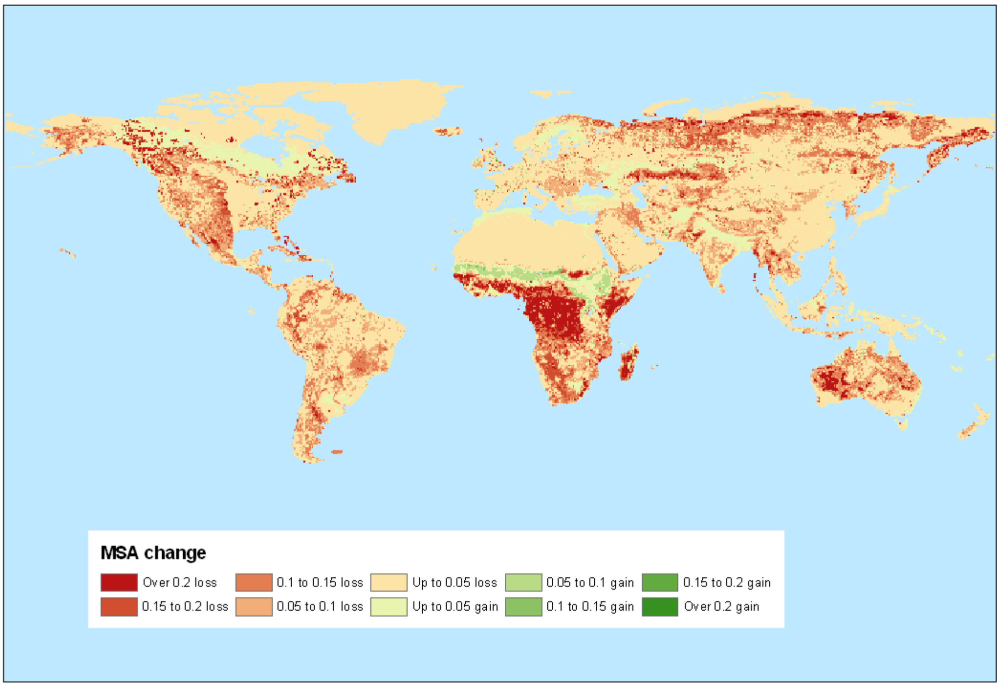
3.6 Coverage of Ecosystems in Monetary Terms

The coverage of ecosystem services in monetary terms is not entirely complete in the models examined. The GUMBO model makes a major attempt and covers 11 biomes, which between them span the entire surface of the earth (Open Ocean, Coastal Ocean, Forests, Grasslands, Wetlands, Lakes/Rivers, Deserts, Tundra, Ice/rock, Croplands and Urban). However, valuation of ocean systems is limited in the literature and links between economic activities and the state of these ecosystems is not fully understood. The IMAGE-GLOBIO model does not cover marine ecosystems at all. InVEST covers both marine and terrestrial environments but, as noted above, they are not assessed within an integrated economic model. The UK NEA study discusses all the ecosystems relevant to the United Kingdom but values only some of them (forests, wetlands, lakes and rivers and croplands). Furthermore it does not value all the services from these biomes – e.g. some of the cultural services associated with birds and services related to biodiversity.

When a model covers a particular biome, the coverage of ESS within that biome is also varied and sometimes difficult to separate by type of service. As noted for the UK NEA, not all services from the ecosystems were valued. In the case of the valuation exercise that was carried out based on the IMAGE-GLOBIO model (Hussain et al., 2011), in principle, all ESS were included for the biomes that were valued but the method of benefit transfer did not allow the individual services to be identified.

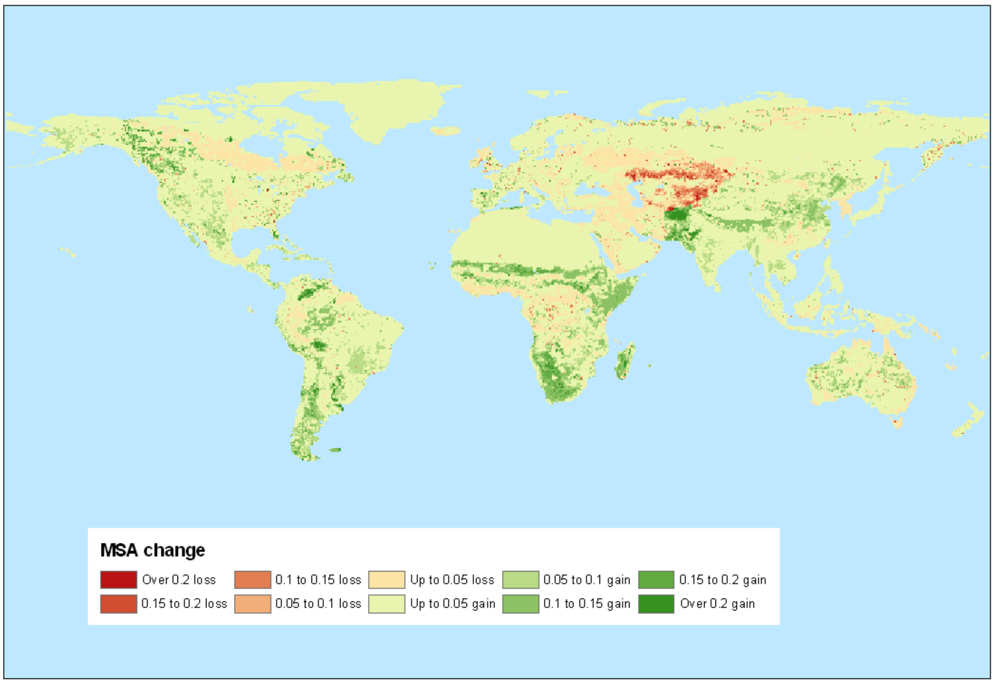
This incomplete coverage is not a comment on the quality of the work undertaken in these studies but simply a reflection of the state of the valuation literature on ecosystems, something that was noted in section I.

Figure 2. MSA Adjusted Change in Areas for Baseline Scenario 2000 to 2050



Source: Hussain et al. (2011)

Figure 3. MSA Adjusted Change in Areas for Agricultural Productivity Scenario 2000 to 2050



Source: Hussain et al. (2011)

4. Potential for Integrating Ecosystem Services into Dynamic CGE Modelling

There is a large and growing literature on the values associated with the services that ecosystems provide. Moreover, such values have been used in some studies to estimate the effects of different growth paths on the level of these services. Thus the link from economic growth to the environment has made a fair amount of progress. Yet even in this direction of causality, a number of issues remain to be resolved. The models do not fully cover all biomes (marine ecosystems are especially under-represented) and the methods used to obtain values of the services provided by the millions of biomes that exist depend on procedures that have high margins of error. Furthermore, the framework for valuing the services provided by the natural environment based on the ecosystem approach does not fully capture the values associated with biodiversity (although some progress has been made to address that gap).

In spite of all these shortcomings the ESS approach has served us well in showing the importance of the natural environment in economic terms: i.e. valuing the services that it provides in units that are comparable with other goods and services. The problem has been in analysing causality in the other direction – i.e. in modelling the linkages from the changes in ESS to the functioning of the economy. Since this is the core of what the CIRCLE project is seeking to address, the gap between what is available and what is needed remains quite large. There have been some initiatives, such as the GUMBO project, that have included natural capital as a factor in the production function for economic goods and services. This has been done at a highly aggregate level, whereas it needs to be carried out in a much more disaggregated way. Furthermore the models used do not have the full general equilibrium structure. Some goods and services will be more affected by the loss of ESS than others. That difference is important and needs an inter-sectoral economy-wide model to pick up the important linkages. Efforts in this direction are ongoing but may take some time to be realised.

Where do we stand in terms of integrating the biodiversity/ESS literature into dynamic CGE models? Given the significant gap between what is available and what is needed to integrate ecosystem services into CGE models, the way forward could consist of two parallel approaches. On the one hand, a soft link could be established. Alternative growth paths can be evaluated in terms of the losses or gains they imply for different ESS and these values can be used to adjust the estimated GDP growth rate, to give a "corrected GDP". This link could be based on taking forward the work done under the IMAGE-GLOBIO model, with the valuation supplements that were made to it as part of the TEEB work carried out by Hussain and others. More work is needed to strengthen the spatially differentiated valuation of the impacts of economic growth on ESS, and to include more biomes into the model.

At the same time, a second approach could be developed in which the integrated CGE models include ESS as specific inputs into key sectors and where the output of these sectors affects the functioning of the ESS. The inclusion of ESS into some sectors such as agriculture and forestry should be relatively straightforward because linkages to marketed goods are well developed (although even here some services such as pollination involve complex and detailed linkages to sub-sectors). It will be more challenging to cover services such as recreation, tourism, and health (air and water quality affect the health of the population and health services, in part, are designed to treat the negative effects of these environmental damages). These links are not really discussed in the modelling literature and need to be developed as part of the integrated modelling exercise. It will also be important to take account of connections between ESS (e.g. the quality of cultural services depend on how well the regulating services are functioning). This stream of work would need to be undertaken in conjunction with the dynamic modellers who are developing the combined framework of the OECD's ENV-Growth model as well as the dynamic computable general equilibrium (CGE) OECD's ENV-Linkages model.

A proposed work plan could then consist of the following steps:

a. Set up a database of state-of-the-art estimates of the value of ESS at a spatially differentiated level so the disaggregated database can be used in conjunction with the economic models.

b. Calculate the losses of ESS associated with alternative growth paths and use these figures to calculate an adjusted GDP figure for each path, indicating the effect that the losses have on "true GDP".

c. Initiate work on integrating ESS into the economic models. This could be done first for agriculture and forestry where there is considerable information on how economic growth effects productivity through its impacts on pollution, climate change etc., and on how reduced output in these sectors feeds back into the other economic sectors. Then one could work to incorporate water-related ecosystems and finally marine ecosystems.

d. Combine the work on adjusted GDP with that on sectoral production links to produce an integrated system that includes both the effects of growth on ESS and the effects of declines in ESS on growth.

REFERENCES

Alkemade R, M Blackens, R Bobbin, L Miles, C Nellermann, H Simons, T Mecklenburg (2006). GLOBIO 3: Framework for the assessment of global biodiversity. In: MNP (2006) *Integrated modeling of environmental change. An overview of IMAGE 2.4. NEAA/MNP*, Bilthoven: 171-186.

Alkemade R, van Oorschot M, Miles L, Nellemann C, Bakkenes M and ten Brink B (2009) GLOBIO3: A framework to investigate options for reducing global terrestrial biodiversity loss. *Ecosystems 12*: 374-390. Available at: *www.globio.info/downloads/14/fulltext%20(artikel%20GLOBIO).pdf.*

Boumans, R., R. Costanza, J. Farley, M.A. Wilson, R. Portela, J. Rotmans, F.Villa and M. Grasso (2002). Modeling the dynamics of the integrated earth system and the value of global ecosystem services using the GUMBO model, Ecological Economics 41 (2002) 529–560

Brander, L., A. Ghermandi, O. Kuik, A. Markandya, P. Nunes, M. Schaafsma and A. Wagtendonk. “Scaling up ecosystem service values: methodology, applicability and a case study”. Report to the European Environment Agency, April 2008.

Brander, L, I. Brauer, H. Gerdes, A. Ghermandi, O. Kuik, A. Markandya, S. Navrud, P. Nunes, M. Schaafsma, H. Vos, A. Wagtendonk (2011) “Using meta-analysis and GIS for value transfer and scaling up: Valuing climate change induced losses of European wetlands”, Environment and Resource Economics, 52 (3), 395-413.

Braat, L. and P. ten Brink (eds) (2008) “The Cost of Policy Inaction (COPI): The Case of Not Meeting the 2010 Biodiversity Target.” Alterra-rapport 1718, ISSN 1566-71 97.

Chevassus-au-Louis et al. (2009) “An economic approach to biodiversity and ecosystems services. Contribution to public decision-making”, CAS, 382 p. *www.cbd.int/doc/case-studies/inc/cs-inc-report-en.pdf.*

CGDD (2011) “Methods and reference values for valuation of services provided by wetlands”, Le point sur n°97, *http://intra.cgdd.i2/IMG/pdf/LPS97E_cle1ea11c.pdf.*

Chiabai A, Travisi C, Markandya A, Ding H and Nunes PALD (2009) Economic Assessment of Forest Ecosystem Services Losses: Cost of Policy Inaction.” Environmental and Resource Economics. 50, 3, 405-455.

Chivian, E. and A. Bernstein (eds.) 2008. *Sustaining life: How human health depends on biodiversity*. Center for Health and the Global Environment. Oxford University Press, New York.

Costanza, R., R. Leemans, R. Boumand and E. Gaddis (2007) Integrated Global Models: in

Costanza, R., L. J. Graumlich, and W. Steffen (eds.). 2007. Sustainability or Collapse: An

Integrated History and Future of People on Earth. Dahlem Workshop Report 96. MIT Press. Cambridge, MA.

Costanza; R., R. De Groot, P. Sutton, S. Van der Ploeg, S.J. Anderson, I, Kubiszewski, S. Fraber and R. Kerry Turner (2014). Changes in the global value of ecosystem services, *Global Environmental Change*, 26, 152–158.

De Groot R, L. Brander, S. van der Ploeg, R. Costanza, F. Bernard, L. Braat, M. Christie, N. Crossman, A. Ghermandi, L. Hein, S. Hussain, P. Kumar, A. McVittie, R. Portela, L.C. Rodriguez, P. ten Brink and P. van Beukering. (2012) Global estimates of the value of ecosystems and their services, *Ecosystem Services*, 1, 50-61.

Grime, J.P. 1997. Biodiversity and ecosystem function: the debate deepens. *Science* 277: 1260–61

Haines-Young R and M Potschin (2010). The Links between Biodiversity, Ecosystem Services and Human Well-Bing in Raffaelli, D. and C. Frid (eds.) Ecosystem Ecology: A New Synthesis, CUP, Cambridge.

Hussain, S., A. McVittie, L. Brander, O. Vardakoulias, A. Wagtendonk, P. Verburg, R. Tinch, A. Fofana, C. Baulcomb, L. Mathieu (2011). The Economics of Ecosystems and Biodiversity: Quantitative Assessment. Draft final report to the United Nations Environment Programme.

Johnston, R.J., S.K. Swallow, D.M. Bauer and E. Uchida. 2014. Connecting Ecosystem Services to Land Use: Implications for Valuation and Policy, chapter 8 in Duke, J.M. and J. Wu, eds. *The Oxford Handbook of Land Economics*. Oxford University Press, pp. 196-225.

Johnston, Robert J. and Rosenberger, Randall S., Methods, Trends and Controversies in Contemporary Benefit Transfer. Journal of Economic Surveys, Vol. 24, Issue 3, pp. 479-510, July 2010. Available at SSRN: *http://ssrn.com/abstract=1622956 or http://dx.doi.org/10.1111/j.1467-6419.2009.00592.x.*

Lindjhem, H, and S. Navrud (2008) How reliable are meta-analyses for international benefit transfers? *Ecological Economics*, 66, 425–435.

Mace, GM, JL Gittleman, and A Purvis. (2003). Preserving the tree of life. *Science* 300: 1707–709.

Markandya, A. and A. Chiabai (2013). “Economic Loss of Ecosystem Services from 1900 to 2050”, Chapter 4. In Lomborg B (Ed) *How Much Have Global Problems Cost the World?: A Scorecard from 1900 to 2050*. Cambridge University Press.

McCann, KS (2000). The Diversity-stability Debate. *Nature* 405: 228–33.

McVittie A., Hussain S. S. (2013) The Economics of Ecosystems and Biodiversity – Valuation Database Manual

MEA (2005). Millennium Ecosystem Assessment: Ecosystems and Human Wellbeing: Current State and Trends. Washington DC, Island Press.

Newman DJ and Cragg GM (2007). Natural Products as Sources of New Drugs Over the Last 25 years. *Journal of Natural Products*, 70, 461-477.

Nunes, P. and J. van Den Berg (2001). Economic valuation of biodiversity: sense or nonsense? *Ecological Economics,* 39, 2, 203-222.

OECD (2011), *Valuing Mortality Risk Reductions in Regulatory Analysis of Environmental, Health and Transport Policies: Policy Implications*. OECD, Paris, *www.oecd.org/env/policies/vsl.*

OECD (2012), *OECD Environmental Outlook to 2050: The Consequences of Inaction*, OECD Publishing, Paris, *http://dx.doi.org/10.1787/9789264122246-en.*

Pearce D., Atkinson G., and Mourato S., *Cost-Benefit Analysis and the Environment*,, ed. OECD. 2006, Geneva

Pimm, S.L., Russel, G.J., Gittleman, J.L. and Brooks, T.M. (1995). The Future of Biodiversity. *Science*, 269, 347-350.

Pimm, S.L. and P. Raven (2000). Extinction by Numbers, *Nature*, **403**, 843-845

Purvis, A., and A. Hector (2000). Getting the measure of biodiversity. *Nature* 405 (May 11): 212–19.

Russi D., ten Brink P., Farmer A., Badura T., Coates D., Förster J., Kumar R. and Davidson N. (2013) The Economics of Ecosystems and Biodiversity for Water and Wetlands. IEEP, London and Brussels; Ramsar Secretariat, Gland.

TEEB (2010) The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB. UNEP.

TEEB (2013) – The Economics of Ecosystems and Biodiversity (2013): Guidance Manual for TEEB Country Studies. Version 1.0.

Ten Brink, P. (ed.) (2011). The Economics of Ecosystems and Biodiversity in National and International Policy Making, Earthscan: London and Washington.

Tilman, D., and J.A. Downing (1994). Biodiversity and stability in grasslands. *Nature* 367: 363–65.