Chapter 3

Measuring biophysical quantities and the use of indicators

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Key messages

- A lack of relevant information at different scales has hampered the ability to assess the economic consequences of the loss of ecosystems and biodiversity.
- Most of the current measures and indicators of biodiversity and ecosystems were developed for purposes other than the economic assessment outlined by TEEB. They are therefore unable to show clear relationships between components of biodiversity and the services or benefits they provide to people, making them less relevant to the audience and aims of TEEB.
- A reliance on these existing measures will in all likelihood capture the value of only a few species and ecosystems relevant to food and fibre production, and will miss out the role of biodiversity and ecosystems in supporting the full range of benefits, as well as their resilience into the future.
- A set of indicators is needed that is not only relevant and able to convey the message of the consequences of biodiversity loss, but must also be based on accepted methods that reflect the aspects of biodiversity involved and the service that is of interest, capture the often non-linear and multi-scale relationships between ecosystems and the benefits that they provide, and be convertible into economic terms.
- While it is possible to obtain preliminary estimates of the consequences of biodiversity and ecosystem loss using existing data and measures, these must be complemented with active research and development into the measurement of biodiversity and ecosystem change, their links to benefit flows and the value of these flows so as to realize the full value of biodiversity and ecosystem management

1 Introduction

1.1 Aim and scope of this chapter

Changes in biodiversity, ecosystems and their services ultimately affect all people (MA 2005b). Global declines in biodiversity and ecosystems, the ongoing degradation and unsustainable use of ecosystem services, and the resultant effects on human wellbeing have led to many international and national responses focussed on halting and reversing this trend (Balmford et al. 2005).

However, attempts to halt or reverse these declines in ecosystems and biodiversity are confounded by a lack of information on the status and changes in ecosystems and biodiversity, the drivers of change, and the consequences of management responses (Pereira and Cooper 2006). The information that does exist remains fragmented, not comparable from one place to another, highly technical and unsuitable for policy makers, or simply unavailable (Scholes et al. 2008; Schmeller 2008).

Over the past decade, several programs have sought to fill some of these information gaps, from local to global levels (Royal Society 2003; Pereira and Cooper 2006; Scholes et al. 2008). The purpose of TEEB and this chapter is twofold: to provide guidance to interested stakeholders on the strengths and weaknesses of available measures and indicators of biodiversity and ecosystem status and change, with a focus on those which can put an economic value on these changes (TEEB 2008); and to outline what is needed to improve the existing science base of biodiversity and ecosystem indicators to better meet the needs of TEEB and associated efforts.

The chapter also describes in detail a set of global and sub-global indicators to highlight the opportunities and challenges associated with developing indicators which can be used in assessing the economic consequences of changes in biodiversity and ecosystems.

1.2 Why are indicators needed?

Ecosystem and biodiversity indicators serve multiple purposes which can broadly be categorized into three key functions: (1) tracking performance; (2) monitoring the consequences of alternative policies; and (3) scientific exploration (Failing & Gregory 2003). This chapter will focus mostly on the first two roles. Indicators are defined here as variables indicating something of interest or relevance to policy- or decision-makers with some logical connection to the object or the process being measured. They reflect, in an unambiguous and usually quantitative way, the status, causes (drivers) or outcome of the process or object (Ash et al. 2009). Indicators simplify and quantify information so that it can be easily communicated and intuitively understood, allowing policy- and decision-makers to base their decisions on evidence (Layke 2009).

It is useful to distinguish between measures, indicators and indices, the key terms used in this chapter. The term *measure* (or measurement) is used to refer to the actual measurement of a state, quantity or process derived from observations or monitoring. For example, bird counts are a measure derived from an observation. An *indicator* serves to indicate or give a suggestion of something of interest and is derived from measures. For example bird counts compared over time, show a trend which can indicate the success of conservation actions for a specific group of species. Indicators are typically used for a specific purpose, e.g. to provide a policy maker with information about progress towards a target. An *index* or multiple *indices* are comprised of a number of measures combined in a particular way to increase their sensitivity, reliability or ease of communication. These are useful in the context of biodiversity assessment where multiple attributes and measurements, related to a wide variety of policies, have resulted in long lists of measures and indicators. To communicate these trends in a small number of simple and meaningful indices is sensible (Balmford et al. 2005). For example, in the Red List Index for birds, changes in threat status over time are expressed as a number, obtained through a specific formula. A concern with composite indices is that the underlying measures often become obscured. Ideally they should be disaggregateable and traceable back to the original measures (Scholes and Biggs 2005).

1.3 What makes a good indicator?

The Convention on Biological Diversity (CBD 2003), as well as a number of other publications (Royal Society 2003; Mace and Baillie 2007; Ash et al. 2009), list multiple criteria to consider when selecting and developing indicators and measures of ecosystems and biodiversity. Of these criteria, perhaps the most pertinent to this chapter and its readers is the need to make the indicators relevant to the purpose. This not only requires setting clear goals and targets in the indicator development process, but also a thorough understanding of the target audience and their needs (Mace and Baillie 2007).

Vagueness in current targets, the diversity of target audiences and their needs, the resources required to turn measures into effective indicators, and the reliance of most current measures and indicators on available data have posed substantial obstacles in the development of relevant and useful indicators (Royal Society 2003; Green et al. 2005; Mace and Baillie 2007; Layke 2009).

Much of the current effort in indicator development has arisen from the CBD's Biodiversity 2010 Target and regional or national responses to this target (e.g. EEA 2009), as well as the work of the Millennium Ecosystem Assessment (MA: MA 2005b). While the latter did not aim to develop indicators, the global and sub-global assessment of ecosystem status and trend collated many measures of ecosystems and ecosystem services (Layke 2009). Both of these initiatives have resulted in substantial effort and resources invested in indicator development and the collation of measures, with good progress in some aspects of the assessment of biodiversity, ecosystem and ecosystem service status and trends (Mace et al. 2005; Mace and Baillie 2007; EEA 2009; Layke 2009; http://twentyten.net; http://www.unep-wcmc.org/collaborations/BINU/). However, many gaps and substantial challenges remain for scientists and policy makers in ensuring that the measures and indicators are sensitive, realistic and useful (MA 2005b; Mace and Baille 2007; Scholes et al. 2008; Layke 2009).

In the context of TEEB it is important to recognize that its objectives and audience differ from existing programs like the Biodiversity 2010 Target and the MA. TEEB moves beyond the measurement of biodiversity and ecosystem status and change, to an assessment of the economic implications of changes in biodiversity and ecosystems (TEEB, 2008). It is therefore possible that existing indicators and measures developed mainly for the Biodiversity 2010 Target and for the MA's purposes, may not best address the objectives of TEEB.

The intended audience of TEEB is wider and more varied than previous biodiversity and ecosystems indicator program audiences and comprises stakeholders at different levels, including individuals whose livelihoods directly depend on harvesting natural resources, resource managers, decision makers at all levels, and civil society in general. The scientific community is also a stakeholder as scientists are involved in the monitoring and observation of a broad range of biodiversity and ecosystem measures over a variety of scales (Schmeller, 2008). This varied audience will require different sets of indicators relevant and understandable within and across sectors and scales. Taking a sectoral perspective also implies combining measures that provide a broad integrated time series of ecosystem status at the relevant scale with relevant socio-economic indicators related to issues such as employment or trade.

TEEB's focus on the economic consequences of changes in biodiversity and ecosystems brings with it new challenges to the science and practice of biodiversity and ecosystem indicator development. First, TEEB is interested in the measurement of *biodiversity change*. This is a concept with which the Biodiversity 2010 Target indicator development has struggled. Not only is biodiversity a multi-faceted, multi-attribute concept of a hierarchy of genes, species and ecosystems, with structural, functional and compositional aspects within each hierarchical level (Noss 1990). Change in biodiversity is also multi-faceted and can include loss of quantity (abundance, distribution), quality (ecosystem degradation) or variability (diversity of species or genes) within all levels and aspects (Balmford et al. 2008). As Mace et al. (2005) highlight, different facets of change will have different implications for different ecosystem services, for example changes in functional and structural variability in species will have broad-ranging impacts on most services, while changes in the quantity and distribution of populations and ecosystems will be important for many provisioning and regulating services. Therefore the most appropriate measures and indicators will involve a consideration of both the aspects of biodiversity involved and the service that is of interest.

Second, in order to assess the consequences of change in biodiversity TEEB is targeted at the *links* between biodiversity, ecosystem services and human wellbeing. While there may be good progress in the development of indicators to measure the status and trends of biodiversity, ecosystem services and human wellbeing, TEEB needs measures that can capture the often non-linear and multi-scale relationships between ecosystems and the benefits that they provide (van Jaarsveld et al. 2005; Fisher and Turner 2008). This is an area of very little current development and investment, especially at global scales.

Finally, TEEB is interested in the *economic* consequences of biodiversity change. Therefore indicators and measures used in TEEB must be convertible into economic terms and suitable for economic analyses. This implies more than the generation of monetary values, and requires the inclusion of livelihood conditions, risk, and access to resources, benefit sharing and poverty considerations (Balmford et al. 2008) (see Chapters 4 & 5). Since TEEB's ultimate aim is to make the use of natural resources more sustainable, indicators should address the sustainability of the use patterns measured. TEEB, although acknowledging the importance of nature's intrinsic worth, does not explicitly address intrinsic values of nature, including the ethical considerations regarding the rights of all species. At this stage, TEEB also does not cover the economic value of the interactions between species that structure ecological processes, though this is relevant to the assessment of ecosystem services and may be attempted in future.

This chapter aims to take these challenges into account and through an assessment of existing measures and indicators to identify which of the available measures are the most appropriate for the purposes of assessing the economic consequences of biodiversity and ecosystem change. In this context, good measures would be measured with known precision and should sample across relevant places or systems, they ideally would be repeatable and have a history, and would have a clear relationship to some benefit that people receive from biodiversity or ecosystems.

In addition to these general characteristics, indicators and measures need to have an appropriate temporal and geographical coverage, and ideally be spatially explicit.

The importance of being spatially explicit has been emphasised in TEEB by Balmford et al. (2008). The production, flow and use of the benefits of biodiversity and ecosystems varies spatially, as do the impacts of policy interventions. Making available data and information spatially explicit helps make assumptions explicit, and also identifies needs for further information. The production and use of the benefits of ecosystems and biodiversity often take place in different geographical areas, so a spatially explicit approach is essential to fully evaluate the importance of ecosystem services and the impacts of related policy actions.

2 Existing measures and indicators

Biodiversity, ecosystem and ecosystem service indicators and measures have proliferated over the past several years, largely in response to the setting of the CBD Biodiversity 2010 Target and the Millennium Ecosystem Assessment and its sub-global activities. An exhaustive review of all these indicators and measures is not intended here (see Mace and Baillie 2007; Layke 2009 for in depth reviews of indicator groups); rather this section highlights what types of indicators and measures are available and reviews their relative strengths and weaknesses in an effort to guide the selection and development of appropriate indicators and measures that can be used to assess and predict the economic consequences of biodiversity and ecosystem change.

Biodiversity and the ecosystems that it structures are notoriously complex entities to measure and assess, and this can be undertaken in a variety of different ways. The MA (2005a) and Balmford et al. (2008) highlighted that biodiversity indicators are available for assessing all the different levels of the biodiversity hierarchy (genes, species, ecosystems), as well as measuring several attributes at these levels, namely *diversity, quantity* and *condition*. These three categories of attributes are used to structure this review and Table 1. A fourth category of indicators is one that measures *pressures* exerted on the environment. This chapter also includes an additional category focussed on *ecosystem service* measures and indicators, in recognition of the large amount of data and measures made available through the MA and its follow up activities, as well as the importance of these measures in linking biodiversity to economic valuation. The ecosystem service measures are separated into *provisioning, regulating and cultural service* categories due to the different relationships between these groups of services and ecosystem elements (see chapter 2), as well as the different tools available for valuing different ecosystem service groups (see chapter 5). TEEB (2009, chapter 3) provides a list of examples of ecosystem service indicators, but this review focuses on only those measures and indicators which are already in use and thus available for review.

This chapter does not propose a specific set of indicators and measures; as discussed earlier, different sets of indicators will be required for different audiences. Rather, the chapter provides an overview of existing indicators and measures of biodiversity and ecosystems and their potential use in economic valuation exercises like those adopted by TEEB. The chapter focuses on existing spatially explicit indicators and measures (with some mention of those known to be in development). This chapter assesses their current application in biodiversity and ecosystem service measurement and in valuing change, their ability to convey information and their data availability. These last two criteria were developed and applied in the WRI review of the MA measures and indicators (Layke 2009). In this review indicators are ranked based on their ability to convey information as a combination of their intuitiveness, sensitivity and acceptability, and their data availability based on the presence of adequate monitoring systems, availability of processed data and whether the data are normalized and disaggregated. This chapter does not provide an evaluation of use, access or human wellbeing indicators.

Table 1: Review of existing biophysical measures in terms of their application to measuring biodiversity and ecosystems, their ability to convey information and current data availability at the global scale

Broad category of origin	Category	Examples	Application	Ability to convey information	Data quality and availability
Biodiversity measures and indicators	Measures of diversity	Species diversity, richness and endemism Beta-diversity (turnover of species) Phylogenetic diversity Genetic diversity Functional diversity	To biodiversity: These measures are used to identify areas of high biodiversity value and conservation priority at global and sub-global scales. Seldom used to measure change at global scales, but have been used to indicate functional and structural shifts associated with declines in diversity at sub-global scales. Trends in genetic diversity of species is a Headline Indicator (HI) for Biodiversity 2010 Target To ecosystem services: Not easily linked to specific provisioning or regulating ecosystem services, with the exception of proposed measures of functional diversity. Analysis of congruence between diversity and service levels shows mixed support. Studies demonstrate importance of species and	Measures and maps of areas of high species diversity and endemism easily understood by wide audience, based on agreed methods and data. Not sensitive to short term change	Species measures for some taxa available globally, but not as a time series Other measures not available globally

			genetic diversity in promoting ecosystem resilience across ecosystem services. Genetic diversity also linked to options for bio-prospecting and food security. Cultural values of diversity, especially education, research and aesthetic values, provide these measures with a link to cultural ecosystem services. To valuation: Not easily valued due to general rather than specific role in providing benefits. Some valuation of bio-prospecting and genetic diversity of crop species possible. Also possible to value the cultural values attached to diversity, although not yet common practice.		
	Measures of quantity	Extent and geographic distribution of species and ecosystems Abundance / population size Biomass / Net Primary	To biodiversity: Descriptive measure of biodiversity used in baseline studies and descriptions; when available over temporal scales they can feed into indicators of biodiversity status and trends, and prioritisation and risk assessment protocols. Trends in selected ecosystems and species are HIs of the Biodiversity 2010 Target To ecosystem services: Measure of status and	Measures and indicators of trends in habitat area and species populations are intuitive to a wide audience (e.g. deforestation rates). Measures of biomass and NPP	Global datasets of broad ecosystems and some taxa available for a single time period. For some species and populations there are good time series data.

		Production (NPP)	trends for ecosystems (e.g. forest, wetlands, corral reefs) and species (medicinal plants, food) which have clear links to provisioning services have been used as measures of stocks and flows of ecosystem services. Similarly useful for ecosystems and species with social and cultural values which have links to cultural services. Some use in measuring regulating services which rely on biomass or a particular habitat / vegetation cover (e.g. carbon sequestration, pollination, erosion control, water flow regulation). To valuation: Measures of provisioning, cultural and regulating services can be valued using the variety of approaches listed in Chapter 5 (e.g. market price, contingent valuation, factor income or replacement cost).	less intuitive. Most measures are based on accepted methods and are sensitive to change (data dependent)	NPP and Biomass measures available at global scales and can be modelled over multiple time series
	Measures of condition	Threatened species/ecosystems Red List Index (RLI) Ecosystem connectivity/fragmentation (Fractal dimension, Core	To biodiversity: These measures are used to assess and indicate the status and trends of biodiversity and ecosystems. Change in status of threatened species, Marine Trophic Index, connectivity/fragmentation, human induced ecosystem failure are HIs of Biodiversity	Threatened species status, RLI and MTI used and understood indicators of biodiversity loss,	Threatened species status and trends available for limited taxa at a global scale. Most other

		Area Index, Connectivity, Patch Cohesion), Ecosystem degradation Trophic integrity (Marine Trophic Integrity - MTI), Changes in disturbance regimes (human induced ecosystem failure, changes in fire frequency and intensity) Population integrity / abundance measures (Mean Species Abundance - MSA, Biodiversity Intactness Index -BII, Natural Capital Index-NCI)	2010 Target To ecosystem services: While providing an indication of the status and trend of ecosystems and their services, these indicators are seldom linked to quantified changes in ecosystem service levels. They are however useful indicators of sustainability, thresholds and the scale of human impacts on ecosystems, particularly where clear and demonstrable linkages exist. To valuation: Not currently converted into monetary values, although potentially useful in determining risk of economic loss	based on acceptable methods and data and sensitive to change. Other measures less intuitive and quite technical, little consensus on methods and data	measures only available at a sub-global scale and often only for one period of time.
	Measures of pressures	Land cover change	To biodiversity: These are measures of the pressures or threats facing biodiversity. They	Many of these measures and	Land cover data available at global

		Climate change Pollution and eutrophication (Nutrient level assessment) Human footprint indicators (e.g. Human Appropriated Net Primary Productivity - HANPP, Living Planet Index -LPI, ecological debt) Levels of use (harvesting, abstraction) Alien invasive species	do not measure the status and trends of biodiversity, but are an indication of the size and trends of the pressures on biodiversity and often feed into biodiversity assessments at national scales in State of Environment Reports. They are frequently used in communicating biodiversity status and trends and many are relevant to Biodiversity 2010 target To ecosystem services: When linked to particular species (e.g. fish) or ecosystems (e.g. wetlands) which provide or support ecosystem services, these measures are useful indicators of ecosystem service levels and declines. They are also used to indicate the sustainability of ecosystem service use and supply To valuation: Changes in ecosystem service levels lend themselves to valuation of the losses or gains in services. If information is available on threshold effects for particular services then these indicators can be useful in determining economic risk.	indicators are used to communicate the status of biodiversity to a wide audience (public and policy), consensus methods are in development, most are sensitive to change Composite footprint indicators are increasingly disaggregateable	scales, but not as a time series. Climate change models are globally available for a range of future time periods, linking these pressures to biodiversity changes remains a gap. Some measures of pollution available globally and over time (e.g. nitrogen deposition). Composite footprint indicators available globally and over time periods.

					Use levels and alien species under development
Ecosystem service measures & indicators[i]	Provisioning service measures	Timber, fuel and fibre production Livestock production Fisheries production Wild animal products Harvested medicinal plants Water yield and regulation Biological infrastructure needed for nature based recreation	To biodiversity: Measures of provisioning services currently used to indicate use and sustainability of use on biodiversity and ecosystems. More recently used to indicate the value of biodiversity and ecosystems To ecosystem services: Direct measures of ecosystem service levels and changes. When calculated as sustainable production measures can be used as indicators for monitoring and managing ecosystem services, contrasting sustainable production with actual. To valuation: Most indicators expressed as biophysical units which can be converted into monetary values where markets exist.	Simple and compelling indicators where they do exist. Methods of modelling and development not yet agreed upon. Sensitive to change	Timber and livestock production available globally Most data only available at sub-global scales and for single time period. Possibility of upscaling and modelling for some (see Section 3.3) Total production and direct use values more common than sustainable production

					indicators
	Regulation service measures	Carbon sequestration Water flow regulation and production Air quality regulation Natural hazard regulation Waste assimilation Erosion regulation / soil protection Disease regulation Pollination Maintenance of genetic diversity Pest control	To biodiversity: Many of these measures of measurements of ecological processes important to the persistence of ecosystems and so can be used to indicate functional biodiversity condition and trends. Recently used to indicate the value of biodiversity and ecosystems To ecosystem services: Direct measures of ecosystem service levels and changes. To valuation: Regulating services are more difficult to value but see Chapter 5 for progress in valuing through avoided / replacement or restoration and other costs. Double counting remains an issue with some of these services.	Less intuitive to a wide audience than the provisioning measures, excluding water and carbon which are increasingly understood. Limited consensus on methods of measurement and modelling. Less sensitive to short term changes	Most measures only at sub-global scales, although many identified as possible global indicators for development Carbon sequestration available globally Where data exist possible to model over time, but not common
	Cultural service	Recreational use Tourism numbers or	To biodiversity: Many of these measures are specific to particular ecosystems or species of	No such measures yet available	Most measures only at sub-global

	measures	income Spiritual values Aesthetic values	cultural value, although tourism can often be linked to habitat and species diversity. More recently been suggested as indicative of the value of biodiversity and ecosystems To ecosystem services: Direct measures of ecosystem service levels and changes. To valuation: Most cultural services are poorly understood and often difficult to value . Tourism and recreation services, as well as existence value more amenable to valuation. Some debate over the economic valuation of spiritual and religious values. See Chapter 5 for progress in valuing.	globally. At sub global levels some measures intuitive e.g. tourism numbers or recreational values. Other measures poorly understood. No consensus on measurement and modelling. Not sensitive to change	scales, although tourism identified as possible global indicator for development

An examination of Table 1 shows that there are a large number of measures and indicators available across geographic scales and regions for assessing biodiversity and ecosystem services. As in previous reviews of measures and indicators of biodiversity and ecosystem services (Royal Society 2003; Mace and Baillie 2007; Layke 2009), much of the existing data and indicators were collected and developed for purposes other than the one TEEB is interested in and are therefore not necessarily the right measures for assessing the economic consequences of biodiversity and ecosystem change. Furthermore most of the existing indicators are developed and applied within specific contexts resulting in some good biodiversity indicators and some progress in the development of ecosystem service indicators, but the current lack of measures and indicators which span contexts and show clear relationships between components of biodiversity and the services or benefits they provide to people is a key gap, making existing measures and indicators less relevant to the audience and aims of TEEB. The categories of indicators presented in Table 1 are reviewed below with two objectives: 1) to identify existing measures useful for economic valuation in the short term; and 2) to highlight the work still required to develop key fit-for-purpose indicators in the longer term.

2.1 Indicators of diversity

At a global level, measures and maps of species diversity, endemism and richness are available for some taxa e.g. mammals and amphibians (Myers et al. 2000; MA 2005a), while at sub-global scales these are supplemented by measures and indicators of genetic and ecosystem diversity (e.g. Bagley et al 2002). Although these indicators are the focus of many conservation agencies and policies and good at conveying their message of high biodiversity value, these measures are seldom used to assess the benefits provided by the diversity of genes, species, and ecosystems to people and economies. This is probably a result of the complex and tenuous relationships between diversity and ecosystem services (Balvanera et al. 2001; Hooper et al. 2005; Mace et al. 2005). While some evidence exists that diversity is important in resilience and adaptive capacity of biodiversity and ecosystems (Johnson et al 1996; Naeem 1998; Swift et al. 2004; Balvanera et al. 2006; Diaz et al. 2006), this “insurance value” is seldom calculated (see chapter 2 for a detailed explanation). A frequently cited example of the importance of diversity is the value of genetic diversity in agriculture and bio-prospecting (Esquinas-Alcázar 2005); however, these benefits are complex given their option-based nature and are therefore hard to quantify and value. Other benefits of diversity include cultural services associated with enjoyment and appreciation of diversity which may be more amenable to valuation, using for example willingness to pay approaches (e.g. Esquinas-Alcázar 2005), but the reliability of these approaches has not been demonstrated (see Chapter 5). Finally, functional diversity (i.e. the diversity of functional groups or types) is said to be important for regulating services (Bunker et al. 2005; Diaz et al. 2006, Chapter 2), but challenges with developing indicators of functional diversity, as well as the challenges associated with valuing regulating services (Chapter 5), limit the numbers and application of these indicators in valuation assessments.

These measures of diversity have good potential to convey a message in that they are intuitive, already widely in circulation, and largely based on accepted and rigorous methods and data. However, their sensitivity to change over policy relevant periods is weak because of data gaps, and because change would require local or global extinctions of species or ecosystems, which as Balmford et al. (2003) point out, is often a longer-term process insensitive to short-term change.

With the exception of genetic diversity, this category of measures is not the current focus of many indicator or valuation efforts, but a need remains for further research into quantifying the currently tenuous links between diversity and human wellbeing.

2.2 Indicators of quantity

Indicators and measures of quantity can be developed at the population, species and ecosystem level. They can express the total number or changes in number at these levels. Widely used indicators of quantity include those that highlight changes in ecosystem extent (e.g. forest area; FAO 2001) and those that demonstrate changes in species abundances (e.g. number of waterbirds; Revenga and Kura 2003). Many of these indicators focus on functional groups rather than taxonomic groupings (e.g. waterbirds, pelagic fish, wetland ecosystems).

When these measures or indicators exist for ecosystems, species or functional groups, and are coupled with good data on the benefit flows and associated economic value of those features being assessed (e.g. fish stocks (FAO 2000) or wetland services (Finlayson et al. 2005)), then these measures form a valuable indicator for demonstrating the economic impacts of biodiversity change. At the global scale changes in important fish stocks have been directly valued (e.g. Wood et al. 2005), while at local scales temporal changes in ecosystem extent have been used to quantify declines in water, erosion control, carbon storage and nature-based tourism (Reyers et al. 2009).

Indicators of quantity also include measures of primary productivity and biomass. These may be seen as undiscerning indicators of biodiversity, in that they do not measure taxonomic or functional units of species or ecosystems (but see Costanza et al. 2007). However, they are potentially useful indicators of ecosystem production which has been linked to several benefits including carbon storage (Naidoo et al. 2008), timber production (Balmford et al. 2008) and grazing (O'Farrell et al. 2007). They currently do not differentiate between natural / indigenous production and human enhanced production, and must therefore be carefully interpreted when calculating the economic consequences of ecosystem and biodiversity change for a specific area.

Data gaps include clear geographical and taxonomic selection biases towards popular, well known and easy to measure species and ecosystems e.g. mammals, birds, forest ecosystems (Royal Society 2003; Collen et al 2008; Schmeller et al. 2009). Further gaps in knowledge and data on the abundance of, for example, useful plants and animals, limit the development of these indicators and may result in a significant underestimation of the economic impacts of species and ecosystem losses.

In reviewing their ability to convey their message, strengths of indicators include their intuitiveness (especially measures of well known species and ecosystems e.g. fish and forests), the general consensus on methods and data, and their sensitivity to change. Weaknesses exist around the methods, use and communication of measures of productivity and biomass, but good progress is being made (Imhoff et al. 2004).

Due to the clear links to easily valued provisioning services, this category of measures and indicators holds much promise for measuring and predicting some of the economic consequences of change in biodiversity and ecosystem services. At a local scale this is already possible where data on ecosystem extent and species abundances exist (Balmford et al. 2002; Reyers et al. 2009); at a global scale this will require the rapid development and collation of global databases on ecosystem extent and information on the abundance of a wide range of useful species, and changes in these measures. Current ability to model changes in ecosystem extent (Czúcz et al. 2009), as well as changes in species abundances (Scholes and Biggs 2005; Diaz et al. 2006; Alkemade et al. 2009) make this a useful focus for TEEB. A focus on functional types or groups could prove highly useful and help avoid the challenges associated with the issue of redundancy, where more than one species or ecosystem is capable of providing a service (Diaz et al. 2006).

2.3 Indicators of condition

These measures reflect changes in the condition or quality of ecosystems and biodiversity, reflecting the degradation of components of biodiversity from the population level to the ecosystem. While they are closely linked to the previous category, these indicators focus less on the quantity of species or ecosystems, and more on the quality or integrity of the element being assessed. Examples include species and ecosystems at risk of extinction (Mace and Lande 1991; EEA 2009), levels of nutrients (e.g. soil condition, nitrogen deposition and depletion; MA 2005b), degree of fragmentation of an ecosystem (Rodriguez et al. 2007), trophic level changes (Pauly et al. 1998), population integrity measures (Scholes and Biggs 2005) and alteration of disturbance regimes (Carpenter et al. 2008).

Changes in species abundances in relation to thresholds (Mace and Lande 1991), and more recently changes in ecosystem extent in relation to thresholds (Rodriguez et al. 2007), have been used to develop risk assessment protocols that highlight biodiversity features with a high risk of extinction. The Red List Index, a composite measure summarizing the overall rate at which a group of species is moving towards extinction, e.g. European birds (EEA 2009), has been widely applied and used in measuring progress towards the Biodiversity 2010 Target. These approaches could prove useful in valuing the economic risk of biodiversity loss, especially if the species and ecosystems under assessment have a high risk of extinction and are clearly linked to benefits, but this has yet to be explored.

Indicators of population integrity include recently developed composite indices focused on changes in abundance. Examples of these are the Biodiversity Intactness Index (BII) (Scholes and Biggs 2005) and the Mean Species Abundance (MSA) Index (Alkemade et al. 2009). These indices use data and expert input on land cover and use impacts on populations of species, and together with information on historic or predicted land use change, model the aggregated impact of change at a population level. While useful tools for assessing the population level consequences of land use change, these mean or summed aggregated measures make it hard to link these changes to shifts in benefit flows (which are usually linked to only a few species, functional types or populations within the set modeled). The disaggregateable and traceable nature of the BII makes this a useful indicator of biodiversity condition, and with more research and data could be extended to measure functional group integrity – providing a clearer link to benefits.

MSA is an index that captures the average effect of anthropogenic drivers of change on a set of species. This measure provides insight into the effects of disturbance, particularly land cover change on species numbers, with the focus on determining the average numbers of species for disturbed versus undisturbed environments. It is also linked to various global scenarios, useful in the context of TEEB. This indicator is not an independently verifiable measure and is strongly influenced by the assumed species assemblages at the outset. Because it is a measure of the average population response, the same MSA values can result from very different situations. Furthermore, this average effect is unable to deal with changing species composition such as extinction or invasion and will miss important functional changes associated with the loss of particular species. This, together with an inability to incorporate changes in ecosystem functions resulting from biodiversity loss, makes the index's links to ecosystem services potentially tenuous.

Many of these measures and indicators have been applied at global and sub-global scales (e.g. MA 2005a; Biggs et al. 2006; EEA 2009) and appear to provide a clear and relevant message on the condition and trends of biodiversity. Some data and methodological gaps exist for determining ecosystem fragmentation or alteration of disturbance regimes and limit these indicators to use at mostly sub-global scales. Generally, these indicators are data and knowledge intensive (but can be supplemented by expert input), and are often only available at sub-global scales.

As they currently stand, few of these condition measures are amenable to the aims of TEEB, but their wide uptake, ease of application and available data and models will make them central to most assessments of biodiversity and ecosystems. However, their links to benefit provision are however tenuous and complicated by inadequate knowledge of the relationship between ecosystem integrity and benefit flow, as well as gaps in our knowledge of functional thresholds.

2.4 Indicators of pressures

In many cases the measurement and modelling of ecosystem and biodiversity change relies on measures of the pressures facing biodiversity and ecosystems as an indicator of biodiversity loss or ecosystem change. These pressures include many of the direct drivers of change highlighted by the MA as the most important factors affecting biodiversity and ecosystems: habitat destruction, introduction of alien invasive species, overexploitation, disease and climate change (Mace et al. 2005). These measures rely on land cover and use data, climate change models, distribution and density data on alien species and data on levels of use. Some indicators are composite indices which incorporate several pressures to indicate human impacts on ecosystems. Chief examples include the Living Planet Index (www.panda.org/livingplanet), the Ecological Footprint (www.ecologicalfootprint.com), and Human Appropriated Net Primary Productivity (HANPP: Erb et al. (2009), Imhoff et al. (2004) and with specific reference to biodiversity Haberl et al. (2007); for maps see http://www.uni-klu.ac.at/socec/inhalt/1191.htm) which are all available at a global scale over a period of time. Many of these composite measures also include thresholds of carrying capacity or total annual productivity to provide an indication of the sustainability of these impacts.

Land cover change is a widely used measure, where remote sensing and satellite imagery have made such data available for all parts of the world (e.g. Global Land Cover (GLC2000); Bartholomé and Belward 2005). Time series data on land cover, as well as models of future land cover change have been used to assess biodiversity and ecosystem service change at all scales from global (Mace et al. 2005) to local (Fox et al. 2005). Levels of pollutants and eutrophication are commonly used measures of human pressures at a global scale (MA 2005b; EEA 2009).

The history and widespread use of many of these pressure measures demonstrates their sound ability to convey the message of human pressures on biodiversity. The recent additions of composite indices relative to some threshold capacity have proven a useful and relevant communication tool.

While land cover should not be confused with ecosystems, these data can still be useful for broad assessments of changes in benefit flows associated with particular classes of land cover. Some of the earliest work on quantifying the economic consequences of land cover change was done in this fashion by Costanza et al. (1997). A few local-scale studies which attempt to measure change in ecosystem services rely on this approach using land cover change data (derived from remote sensing) and ecosystem service value coefficients (usually extracted from Costanza et al. 1997) (Kreuter et al. 2001, Zhao et al. 2004, Viglizzo and Frank 2006, Li et al. 2007). Case studies and simulations of land cover change have also been used to examine the effects on single ecosystem services or processes (nitrogen levels: Turner II et al. 2003; pollination: Priess et al. 2007; livestock production services: O'Farrell et al. 2007; soil organic carbon: Yadav and Malanson 2008). Recent advances in ecosystem mapping (Olson et al. 2001), earth observation (Bartholomé and Belward 2005) and valuation (Chapter 5) should make this kind of approach a complementary and practical way to evaluate the economic consequences of biodiversity and ecosystem change. The ability to use data on drivers of change to predict future change provides a further compelling reason for the adoption of this indicator (e.g. Schroter et al. 2005).

2.5 Indicators of ecosystem services

Several measures of ecosystem services are already in existence and a recent review by Layke (2009) of the indicators used in the Millennium Ecosystem Assessment and its sub-global assessments highlighted that current ecosystem service indicators are limited by insufficient data and an overall low ability to convey information. Of the indicators available, Layke (2009) found them inadequate in characterizing the diversity and complexity of the benefits provided by ecosystem services. Layke (2009) found that regulating and cultural services fare worse than provisioning services in all findings.

Provisioning services were found to have a high ability to convey information for services of food, raw materials, fuel and water provision, but data availability was average and in the case of wild food, capture fisheries and aquaculture it was poor. Genetic resources and biochemicals were found to be both poor at conveying information and poor in terms of data availability.

For the cultural services Layke (2009) found no measures of spiritual or religious values and the measures of tourism, recreation and aesthetic value available showed poor data availability and poor ability to convey information. Balmford et al. (2008) highlight this shortcoming and point to a need to focus on cultural services which better lend themselves to measurement and assessment. They suggest a focus on services like bird watching and scuba diving, where the links between biodiversity and the cultural or recreational benefit are simple and clearly defined, and where valuation studies already exist (e.g. Losey and Vaughan 2006; Tapuswan and Asafu-Adiaye 2008; Lee et al. 2009). Protected area visitor numbers and values are also a potential indicator. However, these indicators are not yet available at global or regional scales.

For regulating services measures are limited to just more than half of the ecosystem services listed by Layke (2009) and where measures do exist data availability and ability to convey information are poor. Water regulation and water purification are listed as the only measures with a high ability to convey information, but are limited by data availability, while climate, air quality and natural hazard regulation were all found to have an average ability to convey information but were also hampered by an average (in the case of climate) to poor data availability.

These shortcomings in all services, but particularly in cultural and regulating services will have serious consequences for the comprehensive economic valuation of all ecosystem services, limiting the valuation to a few provisioning and even fewer regulating services.

However, the review presented in Balmford et al. (2008) as well as some recent studies (e.g. Troy and Wilson 2006, Naidoo et al. 2008; Wendland et al. 2009), indicate that the spatially explicit measurement of ecosystem services at regional and global scales is a rapidly growing research area. Projects such as those of the Heinz Center in the USA (The Heinz Center 1999; Clark et al. 2002; The Heinz Center 2006) and the European-based Advanced Terrestrial Ecosystem Analysis and Modelling (ATEAM) have made good progress in the development of indicators and the mapping of ecosystem services, even to the point of including scenarios of future change (Metzger et al. 2006).

Furthermore, the development of several international programs advancing the measurement and valuation of ecosystem services will help to fill these gaps in the future (e.g. The Natural Capital Project (Nelson et al. 2009), The Global Earth Observation Biodiversity Observation Network GEOBON (Scholes et al. 2008); The World Resources Institute Mainstreaming Ecosystem Services Initiative http://www.wri.org/project/mainstreaming-ecosystem-services/tools). These programs are developing tools and approaches to model, map and value the production of particular ecosystem services based on abiotic, biotic (often from measures listed above) and anthropogenic factors, as well as knowledge of relationships between these factors (Figure 1 presents an example from South Africa where data on rainfall, geology (lithology), vegetation type, recharge, groundwater-quality (electrical conductivity) and land use activities were used to map water flows). Very complex measures relying on species diversity, abundance, distribution and landscape pattern have also been developed at local scales (e.g. pollination; Kremen 2005).

However, Naidoo et al. (2008) observed that evidence of the spatial estimation of ecosystem services and the flow of benefits to near and distant human populations is limited to a few local case studies. Most of the existing quantitative analyses still tend to provide aggregated values for large regions, and data availability and disaggregation of spatial data are still a limitation to the mapping of ecosystem services. Furthermore, the multivariate nature of these ecosystem service indicators makes it hard to isolate the role of biodiversity in ecosystem service supply, which in turn makes the economic consequences of biodiversity loss hard to untangle from the other biotic, abiotic and anthropogenic factors involved in service supply. These are further explored in the following sections.

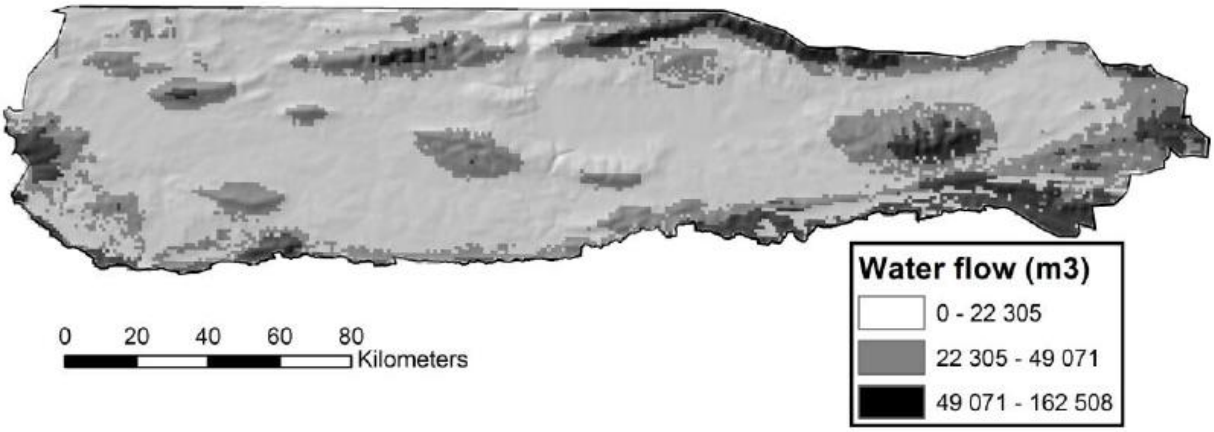

Figure 1: **Map of ecosystem services of water flows for the Little Karoo region of South Africa**. These data were used by Reyers et al. (2009) to assess changes in ecosystem services supply over time.

In summary, few indicators at present move beyond the quantification of a stock or flow of a service to the actual valuing of the service, and despite developments, calculating the contribution of biodiversity and effects of changes in its state to these values remains a challenge.

2.6 Lessons

Despite the array of biodiversity and ecosystem service indicators available, few lend themselves to a direct application of determining the economic consequences of biodiversity and ecosystem change. We will need a representative set of indicators to ensure that all relevant aspects of biodiversity and ecosystem change are captured and valued – from diversity to condition. A reliance on existing indicators will in all likelihood capture the value of a few species and ecosystems relevant to food and fibre production, and will miss out the role of biodiversity and ecosystems in supporting the full range of ecosystem services, as well as their resilience into the future.

An alternative avenue is to focus on pressures and their use in models of the economic consequences of policy inaction in the arena of land cover or climate change. This approach bypasses the actual measurement or modelling of biodiversity and ecosystem change, and investigates the implications for land cover and climate change on ecosystem services directly (e.g. Schroter et al. 2005; Metzger et al. 2006). However, this approach will not necessarily advance the case for biodiversity and ecosystem governance which is the key purpose of TEEB, but it will perhaps highlight the need for land use and climate policy and action in the context of ecosystem service governance.

While it is important to use available tools to meet short term policy and decision maker needs, it is critical to marry these measures of quantity and drivers, with measures of diversity and condition in order to ensure a full accounting of the value of biodiversity and ecosystems into decision making. So the current focus on synthesising existing data must be complemented with active research and development into the measurement of biodiversity and ecosystem change, their links to benefit flows and the value of these flows.

Many of the measures currently available are primarily determined by the existing information, which does not necessarily make them good measures or good indicators. TEEB and other assessments of the economic value and consequences of biodiversity loss will need fit-for-purpose indicators and new data with which to populate them. These fit-for-purpose indicators must address the challenges outlined in Section 3.1 and must not only be relevant and effective in conveying their message, but must also be precise, applicable across relevant systems and places, repeatable and defensible, and demonstrate a clear link between the benefit and the component of biodiversity delivering that benefit.

3 In search of relevant indicators for ecosystem services

3.1 Developing relevant indicators

It is clear from section 3.2 that most existing measures of biodiversity, ecosystems and ecosystem services were not developed for the purpose of TEEB and similar projects: to examine the economic consequences of changes in biodiversity and ecosystem services, and in particular the marginal loss of biodiversity. The InVEST model of the Natural Capital Project does allow for the quantification of economic values and changes in these values under future scenarios and is a powerful tool being explored by many global and sub-global programs (Daily et al. 2009). Rather than argue for a single unified methodology that can apply to all possible circumstances, several parallel approaches and ways of modeling are needed. To support the development of indicators relevant to the aims of TEEB and other projects interested in the economic consequences of biodiversity loss, a few potential indicators are explored below, using them to highlight key opportunities and constraints in these indicators. These include a readily measured provisioning service of timber production, a published model and map of the regulating service of carbon sequestration, and a preliminary assessment of the methods for measuring a less easily measured cultural service of social value of agricultural landscapes. The section also discusses advances made at local scales in indicator development, and ends with some discussion on the importance of baselines and thresholds in indicator development.

3.2 A provisioning service: timber production

Provisioning services (with clear production functions) appear to have received most of the attention in ecosystem service mapping exercises (Balmford et al 2008; Naidoo et al. 2008). A popular provisioning service, timber production, can be modeled and mapped using estimates of DMP - Dry Matter Productivity in forest areas by combining remote sensing imagery with meteorological data (for more information see http://geofront.vgt.vito.be/geosuccess/relay.do?dispatch=DMP_info). The service's production function includes measures of ecosystem extent (forest area) and measures of biological quantity (dry matter). The DMP index provides a measure of the vegetation growth in kilograms of dry matter per hectare. This is the annual amount of new dry matter created by the ecosystems and can be understood as the new timber offered by the ecosystems each year. Comparing DMP across different years can show areas with different vegetation activity, enabling it to be used to derive changes in DMP and find those areas where natural timber production has increased or decreased.

The maps in Figure 2 show a world map which illustrates where the Dry Matter Productivity is more intense (darker green colour). The country-scale maps show the difference between the years 2001 and 2004 for the vegetation activity in West Africa and in Madagascar. In the case of Madagascar, the total DMP dropped by 6% between 2001 and 2004 due to deforestation.

This measure provides good opportunities to measure and model the impacts of changes in forest area and natural timber production (measures of the quantity – Table 1) on the production service. However, it still falls short of the ideal TEEB indicators in that some development is still required in converting DMP units into economic value (i.e. determining commercially important species, use and access). Further useful development could also include information on levels of sustainable production by using, for example the weight of dry matter per hectare grown in a specific year. Disentangling the role of biodiversity from the anthropogenic factors associated with timber production will be a challenge.

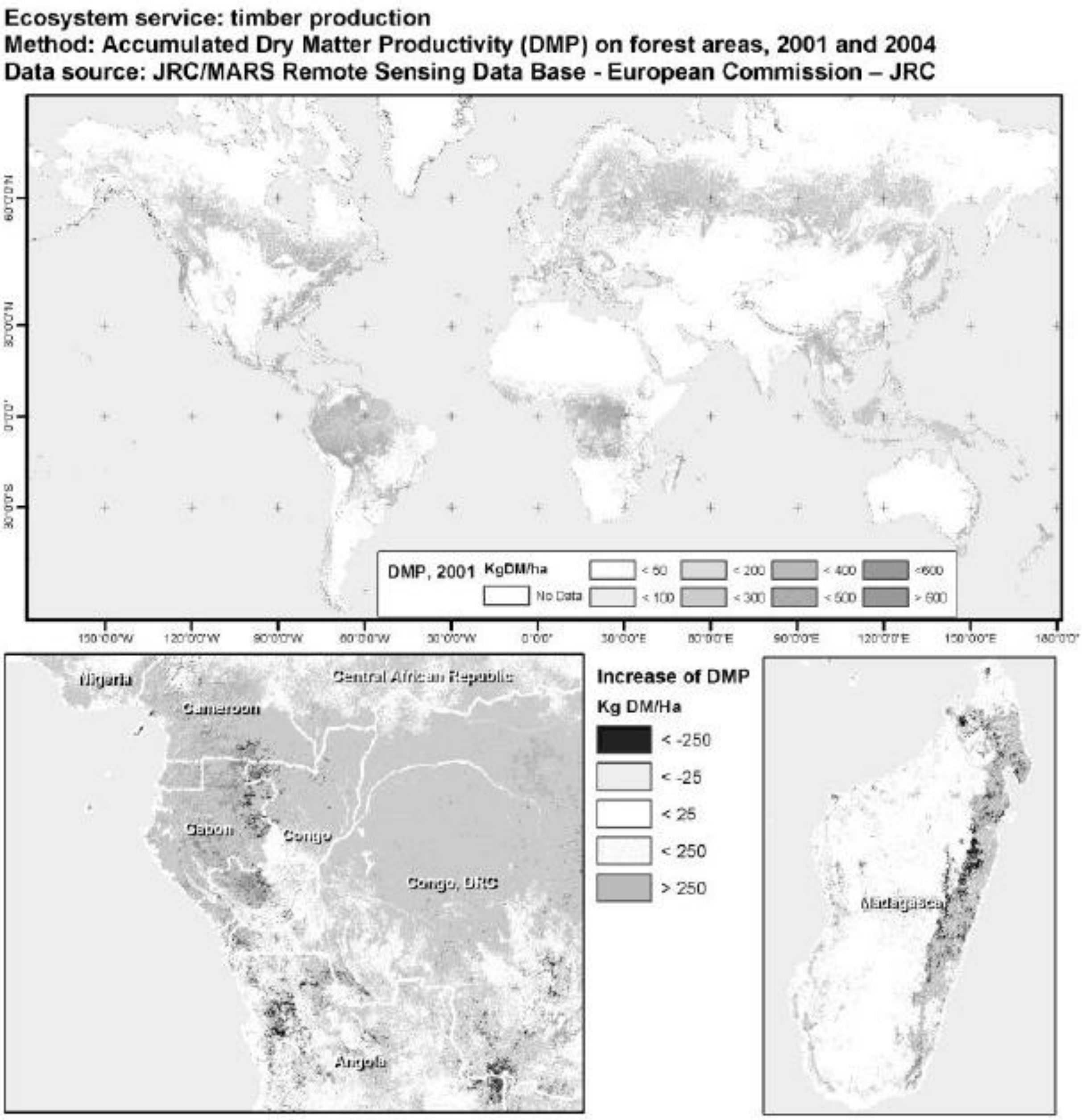

Figure 2: **Maps of timber production, measured as Dry Matter Productivity (DMP) in forest areas for (a) the world in 2001, and highlighting change in timber production between 2001 and 2004 for (b) West Africa and (c) Madagascar**.

Source: JRC/MARS remote sensing data base – European Commission – JRC

Forests provide a bundle of ecosystem services including carbon sequestration, scenic values, watershed protection and cultural services. These services interact with one another in a dependent and non-linear fashion. Harvesting timber will cause declines in many other services from forest (which are more challenging to measure). Quantifying and managing these trade offs is a key challenge to sustainable development. By taking a single service approach – like the timber production service described here – the other services and their values are ignored.

This highlights the importance of taking a multi-service approach to economic valuation taking account of trade-offs over ecosystem services, space and time.

3.3 A regulating service: global carbon sequestration

Ecosystems play an important role in determining atmospheric chemistry, acting as both sources and sinks for many atmospheric constituents that affect air quality or that affect climate by changing radiative forcing. This ability of ecosystems to modify the climate forms the ecosystem services of climate regulation. Carbon sequestration, the removal of carbon from the atmosphere by the living phytomass of ecosystems, is an important component of this climate regulation service. In the map below (Figure 3) carbon sequestration was modeled as the net annual rate of atmospheric carbon added to existing biomass carbon pools, using a proxy of net carbon exchange (NCE) produced in simulations using the Terrestrial Ecosystem Model (TEM) developed by McGuire et al. (2001) and applied by Naidoo et al. (2008). The model simulates carbon exchange between the atmosphere and terrestrial biosphere on the basis of vegetation types, soils, climate, atmospheric CO_2, and land use history.

Naidoo et al. (2008) point to the limitations of using a model based rather than observational approach and the reliance on assumptions, time series and input variables. However, together with the possibility of assigning economic values to the tons of carbon sequestered, Balmford et al. (2008) point to the possibilities presented by these land-use-coupled models to estimate differences in carbon storage, emissions and sequestration under different scenarios (e.g. McGuire et al. 2001). This would make it possible to map the economic value of these services of global climate regulation, and how they might change under different scenarios of ecosystem and land use change.

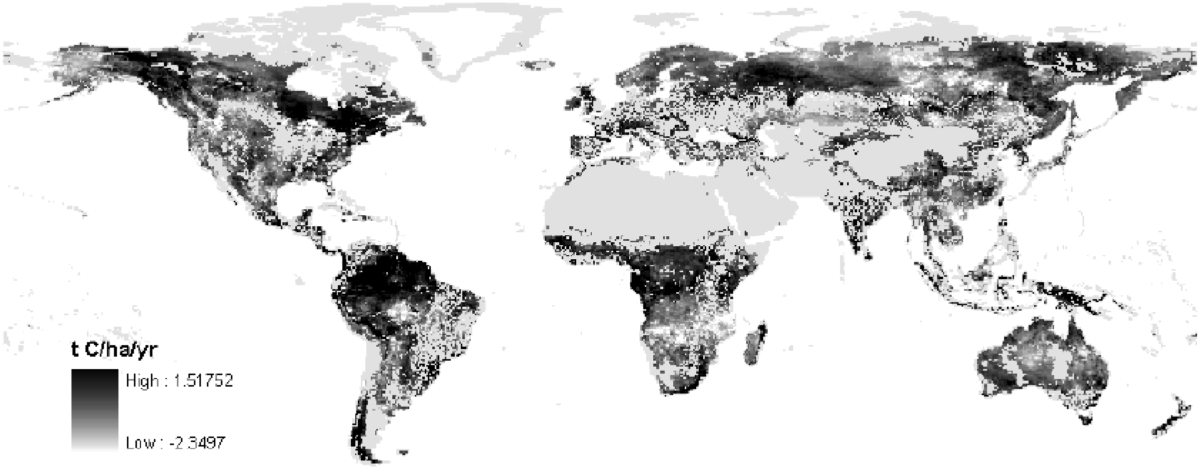

Figure 3: Global map of carbon sequestration developed by Naidoo et al. (2008) using the Terrestrial Ecosystem Model (TEM) developed by McGuire et al. (2001). Source: National Academy of Sciences, U.S.A, 2008.

3.4 A cultural service: social appreciation of agricultural landscape

Cultural ecosystem services refer to the aesthetic, spiritual, recreational, educational and other non-material benefits that humans obtain from contact with ecosystems (MA 2005b; Butler and Oluoch-Kosura, 2006). Little progress has been made in mapping cultural services. Even in the case of the popular cultural service of nature-related outdoor tourism, Balmford et al. (2008) point out that these services or their benefits cannot yet be mapped due to both a lack of knowledge on the links between biodiversity and tourism demand or use and the subjective and context-specific nature of perception and appreciation. Nevertheless attempts can be made to quantify and map cultural services on the basis of proxies that describe societal interest for cultural ecosystem services in specific landscape types. This example represents an attempt to derive an index of social value of the agricultural landscape.

It is currently not possible, in the context of a global or regional assessment, to address landscape perception through targeted enquiries and the use of questionnaires to record people's preferences. Instead in this example three variables were identified as representative of societies' preferences: protected agricultural sites; rural tourism; and presence of labeled products and combined in the map shown in Figure 4.

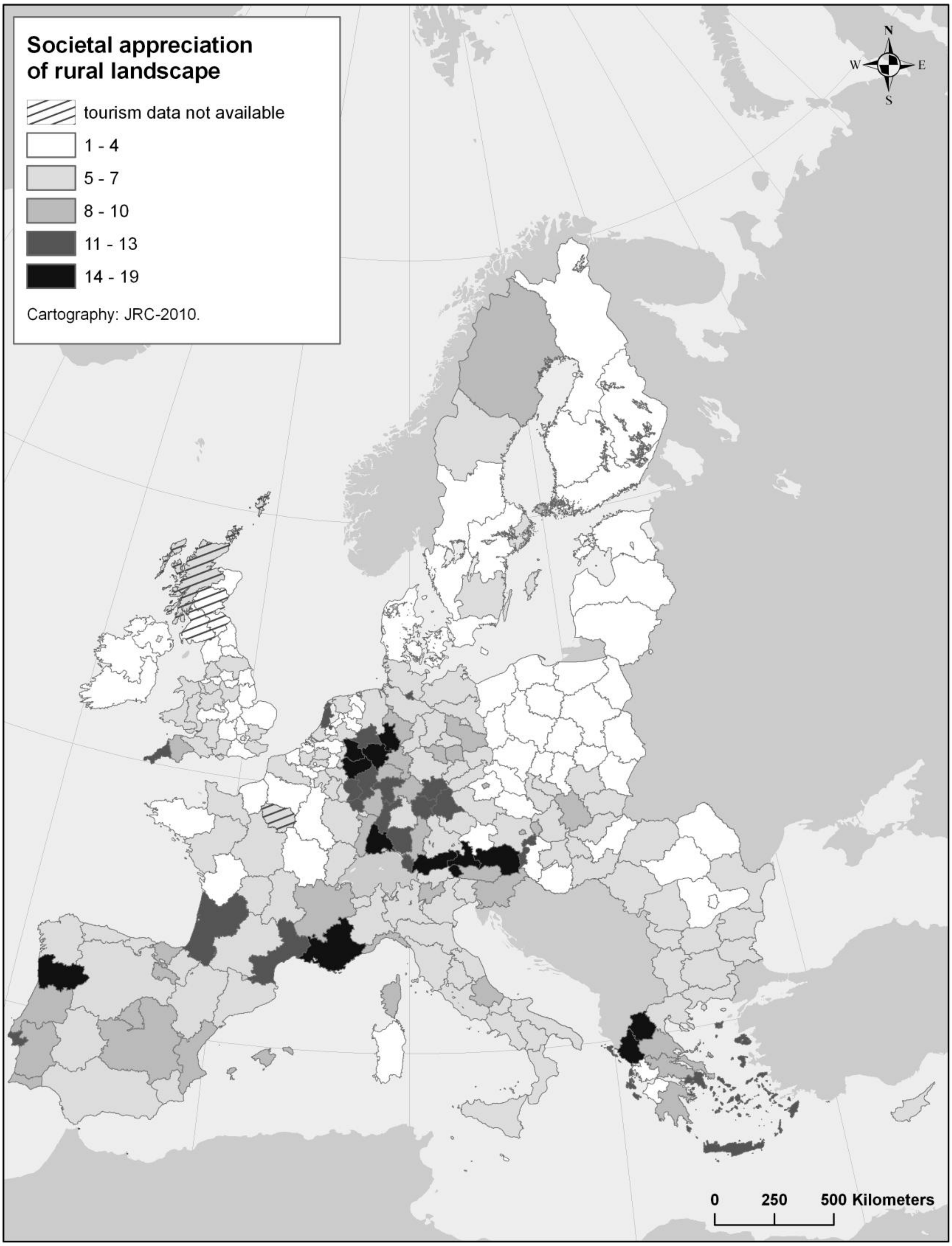

Figure 4: **Social value of agricultural landscapes in Europe determined by protected agricultural sites; rural tourism; and presence of labeled products**

This example of a spatially explicit cultural service, although a novel demonstration of the distribution of regional social value, is still some distance from a fit-for-purpose indicator which can be used to measure and model the economic consequences of biodiversity and ecosystem change. Methods for mapping cultural services are not yet developed or agreed and therefore this model has to be carefully interpreted, in order to avoid the risk of confounding different values or assuming direct transfer of values. Trade-offs and synergies in the input components must be understood and correctly taken into consideration, and underlying measures would have to be made available in a format that can be disaggregated and traceable. Furthermore, assigning economic values to social values will be a challenge (see Chapter 5 for developments in this area), while determining the changing contribution of biodiversity and determining past and future trends in the service are also not yet possible. As Balmford et al. (2008) suggest it might be best to start with cultural services where the links between biodiversity and the cultural or recreational benefit are simple and clearly defined and where valuation studies already exist (e.g. bird watching; Lee et al. 2009). Protected area visitor numbers and values are also a potential indicator which should be explored at regional and global scales.

3.5 Relevant indicators at local scales

The above global and regional scale indicators highlight some of the opportunities and challenges faced in the search for indicators of the economic consequences of changes in biodiversity and ecosystems, and in particular indicators that are convertible into economic values. At the local scale recent publications highlight the progress made in ecosystem service indicator development. Chan et al. (2006), Nelson et al. (2009) and Reyers et al. (2009), used data from a variety of sources on ecosystems and biodiversity (especially functional types), land cover, population, access, hydrology and economic value to model and map multiple ecosystem services at a local scale in the USA and South Africa. These maps were used to investigate trade-offs and planning options by Chan et al. (2006), to quantify the consequences of land use change on ecosystem services by Reyers et al. (2009) and to investigate the consequences of future scenarios on ecosystem services by Nelson et al. (2009).

While some of the indicators are expressed in biophysical quantities, these quantities (litres of water, tons of carbon) are convertible into economic terms. This conversion is clearly demonstrated in another local scale study by Naidoo and Ricketts (2006) in Paraguay where the value of ecosystem services was modelled and made spatially explicit to assess the costs and benefits of biodiversity conservation in the region.

3.6 The way forward

This review has highlighted the following lessons for mapping ecosystem services for economic valuation and for use in scenarios of the marginal costs and benefits of ecosystem change and biodiversity loss:

- The need to be spatially explicit while not resorting to large regional aggregations reduces the set of ecosystem services which currently can be mapped to mostly provisioning services at global and regional scales
- Global datasets of primary productivity and vegetation cover have played a significant role in most of the global maps of services now available (e.g. Naidoo et al. 2008)
- Ecosystem service mapping needs to progress beyond the production of maps that show biophysical quantities or biological stocks of services such as grazing resources to an approach that includes regulating and cultural services and the relationships between these services (i.e. an approach that is cognizant of trade-offs)
- Spatially explicit data on the flow of services and their use at global scales are rare, proving a major obstacle to moving from maps of biophysical quantities to maps of economic value. This is less of an issue at local and regional scales.
- Few of the existing global, regional and local maps of ecosystem services demonstrate clear and indisputable connections between biodiversity to the final benefit quantity or value
- Investment in spatially explicit data and local and regional scales are a first necessary step in improving ecosystem service mapping and in turn economic valuation
- Alignment between available maps of ecosystem services and existing models or scenarios of future change is limited, making it difficult for the assessment of change in service levels and values.

Finally a lesson emerging from this chapter is that using global maps of service production, and changes in these services, as a proxy of value and value change, may miss out on two crucial facets related to ecosystem management thresholds: sustainability and vulnerability. The challenge of sustainability can be highlighted in the case of fisheries where Figure 5 shows fish stocks outside safe biological limits (from http://themes.eea.europa.eu/IMS/ISpecs/ISpecification20041007132227/IAssessment1199788347728/view_content) which would not necessarily be captured by a map of trophic biomass.

This highlights the crucial importance of thresholds in ecosystem service measures and indicators.

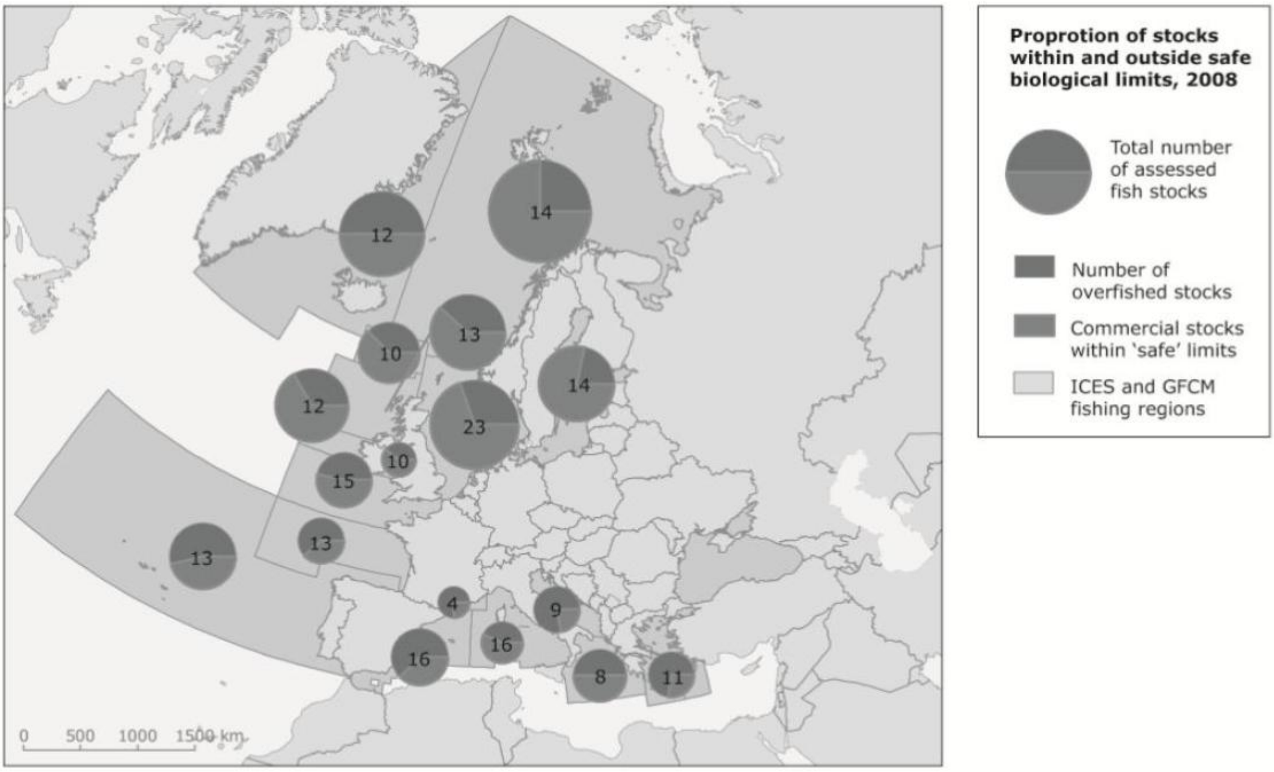

Figure 5: Fish stocks outside safe biological limits, extracted from http://themes.eea.europa.eu/IMS/ISpecs/ISpecification20041007132227/IAssessment1199788344728/view_content). The chart shows the proportion of assessed stocks which are overfished (red) and stocks within safe biological limits (blue). Number in circle is the number of stocks assessed within the given region. The size of the circles is scaled proportional to the magnitude of the regional catch.

In demonstrating the challenge of depicting vulnerability, Figure 6 shows a map of Southern Africa where provision of water has been displayed as a proportion of demand for water (Scholes and Biggs 2004). This map highlights areas of high vulnerability where water supplies do not currently meet water demand. In global or regional maps of this service, high value areas do not accurately depict important areas with a low water supply where social thresholds and local demand are not met. Even small changes in water supply in this important and vulnerable areas would have significant impacts on human wellbeing in those areas, impacts that would not necessarily be illustrated in an assessment of monetary value and changes in that value. Closer examination and differentiation of the demand for services, which should theoretically be linked with supply, may provide a more socially realistic assessment of services.

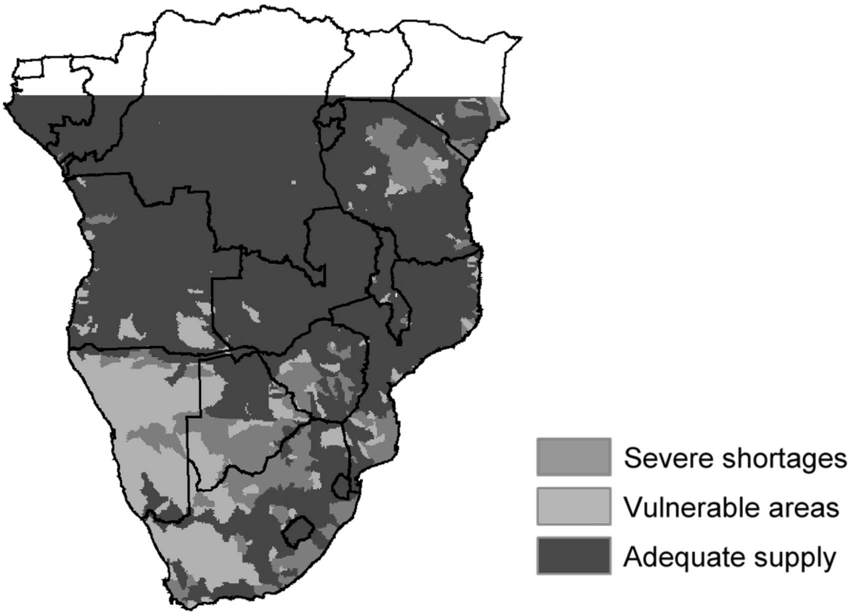

Figure 6: Water availability in Southern Africa expressed as relative to demand for water

Source: Scholes and Biggs 2004

Both of these examples reflect the importance of thresholds highlighted in the MA. Ecosystem service change is seldom linear or independent and can often be accelerating, abrupt and potentially irreversible (MA 2005b). The loss of biodiversity and increasing pressures from drivers of ecosystem change increase the likelihood of these non-linear changes. While science is increasingly able to predict some of these risks and non-linearities, predicting the thresholds at which these changes will happen generally is not possible. Users of indicators and assessments of ecosystem change and its consequences need to bear this in mind, and where possible to reflect known or possible ecological and social thresholds and not to assume linear relationships between biodiversity loss and its consequences.

4 Link to valuation and further work

The flow of ecosystem services from point of production to point of use is influenced by both biophysical (e.g. currents, migration) and anthropogenic (e.g. trade, access) processes which influence the scale of service flow from locally produced and used services (e.g. soil production) to globally distributed benefits (e.g. carbon sequestration for climate regulation). The flow of benefits and scale of flows influences the value of the service due to changes in demand and supply which vary spatially and temporally. Use of the service is intrinsically a human centered process relying largely on socio-economic data and to a lesser degree on biophysical information. Information will include the distribution of users, the socio-economic circumstances of users, governance systems, human pressure on ecosystems and other social measures like willingness and perceptions. Spatial data are likely to include maps of population distribution and economic status, maps of land use, trade data and other spatial data on political units and administrative boundaries.

In order to make a comprehensive and compelling economic case for the conservation of ecosystems and biodiversity it is essential to be able to understand, quantify and map the benefits received from ecosystems and biodiversity, and assign values to those benefits. This all must be done in a fashion that makes it possible to assess the contribution made by biodiversity to this value (separately from the contribution made by abiotic and anthropogenic factors), as well as the consequences of changes in ecosystems and biodiversity for these values. This chapter has focused on reviewing current ability to quantify and make spatially explicit the biophysical quantities (water, food, timber) or benefits provided by ecosystems and biodiversity. It has also aimed to review current ability to make spatially explicit the other beneficial processes from ecosystems and biodiversity which form our life support systems (e.g. pollination, carbon sequestration and cultural services).

Chapter 5 describes in detail the methodologies used and challenges faced when attempting the valuation of biodiversity and ecosystem services. In economic valuation, the focus has been on flows of ecosystem services (the "interest" from the capital stock). Chapter 5 acknowledges that the valuation literature currently does not consider biodiversity in detail. It is indeed not straightforward to assign a value to the actual diversity in a system, as opposed to the biomass present. At the same time, the diversity is linked to production, so measurements of this aspect need to be built in. The instruments described in this chapter, on the other hand, have traditionally focused on biological resources, the capital itself. Biophysical measurements are important since biodiversity underpins the delivery of many ecosystem services and thus forms the underlying basis of value. The framework of Total Economic Value (TEV) (see Figure 2 of chapter 5 - Value types within the TEV approach) is useful to help analyse where indicators need to be further developed. Ecosystem accounting is also addressed in Chapter 3 of the TEEB D1 Report, where several elements of the accounting framework (e.g. data issues, valuation approaches, socio-ecological accounting units) are examined for the three interconnected governance levels, Global/Continental, National/Regional, and Local.

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[1] The data availability and ability to convey messages for ecosystem service measures and indicators are reviewed in detail by Layke 2009

Chapter 3

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