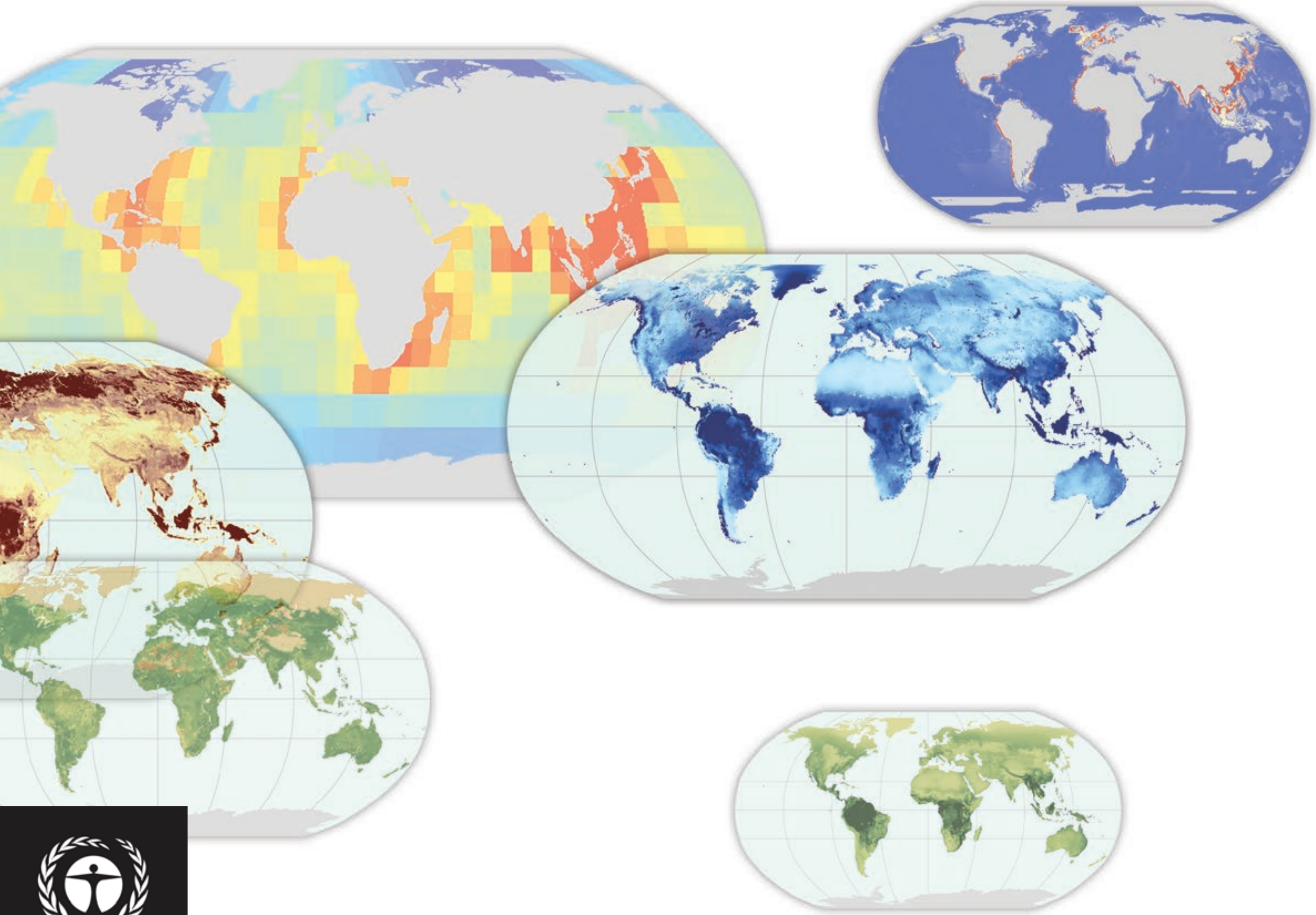
Towards a global map of natural capital: key ecosystem assets



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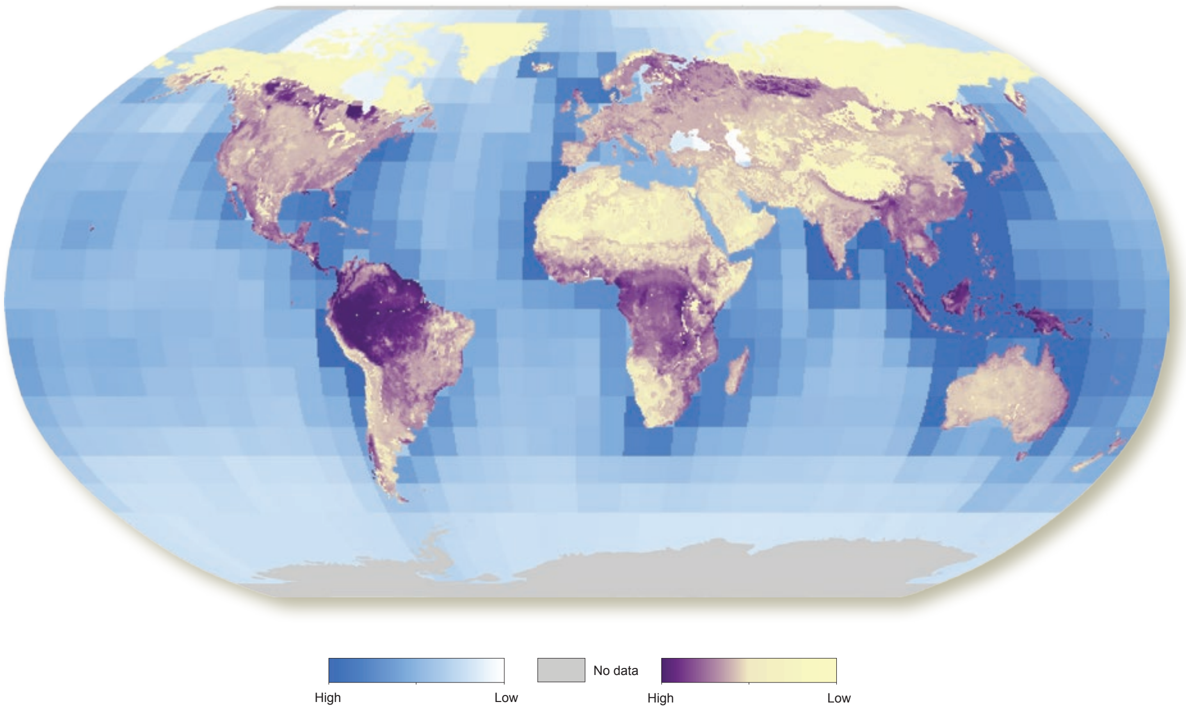
Summary



- Natural capital is fundamental to human well-being, underpinning the global economy.
- Natural capital comprises both ecosystem assets (such as fresh water) and natural resources (such as fossil fuel deposits). This report presents the first attempt to give an overview of the global distribution of ecosystem assets.
- Ecosystem assets have the capacity to generate a basket of ecosystem services, and this capacity can be understood as a function of the extent (quantity) and condition (quality) of the ecosystem.
- The report builds on a considerable body of work in the fields of natural capital accounting and the mapping of ecosystem services. In particular, it draws on the UN Statistics Division's System of Environmental-Economic Accounting (SEEA) and its Experimental Ecosystem Accounting approach, as well as the work by many other researchers.
- The composite map of ecosystem assets is produced by combining a number of existing global spatial datasets to produce a map for both terrestrial and marine realms. The individual datasets represent fresh water resources, soil quality for plant growth, terrestrial carbon, terrestrial and marine biodiversity, and marine fish stocks.
- The individual datasets used here represent a physical assessment of ecosystem assets. The challenges of providing a monetary valuation of those assets are discussed, but this valuation is not undertaken here.
- Marine ecosystem assets are concentrated in Southeast Asia and along coastlines (especially the west coasts of South America, Africa and Europe) while terrestrial ecosystem assets have concentrations in the equatorial regions and parts of Canada and Russia.

- Broken down by asset type, fresh water resources are unevenly distributed throughout the world, with striking quantities in Greenland, the west coast of North America, much of South America, the Congo basin, Madagascar, and large areas of South and Southeast Asia. Good soil quality for plant growth can be found on all continents. Global terrestrial organic carbon stocks are high in tropical and boreal forest regions, with stocks in the tropics being predominantly found in vegetation, and stocks in the boreal regions being predominantly in soils. There are extensive areas of largely intact biodiversity in the tropical rainforests in the proximity of the equator.
- Mapping ecosystem assets at a global level has inherent biases. For example, a relatively low value at a global level does not mean that a given area is not nationally or locally important for well-being or economic activity. In addition, the ecosystem assets mapped differ with regard to the scope of their beneficiaries. Fresh water resources, soil quality and marine fish stocks are significant for economic use in national and local contexts, while carbon and biodiversity values are likely to extend beyond a single country or region.
- This is an initial study which demonstrates that it is possible to map ecosystem assets at the global scale. There are some obvious gaps in our mapping, for example in ecosystem functions such as coastal protection and cultural/aesthetic values. These and other ecosystem assets should be included in future mapping of global ecosystem assets.
- Ecosystem assets represent only a part of natural capital. In order to produce a comprehensive global map of natural capital, the full array of ecosystem assets and natural resources need to be mapped.

Shoal of mackerel. ©Rich Carey, 2011. Used under license from Shutterstock.com

Stag. ©Godrick, 2011. Used under license from Shutterstock.com

- Further work could include:
  - Undertaking spatial analysis of the change in ecosystem asset distributions over time.
  - Investigating natural capital distribution at national and sub-national scales. This can inform decision-making by providing useful insights on the synergies and trade-offs between asset types.
  - Undertaking monetary valuations of ecosystem assets and exploring ways of representing these values spatially.

1. Introduction

The concept of natural capital, which has its theoretical origins in the environmental economics of the 1990s, has experienced increased interest following the publication of the Millennium Ecosystem Assessment and the development of the ecosystem services approach. In recent decades we have learned more about the ways in which nature provides vital life-support functions upon which we depend for our survival. The problem we face is that natural capital has been harvested or degraded at a rate that threatens to undermine both well-being and future economic growth (UNEP, 2007). Natural capital may be transformed to other types of capital, but even manufactured capital is formed from the resources found in nature.

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The growing recognition that the environment plays a fundamental role in determining global economic outputs and human well-being has led to a range of responses, one of which is the integration of the value of natural capital into policy and decision making. As a consequence, governments around the world are grappling with how to better measure the success of their economies. Work is being carried out by the World Bank, OECD, UN, EEA and others on developing methods to incorporate natural capital into national accounts.

There is a considerable body of work in the fields of natural capital accounting and the related area of mapping of ecosystem services. This pilot project builds on these foundations to develop the first global map of the ecosystem stocks of natural capital. The global map combines layers of key ecosystem assets into a composite map covering both terrestrial and marine ecosystems. More specifically, the underlying layers are fresh water resources, soil quality for plant growth, terrestrial organic carbon, terrestrial and marine biodiversity, and global fish catch (as a proxy for marine fish stocks).

Sections 2, 3 and 4 of this report set the context by defining natural capital and ecosystem assets; providing an overview of relevant policy drivers and activities of key actors; and giving a brief summary of approaches for physical and monetary assessment of natural capital and a discussion of the utility of mapping natural capital. Section 5 presents the results of the pilot study, comprising individual maps for key ecosystem assets and a composite map. Section 6 concludes with some reflections on the outcomes of the study and the next steps for developing the mapping of natural capital.

2. Defining natural capital and ecosystem assets

Classical economists of the 19th century such as Ricardo and Faustmann were already treating natural resources as capital in economic theory, while modern thinking begins with Hotelling's work on non-renewable resources (Fenichel & Abbott, 2014). The natural capital concept, as understood here, was popularised in the early 1990s and was born out of theoretical advances to bridge the gaps between economics and ecology (Voora & Venema, 2008). In the 'capital approach', the traditional definition of capital as manufactured factors of production, such as machinery and roads, is extended to include further capital types, like human, social and natural capital (Neumayer, 2003). A large body of work has applied the capital approach to sustainability to assess whether different types of capital are substitutable and whether critical natural capital (unsubstitutable by definition) exists (Atkinson & Pearce, 1995; Ekins, 2001; Costanza & Daly, 1992).

There are various definitions of natural capital, all of which describe natural capital as underlying human well-being. An early, influential definition by Daly (1994) describes natural capital as the "stock that yields a flow of natural services and tangible natural resources". Similarly, OECD (2007) defines natural capital as "the natural assets in their role of providing natural resource inputs and environmental services for economic production". A UNEP definition (2012) emphasizes specific components: "Natural capital includes land, minerals and fossil fuels, solar energy, water, living organisms, and the services provided by the interactions of all these elements in ecological systems". In the System of Environmental-Economic Accounting (SEEA) framework, natural capital is used to refer to all types of *environmental assets*, the naturally occurring living and non-living components of the Earth, constituting the biophysical environment (European Commission *et al.* 2013). SEEA Experimental Ecosystem Accounting provides a definition for a subset of natural capital by defining *ecosystem*[1] *assets* "as spatial areas containing a combination of biotic and abiotic components and other characteristics that function together" (European Commission *et al.* 2013).

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[1] The most widely used definition of an ecosystem is that adopted by the Convention on Biological Diversity (CBD) that defines ecosystem as a "dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit" (CBD, 1992, Article 2).

Natural Capital

Environmental Assets:

Ecosystem Assets

- Biodiversity - the stock of plants (including trees) & animals (including fish), fungi & bacteria (e.g. for food, fuels, fibre & medicine, genetic resources for developing new crops or medicines, or as a tourism asset etc.)
- Soils for producing crops (note that the crops themselves, i.e. the commercial seeds & livestock, are better considered a produced asset in this instance)
- Surface fresh waters (e.g. for drinking water, hydropower, watering crops, washing etc.)
- The store of organic carbon (held in terrestrial plants & soils, as well as in marine organisms)
- Landscapes (in terms of aesthetic values for enjoyment, including tourism use)

Natural Resources

- The recoverable stock of fossil fuels (i.e. coal, oil & gas)
- The recoverable stock of minerals (including metals, uranium etc)
- Aggregates (including sand)
- Fossil water stores (i.e. deep underground aquifers replenished over centuries)
- Deep ocean stores of carbon
- Land (i.e. space for activity to take place)
- Ozone layer (protective value)
- Solar energy (i.e. as a source of energy, including plant growth)

Figure 1: Natural capital: examples of ecosystem assets and natural resources

As illustrated in Figure 1, our definition of natural capital is equivalent to SEEA's definition of environmental assets. That is to say, natural capital is made up of ecosystem assets and natural resources. Used in this way, natural capital includes natural resources such as minerals and energy, and has a broader scope than the ecosystem assets that are the focus of this report.

The distinction between stocks and flows, i.e. between ecosystem assets and ecosystem services, is crucial to the approach at hand. Figure 2 provides a visualization of the role of assets relative to services: ecosystem assets are the stocks that enable the flow of ecosystem services. Services in turn yield ecosystem benefits, often with the help of other capital inputs, such as human, manufactured and social capital.

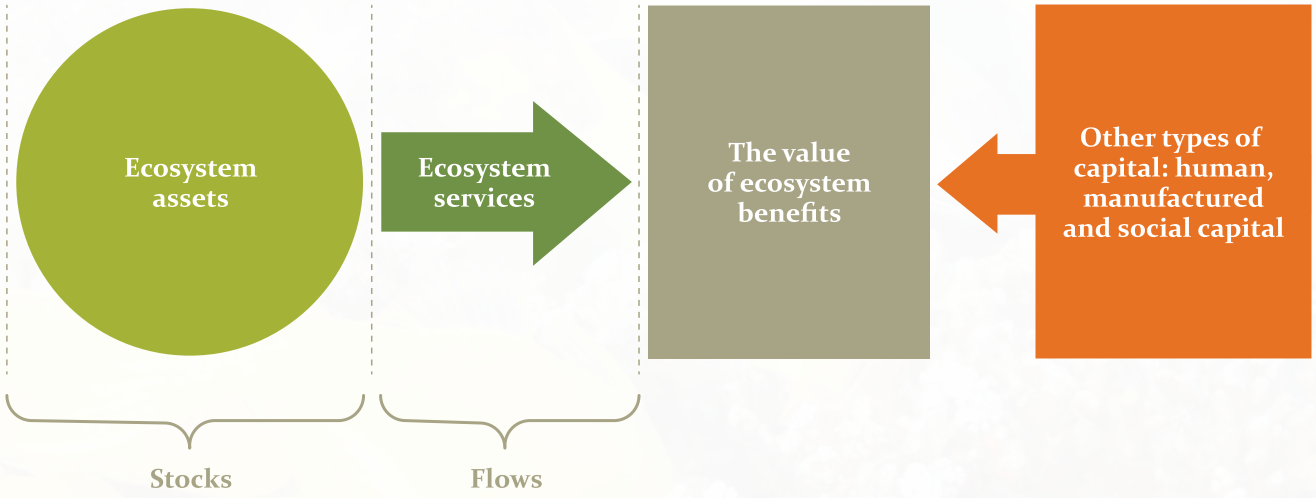


Figure 2: Ecosystem assets and ecosystem services: stocks and flows

Yellow saddle goatfish. ©Anna Segeren, 2011. Used under license from Shutterstock.com

3. Policy drivers and key players

The resurgence of interest in natural capital is a result of the evolution of ecosystems thinking following publication of the Millennium Ecosystem Assessment (2005) and development under the Convention on Biological Diversity (CBD) of the “ecosystem approach” to integrated management of land, water and living resources.

The Millennium Ecosystem Assessment (2005) was an international synthesis by over a thousand scientists, initiated in 2001, analysing the state of the Earth’s ecosystems and the consequences of ecosystem change for human well-being. This was followed shortly by the Potsdam Initiative, and the inception of "The Economics of Ecosystems and Biodiversity" (TEEB), in March 2007, when environment ministers from the G8+5 countries agreed to commission an analysis of “the global economic benefit of biological diversity and the failure to take protective measures versus the costs of effective conservation”. The four initial TEEB study reports were published in 2010, calling for governments to include natural capital values in national accounts. This echoed the findings of the Stiglitz report (on Measuring Economic Performance and Social Progress) the previous year, which recommended a broader definition of wealth, to include natural and human capital.

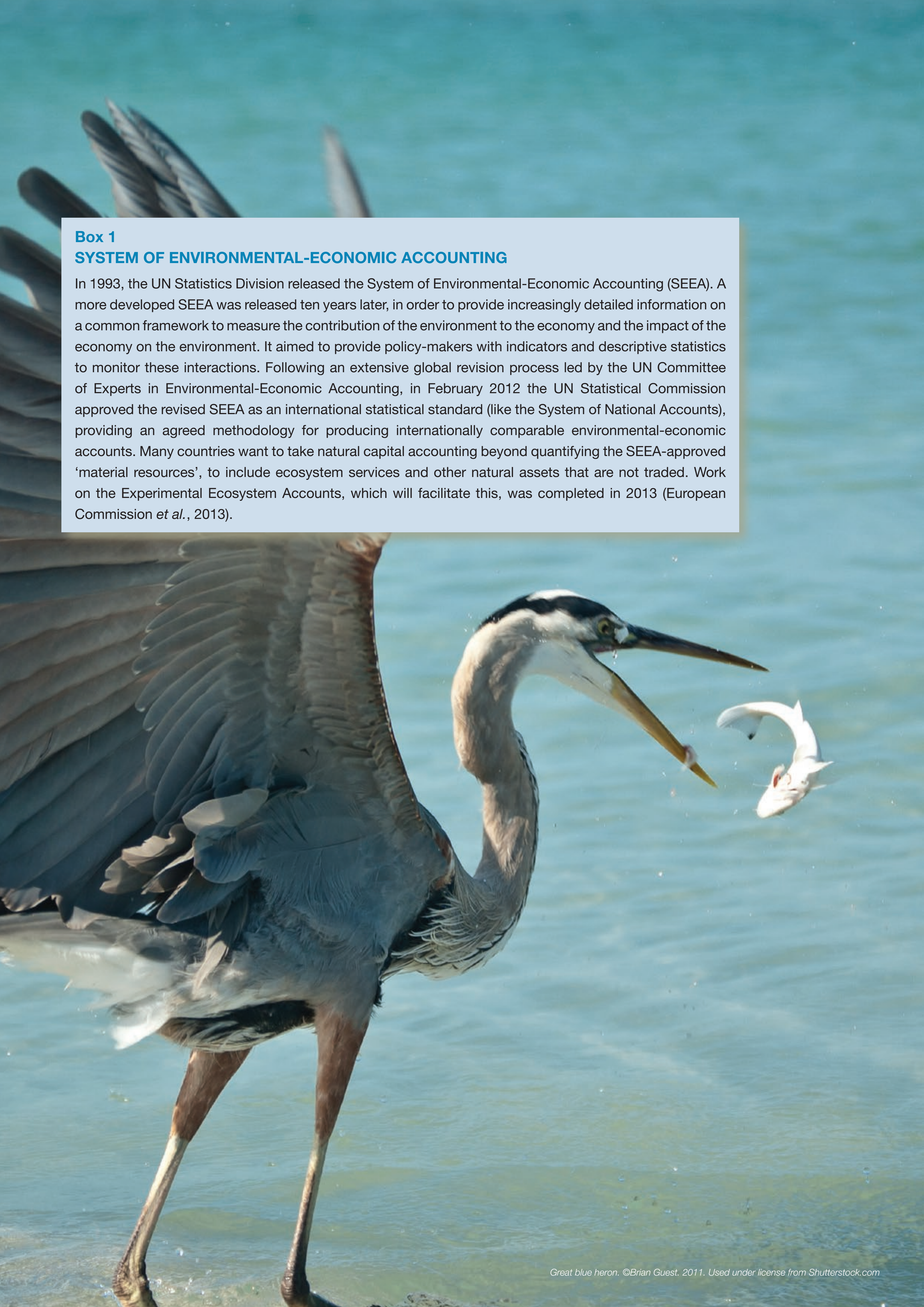
In 2010, at the CBD’s tenth Conference of the Parties (in Nagoya, Japan), the 193 member states agreed to a new Strategic Plan for Biodiversity 2011–2020. The Plan’s Aichi Biodiversity Targets include the need to incorporate the values of biodiversity into national accounts. Meanwhile at the same meeting, the World Bank launched its Wealth Accounting and the Valuation of Ecosystem Services (WAVES) project, which helps partner countries implement natural capital accounting. Also in 2010, the European Environment Agency issued “An Experimental Framework for Ecosystem Capital Accounting in Europe”, setting out a methodology for ecosystem capital accounts.

This momentum was maintained and in 2012 the UN Statistical Commission approved the revised SEEA as an international statistical standard. In June that year the United Nations Conference on Sustainable Development (UNCSD), “Rio+20 Earth Summit”, saw a great deal of support for natural capital accounting and the ecosystem approach. The Natural Capital Declaration was launched by UNEP Finance Initiative, and by the end of the year 41 financial institutions had become signatories to work out how natural capital accounting might be carried out. The UN Inclusive Wealth Report (published by UNU-IHDP and UNEP) featured a framework to quantify broad measures of wealth based on estimates of their manufactured, human and natural capital, and used an index to show changes in inclusive wealth for a number of countries from 1990 to 2008. A report by WAVES provided a synthesis of natural capital accounting, including which countries were already adopting it, and over 60 countries supported a communiqué that called for the implementation of natural capital accounting in countries’ national accounts. The month before, ten African heads of states had held a summit resulting in the Gaborone Declaration for Sustainability in Africa (GDSA), the overall objective of which is “To ensure that the contributions of natural capital to sustainable economic growth, maintenance and improvement of social capital and human well-being are quantified and integrated into development and business practice”. Over the last two years, various countries have made progress in developing and implementing natural capital accounts.

Together these developments relating to the policy framework, accounting methodologies, evidence base and capacity building provide a strong foundation for future development and implementation of natural capital accounting and its integration into national accounts.

Box 1
SYSTEM OF ENVIRONMENTAL-ECONOMIC ACCOUNTING

In 1993, the UN Statistics Division released the System of Environmental-Economic Accounting (SEEA). A more developed SEEA was released ten years later, in order to provide increasingly detailed information on a common framework to measure the contribution of the environment to the economy and the impact of the economy on the environment. It aimed to provide policy-makers with indicators and descriptive statistics to monitor these interactions. Following an extensive global revision process led by the UN Committee of Experts in Environmental-Economic Accounting, in February 2012 the UN Statistical Commission approved the revised SEEA as an international statistical standard (like the System of National Accounts), providing an agreed methodology for producing internationally comparable environmental-economic accounts. Many countries want to take natural capital accounting beyond quantifying the SEEA-approved ‘material resources’, to include ecosystem services and other natural assets that are not traded. Work on the Experimental Ecosystem Accounts, which will facilitate this, was completed in 2013 (European Commission *et al.*, 2013).



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4. Assessing natural capital

4.1. *Physical assessment*

The biophysical quantification of natural capital is an essential step towards safeguarding it. The UN's System of Environmental-Economic Accounting (SEEA) provides an internationally agreed approach to account for material natural resources, and further work (SEEA Experimental Ecosystem Accounting) extends this to include ecosystem assets and services that are not traded. The SEEA Experimental Ecosystem Accounting framework recommends accounting for ecosystem assets in physical terms by considering measures of ecosystem extent and condition (i.e. the stock), and the expected ecosystem service flows. The SEEA (and most other natural capital accounting systems) physical accounts consist of the following key elements:

- Flow accounts: Physical flows of materials and energy within the economy and between the economy and the environment.
- Asset accounts: Stocks of environmental assets, and changes in these stocks (which include the quantity and quality of natural resources such as land, water, fish, soils, forests, minerals and energy, and changes in these stocks within a given time period).

In addition, the SEEA also provides guidance on the compilation of monetary accounts and explains in a clear fashion the principles of recording and presenting accounts and tables for both stocks (assets) and flows.

The physical flow and asset accounts provide the basis for the development of more robust monetary accounts. To some degree, environmental assets have been assessed by governments as part of planning the management of these resources (e.g. land use and water resource planning, fisheries management, timber felling licenses, as well as oil and gas development). However, in general this assessment has focused on environmental assets which are directly used in productive activities, rather than ecosystem assets. In order to assess ecosystem assets, an understanding of the ecosystem services they deliver is required. According to the SEEA Experimental Ecosystem Accounting framework, the capacity of an ecosystem asset to generate a basket of ecosystem services can be understood as a function of the extent (quantity) and condition (quality) of that ecosystem (ecosystem condition can be decomposed into various characteristics). The SEEA Experimental Ecosystem Accounting document recommends selecting particular characteristics of ecosystem condition, where the data can often come from already established indicators, as the basis for developing accounts of ecosystem condition. This provides the opportunity for indicator-based approaches to input into the development of ecosystem accounts; three examples are presented below.

The Norwegian Nature Index gives an overview of the state of biodiversity in Norway's major ecosystems. The first edition of the Nature Index was published in 2010, and values were calculated for 1990, 2000 and 2010. It uses more than 300 indicators and measures deviation from a reference state between one (which is intended to represent ecological sustainability) and zero (very poor state) (NINA, 2014). How the results from the Nature Index can be applied within the SEEA Experimental Ecosystem Accounting framework is being considered (Certain *et al.*, 2013). The results show the state of and trends in biodiversity for the following major ecosystems: forest, mires and wetlands, open lowland, fresh water, coastal waters and the open sea. The indicators are weighted, so that indicators that represent many species count more than the others (NINA, 2014). The indicators are based on monitoring data or assessments by experts (Nybø *et al.*, Undated).

The Natural Capital Index (NCI) Framework, developed by the Netherlands Environmental Assessment Agency (PBL), was designed in order to answer policy questions on the state of biodiversity and pressures on it (PBL, 2012). The NCI Framework can be tailored to the specific scale required and available data. It has two main components: habitat size, or 'ecosystem quantity', and species richness, or 'ecosystem quality' (ten Brink, 2007). Quantity reduction is often estimated by measuring conversion of the natural environment to agriculture or urban development, and quality reduction by measuring impacts on biodiversity, e.g. from pollution and over-exploitation. The base is the natural or pre-industrial state.

The NCI approach was further developed in Scotland (UK) by looking at wider measures of ecosystem quality (beyond biodiversity alone) and by using an explicit weighting system intended to reflect value. The Natural Capital Asset (NCA) index attempts to measure annual changes in Scotland's natural capital based on an evaluation of ecosystem service capacity (SNH, 2012). A number of ecosystems (broad habitats) are identified. Change, compared to the base year of 2000 (though with projection back to 1950), is assessed by measuring indicators of quantity (area) and quality (the capacity to deliver a range of ecosystem services). Although 100 indicators are used, the lack of relevant data is highlighted as an issue, with some measures of flows being used as proxies for stock (SNH, 2011). The weighting adopted for aggregating the indictors and ecosystems is also a critical issue, although subsequent evaluation has shown the results to be robust to plausible weighting variations (Albon *et al.*, 2014). The NCA index was primarily developed to help inform decisions on the degree to which economic development in Scotland is being managed sustainably, and to be easily communicated (Blaney & Fairley, 2012). The index focuses on ecosystem assets and excludes natural resources (such as fossil fuels, minerals, etc).

The OECD has also proposed an index of natural resources (van de Ven, 2012), which would focus on the environmental assets ignored in the approaches outlined above. It takes as its starting point the set of natural resources as defined in the SEEA, and so there is some overlap with the SEEA Experimental Ecosystem Accounting approach. Two examples are explored for Australia (sub-soil assets of mineral and energy resources) and Canada (mineral and energy resources as well as timber resources). It is a composite index, measuring the weighted average of net change in physical stocks, with weights equal to each asset's share in the total value of assets. It has the potential to be combined with the other indices identified above, in order to produce a comprehensive assessment of environmental assets, although care would need to be taken to avoid double-counting if the full range of SEEA defined natural resources were included.

As mentioned previously, the SEEA Experimental Ecosystem Accounting framework not only accounts for ecosystem assets in physical terms by considering measures of ecosystem extent and condition, but also expected ecosystem service flows. Work is currently underway to provide guidance on the fast-track implementation of the SEEA Experimental Ecosystem Accounting, including physical flow accounts. A small number of national studies have already been conducted that assess recent ecosystem service flows (e.g. UK NEA), and these might form the basis for developing physical flow accounts.

4.2. Monetary assessment

In order for natural capital information to be fully incorporated into the decision-making process, it is often thought necessary to attach monetary values to ecosystem assets and services[2]. There are two related but different valuation concepts (European Commission *et al.* 2013), and the motivation for the valuation determines which is appropriate. The first, welfare economic values, estimates the overall costs and benefits associated with changes in assets and the services they provide. The second, exchange values, estimates ecosystem service and asset values as if a market for them had existed (European Commission *et al.* 2013). The former could be said to measure overall value, whilst the latter approach measures price, and the two may not always align. However, where there is interest in including values of ecosystem assets within national accounts, then a consistent valuation basis is required for all entries (i.e. prices, as used in the existing accounts).

For accounting purposes, the ideal source for asset prices are values observed in well-functioning markets. For many environmental assets, there are no relevant market transactions. Therefore, the discounted value of future returns (Net Present Value or NPV) is used. It projects future returns from the use of the asset (i.e. the value of flows), which links stocks with flows. The SEEA Central Framework discusses this approach in relation to mineral and energy resources, timber resources and aquatic resources (European Commission *et al.* 2013). The calculation of NPV-based estimates of ecosystem assets raises various challenges (European Commission *et al.* 2013):

i. The need to make assumptions as to the composition of future ecosystem services flows.

ii. It is also necessary to formulate an asset life – i.e. the expected period of time over which the ecosystem services are to be delivered. Given the potential for ecosystems to regenerate, implicit in determining an asset life is some view on the extent to which the delivery of the current set of ecosystem services is sustainable.

iii. Understanding dependencies between ecosystem services and the underlying assets, and any anticipated changes to these dependencies in future periods, remains a challenge.

iv. The derivation of NPV estimates requires the selection of an appropriate discount rate.

Using an adapted UN SEEA Framework, the Australian Bureau of Statistics currently includes on the National Balance Sheet experimental values for natural capital components such as subsoil assets, timber in forests, fish and land. These sit alongside the valuations for financial and produced assets (e.g. buildings and machinery). The Bureau is investigating the valuation of other components of natural capital (i.e. ecosystem assets such as water, carbon and biodiversity).

However, in general, natural capital valuation has focused on the flows of ecosystem services, with less attention granted to the ecosystem structures and functions of underlying stocks of ecosystems (Potschin & Haines-Young, 2011). In a controversial study on the value of the world's ecosystem services (National Research Council, 2004), Costanza *et al.* (1997) used localized, context-specific valuation studies to estimate this value to be approximately $33 trillion per year, nearly double the global gross national product of $18 trillion. An updated study (Costanza *et al.* 2014) increased this estimate to US$125 trillion/year in 2011 (with the estimated loss of ecosystem services from 1997 to 2011 due to land use change being valued at $20.2 trillion/yr, using the updated values).

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[2] The increasing prevalence of natural capital and ecosystem services thinking has resulted in the increase in assessment methodologies and tools available (Knight, in prep.). Tools such as InVEST, Co$ting Nature, ARIES and MIMES aim to improve the consideration of ecosystem services in decision-making.

Frameworks for ecosystem service valuation have been suggested as a basis for accounting the value of ecosystem assets and services. Several similar valuation frameworks have been proposed by:

- The US National Research Council;
- The Natural Capital Project;
- The US Environmental Protection Agency Science Advisory Board;
- The French Council for Strategic Analysis;
- The Economics of Ecosystems and Biodiversity (TEEB) initiative;
- The UK National Ecosystem Assessment.

These frameworks define ecosystem services as those aspects of ecosystems used to support human well-being, with the ecosystem service being the link between ecosystems and the benefits to humans (Fisher *et al.*, 2009). As such, valuations are attached to the benefits arising from the flow from ecosystem assets rather than to the stock of ecosystems. By separating the ecosystem functions and the services they generate, they aim to eliminate double-counting in economic valuations of ecosystem assets.

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4.3. Mapping natural capital

4.3.1. Why map natural capital?

Mapping enables the illustration of the spatial dimension of natural capital at a finer resolution than seen in adjusted national accounts (Eade & Moran, 1996). The results may be used to assess sustainability and the relationship between natural capital distribution and human welfare. Mapping natural capital may be particularly useful for land-use planning in national and sub-national contexts, i.e. for spatially explicit prioritization and problem identification, and can be used to examine synergies and trade-offs between different ecosystem assets and services.

Mapping is also relevant for national accounting purposes. The merits of a spatial approach to national accounting have been recognised by various actors. In addition to the SEEA framework, the SEEA - Ecosystem Natural Capital Accounts “Quick Start Package" (in preparation by the CBD) advocates a spatially explicit approach to natural capital accounting. WAVES guidance on designing pilot studies for ecosystem accounting also describes steps for data collection for defined basic spatial units, to be aggregated to land-cover/ecosystem functional units (LCEU) (Ahlroth, 2014).

Furthermore, maps can enable the examination of the effects of land-use change on the spatial distribution of natural capital and the provision of ecosystem services. For example, the Mapping and Assessment of Ecosystems and their Services in Europe (MAES) initiative under the EU Biodiversity Strategy to 2020 provides a framework for EU member states to conduct biophysical mapping to assess the state of ecosystems and their services in their national territory. It is envisioned that this work will contribute to meeting the target on the assessment of the economic value of these ecosystems and promote the integration of these values into accounting systems by 2020.

Much of the existing work on mapping natural capital has involved the mapping of ecosystem services. Knight (in prep.) notes the extensive growth in academic research outputs on ecosystem service mapping, as well as in frameworks, tools and implementation, and distinguishes between the different aspects of ecosystem services that can be mapped, including:

- Landscape structure and stock (natural capital);
- Landscape functions (ecosystem service supply or provision);
- Hotspots of landscape functions;
- Flow/consumption and the movement across space;
- Beneficiaries and losers;
- Value (economic, social);
- Contribution to well-being;
- Alternative future scenarios;
- Past situations.

Global-scale studies have mapped some ecosystem services and ecosystem assets (as understood in this report). For example, Naidoo *et al.* (2008) used available global data to map proxies for four ecosystem services at a global scale, and assessed the extent to which this captured all ecosystem services. Larsen *et al.* (2011) conducted spatially explicit trade-off analyses for the selection of priority areas for biodiversity and ecosystem services conservation, and found complementary results, particularly for biodiversity and fresh water. Focusing on terrestrial biodiversity and carbon storage, Strassburg *et al.* (2010) mapped the potential synergies between carbon and biodiversity-oriented conservation.

4.3.2. Challenges in mapping natural capital

Many challenges remain in the mapping of natural capital. On the global scale, data availability and limitations are the main constraint to mapping. While satellite remote sensing can provide globally consistent data, there are a number of limitations to such datasets. For instance, some areas around the world experience more or less permanent cloud cover that obscures the optical sensor (e.g. montane forests). Furthermore, to obtain useful data products from raw sensor data, it is necessary to carry out further processing, classification or modelling, and choices in this data processing influence the results. For example, the GLC2000, MODIS and GlobCover global land products all provide different cover estimates for croplands (Secades *et al.*, 2014).

Not all natural capital stocks can be assessed by remote sensing. Satellite imagery can only go so far in describing below-ground stocks or soil properties, while marine fish stocks and biodiversity can only be measured by proxy parameters. In addition, to get reliable estimates from remote sensing, it is necessary to carry out validation using in-situ measured data which is often very limited. Aerial image data, which typically has a higher resolution than satellite remote sensing data but can be harder to interpret automatically, may provide a means to 'ground truth' remote-sensed data (Ahlroth, 2014).

The interconnectedness of stocks and flows of ecosystem assets poses a further challenge, first because mapping needs to distinguish between the two to meaningfully represent them. Second, the same location may host different types of asset which cannot be simultaneously exploited. For example, a good quality soil for crop production can also support a mature forest with high carbon value. In this case only one asset can be used at any one time (i.e. the forest would need to be cleared for crop production).

5. Towards a global map of natural capital

5.1. Methodology

The SEEA Experimental Ecosystem Accounting approach provided a conceptual starting point for the global map of key ecosystem assets presented here. We adopted a disaggregated approach to the mapping of ecosystem assets, in which key assets were selected and individually mapped. The SEEA framework's land, water, biodiversity, forest, carbon and soil accounts informed selection of assets. We also aimed to include roughly equivalent assets for the terrestrial and the marine realm. Identification of assets and the equivalence between them were, however, constrained by data availability. The key assets identified are global fresh water resources, soil quality for plant growth, terrestrial organic carbon, terrestrial biodiversity, marine biodiversity and marine fish stocks. Following identification of key assets, the best available global datasets were used to map their distribution. Values in each individual ecosystem asset map were normalised (rescaled linearly to values between 0 and 1). The layers were then combined into a composite global map, giving equal weight to each underlying layer. The map thus comprises two composite indices, one summarizing two marine assets, and one summarising four terrestrial assets.

The SEEA Experimental Ecosystem Accounting framework is concerned with assessing changes in ecosystem assets and the services they provide. Our analysis is focused on the stocks of physical ecosystem assets and excludes consideration of services (flows). Due to time and data limitations, the study scope did not include examination of changes over time in the assets chosen. Moreover, many of the datasets used are based on long-term means that do not allow the maps to be dated to a precise point in time. Overall, the composite map can be described as a best estimate of the global distribution of key ecosystem assets at the beginning of this millennium.

Surveying mangroves. ©Tappasan Phurisamrit, 2011. Used under license from Shutterstock.com

Map 1: Global fresh water resources

Fresh water is a key ecosystem asset because we depend upon it to keep ourselves, our crops and our livestock alive and healthy. Its myriad other domestic and industrial uses range from cleaning to energy generation. Natural vegetation such as forest plays a complex role in the water cycle, regulating the flow of water both on land (by absorbing water and slowing run-off) and in the local climate system (through transpiration), and reducing pollutants in the water (Calder *et al.*, 2007).

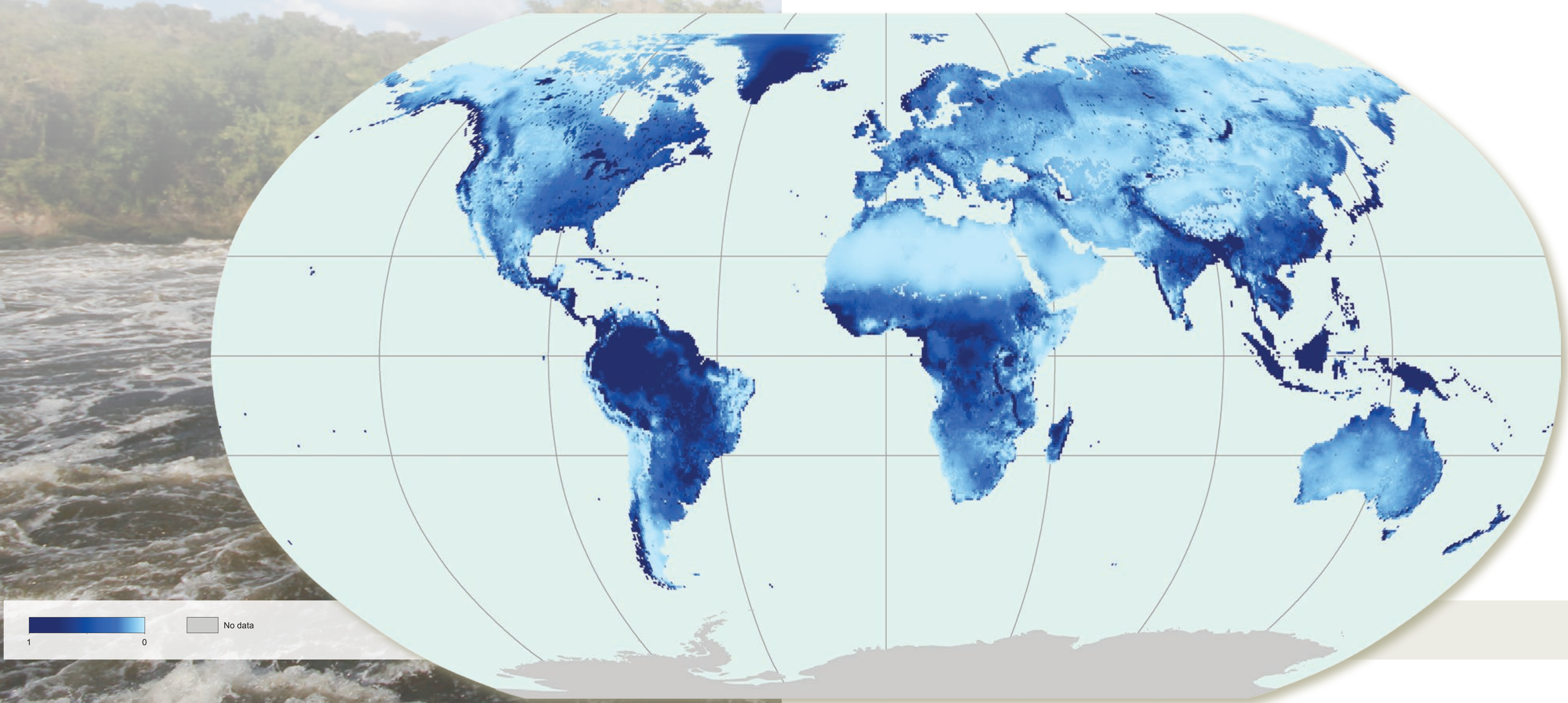
The map of global fresh water resources includes renewable water resources that are replenished annually through the global hydrological cycle, as well as fresh water stored in large lakes, for which renewal takes years to decades. The map combines a long-term mean annual water balance with data on water stored in large lakes. Annual water balance is estimated as the difference between precipitation and evapotranspiration, measured over 50 and 10 years respectively (Hijmans *et al.*, 2005, Mu *et al.*, 2011). Lake volumes were estimated using global data on the depth of over 13 000 large fresh water lakes (Kourzenova *et al.*, 2012).

Fresh water resources vital to human well-being are distributed throughout the world, with striking quantities in Greenland (mainly snow), the west coast of North America, much of South America, the Congo basin, Madagascar, and large areas of South and Southeast Asia.

The map does not directly address the flow of fresh water through streams and rivers – water that flows across the land is not subtracted from the water balance, so is shown in the location in which the water fell. Similarly, underground aquifers are not shown, and include 'fossil water' which is regarded in this study as a natural resource that takes thousands of years to replenish.

Higher resolution, remotely-sensed precipitation data will soon be available based on new satellite products. This new data could be used to improve the accuracy and scale of subsequent versions of this map.

Kolsa lake, Kazakhstan, ©Pikoso.kz, 2011. Used under license from Shutterstock.com



Murchison Falls. ©Julia Hug, 2013.

Map 2: Terrestrial organic carbon in soil and vegetation

The sizable carbon stocks in terrestrial vegetation are a key ecosystem asset because they are vulnerable o land-use change. By retaining these carbon stores, terrestrial ecosystems help to regulate the climate. Climate change mitigation initiatives include efforts to reduce carbon stock losses from deforestation and forest degradation, and to sequester further carbon in natural and agricultural ecosystems.

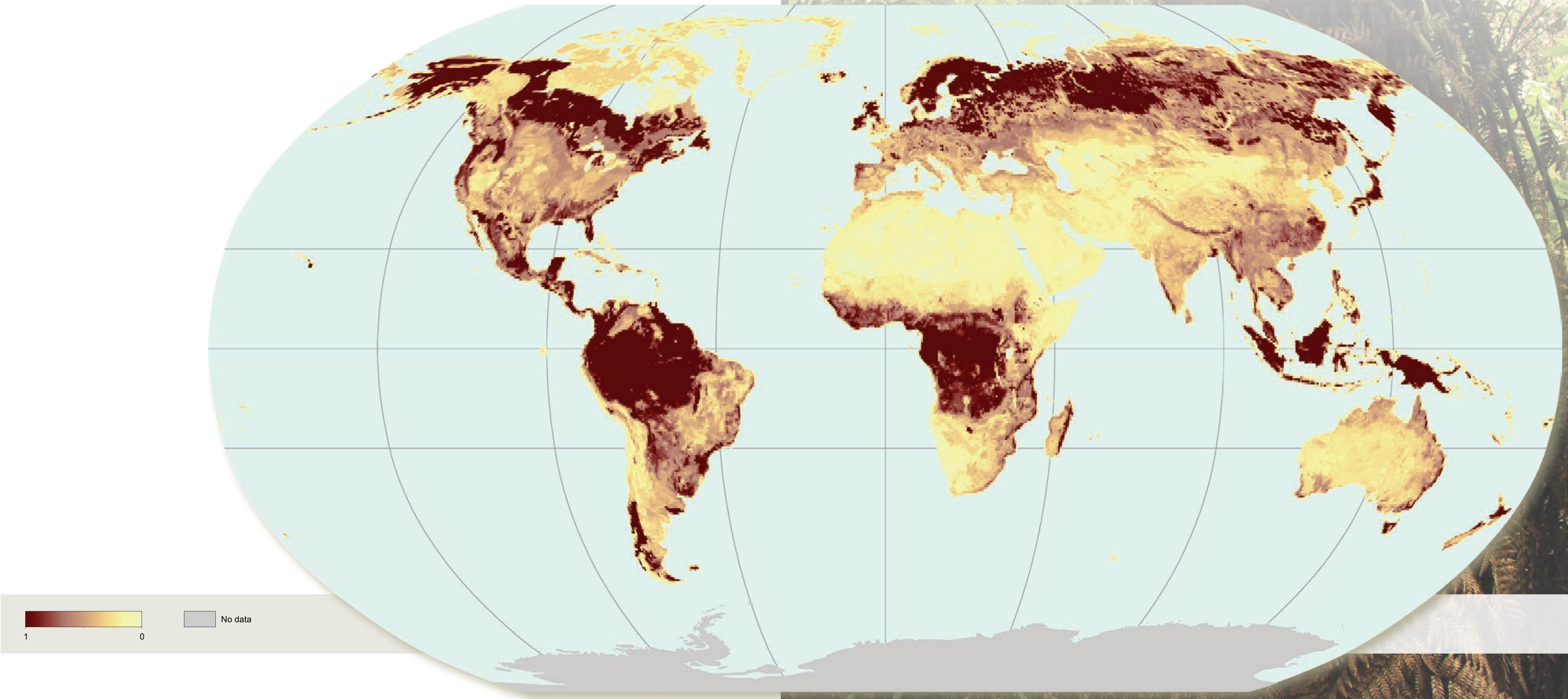
The map of terrestrial carbon is based on the combination of two global datasets, one covering biomass carbon for the year 2000 (Ruesch and Gibbs, 2008), and one covering organic carbon in soil to 1 metre depth (Hiederer and Köchy, 2011). Overall, terrestrial vegetation holds from 450 to 650 PgC (IPCC 2013).

The highest stocks of carbon are visible in tropical and boreal forest regions, with stocks in the tropics being predominantly found in vegetation, and stocks in the boreal regions being predominantly in soils. In additional areas in both hemispheres, soil organic carbon is the more relevant factor (Scharlemann *et al.* 2014).

Whilst both input maps could be improved upon, improvements seem most viable in the short term for the biomass carbon layer, as there is substantial recent and ongoing work on estimating carbon stocks in the vegetation of different regions and ecosystems (e.g. Hutchinson *et al.* 2014).

An equivalent map of marine carbon stocks has not been developed for this report. Such a map would include both oceanic and coastal ecosystems. The marine biota (predominantly phytoplankton and other microorganisms) represent a small organic carbon pool (~3 PgC, with some components mapped in Buitenhuis *et al.* 2013), but significant concentrations of carbon stocks are present in coastal ecosystems. Of these, an above ground biomass map exists for mangroves (Hutchinson *et al.*, 2014). Most of the mangrove area is covered by the terrestrial carbon map, but as for other ecosystems, there is scope to update the values to represent the results of more recent or detailed studies. Global maps of stocks in coral reefs, seagrasses and salt marshes have yet to be developed, and this would give a clearer picture of role of coastal ecosystems in climate change mitigation.

Mangrove trees. ©ckchiu, 2011. Used under license from Shutterstock.com



Forest. ©STILLFX, 2011. Used under license from Shutterstock.com

Map 3: Soil quality for plant growth using maize as a reference crop

Maize. ©US Department for Agriculture, 2013.

Together with water and sunlight, soil provides the basis for food and biomass production, whether in natural or cultivated vegetation. While soil provides multiple other functions, from regulating water quality to storing carbon[3], here we focus on productivity.

Whereas crop production currently uses 11 percent of the world's land surface (FAO, 2011), global population growth, increasing per-capita incomes and increasing consumption of meat are driving increases in food demand and pressure to expand agricultural land (Wirsenius *et al.*, 2010).

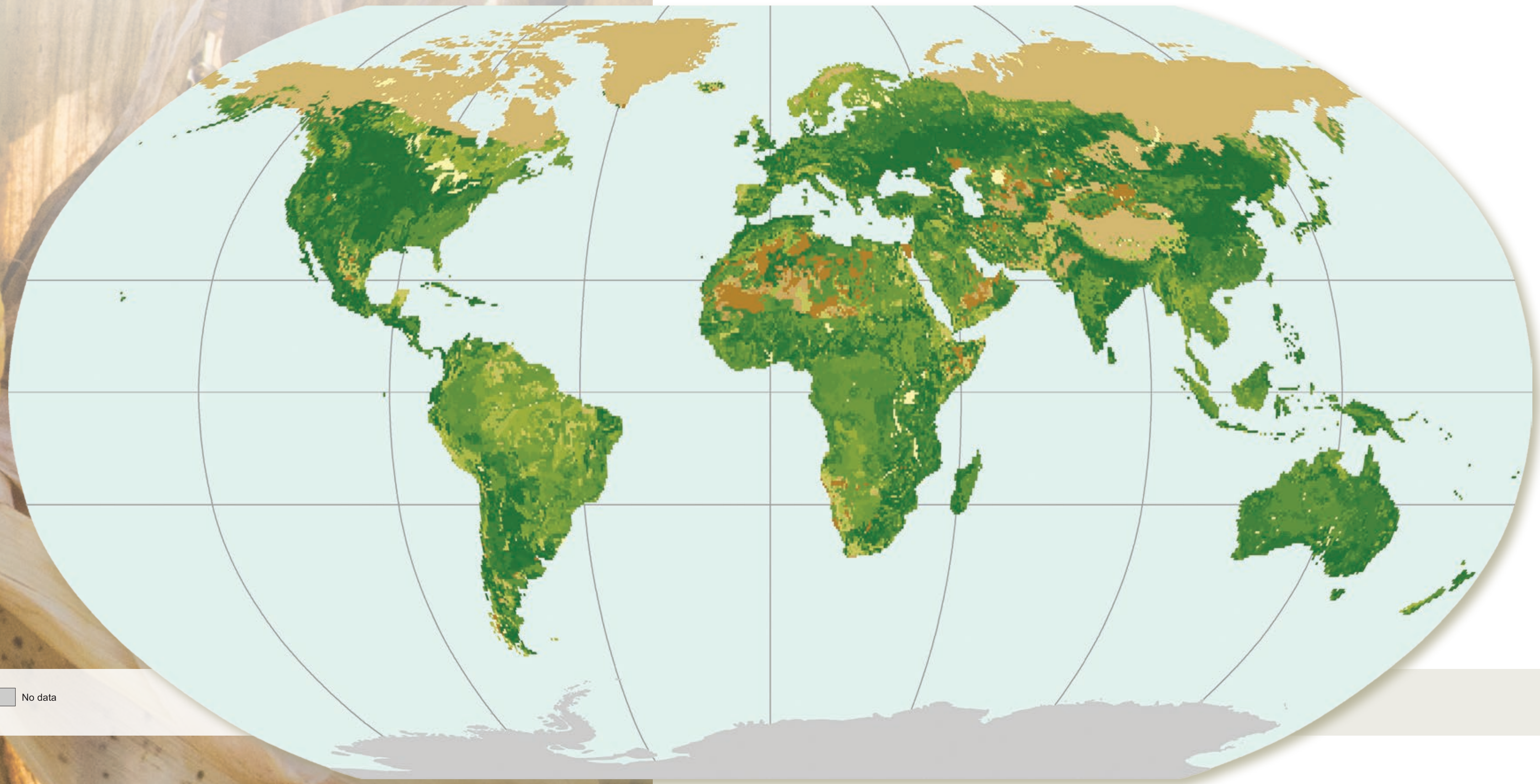
Soil quality for plant growth is determined by its chemical, physical and biological conditions. Agricultural productivity is also affected by the climate, which is not included in this layer.

The map of soil quality is based on seven different soil indicators that are important for crop production (Fischer *et al.*, 2008), which are: nutrient availability, nutrient retention capacity, rooting conditions, oxygen availability to roots, excess salts, toxicities and workability. The global map layers of these key soil qualities are derived from the Harmonised World Soil Database (HWSD v1.1) (FAO/IIASA/ISRIC/ISSCAS/JRC, 2009), which is the most comprehensive global database of soils available, containing more than 16,000 different soil mapping units and combining existing regional and national updates of soil information worldwide.

The map illustrates that soil quality is highest in mid-western USA, Eastern Europe, Russia and north East China, and very low in the Arctic regions due to permafrost. Global warming could potentially lead to these soils becoming available for production.

The key soil qualities that contribute to the map are related to specific crop requirements and tolerances. Here, maize (Zea mays) is selected as a reference crop due to its global importance for food security and its wide distribution. The individual soil indicators were combined into one layer, giving equal weighting to each indicator. While soil quality for maize production is a good indicator for soil qualities at the global scale, other crops or natural vegetation can have different requirements and tolerances which can lead to slightly different spatial distributions. Consideration of reference crops beyond maize would thus constitute an improvement to this layer.

Soil with maize plants. ©Ryo Chijiwa, 2010.



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[3] Soil organic carbon is included in the terrestrial carbon layer presented above.

Map 4: Species richness adjusted by intactness

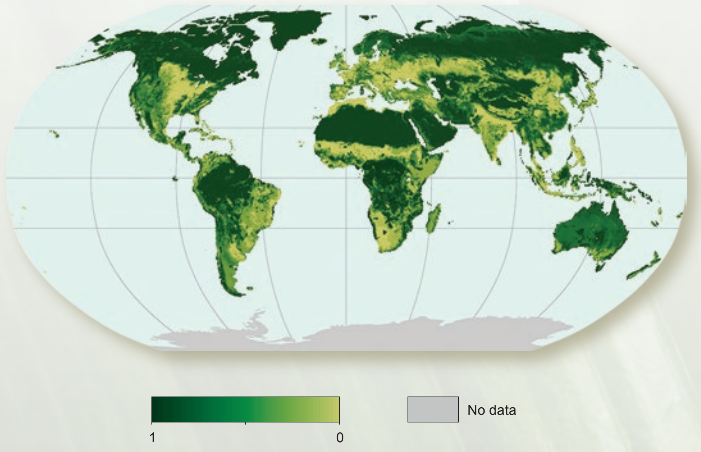
Biodiversity, or the "variability among living organisms from all sources including, (…) terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part" (CBD, 1992), plays a crucial role in ecosystem functioning. The Convention on Biological Diversity notes that at least 40 per cent of the world's economy and 80 per cent of the needs of the poor are derived from biological resources. The richer the diversity of life, the greater the opportunity for medical discoveries, economic development, and adaptive responses to new challenges such as climate change. Even modest proportions of biodiversity loss (20-40% of species) have been shown to substantially impair ecosystem function (Hooper *et al.*, 2012).

The terrestrial biodiversity map presented here focuses on species richness. It was generated by scaling a present-day species richness layer based on broad areas of occurrence (IUCN, 2013) by the fraction of intactness of terrestrial species richness estimated by the PREDICTS project (Newbold *et al.*, in prep.) in each grid cell, to yield an approximation to the remaining species richness. The intactness layer builds on the Natural Capital Index approach (section 4.1), by modelling the richness of species compared to the natural state, based on the impacts of land-use change. The combined layer shows the presence of great, largely intact biodiversity in the tropical rainforests in the proximity of the equator.

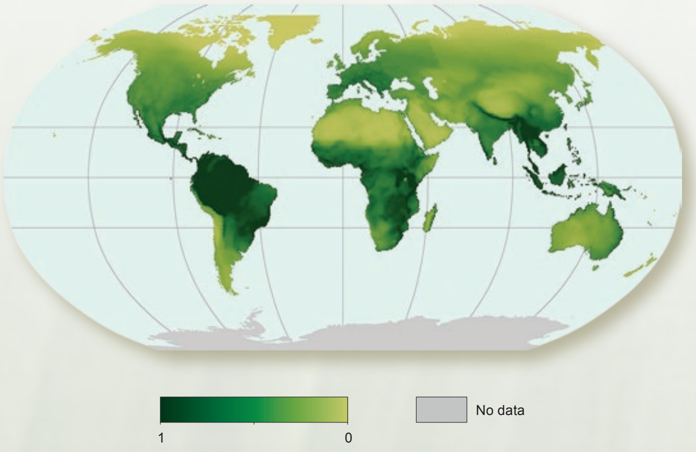
The limitations of the combined biodiversity layer include those of the underlying maps of species richness (e.g. only includes those species for which maps are available (predominantly vertebrates), date and accuracy of maps vary between taxa) and biodiversity intactness (e.g. currently assumes standard responses to land-use change in terms of species loss across all ecosystems, relies on modelled estimates of land use that are not always accurate).

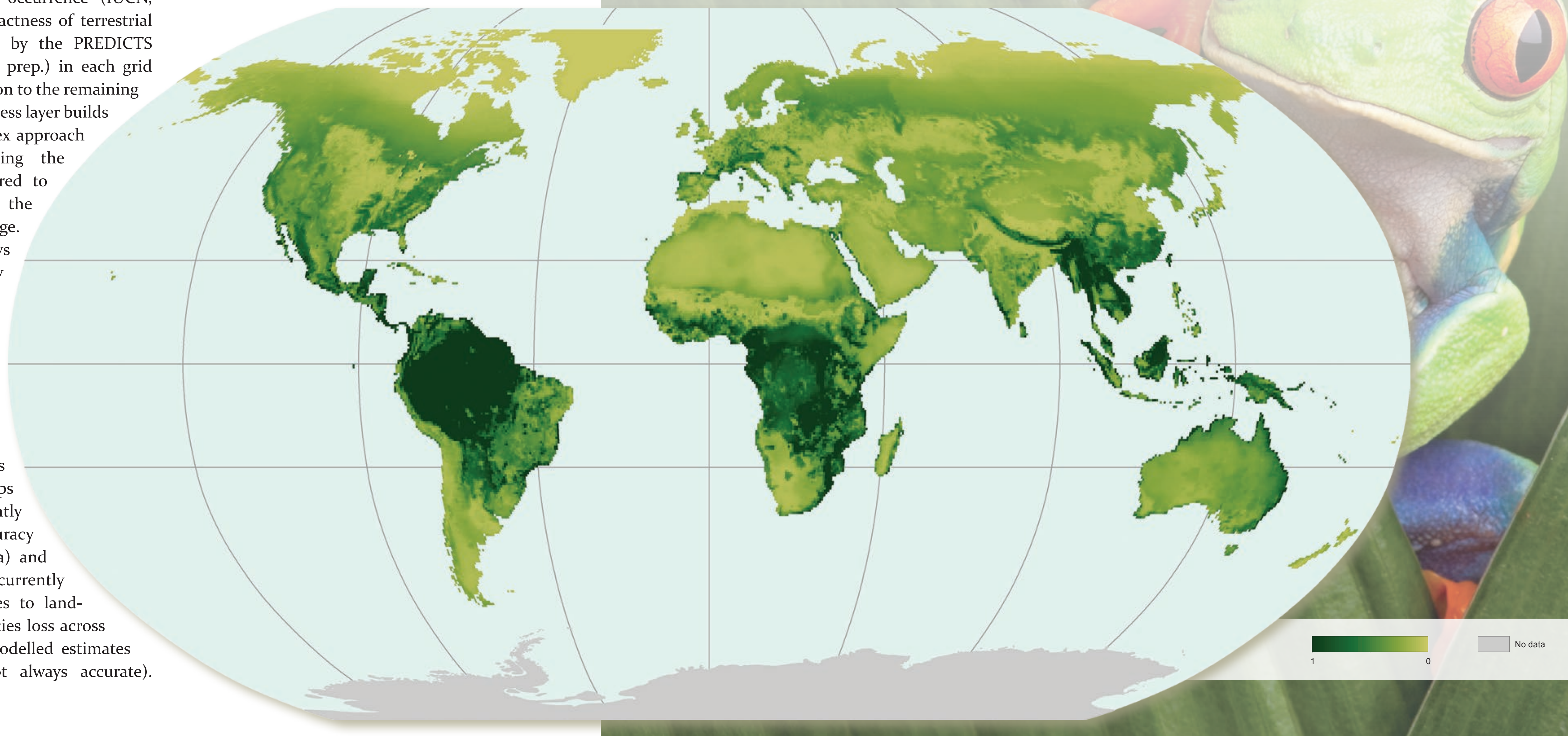
Furthermore, it is possible that the combination of the two layers over-emphasises the impact of land-use change on species richness, because the species richness map already includes some effects of land-use change on species' ranges of occurrence. However, the accounting of human impacts on species' ranges is incomplete, and so the extent of double-accounting will be small. On the other hand, the influence on richness of other pressures such as pollution and hunting are not accounted for in the PREDICTS model, which could lead to an under-estimate of total human impact. For future versions of the map, historic species ranges could be used instead of current ranges, so that land-use change impacts only feature in one of the input layers.

Map 5: Terrestrial biodiversity intactness



Map 6: Species richness





Red-eyed tree frog. ©Dirk Ercken, 2011. Used under license from Shutterstock.com

Map 7: Marine species richness across 13 taxa

Marine biodiversity is central to ecosystem functioning and, hence, the existence and maintenance of ecosystem services such as the provisioning of seafood and the cycling of nutrients.

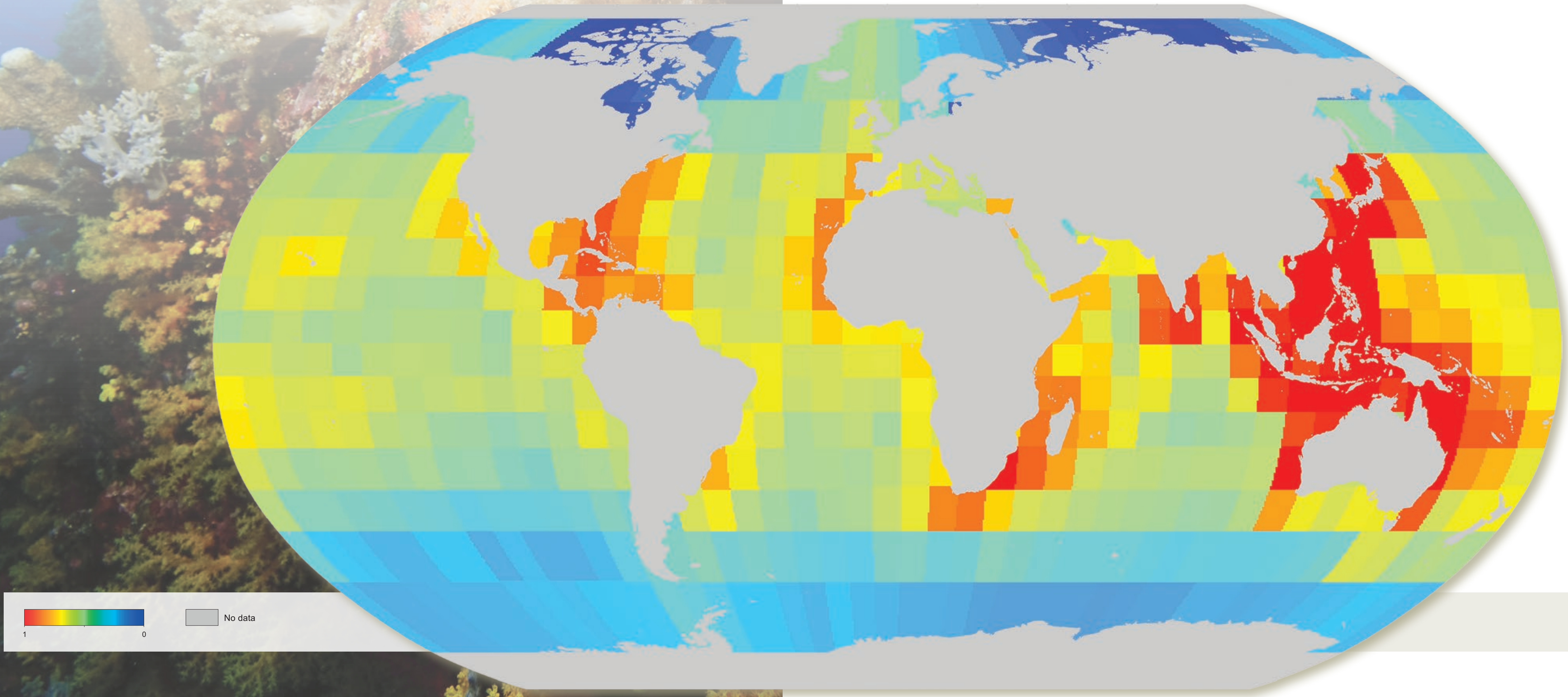
The marine biodiversity layer used in this analysis is based on species richness across 13 major species groups ranging from zooplankton to marine mammals for 11 567 species (Tittensor *et al.*, 2010). These groups include marine zooplankton (foraminifera and euphausiids), plants (mangroves and seagrasses), invertebrates (stony corals, squids and other cephalopods), fishes (coastal fishes, tunas and billfishes, oceanic and non-oceanic sharks), and mammals (cetaceans and pinnipeds). The layer presents one of the most comprehensive biodiversity layers for the marine environment.

Two major patterns emerged from this work: coastal species showed maximum diversity in the tropics, particularly in the Indo-Pacific region, whereas oceanic groups consistently peaked across broad mid-latitudinal bands in all oceans. The findings indicate a fundamental role of temperature in structuring cross-taxon marine biodiversity. Changes in ocean temperature, in conjunction with other human impacts, may in time rearrange the global distribution of life in the ocean.

Nevertheless, there are a number of gaps and limitations within this dataset. For example, the database is limited to taxa for which sufficient records were accessible to determine global distribution, with a large gap being the distribution of deep-sea diversity and marine invertebrates. Furthermore, due to the costs and practical challenges encountered in marine fieldwork, the distribution of species is based upon modeled data at a relatively coarse grain size. This approach was necessary to maximize sampling effort and minimise errors in extrapolation and record accuracy.

The principal way in which this data layer could be improved is to conduct more extensive sampling within the marine environment. However, as mentioned, this will come at a high cost. A more immediate means of improving the layer would be to mobilize pre-existing data such as species distribution records held within museums, government agencies and the private sector, which are potentially informative yet often under-used.

Beluga whales. ©CampCrazy, 2011. Used under license from Shutterstock.com



Starfish. ©Nazir Erwan Amin, 2011. Used under license from Shutterstock.com

Map 8: Global fish stocks

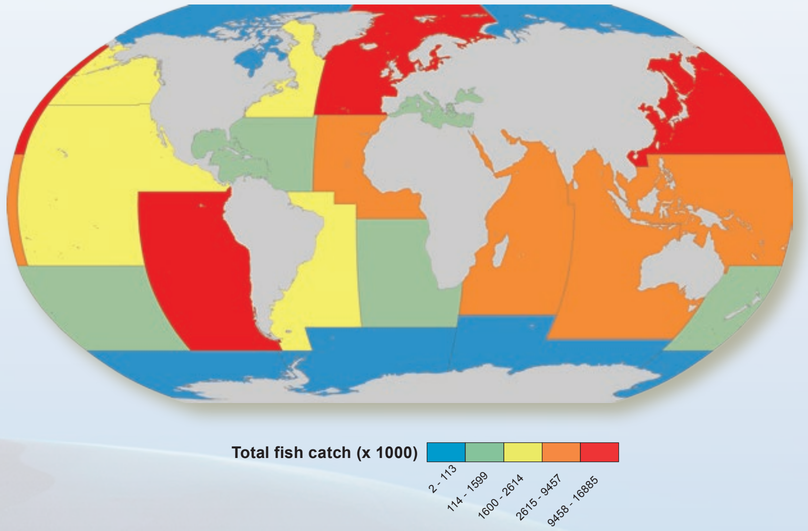
Fisheries make a major contribution to the human food supply, particularly in the world's poorest countries where they are of crucial importance to local food security, nutrition and health (Commission of the European Communities, 2000). The marine fisheries production layer used in this study is based upon a database of global commercial fisheries catch developed by 'Sea Around Us' (http://www.seaaroundus.org/). This database maps global fisheries catch using information from a variety of sources including the Food and Agriculture Organization of the United Nations (FAO), FishBase and experts on various resource species or groups (Watson *et al.*, 2004). Yearly catch values in tonnes were combined to create a long-term (10 years) mean annual product mapped at 0.5 degrees resolution. The spatial distribution of the catch is clearly non-homogenous, for example, most of the world's landings come from the coastal shelf areas. Furthermore, the upwelling of cold, nutrient-rich bottom waters into the coastal zone within the four major eastern boundary current (Canary, Benguela, California, and Humboldt) ecosystems makes these regions the most productive fishing grounds in the world.

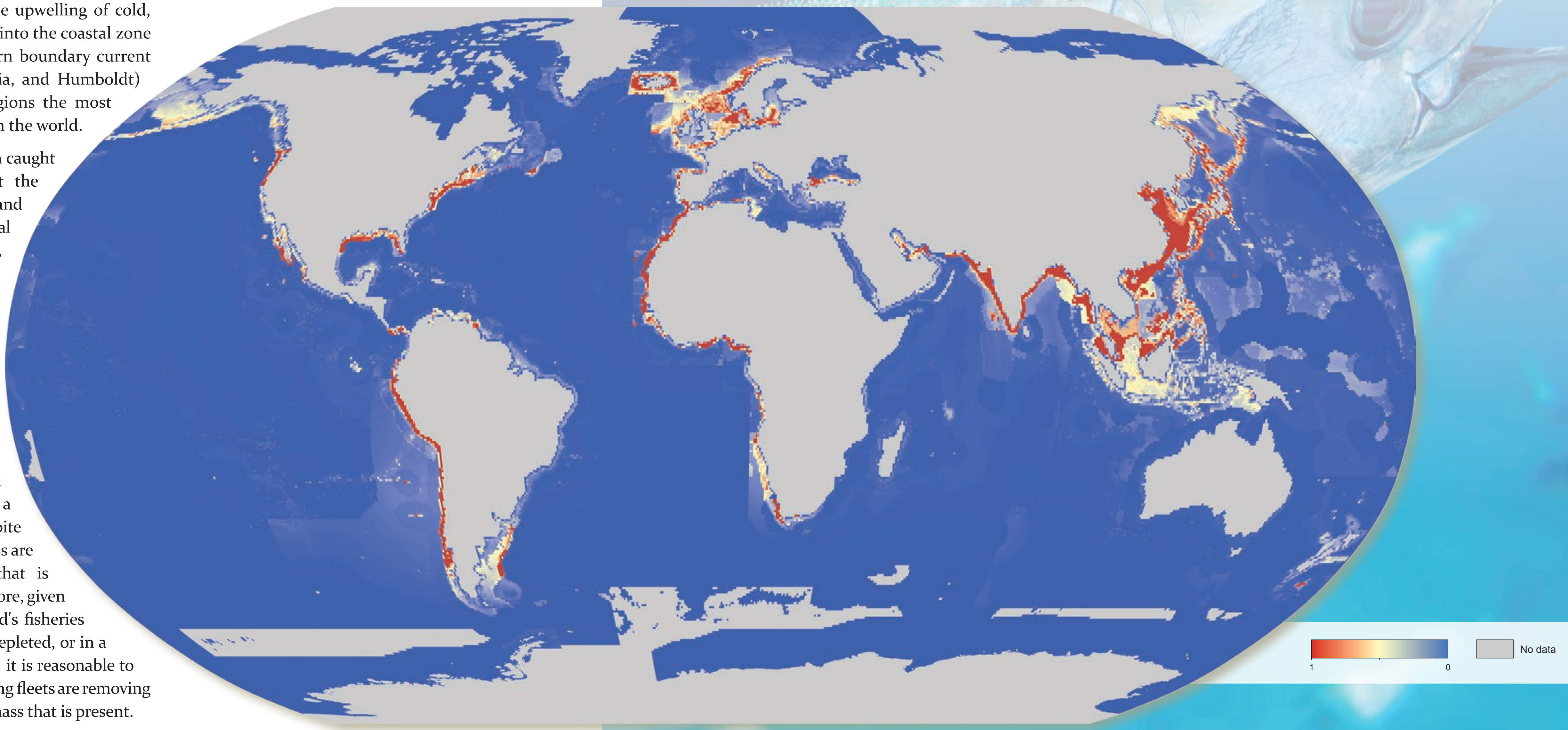
Of course, the amount of fish caught does not necessarily reflect the number of fish in the sea and hence a region's potential production. For example, factors such as a change in management or legislation can influence the annual haul of fish and lead to a disconnect between abundance and catch. However, more realistic estimates of fishable biomass require detailed scientific stock assessments, which, at present, are not available at a global extent. Therefore, despite the limitations, catch statistics are the only global data set that is currently available. Furthermore, given that almost 80% of the world's fisheries are fully- to over-exploited, depleted, or in a state of collapse (FAO, 2009), it is reasonable to assume that commercial fishing fleets are removing a high proportion of the biomass that is present.

An alternative approach would be to use environmental or oceanographic proxies of abundance such as sea surface temperature, chlorophyll a or net primary production (NPP), however, the relationship between these variables and abundance is unclear, for example, fish production is rather weakly related to NPP because of variability in the number of trophic steps in aquatic food-webs and in the transfer efficiency at each step (Friedland *et al.*, 2014). For highly mobile species such as tuna, mesoscale features such as gyres or eddies, which concentrate food, enhance local production and increase habitat heterogeneity, are more effective predictors of abundance (Santos, 2000).

As with any attempt to explore global patterns, several caveats are required. The values that are used to construct the catch layer consist purely of commercially targeted species and thus do not represent the full range of species used by humans. Furthermore, for a number of obvious reasons, fishers usually tend to underreport their catches, and consequently, most countries can be presumed to underreport their catches to FAO, in addition, the figures used do not include illegal, unreported and unregulated fisheries catch.

Map 9: Total fish catch by FAO major fishing areas





Bluefin tuna. ©holbox, 2011. Used under license from Shutterstock.com

Map 10: Composite map of global ecosystem assets

The composite map of global ecosystem assets illustrates a high concentration of terrestrial ecosystem assets in the equatorial regions, particularly in the Brazilian Amazon and the Congo Basin as well as in the boreal forests of Canada and Russia. Marine ecosystem assets are concentrated in Southeast Asia and along coastlines, especially on the west coasts of South America, Northern Africa and Europe.

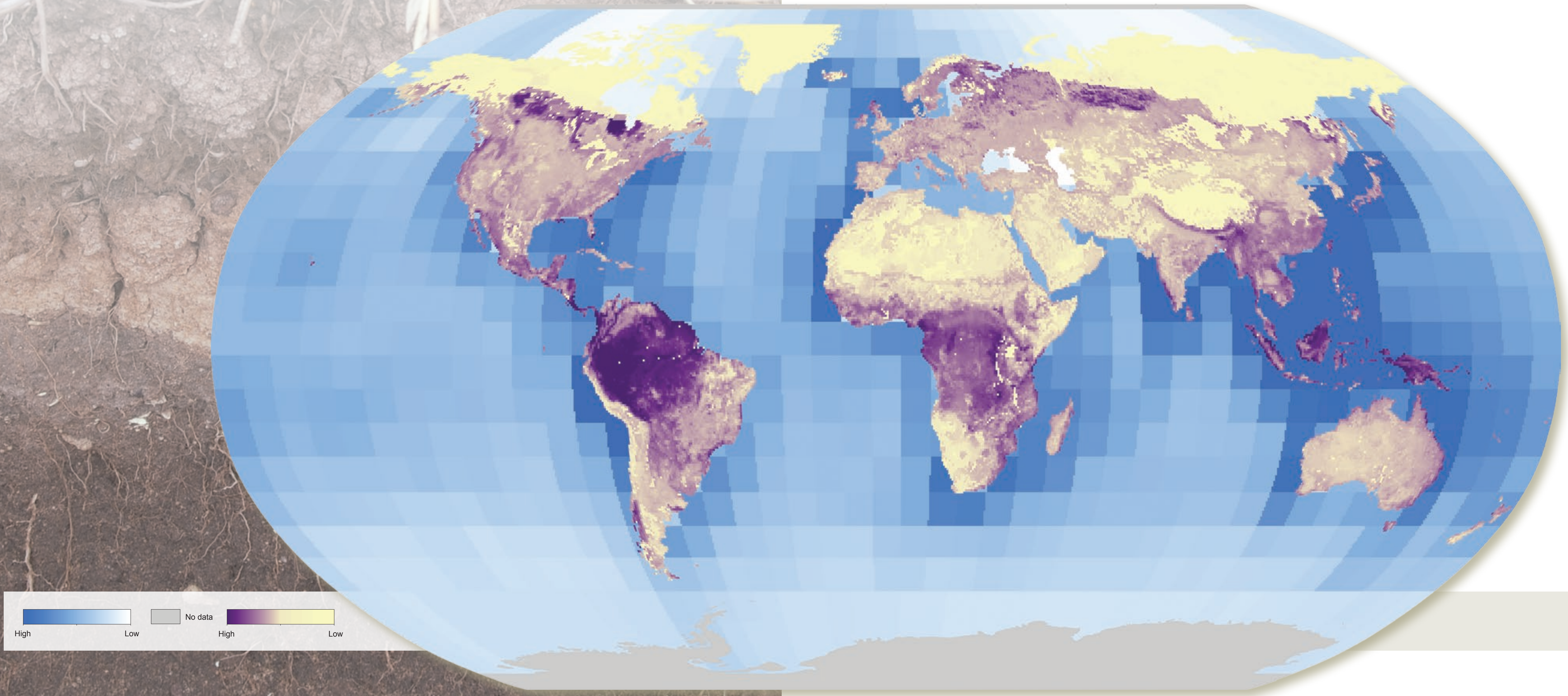
A low value relative to the global distribution of ecosystem assets does not mean that a given area is not nationally or locally important for well-being or economic activity. Instead, it may be the result of the fairly coarse resolution of the map. In addition, the map does not capture all valuable ecosystem assets, with ecosystem functions such as coastal protection and aesthetic value being omitted entirely from this first version.

The question of value to whom is an important one for assessing natural capital. The ecosystem assets mapped differ with regard to the scope of their beneficiaries. While fresh water resources and soil quality are significant for economic use in national and local contexts, carbon and biodiversity values are likely to extend beyond a single country or region. Fish stocks are often captured by fleets hailing from countries far from the fishing grounds.

Whilst the global map displays potential values of ecosystem assets, not all these assets are being realized. This implies that there may be trade-offs between these potential values and that all of them may not be able to exist simultaneously. For example, realizing a forest's soil quality value by crop cultivation could risk losing carbon stocks, if cultivation entailed clearing forest for agriculture.

The global map displays an equal weighting given to underlying ecosystem asset layers. Alternative approaches to weighting might employ valuation, where higher weight would be given to those assets with higher monetary value. A further approach for weighting could be to solicit expert or public opinion on the relative importance of different ecosystem assets via a survey or a panel. Moving from physical to monetary assessment is nevertheless likely to be difficult.

Finally, Antarctica is shown as a no-data area in the global map. Whilst some relevant data does exist for the continent, it tends to be absent from global datasets. Integrating Antarctic data into the analysis is a clear area for improvement.



Soil: ©andesign101, 2011. Used under license from Shutterstock.com

6. Conclusions and next steps in mapping natural capital

Natural capital is fundamental to human well-being, underpinning the global economy. Building on the considerable body of work in the fields of natural capital accounting and mapping of ecosystem services, this report presents the results of a pilot project to develop the first global map of ecosystem assets, i.e. the ecosystem stocks of natural capital. This work builds on the System for Environmental Economic Accounting (SEEA) and its Experimental Ecosystem Accounts component, as well as work by many researchers undertaking physical assessments of ecosystem assets and ecosystem service mapping. The SEEA Experimental Ecosystem Accounting approach provided a conceptual starting point for the global map of ecosystem assets. The biophysical quantification of natural capital is an essential step towards monetary valuation, as well as successful action to safeguard natural capital.

Natural capital accounting and mapping are closely linked. The SEEA Experimental Ecosystem Accounting approach suggests using spatial units for the analysis of physical stocks. When viewing a map, one can identify spatial patterns that are otherwise much harder to understand. The map user can compare datasets, looking for areas where assets are, or are not, co-located, and the map can act as a tool to facilitate discussion and support decision-making. With spatial data, users can visually explore changes through time, build scenarios and observe potential future impacts of management. These are possible next steps in the natural capital mapping work.

There are a number of challenges in mapping natural capital, such as data limitations, especially on the global scale. Whilst there is certainly scope to improve the mapping undertaken here, it provides an initial description of the spatial distribution of ecosystem assets. It should be noted that because of the approach adopted and scale of resolution there will be important national and local ecosystem assets which are not picked up on this map. Nonetheless, there are clear terrestrial hotspots, most obviously the large remaining tropical forests on the planet. The ecosystem assets map reinforces the message that these forests are of global significance, making policies to conserve and restore them a clear priority.

The selection of ecosystem assets for mapping favoured ecosystem service use values over the (more intangible) landscape and aesthetic (i.e. cultural) values. Inclusion of natural World Heritage Sites or protected areas could be a step forward for including some of the non-instrumental values of ecosystems into a global map. Moreover, many significant ecosystem assets underlying ecosystem services have not been included. For example, the assets embodied in coral reefs - an ecosystem that holds great economic and recreational value by supporting fisheries, tourism and providing coastal protection from storm surges – were not mapped.

Ecosystem assets represent only a part of natural capital. In order to produce a comprehensive global map of natural capital, the full array of ecosystem assets and natural resources need to be mapped (but ensuring that there is no double-counting). In the case of the map at hand, increasing the number of ecosystem assets quantified would be a step towards creating a more complete map.

A further next step would be to undertake spatial analysis of the change in ecosystem asset distributions over time, to evaluate the sustainability of ecosystem management. It would be feasible to examine the impacts of land-use change on stocks of ecosystem assets against a baseline, either to identify historical losses, or to estimate future trends using land-cover change scenarios.

More importantly for policy, future mapping of natural capital will need to involve more accurate mapping at the national and local scales. Mapping natural capital and ecosystem asset distribution at national and sub-national scales can provide useful insights on the synergies and trade-offs between asset types, relevant to decision-making processes.

References

Ahlroth, S. E. (2014). Designing Pilots for Ecosystem Accounting: An Overview. In *Designing Pilots for Ecosystem Accounting*. WAVES Working Paper May. Available from https://www.wavespartnership.org/sites/waves/files/documents/PTEC2%20-%20Ecosystem.pdf

Albon, S. and others (2014). A systematic evaluation of Scotland's Natural Capital Asset Index. Scottish Natural Heritage Commissioned Report No. 751.

Atkinson, G. and Pearce, D. (1995). Measuring sustainable development. In *Handbook of Environmental Economics*, D. W. Bromley, ed. Oxford: Blackwell.

Baccini, A. and others. (2012). Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps. *Nature Climate Change* vol. 2 No. 3, pp. 182–185.

BirdLife International and NatureServe (2013). Bird species distribution maps of the world. BirdLife International, Cambridge, UK and NatureServe, Arlington, USA

Blaney, R. and Fairley, R. (2012). Valuing our ecosystems: Scotland's Natural Capital Asset Index. In *Agriculture and the Environment IX, Valuing Ecosystems: Policy, Economic and Management Interactions*, pp 8–13.

Buitenhuis, E.T. and others (2013). MAREDAT: towards a world atlas of MARine Ecosystem DATa. *Earth System Science Data*, vol. 5, No. 2, pp.227-239. Available from http://www.earth-syst-sci-data.net/5/227/2013/.

Calder, I. and others (2007). Towards a new understanding of forests and water. *Unasylva* Vol 58 No 229 [online]. Available from http://www.fao.org/docrep/010/a1598e/a1598e02.htm

Certain, G. and others (2013). The SEEA Experimental Ecosystem Accounting framework: Structure, Challenges, and Links with the Nature Index. Working document prepared for the Expert Group Meeting: Modelling Approaches and Tools for Testing of the SEEA Experimental Ecosystem Accounting, 18 - 20 November 2013, UN Headquarters, New York, USA.

Commission of the European Communities (2000) Fisheries and Poverty Reduction: Communication from the Commission to the Council and the European Parliament. Brussels: Office for Official Publications of the European Communities.

Costanza, R. and Daly, H.E. (1992). Natural capital and sustainable development. *Conservation Biology* No. 6, pp. 37–46.

Costanza, R. and others (1997). The value of the world's ecosystem services and natural capital. *Nature* 387, pp. 253 – 260.

Costanza, R. and others (2014). Changes in the global value of ecosystem services. *Global Environmental Change* Vol.26, pp. 152–15.

Daly, H. (1994). Operationalizing sustainable development by investing in natural capital. In *Investing in Natural Capital*, Ann Mari Jansson and others, eds. Washington, D.C: Island Press.

Eade, J.D.O. and Moran, D. (1996). Spatial Economic Valuation: Benefits Transfer using Geographical Information Systems. *Journal of Environmental Management* No. 48, pp. 97–110.

Ekins, P. (2001). From green GNP to the sustainability gap: recent developments in national environmental economic accounting. *Journal of Environmental Assessment Policy and Management*, vol. 3, No. 1,. pp. 61-93.

European Commission, Organisation for Economic Co-operation and Development, United Nations and World Bank (2013). System of Environmental-Economic Accounting (SEEA) 2012 Experimental Ecosystem Accounting , White cover publication. UN Statistics Division. Available from http://unstats.un.org/unsd/envaccounting/eea_white_cover.pdf

Food and Agricultural Organisation of the United Nations (FAO) (2009). The State of World Fisheries and Aquaculture. Rome: FAO Fisheries and Aquaculture Department.

FAO (2011). The State of the World's Land and Water Resources for Food and Agriculture: Managing systems at risk. Rome: FAO.

Food and Agricultural Organisation of the United Nations (FAO) and others (2009). Harmonized World Soil Database (version 1.1). FAO, Rome, Italy and IIASA, Laxenburg, Austria.

Fenichel, E.P. and Abbott, J.K. (2014). Natural Capital: From Metaphor to Measurement. *Journal of the Association of Environmental and Resource Economists*, vol. 1, No. 1, pp. 1-27.

Fischer, G. and others (2008). Global Agro-ecological Zones Assessment for Agriculture (GAEZ 2008). IIASA, Laxenburg, Austria and FAO, Rome, Italy.

Fisher, B., Turner, R. and Morling, P. (2009). Defining and classifying ecosystem services for decision making. *Ecological Economics*, vol. 68, No. 3, pp. 643-653.

Friedland K.D. and others (2012). Pathways between Primary Production and Fisheries Yields of Large Marine Ecosystems. *PLoS ONE* vol. 7, No. 1, e28945.

Hiederer, R. and Köchy , M. (2011). *Global Soil Organic Carbon Estimates and the Harmonized World Soil Database*. EUR 25225 EN. Publications Office of the EU, Luxembourg.

Hijmans, R.J. and others (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* No. 25, pp. 1965-1978.

Hooper, D. U. and others (2012). A global synthesis reveals biodiversity loss as a major driver of ecosystem change. *Nature*, No. 486, pp. 105–108.

Hudson, L., and others (in prep.) The PREDICTS database: a global database of how local terrestrial biodiversity responds to human impacts.

Hutchinson, J. and others (2014). Predicting Global Patterns in Mangrove Forest Biomass. *Conservation Letters*, vol. 7, No. 3, pp. 233–240.

IUCN (2013). IUCN Red List of Threatened Species. Version 2013.2. http://www.iucnredlist.org. Downloaded on 16th December 2013.

IPCC (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley, eds.. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Knight, S. (in prep.) Review of mapping ecosystem services.

Kourzeneva, E. and others (2012). Global gridded dataset of lake coverage and lake depth for use in numerical weather prediction and climate modeling. *Tellus A* No. 64, pp. 15640.

Larsen, F.W., Londoño-Murcia, M.C. and Turner, W.C. (2011). Global priorities for conservation of threatened species, carbon storage, and fresh water services: scope for synergy?. *Conservation Letters*, No. 4, pp. 355–363.

Millennium Ecosystem Assessment (2005). *Ecosystems and Human Well-being: Synthesis*. Washington, DC.: Island Press.

Mu, Q., Zhao, M., and Running, S.W. (2011). Improvements to a MODIS global terrestrial evapotranspiration algorithm. *Remote sensing of environment* No. 115, pp. 1781-1800.

Naidoo, R. and others (2008). Global mapping of ecosystem services and conservation priorities. PNAS, vol. 105, No. 28, pp. 9497-9500.

National Research Council (2004). *Valuing Ecosystem Services: Toward Better Environmental Decision-Making*. Washington, DC: The National Academies Press.

NINA (2014). The Norwegian Nature Index. Available from: http://www.nina.no/ninaenglish/TheNorwegianNatureIndex.aspx

Nybø, S., Skarpaas, O. and Certain, G. (Undated). Fact sheet: The Norwegian Nature Index (NI)

Netherlands Environmental Assessment Agency (2010). Rethinking Global Biodiversity Strategies. Netherlands Environmental Assessment Agency, Bilthoven, Netherlands. Available from: http://www.pbl.nl/en/publications/2010/Rethinking_Global_Biodiversity_Strategies

Newbold, T. and others (in prep.) Strong mitigation stops inequitable losses of global biodiversity.

Neumayer, E. (2003). *Weak versus Strong Sustainability: Exploring the Limits of Two Opposing Paradigms*, 2nd edition, Cheltenham: Edward Elgar.

OECD (2007) Glossary of Statistical terms. Available from http://stats.oecd.org/glossary/detail.asp?ID=1730

PBL Netherlands Environmental Assessment Agency (2012). What is the Natural Capital Index (NCI)? Available from: http://www.pbl.nl/en/question-and-answer/what-is-the-natural-capital-index-nci

Potschin, M. B. and Haines-Young, R. H. (2011). Ecosystem services: Exploring a geographical perspective. *Progress in Physical Geography*, vol. 35, No. 5, pp. 575–594.

Ruesch, A. S., and H. K. Gibbs. (2008). New IPCC Tier1 Global Biomass Carbon Map for the Year 2000. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee. cdiac.ornl.gov

Saatchi, S. S. and others (2011). Benchmark map of forest carbon stocks in tropical regions across three continents. *Proceedings of the National Academy of Sciences of the United States of America*, Vol. 24, No. 108, pp. 9899–904.

Santos, A.M.P. (2000). Fisheries oceanography using satellite and airborne remote sensing methods: a review. *Fish Res*, No. 49, pp. 1–20.

Scharlemann, J. P., Tanner, E. V., Hiederer, R., and Kapos, V. (2014). Global soil carbon: understanding and managing the largest terrestrial carbon pool. *Carbon Management*, vol. 5, No. 1, pp.81–91.

Secades, C., O'Conner, B., Brown, C and Walpole, M. (2014). Earth observation for biodiversity monitoring: a review of current approaches and future opportunities for tracking progress towards the Aichi biodiversity targets. Technical series no 72. Montreal: Secretariat of the Convention on Biological Diversity.

SNH (2011). NCA index technical document. Available from http://unstats.un.org/unsd/envaccounting/seeaLES/egm/NCAindex_bk.pdf

SNH (2012). Scotland's Natural Capital Asset (NCA) Index. Available from http://www.snh.gov.uk/docs/B814140.pdf

Strassburg, B.B.N. and others (2010). Global congruence of carbon storage and biodiversity in terrestrial ecosystems. *Conservation Letters*, vol. 3, No. 2, pp 98–105.

ten Brink, B. (2007). The Natural Capital Index framework (NCI). Contribution to Beyond GDP Virtual Indicator Expo. Available from http://unstats.un.org/unsd/envaccounting/seeaLES/egm/NCI_bk.pdf

Tittensor, D. P. and others (2010). Global patterns and predictors of marine biodiversity across taxa. Nature, vol. 466, No. 7310, pp. 1098-1101.

van de Ven, P. (2012). Index of natural resources – a measurement proposal (OECD Statistics Directorate). Green Growth & Sustainable Development Forum 2012, Paris, 23 November 2012. OECD.

Voora, V.A. and Venema, H.D. (2008). The Natural Capital Approach: A Concept Paper. Winnipeg: International Institute for Sustainable Development (IISD). Available from http://www.iisd.org/pdf/2008/natural_capital_approach.pdf

Watson, R., Kitchingman, A., Gelchu, A. and Pauly, D. (2004). Mapping global fisheries: sharpening our focus. *Fish and Fisheries*, No. 5, pp. 168–177.

Wirsenius, S., Azar, C. and Berndes, G. (2010). How much land is needed for global food production under scenarios of dietary changes and livestock productivity increases in 2030? *Agricultural Systems*, Vol. 103, No. 9, pp. 621–638.

UNEP (2007). Global Environment Outlook GEO-4: Environment for development. Nairobi, Kenya: United Nations Environment Programme.

UNEP (2012). Global Environmental Outlook GEO-5. Nairobi, Kenya: United Nations Environment Programme.

Annex 1: Technical descriptions for each map

Map 1: Global fresh water resources

Short description/caption: Global renewable fresh water resources and water stored in large lakes and reservoirs

Detailed description: The water layer includes renewable water resources that are replenished annually through the global hydrological cycle as well as fresh water stored in large lakes for which renewal takes years to decades. The layer combines a long term mean annual water balance with a layer of water stored in large lakes. Annual water balance is estimated using the WorldClim (Hijmans *et al.*, 2005) long term mean precipitation dataset which is based on observed precipitation for the period 1950-2000 and the mean global terrestrial evapotranspiration dataset based on MODIS remote sensing data (Mu *et al.*, 2011) for the period 2000-2010. Lake volumes were estimated using a global high-resolution lake depth database developed by Kourzenova *et al.*, (2012) that includes over 13,000 large fresh water lakes.

Limitations and caveats: The WorldClim representation of observed precipitation is based on interpolation of measured precipitation data which leads to higher uncertainties in areas with low gauge densities. Both precipitation and evapotranspiration are based on long-term means, therefore changes in climate and the effects of recent land-use change are averaged out. While the global fresh water lake dataset is the most comprehensive available, many smaller lakes are not included. Furthermore, water stored in large river systems is not included.

Map 2: Terrestrial organic carbon in soil and vegetation

Short description/caption: Organic carbon in living terrestrial vegetation and soils to 1 metre depth

Detailed description: The carbon layer is based on two 30 x 30 arc-second global datasets, the first estimating above and below ground biomass carbon in living vegetation for the year 2000 using IPCC Tier 1 methodologies (Ruesch and Gibbs, 2008), and the second representing organic carbon in soil to 1 metre depth (based on the Harmonised World Soil Database) (Hiederer and Köchy 2011). The combined layer thus includes organic carbon in both soil and vegetation.

Limitations and caveats: Both input maps essentially apply a paint-by-numbers approach to assign values to specific locations based on a typology of the soil and vegetation. There are some differences in the approach taken to map the carbon in soil and vegetation: the soil organic carbon estimates do not take account of degradation, whilst the estimates of carbon in biomass take account of degradation both in considering current vegetation cover (from Global Land Cover 2000), and by adjusting forest carbon downwards outside of relatively undisturbed 'frontier forests'. Whilst more detailed biomass carbon maps exist for the pantropics (Saatchi *et al.* 2011, Baccini *et al.* 2012), Ruesch and Gibbs is the only available peer-reviewed, globally-consistent map of carbon stocks for the planet. The soil carbon map, being limited to the first metre of soil depth, omits deeper stores of organic carbon in peatlands, which in places can reach `11 m depth.

Map 3: Soil quality for plant growth using maize as a reference crop

Short description/caption: Global soil quality important for crop production, specifically for maize crop requirements and tolerances

Detailed description: The soil layer is based on a dataset of seven different soil indicators that are important for crop production (Fischer *et al.*, 2008). These key soil qualities are: nutrient availability, nutrient retention capacity, rooting conditions, oxygen availability to roots, excess salts, toxicities and workability. The indicators are related to specific crop requirements and tolerances, and have been calculated for a variety of crops. Maize was selected as a reference crop as it is of global importance in terms of volumes produced, and distributed widely. The individual soil indicators have a similar spatial distribution. To produce the soil quality map, they were combined into one layer giving equal weighting to each indicator.

Limitations and caveats: The key soil qualities maps represent the quality of soils with regards to agricultural use, specifically for maize. Other crops or natural vegetation can have different requirements and tolerances leading to slightly different distributions. Each indicator is given equal weighting in the final composite map, this may over- or underestimate the impact of individual indicators in determining suitability for plant growth. The maps of key soil qualities are derived from the Harmonised World Soil Database (v1.1) which is based on a number of regional and national databases compiled for different time periods. Reliability of the data is variable and depends on the quality of the underlying datasets.

Map 4: Species richness adjusted by intactness

Short description/caption: Species richness (IUCN) adjusted by intactness (PREDICTS)

Detailed description: Map 4 was generated by scaling a present-day species richness layer based on broad areas of occurrence (Map 6) by the fraction intactness of terrestrial species richness (Map 5).

Limitations and caveats: The limitations of the underlying biodiversity layers (Map 5 and Map 6) also apply to Map 4.

Map 5: Terrestrial biodiversity intactness (Predicts)

Short description/caption: Terrestrial similarity of local biotic assemblages to those in intact ecosystems

Detailed description: Terrestrial biodiversity intactness ranges from 0 (all originally-present species lost) to 1 (all originally-present species still present). Globally, we estimate that assemblages have lost, on average, 17% of the originally-present species (i.e. average intactness is 0.83). Data sets were compiled from publications relating site-level terrestrial biodiversity to human impacts. The resulting database (Hudson, Newbold *et al.* in prep.; www.predicts.org.uk) contains over 1.8 million records from over 400 data sets, representing over 32,000 species from 220 ecoregions and 80 countries. For each land use, site-level species richness was estimated relative to that associated with minimally-used primary vegetation, in a mixed-effects model. Net changes in species richness fail to reflect changes in species composition (i.e. incoming species are treated as equal to the lost originally-present species); the richness estimates for each land use condition were therefore multiplied by the mean within-dataset compositional similarity between that land use and primary vegetation (Newbold, Hudson *et al.* in prep.). The resulting intactness estimates for each land use condition were crossed with global land use estimates (proportion of land in each land use condition in each 0.5 degree grid cell), modelled for the year 2000 (Netherlands Environmental Assessment Agency, 2010) to produce this map. The estimated global mean terrestrial biodiversity intactness for 2000 was calculated by averaging grid cells, weighted by their area and their numbers of native terrestrial vertebrate species.

Limitations and caveats: Geographic coverage of the underlying data is still uneven, with central Asia and sub-Saharan Africa particularly underrepresented. There is significant variation among biomes and realms in how site-level species richness responds to given land-use transitions, which is not captured in the single global model used here. The compositional similarity analysis used here is very preliminary. All of these limitations can be mitigated with additional effort.

Map 6: Species richness

Short description/caption: Species richness in 50×50 km grid cells derived from IUCN species range polygons (BirdLife International and NatureServe, 2013; IUCN,2013)

Detailed description: The extant ranges of occurrence for all species in the Red List of Threatened Species (IUCN, 2013) were overlayed with a global (85°N - 85°S and 180°W - 180°E) grid of 50×50 km grid cells. For each cell the species richness is the count of the number of species ranges overlapping with that cell. The analysis excluded approximately 3% of species with range information because our approach encountered errors in the geometry of those species polygons that prevented analysis.

Limitations and caveats: The species richness value if based only upon those taxonomic groups that have been assessed as part of the Red List of Threatened Species and only for those species for which spatial data has been generated. The broadly defined taxonomic groups covered are: mammals, amphibians, reptiles, birds, mangroves and fresh water species. However, some coastal taxa marine taxa, for example, seagrasses may be captured where their range polygons overlap with the spatial boundaries for terrestrial land masses that were employed for the analysis.IUCN spatial data contains uncertainties and in particular does not take into account fine-scale range gaps.

Map 7: Marine species richness across 13 taxa

Short description/caption: Marine species richness across 13 taxonomic groups

Detailed description: The marine biodiversity layer is based on species richness across 13 major species groups ranging from zooplankton to marine mammals for 11567 species (Tittensor *et al.*, 2010). These groups include marine zooplankton (foraminifera and euphausiids), plants (mangroves and seagrasses), invertebrates (stony corals, squids and other cephalopods), fishes (coastal fishes, tunas and billfishes, oceanic and non-oceanic sharks), and mammals (cetaceans and pinnipeds). The layer presents one of the most comprehensive biodiversity layers for the marine environment.

Limitations and caveats: Uncertainty and data paucity remains, mainly due to the challenges of sampling in the marine realm. This is particularly so for the distribution of deep-sea diversity. Likewise, microbes or viruses were not considered, and there is limited marine invertebrate data. The cephalopod pattern has a higher level of uncertainty, as available data only account for ~25% of known diversity, and are biased towards commercial species. Finally, the results are based on a single, relatively coarse grain size necessary to maximize sampling effort and minimize errors in extrapolation and record accuracy.

Map 8: Global fish stocks

Short description/caption: Global commercial fisheries catch

Detailed description: The marine fisheries production layer is based upon a database of global commercial fisheries catch developed by 'Sea Around Us' (http://www.seaaroundus.org/). This database uses information from a variety of sources including the Food and Agriculture Organization of the United Nations (FAO), FishBase and experts on various resource species or groups to map global fisheries catch (Watson *et al.*, 2004). Yearly catch values were combined to create a long-term (10 years) mean product mapped at 0.5 degrees resolution showing the mean annual total fish catch in tonnes.

Limitations and caveats: The values that are used to construct the catch layer consist purely of commercially targeted species and thus do not represent the full range of species utilised by humans. Furthermore, for a number of obvious reasons, fishers usually tend to underreport their catches, and, consequently, most countries can be presumed to underreport their catches to FAO. In addition, the figures used do not include Illegal, unreported and unregulated fisheries catch.

Map 9: Total fish catch by FAO major fishing areas

Detailed description: The inset map presenting the total fish catch by major FAO marine fishing areas map was produced by summing all fish catch from the global fish stocks layer within each major fishing area with data classified using quantile breaks. There are 19 major marine fishing areas that are internationally established for statistical purposes covering the waters of the Atlantic, Indian, Pacific and Southern Ocean with their adjacent seas.

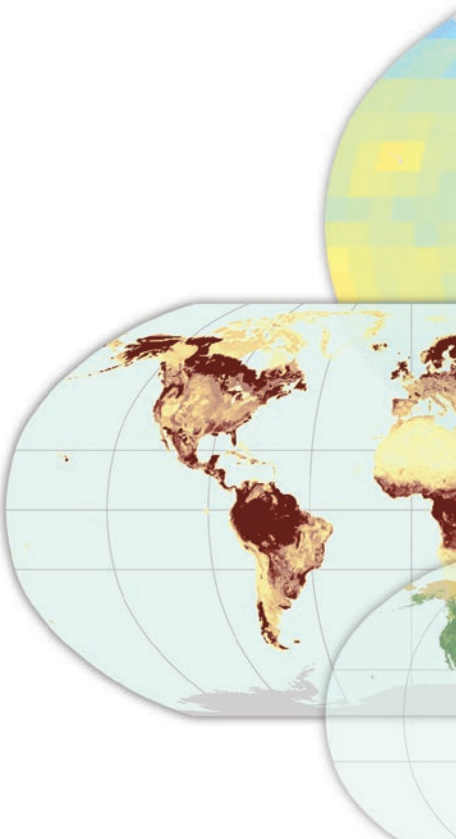
Limitations and caveats: The limitations of Map 8 also apply to Map 9.

Map 10: Composite map of global ecosystem assets

Short description/caption: Composite map of global ecosystem assets based on four terrestrial and two marine ecosystem asset indicators

Detailed description: The composite map of global ecosystem assets combines all four terrestrial ecosystem asset maps and two marine ecosystem asset maps. Using normalised values (rescaled between 0 and 1) all terrestrial maps were added together to create a single terrestrial ecosystem asset map scaling between 0 and a potential maximum of 4. In order to combine the maps, they were aggregated to a common resolution of 0.5 degrees (~ 50 x 50 km). A similar approach was taken for the marine ecosystem asset map. However, since the native resolution of the marine biodiversity layer is 8 degrees (~880km), it was necessary to aggregate (sum) the fish catch layer (with native resolution of 0.5 degrees) to this lower resolution before combining them. The final combined terrestrial and marine ecosystem asset layer is displayed at 0.5 degree resolution. However, the coarseness of the underlying marine biodiversity data can be seen in the marine realm of the final composite layer.

Limitations and caveats: The composite layer gives equal weighting to each indicator of ecosystem asset. Since there are only two marine layers compared to four for terrestrial, individual values in each of the marine ecosystem asset maps (biodiversity and fish catch) have a greater overall impact on the composite map. Due to the aggregation to a common resolution, finer scale representation of ecosystem assets is lost. While the individual layers can be considered the best available datasets, there are many limitations and uncertainties as described for each layer that need to be taken into account when interpreting the global composite map.



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