WORKING PAPER

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Measuring Nature's Benefits: A Preliminary Roadmap for Improving Ecosystem Service Indicators

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EXECUTIVE SUMMARY

Ecosystem services are the benefits that people derive from nature. Some benefits, such as crops, fish, and freshwater (provisioning services), are tangible. Others such as pollination, erosion regulation, climate regulation (regulating services) and aesthetic and spiritual fulfillment (cultural services) are less tangible. All, however, directly or indirectly underpin human economies and livelihoods.

Despite their critical importance, the capacity of ecosystems to provide these myriad services are being degraded at an alarming rate. In 2005 the Millennium Ecosystem Assessment (MA), a four-year study of the state of the world's ecosystems involving more than 1,300 experts from 95 countries, reported that over 60 percent of ecosystem services were already degraded. This negative trend, they concluded, was set to continue at an accelerating pace over the next half century.

The ecosystem services conceptual framework provided by the MA has proven effective for communicating how ecosystems underlie human well-being. Early efforts to apply ecosystem services concepts and information have strengthened both public and private sector development strategies and improved environmental outcomes.

However, mainstreaming ecosystem services concepts more broadly will require information designed for policy-makers, including data, decision-support tools, and "indicators"—information that condenses complexity to a manageable level and informs decisions and actions (Bossel, 1999). Knowing where indicators and data are already sufficient to inform policy-makers' understanding of ecosystem services, and where they fall short, will help inform such mainstreaming efforts in international and national arenas. This paper compiles and assesses current ecosystems services indicators in order to inform and advance such efforts.

Content

Measuring Nature's Benefits provides:

- A compilation of ecosystem service indicators used in the Millennium Ecosystem Assessment (Box 1);
- A preliminary assessment of each indicator's capacity to support policy, measured by "ability to convey information" about ecosystem services and the availability of data to apply the indicator;
- A synthesis of key complications and opportunities associated with developing and operationalizing ecosystem service indicators and
- Preliminary recommendations for next steps toward improving ecosystem service indicators and data compilations, and their application in decision-making processes.

Key Findings

The analysis found significant limitations in the capacity of the indicators assessed to support policy-makers' use of ecosystem service concepts, specifically:

- The ability of indicators to convey information about ecosystem services is low overall, although it varies widely among services;
- The indicators available for most ecosystem services are not comprehensive and are often inadequate to characterize the diversity and complexity of the benefits they provide;
- Data are often insufficient to support the use of these indicators; and
- Indicators for regulating and cultural services lag behind provisioning services in each of the limitations identified above.

Audiences

The findings and preliminary recommendations contained in this Working Paper aim to improve the supply of ecosystem services information and the demand for that information by policy-makers. The target audiences include actors whose work contributes directly or indirectly to improve indicators, data, and policy-support tools, as well as those who will apply ecosystem service indicators to improve decision-making in their institutions.

Primary audiences include institutions developing and applying ecosystem service indicators, data gathering methodologies, data sets, analyses, and tools to support policy decisions. Examples include:

- Policy research institutions supporting the public and private sectors' ability to apply ecosystem services concepts;
- Scientific institutions with expertise to research and propose policy-relevant indicators of ecosystem services to fill outstanding gaps;
- Ecosystem assessments building on and improving the approaches, indicators, data sets, and policy input developed for the MA; and
- International organizations—including environmental and development agencies—supporting assessments, governments, and other institutions building capacity to apply ecosystem service approaches.

Secondary audiences include:

- International organizations responsible for gathering, analyzing, and disseminating data about environment and economic development;
- National data gathering entities, including national statistical accounts and scientific agencies. International organizations such as the UN Statistical Agency and international aid organizations that support national and sub-national capacity for data gathering;
- Public sector policy-makers at sub-national, national, regional, and international levels who will benefit from incorporating ecosystem service considerations into policy dialogs; and
- Decision-makers in the private sector whose companies can use ecosystem service indicators to inform strategic decisions.

1. INTRODUCTION

Ecosystem services are the myriad benefits that people derive from nature. These include provisioning services such as food, water, and fiber; regulating services such as climate regulation and pollination; aesthetic services including recreation and spiritual well-being; and supporting services such as bedrock weathering and nutrient cycling (see Table 1 and Appendix 1 for key terms and definitions). A growing body of work is starting to make the case for how information on ecosystem services can strengthen public and private sector development strategies and improve environmental outcomes (see for example: Ranganathan et al., 2008; Hanson et al, 2008). If current trends of ecosystem degradation are to be reversed, it is an urgent priority to integrate ecosystem service considerations into mainstream economic planning and development policy at all scales. Doing so will require tools and approaches that communicate the value and condition of ecosystem services to policy-makers and help them integrate this information with social and economic indicators.

Preliminary Recommendations and Next Steps

The primary recommendation is to establish an international partnership of organizations working on ecosystem service indicators. This partnership would coordinate approaches and activities to develop and strengthen ecosystem service indicators, gather data, and promote their use by policy-makers. WRI recommends the partnership's common agenda include:

- Test ecosystem service indicators in national level policy processes;
- Engage sub-global assessments to capitalize on the scientific and policy analysis expertise gathered for these undertakings;
- Support research focused on developing improved indicators;
- Develop models to organize ecosystem service indicators and visualization tools to help policy-makers apply ecosystem services concepts;
- Ensure data availability and quality, in part by incorporating indicators for all ecosystem services into data-gathering institutions' mandates.

A key priority moving forward will be to identify a refined set of recommendations that reflect the input and priorities of other organizations working on ecosystem service indicators. These revised recommendations should also incorporate lessons from other efforts to measure ecosystem services, including the Biodiversity Indicators Partnership, the Cost of Policy Inaction on Biodiversity, The Economics of Ecosystems and Biodiversity, the State of the Nation's Ecosystems, and others.

The Millennium Ecosystem Assessment (MA) made great strides in raising awareness of how people rely on ecosystems for the services they provide (see Box 1). Evaluations of the MA found that policy-makers' recognition of ecosystem services as a fundamental contributor to human well-being has increased. However, those evaluations also found that translating this increased recognition into concrete policy changes will require longer-term engagement and the development of new tools and approaches (Wells et al., 2006). The lack of a robust set of ecosystem service indicators to support policy-makers' application of ecosystem services concepts was among the key constraints that need to be addressed.

Why Indicators Matter

Indicators simplify information so that it can be easily communicated and intuitively understood (IIUE, 1997). With indicators, policy-makers can base decisions on evidence, identify and prioritize interventions, track progress toward goals, and inform corrective action in a timely fashion.

Indicators are not new to policy-makers. GDP and unemployment rates provide information about the economy, while graduation rates and the percentage of students passing standardized tests help inform education policy. Poverty rates and the human development index convey information about social well-being. Emissions of nitrogen and sulfur oxides that acidify rain, deforestation rates, and concentrations of air pollutants such as ozone and particulates convey information about the state of the environment.

Box 1 | **The Millennium Ecosystem Assessment**

The Millennium Ecosystem Assessment (MA), a four-year global effort involving more than 1,300 experts, assessed the condition and trends of the world's ecosystem services. The assessment found that in the last half of the 20th century, humans changed ecosystems more rapidly and extensively than in any comparable period of history, primarily to meet growing needs for food, freshwater, timber, fiber, and fuel. These changes have resulted in significant benefits to humans, including improvements in health and a reduction in the proportion of malnourished people. However, these gains have come at an increasing cost. The MA found that 60 percent of ecosystem services assessed are currently used unsustainably and concluded that "any progress achieved in addressing the goals of poverty and hunger eradication, improved health, and environmental protection is unlikely to be sustained if most of the ecosystem services on which humanity relies continue to be degraded" (Ranganathan et al., 2008).

The MA developed a conceptual framework that described the links between ecosystems and human well-being and then applied the concept in assessing the capacity of ecosystems to provide the goods and services on which people rely. The clarity with which this ecosystem service framework communicates people's dependence on ecosystems provides policy-makers with a basis for reconciling economic development and ecosystems.

The MA's findings were based on numerous indicators and data sources identified and applied by the experts who conducted the global and sub-global assessment. Indicators supporting different elements of the MA conceptual framework—including biodiversity and ecosystem state, human well-being, direct and indirect pressures, and the flow of ecosystem services—were applied to inform the assessments. The effectiveness of the indicators in communicating information on the flow of ecosystem services is the subject of the present paper.

Given policy-makers' widespread dependence on these tools, a serious effort to develop and refine ecosystem service indicators (Box 2) must be an important element in attempts to mainstream ecosystem services concepts into policy-making (MA Follow-up Advisory Group, 2008[1]). A better suite of indicators is also necessary for undertaking future assessments following on the Millennium Ecosystem Assessment, whether at a global or sub-global scale (MA, 2005b).

Approaches to analyze and apply information about ecosystem services are relatively young and still evolving. Up to now most indicators used for ecosystem services have been adopted from narrower environmental fields such as biodiversity, ecology, and climatology, and from economic sectors such as agriculture, forestry, and fisheries. For example, indicators such as crop or livestock production are drawn from economic accounts and agricultural census data. Data for indicators such as tourist visits and spending are drawn from tourism boards. Others, such as carbon storage capacity, deforestation rates, and air quality indexes, are drawn from the environment sector.

This reliance on diverse existing indicators provides a necessary starting point for ecosystem service indicators. However, relying on indicators that were developed for other fields should be seen as an interim strategy. The indicators applied in ecosystem assessments to this point were developed for a variety of purposes. They do not focus with sufficient depth on effectively communicating the contributions of ecosystem services to human well-being and helping policy-makers integrate ecosystem services into broader policy dialogs and decisions. In its final report, the MA stated that there were "no widely accepted indicators to measure trends in [many] ecosystem services, much less indicators that measure the effect of changes on human well-being" (MA, 2005). This paper demonstrates the extent to which the indicators applied thus far in ecosystem services assessments leave significant gaps in our ability to measure and communicate knowledge about ecosystem services.

2. COMPILING AND RATING THE MA INDICATORS

To assess the state of ecosystem service indicators, WRI compiled the indicators used in the MA global assessment and three sub-global assessments for Portugal, Southern Africa, and Western China. The sub-global assessments were chosen to ensure geographic diversity, and were limited to three due to resource constraints. Since the MA authors had not systematically organized the indicators they used into tables or databases, the indicators were identified and pulled from the text of each assessment[2] (see Tables 3, 4, and 5 for indicators extracted from the MA global assessment and Appendix 3 for indicators compiled for sub-global assessments).

This assessment focuses specifically on ecosystem service indicators—on the *flow* as opposed to the *stock* of ecosystem services (see Appendix 1 for more on these terms). This focus helps to assess how well ecosystem service indicators communicate to policy-makers the importance of these services to their citizens' economic, physical, and spiritual well-being. In other words, how well do they convey the range and quantity of benefits people and businesses derive from ecosystems? This is not the same as asking how well they communicate the state of ecosystem health or the capacity of ecosystems to continue to provide services. When posing these questions, one would focus more on the *stock* of ecosystem services. It should be noted, however, that both indicators of stocks and flows will often be needed for informing policy, and it is a priority to develop and deploy indicators of both.

To reduce the number of indicators in the compilation that convey very similar information, the indicators were compiled in their "root" form rather than their disaggregated form. For example, the MA and sub-global assessments used numerous indicators on crop production, often listing the production of all major crops. In this case, only *crop production* as the "root" indicator was included, as opposed to including *maize production, rice production,* and *millet production*.

The indicators from the global assessment were then rated by the author according to criteria of "ability to convey information" and "data availability." As a separate exercise the indicator sets available for each ecosystem service were assessed for their level of "comprehensiveness."

Box 2 | Ecosystem Service Indicators Defined

Ecosystem service indicators are information that efficiently communicates the characteristics and trends of ecosystem services, making it possible for policy-makers to understand the condition, trends and rate of change in ecosystem services. The analysis in this report considers only indicators of the *flow* of an ecosystem service (the benefits people actually receive) rather than the *stock* of an ecosystem service (the capacity of the ecosystem to deliver a service). Ultimately, information on both stocks and flows are necessary and it is hoped that this initial work on flows will create momentum for further work and experimentation on indicator development and use by decision makers.

Rating Ability to Convey Information and Data Availability

Each indicator from the global assessment was rated as high, medium, or low for two key aspects that evaluate its utility for policy-making: the ability to convey information, and the availability of data on which the indicator is based (see Box 3 for more detail on the rankings). After scoring the indicators compiled for each ecosystem service, the scores were averaged to provide an overall score for that service.

The indicators compiled from sub-global assessments were not rated. Instead, an informal comparison was made between the indicators from the three sub-global assessments and the global MA in order to assess similarities and differences between the indicators available at national and sub-national scales versus those available across broader areas. While the comparison between indicators used for the sub-global and global assessments was limited, the overall pattern of fewer and less developed indicators of regulating services compared to provisioning services was largely consistent.

Assessing Comprehensiveness

Building on the rating of indicators, three questions were posed to determine how comprehensive an understanding

Table 1 | **Definitions of Ecosystem Services, Version 1.1**

Service	Sub-category	Definition	Examples
PROVISIONING SERVICES: The goods or products obtained from ecosystems.			
Food	Crops	Cultivated plants or agricultural produce harvested by people for human or animal consumption as food	· Grains · Vegetables · Fruits
	Livestock	Animals raised for domestic or commercial consumption or use	· Chicken · Pigs · Cattle
	Capture fisheries	Wild fish captured through trawling, nets, lines & hooks, and other nonfarming methods	· Cod · Crabs · Tuna
	Aquaculture	Fish, shellfish, and/or plants that are bred and reared in ponds, enclosures, and other forms of freshwater or saltwater confinement for purposes of harvesting	· Shrimp · Oysters · Salmon
	Wild foods	Edible plant and animal species gathered or captured in the wild	· Fruits and nuts · Fungi · Bushmeat
Biological raw materials	Timber and other wood fiber	Products made from trees harvested from natural forest ecosystems, plantations, or nonforested lands	· Industrial roundwood · Wood pulp · Paper
	Fibers and resins	Nonwood and nonfuel fibers and resins extracted from the natural environment	· Cotton, hemp, and silk · Twine and rope · Natural rubber
	Animal skins	Processed skins of cattle, deer, pig, snakes, sting rays, or other animals	· Leather, rawhide, and cordwain
	Sand	Sand formed from coral and shells	· White sand from coral
	Ornamental resources	Ecosystem-derived products that serve aesthetic purposes	· Tagua nut, wild flowers, coral jewelry
Biomass fuel		Biological material derived from living or recently living organisms – both plant and animal – that serves as a source of energy	· Fuelwood and charcoal · Grain for ethanol production · Dung
Freshwater		Inland bodies of water, groundwater, rainwater, and surface waters for household, industrial, and agricultural uses	· Freshwater for drinking, cleaning, cooling, industrial processes, electricity generation, or mode of transportation
Genetic resources		Genes and genetic information used for animal breeding, plant improvement, and biotechnology	· Genes used to increase crop resistance
Biochemicals, natural medicines, and pharmaceuticals		Medicines, biocides, food additives, and other biological materials derived from ecosystems for commercial or domestic use	· Echinacea, ginseng, and garlic · Paclitaxel as basis for cancer drugs · Tree extracts used for pest control
REGULATING SERVICES: The benefits obtained from an ecosystem's control of natural processes.			
Air quality regulation		Influence ecosystems have on air quality by emitting chemicals to the atmosphere (i.e., serving as a "source") or extracting chemicals from the atmosphere (i.e., serving as a "sink")	· Lakes serve as a sink for industrial emissions of sulfur compounds · Vegetation fires emit particulates, ground-level ozone, and volatile organic compounds
Climate regulation	Global	Influence ecosystems have on global climate by emitting greenhouse gases or aerosols to the atmosphere or by absorbing greenhouse gases or aerosols from the atmosphere	· Forests capture and store carbon dioxide · Cattle and rice paddies emit methane
	Regional and local	Influence ecosystems have on local or regional temperature, precipitation, and other climatic factors	· Forests can impact regional rainfall levels

Table 1 | **Definitions of Ecosystem Services, Version 1.1, *continued***

Service	Definition	Examples
REGULATING SERVICES *(continued)*		
Water regulation	Influence ecosystems have on the timing and magnitude of water runoff, flooding, and aquifer recharge, particularly in terms of the water storage potential of the ecosystem or landscape	· Permeable soil facilitates aquifer recharge · River floodplains and wetlands retain water – which can decrease flooding during runoff peaks – reducing the need for engineered flood control infrastructure
Erosion regulation	Vegetative cover retains soil; coral reefs protect coastal areas	· Vegetation such as grass and trees prevents soil loss due to wind and rain and prevents siltation of water ways · Forests on slopes hold soil in place, thereby preventing landslides
Water purification and waste treatment	Role ecosystems play in the filtration and decomposition of organic wastes and pollutants in water; assimilation and detoxification of compounds through soil and subsoil processes	· Wetlands remove harmful pollutants from water by trapping metals and organic materials · Soil microbes degrade organic waste, rendering it less harmful
Disease regulation	Influence that ecosystems have on the incidence and abundance of human pathogens	· Intact forests reduce the occurrence of standing water – a breeding area for mosquitoes – and thereby can reduce the prevalence of malaria
Soil quality regulation	Role ecosystems play in sustaining soil's biological activity, diversity and productivity; in regulating and partitioning water and solute flow; and, in storing and recycling nutrients and gases	· Some organisms aid in decomposition of organic matter, increasing soil nutrient levels · Some organisms aerate soil, improve soil chemistry, and increase moisture retention · Animal waste fertilizes soil
Pest regulation	Influence ecosystems have on the prevalence of crop and livestock pests and diseases	· Predators from nearby forests – such as bats, toads, and snakes – consume crop pests
Pollination	Role ecosystems play in transferring pollen from male to female flower parts	· Bees from nearby forests pollinate crops
Natural hazard regulation	Capacity for ecosystems to reduce the damage caused by natural disasters such as hurricanes to maintain natural fire frequency and intensity	· Mangrove forests and coral reefs protect coastlines from storm surges · Biological decomposition processes reduce potential fuel for wildfires
CULTURAL SERVICES: The nonmaterial benefits obtained from ecosystems.		
Recreation and ecotourism	Recreational pleasure people derive from natural or cultivated ecosystems	· Hiking, camping, and bird watching · Going on safari
Ethical values	Spiritual, religious, aesthetic, intrinsic, "existence," or other values people attach to ecosystems, landscapes, or species	· Spiritual fulfillment derived from sacred lands and rivers · Belief that all species are worth protecting regardless of their utility to people – "biodiversity for biodiversity's sake"
SUPPORTING SERVICES: The natural processes that maintain the other ecosystem services.		
Nutrient cycling	Flow of nutrients (e.g., nitrogen, sulfur, phosphorus, carbon) through ecosystems	· Transfer of nitrogen from plants to soil, from soil to oceans, from oceans to the atmosphere, and from the atmosphere to plants
Primary production	Formation of biological material by plants through photosynthesis and nutrient assimilation	· Algae transform sunlight and nutrients into biomass, thereby forming the base of the food chain in aquatic ecosystems
Water cycling	Flow of water through ecosystems in its solid, liquid, or gaseous forms	· Transfer of water from soil to plants, plants to air, and air to rain

Source: Adapted from the reports of the Millennium Ecosystem Assessment, 2005; The Cost of Policy Inaction, 2008; the Corporate Ecosystem Services Review, 2008; and Ecosystem Services: A Guide for Decision Makers, 2008.
For more information go to www.wri.org/ecosystems/esr

the set of indicators for each service provides. The answers to these questions were considered separately from the questions of "ability to communicate information" and "data availability." The questions were:

1. Do the indicators for each ecosystem service provide a complete picture of the service, as described in Table 1? For example, do indicators cover a number of issues related to that service, or are they all focused on only one aspect?

Box 3 | **Rating Ecosystem Service Indicators**

Indicator Criteria

Useful, policy-relevant indicators share many characteristics. These similarities have led to the development of criteria for assessing the effectiveness of indicators (see for example MA, 2005; EPA, 2000). This study adapted existing criteria for the purposes of assessing the ecosystem service indicators compiled from the global MA. The criteria are grouped into two elements:

1. **Ability to convey information,** i.e. what is the indicator's capacity to summarize the characteristics of the flow of an ecosystem service at multiple spatial and temporal scales and communicate these characteristics to non-technical policy-makers.
2. **Data availability,** i.e. whether sufficient data are available to support policy-makers' use of the ecosystem service indicator.

The criteria within each of these elements are:

Ability to Convey Information:

1. **Intuitive.** Indicators communicate information about ecosystem services clearly without ambiguity. Good indicators avoid differing interpretations of the ecosystem service state or trend being presented. Indicators must be easily understood by policy-makers and other non-technical audiences.
2. **Sensitive.** Sensitive indicators are able to detect changes in time for policy adjustments before the changes are profound and the ability to take remedial or adaptive action is compromised.
3. **Accepted.** Accepted indicators adhere to agreed scientific methods and available data sets where possible.

Data Availability

1. **Monitoring systems gather data at sufficient temporal and special scales.** Applying the ecosystem services framework requires information at multiple spatial and temporal scales; monitoring systems therefore need to gather data with sufficient regularity and at a relevant scale to track changes at a rate appropriate to the "characteristic scale" of ecosystem processes and flow of services (MA, 2005).
2. **Processed and available.** For data to be available to populate indicators, they must be processed into formats that are widely used and made available for easy access. Effective data processing and sharing can take different forms, but often includes posting GIS data files, databases, or spreadsheet files on the internet or publishing them on CD.
3. **Normalized and disaggregated.** The ability to normalize and disaggregate1 data is necessary in order to conduct assessments and policy analysis at "spatial and temporal scales appropriate to the process of phenomenon being examined" (MA, 2005). Data need to be able to support normalizing—e.g., total cereal harvest is normalized by fertilizer application to become cereal harvest per ton of nutrient applied,and disaggregating—e.g., separating cereal harvest into production of maize, wheat, and sorghum so as to inform analysis and possible policy actions.

Applying the Ratings

As a means to assess the ecosystem service indicators compiled from the global MA, a rating of "high", "medium", or "low" (numerically 3, 2, or 1 respectively) was assigned for each criterion listed above for each indicator. The scores for the three criteria under each element--ability to convey information, and data availability—were then averaged (using a simple arithmetic mean) to reach an overall score for that element.

1. Normalizing makes an indicator easier to compare between regions by dividing a measure—such as crop production—by a common denominator such as population, area, or inputs such as fertilize application. This results in crop production per person, crop yield per area, and crop yield per amount of fertilizer. Disaggregating allows for analysis of the specific elements that are driving trends within a larger sector.

2. How consistent or varied are the scores for indicators within a service?

3. Is "data availability" or "ability to convey information" the greatest limitation and does this vary by ecosystem service and category (i.e., whether the service is a provisioning, regulating, or cultural service)?

Limitations of the Study

The approach for this analysis was carefully designed. However, a number of limitations remain:

1. Limited scope: This paper is based on an analysis of the indicators used in the Millennium Ecosystem Assessment (MA), and in the global MA in particular. Because there are indicators of ecosystem services that were not included in the MA, and the method of extracting indicators from the text may have overlooked some, this study is based on only a subset of available indicators. Specifically:

   - Because this analysis focused on indicators compiled from the global MA, only globally relevant indicators for which there was sufficient data for the global MA were included.

   - Important regulating and cultural services—including pollination services, disease regulation, erosion regulation, and spiritual services—were not assessed by the MA, making it impossible to assess the indicators for those services here.

   - Research for MA follow-up and other activities since the MA's publication may address some of the gaps identified here by developing new indicators or gathering new data.

   - Because this analysis focuses on indicators of the flow of an ecosystem service, the strengths and limitations of indicators of stocks of an ecosystem service are not assessed. This choice was made based on an early conclusion that the MA, out of necessity, often relied on indicators of ecosystem state (stock) as proxies for ecosystem services (flows). The author therefore determined to specifically assess indicators of ecosystem services. However, this represents a gap because indicators of both ecosystem state and ecosystem services are needed to fully inform policy decisions. Future work should consider both, by assessing how other indicator compilations such as those developed by the Biodiversity Indicators Partnership, the Convention on Biological Diversity, and others, can integrate with indicators of ecosystem services.

   - This study did not assess supporting service indicators. This choice was made because many supporting services occur outside the influence of policy-makers due to the time scale at which the ecological functions that provide these services occur. However, supporting services should not automatically be excluded from future efforts to develop ecosystem service indicators. Where these services do occur in a policy-relevant time frame and can be supported or undermined by management decisions, indicators to understand, communicate and help manage these ecosystem functions should be developed.

   As efforts to develop and apply indicators relevant for mainstreaming ecosystem services are conceived and implemented, post-MA initiatives such as the Biodiversity Indicators Partnership, The Economics of Ecosystems and Biodiversity, and the State of the Nation's Ecosystems[3] should be consulted to ensure that information developed since the MA was completed can inform any efforts moving forward.

2. Subjectivity: While concrete criteria were identified with the intention of guiding the ratings applied for each indicator, the ratings remain subjective. It is therefore reasonable to expect that there will be disagreements about the ratings assigned to various indicators. Future indicator assessments will seek to include partners to reduce subjectivity and improve confidence in the lessons provided from the results.

3. Data: Because the discussion of data availability focuses on the global MA, lessons from this analysis may not be applicable to a specific country or region, as data constraints vary dramatically among countries.

3. THE STATE OF ECOSYSTEM SERVICE INDICATORS

Based on this analysis, ecosystem service indicators need to be expanded and improved before they can fully support mainstreaming of ecosystem service concepts into policy-making (Table 2). Data collection and compilation also need to be strengthened. While our analysis was primarily focused on the global MA, indicators compiled from three sub-global assessments support these overall conclusions (see Appendix 3 and Box 4 for more on these indicators).

Four limitations characterize ecosystem service indicators:

1. The ability of indicators to convey information is low overall, although it varies widely among services.
2. The indicators available for most ecosystem services are not comprehensive and are often inadequate to fully characterize the diversity and complexity of the benefits provided.
3. Data are often insufficient to support the use of these indicators.
4. Indicators for regulating and cultural services lag behind provisioning services in each of the limitations identified above.

These findings point to a significant gap in the availability of ecosystem service indicators to communicate information about the benefits ecosystems provide to people. Left unaddressed, these gaps will constrain adoption of ecosystem service concepts into policy making.

Summary Findings for Ecosystem Service Indicators

Average scores for the indicators compiled for each ecosystem service[4] are presented in Table 2, along with the name of the institution that has responsibility for compiling data for each indicator, where relevant. These scores illustrate the strengths, weaknesses, and gaps in ecosystem service indicators and allow for a comparison between provisioning, regulating, and cultural services.

The overall performance of indicators is low. Less than one third are supported by indicators that earn an average score of *high* for "ability to convey information." The scores for "data availability" are worse: none of the ecosystem services assessed had an aggregate score of *high*.

Provisioning services have the best scores for their ability to convey information and for data availability. Of the 11 provisioning services, nearly half (5) earn an aggregate score of *high*, while 4 rank *medium* for ability to convey information. Two services (*genetic resources* and *biochemicals and natural medicines*) rank *low* on this measure.

Regulating service indicators are weaker overall than provisioning service indicators. Less than one third (two) of the regulating ecosystem services assessed received an average score of *high* for ability to convey information. Over half (four) received a score of *medium* for this element, while one ranked *low*. For data availability, four of the six services received rankings of *low*.

Cultural services score poorest compared to both provisioning and regulating services. Of the two services assessed, neither scored *high* for conveying information. Only one, *recreation and tourism*, scored *medium* while the other scored *low*. Both services scored *low* for data availability.

Indicator Comprehensiveness

The individual indicators compiled for each ecosystem service are presented in Tables 3, 4, and 5. By providing the scores for each indicator as well as whether the indicator is a proxy measure (see Appendix 1 for a definition), these tables provide a more nuanced picture of the indicators for each service than the average scores in Table 2. The individual indicators allow for an assessment of how each contributes to understanding the ecosystem service, and how comprehensive a picture of the service the indicators give when viewed as a whole. The key findings from the assessment of indicator comprehensiveness are:

- The indicators for most provisioning services provide for a more complete understanding of the service than for most regulating and cultural services.
- The indicator ratings for ability to convey information and data availability were broadly consistent for indicators compiled for any given ecosystem service. There

was significant variability, however, in the indicator scores between services. This variability exists within the broader provisioning, regulating, and cultural categories as well as among them.

- Data availability significantly limits the state of knowledge for all services, but is particularly acute for regulating and cultural services. Institutional responsibility for compiling data by organizations such as the Food and Agriculture Organization of the United Nations (FAO) translates into greater data availability. Those indicators with institutional support have better data availability overall.

Table 2 | **Rating the Ability of Compiled Indicators to Inform Policy-Making**

Ecosystem Service	Number of Indicators Identified	Ability to Convey Information	Data Availability	Global Compiling Agency
PROVISIONING				
Food				
Crops	4	Medium	Medium	FAO
Livestock	3	Medium	Medium	FAO
Capture fisheries	7	High	Low	FAO
Aquaculture	2	Medium	Low	FAO
Wild foods	1	High	Low	None
Biological raw materials				
Timber	6	Medium	Medium	FAO
Fibers and resins, animal skins, sand, and ornamental resources	4	High	Medium	FAO
Biomass fuel	4	High	Medium	FAO
Freshwater	5	High	Medium	FAO
Genetic resources	3	Low	Low	None
Biochemicals, natural medicines, and pharmaceuticals	2	Low	Low	None
REGULATING				
Air quality regulation	2	Medium	Low	None
Climate regulation				
Global climate regulation	7	Medium	Medium	IPCCC
Regional and local climate regulation	4	Medium	Medium	None
Water regulation	2	High	Low	None
Erosion regulation		No Indicators Identified		
Water purification and waste treatment	3	High	Low	None
Disease regulation	3	Low	Low	None
Soil quality regulation		No Indicators Identified		
Pest regulation		No Indicators Identified		
Pollination		No Indicators Identified		
Natural hazard regulation	7	Medium	Low	None
CULTURAL				
Aesthetic/ ethical values	4	Low	Low	None
Spiritual and religious values		No Indicators Identified		
Recreation and ecotourism	5	Medium	Low	None

Low: Indicators and data availability are inadequate for support policy-making

Medium: Indicators and data availability are sufficient to partially inform policy-making

High: Indicators and data availability are sufficient to inform policy-making

The comparative strength of provisioning services in this "comprehensiveness" analysis appears to be partly due to the fact that most provisioning services have compiled indicators that score either "medium" or "high" (see Table 1 for a comparison of the variability and complexity of definitions and examples for each service).

Comprehensiveness of Provisioning Service Indicators

An assessment of the individual indicators for most provisioning services reinforces the findings of the aggregate scores for the indicators. Of the 11 services, the indicators for 8 provide for a reasonably comprehensive understanding of the service. For example, the *biomass fuel* service has four indicators that provide information about the service from the standpoint of production, value, and its contribution to industrial fuel demand. Similarly, *capture fisheries*, is supported by varied indicators that provide insight into different aspects of how people benefit from this service.

The compiled indicators for some provisioning services, however, are not able to convey a very complete picture. The indicators for *genetic resources* and *biochemicals, natural medicines*, and *pharmaceuticals* are focused on investments people are making into finding useful species and the number and economic value of the species they find. These indicators provide only a partial understanding of these services, an acknowledgment on the part of companies that the services hold value, but not any sense of how much that value is or what form it takes. The provisioning service of *wild foods* faces a different constraint. Its lone indicator is *number of wild species used for human food*, which doesn't provide sufficient insight into the quality or volume of this service.

Comprehensiveness of Regulating Service Indicators

The indicators for regulating services vary significantly in their comprehensiveness. Only one of the regulating services assessed by the global MA was deemed to have a relatively comprehensive set of indicators (Table 4). Even this one—*global climate regulation*—would benefit from additional indicators to fully illuminate how the service contributes to climate regulation. For most other regulating services, the small number of indicators conveys only a narrow understanding of the service.

Global climate regulation is the regulating service with the most comprehensive set of indicators, with seven. However, most of the indicators earned only medium scores for "ability to convey information," indicating that they still require improvement. Water regulation, in comparison to global climate regulation, has two indicators—*soil water infiltration* and *soil water storage*— that both rank high for ability to convey information. However, both indicators are technical measures of soil's role in this service, excluding other aspects of water regulation. Other indicators will need to be identified to increase indicator comprehensiveness for this service. Similarly, two of the three indicators for *disease regulation* are focused on disease vectors, while the third looks at overall disease burden. Indicators for other aspects of disease regulation will be needed to round out the overall understanding of this service.

The indicators for global climate regulation earn mostly medium or high marks for "data availability." This is the only regulating service that has more indicators ranking higher than "low." In fact, all indicators for every other regulating service except *regional and local climate regulation* were ranked "low" for data availability.

Comprehensiveness of Cultural Service Indicators

The comprehensiveness of the two cultural services assessed by the global MA are quite different. The indicators for *aesthetic values* are nearly all focused on economic expressions of peoples' appreciation of the aesthetic value of ecosystems. This provides for only a limited understanding of this service. Indicators for *recreation and ecotourism* are more evenly split between indicators of economic value and the number of people who make use of recreation and ecotourism services. Indicators for the number of visitors to natural areas, tourism employment, and numbers of hunters and anglers provide a relatively complete understanding of this service.

Box 4 | Indicators Used in Sub-global Assessments

To facilitate comparison between the ecosystem service indicators applied in sub-global assessments and those used in the global MA, ecosystem service indicators were compiled from the Portugal, Western China, and Southern Africa sub-global assessments. As with the global MA, the focus from the sub-global assessments was on indicators that communicate the flow of services rather than ecosystem state.

Similar Constraints to Global MA Indicators

Indicators of ecosystem services used in sub-global assessments were constrained in similar ways to those compiled from the global MA. In fact, the sub-global assessments amplified some of the shortcomings of global MA indicators. Even more than in the global MA, indicators for provisioning services were stronger than those for regulating and cultural services, which were weak overall.

There were not necessarily a greater number of provisioning service indicators applied in the sub-global assessments, but those that were used were more specifically aligned with local priorities. Water resources and fish production were highlighted in the Portugal study. Rural livelihoods, including fishing, water provision, and crop production was a major focus of the Southern Africa assessment. While difficult to assess with certainty, the dominance of provisioning service indicators in the sub-global assessments appeared to reflect the comparative abundance of data at both the national and sub-national scales for these services compared to regulating and cultural services.

Our comparison found that regulating service indicators were weaker overall in the sub-global assessments than in the global MA. One possible reason for this is that data for many regulating services are difficult to monitor and quantify at a detailed level, and as a result these services were not considered in the sub-global assessments. For example, soil infiltration and soil water storage are potentially useful indicators of water regulating services, but are not broadly supported by available databases. Overall, the global MA was more comprehensive in terms of how many services it considered and it applied a number of indicators with spotty data. Given the lack of local data, sub-global assessments may have chosen to not consider those services for which they had few indicators or inadequate data.

The application of cultural service indicators was broadly similar to that of the global MA. However, some aspects of cultural services were explored at the sub-global level that the global MA was not able to address. In some cases sub-global assessments can explore issues that do not make much sense at larger geographic scales. For example, the Southern Africa assessment inventoried and ranked which resources a local tribe considered most important, in which cultural services ranked higher than provisioning. Other examples included the monitoring of tourist preferences.

Data Driven Assessments?

Variability in the availability of data for different topics and sectors in different parts of the world was highlighted by the sub-global assessments. The topics covered appeared to be shaped by the data available to the authors from national statistical accounts and other locally accessible data compilations. There were also some meaningful similarities among the topics treated in sub-global assessments, in particular, the inclusion of freshwater and rural livelihood-related indicators. However, the lack of trend data highlighted the need to strengthen data gathering institutions.

There were also some instances of data being available for sub-global assessments that were not available for the global assessment. These include several cultural service indicators, as well as detailed biodiversity overviews at the local level. Data on households, including consumption, population density, and agricultural needs and production were also noted.

Use of Spatial Data

Some sub-global assessments—notably the Southern Africa assessment and, to an extent, the Western China assessment—made strong use of data presented using maps, demonstrating one approach that can help facilitate multi-scale assessments. The use of spatial data allows for easier comparisons of regions and sectors within and between study areas.

Table 3 | **Indicators Compiled for Provisioning Services**

Indicator	Proxy Indicator?	Data Units	Ability to Convey Information	Data Availability	Global Compiling Agency
PROVISIONING					
FOOD					
Crops					
Crop production	No	Metric tons			FAO
Dietary energy supply	No	Kilocalories			FAO
Employment in crop production and processing	No	Number of people			FAO
Value of crop production	No	Currency			FAO
Livestock					
Livestock production	No	Metric tons			FAO
Livestock products production	No	Metric tons			FAO
Value of livestock products production	No	Currency			FAO
Capture fisheries					
Employment in the marine products sector	No	Number of people			FAO
Fish meal in animal feed	No	Percent			FAO
Fish products as a percent of total animal protein in peoples' diets	No	Percent			FAO
Total fish catch	No	Metric tons			FAO
Total marine production	No	Metric tons			FAO
Total value of marine products	No	Metric tons			FAO
Value of coastal products used for jewelry and curios	No	Currency			FAO
Aquaculture					
Fish production from aquaculture	No	Metric tons, percent of total fish production			FAO
Total aquaculture production (including non-fish products)	No	Metric tons			FAO
Wild foods					
Number of wild species used for human food	No	Number of species			FAO
BIOLOGICAL RAW MATERIALS					
Timber and other wood products					
Employment in forest sector	Yes	Number of people			FAO
Forest biomass production	No	Cubic meters, tons			FAO
Roundwood production	No	Cubic meters, tons			FAO
Value of forest products	No	Currency			FAO
Volume of forest products used for local crafts	No	Metric tons			FAO
Wood pulp production	No	Cubic meters, tons			FAO
Fibers and resins, animals skins, sand, and ornamental resources					
Employment in fibers production	Yes	Number of people			FAO
Fibers production	No	Metric tons			FAO
Production of wildlife-derived skins, wool, and feathers	No	Metric tons			FAO
Value of fibers production	No	Currency			FAO
BIOMASS FUEL					
Charcoal production	No	Cubic meters			FAO
Fuelwood production	No	Cubic meters			FAO
Industrial energy production from forest systems	No	Terawatts			FAO
Monetary value of fuel production	No	Currency			FAO

Table 3 | **Indicators Compiled for Provisioning Services, *continued***

Indicator	Proxy Indicator?	Data Units	Ability to Convey Information	Data Availability	Global Compiling Agency
FRESHWATER					
Population served by renewable water resource	No	Number of people	High	Medium	FAO
Renewable water supply	No	Cubic kilometers	High	Medium	FAO
Renewable water supply accessible to humans	No	Cubic kilometers	High	Medium	FAO
Water storage capacity	No	Days of river discharge	Medium	Medium	FAO
GENETIC RESOURCES					
Investment into natural products prospecting	Yes	Currency	Low	Low	None
Number of species that have been the subject of major investment or have become a commercial product	Yes	Number of species	Low	Low	None
Value of genetic resources	No	Currency	Low	Low	None
BIOCHEMICALS, NATURAL MEDICINES, AND PHARMACEUTICALS					
Number of organisms from which drugs have been derived	No	Number	Low	Low	None
Value of pharmaceutical products developed in natural systems	No	Currency	Low	Low	None

Low: Indicators and data availability are inadequate for support policy-making

Medium: Indicators and data availability are sufficient to partially inform policy-making

High: Indicators and data availability are sufficient to inform policy-making

Data Gathering and Dissemination

Comprehensive data availability at multiple scales and across different geographies is necessary if decision-makers are to use ecosystem service indicators to maximum effect. While this study was only able to look at data available at the global level, it is striking how few agencies compile and disseminate data for easy access and use (see Table 2). The availability of ecosystem services data for smaller regions, including at national and sub-national scales, varies greatly by location and by the kind of data required for each indicator. In some cases, data constraints at sub-global scales will be greater than at the global scale, and vice versa. While the specifics will vary, data will be a constraint in applying ecosystem services concepts in nearly all countries. For example, The Heinz Center found data limitations to be a major obstacle in their series of studies on the state of ecosystems in the United States—one of the world's most data-rich countries (Heinz Center, 2008b).

The Food and Agriculture Organization of the United Nations (FAO) and the Intergovernmental Panel on Climate Change (IPCC) are the only two organizations identified in this assessment that had a significant role in gathering and disseminating data that inform ecosystem service indicators. The IPCC provides data on global climate regulation services. The FAO compiles and provides data for 8 of the 11 provisioning services. Indicator data provided by the FAO and IPCC suffered from a number of weaknesses. For example, data presented in spatial formats, helpful in supporting their application at multiple scales, were only rarely available. In addition, disaggregating and normalizing data to support further analysis of the patterns within the aggregate data was usually not possible. Still, all 9 of those ecosystem services for which the FAO and IPCC provide data received an average rank of *medium*. Of the 11 services assessed in this study that are not supported by the FAO or IPCC, 10 received aggregate scores of *low* for data availability.

Table 4 | **Indicators Compiled for Regulating Services**

Indicator	Proxy Indicator?	Data Units	Ability to Convey Information	Data Availability	Global Compiling Agency
REGULATING					
Air quality regulation					
Flux in atmospheric gases	Yes	Teragrams carbon, nitrogen per year,			None
Atmospheric cleansing (tropospheric oxidizing)	No	No units noted			None
CLIMATE REGULATION					
Global climate regulation					
Atmospheric gases flux (CO_2, CH_4, etc)	No	Teragrams carbon, nitrogen per year,			IPCC
Carbon accumulation	No	Teragrams, metric tons			IPCC
Carbon uptake	No	Teragrams, metric tons			IPCC
Cloud formation	No	No units noted			IPCC
Evapotranspiration	No	Percent			IPCC
Carbon sequestration capacity	No	Megagrams per hectare, metric tons			IPCC
Surface albedo	No	Albedo			IPCC
Regional and local climate regulation					
Canopy stomatal conductance	No	No units noted			None
Cloud formation	No	No units noted			None
Evapotranspiration	No	Cubic meters			None
Water regulation					
Soil water infiltration	No	No units noted			None
Soil water storage	No	No units noted			None
Erosion regulation		No Indicators Identified			
Water purification and waste treatment					
Amount of waste processed by ecosystems	No	Volume/mass of waste processed			None
Capacity of ecosystem to process waste	No	Volume/mass of waste potentially processed			None
Value of ecosystem waste treatment and water purification	No	Currency			None
Disease regulation					
Disease vector predator populations	Yes	Number			None
Estimated change in disease burden as a result of changing ecosystems	Yes	Number of disease cases			None
Population increase in disease vectors mosquitoes following ecosystem conversion	Yes	Mosquito population			None
Soil quality regulation		No Indicators Identified			
Pest regulation		No Indicators Identified			
Pollination		No Indicators Identified			
Natural hazard regulation					
Changes in seasonality of flood events	Yes	Percentage change in number of events			None
Economic losses associated with natural disasters	Yes	Currency			None
Flood attenuation potential: residence time of water in rivers, reservoirs, and soils	No	Days required for water falling as precipitation to pass through system			None
Floodplain water storage capacity	No	Days of river discharge floodplain can store			None
Soil capacity to transfer groundwater	No	No units noted			None
Soil water storage capacity	No	No units noted			None
Trends in number of damaging natural disasters	Yes	Number of events			None

Low: Indicators and data availability are inadequate for support policy-making

Medium: Indicators and data availability are sufficient to partially inform policy-making

High: Indicators and data availability are sufficient to inform policy-making

Table 5 | **Indicators Compiled for Cultural Services**

Indicator	Proxy Indicator?	Data Units	Ability to Convey Information	Data Availability	Global Compiling Agency
CULTURAL					
Aesthetic/ ethical values					
Comparative value of real estate near cleaner water bodies	Yes	Yes/no, Currency			None
Comparative value of real estate nearer to nature (proxy)	Yes	Currency			None
Number of nature/rural visitors	Yes	Number of people			None
Willingness to pay for improved water quality in local water bodies	Yes	Currency			None
Spiritual and religious values		No Indicators Identified			
Recreation and ecotourism					
Nature and/or rural tourism employment	Yes	Number of people			None
Number of recreational anglers and hunters	Yes	Number of people			None
Spending on nature tourism	Yes	Currency			None
Total recreational value	Yes	Currency			None
Visitors to natural areas	Yes	Currency			None

Low: Indicators and data availability are inadequate for support policy-making

Medium: Indicators and data availability are sufficient to partially inform policy-making

High: Indicators and data availability are sufficient to inform policy-making

If availability of data to support ecosystem service indicators is to improve, institutions at multiple scales—international, national, and sub-national—will need to add gathering and disseminating information on ecosystem services to their responsibilities. Because the data will be needed at multiple scales, in spatial and non-spatial formats, and include ancillary information to support normalization and disaggregation, many agencies will need to be involved. Developing the structures and procedures to support this transition will require input and guidance from international bodies as well as counterparts within countries. Given its institutional strengths, FAO could potentially play a positive leadership role in this transition, particularly in light of recent evaluations of the FAO, which called for the organization to "totally re-examine the statistical needs for the 21st century and how they can best be met" (FAO, 2008). In addition, The Economics of Ecosystems and Biodiversity study (TEEB) (EC, 2008), calls for leadership from the United Nations in helping countries improve national statistical accounts to include ecosystem service indicators. These and other efforts to improve data gathering at all levels will be required to successfully mainstream ecosystem service indicators.

The rapidly growing capacities of online tools such as Google and Microsoft's online mapping programs present a significant opportunity to facilitate data gathering and dissemination. These tools support the ability of many organizations to contribute data, and the spatial format meets the need to display information across multiple scales. The potential of online databases and mapping approaches should be harnessed to help meet the challenge of providing relevant and high-value information in easy-to-use formats.

4. GAPS AND OPPORTUNITIES: LESSONS FROM THIS ANALYSIS

The finding that ecosystem service indicators are currently inadequate to support full understanding of the quantity and quality of services that ecosystems provide is not unexpected. Understanding of how ecosystem services underpin human well-being is relatively new and methods to apply this understanding in policy dialogs are still evolving. Identifying specific knowledge gaps can reveal opportunities to focus research where it can accelerate development of new or conceptually strengthened indicators.

Developing Regulating and Cultural Service Indicators: A Key Priority

The overarching finding of this study is that indicators for most regulating and cultural services are weak, lagging behind those for most provisioning services. If efforts to include an ecosystem services framework into policy-making are to succeed, concerted effort to identify appropriate indicators and establish data gathering structures will be required. The comparative weakness of indicators for regulating and cultural services parallels the MA's findings regarding the health of these services (MA, 2005c). The MA found that a greater share of regulating and cultural services were degraded, compared to provisioning services. The health of regulating and cultural services compared to provisioning services and the strength of indicators needed to measure them likely reflects the value—both literally and figuratively—we place on these services.

The comparative strength of provisioning services can probably be attributed in part to people's clear and immediate dependency on many of these services. People have always relied directly on the food, water, and shelter provided by provisioning services. This dependency led to a long history of measuring, communicating, and trading these services. Provisioning services are conceptually clear and viewed more or less consistently even across cultures, although the value placed on these particular services relative to others may vary. By comparison, many regulating and cultural services are not as tangible, nor are they perceived consistently by people. Aesthetic and spiritual services, for example, are difficult to express in quantitative terms and are experienced differently across cultures and individuals. Similarly, while the concept of disease regulation is less subjective than spiritual or aesthetic services, it is still not as widely recognized or clearly understood as are most provisioning services.

The oft-cited phrase that you "manage what you measure" appears to apply here (EC, 2008). Until the measures are right, the contributions of regulating and cultural services will not be fully understood and accounted for by policy-makers in the decisions they make. However, the additional saying, that you "measure what you care about", must also be taken into consideration. Until there is broad recognition that ecosystem services beyond provisioning services need to be included in policy-making, the resources and will to develop measures and gather needed data on these services will not be forthcoming.

Fortunately, the ecosystem services framing has resonated with policy-makers (Wells et al., 2006). This combined with some dramatic impacts of degraded regulating services such as floods, pest outbreaks, widespread erosion, and other natural disasters have built awareness of regulating and cultural services as important contributors to human well-being. This awareness is already driving new research into how regulating services can be measured and communicated.[5] New policies such as nutrient trading that make use of regulating services are also being explored (Selman et al., 2008). This virtuous cycle should accelerate in the coming months and years. As our ability to measure and communicate cultural and regulating services gets better, demand for this information will likely increase, which will further improve supply.

Markets and Government Regulation Require Ecosystem Service Indicators

Among the patterns noted in this analysis is that indicators are stronger for services that are traded or subject to government regulation than for those that are not. The implication is that demand and supply of indicators go together. Applying indicators in policy and economic arenas creates demand for improved indicators and provides iterative feedback about what is useful and why.

Ecosystem Services in Markets

Given humanity's long history of harvesting and trading many provisioning services as commodities in markets, it is not surprising that these services have the best indicators and strongest established data collection and dissemination mechanisms. For centuries, provisioning services such as crops, timber, fish, livestock, fuel, and fibers have been part of the formal market economy, so accepted methods for measuring and communicating these services have been developed and adopted into national statistical accounts.

This pattern extends beyond provisioning services. Within cultural services, recreation and tourism are supported by a much stronger collection of indicators than aesthetic values. To some extent, this can be attributed to the existence of markets around recreation and tourism, including park entry fees, hotels, equipment, and other recreational goods. Although few regulating services have become fully integrated into economic markets, some such as water purification and waste treatment, have been used in place of expensive engineering projects and are being included in payment for ecosystem service (PES) pilots. For example, in some such pilots farmers are able to sell the reduction in nutrient loading into surface water caused by management actions that enhance the water purification and waste treatment services on their land (Selman et al., 2009). Another example is global climate regulation, for which there are multiple mechanisms already in force and being prepared to commoditize ecosystems' capacity to sequester carbon (e.g. Regional Greenhouse Gas Initiative, 2008; Hamilton et al., 2009). Compared to some regulating services that are further from becoming traded commodities, such as disease, natural hazard, and air quality regulation, those services that are becoming integrated into economic markets have stronger indicators and are supported by better data.

Government Regulation

In addition to economic markets, ecosystem services subject to government regulation—such as water regulation, erosion regulation, and water purification—have stronger indicators than those that have not been regulated. Such services all received aggregate indicator scores of *high* or *medium* for their ability to convey information. Governments often legally limit or provide incentives to reduce the scale of activities that degrade these services in an attempt to protect them. For example, numerous countries have incentives to plant and harvest crops in ways that maintain erosion regulation. Similarly, limits on logging exist in certain areas to protect water regulation, water purification, and natural hazard regulation services.

The fact that services that participate in economic markets and are subject to government regulation have relatively strong indicators is encouraging. As policy-makers seek to apply ecosystem service concepts in their decision-making processes, the demand for information is likely to lead to better indicators and data collection regimes.

Conceptual Challenges to Measuring Regulating Services

The relative weakness of indicators for regulating services can only be partially explained by the lack of extensive markets for these services. Many of these services are inherently difficult to quantify and consequently pose serious measurement challenges.

Measuring Ecological Processes versus Tangible Goods

Provisioning services are tangible goods that allow for quantification. These include, for example, tons of grain, cubic meters of timber, or cubic kilometers of freshwater. Regulating services, on the other hand, are processes which do not allow for quantification in the same way. This difference has been explored in recent studies seeking to place values on ecosystem services, including the "Review on the Economics of Biodiversity Loss: Scoping the Science" (Balmford et al., 2008) and "Cost of Policy Inaction on Biodiversity Loss" (COPI) (Braat & ten Brink, 2008), as well in the development of the Artificial Intelligence for Ecosystem Services (ARIES) visualization tool (Villa et al., 2007). The approach applied by some of these studies, broadly termed the "benefits model," separates ecosystem services that can be concretely measured, called *benefits,* from *processes* that underlie these benefits (Figure 1). In this framework, benefits primarily consist of provisioning, and cultural and aesthetic services, while beneficial ecosystem processes primarily consist of regulating services.

Within the benefits model, the value of beneficial ecosystem processes is derived from the values determined for the directly measured benefits that the processes underpin. For example, the value of pollination is based on the value of the crops that depend upon the pollination services. The value of waste assimilation could be partially estimated based on tourism receipts from visitors to a clean bay with large fish populations. This approach of measuring only the benefits accruing directly to end users is used in this valuation approach to avoid double counting. However, for policy-makers to more fully understand how these processes—regulating services—are contributing to the well-being of their constituents and economic development, it will also be necessary to measure and communicate the processes themselves more directly.

The benefits model provides a number of lessons relevant to improving ecosystem service indicators. Most basically, the approach holds promise for improving the valuation of ecosystem services, which is a useful indicator for most ecosystem services in its own right. More broadly, the delineation of services into two groups—benefits that can be directly measured and processes that cannot be measured directly—helps to clarify the challenges associated with developing indicators for regulating services. More work is needed to identify ways to estimate these services that goes beyond using state indicators as proxies.

Functional Traits as Indicators

Another approach that may hold promise for developing indicators of regulating services is based on identifying and measuring the functional traits within an ecosystem that provide given services. Traits, defined as "characteristics … required for service provision" (Vandewalle et al., 2008), can be identified at multiple ecological levels, from the microbial to the landscape, depending on the service the trait provides (Kremen, 2005). For example, at the species and field level the rooting depth and structure of a plant are traits that provide erosion and nutrient regulation services. At the landscape level, nectar-producing flowers and structurally diverse vegetation for nesting provide bee habitat that enable pollination services (Vaughan et. al., 2004).

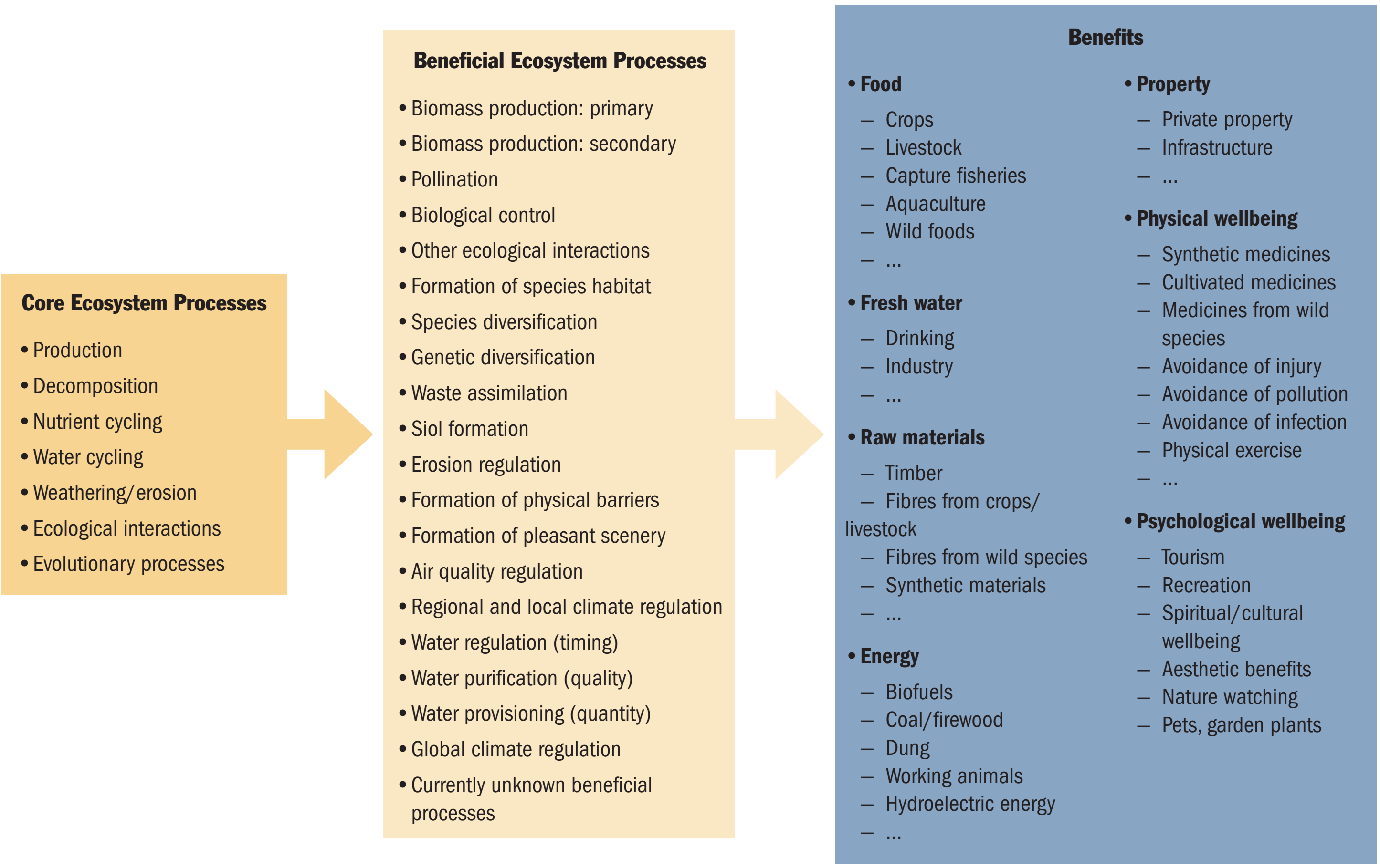
Applying the traits concept to develop high-quality indicators of regulating services will require establishing clear links between various ecological traits and the quantity and quality of services enabled. Moreover, for the trait-based indicators to have broad applicability, it will be necessary to identify traits that can be measured at landscape scales via remote sensing technologies, as well as those that can be measured using more resource-intensive methods. Approaches to conduct a "functional inventory"—an inventory of the functional traits that enable an ecosystem service in a given area—has been proposed and applied (see Kremen, 2005, Vandewalle et al., 2008). The potential of these concepts to underpin indicators of regulating services that can be measured efficiently at relevant spatial and temporal scales should be further explored.

Figure 1: Benefits model building on the ecosystem services framework, as depicted in Balmford et al. (2008). In this model, services directly enjoyed by people are identified as "benefits" while services that underpin these benefits are termed "processes". In this framework, benefits mostly include provisioning and cultural services while beneficial ecosystem processes include mostly regulating services (with water provisioning a notable exception).

The Reverse Logic of "Avoided Change"

Another challenge to identifying indicators for some regulating services is that the measure of some services is a measure of "avoided change." The question that must be answered in these cases is: how does one measure a negative occurrence, such as a forest fire or water pollution, that has not happened (a "counterfactual") due to the contribution of a regulating service? It seems impossible to measure a forest fire, disease outbreak, natural hazard avoidance or nutrient fluctuation that does not happen. Researchers concerned with measuring vulnerability and adaptation to climate impacts have met with the same difficulty. The Global Environment Facility, for example, notes "the difficulties of evaluating adaptation to climate change, such as having a reverse logic of being successful when impacts are avoided" (GEF, 2008).

Figure 1 | **Benefits Model Building on the Ecosystem Services Framework**



Source: As depicted in Balmford et al. (2008). In this model, services directly enjoyed by people are identified as "benefits" while services that underpin these benefits are termed "processes". In this framework, benefits mostly include provisioning and cultural services while beneficial ecosystem processes include mostly regulating services (with water provisioning a notable exception).

The problem is that "success" in preserving a regulating service in a healthy state would, in some cases, not produce a measurable change in ecosystem state, but would appear as simply maintaining the status quo. For example, if nutrient regulation services are maintained in a watershed, nutrient levels in the water will remain stable. Similarly, if disease regulation services are maintained, disease levels should remain stable. It should be noted that this is not applicable in cases where regulating services have been degraded and there are efforts to restore them; in these cases, restoring a degraded service should result in a measurable improvement. We know from the MA that ecosystems' capacity to provide regulating services is already degraded and appears to be worsening, but do not know to what degree regulating services are helping to mitigate the impacts of human activities, helping sustain ecosystem functions, and keeping ecosystem state above a threshold below which one or more ecosystem service would collapse. Because the ecosystem functions that provide ecosystem services often rely on a minimum level of ecosystem health, the decline in delivery of services does not always progress linearly. Ecosystems are often resilient, absorbing pressures with little reduction in service delivery. On the other end of the scale, once a threshold is past, ecosystem functions can cease suddenly. We need to be able to understand how regulating services are avoiding additional degradation and by how much, especially where an ecosystem service may be nearing a threshold beyond which it could collapse.

In the absence of approaches to effectively measure the positive contribution of some services such as disease regulation, the indicators of some regulating services compiled for this study track the negative trends associated with the loss of those services. For example, the indicators for disease regulation and natural hazard track the worsening trends resulting from these services being degraded. The indicators for disease regulation include increase in disease vector populations and disease incidence following ecosystem change. For natural hazard regulation, the indicators tracking the implications of the loss of the service include increases in the number of fires, floods, pest outbreaks and other natural disasters that are often kept in check by regulating services, and increases in economic losses associated with natural disasters.

Because these indicators provide information about the negative consequences of the loss of a service after the fact (or alternatively, the positive consequences if ecosystem services have been restored), they are called lagging indicators. Although these indicators are helpful in raising the alarm about overall trends, lagging indicators do not provide timely information to avoid degradation of a specific ecosystem in the first place. Helping policy-makers craft policies that proactively maintain ecosystem services will require leading, as well as lagging, indicators.

5. PRELIMINARY RECOMMENDATIONS FOR NEXT STEPS

This preliminary analysis highlights the need to strengthen and expand current ecosystem service indicators and supporting data, especially for regulating and cultural services. Improving ecosystem service indicators and integrating them into policy processes will require diverse activities undertaken by a variety of actors. Fortunately, the many institutions involved in MA follow-up work have generated significant momentum that, if effectively harnessed, can help drive the development of a robust set of ecosystem service indicators. The key recommendation for next steps to achieve these ends is to establish a partnership of organizations working on ecosystem service indicators to help coordinate approaches and activities aimed at improving the indicators, gathering requisite data, and encouraging their use by policy-makers. Specific recommended activities for such a partnership's common agenda include:

- Test ecosystem service indicators in national level policy processes;
- Engage sub-global assessments to capitalize on the scientific and policy analysis expertise gathered for these undertakings;
- Support research focused on developing improved indicators;
- Develop models to organize ecosystem service indicators and visualization tools to help policy-makers apply ecosystem services concepts;
- Ensure data availability and quality, in part by incorporating indicators for all ecosystem services into data-gathering institutions' mandates.

Note that these recommendations are intended to be preliminary. Final recommendations will be issued based on consultation with other organizations working to develop and implement ecosystem service indicators. The remainder of this section provides more detail on each one.

Identifying and developing better indicators, ensuring that data for such indicators are available, and helping policy-makers to apply the indicators are iterative processes that will take time and require flexibility and adaptability on the part of the institutions involved. Viewed as a discrete set of activities, these recommendations may appear very ambitious. However, each institution engaged in mainstreaming ecosystem services probably pursues activities in support of them. For this reason, the overarching recommendation is to convene a partnership of organizations engaged in developing and applying ecosystem service indicators.

Launch Ecosystem Service Indicators Partnership

Implementing these recommendations requires diverse activities by numerous institutions committed to mainstreaming ecosystem services concepts. Encouragingly, numerous efforts relevant to these recommendations are already underway. However, there is no mechanism currently in place for sharing developments, ideas, and evolving approaches for ecosystem service indicators, nor for coordinating activities toward a common set of goals.

By facilitating the sharing of ideas, developments, and successes, a partnership of relevant organizations could play an important role in developing and operationalizing ecosystem service indicators. The partnership, as envisaged by WRI, would incorporate lessons from other indicator partnerships such as the Biodiversity Indicators Partnership (BIP). It would include organizations seeking to develop indicators, establish methodologies for gathering data at multiple scales, apply indicators in assessments, and help policy-makers make use of these tools.

Collaborating organizations would determine the specifics of how such an indicators partnership should be set up and function. Given sufficient resources, members should include non-governmental organizations, multi-lateral institutions, and policy-makers in both government and the private sector that represent multiple scales and geographies.

Test Indicators with Policy-makers

Policy-makers are a key target audience for proponents of ecosystem service indicators. Successful indicators must be able to communicate information effectively to diverse policy-makers. Where they do not, indicators should be revised. Intentional engagement with this audience to ascertain where ecosystem service indicators successfully support policy dialogs, and where they do not, should therefore be a key element in efforts to iteratively improve indicators.

Indicators often vary in their effectiveness depending on the conditions in which they are applied. Therefore, testing needs to take place in different geographies and economies; at multiple scaleslocal, national, regional; within different cultures; and among different levels of income, well-being, and power regimes. In addition, decision-makers of all kinds should be engaged, including public officials, businesses, sectoral partnerships to increase the sustainability of forestry or agriculture, and agencies responsible for administering market-based approaches, such as payments for ecosystem services.

Engage Ecosystem Assessments

Future ecosystem assessments have the potential to support each of the recommendations mentioned here. These efforts typically compile data from many sources and would benefit from integrated databases, once developed. In the meantime, sub-global assessments will compile and, in some cases, collect new data. Such sub-global assessments may also conceptualize new indicators to fill existing gaps. Ideally, each will also communicate their findings to policy-makers and help identify which indicators are effective and which are not. By applying ecosystem service indicators and engaging government agencies, sub-global assessments will play an important role in influencing governmental indicator compendia and data-gathering regimes, and in mainstreaming ecosystem service concepts.

For these reasons, an ecosystem service indicators partnership should seek to include and build strong collaborations with organizations responsible for facilitating sub-global assessments. These should include, but are not be limited to, UNEP's MA Implementation Coordinator, the Secretariat for sub-global assessments collaboratively managed by United Nations University, UNEP, UNEP-WCMC, and The Cropper Foundation, which jointly support sub-global assessments in developing countries; the Department for Environment, Food and Rural Affairs (Defra) and UNEP-World Conservation Monitoring Centre (UNEP-WCMC) for the UK Assessment; the European Environment Agency (EEA) for the European Ecological Assessment; the Heinz Center for the United States; and the Helmholtz-Centre for Environmental Research, among others, for The Economics of Ecosystems and Biodiversity (TEEB).

Along these lines, WRI has already begun compiling indicators from previous sub-global assessments into a database. This resource should help new ecosystem assessments build on previous MA work. The database will also provide an opportunity to continuously expand the knowledge base for other assessments by creating a storehouse for new indicators. As future assessments use these indicators it will become possible to identify which ones are best for various purposes. Over time, this compilation can serve as a clearing-house, building consensus around a consistently used set of effective ecosystem service indicators.

Beyond providing an opportunity to road test new indicators and share lessons, engaging those participating in future ecosystem assessments can support other steps outlined here. The extent of work required to complete an assessment means, in most cases, that scientific institutions and civil society organizations will have an active role in contributing ideas and data. By challenging these diverse organizations to contribute ideas for better ways to measure and communicate ecosystem services, assessments could play an important role in identifying new indicators.

Support Research to Develop Ecosystem Service Indicators

Efforts intentionally focused on the application of ecosystem services concepts in policy-making (see Appendix 2) are helping to drive the development and refinement of improved indicators. While these activities are impressive in their scope and diversity, additional efforts are needed to fill indicator gaps for some services. It will be important to enlist scientific and policy research organizations from outside the MA follow-up or biodiversity research communities to help. The diverse and novel approaches these organizations bring to bear could be helpful in identifying ecosystem service indicators which can support policy-making with low-cost data. Supporting these organizations should accelerate progress, particularly in the less well understood areas of regulating and cultural services.

Develop Models and Tools

Fully testing ecosystem service indicators with policy-makers—and over the long term, getting them adopted into policy processes—will require tools that help them visualize and understand ecosystem service information and how it integrates with social and economic data. Supporting policy-makers' ability to apply ecosystem service indicators will depend in particular on two tools: online databases and spatial visualization tools.

Online Databases

Ecosystem service indicators need to be integrated with information on human well-being, direct and indirect drivers of ecosystem change, and policy responses—including fiscal investments. Villa et al. (2007), for example, note that integrated databases will be necessary for efficiently applying valuation at large scales.

Priority actions in launching online ecosystem services databases include:

- Develop online database tools that practitioners can use as they gather and compile ecosystem service data for assessments and policy input. These tools should be designed to be flexible. For example, they would need to hold data at multiple scales and across time; accommodate different types of data; allow for normalization, aggregation, and disaggregation; and provide ancillary data such as area and population.
- Choose one or multiple organizations to maintain elements of the database online, and include the ability for data to be uploaded by scientists, environmental organizations, and other possible data providers. The FAO, for example, would be a strong candidate for hosting such a database.
- Include ecosystem service indicators in data-sharing protocols intended to facilitate the exchange of information between databases. One such exchange protocol is being developed by IUCN, the Nature Conservancy,

Conservation International, and others in collaboration with OASIS. These data-sharing protocols will complement large databases—such as those proposed above—by allowing locally gathered data held in disparate databases to be seamlessly shared, aggregated, and processed into the value-added indicators that policy-makers need.

Characteristics required for online databases to support ecosystem service indicators include:

- *Multi-scale and temporal:* The database must support the ability to store information at scales ranging from local to global.
- *Ecological and administrative boundaries:* Information must be available for diverse types of ecological and political boundaries, as well as for raster and vector data.
- *Ability for diverse contributors to upload information:* Ensure traditional and local knowledge can be added to the database.
- *Entire MA conceptual framework:* Indicators and data for human well-being, drivers of ecosystem change, policy responses, ecosystem state and ecosystem services should be included.

Data Visualization Tools

Because ecosystem services vary across space, spatial representation of ecosystem service information needs to be a priority. The relative importance of ecosystem services changes as the scale being examined changes. Potential impacts of degradation or restoration of services cross geographic boundaries and can impact communities far away. Similarly, the benefits from ecosystem services can be captured by people in close proximity to the service or by populations hundreds or thousands of miles away. The need to present information spatially was recognized in the MA, and was especially embraced by the Gariep Basin Sub-global assessment (Bohensky et al., 2004), which used Geographic Information System (GIS) maps as a way of presenting information on many of the issues addressed in that assessment.

Ensure Data Availability and Quality

Without data to populate ecosystem service indicators, policy-makers and scientists will not be in a position to realize the promise that the ecosystem service framing holds for reversing ecosystem degradation and improving peoples' livelihoods. Given the current paucity of data at the global and sub-global levels that this and other studies (e.g., The Heinz Center, 2008) have identified, it should be a priority to ensure that ecosystem service data is gathered. Toward this end, a dual strategy should be enacted of (1) actively developing indicators, and gathering and applying data for them, and (2) building the case among large institutional data gatherers to incorporate ecosystem service indicators into their compilations.

Many elements of the first portion of the strategy are included in the other recommendations made here. A strategy for part two should build on the successful identification and application of indicators in multiple locations, sectors, and scales, and would best be formalized by an ecosystem service indicators partnership.

Include More Ecosystem Services in Institutional Data Providers' Compilations

This analysis points to the positive role an international institution or combination of institutions could play by accepting responsibility for gathering and disseminating ecosystem service data. In nearly all cases, the indicators considered in this study that scored medium or high for data availability are supported by an institutional data provider such as FAO or the IPCC. It will therefore be important to build the case and develop methodologies that will allow institutional data providers to integrate ecosystem service indicators into their portfolios. Identifying ways for the FAO, for example, to add regulating services to their current focus on provisioning services, could play an important role in realizing the ability to provide a suite of ecosystem service indicators that are functional and policy-relevant.

Improving Data Gathering and Reporting

Ensuring data quality is also a critical concern. This includes gathering data at relevant scales and with the background information needed for analysis. Specific requirements for data gathering include:

- Covering all relevant scales, from the sub-national to national to international levels;
- Collecting ancillary data that support disaggregation and normalization including, for example, area planted in different crops and fertilizer application by crop, to support understanding of trends in agricultural yields and farmers' choices of types of crops to plant; and
- Gathering data with sufficient frequency to support trends analysis.

To keep data gathering efforts and costs to a minimum, ecosystem service indicators should be integrated into existing data-gathering and dissemination processes wherever possible. For example:

- New indicators should build on existing data, where possible, instead of requiring the development of new data-gathering processes;
- Where new data need to be gathered, this should be integrated into existing data-gathering processes such as national accounts, adding questions to censuses, household surveys and other survey-based processes, encouraging graduate students to consider focusing on ecosystem services, etc.; and
- Make existing data more widely available by entering data into online databases that facilitate compilation, aggregation, and sharing.

By laying out limitations in existing ecosystem service indicators and some opportunities for filling those gaps, this analysis provides a starting point for action. Only by improving indicators will ecosystem services become mainstreamed in public and private sector decision-making.

APPENDIX 1: KEY DEFINITIONS

Ecosystem services are benefits that people get from nature. Examples include fresh water, timber, climate regulation, recreation, and aesthetic values.

Provisioning services are goods provided by ecosystems, and include crops, timber, and livestock as well as genetic resources for medicines.

Regulating services maintain healthy ecosystem functioning, and include water purification, pollination, water regulation, and climate regulation.

Cultural services are intangible and non-material value people derive from nature, and include spiritual and aesthetic benefits as well as recreation and tourism. Table 1 provides more in-depth information about provisioning, regulating, and cultural services.

Ecosystem services are sometimes discussed in terms of stocks and flows. The flow of services refers to the actual benefits people receive from ecosystems. Stocks refers to the capacity of ecosystems to deliver those benefits. An ecosystem that is degraded has a reduced stock of services, and the flow of benefits is lower as a result.

An ecosystem "is a dynamic complex of plants, animals, and micro-organisms interacting as a functional unit" (United Nations, 1992). Examples include a rainforest, desert, coral reef, or a cultivated system. Ecosystems vary in size, complexity of interactions and are interconnected and impacted by natural processes such as fluctuating rainfall regimes. Human management impacts ecosystems dramatically, as when forests are converted to cultivated systems, or more subtly when water regimes in a stream are altered. These changes to ecosystems impact ecosystem services, but not always in a predictable and linear fashion. **Ecosystem integrity**, **state** or **health**, is determined by how intact the complex of plants, animals, and micro-organisms are, and the robustness of the complex interactions that sustain ecosystems. Ecosystems' ability to deliver services depends on ecosystem integrity. As with biodiversity, ecosystem integrity is a complex concept that is very difficult to measure (Bohensky et al., 2004). Indicators such as ecosystem extent and measures of biodiversity are often employed as proxies for ecosystem integrity.

Biodiversity "is the variability among living organisms from all sources including 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" (United Nations, 1992). Biodiversity itself is not an ecosystem service, but, like ecosystem integrity, is rather an underpinning for ecosystems to provide services (see the ecosystem service conceptual framework (MA, 2005c)). The term biodiversity is often applied very broadly and almost interchangeably with ecosystem integrity or ecosystem state (see for example TEEB, 2008).

Indicators "summarize complex information of value to the observer. They condense […] complexity to a manageable amount of meaningful information […] informing our decisions and directing our actions." (Bossel, 1999). Indicators can be presented in the form of statistics, maps, or in other ways such as a rating or color. Direct measures of an issue or phenomenon often serve as indicators, but indicators often aggregate multiple measures into an index in order to condense information (Hammond et al., 1995). Carbon dioxide emissions, for example, is an important indicator of the rate at which humans are driving climate change along with Greenhouse Gas Emissions (GHGs), an indicator that aggregates multiple gases that drive climate change. Similarly, the population of wild honeybees per hectare is a measure that provides an indicator of pollination services. However, because honeybees are only one of many species that pollinate crops, wild honeybee populations alone only provide policy-makers with a piece of the larger picture, and are probably best considered a measure. A possible indicator could be developed from this measure by aggregating populations of pollinators until the species responsible for the majority of pollination are represented.

A **proxy indicator** is a substitute measure used to provide insight into the area of interest when it is not possible to measure the issue directly. Proxy measures must behave reasonably in sync with a good direct measure. In the context of ecosystem services, the number of people visiting natural areas could serve as a proxy measure for spiritual services. While the number of visitors does not directly measure the spiritual benefits people garner from ecosystems, it does serve as a proxy by providing some insight into the level of this service provided by the natural areas.

Environmental indicators are information that provide insight into the environment and humans' impact and management of it. Examples include air quality—sometimes translated into a form that is easy for the public to comprehend such as "code red", toxic releases into the atmosphere, carbon footprint, and the environmental performance index. Ecosystem state and ecosystem service indicators are subsets of environmental indicators.

Ecosystem indicators provide understanding of the *state* of ecosystems, and because ecosystem state determines their capacity to provide ecosystem services these indicators are often employed as indicators of ecosystem services stocks. Ecosystem state indicators can help policy-makers understand how decisions and policies may impact the flow of services, and are an important contributor to incorporating the ecosystem services framework into policy-making. Examples of ecosystem state indicators include forest extent, nutrient levels in streams, percentage of non-managed vegetative cover in agricultural landscapes, and prevalence of non-native species.

Ecosystem service indicators communicate the characteristics and trends in ecosystem services. Indicators of ecosystem services ideally convey information about the *flow* of service—the benefits people receive (only indicators of the flow of ecosystem services were considered for this analysis). However, proxy indicators, especially those based on ecosystem state have often been used to this point. Due to the difficultly in measuring the flow of benefits from some regulating and cultural services, it may be necessary to rely on proxy indicators for some ecosystem services in the long term. Examples include tons of wheat produced on a hectare of land, the amount of nutrient removed from agricultural runoff by wetlands, cubic kilometers of water stored in a forest, and the tourist income received by a coastal community.

APPENDIX 2: ECOSYSTEM SERVICE INDICATORS WITHIN THE BROADER LANDSCAPE

Numerous institutions are engaged in MA follow-up efforts intended to further these objectives. Many of these efforts relate to the task of improving ecosystem service indicators explored in this paper by either contributing to the development of indicators or depending on improved indicators to strengthen their work. This appendix expands on how ecosystem service indicators contribute to some of these efforts.

- **Environmental Indicator and Data Initiatives:** There are a number of ongoing efforts to identify indicators that inform policy-makers' understanding of interactions between ecosystems and humans and to gather and make available the databases needed for these indicators to be applied. Projects to identify and apply biodiversity and ecosystem indicators, such as the expert meetings under the Convention on Biological Diversity (CBD) and the Biodiversity Indicators Partnership (BIP) and to compile and disseminate data, including the Global Biodiversity Information Facility (GBIF) and the World Database on Protected Areas (WDPA), will provide important guidance for efforts to provide indicators and data for ecosystem services.
- **Ecosystem Services/Biodiversity-science interface:** The Intergovernmental Panel on Climate Change (IPCC) provides scientific assessments of the risks associated with climate change based on the best available technical and socio-economic information, and provides input to policy-makers by issuing reports at regular intervals. UNEP has proposed a similar panel, called the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), to support policy-makers with scientific information about the state of ecosystems and biodiversity. A preliminary concept for IPBES has been presented to the UNEP Governing Council and is undergoing refinement. When IPBES is launched, it will play an important role in supporting developing and operationalizing ecosystem service indicators, including building the data-gathering networks that will be required.
- **Sub-global assessments:** The MA follow-up strategy calls for expanding and improving sub-global ecological assessments. The Secretariat for sub-global assessments, collaboratively managed by United Nations University, UNEP, UNEP-WCMC and The Cropper Foundation, are currently preparing for a number of new assessments. A number of others are also planned or are already underway, including a United Kingdom assessment being managed by UNEP-World Conservation Monitoring Centre (UNEP-WCMC) for the Department for Environment, Food and Rural Affairs (Defra); the European Environment Agency's (EEA) European Ecological Assessment, (EURECA); and UNEP and UNDP's joint Poverty-Environment Initiative's (PEI) second round of Pilot Ecosystem Assessments. These sub-global assessments will benefit from easily accessed compilations of indicators from the past assessments at various scales and can be expected to contribute new indicators from their own research. In addition, these sub-global assessments can serve as a testing ground for which indicators work best in conveying ecosystem service information to policy-makers; the challenges encountered will help identify persistent indicator gaps that can focus future research.
- **Guide for conducting Sub-global assessments:** The United Nations Environment Programme-World Conservation Monitoring Centre (UNEP-WCMC) is preparing a how-to guide to provide future sub-global assessments with lessons from the global and sub-global assessments prepared as part of the MA. Issues to be considered in choosing and applying ecosystem service indicators are included in the guide. Compilations of indicators and data sources used in other assessments, as well as new indicators to be added as they are developed, will complement this guide.
- **Policy and environmental management policy dialogs:** Testing the usefulness of ecosystem service indicators for policy-making will require engaging with policy and management activities using an ecosystem service framework at different scales and locations in different parts of the world. One example is the Puget Sound Partnership, which seeks to incorporate the ecosystem services framework into policy-making as part of efforts to restore Washington State's Puget Sound (Ranganathan et al., 2008). Incorporating indicators into this and similar projects will make it possible to assess their ability to convey ecosystem service information to policy-makers.
- **Sector-focused efforts to improve ecosystem management:** In addition to understanding how well indicators support policy dialogs in specific locations, ecosystem service indicators can help support initiatives to improve the environmental performance of specific economic sectors. For example, initiatives seeking to foster greater sustainability in agriculture are interested in whether an ecosystem services approach could support this effort. A mediation group called The Keystone Center has brought industry, grower, and environmental groups together through their "Creating Sustainable Outcomes for Agriculture" program (primarily focused on North America). The Sustainable Food Lab has a similar effort in North America and Europe. Agriculture has also been identified as one of the focal areas for the upcoming European Ecological Assessment. Indicators can contribute to these efforts by clarifying ways in which ecosystem services support agriculture; how ecosystem services, including regulating and cultural services, are impacted both positively and negatively by agriculture; and how agricultural approaches can be adapted to achieve balance between provisioning, regulating, and cultural services.

- **Poverty reduction and human development:** The poor, especially the rural poor, are particularly dependent on ecosystem services for their livelihoods, health, and well-being (WRI, 2005; Bass et al., 2006; DFID et al., 2006; OECD, 2006; EC, 2008). Integrating ecosystems into fiscal decisions and economic and human development policies must play a role in shaping poverty reduction strategies and overall policy decision-making in countries with significant poverty. Integrating these topics, however, is challenging. Along with other multilateral and bilateral agencies, the Poverty-Environment Partnership created by the United Nations Environment and Development Programmes (UNEP and UNDP) is working with country governments and civil society to support this approach. Reviews of ecosystem assessments and other related projects have revealed that the ecosystem services framework can help identify cross-boundary impacts and unintended consequences of development decisions. However, the reviews have also highlighted the lack of an information base and toolkits to support the wider application of these concepts. Better indicators, data availability, and toolkits called for in this paper will help overcome some of the challenges limiting policy-makers' understanding of ecosystem services and their ability to integrate these considerations into broader policy debates and decisions.

- **Valuation of ecosystem services:** Multiple efforts are underway to improve the ability to assign value to the services ecosystems provide. These projects include the Potsdam Initiative (elements of which are known as Cost of Policy Inaction (COPI) and The Economics of Ecosystems and Biodiversity (TEEB)) and two models being developed by the University of Vermont's Gund Institute for Ecological Economics (the Multi-scale Integrated Models of Ecosystem Services (MIMES) and ARIES). These initiatives have proposed ways to sort elements of the MA conceptual framework to better support valuation of ecosystem services. The valuation frameworks may also prove helpful for identifying ways to quantify ecosystem service indicators other than valuation.

- **Ecological research:** As the concept of ecosystem services becomes better known and accepted, universities and other institutions are increasingly conducting research into how ecosystem services, especially regulating and cultural services, can be better understood and measured. The European Ecological Society, for example, dedicated a track at their 2008 meeting for professors and students to present their research into ecosystem services. The Council for Scientific and Industrial Research (CSIR) in South Africa has been leading a process with the government to identify what indicators already being tracked can be applied to ecosystem services and to develop new ones where necessary. This kind of detailed research will lay the groundwork for developing new and better ecosystem service indicators to communicate information about these services to policy-makers.

- **Payment for Ecosystem Services:** PES schemes are voluntary systems where a buyer pays for the maintenance of an ecosystem service. In most instances, the seller receives payment to guarantee land management activities that maintain or enhance ecosystem services such as freshwater provisioning, freshwater regulation, waste regulation, or aesthetic services. Management activities may include conservation, restoration or other sustainable measures. Payments to manage lands in a specific way such as maintaining forest cover in watersheds to sustain cities' water supplies, and tax incentives for conservation easements that support aesthetic services, have been in place for a long time. The ecosystem services approach provides a larger framework for such services and may help to provide incentives for efficiently improving ecosystem services at a much larger scale. Some PES schemes, such as carbon and water quality trading, are growing into active markets where buyers and sellers can find each other on regulated, open exchanges. Proposals for very large PES schemes such as the Reduction in Emissions from Deforestation and Degradation (REDD) are also being proposed. Since many of the emerging PES markets are for regulating services that have not previously been recognized by financial markets, it will be necessary to develop indicators that reliably measure the delivery of these services. Only when the quantity and quality of services delivered by specific land management actions are thoroughly understood will financial markets trust them sufficiently for these markets to thrive and expand. The Ecosystem Marketplace (www.ecosystemmarketplace.org) is a resource for more information on PES schemes.

- **Corporate Ecosystem Services Review:** The ESR is a structured methodology that helps managers develop strategies to manage their company's dependence and impact on ecosystems. It is being used by scores of companies to improve corporate performance. While most environmental management systems and due diligence tools focus wholly on the impacts business has on the environment—pollution and natural resource consumption--the ESR includes an analysis of the dependencies that corporations have on ecosystem services. In addition, firms that use the ESR can expand their risk and opportunity analyses to include all ecosystem services, not just those well studied prior to the MA's release. Firms are using the ESR to reduce risks and find new product and market opportunities up and down their supply chains, in their land management practices, and with their customers. Many companies are weaving the ESR's core concepts into existing environmental impact assessments, plant audits, and management systems.

APPENDIX 3: ECOSYSTEM SERVICE AND ECOSYSTEM STATE INDICATORS IN SUB-GLOBAL ASSESSMENTS

Ecosystem Service Indicators Compiled from Portugal, Southern Africa, and Western China Sub-Global Assessments

Indicator	Data Unit	Page Number
PORTUGAL ASSESSMENT		
PROVISIONING SERVICES		
Crops		
National food self-reliance	Percent	37
Grain production	Metric tons	48
Grain yields	Metric tons/hectare	
Livestock		
Total head of cattle, pigs, poultry, sheep, and goats	Head	53
Capture Fisheries		
Fish landings	Metric tons	29
Fish landings-value	Euros	30
Wild Foods		
Production of wild foods in forests	Metric tons	
Timber and Other Wood Products		
Forest yield	Cubic meters/hectare/year	33
Timber forest products-value	Euros	32
Non-timber forest products-value	Euros	32
Timber production	Cubic meters	33
Cork production	Metric tons	33
Freshwater		
Water consumption by sector	Percent	27
REGULATING SERVICES		
Global Climate Regulation		
Standing stock of carbon	Metric tons/hectare	34
Soil carbon storage	Metric tons/hectare	
Value of forest carbon sequestration	Million Euros	32
Water regulation		
Value of forest water resources protection	Million Euros	32
CULTURAL SERVICES		
Aesthetic Values		
Recreational visits to forest	Visiting days/year	35
Recreation and Ecotourism		
Spas	Number	48
Tourist facilities on the coast	Number	30
Tourism income	Billions Euros	30
REGULATING AND CULTURAL SERVICES COMBINED		
Total value of regulating and cultural services	Million Euros	32
SOUTHERN AFRICA ASSESSMENT		
PROVISIONING SERVICES		
Crops		
Cereal production	Metric tons	46
Agriculture's contribution to GDP	Percent	24
Livestock		
Livestock biomass	Number	47
Red meat production	Metric tons	47
Average income from selling goat / sheep	Rand	13

Ecosystem Service Indicators Compiled from Portugal, Southern Africa, and Western China Sub-Global Assessments, *cont.*		
Indicator	**Data Unit**	**Page Number**
SOUTHERN AFRICA ASSESSMENT (continued)		
Wild Foods		
Income from commercial game farming	Percent of total income	47
Biomass Fuel		
Biofuel consumption	Percent	53
Fuelwood consumption	Kilograms	56
Savings from using fuelwood instead of commercial energy	Rand/family	5
Freshwater		
Per capita water availability	Cubic meters/person	24
Groundwater use, by sector	Millions cubic meters, percent	26
Hydropower potential	Megawatts	55
REGULATING SERVICES		
Pest Regulation		
Livestock industry losses due to blackfly pest	Million Rand	10
CULTURAL SERVICES		
Ethical Values		
Value placed on various resource types by the Amaxhosa people, such as water, animals, fuelwood, etc.	Rank ordering	72
Aesthetic Values		
Average size of yard, by income	Meters square	102
WESTERN CHINA ASSESSMENT		
PROVISIONING SERVICES		
Crops		
Ecosystem food production	Metric tons	48
Crop production	Metric tons	40
Freshwater		
Gross water resource	Cubic meters	56
Groundwater availability	Cubic meters	47
Water consumption by sector	Percent	58
Average annual water resource	Cubic meters	58
Available water resource	Cubic meters	58
Timber		
Non-timber forest products production	Metric tons	38
Wood production	Metric tons	37
REGULATING SERVICES		
Global climate regulation		
Carbon exchange in the vegetation-soil-atmosphere (CEVSA)	Number	19
Regional and local climate regulation		
Humidity index	Number	21
Net primary productivity (NPP)	Number	45
Potential evapotranspiration ratio (PER)	Percent	32
Water Regulation		
Average total annual precipitation (TAP)	Millimeters	32
Natural disasters	Percent	57
River runoff	Cubic meters	46
Cultural Services		
None noted		

Ecosystem State Indicators Compiled from Portugal, Southern Africa, and Western China Sub-Global Assessments		
Indicator	**Data Unit**	**Page Number**
PORTUGAL ASSESSMENT		
PROVISIONING		
Crops		
Area in grain production	Hectares	53
Percentage of wildlife species that affect or are affected by agriculture	Percent	36
Percentage of soil with permanent soil cover	Percent	53
Capture Fisheries		
Fish landings	Metric tons	30
Aquaculture		
Benthic species	Number	47
Timber		
Adult tree density	Number/hectare	55
Percentage of wildlife species that affect or are affected by forests	Percent	33
Growth in forests for harvesting	Cubic meters/hectare/year	33
REGULATING SERVICES		
Water Regulation		
Mean rainfall going to run-off versus evapotranspiration	Millimeters	
Erosion Regulation		
Soil cover-permanent	Percent	53
Water Purification and Waste Treatment		
Nitrate concentration	Milligrams/liter	36
CULTURAL SERVICES		
Recreation and Ecotourism		
Animal species (fauna)	Number	25
Area affected by forest fires	Hectares	32
Average burnt area	Hectares/year	32
Plant species (flora)	Number	25
SOUTHERN AFRICA ASSESSMENT		
PROVISIONING SERVICES		
Crops		
Total area suitable for crops	Percent	44
Cropland yields	Kilograms/hectare	48
Livestock		
Livestock biomass	Large Stock units	
Freshwater		
Percentage of groundwater exploited	Percent	25
Potentially exploitable groundwater resource	Million cubic meters	24
CULTURAL SERVICES		
Ethical Values		
Percent of total land in natural state	Percent	81
WESTERN CHINA ASSESSMENT		
PROVISIONING SERVICES		
Crops		
Ecosystem productivity	Kilograms/square hectometer	39
Normalized difference vegetation index (NDVI)	Index ranging from -1 to 1	61
REGULATING SERVICES		
Regional and Local Climate Regulation		
Change in extent of ecosystems	Percent	34
Mean annual bio-temperature (MAB)	Degrees centigrade	28

Ecosystem State indicators compiled from Portugal, Southern Africa, and Western China Sub-Global Assessments, *cont.*

Indicator	Data Unit	Page Number
WESTERN CHINA ASSESSMENT (continued)		
Erosion Regulation		
Area affected by erosion	Square kilometers	57
Sloping farmland of 25 degrees or above	Square hectometer	40
Natural Hazard Regulation		
Vegetation coverage ratio	Percent	67
Water Purification and Waste Processing		
Percent of water below minimum quality standards	Percent	58
CULTURAL SERVICES		
Recreation and Ecotourism		
Biolife population	Percent	38
MULTIPLE SERVICES		
Land uses, by use	Hectares	44

NOTES

1. The MA Follow-up Advisory Group represents a consortium of institutions "established to facilitate a coordinated MA follow-up effort." (MA Follow-up Advisory Group, 2008)
2. For example, the indicator for global climate regulating services, carbon sequestration capacity, was extracted from the following text: "Agroforestry systems have an annual sequestration capacity of 0.2-0.3 megagrams of carbon per hectare per year" (MA, 2005).
3. for more information on these efforts, see the following websites: Biodiversity Indicators Partnership: http://dnntest.unep-wcmc.org/Indicators/tabid/59/language/en-US/Default.aspx'; The Economics of Ecosystems and Biodiversity: http://ec.europa.eu/environment/nature/biodiversity/economics/teeb_en.htm; State of the Nation's Ecosystems: http://www.heinzctr.org/ecosystems/.
4. The global MA did not assess four ecosystem services: erosion regulation, pest regulation, pollination, and spiritual and religious values. For this reason, it is not possible to characterize the state of indicators for these services.
5. See, for example, *RUBICODE International Workshop on Ecosystem Services and Drivers of Biodiversity Change. Background Report.* Available online at: http://www.rubicode.net/rubicode/RUBICODE_Workshop3_BackgroundReport.pdf

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