GROUP ON EARTH OBSERVATIONS | GEO BON

Group on Earth Observations

Biodiversity Observation Network

(GEO BON)

Detailed Implementation Plan

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Technical Summary

Purpose, origin and scope of this document

This summary of the GEO BON 2010 Detailed Implementation Plan also draws on material in the GEO BON Concept Document and the Implementation Overview, both dated 2008. The latter two foundation documents were drafted through a broad, consultative process, involving increasing numbers of stakeholders as GEO BON progressed from an idea to a reality. The Detailed Implementation Plan was drafted in the first quarter of 2010 by over a hundred experts, organised into eight working groups. This Technical Summary reflects the key ideas and proposed actions in the three underlying documents in a brief and integrated form. Its purpose is to provide an overview of the GEO BON Implementation Plan, in sufficient detail so that readers with a working knowledge of the fields of biodiversity and Earth observation can easily understand the objectives and plans of the network. For further details the full Detailed Implementation Plan can be consulted. GEO BON is an evolving concept, responsive to user needs and changing technologies. The Implementation Plan will adapt accordingly, and should thus be considered as a living document.

The Vision, Mission and Goals of GEO BON

The Vision of GEO BON is for a coordinated, global network that gathers and shares information on biodiversity, provides tools for data integration and analysis, and contributes to improving environmental management and human well-being.

GEO BON has as its mission the improved delivery of biodiversity information and services to users, particularly decision-makers. GEO BON focuses on observing and analysing changes in biodiversity over time. [CD 3][1]

GEO BON is intended to facilitate linkages among the many countries, organisations and individuals contributing to the collection, management, sharing and analysis of observations on the status and trends of the world's biodiversity. It will also identify gaps in and between existing biodiversity observation systems and promote mechanisms to fill them. [IO]

The scope of GEO BON includes primary observations and observation-based inferences on changes:

[1] Bracketed references are to pages or sections of the Concept Document [CD], Implementation Overview [IO] or Detailed Implementation Plan [DIP]. See reference list and http://www.earthobservations.org/GEOBON_docs.shtml.

- In biodiversity composition, structure and function;
- At the ecosystem, species and genetic levels of biological organisation;
- Plus the associated ecosystem services;
- In the terrestrial, freshwater, coastal and open ocean marine domains;
- Worldwide;
- Particularly over the past few hundred years and into the foreseeable future

In addition to collating time series of observations on the presence, abundance and condition of elements of biodiversity, GEO BON intends in future implementation plans to also collate information on interactions between organisms, their functional attributes and their use by people. It will link to supporting data on the abiotic environment, the current taxonomic status of the organisms, the classification of ecosystems, drivers of biodiversity change and measures taken to protect biodiversity. GEO BON will conduct limited observation-based analyses itself, such as change detection, trend recognition, range interpolation, forward projections, and model-based estimations of the supply of ecosystem services. GEO BON will support more detailed analyses undertaken by biodiversity and ecosystem assessment bodies. [CD 3]

The guiding principles on which GEO BON is based are listed in the Concept Document [CD 1.4.1]. They derive from the GEOSS (Global Earth Observation System of Systems) principles, and include issues such as information sharing, interoperability, standards, user-orientation and scientific rigor. The "value proposition" of GEO BON is to build on, coordinate and link existing major initiatives working with biodiversity data and information, in order to derive higher-level "value-added" analytical products not currently available through the existing activities when considered separately. It aims to provide a global, scientifically-robust framework for observations that can detect biodiversity change; provide access to observations, models, assessments and forecast information; help build a global system of systems based on the integration of *in situ* and remote observation systems; coordinate aspects of data gathering and the delivery of biodiversity change information; ensure long-term continuity of data supply; and provide a set of innovative and relevant products based on the integration of datasets. [DIP 1.1]

How GEO BON is organised

GEO BON is a specific example of a "community of practice", within the Group on Earth Observations (GEO). It is the main implementation platform of the Biodiversity "Societal Benefit Area". As such, it is a "network of networks", a structure with minimal parts of its own, designed to help strengthen and coordinate the activities of a diverse set of partners towards a common goal—improved biodiversity information for a wide range of users. The only GEO BON standing body is its Steering Committee, consisting of both biodiversity information users and providers. The Steering Committee members[2] serve for a period of three years, renewable once. The Steering Committee meets as needed, and consults electronically between meetings. It reports to the Group on Earth Observations (GEO) plenary. The coordination actions of GEO BON are conducted by working groups, established by the Steering Committee, with a defined purpose and for a limited period. The members of the working groups are experts, appointed on a voluntary basis and in their own capacities, selected to provide the necessary skills, experience and connections to achieve the task.

Eight working groups were ratified at the first meeting of the Steering Committee in June 2009. This Technical Summary largely reflects their efforts in drafting implementation plans within their domains, culminating in an all-working group meeting in February 2010. The working groups are pragmatically constituted, reflecting the way the biodiversity community is organised and interacts rather than being an abstract logical structure. Thus, for instance, collations of observations at the species level—and especially of land-based species—are in a more advanced state than, for instance, those for freshwater species or for biodiversity-oriented observations at gene level, and are therefore separated out as a working group on their own. The number and focus of working groups will evolve over time as needs dictate. The underlying Detailed Implementation Plan is organised by Working Group—because that arrangement facilitates implementation—but this Technical Summary is arranged by the three main "levels" of biodiversity (genes, species and ecosystems), subdivided into land, freshwater and marine systems, to provide a more integrated view.

GEO BON is a "network of networks". Two types of constituent networks are especially important to achieve its mission: the Regional BONs and the Topical BONs. Regional BONs are autonomous networks that form—largely spontaneously—to serve the biodiversity observation needs of a group of neighbouring countries. If the Regional BON subscribes to the GEO BON mission and guiding principles, it is welcome to become part of the GEO BON brand and thus gain improved access to the networked GEO datasets that follows from the adoption of agreed standards. Topical BONs are similar, but are typically global in geographical scope and focussed on a particular range of biodiversity issues—for instance, one taxonomic group, or one type of data.

[2] Bob Scholes, CSIR, South Africa (Chair); Dora Ann Lange Canhos, CRIA, Brazil; Daniel Faith, Australian Museum, Australia; Simon Ferrier, CSIRO, Australia; Gary Geller, NASA/JPL, USA; Carlo Heip, NIOZ, Netherlands; Leonard Hirsch, Smithsonian Institute, USA; Robert Höft, CBD, Canada; Jon Hutton, UNEP-WCMC, UK; Rob H.G. Jongman, EBONE, Wageningen UR, Netherlands; Norbert Jürgens, University of Hamburg, Germany; Nick King, GBIF, Denmark; Anne Larigauderie, DIVERSITAS, France; Jan de Leeuw, NIOZ, Netherlands; Georgina Mace, Imperial College, UK; Hal Mooney, Stanford University, USA; Marc Paganini, ESA, Italy; Terry Parr, ILTER, UK; Henrique Miguel Pereira, Universidade de Lisboa, Portugal; Roger Sayre, USGS, USA; Woody Turner, NASA, USA; Sheila Vergara, ASEAN Centre for Biodiversity, Philippines

Who are the users?

The main users of GEO BON will be countries (especially in relation to their obligations under biodiversity-related conventions); national natural resource and biodiversity conservation agencies; international organisations and the biodiversity-relevant treaty bodies; non-governmental organisations (both national and international) in the fields of biodiversity protection and natural resource management; and scientific research organisations and individuals both in and out of academia. [CD 3, IO 3.1]

Integrating and enhancing observations using models

GEO BON recognises that primary observations and models are often not easily separated. Together, they are complementary and synergistic. Modelling will be the main tool in GEO BON for integrating observations across space and time; filling taxonomic gaps through the use of proxies and inferences; filling geographical gaps by linking remotely sensed, *in situ* and collection-based observations; predicting the consequence of biodiversity change for ecosystem function and the delivery of ecosystem services; and making observation-based projections of future change. [CD 2.5]

The needs for, and capabilities of, models in the biodiversity observation domain will first be comprehensively reviewed to inform and guide future modelling initiatives aimed at filling critical gaps. Early attention will also be directed to facilitating establishment of a collaborative framework for inferring global change in compositional diversity, by linking both species distribution (ecological niche) models and community-level distribution models to remotely sensed changes in ecosystem intactness. [DIP 7]

Initial challenges in establishing this framework will be to derive measures of terrestrial ecosystem intactness from remote sensing and to use networks of *in situ* sites to develop, calibrate and validate models of biodiversity change. Trial applications of the framework in the terrestrial, freshwater, marine and microbial metagenomics domains will be demonstrated. [DIP 7]

Interoperability and data integration

GEO BON sets out to help coordinate, harmonise, standardise and manage the *in situ* biodiversity data that are collected by disparate organisations, institutions and individuals for differing purposes, to the degree necessary to achieve collective objectives. It will work with existing networks and initiatives to help develop an efficient and effective informatics network for biodiversity data, adding components and links as necessary. Key design principles will include:

- Spatial elements will need to cover the full range of possibilities from point locations, through linear features, areas and volumes, and be compatible with the *OGC Observations and Measurements specification;*
- Both centralised and service oriented architectures must be catered for in linked networks;
- Discovery services and registers will make use of the GEOSS clearinghouse mechanism, and exploit existing metadata catalogues;
- As far as possible, a unified approach to the construction and deployment of ontologies (specialised vocabularies) will be followed;
- Organism names and habitat classifications need to be compatible with the names used by various networks making up GEO BON, noting important rationalising initiatives such as ITIS, Species 2000, the Catalogue of Life, World Register of Marine Species and Global Names Index and the EBONE General Habitat classification;
- GEO BON must be able to support workflows for services and integration of applications;
- GEO BON must be compatible with the GEO Portal and other web-based interfaces;
- GEO BON must be committed to open data access, while recognising and promoting the need to acknowledge sources [DIP 8]

In order to put these principles into effect, GEO BON proposes to establish a technical coordination capability which will review existing data provider networks, establish partnerships, review the data processing needs of the GEO BON working groups, design an information architecture, build the necessary components, register data and services, and provide helpdesk facilities, training and outreach. [DIP 8]

Observations of biodiversity at the genetic level

The most fundamental unit of biological diversity is variation in the nucleic acid sequences that make up the genetic code of life. This is the basis for variation between species (and thus of ecosystems comprised of different species), but also of variation among individuals and populations within species. It is important in three main ways: as the source and record of evolutionary potential that provides useful new features, some of which help support human well-being now and in the future; as a necessary condition for the viability of species, especially when their populations are reduced to low numbers; and as the basis of functional traits that ultimately determine ecosystem function and ecosystem services. The focus in genetic diversity observations to date has been disproportionately on genetic variation in economically important species, for instance crop plants, domesticated animals and disease organisms. GEO BON covers those issues, but also genetic variation in wild organisms. The concepts to be implemented by the observation system at the gene level include:

- Repeated measurements, over time, of specific genetic components of interest, in selected target species and clades;
- Linking (in both directions) genetic diversity to the species and ecosystem levels of biodiversity;
- Model-based inferences on change in genetic diversity and its consequences, based on observations of patterns of biodiversity [DIP 1]

Although the technology for observing genetic diversity is rapidly becoming cheaper and more powerful, it will be some time before it is feasible to observe genetic diversity change in all species. GEO BON will focus on three main groups:

1) Rapidly declining species, e.g., IUCN "red list" species and Evolutionarily Distinct Globally Endangered (EDGE) species—those with few close relatives on the tree of life, and whose loss would thus prune entire branches;
2) Rapidly increasing species, such as invasive alien species and novel pests and diseases;
3) Species selected for largely scientific reasons, as reference groups ("controls") ecological keystone, economically important or flagship species; wild model organisms (e.g., *Arabidopsis*, *Mus* and *Drosophila*), or species with good historical records. [DIP 1]

Initially, while the protocols are under development, the collection of new genetic observations will be associated with core sites, often co-located with Long Term Ecological Research (LTER) sites. [DIP 1]

A novel GEO BON product will be maps of phylogenetic diversity. These are a fundamental basis for conservation planning, which will complement the currently-used species richness maps in helping to identify areas to prioritise for protection. [DIP 1]

Genetic diversity provides a good tool for understanding patterns and changes in microbial biodiversity, where many species are either undescribed or poorly defined. Specifically, a set of ribosomal sequences known as 16S will be used to map the distribution and turnover of microbial diversity and relate it to macro-ecological features, through a procedure known as metagenomics. Metagenomics will be an important platform in the marine environment, both in sediments and for phytoplankton diversity. [DIP 1, DIP 5]

The embedding of sequence data in a spatial, temporal, taxonomic and ecosystem context is an important step that will be championed by GEO BON. This will be achieved by advocating that sequence data entering the several large databases created for their storage and exchange (e.g., GENEBANK) be associated with the appropriate metadata regarding the organism from which the sequence was obtained and the time and place where it was collected. A metadata standard called MIENS (Minimum Information about an Environmental Sequence) will be adopted. [DIP 1]

Species-level biodiversity observations

The variety of species is perhaps the most intuitive aspect of biodiversity, and the best-developed in terms of information systems. Established organisations such as the Global Biodiversity Information Facility (GBIF), and the International Union for Conservation of Nature (IUCN), themselves multi-partner international networks as well as being linked to GEO BON, have laid the foundation for sophisticated biodiversity information systems in this domain, already populated with hundreds of millions of records. The basic data record is an observation that a certain species was present at a given location and time, and has two main origins: specimens in collections in museums and herbaria; and observation lists by field biologists and lay specialists.

These information sources allow maps of distribution ranges to be developed (usually filled-in using "environmental niche models"), and changes in the range over time to be detected. The total number of species recorded at a location is the species richness, a widely-used biodiversity measure. But changes in presence or absence give little advance warning of biodiversity change and are not very helpful for resource management. For these purposes they need to be supplemented with measures of the abundance of organisms of a given species.

Species on land

The species for which time-series data on abundance and distribution will be advocated by and made accessible through GEO BON will be selected according to two broad criteria: feasibility and functional importance. The first includes organisms where monitoring already exists and is conducted by current or potential GEO BON contributors. This includes information from conservation agencies, NGOs and many citizen science networks organised around particular taxonomic groups. The second includes species with economic or ecological importance, such as game species or timber species. The resulting priority groups are terrestrial vertebrates (initially birds, then mammals, amphibians and reptiles), invertebrates (initially butterflies), and vascular plants. Within each group both common and rare species will be monitored, requiring different approaches. In general extensive rather than intensive monitoring is favoured (i.e., less detail at many sites rather than more effort at a few sites). [DIP 2]

There are about 10,000 known bird species. Observations for the annual wild bird indicators (WBI), based on standardised counts of breeding birds, will be extended from those regions where they are already established, with the intent to cover the entire globe by 2020. An observation programme focusing on birds identified by the IUCN as critically endangered (currently 192 species) will be developed, along with a Critically Endangered Bird Indicator

(CEBI). The CEBI will act in support of the Red List Indicator (RLI), one of the indicators in the 2010 targets, in much the same way as the Water Bird Indicator is currently used.

There are currently approximately 5500 known mammal species. For some mammal groups standardised monitoring schemes have been established at the regional level (e.g., iBats for Europe). The aim is to extend these to other regions and taxa, using appropriate sampling methods. These data will extend and improve the Living Planet Index (LPI). For the about 6200 amphibian and 9000 reptile species, existing protocols are even rarer, and development work is needed. [DIP 2]

Insects are the most species-rich group of animals. Among them, butterflies are well documented and are a popular and relatively easily-identified group. They are also sensitive indicators of habitat loss and climate change. Reasonably standard monitoring protocols for butterflies are established in Europe and can be extended to new regions, often using citizen observers. No widely-used standard protocols yet exist for other terrestrial invertebrate groups. [DIP 2]

There are about 400 000 known vascular plant species, and about 2000 per year are still being described. Herbaria records form a large (but spatially patchy) existing data source for historical presence mapping, but do not generally provide good information on abundance or change. The GEO BON aim is to survey, by 2015, as many threatened species as possible from a globally-representative sample, and repeat this analysis thereafter at 5-year intervals. The strategy to achieve this is to prioritise geographical "hotspots" of threatened plants. [DIP 3]

Species associated with freshwater ecosystems

A comprehensive, accurate and regular update of the ecology, distribution, abundance and conservation status of freshwater species is the goal of this part of GEO BON. Working through the IUCN's Species Information System and prioritising *Red List* is planned. This will be carried out in collaboration with regional and specialist BONs and partners from specialist organisations such as the IUCN Species Survival Commission. Some freshwater taxa, for example, freshwater crabs, amphibians, the Odonata (dragonflies and damselflies) and freshwater fishes already have reasonably comprehensive databases regionally if not globally. Most other freshwater taxa remain poorly known, especially in the tropics. Improving the coverage and standardisation of observation efforts is a GEO BON priority. [DIP 4]

Species of coasts, continental shelves and deep oceans

Several recent efforts, including the Census of Marine Life and the Ocean Biogeographic Information System, have advanced the information on marine species diversity substantially, and will form a basis for GEO BON activities. GEO BON priorities include facilitation of:

- Mobilisation and accessibility of online primary biodiversity data;

- Consensus on data collection protocols;
- Rescue of historical datasets and making them accessible;
- Coordination of the marine biodiversity observation efforts of independent institutes and countries to help ensure more systematic coverage. [DIP 5]

Ships of convenience will form the basis of marine basin-scale monitoring efforts. An example is the Continuous Plankton Recorder programme in the North Atlantic. New routes will need to be set up to achieve global coverage, especially in climatically-sensitive areas such as the Arctic. [DIP 5]

Long-term abundance and distribution changes in large marine organisms (cetaceans, seals, birds, turtles, sharks and fish, for example) can be monitored using a range of techniques, including acoustic tracking arrays and tagging programmes. Some of these species are of commercial fisheries importance, and are also of relevance in the context of Ecosystem Services, noted below. The role of GEO BON here is to stimulate the observations and help to link or provide the databases for them. [DIP 5]

Ecosystem-level biodiversity

Many biodiversity protection organisations have adopted “the ecosystem approach”. For this to be effective, consistent and accurate information on ecosystem location, composition and status must be readily available. GEO BON’s goal is to harmonise the mapping and monitoring of ecosystems worldwide, including terrestrial, freshwater and marine ecosystems. The key metrics of ecosystem change are extent (including the size and connectivity of fragments), condition, and change in functional parameters.

Ecosystem services

Ecosystem services are the benefits that people derive from nature. Such services are based, in complex and not fully-understood ways, on biodiversity, and are one important reason to prevent biodiversity loss. Ecosystem services are often related to the functional aspects of biodiversity at the ecosystem level. Information on changes in the capacity of ecosystems to deliver services is of great importance to many users, and is one way to define “ecosystem condition”.

The ecosystem services activities in GEO BON are not primary observations, but information derived from the integration of observations taken for a variety of purposes. [DIP 6]

GEO BON is planning a biennial accounting of ecosystem service delivery at national resolution. The key GEO BON activity is the development of databases and tools in support of such efforts. An initial set of services are proposed as the elements of these accounts, based on their economic or social importance, rate of change and availability of data. They include provisioning services such as crops, forest products, wild-harvested fish and fresh water, for which most countries have monitoring systems. Models, based for instance on remotely-sensed net primary productivity and ecosystem disturbance, will help to extend this basic set of services into those for which national statistics are not widely kept—for example, the services of carbon sequestration and erosion control. "Bundling" of related services will help in the communication of changes, since changes in the relative proportions of services is usually less important than that the sum of services does not decline. [DIP 6]

At a subnational level, the GEO BON ecosystem services activity will focus mainly on the provision of standards and recommended protocols for the estimation of service flows. [DIP 6]

Terrestrial ecosystems

The Ecosystem Mapping Task of the GEOSS Ecosystems Societal Benefit Area (SBA) is an important element of the GEO BON strategy. The hierarchical stratification and classification of terrestrial ecosystems is a first step, followed by their spatial mapping. Monitoring changes in ecosystem extent (and related measures, such as fragmentation and connectivity) will be based on the combination of *in situ* observations and remote sensing techniques. GEO BON will be an advocate for such coverage and will help to standardise GEO BON methods and reporting from a biodiversity perspective. A GEO BON activity is to extend and elaborate the FAO Land Cover Classification System to satisfy the needs of biodiversity monitoring. Close collaboration with the Global Observations of Forests Cover-Global Observations of Land Dynamics (GOFC-GOLD) GEOSS task is a key part of the strategy. [DIP 3]

A global network of *in situ* field stations ("GEO BON Observation Nodes") is needed for ecosystem condition and function monitoring, and the development of harmonised field protocols is an important element of that endeavour. Some regional examples are extant or under development (e.g., ILTER, NEON and BIOTA), and can serve as prototypes. GEO BON will integrate key ecosystem functional parameters, many monitored from space with *in situ* calibration, into a Terrestrial Ecosystem Function Index (TEFI). TEFI will be based on a data assimilation model of measurements of the energy, carbon and nutrient balance, and will require research and development by partner groups. [DIP 3]

Freshwater ecosystems

It is widely agreed that freshwater ecosystems and their associated biodiversity are among the most altered on the planet. An early GEO BON deliverable will be directories of global datasets on freshwater biodiversity and on the drivers, threats and pressures operating on freshwater ecosystems. [DIP 4]

A global observation system for freshwater ecosystems does not yet exist. A prerequisite for such a system is a widely accepted and consistently applied set of spatial units. The HydroSHEDS geospatial database and tools are proposed by GEO BON as the basis for delineating such units. Another critical step is the global classification of freshwater ecosystems based on data obtained globally at the spatial resolution of these units. This issue is highly akin to the classification and mapping task described under terrestrial ecosystems, above, and for marine ecosystems, below, although the procedures differ in the three cases.

The major proposed early product is a global atlas of freshwater biodiversity. [DIP 4] Mapping the current extent of wetlands is also a priority. It requires the development and worldwide testing of a protocol for the application of remote sensing to this issue. [DIP 4]

Remotely observed changes in the drivers of freshwater ecosystem function, and landscape feature surrogates for freshwater compositional biodiversity, will be used to produce estimates of change in freshwater ecosystem condition. Estimates of collective properties of biodiversity, such as compositional turnover among spatial units within the framework, will be derived by integrating species level data at the ecosystem scale, using models. [DIP 4]

Marine ecosystems

Defining marine realms and their associated ecosystems is a major challenge, given the fluid and three-dimensional nature of the system and its relative inaccessibility. The geographic marine realms used by CoML will be the pragmatic starting point adopted by GEO BON. Each of these realms contains many ecosystems. For coastal and shelf systems the Marine Ecoregions of the World (MEOW) will be adopted, and the development of a complementary Global Open Oceans and Deep Sea-habitats (GOODS) for the open ocean will be supported by GEO BON. The visualisation of these marine ecosystems, for which static, two-dimensional maps are inappropriate, is a research development topic. [DIP 5]

Phytoplankton ocean colour and inferred primary production are key marine ecosystem observation products, requiring the integration of *in situ* and remotely sensed data. Acoustic techniques are increasingly used for mapping water layers and the sea floor, and for benthic habitat mapping and monitoring. Time-series observations of seawater chemistry and temperature throughout the profile are key ancillary data for biodiversity observations, along with currents and surface winds. Since there is no dedicated marine SBA, this requires co-development with the Climate SBA, which provides such data for purposes of climate modelling. [DIP 5]

Other GEO BON marine ecosystem priority activities are to stimulate the monitoring of key human-induced changes to the ocean environment that have biodiversity consequences such as pH, nutrients and oxygen levels and currents; and the development of process and forecast models for more marine ecosystems. [DIP 5]

References

Group on Earth Observation Biodiversity Observation Network (2008) GEO BON Concept Document. GEO-V document 20, Geneva, Switzerland. URL: http://www.earthobservations.org/documents/cop/bi_geobon/200811_geobon_concept_document.pdf

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GEO BON Detailed Implementation Plan

Introduction

GEO BON, the Group on Earth Observations Biodiversity Observation Network, is the biodiversity arm of the Global Earth Observation System of Systems (GEOSS). Its primary goal is to build an integrated global biodiversity observation system. To achieve this goal, GEO BON will provide a framework to increase coordination among the people and organisations collecting, managing, and utilizing biodiversity observations, thereby increasing the ability of others to access, share, and analyse these observations. GEO BON is a concept for two closely related global networks: a social network—a Community of Practice for those engaged in collecting, managing, and utilizing biodiversity observations; and a physical network—the interoperating systems that collect, store and distribute biodiversity information of all kinds that is held by a great number organisations.

Although the number of existing biodiversity observations is very large, these observations are very uneven in spatial, temporal, topical, and taxonomic coverage. Additionally, the observations exist in a variety of disparate formats, scattered among thousands of independent systems, often making them difficult or impossible to access, and hampering the ability to do global or regional assessments (for example, see ETC Biodiversity 2008[3]). Coordinating the collection of biodiversity observations, as well as their storage, management, and distribution, will improve data coverage and quality, enhance efficiency, and increase the value extracted from the collected observations.

With this in mind, GEO BON will coordinate, link, and build upon existing major initiatives, as well as identify gaps in existing biodiversity observation systems and promote mechanisms to fill them. It will also conduct limited, observation-based analyses itself, including change detection, trend recognition, forward projections, and model-based estimates of the supply of ecosystem services. And GEO BON will support biodiversity and ecosystem assessment bodies, such as the Intergovernmental science policy Platform on Biodiversity and Ecosystem Services (IPBES, if established) that are engaged in more detailed analyses. Thus, the GEO BON Vision and Mission are:

[3] ETC Biodiversity (2008). Habitats Directive Article 17 Report (2001–2006), Data completeness, quality and coherence. pp24.

GEO BON Vision:

A coordinated, global network that gathers and shares information on biodiversity, provides tools for data integration and analysis, and contributes to improving environmental management and human well-being.

GEO BON Mission:

Improved delivery of biodiversity information and services to users, particularly decision-makers, with a focus on observing and analysing changes in biodiversity over time.

GEO BON aims to provide a global, scientifically robust framework for observations that can detect biodiversity change. It will provide access to observations, models, assessments and forecast information; help build a global system of systems based on the integration of *in situ* and remote observation systems; coordinate aspects of data gathering and the delivery of biodiversity change information; ensure long-term continuity of data supply; and develop new, derived analytical products not currently available through existing activities when considered separately.

Context

Within the GEO framework, GEO BON is co-led by three organisations (DIVERSITAS, NASA, and EBONE, the European BON) and guided by a Steering Committee of 22 members. The GEO BON Concept Document, which outlines in considerable detail the scope and focus of GEO BON, was completed in November 2008 after a two-year process of collecting inputs from a wide range of participants. The GEO BON Implementation Overview, which presents the overall approach for implementing the concepts in the Concept Document, was released in November 2009. These documents, details on Steering Committee membership, and other information about GEO BON, can be found at the GEO BON website at http://www.earthobservations.org/GEOBON.shtml.

GEOSS is composed of nine Societal Benefit Areas (SBAs) each of which has a number of tasks, and Biodiversity is one of the SBAs, with GEO BON as its primary task. GEO BON will interact with other tasks and SBAs—for example, the Ecosystems SBA is closely related, and interactions with Agriculture, Water and Climate are anticipated. GEO itself is composed of (currently) 80 national governments, the European Commission and 58 participating organisations. Because GEO contributors collect large volumes of biodiversity data, and operate many of the systems of interest, these governments and organisations have a critical role to play in GEO BON, and GEO provides a forum for facilitating much of the work that needs to be done.

At a meeting of the interim GEO BON Steering Committee in January 2009, it was proposed to create eight Topical Working Groups (WGs) to begin the planning process for GEO BON implementation. While these eight working groups were selected to cover many of the concepts described in the Concept Document, their selection was also based on practical factors such as what observation systems and networks already exist. It was also recognized that some areas, such as citizen science, would be addressed at a later time, consistent with an incremental implementation approach.

A continuous and active effort is made to ensure good interaction and coordination among the WGs. In February 2010 a four-day meeting was held in California to bring the WGs together to facilitate work on implementation planning and coordination. However, good progress also depends on each WG being a coherent entity with a sense of self and an ability to move forward, and GEO BON implementation can be viewed as being executed by a confederation of coordinated WGs, under the overall guidance of the GEO BON Steering Committee. Consistent with that approach, each WG developed its own material for this Implementation Plan, in close coordination with the other WGs.

The core of this Plan consists of the eight sections corresponding to and written by the eight WGs. In addition, to provide an overall view of GEO BON, two Appendices are included that contain complete lists of the planned Activities and Deliverables.

Implementation Approach

GEO is a voluntary partnership, and the GEO model for implementing GEOSS relies on engagement of GEO members and participating organisations and their partners. This makes implementation a dynamic process as it depends on resources that cannot be fully anticipated and arranged before implementation begins. As a result, the Implementation Plan anticipates that GEO BON will grow incrementally and rather organically, as partnerships emerge, resources become available, experience is gained, and biodiversity science and information technology advance. So GEO BON implementation will be an iterative and dynamic process, with planning and replanning an expected and important part. This initial Detailed Implementation Plan represents the first major iteration.

Figure 1 is a conceptual diagram of the overall implementation approach for GEO BON. The first step was for the Topical WGs to map the concepts in the GEO BON Concept Document to a suite of activities that implement those concepts; these activities are described in this Implementation Plan. To the extent possible, this mapping has been done in conjunction with partners, however, there is a “chicken and egg” challenge here: until those activities are worked out, it is difficult to determine who the partners might be. This is an important point, and one that the reader will see manifested in this version of the document, which does not yet contain many details on the implementing partners. So, an important purpose of this initial version of the Plan is to provide a mechanism to inform potential partners. As discussions with those potential partners progress the plans for implementation will be updated to be consistent with the mission and resources of the implementing partners.

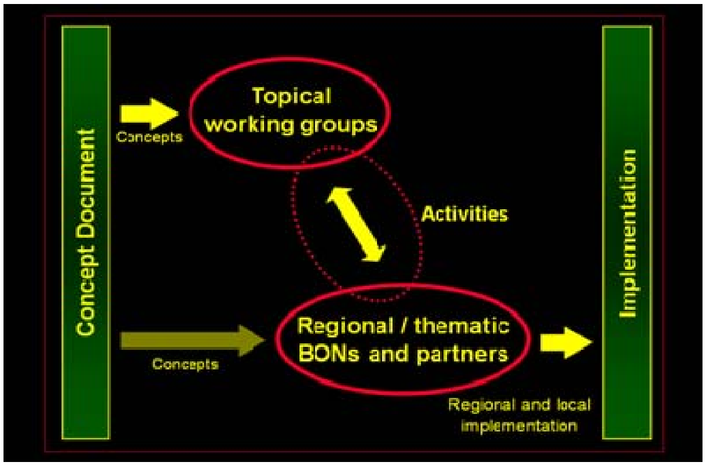

Figure 1: Conceptual overview of the GEO BON implementation approach.

Since GEO BON is a network of networks one of its major tasks is to bring together existing networks of various types. Two types of constituent networks are particularly important. A Regional BON is a network that serves the biodiversity observation needs of a group of neighbouring countries; these can form spontaneously, or with facilitation by GEO BON when there is a recognized need. It is expected that Regional BONs will often be composed largely of a network of national BONs for the countries of the region. Such participation by national governments in Regional BONs brings a great deal of observation data, systems, and expertise into play, and also helps align GEO BON implementation with GEO member countries. It may also be appropriate for national BONs to join GEO BON directly. A Regional BON that follows the GEO BON mission and guiding principles can be recognized as an affiliate and is welcome to use the GEO BON "brand". Topical BONs are similar, but rather than being geographically defined are instead focussed on a particular set of biodiversity issues—for example, a taxonomic group, or one type of data. Note that the opportunistic and organic growth of GEO BON can lead to some overlap of BONs; this is consistent with the network of networks approach.

The GEO BON Concept Document made the initial case for GEO BON and provided a framework upon which GEO BON could be implemented. This Detailed Implementation Plan adds flesh to that framework, outlining the primary activities needed to implement those concepts. It also includes descriptions of the primary deliverables, and an initial notional schedule. Consistent with an iterative development approach, the information included here will be updated as GEO BON moves forward.

1 Genetics / Phylogenetic Diversity (Working Group 1)

1.1 Introduction

The Genetics / Phylogenetic Diversity working group (hereafter referred to simply as the Genetics working group) is one of the eight topical working groups (WGs) which will begin implementation of GEO BON. In parallel with GEO BON goals for ecosystems and species, this group will facilitate the global observation and monitoring of genetic diversity, using a combination of remote sensing and *in situ* approaches. The Genetics WG will work on genetic diversity in the broad sense, defined as diversity expressed at the levels of genes, species and ecosystems, and monitored by genetic/phylogenetic approaches. This broad definition is needed because phylogenetic comparison using DNA sequences is applicable to all three levels. Further, recent technical developments such as new generation sequencing has enabled us to observe and monitor genetic backgrounds of trait diversity that determines ecosystem functions.

The Genetics WG has identified, broadly, three ways in which genetic diversity is important:

1) Evolutionary potential of populations and species provides useful new features supporting human well-being;
2) Viability of populations and species is threatened by reduced levels of genetic diversity and by inbreeding;
3) Genetic backgrounds of functional traits determine ecosystem functions and services.

Genetic diversity, as for biodiversity generally, is linked not just to current human uses but also to potential future uses (so-called "option values"). Loss of genetic diversity therefore is a critical part of the broader biodiversity extinction crisis. Much of the focus to date has been largely restricted to links from genetic diversity to known ecosystem services—for example, the genetic diversity of crop plants. The Genetics WG, through key partnerships, will promote observations not only on crop plants and other economically important species, but also on wild genetic diversity.

1.2 Concepts to be Implemented

The concepts addressed by this group include those outlined in Section 2.3 of the GEO BON Concept Document, where three broad strategies for observations and analyses of genetic diversity have been recognized. The three strategies are here modified as follows:

1) Repeated observations, over time, of specific genetic/phylogenetic components of interest, in selected target species and clades;
2) Repeated observations, over time, of other biodiversity components (e.g., range extent of species), integrated with models that link these observations to genetic diversity;

3) Repeated observations, over time, of changes in land/water condition, *in situ* or remotely sensed, and integrated with models that allow us to infer corresponding changes of genetic/phylogenetic diversity.

The first strategy now covers not only species but also clades. By this extension, the Genetics WG will facilitate monitoring of phylogenetic diversity loss in particular lineages.

These strategies begin to define initial activities, and help the Genetics WG start to address the challenges of balancing different perspectives on genetic diversity—for example, observations relating to overall patterns of genetic diversity versus those on specific priority species of interest. Similarly, at a lower level, a balance will be sought between observations on overall genetic diversity of a given species versus on key functional traits of that species.

These overlapping strategies will be promoted as a way to enable a range of monitoring approaches, extending from detailed observations for target species to model-based inferences of more general changes in genetic diversity.

Here, no attempt will be made to cover the full spectrum of concepts referred to in the Concept Document; the starting point will be modest activities that follow achievable yet innovative approaches, and build on already established work. Initial activities that are synergistic with those of the other working groups will be favoured.

1.3 Activities

1.3.1 Published papers

This activity involves production of key reviews and position papers. New ideas as well as new techniques are rapidly growing in the science of genetic diversity. Some of these will establish new links between the Genetics WG and the other WGs. The Genetics WG and its partners will publish comprehensive reviews including updated perspectives for genetic diversity observations to promote collaborations with non-genetic approaches (see Deliverables).

1.3.2 Abundance/range to predict genetic diversity

It will not be practical to monitor within-species genetic diversity over time on any but a small sample of species, given funding and other constraints. Therefore methods will be developed and promoted that allow changes in genetic diversity to be inferred even when only observations over time at the *species* level are available. Here, the inference of likely changes in genetic diversity from changes in population size (abundance) and range extent of species will be explored.

GEO BON can help to extend existing global observation strategies that already make use of a broad representative set of species. An exemplar approach is the Sampled Red List Index

(SRLI), which seeks to automate the measurements of geographical range that are already used in IUCN assessments (Nic Lughadha et al. 2005). Also, the Living Planet Index (LPI) is calculated using time-series data on several thousand species of mammal, bird, reptile, amphibian and fish. Activities will involve links to such species-level observations on trends in abundance and range extent within Terrestrial Species WG.

1.3.2.1 Inferences based on changes in range extent

The use of range size or extent to estimate changes in genetic diversity will be investigated. The logic is that range size is a surrogate of population size and there is already empirical data establishing that it is related to within-species genetic diversity for both plants and animals (Hamrick & Godt 1989; Frankham 1996). Faith et al. (2008) refer to candidate models to be investigated—Rauch & Bar-Yam (2005) proposed a general relationship in which genetic diversity (B) is proportional to r $(\log(r))^2$, where r is current range extent of a species. They argued that habitat loss causes a dramatic loss of genetic diversity relative to species diversity: "while the observed number of species scales as a weak power of the area, so that a reduction in area by a factor of 16 causes a reduction in number of species by a factor of 2, the effect on genetic diversity is much more dramatic. A reduction in area by a factor of 2 causes a reduction of genetic diversity by more than a factor of 2."

The integration of range extent data with this kind of model will be explored so that changes in range extent of a species can be used to predict corresponding changes in genetic diversity. Links to SRLI and other sources for range information will extend to include invertebrates. For example, Collen and colleagues (Clausnitzer et al. 2009) have estimated range-related information for Odonata: "A randomly selected sample of 1500 (26.4%) of the 5680 described dragonflies and damselflies was assessed using IUCN's Red List criteria."

1.3.2.2 Population size (abundance)

1.3.2.2.1. Another focus will be on abundance data from species-level assessments in Intactness indices and MSA (Mean Species Abundance) approaches. Models allowing this information to extend to inferences about levels of genetic diversity will be developed and applied.

One model extends the relationship between range size and genetic diversity. While the rate of loss of genetic diversity becomes smaller as loss of range size progresses, the rate of loss of genetic diversity relative to changes in abundance fractions is larger for smaller abundance fractions (Faith et al. 2008).

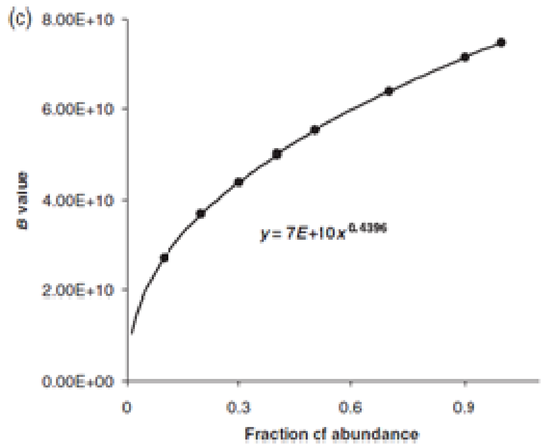

Figure 1.1 The rate of loss of genetic diversity (vertical axis) relative to changes in abundance fractions (horizontal axis) is larger for smaller abundance fractions. In log–log space, this relationship is linear (Faith et al. 2008).

In general, the model suggests that genetic diversity is related to fractional abundance raised to some power; the power value depends on the nominated relationship between abundance and range size.

1.3.2.2.2. Another candidate model links abundance to heterozygosity. The logic is as follows:

1) Population genetic theory predicts a causal relationship between effective population size (Ne) and genetic diversity

2) The relationship has been validated empirically across a broad array of taxa (Soulé 1976; Frankham 1996; Leimu et al. 2006)

Genetic impacts depend on Ne, with genetic diversity being lost at a rate of 1/(2Ne) per generation within closed populations (Traill et al. 2010). One can use the empirical data from long-term sampling of species abundance (e.g., for Living Planet Index component species, long term data sets from NCEAS; marine eukaryotes COML data; Mean Species Abundance information through GLOBIO), and read off the predicted changes from an updated version of the empirical relationship in Frankham (1996). The method is to simply predict the change in heterozygosity from the two population size values from the best fitting equation (Frankham 1996). Reduction in genetic diversity will only occur when the population size decreases.

The immediate loss of genetic diversity also can be predicted. One can predict proportional genetic diversity (heterozygosity), retained after a nominated number of generations, from abundance data and an estimate of the ratio of effective to census population size (Frankham 1995 provide estimated values; see also Frankham et al. 2010).

To explore the practical implementation of the Faith et al. model and the heterozygosity models, the different groups working on global genetic models (i.e., the groups working on SRLI and

Living Planet) will need to collaborate to trial methods. Trials will estimate changes in genetic diversity for a large number of terrestrial species. It should be feasible to obtain estimates over about the last 40 years. Subsequently, other abundance data sets will be utilized, especially for data sets not covered by LPI (e.g., marine eukaryotes and plants). A global consortium to develop this over different regions will be organized.

1.3.3 Genetic diversity loss in selected species

Because genetic diversity loss cannot be observed in all species, there is a need to develop realistic but challenging criteria for selecting target species. Among the multiple criteria that may be used, the Genetics WG has considered the rate of abundance change as a motivation to distinguish the following three primary categories:

1) Rapidly declining species, including those listed as Critically Endangered on the IUCN Red List, and EDGE;
2) Rapidly increasing species, including invasive alien species;
3) Other species as a control, such as important food species (potato, rice, banana), soil biodiversity species and flagship species.

For the first category, the Genetics WG and partners will promote "ubiquitous genotyping" (Isagi et al. pers. Comm.), that is, the genotyping of all living individuals. In the ubiquitous genotyping project on critically endangered plants in Japan, all living individuals of some plant species are already genotyped and researchers are working on additional species. In South Africa, all living individuals of a large fraction of Cycad species are genotyped. Locations of all living individuals genotyped should be georeferenced and mapped in detail. Then, changes in genotypic diversity can be monitored exactly by monitoring death of individuals and birth of new individuals that are genotyped every time. This approach is particularly useful in sessile organisms, typically in plants. The Genetics WG will organize a global consortium for promoting ubiquitous genotyping projects for various plants of various regions. To develop corresponding activities for animals, one needs to catch all the living individuals. This may be possible for some species under a well-managed protection program (Isagi et al. pers. comm.).

For the second category, the Genetics WG and partners will promote monitoring of "contemporary evolution" of invasive alien species, pests and diseases. There is a growing body of evidence showing that adaptive evolution is going on in such species, thus evolutionary changes need to be monitored to develop better management systems for them. For detecting evolutionary changes, three primary approaches can be integrated. First, observations using neutral genetic markers provide evidence for gene diversity and phylogenetic origin of alien lineages. Second, observations on phenotypic changes associated with growth, dispersal and biotic interactions provide primary evidence of adaptive evolution. Third, a large collection of ESTs (Expressed Sequence Tags) could provide genetic bases of phenotypic adaptive changes by detecting non-synonymous substitutions and also changes in transcription profiles (Yahara et al. 2010). Again, the Genetics WG will organize a global consortium for promoting monitoring of invasive species evolution.

For the third category, the Genetics WG will explore possible target species using the following multiple criteria:

- Keystone species that have large influence of ecosystem functions;
- Flagship species that attract high social attention;
- Commercially important species (crops, horticultural plants, domesticated animals, etc.) and their wild relatives;
- Economically important wild species (wild timber species, fish under massive fishing pressure and/or captive breeding, etc.);
- Wild model organisms (*Arabidopsis*, mouse, etc.) and their relatives;
- Species having good historical records.

The Genetics WG and partners will promote monitoring activities on these species by calling attention to the importance of these multiple criteria and by reviewing progress in genetic monitoring in each category. The Genetics WG will rely on key partnerships with programs/projects (for example, linked to FAO (Food and Agriculture Organization of the United Nations) or CGIAR (Consultative Group on International Agricultural Research)), that have established work on species of economic importance.

1.3.4 **Genetic diversity monitoring in biodiversity observation core sites**

For ecological observations, sites for LTER (Long Term Ecological Research) have been developed in many countries and ILTER (International Long Term Ecological Research) is organized as an international organisation networking observation activities on these sites. The Genetics WG will promote corresponding activities for biodiversity observations by developing BIodiversity Observation CORE Sites (BIOCORES). While most LTER sites are developed as research sites, often in well-protected ecosystems that ensure long-term monitoring, the Genetics WG will explore placing BIOCORES in areas where biodiversity is seriously threatened. This is because the aim of BIOCORES is to assess the processes, trends and outcomes of ongoing biodiversity loss during shorter terms than those of LTER and provide data useful for further conservation planning. It is desirable that monitoring and assessment activities in BIOCORES are integrated with conservation and adaptive management activities in the same area.

The following BIOCORES are developed by the Global Center of Excellence (COE) program of Asian Conservation Ecology in Kyushu University and the University of Tokyo. The Genetics WG activities will be extended to other core sites, based on linkages to other GEO BON working groups and to new partners. In these BIOCORES, organisms listed are inventoried in a series of plots placed along an environmental gradient, and abundance of each taxon in each plot is recorded to quantify species diversity. DNA sequences are determined for all taxa collected within plots to describe spatial distribution of phylogenetic diversities. In addition, functional traits such as leaf size and leaf nitrogen of plants and body size and body shape of animals are recorded and spatial distribution of functional trait diversities are measured in order to relate them with spatial differences of environmental variables. The Genetics WG will project changes of biodiversity by modelling spatial distributions of species diversity, phylogenetic diversity and trait diversity and examining sensitivity of these diversities to environmental changes. Some example BIOCORES developed by the COE program are listed below but additional sites need to be developed with other partners.

Tai-hu and Xiao-si, China: Tai-hu is a big lake located in the west of Shang-hai city, and Xhai-si is a river flowing into Tai-hu. While rich biodiversity still remains there, serious eutrophication and rapid biodiversity loss is going on. The Genetics WG will monitor changes of diversity for aquatic plants and freshwater fish using genetic approaches.

Tropical lowland forests in Cambodia: In Cambodia, large areas of lowland tropical forests still remain but are decreasing under rapid economic growth and increasing human population. More than 30 permanent sample plots for forest inventory are developed and maintained by the Forest Administration. The Genetics WG will monitor changes of diversity for plants and some insects using genetic approaches.

Yakushima, Japan: Yakushima is a small island with a high peak of 1986m. Forest vegetation includes conifer forest dominated by *Cryptomeria japonica* and much of the island is protected as a UNESCO World Heritage Site. However, biodiversity in the protected forest, including many endemic plant species, is seriously threatened by a rapid increase of wild deer. The Genetics WG will monitor changes of both the deer population and plant diversity using genetic approaches.

Ito campus of Kyushu University and Imazu tidal flat, Japan: Ito campus of Kyushu University is being constructed by developing a small hill. In the 275 ha area of Ito campus, a biodiversity protection project aiming at “no species loss” and “no forest loss” is in progress, using challenging new techniques such as forest transplantation. The Genetics WG will monitor changes of biodiversity under rapid land use change and intensive protection activity using genetic approaches. The Genetics WG will also monitor biodiversity changes in Imazu tidal flat that is adjacent to the Ito campus, providing a habitat for many endangered animals including migratory birds, fish, arthropods, and molluscs.

1.3.5 Phylogenetic diversity mapping

The Genetics WG its and partners will address monitoring at the phylogenetic level because such monitoring may capture aspects of biodiversity not captured at the conventional species level (see Faith et al. position paper, in review). This will help increase not only the availability of phylogenies but also the geo-referencing of species data, so that changes in phylogenetic diversity may be interpreted using remote sensing data.

The total phylogenetic diversity (PD) of any subset of lineages or taxa (e.g., species, haplotypes or other terminal taxa) from a phylogenetic tree is given by the total branch length spanned by the members of the subset. PD can be estimated using existing taxonomy in the absence of phylogeny. However, the increase in estimated phylogenies means that biodiversity assessment at this level is rapidly increasing. PD reflects the total evolutionary history of the set of taxa, and may be equated with amounts of "evolutionary potential"

Useful existing databases extend also to the phylogenetic level (e.g., through the "Tree of Life" program). DNA barcoding and similar approaches such as those used for microbes (e.g., Lozupone et al. 2007) provide patterns of genetic variation summarized as phylogenetic patterns.

One activity will explore PD indices that allow mapping of changes in phylogenetic diversity over a range of taxonomic groups. Conventionally, workers have considered maps of phylogenetic richness, but mapped indices should reflect gains and losses through PD indices of endemism and complementarity. An initial activity will explore new indices collaboratively with colleagues working on Fishbase and related databases. The Genetics WG also will further develop collaboration on a toolbox for these PD indices through the Atlas of Living Australia (with the *In situ*/Remote Sensing WG).

Another activity will examine analyses of phylogenetic diversity loss for corals, based on new "supertrees" for coral taxa.

1.3.6 Evolutionarily Distinct & Globally Endangered species (EDGE)

Evolutionarily Distinct and Globally Endangered (EDGE) species have very few or no close relatives on the Tree of Life, and therefore tend to be extremely distinct from other species in many ways, including their genetic composition. They often include some of the most unusual species and represent a unique part of the world's natural heritage. The EDGE of Existence programme (http://www.edgeofexistence.org/), aims at identifying the most evolutionary distinct and globally endangered species, to raise awareness about threats they are facing and eventually to secure the protection of these unique species. The programme was launched by the Zoological Society London and was first applied to mammals and amphibians. This activity will build on the existing EDGE groups and the addition of new ones, particularly in plants, and covers the ongoing and future programmes that will apply the EDGE approach to five major groups of plants being assessed for the Sampled Red List Index, specifically Gymnosperms, Monocots, Legumes, Pteridophytes and Bryophytes.

EDGE scores can be calculated for any clade of more than 100 species, providing that a dated species-level phylogeny exists for the group, and that each species has been assessed using the IUCN Categories and Criteria. Gymnosperms are the first group of plants to fulfil both these requirements, and the collection of data for this group has recently been completed. EDGE scores for species of Gymnosperms should be available shortly. For the other groups under study, the species sampling used will be defined by the Sampled Red List Index (SRLI) for plants, which links this activity to other activities in the Terrestrial Species WG.

Activities will include one or more trials and reviews of EDGE and alternative methods (Faith et al. 2008), including "phylogenetic risk analysis" methods.

1.3.7 Microbial 16 S diversity study—Mapping, models of community turnover

1.3.7.1 Map-based visualisation

The Rob Knight lab at the University of Colorado at Boulder is constructing a database to house microbial community profile data, while enforcing the MIENS (Minimum Information about an ENvironmental Sequence) standard for all associated metadata. As an early deliverable, the Genetics WG plans to utilize the database to generate visualisations of microbial community alpha (within-sample) diversity and beta (between-sample) diversity in the context of geographic maps, likely via the Google Earth or Google Maps API. Users will, for example, click on a single site to obtain information about that site including its phylogenetic diversity (PD) score or pie charts illustrating the relative abundance of phylotypes, or click on a pair of sites to get information about the differences between those sites, such as the UniFrac distance between them.

While recent studies suggest that one should not expect to observe geographic clustering of microbial communities, this map-based visualisation will allow users to interactively explore and compare microbial diversity, and will provide a framework for mapping phylogenetic diversity of macroscopic species (linked to Activities 1.3.5 and 1.3.6).

1.3.7.2 Integration of remote sensing observations and in situ observations

The Genetics WG, in collaboration with the *In situ*/Remote Sensing WG, will address the integration of remote sensing observations and *in situ* observations at the genetic level. Activity 1.5 links emerging large scale DNA sequence data bases to models and inference of biodiversity change through the "lens" approach (described below and in the GEO BON Concept Document). GEO BON will use approaches that sidestep the accumulation of genetic observations over time and instead rely on remotely sensed observations, over time, of changes in land/water condition. Here, spatial genetic variation models act as the "lens" for interpreting these changes. An example context is found in molecular approaches such as those used for microbes that provide patterns of genetic variation summarized as phylogenetic patterns. These patterns of genetic variation may be quantified using a measure of phylogenetic diversity or dissimilarity. The links from phylogenetic dissimilarities to environmental variables provide a basis for developing spatial models of genetic variation, as in the striking finding that global bacteria genetic diversity patterns (using 16S ribosomal RNA sequences) are strongly linked to salinity factors (Lozupone et al. 2007). This working group and the *In situ*/Remote Sensing WG will together promote the use of such spatial biodiversity models as a "lens" to interpret the observed changes over time (in ecosystem and habitat metrics such as the presence or absence of particular ecosystems, their surface area, and degree of fragmentation) derived from remote sensing. GEO BON will explore the extension and standardisation of these strategies.

One activity is a case study, initiated with the Colorado database referred to above, that will illustrate how phylogenetic beta diversity models, summarising differences from place to place in DNA sequence data for microbes, can link to measures of biodiversity change and the lens approach.

As a related long-term deliverable, the Genetics WG plans to facilitate the integration of existing microbial community diversity data with detailed ecoregion mapping data generated by the USGS to make predictions about microbial diversity in unsampled areas. These ecoregion maps, which provide ecoregion descriptions to a resolution of 60m for the United States, and are being developed for other regions, provide a framework on which to extend existing knowledge of microbial community structure from directly sampled areas to areas which have not yet been sampled based on ecoregion similarity.

1.3.7.3 MIENS and database integration section

The MIENS (Minimum Information about an ENvironmental Sequence) standard is a metadata annotation standard to describe sequences which were used as genetic markers and are derived from environmental samples. Microbial data used in the initial deliverables from the Genetics WG will adhere to the MIENS standard. Adoption of the MIENS standard by other working groups and regional BONs will allow direct relation of microscopic and macroscopic diversity data. Details on the MIENS standard can be found at http://gensc.org/gc_wiki/index.php/MIENS.

This work will be expanded through new partnerships to encourage standards for including associated geographical and date metadata with archived sequences.

1.3.8 Microbial metagenomic diversity study

At this early stage, specific activities are hard to define, but the task has gained impetus though links to the Marine WG and the shared interest in metagenomics, and the need for interpretive methods and tools.

Carola and Rolf (2009) summarise advances using metagenomics data bases: "Metagenomics has paved the way for cultivation-independent assessment and exploitation of microbial communities present in complex ecosystems. In recent years, significant progress has been made in this research area. A major breakthrough was the improvement and development of high-throughput next-generation sequencing technologies. The application of these technologies resulted in the generation of large datasets derived from various environments such as soil and ocean water. The analyses of these datasets opened a window into the enormous phylogenetic and metabolic diversity of microbial communities living in a variety of ecosystems."

Initial activities will involve meetings, including a new Genetics WG member recommended by the Marine WG.

1.3.9 Genetic diversity assessment using gene trees

Datasets containing DNA sequences of many different genes are now rapidly expanding. These datasets, provided by various strategies of genome-wide sequencing such as metagenomics, shotgun sequencing of transcripts, massive collection of ESTs, and whole-genome sequencing, have enabled us to compare a group of genes among lineages. Each individual organism has some (often many) genes with similar function derived from a common ancestral gene. In traditional phylogenetic comparisons, these multicopy genes have been neglected. However, diversity of multicopy genes constitutes a part of genetic backgrounds characterizing unique function of a particular lineage, e.g., EDGE. Standardized methods will be developed to compare multicopy gene diversity and apply them to genetic diversity assessment. A basic unit of comparison is a gene tree that is a phylogenetic tree of genes on a genome of an individual. This comparison is theoretically similar to comparison among microbial (or other groups') communities. Workshops will be organized to explore this approach and to plan a case study.

1.4 Deliverables

1.4.1 Published papers

The following papers, while not GEO BON "Deliverables", are the earliest products of the Genetics WG, intended to contribute to the documentation of key concepts and approaches of the group.

1) Faith et al. "PD and GEO BON—Evosystem Services: an Evolutionary Perspective on the Links Between Biodiversity and Human Well-Being" *Current Opinion in Sustainability*, to appear Early 2010;
2) Yahara, T., M. Donoghue, R. Zardoya, D. Faith, and J. Cracraft: "Genetic diversity assessments in the century of genome science" *Current Opinion in Sustainability*, to appear April or May 2010;

3) *BioEssays* invited Review Article paper on the Genetics WG plans/challenges, to be co-authored by the Genetics WG members. Topic: "an article on the topic of attempts to monitor genetic phylogenetic diversity at the global/regional scale";
4) *Botanical Journal of Linnean Society* invited Review Article, for special issue on International Year of Biodiversity, on phylogenetic diversity at global, regional scales. Submission mid-2010, with Felix Forest of the Genetics WG;
5) *Methods in Ecology and Evolution*, paper on ED-type methods for linking genetic/phylogenetic beta diversity models to indices of biodiversity change; submission early 2010.

1.4.2 Abundance/range to predict genetic diversity

Reports will be targeted on major taxa of eukaryotes (mammals, birds, other vertebrates, Gymnosperms, Angiosperms, invertebrates) and threatened versus non-threatened species. Special consideration will be required for species that have diverse breeding systems. After the initial report, future reports would only be appropriate at perhaps 5–10 year intervals.

The Genetics WG will plan meetings to review alternative models and anticipates a review paper as an output from those meetings.

Longer-term outputs will include tools to assess genetic diversity based on species-level observations from monitoring programs in the Terrestrial Species WG.

1.4.3 Genetic diversity loss in selected species

Through the GCOE, existing consortia exploring ubiquitous genotyping of endangered species (UbiGES) and monitoring of invasive species evolution (MIS-evolution) will be expected to form subprograms, under a unified flag of Actions for Genetic Diversity Assessment (AGenDA). Through discussion with participants (during the period up until 2011), web pages will be developed, containing standardized protocols of these monitoring activities.

A "genetic diversity report" will be released in 2012, before CBD COP11. Subsequently, a genetic diversity report will be released every two years to correspond with when a CBD COP is held. The first report is expected to contain the results of ubiquitous genotyping for 50 plant species and monitoring of invasive species evolution for 10 plant species, and a review of genetic diversity monitoring in other species.

1.4.4 Genetic diversity monitoring in biodiversity observation core sites

A summary of observed biodiversity changes in the four BIOCORES will be included in the first "genetic diversity report" in 2012. Additional BIOCORES will be established in Mongolia, Vietnam, Thailand, Malaysia, Singapore and Indonesia by 2012.

1.4.5 Phylogenetic diversity mapping

Deliverables include tools to map a variety of PD (phylogenetic diversity) indices, including those linked to various biological databases, and those that reflect PD richness, endemism and complementarity. In addition, for early trials with FISHBASE, reports on indices include those for a Japanese study for ferns, SW Australia regional PD, a Chilean PD map, and maps counting the number of EDGE top-ranked species in different areas. In the longer term, the Genetics WG plans for a Global plant PD report (by roughly 2020). Other deliverables depend on the success in engaging new partners.

1.4.6 Evolutionarily Distinct & Globally Endangered species (EDGE)

The Genetics WG and partners will apply the EDGE approach to five major groups of plants being assessed for the Sampled Red List Index. The group will also make these results available on the EDGE website; provide regular updates following acquisition of new material and changes in level of threat; and make a presentation in a colloquium at the Botany 2010 meeting in Providence, U.S.A.

1.4.7 Microbial 16 S diversity study—Mapping, models of community turnover

Several deliverables are planned in this area:

- Visualisation Unifrac maps linked to microbial community database—showing turnover in microbial diversity from place to place;
- Modelled and mapping GDM (with *In situ*/Remote Sensing WG)—this deliverable will show how turnover information can be extrapolated to other pairs of sites regionally and globally;
- Example analyses reporting complementarity values and endemism—based on the ED approach. Which places have relatively unique or unusual component of microbial diversity?

Future applications deliverables build on these basic approaches to provide, for example, survey design, scenario analyses relating to loss of intactness of places, and the "lens" approach where remotely sensed information is integrated with the microbial turnover mapping.

The deliverables may also include a form of ground-truthing or testing of the geographic turnover models as predicted sites are actually sampled.

1.4.8 Microbial metagenomic diversity study

It is too early to identify clear deliverables for this study; the WG is seeking a new partner and a key case study context in the marine biome. An early deliverable should be methods-based and answer the question: How can these data be used to provide useful biodiversity information? A candidate methodology will use gene-based phylogenetic dissimilarities among samples, with application of the same GDM type models as in 1.4.7, to create a turnover geographic surface; a review paper is an anticipated deliverable.

1.4.9 Genetic diversity assessment using gene trees

A workshop will be held to explore the rationale for this PD approach, and to write a position paper to standardize methods of comparison. Up until 2012, it is expected that nearly whole genome sequences are determined for some species of the same family for a considerable number of plant and animal families. Then, another workshop will be held to apply the standardized method to comparison of gene trees among species of these families and to evaluate how "multigene diversity loss" matters among various outcomes of biodiversity loss.

1.5 Data

1.5.1 Papers

There are no special data issues to be highlighted in this section.

1.5.2 Abundance/range to predict genetic diversity

Data sources for time series on abundance and range extent will, in the early phases, rely on existing species-level programs (depending on building of partnerships). These include: Living Planet Index component species, Long term data sets from NCEAS; marine eukaryotes from COML; and Mean Species Abundance linked to GLOBIO assessments.

The Genetics WG has established a funded partnership to explore these models, with Dr. Musters and colleagues at the Institute of Environmental Sciences, Leiden University. The keen interest in extending MSA/GLOBIO models and data to reflect species-level diversity opens the door to also considering models that allow genetic diversity inferences.

1.5.3 Genetic diversity loss in selected species

For ubiquitous genotyping of endangered plant species, some data are already available for Japanese plants and South African cycads. Additional data will be obtained by the project directed by Yuji Isagi. In order to develop global monitoring, however, data of various taxa in various regions is critical. This deficiency will be filled by activities of the international consortium that will be organized by the Genetics WG. For genetic backgrounds of invasive species evolution, some cutting-edge studies are already made for *Spartina anglica* and others. However, as far as the Genetics WG knows, more advanced techniques such as new generation sequencing have never been applied to invasive species evolution. To carry out "monitoring" of evolutionary changes, application of advanced sequencing techniques is critical. In addition, genetic diversity of any invasive species has never been monitored in its whole range. To fill these deficiencies, it is critical to organize an international consortium.

1.5.4 Genetic diversity monitoring in biodiversity observation core sites

Some data are already available, and additional data will be obtained in four BIOCORES established by Kyushu University. However, it is critical to increase the number of BIOCORES in order to develop global assessments of biodiversity changes.

1.5.5 PD mapping

Data for early deliverables comes from FISHBASE and related databases, as well as Kew Gardens collaborators and partners. Data for trialling tools also may be available through the Atlas of Living Australia, through which PD mapping tools are being programmed.

1.5.6 Evolutionarily Distinct & Globally Endangered species (EDGE)

- DNA samples from GENBANK;
- Phylogenetic trees from Tree-of-Life and partners;
- SRLI species conservation assessments from IUCN and partners.

1.5.7 Microbial 16 S diversity study—Mapping, models of community turnover

- The UNIFRAC associated data base (Rob Knight lab at the University of Colorado at Boulder) is the core microbial data source for early deliverables;
- Data needs notably include environmental predictor values for other sites.

1.5.8 Microbial metagenomic diversity study

- Data sources will be linked to one or more of the marine databases such as ICoMM;
- Genetic diversity assessment using Gene trees and PD.

1.5.9 Genetic diversity assessment using gene trees

It seems likely that early data sources will be through the GCOE.

1.6 Implementation Partners

The Genetics WG will seek partners for each of the activity areas listed above, recognising that it will be involved in early stages of implementation for some activities, while longer-term implementation will be achieved by new and old partners. For example, the group will seek new partners with novel phylogenetic data. Early stage discussions already have resulted in a list of actual or potential partners including: FISHBASE; AquaMaps; GCOE; AP-BON; Australia

Museum; Kew Gardens, EDGE workers (Kew; ZSL; NHM; SRLI); Institute of Environmental Sciences, Leiden University; University of Colorado; FAPESP; Atlas of Living Australia; Living Planet Index; COML; GLOBIO.

The WG is fortunate to be able to gain direction and support from the Center of Excellence of Asian Conservation Ecology, co-led (with Izumi Washitani) by Tet Yahara (who is co-lead of the Genetics WG and of bioGENESIS).

The BIOTA/FAPESP Program in Brazil (http://www.biota.org.br) has a work program on biodiversity conservation and sustainable use policies of the State of São Paulo (Speglich & Joly 2003). The Genetics WG has established a partnership, particularly focussing on phylogenetics aspects.

The Genetics WG has established a partnership with colleagues at the Institute of Environmental Sciences, department of Conservation Biology (CML-CB), Leiden University, to explore tools for activities listed under 1.3.2 (models value-adding to abundance data).

1.7 Coordination

The Genetics WG has links to and is coordinating with all the other GEO BON working groups included in this Implementation Plan. It also has links to emerging regional BONs. For example, the group is working with AP-BON, J-BON and the associated GCOE, which are providing important guidance as well as funding. And discussions so far suggest that the Genetics WG can similarly establish links to Brazil, through FAPESP, for a potential regional BON, with activities relevant for the Genetics WG and partners (contacts: Drs. Joly and Verdade).

Interactions with other GEOSS tasks are also anticipated, in particular, with the Ecosystems SBA Classification Task (EC-06-02) and with the Agriculture SBA.

1.8 Schedule

Activity/Deliverable	2010	2011	2012	2013	2014	2015	2016	2017	2018
Paper	X	X							
Abundance/range		X	X	X	X	X	X		
Genetic changes in selected taxa			X		X		X		X
Genetic diversity in core sites			X		X		X		X
PD mapping		X	X	X	X	X	X	X	X
EDGE		X		X	X		X		X
Microbial 16 S diversity		X	X		X				
Metagenomics			X		X		X		X

Gene tree PD			X		X		X		X
Partnerships	X	X	X	X	X	X	X	X	X

1.9 Barriers and Their Implications

The major barriers to progress for this WG are:

- Distributed participants. While the Genetics WG already has some active partners, key players in areas relevant to genetic diversity observations are widely distributed over many different places and organisations and have their own agendas and goals. This may make it hard to advertise GEO BON and attract potential partners.

- Geo-referenced data. Although huge volumes of genetic data have been accumulated in DNA databases, most of it is not geo-referenced, and thus not used for drawing maps of global and regional biodiversity patterns.

- Capacity. There is a need for capacity building (involving scientists from developing countries, sharing information regarding performing genetic and phylogenetic diversity analysis, DNA extraction protocols, advances in data analysis techniques).

- Restrictions on movement of genetic material. There are increasing trends of restricting movement of genetic samples across political boundaries (which may threaten genetic diversity monitoring at global scale).

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2 Terrestrial Species Monitoring (Working Group 2)

2.1 Introduction

The Earth is facing a biodiversity crisis, with very high rates of biodiversity loss and biodiversity change (Duraiappah et al. 2005). Many of these changes are occurring at the level of the abundance and distribution of individual species. Although much information has been compiled from existing monitoring programs and integrated into global biodiversity indicators (Walpole et al. 2009), the picture of what is happening to biodiversity at the species level remains incomplete, and this picture is biased towards a few taxa and towards the temperate zones (Pereira and Cooper 2006).

This working group focuses on monitoring terrestrial biodiversity at the species level. It aims to integrate available data, identify gaps, develop standard protocols and stimulate new monitoring programs.

2.2 Concepts to be Implemented

The GEO BON Concept Document defines two concepts that should be implemented for monitoring of biodiversity at species level: (a) changes in species distribution and abundance; (b) distribution range maps for a large number of species. However, the Terrestrial Species WG decided to focus mainly on (a). There are already several ongoing projects aimed at compiling distribution range maps (notably trough the IUCN Red List process). These maps can tell us about the status of a species or define a baseline, but give little information about change over a short time frame. GEO BON is about monitoring change, therefore the implementation plan of Terrestrial Species WG is focused on monitoring changes of species distributions and abundances.

It would be impossible to monitor change for all extant taxa. Therefore GEO BON will monitor a set of selected taxonomic groups. The taxa were selected using two types of criteria:

1) Feasibility—including the existence of ongoing monitoring programs, the availability of networks of volunteer observers or citizen scientists (Schmeller et al. 2008), and the simplicity of the field protocols or the availability of technological devices to support monitoring;
2) Functional importance—the role of that taxonomic group in delivering important ecosystem services or in sustaining ecological processes.

The taxa selected are: terrestrial vertebrates (birds, and as second priority mammals, amphibians and reptiles), invertebrates (butterflies, and as second priority other invertebrates), and vascular plants. Although, the main criterion to choose vertebrates and butterflies was feasibility, these taxa also play important roles across a range of provisioning, regulating, cultural and supporting services (Table 2.1). In contrast, plants were chosen mainly for their functional importance, but considering that, although challenging, it would be feasible to monitor globally a subset of these plant species. Another important consideration is that these taxa respond differently to the drivers of biodiversity change. For instance, vertebrates and butterflies have, in general, high mobility, being able to spatially average the effects of land-use change. Thus, it is not necessary to measure biodiversity responses in the exact place where the land-use change has occurred, as vertebrates and butterflies that are near that place are likely to respond as well. Complementarily, plants provide very local measures of land-use change. There are also differences in the sensitivity of each taxonomic group to different drivers: mammals are particularly affected by hunting and direct persecution (Baillie et al. 2004), butterflies by climate change (van Swaay 2010), and plants by invasive species (Gurevitch et al. 2004).

In each group both common and threatened species will be monitored using a representative set. This distinction is made because often the monitoring schemes have to be designed differently for these two groups of species. Still, a representative picture of what is happening to biodiversity must include both groups. Common species are very important for ecosystem services and ecosystem functioning, and rare species are particularly vulnerable to extinction.

Another issue considered was whether GEO BON should focus only on monitoring changes in distribution, by mapping presences/absences over time, or should also gather information on abundance. While many efforts in the past have focused on presence/absence, more precise measures of biodiversity change and the consequences for ecosystem services can be obtained from measuring abundance. Furthermore, in many cases the two types of information can be obtained simultaneously.

In designing a global sampling scheme for biodiversity at species level, one is confronted with two possibilities: (1) intensively monitoring a large set of taxa and other environmental variables in a few sites across the world (this is the approach taken, for example, by ILTER); (2) monitoring each taxa group in a set of sites as extensive as possible, with the sites being chosen based on the characteristics of that taxa and the observer availability (this is the approach followed for instance in the Breeding Bird Survey in North America). The Terrestrial Species WG has chosen to favour the latter approach, as it is easier to develop a global monitoring network building on existing networks and programs developed for each taxonomic group. Nevertheless, methods for integrating data from intensive site monitoring into taxon-specific regional monitoring will be explored.

The extensive monitoring approach will allow the species datasets to be compared with spatial datasets developed by other GEO BON working groups, particularly ecosystem change maps (Terrestrial Ecosystems WG), genetic diversity change maps (Genetics WG), and maps of other drivers of biodiversity change. It will also allow the Terrestrial Species WG to provide spatial maps of the response of ecosystem services based on a stratified analysis.

To implement this sampling scheme a combination of top-down and bottom-up approaches will be used to organize the network of data providers. Rather than duplicating existing *in situ* monitoring efforts within particular countries or regions, GEO BON will seek to complement and, where appropriate, coordinate these efforts from a global perspective. This monitoring scheme will then be the basis for a global indicator of biodiversity change at the species level, which could be subdivided regionally according to user needs.

2.3 Activities

2.3.1 Developing a network for global species observations

The development of this network will be organized around each taxonomic group.

2.3.1.1 Birds

Birds represent a widespread and diverse group comprising around 10,000 species living in most habitats across the globe. They are relatively easy to detect, identify and survey. They are high in food chains and are sensitive to land use and climatic changes. Long time-series exist and a mass of ancillary knowledge and information is available to aid interpretation and analysis. Survey data are realistic and relatively inexpensive to collect (if done by skilled volunteers), analyse and report. Methods of survey design and analysis are developed and proven. Birds are familiar and popular with people and have a connection and resonance with the public and decision makers alike. Bird trends can in some circumstances faithfully reflect trends in the abundance of other animals and plants.

GEO BON will coordinate the development of an observation network to support two global bird indicators. The Wild Bird Indicator (WBI) covers widespread and common bird species in the environment and is already operational in a number of regions. The Critically Endangered Bird Indicator (CEBI) covers the most threatened bird species and will have to be built from scratch, although a good deal of dedicated monitoring already exists for these species, especially through the work of BirdLife International. Trends among widespread species tell us how the environment around us is changing and thus about the sustainability of human land use at a broad scale. Trends among the rare and threatened species provide more localised information on extinction processes and the efficacy of conservation actions at a narrow scale. Both gauge extinction processes, the former at a local scale the latter at a global one.

1) Wild Bird Indicator (WBI)

GEO BON will expand the existing monitoring network supporting WBI to include progressively more countries and regions across the globe, delivering a global wild bird population indicator by 2018. The indicator would be updated annually.

In Europe and North America, wild bird indicators (WBIs) have been developed using annual count data from national surveys of breeding birds (Gregory et al. 2005; Gregory et al. 2008, U.S. NABCI Committee 2009, http://www.twentyten.net/wbi). In Europe, over 20 countries have national surveys of widespread/common breeding birds in place and new schemes are developing all the time. The survey designs differ to some degree across countries (this mostly reflects traditions in counting and the habitats involved). The former vary from random stratified designs to free observer choice. The latter include line and point transects and spot/territory mapping. Countries use a common software package called TRIM to analyse and supply trend information. Trend data are then brought together centrally to create European and European Union (EU) indices for species and multispecies European and EU indicators (http://www.ebcc.info/pecbm.html). The EU and nearly 20 national governments in Europe have adopted the indicators for use within strategies to assess sustainability and environmental health. In North America, an equivalent approach has used data from the North America Breeding Bird Survey, the Christmas Bird Count, and the Waterfowl Breeding Population and Habitat Survey to create WBIs. A similar approach is being tested in Australia using presence/absence data from their national atlas (Cunningham & Olsen 2009).

The WBI is an average population trend in a group of species (calculated using a geometric mean). WBIs are particularly suited to tracking trends in the condition of habitats. A decrease in the WBI means that the balance of species' population trends is negative, representing biodiversity loss. WBIs measure biodiversity change in a very similar fashion to the Living Planet Index (LPI), but whereas the LPI takes data available from any source, the WBI uses trend data from formally designed surveys. The WBI and LPI are entirely complementary and data from the former will feed into the latter. WBIs thus potentially provide a more precise and representative measure of biodiversity change, however, the need for robust count data currently limits the geographical coverage of the WBI. That coverage will be considerably extended.

Implementation of a WBI at a broader scale will require new monitoring to be established in those regions and countries where there are current gaps, of which there are many. An optimum and efficient design will need to be developed both in terms of a sampling strategy and fieldwork methods. One could envisage a regional design that randomly or systematically picked countries where national breeding bird surveys would be established, and their trend data would in time be combined to provide a regional overview, as well as a national one for the participants (if sampling was sufficiently intense). An alternative regional design might be to establish many survey plots of some kind for breeding birds, spread randomly or systematically across the region that would in time be combined to provide a regional overview. However, in that case the level of national sampling is unlikely to provide a national overview. There are strengths and weaknesses in both approaches. Both approaches might incorporate stratification of different kinds, such as biome type, site protection status, even observer density, to ensure representative but practical coverage of sites. GEO BON might encourage a single generic fieldwork method across sites because that would greatly simplify training, data entry and analysis. Many European countries have been encouraged, to good effect, to use a method based on the UK Breeding Bird Survey. This is based on line transects with distance bands in 1-km squares of the national grid. Squares are chosen for survey using a stratified random design (see Vorisek et al. 2008). There would be much to be gained by the use of standard approved sampling design and count method, but this would need very careful evaluation.

2) Critically Endangered Bird Indicator (CEBI)

GEO BON will support the development of an observation network, based on existing conservation and monitoring initiatives for highly threatened birds, to deliver a global Critically Endangered bird population indicator by 2018, the CEBI. The indicator will be updated annually.

The CEBI will focus on 192 bird species across the globe identified by IUCN as Critically Endangered. The index will be built on annual or repeated surveys or censuses of Critically Endangered birds. A very large number of different organisations play a role in the conservation and management of Critically Endangered birds and all might contribute to this new initiative. Foremost is BirdLife International with over a hundred national partners spread across the globe with active involvement in the conservation and monitoring of endangered species and specific programmes for this group of birds, such as their Species Champions and Species Guardian programmes. A CEBI could be constructed across species using methods equivalent to those developed for the WBI above, but could use a different approach if that proved more practical. Principles of good survey design (sampling strategies and fieldwork methods) apply equally to common and to rare birds, although for rare birds, designs are likely to vary species by species and will depend on the local conditions and constraints (in people and money, as monitoring rare species is often more expensive). It is simply impractical, and would be very costly, to census all the rare breeding birds in a country or region on an annual basis or anything approaching it, and that is why focus is placed on Critically Endangered birds. Bird counts might be annual, biannual or at some other interval (e.g., five years) depending on circumstances and practical constraints. Trend analysis and indicator production will require careful thought and development, but no barriers to creating a robust indicator for Critically Endangered birds with measured precision are foreseen. The CEBI and Red List Index (RLI) are entirely complementary and data from the former will feed into the latter.

Note that the RLI is available for all birds, mammals, amphibians and corals worldwide (with RLIs for other groups in development), but the data are most robust and have the longest time series for birds. The RLI measures change in extinction risk based on movements of species through categories on the IUCN Red List (based on genuine improvements or deterioration in status, i.e., excluding re-categorisations resulting from improved knowledge or taxonomic revisions). Red List assessments are based on application of the best available data on population size, structure, trends and range size, to the quantitative thresholds of the IUCN Red List criteria. The great strength is that it has global coverage (all species are included except the 0.7% that qualify as Data Deficient), but a potential weakness as an indicator of biodiversity trends is that it is moderately insensitive (as the Red List categories are relatively broad) and can only be updated every 4–5 years. The development of a CEBI will act as a highly useful complement to the RLI in providing an indicator for the most threatened birds in the world on an annual basis and hence will be more sensitive in the short-term.

2.3.1.2 Other terrestrial vertebrates

Besides birds (~10,000 species), there are three other classes of terrestrial vertebrates: reptiles (~9,000 species), mammals (~5,500 species), and amphibians (6,200 species). Standardized sampling schemes exist across several mammal taxa at a regional level, for example iBats (Indicator Bats Program), and the European bat monitoring scheme. However, unified regional or global schemes for monitoring reptiles and amphibians are not commonly in place (one exception is the National Amphibian Research and Monitoring Initiative, ARMI). Certain techniques will be applicable across a range of taxa (e.g., repeated camera trapping grids), however, a wide variety of techniques will be needed. Any initial baseline data could feed into building occurrence datasets. Primary data gaps are in tropical regions across all classes, particularly reptiles and amphibians.

Therefore GEO BON will facilitate the development of standardized protocols for monitoring, initially for echolocating bats (as part of the iBats programme) and medium to large sized forest mammals (as part of the Wildlife Picture Index camera trap monitoring scheme). Developing these protocols will have the added advantage of strengthening existing indicators, particularly the LPI and RLI.

2.3.1.3 Butterflies

Insects are by far the most species-rich group of animals, representing over 50% of terrestrial biodiversity. Contrary to most other groups of insects, butterflies are relatively well-documented, easy to recognize and popular with the general public. Although many people think of butterflies as the adult form pollinating flowers in summer, most species occur as herbivorous caterpillars for a large part of the year, occupying all seral stages and terrestrial niches, except for dead wood. Butterflies use the landscape at a fine scale and react quickly to changes in management, intensification or abandonment. Furthermore, a sustainable butterfly population relies on a network of breeding habitats scattered over the landscape, where species exist in a metapopulation structure. This makes butterflies especially vulnerable to habitat fragmentation. Moreover, many butterflies are highly sensitive to climate change and they have been used in models predicting the impact of climate change on wildlife; they have also been used successfully to build a European Climate Change Indicator.

So far butterfly monitoring activities are concentrated in Europe and the US, all of them built on the concept of transect counts under standardized conditions. In Europe data from fourteen countries has been brought together to build a European Grassland Butterfly Indicator. This has proven to be a successful and sensitive indicator for changes in the European wider countryside. GEO BON will facilitate the expansion of present monitoring schemes to more countries and states in Europe and the US, and to other continents. These could then be used to build butterfly indicators.

Although field methods differ to some degree across countries, most counts are conducted along fixed transects of about 1km, consisting of smaller sections, each with a homogeneous habitat type. Visits are only conducted when weather conditions meet specified criteria. Most of the transects are recorded by skilled volunteers, but their results are usually checked by butterfly experts. Site selection varies from random stratified designs to free observer choice. Countries use a common software package called TRIM to analyse and supply trend information. Trend data are then brought together centrally to create population indices for species and multi-species indicators.

Such indicators are average population trends in a group of species (calculated using a geometric mean). Like WBIs such an indicator is particularly suited to track trends in the condition of habitats. Implementation of these butterfly indicators at a broader scale will require new monitoring to be established in those regions and countries where gaps, of which there are many, now exist. The best approach is to focus on a regional design, in which continental or subcontinental groups of countries work together to build regional indicators. An initial strategy should start with one or two countries in each region, then gradually add new Butterfly Monitoring Schemes, using the experience gained. For example, Japan could be a starting point for the Asia-Pacific region, Russia and China for Central Asia, South Africa, Morocco and Egypt for Africa, Brazil and Argentina for South America and the US for North America.

The European Butterfly Monitoring Schemes are based on 7–20 counts in the season on many sites. They deliver good data on population trends for most species. Alternatively, repeat assessments of presence/absence of species (that is, full species lists for sites) may be explored when the above methods are deemed impractical. Though less sensitive to changes, it would require much less effort.

2.3.1.4 Other invertebrates

To our knowledge, no international monitoring schemes, similar to what exist for birds and butterflies, exist for other invertebrates. Several areas will be explored:

- Develop a database to integrate observations of invertebrate taxa using standardized protocols (e.g., pitfall traps for surface dwelling arthropods, interception traps for flying insects). Such standardisation allows samples to be compared in space and through time. Three critical issues must be tackled in the development of such a database: (1) selection of protocol to be included; (2) quality criteria for a given sample to be included; (3) handling the complex and moving taxonomy of invertebrates, with minimum cost for contributors;
- Observation by non-specialists. This approach may be useful thanks to the many observers that may be mobilized. Some existing examples include: WormWatch in Canada, survey of spider webs in Australia, and photographing pollinators in France. Most of these initiatives are appealing, but very young, implying that they may not be sustainable or that there is still room for assessment of usefulness;
- Observations of worms by agriculturalists. Large worms, like *Lumbricidae*, are soil emblematic species. The restricted number of species favours their choice as an indicator of soil fauna. Given their agricultural importance, observers in the agricultural community could be recruited. An indicator based on these species would be resonant with the public, given the role of worms in soils, and the major importance of soil fertility for human societies.

2.3.1.5 Plants

Plants are the primary producers for all terrestrial and almost all aquatic ecosystems. They have roles of fundamental importance in providing food, shelter and building materials for humans as well as for many animal species, for regulating climate, providing ecosystem services such as freshwater and preventing soil erosion and desertification, and for structuring habitats. Current deforestation of tropical habitats also accounts for about 20% of global carbon emissions, so efforts to conserve hotspots of plant diversity can help ameliorate global climate change. Plants are therefore essential for any initiative to monitor biodiversity, but are challenging for a global observation network because (1) there are almost 400,000 known species (Paton et al. 2008), with almost 2,000 described as new each year but a declining corpus of well trained and active field botanists, and (2) consequently most species are poorly known, often with no more than an initial description ever published, and often difficult for the lay public to distinguish from closely related species. Globally, the most comprehensive and representative "observations" of plant species are preserved specimens in the world's herbaria (and, increasingly, served through GBIF;

Nic Lughadha et al. 2005), though specimens usually lack information on the size or status of the sampled population.

A comprehensive assessment of all the world's plants is currently prohibitive in terms of time, effort and resources available and a globally representative sample of species would itself contain a majority of poorly known species. Work to assess the current conservation status of plants using IUCN Red List criteria is currently focused on a set of priority groups, including cacti, cycads, conifers, legumes, certain groups of orchids, carnivorous plants, and selected groups of trees, with assessments also underway for a number of sampled groups.

Time-series data only exists for a very small proportion of species globally (usually selected for interest *a priori* in their population dynamics and therefore not a representative sample); however, these data could be mobilized within a short period of time to provide a first snapshot of plant population trends across a diverse assemblage of species.

Appropriate monitoring standards and sampling schemes are needed. These should be suitable for use by non-specialists in developing countries to help them provide rigorous, high-quality, population-based, time-series data. Such standards need to be chosen and adopted, and a database for recording and processing the data developed to complement existing species' range and conservation status information. Online, user-friendly identification tools need to be provided to assist in-country partners in planning and executing ground-truthing surveys and reliably identifying the correct species.

The aim will be to survey as many Threatened species as possible by 2015, using a globally representative sample, by focusing on hotspots of Threatened plants and working with the appropriate counterpart organisations within each priority country (for example, INBio in Costa Rica). Global annual monitoring of a significant number of plant species is not feasible; a five-year window is more reasonable for establishing an international network and gathering sufficient data.

2.3.2 Integration of species monitoring with drivers and ecosystem services

This activity will first develop a stratified analysis of the species spatial data by ecosystem service. That is, for each type of ecosystem service, a set of species (a stratum) will be selected from the species being monitored in Activity 2.3.1. The species that will be selected for each ecosystem service are species that play a key role in the delivery of that service or that are involved in the ecosystem functions supporting that service (Table 2.1). Each monitored species/populations may be classified in more than one stratum and some strata may comprise other strata (e.g., Treaty species comprise CITES species, Bonn Convention species, etc.). The choice of ecosystem services to develop the strata and the choice of indicator species to be used will be done in articulation with the Ecosystem Services WG. During this work, gaps in the current taxonomic coverage of the monitoring programs proposed by the Terrestrial Species WG may be detected, and this will lead to an analysis of the need and feasibility of expanding the taxonomic coverage to include those species.

A second component of this activity will be the integration of the spatial species monitoring data with spatial data on drivers of ecosystem change. Species or populations are differently affected and/or respond differently to drivers of change. Analyzing datasets of species divided according to common characteristics (e.g., habitat affinity, trophic level, main threats) may reveal response patterns that would not be distinguishable from the analysis of the complete data set. This work will build on the ecosystem service strata developed and will support the analysis of the links not only between drivers of ecosystem change and biodiversity but also between drivers and ecosystem services. The Terrestrial Species WG will lead the development of a spatial database integrating at the same scales both time series data of the abundance of monitored species/populations and data on proxy variables of selected drivers (e.g., deforestation, number of households). This work will be developed in collaboration with the Terrestrial Ecosystems WG and the *In situ*/Remote Sensing WG.

2.4 Deliverables

2.4.1 Report on sampling methods

A report with standard sampling methods and guidelines for the implementation of national monitoring schemes for each taxa group.

2.4.2 Global bird monitoring data and indicators

- Harmonized bird count data at the global scale for widespread/common and highly threatened bird species;
- Wild Bird Indicators and Critically Endangered Bird Indicator at national, regional and global scales.

2.4.3 Global monitoring data for bats and large mammals and an improved LPI

Harmonized population data for echolocating bats, medium- to large-bodied forest mammals, and other well-studied vertebrate groups. The Living Planet Index will be improved with this data (and data from 2.4.2), in terms of geographical balance, temporal resolution, and taxonomic coverage.

2.4.4 Global butterfly monitoring data and indicator

Harmonized transect count data at the global scale for butterfly species. These counts will be used to produce Butterfly Indicators at national, regional and global scales.

2.4.5 **Global plant monitoring data and indicator**

Harmonized data for *in situ* changes in the abundance and status of selected plant species covering all major taxonomic groups of plants at the global scale. A global index of changes in abundance for threatened plant species.

Service	Amphibians	Birds	Mammals	Butterflies	Plants
Provisioning					
Food/feed/crops	Common water frog, Chinese giant salamander	Game birds	Antelopes, wild pig, deer		Wheat, yams, cowpea, broad bean, palm
Medicinal	Poison dart frogs	Ptarmigans, loons	White rhinos		*Aloe* spp., *Dioscorea* spp., *Daemonorops* spp.
Construction/raw material					Bamboo, cork oak, rattans, timber trees
Oil/resin		Geese	Beavers, minks		Pine, palm, jojoba eucalyptus, *Jatropha* sp.,
Crafts/ornaments	Toads	Birds of paradise	Cheetahs, bears, elephants	Swallowtails	Timber trees, legume fruits
Cultural					
Charismatic species	Tree frogs, axolotl	Raptors, swallows	Rhino, hippo, primates, wolves, pandas, Iberian lynx	Monarchs, swallowtails, birdwings	Giant sequoia, orchids, banyan redwoods, sacred fig
Treaty Species	Dendrobatid frogs, Luristan newt	Migratory passerines, waterfowl, goshawks	Large cats, bats, bears	Swallowtails, Karner blue	Orchids, ginger lily, cycads
Regulating					
Indicator Species	Newts, frogs, salamanders	Cerulean warblers, Cassin's auklets	River otter, muskrat, swamp rabbit	Alcon blue, monarch	Wild garlic, common wood sorrel, bryophytes, lichens
Vectors and pests	Frogs + chytrid fungus	Sparrows, pigeons	Bats, small rodents, deer		Purple loosestrife, kudzu, mistletoe
Invasives/aliens	Cane toads	Starling, Indian myna bird	Indian mongoose, domestic cat, macaque monkey		African tulip tree, weeds, tamarisk
Natural enemies (pest control)	Frogs	Birds of prey	Carnivores		
Pollination		Hummingbirds, honeyeaters, sunbirds	Bats, tapirs, chimpanzees	Many	
Seed dispersal		Cassowaries	Bats, squirrels		Jewelweed
Soil conservation					Sumac, juniper
Water conservation					Palms, cycads
Supporting					
Evolutionary distinct clades	Chinese giant salamander, limbless sagalla, caecilian	Asian crested ibis, scale crested pygmy tyrant, kiwi, kakapo	Aardvark, echidna, duck-billed platypus	*Toxidia* spp., skippers	Cycads, redwoods, gingkos, lycophytes, gnetophytes, monkey puzzle trees, bryophytes,
Herbivory		Seed eating passerines	Giraffes, ungulates	Most	Dodder
Decomposition		Vultures	Foxes, racoons		
N-fixation					Leguminous spp.

Table 2.1. Aggregation of species by thematic strata based on ecosystem services categories. For each taxa, examples of species playing a key role in each ecosystem service are given.

2.4.6 Spatial population times series aggregated by thematic strata

A time series data library containing population abundance data aggregated by thematic strata at the infra-national, national, regional and global spatial scales. Organisation of thematic strata will follow a nested scheme, e.g., game birds < food species < species associated with provisioning services. These themes could then be analysed together with spatial datasets of ecosystem change to identify the most important drivers of ecosystem change for biodiversity and ecosystem services.

2.5 Data

2.5.1 Birds

Currently, bird monitoring is most well-established and developed in North America and Europe, especially monitoring of widespread and abundant species (terrestrial, freshwater and marine). Monitoring of rare species is good here too, but it is spread more thinly and widely elsewhere with some notable exceptions, and population data lacks coherence and synthesis (except as part of BirdLife International's Red List assessments). Hence, major gaps exist in Central and South America, Africa, Asia, and Australasia. These are all areas of outstanding biodiversity richness and where GEO BON will focus its efforts in expanding the WBIs and CEBIs coverage.

2.5.2 Other vertebrates

The living planet index database holds trends in abundance data for 11,000 populations across 2,100 species (species split: fishes 366; amphibians 157; reptiles 55; birds 1240; mammals 389—split is roughly even across tropical and temperate regions). Other abundance databases exist (e.g., site level change in response to landuse change: GLOBIO, Alkemade et al. 2009).

2.5.3 Butterfly monitoring

Butterfly monitoring is being established in Europe and there are also some monitoring initiatives being developed in the US. In many other regions, the monitoring programs will have to be stimulated by GEO BON.

2.5.4 Plant monitoring

Recently, range estimates and conservation assessments were compiled by IUCN (Baillie et al. 2008), based on a taxonomically and geographically representative sample of almost 7,000 species from five major plant groups: bryophytes, pteridophytes, gymnosperms, monocots and dicots (legumes; Brummitt et al. 2008). Future work will shift to ground-truthing of Threatened plant conservation status for the SRLI, through standardized field surveys and monitoring, which will produce a global index of changes in abundance of plant species from this (equivalent to a plant LPI).

In-country monitoring of plant species is currently developed in Western Europe and to a lesser extent in North America, South Africa and Australasia, but poorly developed in most other parts of the world. Representative data exists across a small number of large, Western institutions but most still needs to be mobilized. Many national recording systems are in place in developed countries and it would be sensible to access these data for species from the global sample which occur there; most developing countries lack the capacity to carry out long-term monitoring of native plant species.

2.6 Implementation Partners

2.6.1 Bird monitoring

Many and varied from national to global scale. Some possible partners include: Birdlife International/Asia; Birdlife International/South America; Birdlife International/Africa; European Bird Census Council; North American Bird Conservation Initiative / USGS; and Wetlands International. It will be important to engage also the Convention on Migratory Species and the Ramsar Convention.

2.6.2 Butterfly monitoring

In Europe the production of the indicators has been coordinated by Butterfly Conservation Europe (http://www.bc-europe.eu), together with its partners. In the Americas, there is the North American Butterfly Association. In other regions GEO-BON will work with national or local entomology or butterfly organisations. As a starting point it would make sense to begin with one or two countries in each region, and after that encourage other countries to join in.

2.6.3 Plant monitoring

The following are currently involved in monitoring activities: Royal Botanic Gardens, Kew; Natural History Museum; Missouri Botanical Garden; and IUCN. GEO-BON will expand this network to include other institutions such as New York Botanical Garden; Muséum National d'Histoire Naturelle, Paris; Komarov Botanical Institute, St. Petersburg; Jardim Botânico do Rio de Janeiro; and Botanic Gardens Conservation International.

2.6.4 Crosscutting

SAEON. The South African Environmental Observation Network seeks to coordinate and support long-term, *in situ* environmental observation systems through political, technical and operational stakeholder advisory committees. SAEON's scientific design is adaptively refined to be responsive to emerging environmental issues and corresponds largely with the societal benefit areas of the intergovernmental Group on Earth Observations (GEO). More information can be found at http:/www.saeon.ac.za/.

NEON. The National Ecological Observatory Network (USA) mission is to design, implement, and operate continental-scale research infrastructure. NEON will create a new national observatory network to collect ecological and climatic observations. NEON has partitioned the United States into 20 ecoclimatic domains, and data will be collected from strategically selected sites within each domain. More information can be found at http://www.neoninc.org.

ILTER. The International Long Term Ecological Research Network is a collaborative "network of networks" involving research sites in diverse ecosystems around the globe. ILTER is a site-based approach that aims to understand ecological processes over long temporal and broad spatial scales. More information can be found at http://www.ilternet.edu/.

TERN. The Terrestrial Ecosystem Research Network is a recently created Australian network through which collaborations, infrastructure and programs will be developed that are required to meet the need of terrestrial and coastal ecosystems research. More information can be found at http://ncris.innovation.gov.au/Capabilities/Pages/TERN.aspx

AP-BON. The Asia-Pacific Biodiversity Observation was established in July 2009, and functions as a regional GEO BON partner. With the support of the Japanese government, AP-BON plans to enhance the observation activities and information facilities regarding biodiversity in the Asia-Pacific region. AP-BON aims to: engage appropriate parties required for development; open communication channels among participants; create a preliminary list of indicators and other data products; provide an assessment of the existing major systems and databases that would comprise an initial AP BON; publish an overview of activities by May 2010.

NIES. The Project on Demonstration of Technology for Monitoring Major Species Resources in China (2008–2011) has three main objectives: (1) to develop technical standards for monitoring species resources; (2) to establish 12 large monitoring plots (20 ha each plot) to monitor species resources so as to provide guidance for dissemination and application of monitoring standards across China; and (3) to assess the status of species resources in China. The project is lead by Nanjing Institute of Environmental Sciences, Ministry of Environmental Protection of China.

EBONE. The European Biodiversity Observation Network is developing an integrated monitoring system and is funded by the European Commission for the period 2008–2012. The goal is to develop a system of monitoring data for key biodiversity indicators, and to propose implementation within an institutional framework across Europe. This framework provides an approach for harmonisation of data for the European Habitats and Birds Directive. EBONE's deliverables include: a handbook on habitat monitoring; software for field computers for habitat and species monitoring; intercalibration results of remote sensing (low and high resolution) and *in situ* data. However, implementation will take a longer time as it requires adjustment of technical approaches and institutional arrangements in the countries and regions involved. More information is available at http://www.ebone.wur.nl/UK/.

2.7 Coordination

The implementation of this plan will be coordinated by the Terrestrial Species WG (note that the membership of the WG is still open). Subworking groups for each subactivity will be established (bird monitoring, mammal monitoring, etc.). These subworking groups will have at least one representative of each continent. Finally, there will be regional working groups with national representatives for each subactivity in each continent.

The Terrestrial Species WG will interact significantly with the *In situ*/Remote Sensing WG and the Ecosystem Services WG on activity 2.3.2. Much of the work in terms of information management could be developed under the guidelines from the Data Integration WG. Finally it is important to integrate the work with the Genetics WG and the Terrestrial Ecosystems WG, so that understanding of the relationship between changes at the genetic level, at the species level, and at the ecosystem level is improved. Some consideration has also to be given to integration with the Freshwater and Marine WGs, both for organisms that migrate between terrestrial and freshwater or marine environments, and to develop a cross-ecosystem understanding of biodiversity change.

2.8 Schedule

Activity/Deliverable	10	11	12	13	14	15	16	17	18	19	20
2.3.1 Developing a global network for species observations											
Establish WGs, complete gap analysis and survey designs	X										
Regional workshops		X	X								
Roll out			X	X	X	X					
Trend analysis, indicator production and synthesis (Europe and North America)				X	X	X	X	X			
Trend analysis, indicator production and synthesis (Global)									X	X	X
2.3.2 Integration of species monitoring with drivers and ecosystem services											
Workshop for statistical modelling and data integration			X								
Roll out				X							
Maps of biodiversity change for each stratum					X	X	X	X	X	X	X

2.9 Barriers and their Implications

The major barriers to progress for this WG are:

- Intellectual property and differences in sampling designs are a barrier to data exchange. It is an all-win situation if the exchange of metadata, i.e., estimates derived per scheme with standard statistical procedures, is supported by all involved parties. However, it needs training and a discussion among monitoring coordinators and other stakeholder groups. A more complicated issue is the sharing of the raw data, i.e., the point or transect counts. This is the focus of some initiatives such as the Conservation Commons (http://conservationcommons.net/) and GBIF, but much work lies ahead to fully deliver the potential of such initiatives;
- Differences in monitoring protocols across regions, observers and institutions are a barrier to the integration of biodiversity monitoring data. Much more effort should be placed in harmonizing protocols and developing statistical tools (cf. meta-analysis methods, interpolation models, models mixing different data sources, cross-validation) to increase the level of integration of monitoring data. Policy makers would benefit from more robust conclusions, at more appropriate spatial and temporal scales;
- Monitoring duties and budgets are not distributed according to the international importance of a nation's biodiversity. Fixing this is important for the establishment of an international monitoring framework. Here, the determination of national responsibilities and setting conservation priorities will help. Conservation decisions would become more transparent, allowing an optimal allocation of the limited financial and human resources across supra-national states (USA, Canada, Australia) and state unions (European Union) in a comprehensive way. Developing countries, located in biodiversity rich regions, may also use such a common approach to explain demands for financial support for the conservation of populations and species of high international importance. A common approach would also make clear to decision makers where biodiversity monitoring needs to be intensified and improved in order to close information gaps in regards to distribution, abundance, and taxonomic status of species.

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3 Terrestrial Ecosystem Change (Working Group 3)

3.1 Introduction

The goal of the Terrestrial Ecosystem WG is to harmonise ecosystem mapping and monitoring so that the data are exchangeable; this will facilitate collaboration in a global context. To meet this goal global information and approaches for exchange and harmonisation on terrestrial ecosystems will be provided, focusing on distribution, extent, condition, change in parameters of ecosystems, and identification of major players, gaps, barriers and opportunities. The GEOSS Global Ecosystem Mapping Task, from the Ecosystems Societal Benefit Area, is an important input to Terrestrial Ecosystem Change Monitoring.

An important issue is the development of comparable approaches for different continents to enable reporting at a global level. Analyses on the ecosystem level allow comparisons between continents, such as Latin American and African savannahs and deserts, wetlands, and tropical rain forests over the world. This requires globally exchangeable definitions, methods, standards and metadata.

Monitoring of ecosystem change seeks to observe both year-by-year changes and long term changes in ecosystems under natural succession, as well as under the influence of human impact such as land use change and climate change. The important issue is to detect the difference between natural and human-induced changes and the resulting impacts.

An ecosystem is a natural unit consisting of interdependent organisms (plants, animals and micro-organisms) that share the same habitat and are functioning together with all abiotic factors of the environment (Naeem et al. 1999). Ecosystems are conceptualized and mapped by their major structural elements, including biogeographic region, bioclimatic region, landform, geology, surface moisture potential, and land cover (Figure 3.1). Ecosystems are inherently hierarchical since they can be nested within other ecosystems. The largest ecosystem is the biosphere itself. At the next level down, about twenty global terrestrial "biomes" (major ecosystem zones such as the polar system, the tropical rain forest, the savannah system) are recognised.

Various terms are in use to describe ecosystems, and there are different thresholds for detecting change in ecosystem function, extent, and composition. The terms ecotope and habitat are being used to describe the spatial expression of ecosystems. Global comparison, global modelling and statistics require that definitions used in different parts of the world are comparable and exchangeable and that data are standardised. Global standardisation does exist for species through the Linnaean classification, but not yet for ecosystems.

The word “biodiversity” is used to describe the diversity of life at all levels, from genes to the

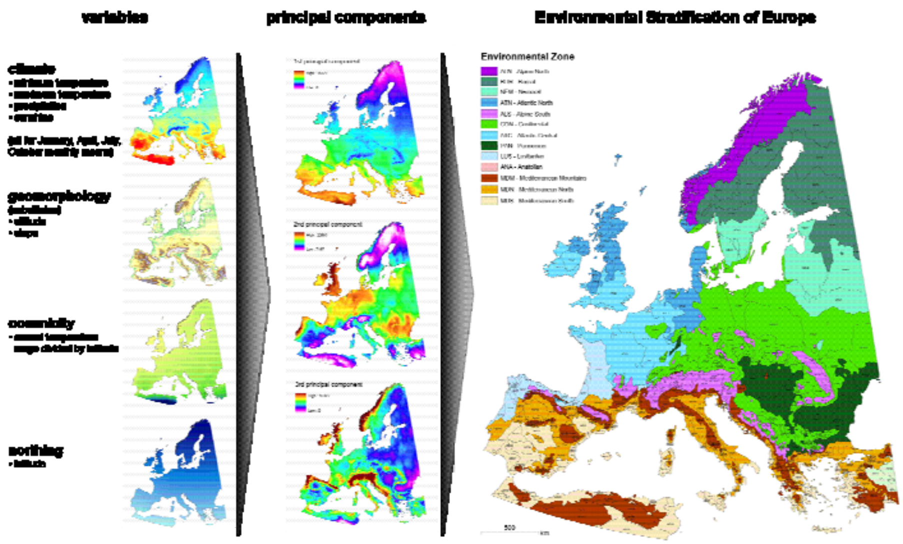

Figure 3.1. The Environmental Stratification of Europe was constructed by statistical clustering of the principal climatic gradients derived form 20 mainly climatic variables. The resulting 84 strata have been aggregated to thirteen Environmental zones. (From Metzger et al. 2005)

biosphere. This term is widely used at all levels of society and information is provided by a wide range of players. In some fields of biodiversity, coordinating institutions exist at the global and national level and these act as clients for information and/or coordinators of data. Most organisations have historically grown on an ad hoc basis dealing with problems and issues as biodiversity interest groups. The historic, political and scientific situation has changed over time and the institutions have changed with them. Therefore, there is now a wide range of institutions that represent the multiple levels of governance and the broad range of interests involved (UNEP-WCMC 2009).

The major clients for biodiversity information are the biodiversity-related Conventions such as the Convention on Biological Diversity (CBD), the Convention on Migrating Species (CMS) and the Wetlands Convention, as well as the nascent Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES), the European Commission, and national and regional governments. These different types of institutions are interlinked through mutual exchange and all make use of each other’s reports and knowledge.

3.2 Concepts to be Implemented

3.2.1 Terrestrial ecosystem stratification and classification

Environmental stratification into homogeneous biophysical regions helps in the comparison between sites across large heterogeneous areas (Bunce et al. 1996; Jongman et al. 2006). A global stratification system can provide a flexible framework suitable for a wide range of applications, including the coordination and analysis of global biodiversity observation efforts and environmental assessments. Statistical clustering of climatic data has proved successful in creating more detailed stratifications, e.g., in the UK (Bunce et al. 1996), Europe (Metzger et al. 2005, Figure 3.1) and New Zealand (Leathwick et al. 2003). The stratifications are flexible, and can be adapted for specific analyses or objectives.

Within the context of biophysical stratifications ecosystem structure can be mapped over continental scales and regions and then integrated and reconciled to expert-derived ecosystem classifications to produce ecosystem maps. This approach develops a database containing maps of the vegetation types that occur or are expected to occur (potential ecosystems) in unique biophysical environments, and when combined with satellite image-derived land cover produces maps of natural remaining ecosystems and converted landscapes (Sayre et al. 2006, 2009). This is the approach taken by the GEO Ecosystem SBA and, to date, has been implemented for South America, the United States (Figure 3.2) and sub-Saharan Africa.

A terrestrial Ecosystem GIS database will be a central product and have several potential uses for GEO BON. It can be linked to the oceanic biogeographic realms and provinces that have already been described through the Large Marine Ecosystem (LME) Concepts (see Figure 5.1, http://www.lme.noaa.gov, Longhurst 1998).

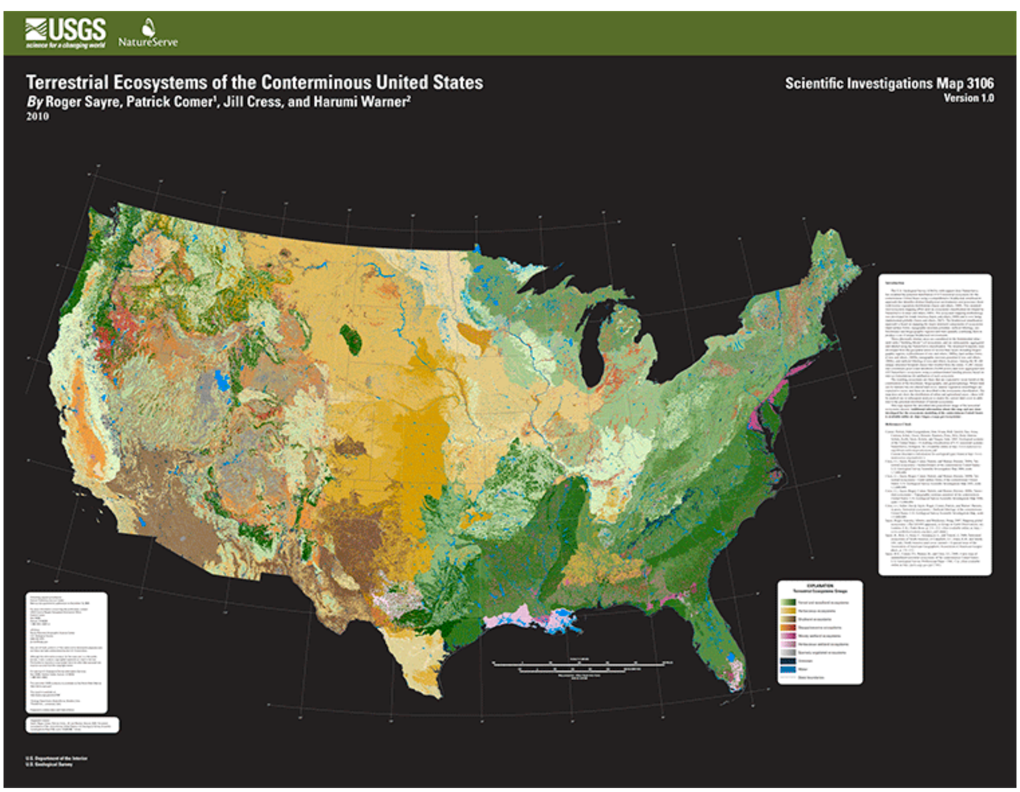

Figure 3.2. An ecosystem map of the USA as part of the output of the GEOSS ECO-09-01b Task. The map shows 419 ecosystems mapped at a 30 m base resolution for the United States. The Ecosystem map includes not only biophysical, but also biotic information on land cover and ecosystems. (From Sayre et al. 2009)

Changes in ecosystem distributions can be assessed by replacing the original input layers with new data layers and remapping the ecosystem occurrences. This methodology therefore allows for a simple assessment of changes in ecosystem extent after incorporating changes in land cover or climate regions.

3.2.2 Monitoring terrestrial ecosystem change

Ecosystem change monitoring looks at annual as well as long term changes in ecosystems due to natural succession as well as human influence. As noted in the GEO BON Concept Document, "… GEO BON will provide global information on terrestrial, freshwater, and marine ecosystems, focusing on their distribution, extent, and condition, and how these parameters are changing over time." When monitoring ecosystems *in situ*, the difficulty has always been to reconcile the field measurements with recognisable ecosystem categories that can be consistently applied and used for continental, national and regional estimates, and, if needed, harmonised for global purposes.

Ecosystems within each biome share a suite of biological, climatic, and social factors, and for each of these a number of variables should be measured in order to monitor ecosystem changes. GEO BON plans to use seven factors: Climate, Geophysical, Land Use, Surface cover, Processes, Species composition, and Management.

During the GEO BON Implementation Plan Meeting of 22–25 February 2010, the Terrestrial Species, Terrestrial Ecosystems, Freshwater, and *In Situ*/Remote Sensing WGs identified *in situ* data for parameterizing and testing spatial models of ecosystems as a vital need. Such data are recorded from primary field observations—they are essential deliverables and important for future interpolations of biodiversity observations. The quality of model results is directly linked to the quality and quantity of *in situ* data inputs as well as the distribution of the sampling sites across environmental and geographic space. However, the geographic distribution of sites that could provide *in situ* data is inadequate for global application and therefore present a major limitation to global modelling of biodiversity components (genes, species, ecosystems) across space and time.

3.2.3 Terrestrial Ecosystem Functioning Index (TEFI) and other indices

GEO BON plans to develop a Terrestrial Ecosystem Functioning Index (TEFI) that will characterize the health of ecosystems and help monitor how it is changing. Summarizing aspects of biodiversity and ecosystem function into a single index is not a new idea, and precedents such as the Biological Intactness Index (BII; Scholes and Biggs, 2005) have demonstrated potential pathways forward in this area. However, most indicators focus on trends in species and area. In contrast, TEFI will focus on ecosystem functioning; development of TEFI, including testing, is planned to be a major early activity of GEO BON.

TEFI will need to encompass a range of ecosystem processes that links different SBA measurements through ecosystem functions that at minimum include regulation of energy, water, carbon, and nutrient balances. The index can be constructed either in absolute terms or in relation to reference systems in a given biome. It could be built on some or all of the following:

The energy balance component, as it includes the exchange of absorbed and reflected radiation (summarized by albedo) and the re-emission of IR radiation by the system;

The water balance component, as it includes the inputs, outputs, and storage of water. Inputs are generally dominated by precipitation (rain and snow) but may include important components of fog interception, dew, and even advection of groundwater or irrigation (in managed systems);

The carbon balance component, as it reflects the ecological processes of growth recruitment, mortality, primary productivity and respiration;

The nutrient balance component, as it includes the inputs and outputs of nutrients and the important internal recycling.

The balances of energy, water, carbon, and nutrients are already routinely measured at a number of sites, which could be designated as GEO BON Observation Nodes. Expanding the network of GEO BON Observation Nodes can also expand the data available to measure TEFI (see section 3.3.2).

The CBD Ad Hoc Technical Expert Group (AHTEG) has considered several indicators that could express ecosystem health such as the established "Marine Trophic Index". Other indicators of ecosystem integrity for freshwater and terrestrial ecosystems would be policy relevant but they would be based on species characteristics such as body size and lifespan. Nitrogen deposition is one of the few elaborated indicators that is related to ecosystem functioning (http://www.twentyten.net/indicators/hl_trophicintegrityofotherecosystems).

3.2.4 Common denominators and data harmonisation

The development of a global biodiversity monitoring system under GEO that links *in situ* and remote sensing (RS) information needs common denominators. This means that common terminology and standards have to be developed to define comparable ecosystems in the same way and make databases exchangeable. However, global guidelines mean that methods will have to be compared and tested in all biomes of the world.

Forest definitions differ between international organisations such as FAO, CBD and UNFCCC (Schoene et al. 2007), and between European countries (EEA, 2006). In these definitions, height, tree density, area and species composition play a major role. In Europe differences also exist between countries in defining grazing land; in some countries heath lands (low scrub) are included while in others they are excluded, depending on farming practice. Differences in these definitions are important when identifying and reporting on forest decline, land conversion and carbon sequestration.

The Land Cover Classification System (LCCS) approach of the FAO for classification of land cover data is based on Plant Life Forms (Raunkiaer 1934) as a global unifying concept (Di Gregorio and Jansen 2000). In Europe EBONE[4] is developing a classification system in a comparable way for the Temperate, Mediterranean and Desert ecosystems to be used for *in situ* observation and to link *in situ* and RS observations (Bunce et al. 2008). Many qualifiers have already been added to cover situations outside Europe but they will need testing in a variety of situations to ensure they are robust. This classification system includes detailed information on environment, site, management and species composition that can be used as the primary structure for recording ecosystems. It also provides links to national and other higher level, continental ecosystem classifications. A GEO BON activity is to extend and elaborate the FAO Land Cover Classification System into a global habitat and ecosystem classification system that satisfies the needs of biodiversity monitoring.

Organising *in situ* monitoring in a modular way provides flexibility so that it can be adapted to local conditions such as regional biodiversity, need, budget, the area to cover and the knowledge available in a region. Such modules will be essential in developing global biodiversity monitoring guidelines for different biomes, as well as enable a common exchangeable approach as is required for international cooperation projects. A modular approach can also link species monitoring with ecosystem monitoring and so allow ecosystems to be used as proxies for species that cannot be monitored easily due to technical, budgetary or capacity restrictions.

Ecosystem monitoring implies a definition of the scale on which the systems are being observed. An ecosystem is a community of organisms and their physical environment that exist within a defined habitat, plus the interactions among them. Ecosystems occupy a more-or-less defined area, and can be nested within other ecosystems. Common approaches for *in situ* monitoring of changes in ecosystem extent require definitions that are harmonised continentally and globally.

Habitat quality can often be used as a proxy for species occurrence. Because the methodologies of habitat data collection are similar for all wetlands, a common or at least exchangeable habitat monitoring approach can be used as the basis for biodiversity monitoring and reporting on the status of wetlands and wetland species.

3.2.5 Clients and data access

Developing a global ecosystem change monitoring system depends upon adequate access to the observational data that have been collected; a variety of issues affect such access.

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[4] European Biodiversity Observation Network, EBONE (http://www.ebone.wur.nl/UK/) is a GEO BON Regional BON for the European region.

The United Nations system and related governance processes have demonstrated a steadily increasing interest in drawing on scientific information and advice to fulfil their responsibilities to advance human health, welfare, and development, while better managing and conserving the environment and natural resources. This has often been done via Multilateral Environmental Agreements through, for example, the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) of the Convention on Biological Diversity (CBD), the Animal and Plant Committees of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), and the Scientific and Technical Review Panel (STRP) of the Ramsar Convention on Wetlands.

Also UN scientific advisory groups such as the Intergovernmental Panel on Climate Change (IPCC), the leading body for the assessment of climate change, makes use of monitoring information through the models that it applies. Ecosystem and biodiversity information is part of its data needs. The UNEP World Conservation Monitoring Centre (UNEP-WCMC) is an organisation working in support of governance processes to improve the information available for decision making.

In most countries sensitive data, such as the exact number and location of "red list species", are protected. Data on sensitive regions such as mining areas and military areas are excluded in many countries. The *in situ* data providers are partly organised as national or regional agencies. In some cases official data collection organisations are decentralised agencies within a country or a region. Besides the national and regional agencies, data can also be collected by universities (Northern Ireland, Sweden), and in many cases NGO's collect data on special species groups. In China field data is normally personally (or small group) owned and the confidentiality depends on the personality of the owner. Here national data coordination does not yet exist, data are mostly collected and stored through research projects. This might lead to variability and incompatibility of data and probably in the end loss of data.

Information on biodiversity is widespread, but the ownership and intellectual property rights are with the data collecting organisations that are not always the clients or users. In many cases *in situ* data are only provided under certain conditions. Global collaboration and exchange requires that these conditions are harmonised and guarantees are given to the data owners for appropriate use and acknowledgement. This also means that the clients get access to national and regional information and that cross-border harmonisation is agreed upon.

3.3 Activities

3.3.1 Ecosystem stratification at global scale

This activity has two major components: (1) the development of a Global Environmental Stratification (GEnS) based on a statistical clustering of climate data into quantitative and objective macroclimatic regions, and (2) the development of a global Ecosystems Database consisting of maps at spatial and thematic resolutions finer than existing global ecoregion classifications. This latter activity is a direct linkage and incorporation into GEO BON of the environmental layers produced by the GEOSS Task EC-09-01b from the Ecosystems Societal Benefit Area.

Based on the procedure used for Europe (Figure 3.1), a global GEnS will be constructed. It will recognize approximately 120 strata, which should provide sufficient detail to link similar environments within and between continents. The resulting dataset will provide a flexible GIS layer, which can be combined with biogeographic realms, detailed landforms (e.g., those by USGS), and other ancillary datasets as required or can form input to Global Ecosystem mapping activities, described below. Furthermore, detailed regional stratifications can be developed within the GEnS strata, as demonstrated for Europe.

The initial development of the GEnS will be completed as part of the European Commission-funded FP7 EBONE[5] project to provide a framework for linking activities in Southern and Northern Africa, Western Australia and Israel to the Mediterranean activities in Europe. The development of the GEnS will involve the following steps:

1) Identification of the most appropriate data (biome, climate, land forms);
2) Statistical clustering;
3) More detailed assessment and interpretation of results for Mediterranean strata.

Concepts and data products from the ongoing Ecosystems Task will be used in GEO BON to produce a baseline map of global terrestrial ecosystems. That Ecosystems task is a global ecosystem classification and mapping effort and is currently underway. The Task charge is as follows: *Develop a standardized, robust, and practical global ecosystems classification and map for the planet's terrestrial, freshwater, and marine ecosystems.*

For the global Ecosystem Database, several large areas remain to be mapped, and discussions are currently underway with the appropriate governmental and non-governmental entities in Canada, Central America, Mexico, Australia, China, the Asia and Pacific region, and Europe. Data from GEnS will greatly facilitate the global ecosystem classification and mapping effort through the provision of key input data layers.

3.3.2 GEO BON observation nodes

There is currently no global network of *in situ* field stations and no coordinated worldwide effort that can provide consistent *in situ* data for biodiversity monitoring. As discussed with NEON

[5] European Biodiversity Observation Network, EBONE (http://www.ebone.wur.nl/UK/) is a GEO BON Regional BON for the European region

and ILTER, a well-distributed system of "GEO BON Observation Nodes" is important for integration of biodiversity into global modelling. Such a system of sites could deliver coherent and consistent data for climate modelling, agricultural potential modelling, water availability assessment and change in biodiversity, as well as be useful for capacity building. During the GEO BON Implementation Plan Meeting of 22–25 February 2010, the Species, Ecosystem, Freshwater, and *In Situ*/Remote Sensing working groups discussed and agreed internally on the need for a global network of Observation Nodes.

GEO BON will build on existing monitoring and scientific capacities. It is recognized that many potential partners exist worldwide, although many of the potential partner organisations and sites (such as ILTER, NEON, BIOTA) have research as their primary orientation as opposed to monitoring. To initiate formation of a network of existing sites and attract new partners, GEO BON will create a "label" indicating membership in the network of GEO BON Observation Nodes. Being labelled "GEO BON Observation Node" should help sites with funding; shared tools and data from other GEO BON Observation Nodes will also be available.

Development of the network of GEO BON Observation Nodes requires that new sites, with appropriate physical infrastructure and a practical system of research, be identified. Education and training will be required, especially in developing countries.

A well-distributed network of GEO BON Observation Nodes is important for global biodiversity modelling because it can deliver coherent and consistent data, but it is also important for climate modelling, modelling of agricultural potential, and water availability assessment. Therefore, both a collaborative network of field stations as well as a global biodiversity database are needed. GEO member nations with remote sensing resources could provide a stream of site-specific imagery for station managers and scientists. Such a network could open up opportunities among GEO member states for bilateral and multilateral cooperation in biodiversity science. The Global Environmental Stratification, available in 2010, will help determine the preferred locations of the GEO BON Observation Nodes.

The Observation Nodes will utilize a modular data gathering approach, where various levels of monitoring can be chosen depending on the available capacity. This allows countries or institutions to participate even when they have a relatively low level of technical facilities. The module with minimum observation effort would collect a minimum data set whereas the most complete module would represent a nearly ideal data collection system. As an example, for observation of terrestrial productivity and biodiversity, the following approach might work well:

- Observation Module 1
    - Meteorological measurements = temperature, precipitation
    - Productivity measurement = biometric measurements of above-ground biomass (AGB) and AGB-change.

  - Biodiversity = ecosystem mapping, plant species, birds, invasive species
- Observation Module 2
  - Meteorological measurements = Photosynthetically Active Radiation (PAR), humidity, evapotranspiration
  - Productivity measurement = biometric measurements of below-ground biomass and BGB-change
  - Biodiversity: vegetation composition, pollinators, mammals, management
- Observation Module 3
  - Meteorological measurements = upwelling and downwelling longwave and shortwave radiation, diffuse and direct PAR, atmospheric deposition
  - Productivity measurement = eddy covariance flux measurement of net ecosystem exchange, high resolution LiDAR and hyperspectral annual remote sensing coverage
  - Biodiversity: selected soil fauna, insects, population dynamics for selected species, genetic information

Development of a set of GEO BON Observation Nodes will require a small working group that needs one year to identify existing sites and to analyse gaps as a first phase. A second phase of four to nine years duration will recruit new sites and new funding to fill gaps and develop capacity building programmes, as well as build up the monitoring sites and embed them in an appropriate structure that guarantees long term functioning.

3.3.3 Terrestrial Ecosystem Functioning Index (TEFI)

The initiative to develop a Terrestrial Ecosystem Functioning Index should be discussed within the fora that develop and assess biodiversity indicators such as CBD, OECD and EEA/SEBI. If the indicator is considered to fill a gap then a Working Group can be assembled to initiate TEFI development by bringing together several approaches used for International Long Term Ecosystem Monitoring (ILTER, BIOTA, NEON). The objective of this group will be to compare approaches in different continents, to identify key issues to be carried out, gaps in geographical distribution, and to harmonise long term studies in ecosystem functions. For example, in Africa many of the biodiversity and ecosystem surveys have been done in the context of the BIOTA-Africa project (http://www.biota-africa.org) that conducts standardised surveys in Namibia, South Africa, Ivory Coast, Benin, Burkina Faso, Kenya and Morocco. In Europe coordination within LTER has just started.

A strategy for development of the TEFI as a global measure will depend upon the acceptance of the indicator as such, the ease of data collection and modelling, and extrapolation based on the GEO BON Observation Nodes.

The Observation Nodes will provide sets of standardised data for deriving the TEFI and developing ecosystem change reports; ground truth data from the Nodes will support remote sensing and modelling approaches. An ideal TEFI requires intensive measurement but can be build upon the network of GEO BON Observation Nodes and make use of globally existing observation points.

The strategy for further TEFI development will depend upon measurements at the GEO BON Observation Nodes. The ground-based measurements should ideally be complemented by airborne hyperspectral and LiDAR measurements taken approximately annually over the GEO BON Observation Nodes. Such airborne data can be used to provide scaling information for model calibration and validation.

3.3.4 Guidelines for measuring *in situ* and RS terrestrial ecosystem change

In cooperation with the Species, Freshwater, and Ecosystem Services working groups a new working group will be formed to define a standardized set of ecosystem state and process variables and the potential drivers of ecosystem changes that should be monitored, as well as the protocols and standards to collect and record them. This requires baseline information about the natural variation of ecosystem state and process variables in order to identify thresholds that could be interpreted as indicators of ecosystem changes and a quality assurance policy. It is also necessary to link *in situ* records to a standardised framework and develop comparable definitions for *in situ* and RS ecosystem observations.

The task of the new working group will be to propose common definitions of ecosystems and their environmental qualifiers. Harmonised standards and protocols are a prerequisite for measuring and sharing data on global change. The working group will help make data mutually exchangeable between groups, agencies and countries; common standards and protocols based on common data types and spatial and temporal scales will allow global reporting.

The working group will facilitate development of a standardized, spatially and temporally integrated global process for ecosystem monitoring. International nomenclatures are already being used for ecosystem description. However, the definitions as used by organisations such as the UN Conventions, FAO, and UNFCCC and by countries such as in Europe should be included. Although internationally accepted definitions are being used by policy makers, industry and researchers, there are too many to be consistent.

The activities are:

1) Set up a working group in charge of defining the key variables and the protocols to

collect and record them at different scales (see also http://www.ebone.wur.nl);

2) Identify the major habitat definitions used globally in ecology as well as in RS work;

3) Coordinate and harmonise global definitions of ecosystems, develop protocols for harmonising data according to common standards, and support observation of ecosystem change. This includes the adjustment of data standards of the FGDC (USA), INSPIRE (EU) and other data standardisation committees. Use should be made of recent results developed under GEOSS and within national and international research programmes;

4) Identify the monitoring approaches that allow data harmonisation among global biomes and continental and national monitoring protocols through common denominators of ecosystem state and change variables; qualifiers defining the dynamics of natural environmental fluctuations, such as temperature, precipitation, and other abiotic factors should be included.

3.3.5 Data exchange, intellectual property rights and confidentiality

This activity is shared with the Genetics, Species, Freshwater, and Marine WGs, as it concerns all species and ecosystem data, especially those collected *in situ*. Owners of sensitive data that are often protected, such as the exact number and location of "red list species", will be included in a working group on the use of data and intellectual property rights. The field data providers, partly organised as national or regional agencies and partly as NGOs, are important parties to be involved. Some of these data owners are decentralised agencies within a country or a region, or institutions such as universities that are intellectually or financially dependent on the data. In some countries institutions have developed procedures for user agreements or confidentiality contracts when exchanging data; in other countries data are not shared, get lost or do not become available at all. A general provision on formats and data strategy must be developed especially for ecological *in situ* data to help overcome the unavailability, the variability and incompatibility of data.

Activities that fall under this heading include:

- Identification of the different data owner groups and inventory of the rules they apply;
- Identification of legal procedures for data sharing and Intellectual Property Rights (IPR) and identify barriers for data sharing;
- Development of coordinated procedures for sharing data between data owners and clients, taking care that data are only used in agreement with the conditions set;

- Development of standardised protocols on intellectual property rights, valuing the ownership in intellectual and/or financial recognition and taking into account the restrictions of different GEO partners.

3.4 Deliverables

The following deliverables will be produced.

3.4.1 Global environmental stratification and global ecosystem classification

This deliverable consists of two related products. A system of Global Environmental Strata will be produced available to the GEO community. This can be used for stratification of monitoring activities and as a basis for refined global modelling and reporting such as climate modelling and MA reporting. Based on this, continental ecosystem mapping activities are being elaborated for the parts of the globe that are not yet covered by GEOSS Task EC-09-01b.

3.4.2 Network of GEO BON observation nodes

This deliverable is a global network of Observation Nodes that can be used for measuring change in species diversity and abundance as well as ecosystem quality and extent. It will build on existing networks, but improve global balance by using the Global Environmental Stratification. To balance the dominance of sites in Europe and northern America a proposal will be made to develop new permanent Observation Nodes in the New Economies and Developing countries.

3.4.3 Terrestrial Ecosystem Functioning Index (TEFI)

This deliverable is the Terrestrial Ecosystem Functioning Index (TEFI) that will indicate how ecosystems are functioning; it includes data on energy, water, carbon and nutrient balance as well as biotic information. The TEFI is under development but further modelling effort is needed to develop it into a well-balanced indicator.

3.4.4 Harmonised definitions and approaches for *in situ* and RS observation

Because there are many approaches for defining habitats, ecosystems and RS data, continental and global data tend to be coarse or incomparable. This deliverable will provide common definitions, derived from the existing definitions and formulated by conventions and national and international data standardisation committees. A related product will be a set of guidelines for global data harmonisation for data relating to ecosystem change.

3.4.5 Guidelines for data sharing and IPR

This deliverable is a set of guidelines for sharing data between data owners and clients, including national data owners, institutes, university research groups and NGOs. Covering both *in situ* and RS data, it will focus on standardised protocols for handling intellectual property rights, including provision of intellectual and/or financial recognition and taking into account the restrictions of different GEO partners.

3.5 Data

Ecosystem monitoring is carried out in Europe as habitat monitoring, but different countries apply it in different ways. The reporting on the Habitats and Species Directive showed that within Europe data are collected in such variable ways that comparison and joint reporting was not yet possible beyond the national level.

The most often used proxy for ecosystem data is land cover, but this can only be used for the main ecosystem types such as "tropical forest" because it does not distinguish between, for example, primary and secondary forest, and it combines evergreen and deciduous forest into a single category. Land cover definitions depend on the agencies that interpret the reflectance data. New hyperspectral and LiDAR tools will provide improved performance in the near future, but the results will need to be well-coordinated.

Ecosystem data are essential for data integration among GEOSS Societal Benefit Areas. Such data are at the basis of species diversity as well as ecosystem health, ecosystem services and climate modelling impacts. The present situation of poor data availability calls for an effort to set up a globally accepted system of ecosystem monitoring data in a harmonised way as described above in the deliverables.

3.6 Implementation Partners

The implementation of the Terrestrial Ecosystem Change component of GEO BON requires global cooperation. This means that wide-reaching institutions such as GBIF and UNEP-WCMC are needed and can help coordinate global activities; but national and subnational partner organisations, mandated by their governments to carry out observation tasks, are needed as well. For all actions the partnership has to be well-developed and include all continents and major countries and institutions.

Key partners in the ecosystem classification and mapping work for different regions generally include: government mapping agencies; ministries of environment, forestry, or science and technology; government and non-governmental conservation groups; and university research institutes. These are essential for harmonising *in situ* and RS observation definitions and approaches.

The Long Term Ecological Research Sites should be included as GEO BON Observation Nodes. There are a variety of ecological/biological field station membership groups such as ILTR, LTER, OBFS, NEON, BIOTA Neotropica, and BIOTA Africa. Their representatives and experts in monitoring, partnering with the GEnS developers, can develop a system and estimate the cost per site and for the network as a whole.

Activities such as the GEnS and the Ecosystem Database system can be carried out by rather small dedicated groups, as they mainly require dedicated coordinators and scientists who carry out the work and who have access to the data.

Actions such as data confidentiality, data ownership and data sharing could be integrated as a sub task in the data sharing activities of GEO, but it requires access to the policies of the individual global and national organisations such as Birdlife International, Wetlands International, national NGOs, national and regional agencies, research institutes, and individual researchers.

3.7 Coordination

The work of the Ecosystems WG should be coordinated with the following groups and partners:

- For Deliverable 1, the GEnS and the Ecosystem Mapping task, coordination and close cooperation does exist with the GEO Ecosystem Task EC-09-01b. This Deliverable will be coordinated with other WGs and SBA's when finished;
- The realisation of the network of GEO BON Observation Nodes is an activity that requires coordination with other WGs, such as Species, Freshwater, and *In Situ*/Remote Sensing. The Nodes can only be developed successfully if done in close cooperation with as many partners as possible. The communities of practice of other SBAs should also be involved;
- For the TEFI the main coordination is with the organisations that are involved in the development of indicators;
- For the working group on definitions and harmonisation of approaches, coordination is needed with at least the Species, Freshwater, and Ecosystem Services WGs, and probably the Marine WG as well;
- Data sharing and Intellectual Property rights are an issue that concerns all GEO, but it is recognised that the data ownership in the Biodiversity SBA might be more complex than elsewhere due to the many organisations involved. However, the first organisation to pick this up is GEO itself with an input from the Genetics, Species, Ecosystems, Freshwater, and Marine WGs.

3.8 Schedule

Deliverable	2010	2011	2012	2013	2014	2015	2016	2017	2018
1a. Global Environmental Stratification	X								
1b. Global ecosystem classification and map		X	X	X	X				
2. GEO BON Observation Nodes		X	X	X	X	X	X	X	X
3.TEFI: Terrestrial Ecosystem Functional Index			X	X	X	X	X	X	X
4. Harmonisation of definitions and standardisation of data for field and RS observation data, including guidelines for collecting and measuring ecosystem change variables and drivers	X	X	X	X	X				
5. Advice on data sharing of biodiversity data at the international level including field and RS observation data		X	X	X	X				

3.9 Barriers and their Implications

The major barriers to progress for this WG are:

- Lack of standardisation and incomplete coverage. Ecosystem monitoring currently consists of disparate approaches, limited mostly to Europe and northern America. This is the greatest barrier, but it also offers opportunities for setting up a coordinated global system building on existing experiences. The European pilot project provides an especially important opportunity to set up a coordinated and harmonised system.

- Partner identification and development. Because of the fragmented and incomplete approach at present it is not easy to identify partners in the different continents and convince them and their funders of the importance of ecosystem mapping and monitoring for global biodiversity assessment and for input to other SBAs. However, developing such a global partnership may provide an opportunity to also include arrangements for data sharing, database development and common tools.

- Development of GEO BON Observation Nodes network. Developing this network constitutes a special challenge as this is planned as a physical network that requires long term funding especially for Africa, Asia and Latin America. It requires not only identification of sites and responsible local organisations, but also the permanent infrastructure that coordinates the data flow, helps capacity building and maintains equipment. This calls for significant initial investments, perhaps via global funders, but permanent funding via national budgets is also needed, as well as exchange of observer teams to maintain capacity and high quality data.

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4 Freshwater Ecosystem Change (Working Group 4)

4.1 Introduction

GEO BON's Freshwater WG aims to facilitate the development of a global system for detecting changes in species, ecological values and ecosystem services in freshwater ecosystems. Around 10% of all the Earth's species live in fresh water, including one third of all known vertebrates. Since these ecosystems occupy <1% of global surface area, they are disproportionately rich in biodiversity, yet they face exceptionally high levels of threat. Freshwater biodiversity in some parts of the world is already declining at a faster rate than its marine or terrestrial counterparts due to a multitude of human impacts (reviewed by Dudgeon et al. 2006): pollution of many types; dam building and flow regulation; over-extraction of water; over-exploitation of fishes and other freshwater species; invasive species (e.g., Wittenberg & Cock 2001; LePrieur et al. 2008; Jenkins et al. 2009) and the interaction among these stressors. Further declines can be expected: global climate change will profoundly alter the hydrologic cycle, and hence the patterns of flow and timing of inundation of rivers and wetlands, and there is evidence that the impacts of climate change will become one of the major drivers of biodiversity change and loss in the 21st century (Forslund et al. 2009). Human responses to such changes will include more water extraction and dam building for water storage and irrigation, hydropower generation and flood prevention, and a decline in the amount of water available to sustain ecosystems. The consequential effects will further increase the already intense anthropogenic pressures on freshwater biodiversity (Millennium Ecosystem Assessment 2005). Development of a global monitoring system to document the ongoing and anticipated impacts and declines in freshwater biodiversity is thus a matter of great urgency.

4.2 Concepts to be Implemented

The concepts to be implemented by the Freshwater WG are defined below. These are loosely based on the GEOSS 10 year implementation plan and the GEO BON Concept Document. Several of the concepts that are highlighted as priorities of the Freshwater WG are already being addressed by global and multi-institutional programs (see section 4.6—Implementation Partners). The role of the Freshwater WG will be to assist in integrating the objectives, methods, and results of these various programs (i.e., creating a network of networks, as defined in the Concept Document) such that they have the greatest potential application to multiple users. The Freshwater WG will thereby identify key research questions, create networks of researchers interested in addressing these questions and, where possible, support applications for funding.

In contributing to the short-term goals of GEO BON (see Concept Document, Appendix 1) the main role of the Freshwater WG will be to facilitate and coordinate current activities and synthesize existing knowledge. However, realizing GEO BON's long-term vision will require new programs to be initiated, advances in research in key areas, and the collection of new data. The primary role of GEO BON's Freshwater WG in addressing the long term goals will be as a motivator and initiator of new programs in the field of global freshwater biodiversity monitoring and assessment including data collection, research, monitoring, reporting and evaluation.

4.2.1 Spatial context of biodiversity observations for freshwaters

GEO BON will make it possible for biodiversity observations anywhere in the world to contribute to improved understanding of the current status of global biodiversity. A prerequisite for this is the capacity to associate biodiversity observations with universally accepted, consistently applied, and biogeographically meaningful spatial units. For freshwater biodiversity observations the most appropriate spatial units are likely to be ones defined by boundaries of surface watersheds. The HydroSHEDS geospatial database and tools (Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales; Thieme et al. 2007; USGS 2008) provide a possible basis for delineating a standardised set of watersheds across the globe. The hierarchical organisation of the units in the landscape allows them to be aggregated into larger ones in a consistent manner across regions, continents and the world. Hence the size of the spatial units can be readily adjusted for the spatial scale of the data which may depend on the region and type of observation. Having this flexibility may be critical for determining the relationship among two different types of observations (e.g. biodiversity and disturbance) if their spatial resolution does not match. Determining this relationship also requires the capacity to readily characterise landuse and a range of disturbances upstream from any point on a river or wetland. Coding systems that identify the hierarchical relationship among the spatial units allow the condition of freshwater biodiversity at any location to be predicted as a function of these estimates of upstream cumulative disturbances (see Turak et al. 2010).

Meaningful interpretation of biodiversity observations within these spatial units, including the determination of the amount of change over time, is likely to require reference to at least two other spatial frameworks: freshwater ecoregions and a global typology of freshwater ecosystems. Assigning spatial units to an ecoregion and identifying the ecosystem types associated with each one will allow the determination of benchmarks of biodiversity condition that are specific to ecosystem type and region. A global map of freshwater ecoregions is currently available (Freshwater Ecoregions of the World; Abell et al. 2007) but mapping of ecosystem types can only be completed once a global ecosystem classification has been developed. Development of such a classification for freshwaters is one of the goals under the Ecosystems GEOSS Theme (Task EC-09-01). The Freshwater WG will collaborate with and provide all necessary support to the Ecosystems theme to complete this work.

Tasks related to this concept will be completed via Activities 4.3.2. and 4.3.6.

4.2.2 Types of observations of freshwater biodiversity

GEO BON observations will capture changes in biodiversity at the level of species, ecosystems and genes, and in terms of the ecosystem services such biodiversity provides.

The role of the Freshwater WG in analyzing genetic diversity and assessing ecosystem services will be restricted to advising and supporting the working groups that have these topics as their primary focus. The Freshwater WG can assist the Genetics WG with data on regional taxonomic diversity and endemism that may be informative to their analyses on regional genetic variation, co-evolution, impacts of introduced species on genetic diversity, etc. The Freshwater WG can assist the Ecosystem Services WG by identifying data sets on freshwater biodiversity that will allow proper evaluation of the indirect and non-use values (Emerton 2005) of ecosystem services provided by the species present in freshwater systems. This work will also require collaboration with the GEO Water theme and the eFlowNet group to assess the environmental flows necessary to sustain freshwater biodiversity and associated ecosystem goods and services, and to meet human needs from fresh water (e.g., water for irrigation, power, industry, fisheries, etc.). The Freshwater WG will, in particular, work with partners on observations of the status of freshwater species and biological health of freshwater ecosystems using species- and community-level biological data together with information on potential abiotic drivers. Activities 4.3.3. and 4.3.7 will address this topic.

4.2.2.1 Species

A comprehensive, accurate, and regularly updated database on distribution, ecology, abundance, and conservation status of freshwater species is essential. IUCN's Species Information Service (SIS) and Red List of Threatened Species is currently the most suitable tool to achieve this and includes globally comprehensive data for some freshwater species of several groups (e.g., crabs, amphibians, birds, mammals) as well as considerable information on several other groups at a regional level (Darwall et al. 2009). NatureServe provides a comparable database of species in Canada, USA, Latin America and the Caribbean (NatureServe 2009), including large datasets for several groups of freshwater invertebrates. Intensive programs of data collection are also provided (or are in development) by Wetlands International's International Waterbird Census and Ramsar's Global Wetland Observing System (G-WOS). The Freshwater Animal Diversity Assessment (FADA; Balian et al. 2008a) is another important source which contains information on major taxa compiled at the scale of zoogeographic regions. However, many invertebrates and most microbes remain poorly known, especially in tropical regions (Balian et al. 2008b), and the success of efforts to improve the global state of taxonomy (see http://www.bionet-intl.org/opencms/opencms/index1.jsp) may have a major bearing on the success of GEO BON in the long term. Four main issues have been identified specifically for freshwaters (Kottelat & Whitten 1996; Dudgeon 2003): (1) a lack of expertise and capacity in many countries and for many taxa especially in the tropics; (2) incompleteness of site-specific databases and national inventories; (3) inaccuracies or misidentifications in existing databases and national inventories; (4) even in cases where they are taxonomically correct, the existing inventories tend to reflect historic rather than present-day conditions of inland waters. Regional capacity development will be an important challenge to the ongoing development of GEO BON.

GEO BON's Freshwater WG will collaborate with the aforementioned organisations to identify priorities for collation of further data, and will liaise with the Terrestrial Species WG to ensure consistent and non-duplicated coverage of taxonomic groups that live in both the freshwater and terrestrial environments (e.g., many invertebrates, amphibians). Activities 4.3.1, 4.3.3, and 4.3.4 will address this topic.

4.2.2.2 Ecosystems: condition and extent

For the purposes of GEO BON, freshwater ecosystems include all inland waters, including seasonal and non-seasonal wetlands, "saline" lakes, and all other types of inland lentic and lotic environments and their associated aquifers.

Generating spatial data layers representing both the current and historical extent of freshwater ecosystems, and using these to help interpret the significance of current and future increases and reductions in extent are essential activities that will be particularly relevant when assessing the effects of climate change, and consequential adaptation and mitigation efforts. Knowledge of the rates and magnitude of change in both condition and extent are vital for sustainable management of water resources for people and nature. The widespread use of rapid biological assessments for assessing ecosystem health—especially in rivers—provides a potential base upon which to build globally consistent methods for assessing freshwater ecosystem condition. This will generally be done by using measures of the integrity of biological assemblages (e.g., macrophytes, macroinvertebrates, fish, and amphibians) as surrogates for the status of freshwater biodiversity.

The analyses of ecosystem condition and extent, conducted by the GEO BON Freshwater WG and partners will be applied across geographic scales, working from case study sites (e.g., single subcatchments, and key biodiversity areas; see Ricketts et al. 2005; Langhammer et al. 2007) up to landscape- or catchment-level approaches that may link together multiple key biodiversity areas. The analyses of freshwater ecosystem status should thus run from "ridge-to-reef" and will integrate the analyses of the freshwater ecosystems with the status of the terrestrial and marine ecosystems with which they are closely linked. In this respect the Freshwater WG will collaborate closely with the Terrestrial Ecosystems WG and the Marine WG for integrated coverage at these biome interfaces. Activities 4.3.3, 4.3.5, 4.3.6, 4.3.7 and 4.3.10 will address this topic.

4.2.3 Detection of change in freshwater ecosystems

Facilitating the detection and quantification of changes in freshwater biodiversity across the world is a primary objective of the Freshwater WG. Data that form the basis of the IUCN Red List of Threatened Species (IUCN 2009), have been used to indicate global patterns of change for several taxonomic groups (Stuart et al. 2004; Schipper et al. 2008; Cumberlidge et al. 2009). Application of this information can be significantly strengthened by including remotely sensed data that may act as surrogates for direct observations of biodiversity. Models for estimating the condition of freshwater biodiversity from surrogate landscape features and drivers may be used to generate a prediction of changes at a global scale. Such models may be developed for some species but is more likely to be useful for ecosystem-level observations. Estimates of collective properties of biodiversity such as species richness, compositional turnover among spatial units within a biogeographic spatial framework (Ferrier et al. 2004) and community level observations (Ferrier et al. 2009) are particularly suited for such modelling exercises. In developing such models for freshwaters, it will be necessary to relate changes in land use, water use and other human activities in river basins to freshwater biodiversity for each spatial unit. To do this methods available for estimating the condition of freshwater biodiversity at the community level across entire river basins (e.g. Turak et al. 2010) may need to be adjusted for application at continental or global scales. The Freshwater WG will work closely with the *In Situ*/Remote Sensing WG in guiding and facilitating the development of the models. Activities 4.3.3, 4.3.7 and 4.3.10 will address this topic.

4.2.4 Improvements in data collection

In the long term, sampling of freshwater taxa should be improved such that, for multiple components of freshwater biodiversity in every bioregion of the world there are:

Sufficient observations made within spatial units of appropriate sizes (see 4.2.1) to represent the condition of freshwater biodiversity within its boundaries;

Data from a representative number of spatial units for each major freshwater ecosystem type;

Accordingly, temporal and spatial trends in freshwater biodiversity can be detected at global, continental and regional scales.

The Freshwater WG will play a key role with other collaborators and partners in guiding and coordinating the development of globally applicable protocols for collecting such data so as to ensure that they are of adequate quality. This will be achieved by Activities 4.3.3, 4.3.8, and 4.3.10.

4.2.5 Data provision

It is a central assumption of GEO BON that it will be based on, and contribute to, publicly accessible data, via online and widely distributed reports/publications. This will help to ensure that the data are used by NGOs, governmental organisations, civil society and private sector stakeholders (e.g., developers and planners) in their policy and programmatic work for conservation planning and integrated wetlands management to support human livelihoods. This will be achieved by Activities 4.3.11.

4.3 Activities

The Freshwater WG will initiate, coordinate, support, and otherwise integrate with a wide range of activities that help implement the concepts listed above**.** Several of these activities are already in development under the framework of existing regional and global projects and in these cases the role of Freshwater WG will be to look for connections between activities that will promote the application of their results (i.e., the deliverables) to future research and, most importantly, to conservation planning and policies, and sustainable management of freshwater ecosystems.

4.3.1 Review of global projects and datasets related to freshwater biodiversity

The first step is to identify knowledge gaps and determine mechanisms whereby existing data can be integrated for analytical purposes. The next step will be to facilitate the resolution of intellectual property and data provision matters including formats and access protocols. This will be done in close collaboration with the Data Integration WG and will cover global, regional and continental datasets on species, biophysical characteristics of freshwater ecosystems, and drivers of change. This activity extends to setting of parameters that define "freshwater taxa," compilation of sources of global datasets (e.g., IUCN's Species information Service and Red List IUCN 2009, World Biodiversity Database, etc.), and identification of global data sources on threats and drivers (e.g., GWSP/DIVERSITAS river threats dataset; Global Invasive Species Database). This work will contribute to deliverables 4.4.1, 4.4.2, and 4.4.7, as well as contributing to the set of core research questions developed in Deliverable 4.4.3.

4.3.2 Delineation of spatial units for analyzing global freshwater biodiversity data

These will be: (1) based on potential hydrological (i.e., modelled elevation) boundaries defined consistently across the world; (2) defined at the finest spatial resolution at which observations of biodiversity and measurements of drivers can be matched; (3) linked hierarchically so that the units can be aggregated to achieve consistency across any region to suit needs of the analysis. The HydroSHEDS database (Thieme et al. 2007; USGS 2008) is currently being refined by the database developers to include a hierarchical set of basin boundaries (scaling up from microbasins of small tributaries to large river basins that comprise multiple connected subbasins; see Deliverable 4.4.5).

4.3.3 Determination of standard field methods for collecting biological and environmental data

In addition to the definition of standard biological sampling methods, this activity will include the evaluation of an array of environmental variables (including ecosystem service variables) to accompany *in situ* biodiversity assessments and development of protocols that describe globally standardized methods for collecting such data. This work will be developed through broad collaboration with partners and other organisations; and utilize existing published recommendations of field sampling techniques including IUCN's Integrated Wetland Assessment Toolkit (Springate-Baginski et al. 2009) and rapid bioassessment protocols such as those developed by the United States Environmental Protection Agency for algae, macroinvertebrates and fish in flowing waters (Barbour et al. 1999). Data on driver variables will be used for predicting ecosystem change in freshwaters across the globe, applicable to both actual and modelled observations. This information will then be used for creating maps of freshwater ecosystem compositional turnover. Special attention will be given to filling knowledge gaps on threats datasets. The work on threats will be conducted in communication with the GEO Biodiversity SBA Task BI-07-02 (Invasive Species Monitoring System). Also, lead by the World Wildlife Fund, procedures will be defined for retroactively geo-referencing freshwater species localities to mapped river networks (for cases where original locality data are imprecise), and field tools for snapping locality points to river networks. This work will contribute to Deliverables 4.4.4 and 4.4.6.

4.3.4 Development of biodiversity indices

These indices will provide measures of the status of biodiversity typically represented by the measures of the integrity of biological assemblages based on presence/absence data . Where possible, indices should also be developed which allow the detection of changes in population sizes based on regional/global abundance data on selected species. The indices should be consistently applicable in all major types of freshwater ecosystems across the world (e.g., floodplain rivers, alpine streams, upland swamps, coastal creeks, large lakes, etc.). The information can then be combined with other outputs, such as the IUCN Red List, that provide an assessment of the conservation status of species. This work will contribute to Deliverables 4.4.4 and 4.4.6.

4.3.5 Trial exploration of a small global data set

This trial will be conducted in close collaboration with other working groups, in particular the *In Situ*/Remote Sensing WG and the Data Integration WG, to evaluate the potential of using a variety of existing freshwater biodiversity datasets to assess biodiversity status within appropriate spatial units and for modelling biodiversity condition across large regions. The trial would involve using data from a small set (~12) of spatial units spread across all continents (except for Antarctica). Issues explored in the trial will include: comparability of sampling methods and effort; taxonomic resolution, data quality and other matters of data interoperability; and feasibility of deriving ecoregion-specific relationships between biodiversity observations and environmental features/drivers. Deliverable 4.4.4 will be produced through this activity.

4.3.6 Classification of freshwater ecosystems worldwide

The Freshwater Ecoregions of the World (Abell et al. 2008) will be used as the starting point, with the intention of producing a classification which will allow (1) recognition of important distinctions among freshwater ecosystems within an ecoregion; and (2) recognition of similarities and differences of any given ecosystem type across different ecoregions. This activity will be taken on together with the GEOSS Ecosystems SBA (Task EC-09-01) as well as the Terrestrial Ecosystems WG and the Marine WG and lead to deliverable 4.4.10.

4.3.7 Modelling ecoregion-scale spatial patterns in freshwater biodiversity

Models will be developed which allow mapping the condition of freshwater biodiversity across the world based on remotely derived data on drivers, threats and pressures for each ecosystem type within each freshwater ecoregion. This will be done by directly linking landuse and other disturbance factors alongside runoff and physical attributes for each of the spatial units to measures of freshwater biodiversity condition. The primary biodiversity data input into these models will come from *in situ* biodiversity observations in data-rich ecoregions where the accuracy of the predictions can be comprehensively tested. This work will draw on several different data sets (e.g., the global river threats database presently being developed by GWSP-DIVERSITAS and regional biodiversity datasets such as those provided in IUCN's Red List of Threatened Species). This activity will contribute to Deliverables 4.4.3, 4.4.4 and 4.4.8.

4.3.8 Identification of priority regions for monitoring

Using global maps of biodiversity condition, generated through modelling (see activity 4.3.7) and other relevant information, regions will be identified which are of greatest priority for improving biodiversity observations. These regions will be promoted to conservation managers and practitioners as priority areas for field assessments. The Freshwater WG may assist in identifying regional experts who can contribute to the assessment of biodiversity status in these regions (e.g., from Wetlands International wetland watch; regional offices of IUCN, Conservation International, TNC, and other international and regional conservation NGOs). This activity will contribute to Deliverables 4.4.8 and 4.4.9.

4.3.9 Facilitation and coordination of research

The Freshwater WG will identify research needed to support a global freshwater biodiversity observation network, integrated with and complementing existing programs (eg., IUCN Red List IUCN 2009, Wetland Observation System). It will actively promote the need for this research and support funding applications by those engaging in such research. This activity will lead to Deliverable 4.4.3.

4.3.10 Mapping of historic and current extent of wetlands worldwide

To achieve this, it will be necessary to first develop a protocol for the application of remote-sensing techniques for mapping wetlands and define the context for historic extent to serve as a baseline in different parts of the world. This activity will contribute to Deliverable 4.4.11.

4.3.11 Communication of the GEO BON implementation plan and implementation outputs

The GEO BON Detailed Implementation Plan will be communicated to all current and potential implementation partners and stakeholders with involvement in freshwater biodiversity observations and freshwater conservation. The deliverables from implementation will be communicated using a wide range of media. In constructing each communication product specific audiences will be targeted that are likely to play a significant role in translating the implementation outputs into beneficial outcomes for freshwater biodiversity and for human-well-being.

4.4 Deliverables

4.4.1 Directory of global sources of freshwater biodiversity data

A directory will be generated that includes information on the nature and source of biodiversity data available from freshwater ecosystems across the world as well as information on data accessibility and intellectual property. The directory will be used to assist GEO BON program management and delivery of data via the GEO BON web portal.

4.4.2 Directory of global sources of datasets on drivers, threats and pressures

A directory will be generated of sources of information on drivers of threats to, and pressures on, freshwater biodiversity. This will include an evaluation of climatic and other measures or projected data needed for modelling the impacts of climate change on freshwater ecosystems at a global scale. The directory will be used to assist GEO BON program management and delivery of data via the GEO BON web portal.

4.4.3 List of core research questions, and a strategy to address these questions

Research questions will be defined that need to be addressed to facilitate the development and implementation of the observation processes. Accompanying this list will be the anticipated timelines for delivering research outputs and potential sources of research funding. The list will published on the GEO BON website and communicated by email to key international and national funding bodies and prominent researchers in academic and research organisations.

4.4.4 Publication on the findings of the exploratory trial of global datasets

The findings of the exploratory trial of global datasets (see 4.3.5) will be published as a scientific, peer-reviewed journal article and will establish directions for further research in key topics including development of standard protocols and modelling of collective properties of biodiversity in freshwater ecosystems.

4.4.5 Standard set of hierarchically nested spatial units based on watersheds

These units will be based on surface water basins and the subbasins comprised within them. Accompanying each spatial unit will be information on the spatial relationships with other units. The spatial units will be based on the HydroSHEDS geospatial database and tools (**Hydro**logical data and maps based on **SH**uttle **E**levation **D**erivatives at multiple **S**cales, Thieme et al. 2007; USGS 2008). This work is currently being conducted by the HydroSHEDS database developers.

4.4.6 Standard field methods for freshwater biota and environmental attributes

Guidelines and protocols will be provided for field assessments. These will include recommendations for standard methods of sampling or observing species and assemblages as well as guidelines for recording additional environmental observations at field sites. Biological assessments will focus on those groups that are of highest priority for field surveys and inventories such as fish, macroinvertebrates, macrophytes, because: (1) they are known to be highly sensitive to environmental change; (2) they are used as surrogates for all freshwater biodiversity; and (3) information on them is often needed to implement conservation / management programs.

4.4.7 Global atlas of freshwater biodiversity

An up-to-date searchable, geospatial biodiversity atlas of freshwater species records for the globe will be compiled. This will integrate species data at the best possible geospatial accuracy with relevant hydrographic units. The needs of potential users of the database will be identified as part of the process of its design, to ensure that it provides suitable information for application to diverse conservation and management programs. The “atlas” will incorporate:

A definition of parameters that define freshwater taxa;

Data from existing geospatial databases compilation of sources of global datasets (e.g., IUCN's Species information Service and Red List (IUCN 2009), World Biodiversity Database, etc.);

Grey literature and personal records;

An accepted method of data quality control (and consistent recording/capturing locality information; linked to relevant authority files, e.g., HydroSHEDS, etc.);

A mechanism for users to identify biodiversity according to their own geographic parameters rather than predefined ones.

4.4.8 Global maps of the condition of freshwater biodiversity

Predictions generated through modelling will be used to produce maps of freshwater biodiversity condition at the resolution of watershed-based spatial units.

4.4.9 List of priority regions and ecosystem types for *in situ* monitoring

Regions (and ecosystem types within these) with inadequate amounts of *in situ* biodiversity data to validate the models (see 4.4.8) will be identified. These will then be priority regions for obtaining new data.

4.4.10 Global typology of freshwater ecosystems

The major types of freshwater ecosystems across the globe will be defined and rules will be determined for assigning any freshwater ecosystem to a type.

4.4.11 Global map of historic and current extent of wetlands

A global map of existing wetlands will be generated using advanced remote sensing techniques. Best historic knowledge in each region will be than be applied to generate maps of extent for an appropriate historic reference point in each ecoregion. These maps will serve as ecoregion-specific baselines for estimating wetland loss and deriving potential wetland extent. The maps together with accompanying synthesis and interpretation will be published on the GEO BON website.

4.5 Data

A range of sources for biodiversity and environmental data have been identified in the Concept Document. GBIF, the IUCN Red List (IUCN 2009), and the Integrated Biodiversity Assessment Tool (IBAT) (referenced earlier) serve as major portals to biodiversity data. However, other sources and avenues specific to biodiversity data also need to be explored (e.g., the World Biodiversity Database). Processed data such as "global threats analysis of rivers" will come from specific programs (e.g., GWSP-DIVERSITAS global threat analysis of river systems).

4.6 Implementation Partners

Producing the intended deliverables of the Freshwater WG will involve integration of information from several existing programs coordinated by other organisations. It will be essential to GEO BON's success to establish good collaboration and, where appropriate, formal partnerships with these organisations and institutions. Although a preliminary list of potential collaborators and partners is given here, many of these organisations have not reviewed all elements of this plan. Indeed, input from these and other partners is likely to result in some modification of the proposed deliverables and activities as they become implemented. Additional partners will also be identified as work progresses. Some partners for which key roles in implementation have been identified include the following:

Ramsar, (through several of Ramsar's activities, especially the Global Wetland Observing System);

Wetlands International (WI, via several programmes, including the IWC Programme , which encompasses 2 million records over the last 40 years);

IUCN's Species programme and Species Survival Commission, ensuring links with the *Red List of Threatened Species*; see http://www.iucnredlist.org/) and the associated Conservation International (CI) /NatureServe *Global Freshwater Biodiversity Assessment* (GFBA, see http://www.iucn.org/about/work/programmes/species/our_work/about_freshwater/);

World Wildlife Fund (WWF) and the Nature Conservancy (TNC) ensuring links to the *Freshwater Ecoregions of the World* (FEOW, http://www.feow.org/);

- United States Geological Survey (USGS), ensuring links to the "*Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales*" (HydroSHEDS; http://hydrosheds.cr.usgs.gov/) and providing models and tools for synthesis of biohydrogeochemical data for watersheds with data on drivers such as landuse and climate;

Some other potential partners that may play an important role in implementation are as follows:

EU-BioFresh consortium study of "Biodiversity of Freshwater Ecosystems: Status, Trends, Pressures, and Conservation Priorities" (http://www.iucn.org/about/work/programmes/species/our_work/about_freshwater/what_we_do_freshwater/bio_fresh/);

Freshwater Animal Diversity Assessment (FADA, http://fada.biodiversity.be/);

Global Water System Project (GWSP, http://www.gwsp.org/);

DIVERSITAS (http://www.diversitas-international.org/) ;

Society for Conservation Biology Freshwater WG (SCB FWG, http://www.conbio.org/workinggroups);

Global Invasive Species Program (GISP, http://www.gisp.org);

EFlowNet (http://www.eflownet.org/index.cfm?linkcategoryid=1&siteid=1&FuseAction=main).

Reviewing all existing projects and datasets, identifying gaps, resolving data access issues, standardizing the collection of biophysical data, and so on, will be undertaken in close collaboration with the partners.

Another important role of the Freshwater WG will be to help ensure that freshwater data products are made available for integration into consolidated databases for scientists and conservation practitioners (e.g., the World Biodiversity Database (http://nlbif.eti.uva.nl/bis/index.php), and for resource managers and policymakers. For example, the Integrated Biodiversity Assessment Tool (IBAT) suite of tools, including IBAT for business (http://www.ibatforbusiness.org).

4.7 Coordination

The Freshwater WG will coordinate its activities with other GEO BON working groups as specified under activities. It will also coordinate relevant activities with other GEOSS areas as follows:

- Ecosystems SBA, Task EC-09-01. Ecosystem classification. Work on freshwater ecosystem classifications;
- Water SBA:
  - WA-07-01: Global Water Quality Monitoring;
  - WA-07-02: Satellite Water Quantity Measurements and Integration with *In situ* Data;
- Biodiversity SBA:
  - BI-07-02: Invasive Species Monitoring System;
  - BI-06-03: Capturing Historical Biodiversity Data;
- Health SBA: HE-07-02: Environment and Health Monitoring and Modelling;
- Agriculture SBA: AG-06-02: Data Utilization in Fisheries and Aquaculture;
- Climate SBA: CL-09-03a: Integrated Global Carbon Observations (IGCO);
- Disasters SBA: DI-07-01: Risk Management for Floods.

4.8 Schedule

It is difficult, at this stage, to assign timelines for providing the deliverables. The rough indication of possible timelines given in Table 4.1 might change significantly once planning for each of the specific activities commences.

Table 4.1. The possible times of completion for each deliverable

Deliverable	2010	2011	2012	2013	2014	2015	2016	2017	2018
4.4.1 Directory of global biodiversity sources		X							
4.4.2. Directory of threats, drivers and pressures			X						
4.4.3. A list of core research questions		X							
4.4.4. Publication of exploratory trial			X						
4.4.5. Spatial units					X				
4.4.6. Standard field methods				X					
4.4.7. Freshwater biodiversity atlas			X		X				
4.4.8. Maps of freshwater biodiversity condition									X
4.4.9. Priorities for monitoring							X		
4.4.10. A global typology of freshwaters						X			
4.4.11. Global map of wetland extent									X

4.9 Barriers and their Implications

Some of the main barriers to progress for the Freshwater WG are:

- Absence of high-level agreements and coordination between GEO BON (or GEOSS) and some of the key implementation partners (e.g., Ramsar, IUCN, BioFRESH, GWSP, WWF, TNC, CI). Effective involvement of these key partners in GEO BON will be critical and depends on the resolution of roles, identification of shared interests, avoidance of duplication of effort, and dissemination and ownership of outputs, as well as commitment of staff time and resources. These matters will require careful cross-disciplinary communication and partnership at the level of the working group.
- Lack of an operational budget. Although most activities in the Implementation Plan (especially the costly ones) will need to be resourced through major existing and future programs, there is likely to be a need for some operational funding for coordination and for carrying out some of the less costly activities in the plan (e.g., Activity 4.3.5).

Planning for these will be difficult if the only operational support is post-hoc, one-off and event-based.

- A lack of taxonomic expertise and capacity in many countries and for many taxa (especially in the tropics) alongside inaccuracies and gaps in site-specific databases and national inventories. These present a major risk of exclusion of data-poor regions of the world (mostly developing countries) from the observations and assessments. This also relates back to the first bullet above, and the need for clear partnership between organisations and programs to identify and address gaps in existing data in a consistent, comprehensive and complementary fashion.
- Current bias towards terrestrial systems in relevant modelling activities. Modelling techniques may need to be modified to accommodate special features of freshwater ecosystems and biota. Foremost among these is the longitudinal connectedness of river systems which means that impacts are promulgated, usually in one direction (up to down). Applying these modelling techniques to freshwaters might also require additional technical support (e.g GIS) to generate input layers for the models.

4.10 References

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5 Marine Ecosystem Change (Working Group 5)

5.1 Introduction

The need to comprehensively determine and monitor marine diversity is fundamentally important to our societal needs. Past and existing efforts of global, regional and national organisations, marine institutes and biological stations of universities as well as individual scientists have laid a strong foundation for this work. Long term time series of biodiversity data have been and are being collected by many marine institutes and stations in developed and some developing countries, mainly focusing on coastal marine environments but increasingly on the open and deep oceans as well. One example is the Census of Marine Life (CoML), which has had major funding for the last ten years and involved roughly 2000 active scientists worldwide. CoML has given an enormous boost to the understanding of marine biodiversity. Biogeographic data generated by CoML are integrated, together with data from many other sources, into the Ocean Biogeographic Information System (OBIS, http://www.iobis.org). CoML will officially end in 2010; since it has been very successful it may serve as a template for the Marine

What Marine Biodiversity?

The oceans and marine sediments cover almost three quarters of the Earth's surface with an average water depth of 3.8 km and a subsurface sedimentary biosphere of about 1 km depth on average. The microbial component accounts for 50–90% of the marine biomass: One liter of seawater contains on average 10^9 Bacteria, a similar amount of Archaea, an order of magnitude more viruses and about 10^3 microbial eukaryotes. The number of bacterial "species" in one liter of sea water is about 20,000 and in one kg of surface marine sediment probably much more than that, but mostly unknown, i.e., not in culture (Amaral-Zettler, 2010/ICoMM). Moreover, the "species" composition of Bacteria and Archaea is very different in different marine ecosystems and varies tremendously in different marine environments on different time scales (days, months, years) and upon natural and man-induced climate change. Since microbes "rule the world", i.e., regulate biogeochemical cycles and thus climate and climate change, it is of utmost importance not only to determine their biodiversity *per se* but also to understand their metabolic processes and changes.

This complex situation also holds, maybe to a somewhat lesser extent, for larger organisms in seawater and the sea floor (hard substrates and sediments). Eukaryote organisms vary enormously in size from less than 10 µm to 40 m in length. Many zooplankton species are barely visible to the naked eye. As for the microbes, a large part of this marine biodiversity is still unknown and new species are routine for nearly every sampling effort, even in coastal areas. Moreover, large organisms are important to society as they present ecosystem goods and services such as food, carbon sequestration (blue carbon) and natural products. Top-down regulation of marine food webs may be as important as bottom-up regulation and the elimination of top predators and top herbivores such as large mammals, birds, marine reptiles, fish and sharks may be changing the ocean's ecosystems as intensely as temperature rise, eutrophication or acidification.

component of GEO BON. CoML provides relevant experience on the challenges, concepts, activities, logistics, data integration and deliverables, both short and long term, that GEO BON will face. CoML has analogues to the Regional BON's of GEO BON, such as the National and Regional Implementation Committees (NRIC) but also other organisations active in certain regions or ecosystems of the oceans such as the newly established Circumpolar Biodiversity Monitoring Program (CBMP, http://www.cbmp.is) which may also be the Arctic Regional BON for GEO BON.

What is needed now is to integrate the outputs from these various marine monitoring and observation efforts into a cohesive "system of systems" which will enable researchers, resource managers and policy makers to: rapidly assess what is known about a particular marine region, ecosystem, species or population; identify changes or trends at these various levels; forecast future trends based upon different possible scenarios (in those areas where appropriate models exist). The magnitude of this task is challenging—but technological advances, the existence of a global community of scientists and institutions, and the potential for global cooperation make it feasible.

Looking into the future, then, the challenge for GEO BON in the marine realm is to identify, assimilate and integrate datastreams which reflect the broad diversity of marine life as well as the extreme complexity of marine ecosystems, from top predators like sharks and whales to the vast majority of marine organisms—the microbes which pervade the entire volume of this, the largest living space on planet Earth. Data assimilation frameworks exist for some data types (e.g., genetics with GenBank, species distribution information with OBIS), but have to be developed for the many other types of data GEO BON will have to deal with (e.g., physiology, communities, interactions, habitats). Even for the established frameworks, mechanisms and incentives are needed for data custodians to share these data with the wide community of users.

5.2 Concepts to be Implemented

The primary concepts that the Marine WG will focus on are:

Facilitate the mobilisation and accessibility of online primary biodiversity data;

Facilitate consensus on data collection protocols, data quality control and coordination of development of interoperability among monitoring programs;

Facilitate data rescue activities—recovering data in paper publications or other forms to make them available for analysis;

Facilitate the global monitoring of ecosystems using a combination of remote sensing and *in situ* approaches;

Coordinate the efforts of individual institutes, countries and large programs to perform *in situ* measurements in a sustainable way;

Stimulate/Coordinate all activities to define a marine ecosystem classification and visualisation thereof;

Help to provide *in situ* data to develop process models and forecasting related to biodiversity;

Stimulate long term observations for monitoring human-induced changes of critical ecosystem parameters linked to biodiversity change such as pH, T, nutrients, oxygen, chlorophyll, currents;

Facilitate research to characterize the state of ecosystems by metagenomic tools;

Identify gaps in monitoring of crucial ecosystems by a detailed inventory of ongoing and past monitoring activities;

Stimulate the embedding of biological and sequence data in a contextual and metadata context;

Stimulate capacity building through major international programs related to POGO, the NIPPON Foundation, SCOR , IOC and others.

5.3 Activities

To recognize, understand and evaluate biodiversity changes due to climate and other global change processes (e.g., temperature rise, ocean acidification, pollution), long-term data on marine ecosystems and their biodiversity are essential. The primary activities required to do this are based on monitoring of the marine realms and ecosystems.

5.3.1 Define marine realms and associated ecosystems

Given the huge volume and extent of the oceans and the underlying seafloor and sediments and the nearly unlimited exchange of ocean water masses, a rigid compartmentalisation of the marine environment is not straightforward. Oceanic biogeographic provinces have been described through the Large Marine Ecosystem (LME) Concepts, defining 64 LME´s worldwide based on physical and biological characteristics (http://www.lme.noaa.gov) and through the work of Longhurst (1998).

It seems pragmatic and efficient to follow the ecosystem approach described by the Census of Marine Life (CoML) in its Scientific Framework implementation plan (http://www.coml.org/census-framework), since the individual realms are well-linked to the related CoML projects, which have been, and are, crucial in our understanding of marine biodiversity in these realms.

These marine realms cannot be considered marine ecosystems—rather, they serve as *geographical* marine domains, each consisting of many highly different ecosystems due to different physical , chemical and / or biological boundaries. For example, the near shore zone may consist of sandy, rocky or (coral) reef coasts in different climate zones with different temperatures, salinities, seasonalities, terrestrial input, etc.

Therefore, the Marine WG will adopt a recently defined global system for coastal and shelf areas, the Marine Ecoregions of the World (MEOW) on the one hand and a highly complementary system under development, i.e., the Global Open Oceans and Deep Sea-habitats (GOODS), for the open oceans.

The MEOW classification will serve as a nested and much more detailed ecosystem classification of the Near Shore and Coastal Zone areas mentioned above. This bioregionalisation of Coastal and Shelf Areas represents a nested system of 12 realms, 62 provinces and 232 ecoregions (Figure 5.2).

The recent attempt to define a nested open ocean ecosystem classification, the Global Open Oceans and Deep Sea-habitats (GOODS, http://www.ias.unu.edu) covering the other CoML zones mentioned above, may very well serve as the basis for open ocean ecosystem monitoring activities. GOODS classifies 29 pelagic provinces, 9 lower bathyal provinces (800–3500 m), 10 abyssal provinces (3500–6500 m), 10 hadal provinces (> 6500 m.) and several hydrothermal vent provinces.

However, even at the lowest level of these two complementary ecosystem classifications—the ecoregions—a further subclassification is needed. For example, one of the MEOW ecoregions is defined as the North Sea. For ecosystem monitoring purposes one has to "split up" the North Sea into sub-ecoregions (ecotypes/habitats) such as the Channel region, the Southern shallow not stratified North Sea, the Northern deeper and seasonally stratified North Sea, the very different types of estuaries, the Wadden Sea tidal flats, etc. Similarly, the GOODS classification has to be fine tuned as well, taking into account important biodiversity hot spots such as sea mounts, mud volcanoes, cold corals, deep-sea canyons, ridges, etc., for the hadal provinces.

Apart from these two types of classifications and their possible extensions an additional separate classification must be considered. For example, in the open ocean one may have to refer to High Nutrient Low Chlorophyll (HNLC) ecosystems in different temperature, salinity and light conditions, downwelling and upwelling systems, etc., and to the ThermoHaline Current (THC)-related water masses which can be considered as "moving ecosystems" with their own characteristics as shown for the microbial populations within and outside North Atlantic Deep Water (NADW) and other water masses (Amaral-Zettler et al. 2010) or to all kind of different chemo- and pycnocline ecosystems with their steep vertical temperature, density, nutrient and oxygen gradients occurring at virtually all latitudes and longitudes. Finally, in addition to improving upon these marine ecosystem classifications, there is also an explicit need for ongoing assessments of the distribution, quality, and change of specific marine and coastal ecosystems that are particularly vulnerable to perturbation(s) and/or significant in terms of ecosystem service provision. These include, for example, warm and cold water corals, seagrasses, saltmarshes, estuaries, seamounts, mangroves, etc, and many are listed explicitly in various international conventions (including the Convention on Biological Diversity, Ramsar Convention, World

Summit on Sustainable Development Plan of Implementation). Currently global datasets for these critical ecosystems are of variable quality and coverage, and most importantly, typically lack measures of change in extent or quality. As such, UNEP-WCMC is initiating a Global Marine Data Partnership for Critical Marine and Coastal Ecosystems, to convene a network of agencies, institutions and individuals working together to develop, collate, maintain and deliver high resolution, datasets for these critical ecosystems. This Partnership will function as a direct contribution to GEO-BON, with the intent of providing further efforts to improve existing marine ecosystem classifications.

The ultimate marine ecosystem classification will remain a matter of ongoing discussions building on insights and expertise of local and regional ecosystem experts (Costello 2009), but, as stated above, the Marine WG will adopt the two complementary ecosystem classifications mentioned and will help to further detail these to recognize and map ecosystem-related biodiversity changes as clearly as possible.

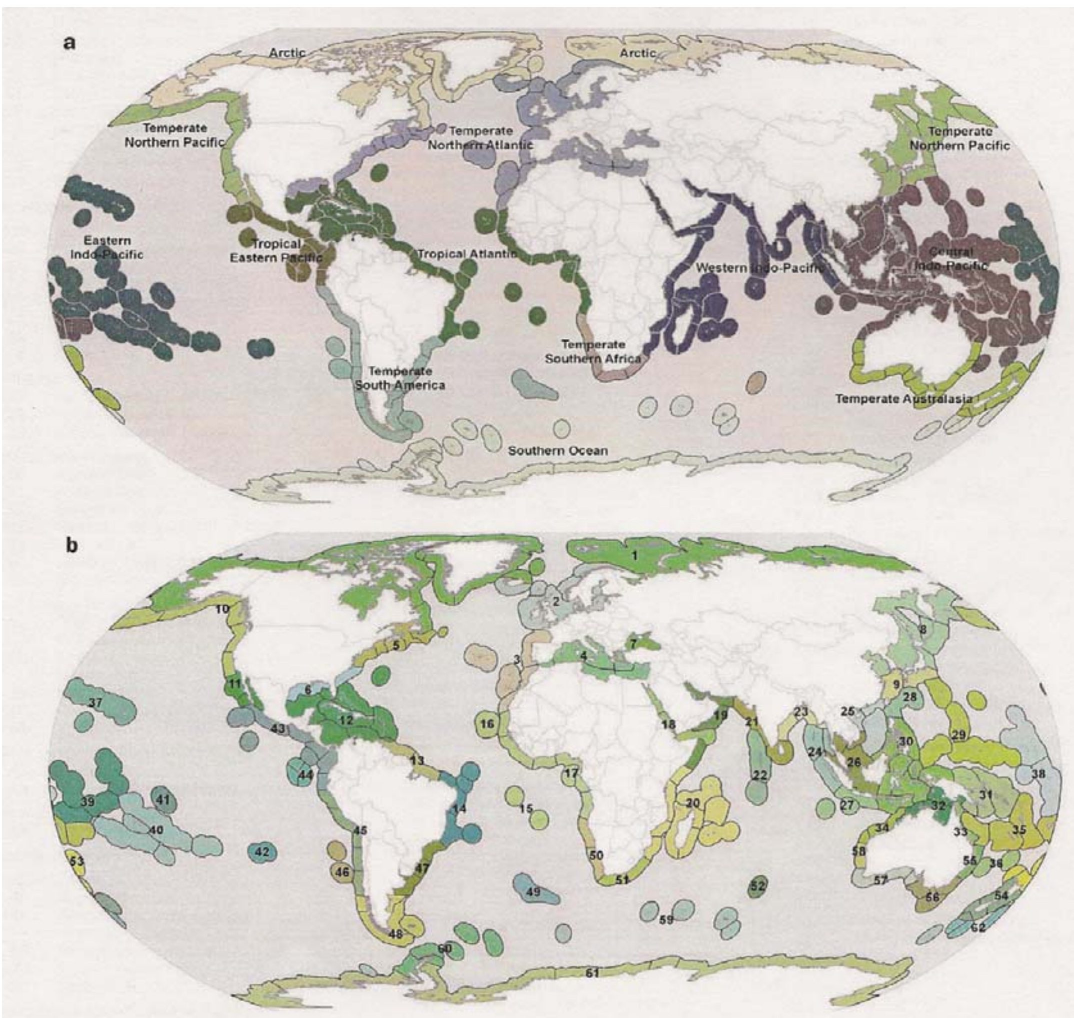

Figure 5.2. Final biogeographic framework: Realms and provinces. (a) Biogeographic realms with

ecoregion boundaries outlined. (b) Provinces with ecoregions outlined (from Spalding et al. 2007)

As an aid to interoperability and access, all such region definitions and biogeographic compartmentalisations should be made available through standards-based web services, e.g., as maps with accompanying information.

The ecosystem classification for the marine environment as described above will be incorporated in the reports of GEO Ecosystem SBA, task ECO-09001b.

5.3.2 Monitor and observe

The Marine WG will work with partners to help coordinate existing monitoring activities and facilitate filling in observational gaps.

To address the complexity of the marine environment, a variety of platforms will be used to monitor changes in marine biodiversity. This will involve both remote sensing and *in situ* sampling platforms. A key requirement that is essential to underpin monitoring is that these activities must be funded sustainably over the long term (~decadal periods) separately from short-term research funding.

Remote sensing of the marine environment will be used to generate sea-surface information particularly for phytoplankton ocean colour and for primary production. Platforms and algorithms for these are well established. Although satellite remote sensing provides synoptic views of the ocean, the results require periodic verification by *in situ* samples. Remote sensing also depends upon cloud-free conditions and low turbidity of water. This can cause problems in high latitude seas and in turbid coastal waters. In coastal areas, direct observation from aircraft and satellites will be used to monitor changes in plant (e.g., phytoplankton and seagrasses) and animal (e.g., coral reef) communities. By combining remote sensing and *in situ* data it may become possible to interpret changes in microbial populations, e.g., by ground-truthing ocean colour imagery, or in coral reefs and seagrass meadows, possibly in collaboration with the *In Situ*/Remote Sensing WG. A challenge is to link remotely sensed surface properties to the characteristics of the deeper ocean, including bottom topography and bathymetry.

Besides remote sensing, acoustic techniques may be used to map water layers and the sea floor and are now increasingly used for benthic habitat mapping and monitoring. A variety of *in situ* sampling platforms will also be used. These compliment remote sensing approaches providing samples for analysis (often essential for biodiversity) at all depths in the water column down to and including the seafloor.

Geostationary time series stations will continue to be used since these allow for the fine temporal scale observations, which are essential for monitoring transitory events such as harmful algal blooms. Time series stations also generate samples through regular water sampling at fixed depth intervals that can be used for further laboratory analyses.

Basin-scale observations will continue to monitor decadal scale changes. These will use existing standard set routes at monthly frequency using ships of opportunity. New routes will need to be set up to achieve global coverage particularly in climatically sensitive areas such as the Arctic. Coupling basin scale observation with high throughput sequencing techniques will offer long-term monitoring at a range of frequencies (minutes to months and years).

Determining long term diversity changes of larger marine organisms is challenging but can be achieved through a permanent acoustic tracking array to monitor various fishes utilizing the continental slope. Large tagging programs of pelagic predators will monitor their distribution, abundance and migratory behaviour. Such studies play an important role in identifying critical habitat regions for highly migratory species—many of which are commercially valuable. Furthermore, the sensors used to track these animals also carry environmental sensors (e.g., depth, temperature, salinity) that will generate unique oceanographic datasets—often with multiple daily profiles along the animals' migratory path. Stimulating these "mobile modes of monitoring" is another GEO BON task. In benthic habitats image recognition and other software can be developed and used to process *in situ* recorded images obtained using tracked, autonomous or profiling image acquisition tools and devices.

Platforms currently used for physico-chemical observation networks should be extended as much as possible and the use of *in situ* sensors for ocean colour, temperature and fluorescence in these networks must be linked to biodiversity properties. Although in their initial stages, plans will be developed to use automated monitoring devices originally meant to make physical and chemical observations to monitor biodiversity both directly and indirectly.

Coordination of such monitoring will require cooperation at international and national levels. At the international level, organisations such as POGO (http://www.ocean-partners.org) and IOC (Intergovernmental Oceanographic Commission; http://ioc-unesco.org/) will be used.

There is also a wide variety of National Monitoring Programmes that will be used to build up a more complete global picture. Obtaining information from such national programmes will require an enormous coordination effort but will be essential to establish regional baselines at the right scales allowing for detection of significant changes in the future, especially in coastal areas.

5.3.3 Make data available

To place marine biodiversity in its oceanographic context, access will be needed to large data stores of physical and oceanographic data. Much of the existing data is in principle available through the network of National Oceanographic Data Centres and World Data Centres on Oceanography, coordinated by the Intergovernmental Oceanographic Commission. The available data often reflect the interest of the military and of the meteorologists: bathymetry, temperature and salinity measurements are the only data types available for many stations; parameters very relevant to biology, such as bottom type, nutrient concentrations, oxygen and pH are often too sparse to be of use in modelling. Also, it must be noted that many of the parameters needed for marine biodiversity cannot be obtained through Remote Sensing techniques, but need *in situ* measurements. A list of available data types, and a discussion of their density, will be compiled together with the data interoperability work group. In what follows, the focus is on the biological data needs.

5.3.3.1 Historical data

Among the marine biological scientific communities it is common knowledge that a huge amount of historical marine biological data, including very precious long-term data series, are still hidden in notebooks in drawers of desks of individual researchers or in dusty archives of marine stations, institutes and museums worldwide. These biological data, including textual data (e.g., longitude, latitude, water depth, sediment depth, temperature, salinity) and metadata (who did the sampling, what was the sampling protocol, how were/are the samples stored, how were they processed, etc.) if available, should be surfaced and if necessary digitalized to populate free-accessible databases according to international protocols set by OBIS, GBIF, etc. The need for this exercise, for example, is illustrated by Lotze & Worm (2009). They analysed 256 historical records of marine mammal populations, concluding that exploited populations have declined 89% from historical abundance levels. While long-term fluctuations were mainly related to climate variation, there were rapid declines due to overexploitation. They also conclude that conservation measures are responsible for some observed recent recoveries.

In particular, both OBIS and IUCN can play an important role in continuing to drive the mobilisation and accessibility of online primary biodiversity data through their extensive networks of participating institutions, countries, organisations and data providers.

It is clear that GEO BON has to structure this activity through its Regional BONs (e.g., the NRICs of CoML) asking them to branch further out to regional, national and local organisations to get the job done. Hence, a tree-like approach is called for which can only become successful if sufficient funding is available at the national and regional level. The Marine WG of the Asia Pacific Regional BON is including plans for surfacing and digitizing historical data in their Implementation Plan.

5.3.3.2 Anecdotal, archaeological and fossil data

To trace the status of marine biodiversity and changes beyond the historical data period, it is necessary to rely on anecdotal data (e.g., menu cards, paintings, ship logs, fish market logs, etc.), archaeological data (e.g., shipwreck materials, domestic dumping sites, etc.) and fossil data (e.g., dinoflagellates, diatoms, radiolarians, foraminifera, ostracods, fish bone assemblages and remains in well-dated sediments).

As far as the anecdotal data is concerned, the activities of the CoML programme HMAP (History of Marine Animal Populations, http://www.coml.org/projects) are good examples to assemble these kinds of data in a biodiversity context and to make them freely accessible. For example, MacKenzie et al. (2002) analysed the archives of Baltic countries for tax records, topological information and changes in laws to reconstruct the magnitude of fisheries in the Baltic during past centuries.

Regarding fossil data it is important to realize that these data are not commonly reported within a biological/biodiversity context, with some remarkable exceptions. Moriaki et al. (2009), for instance, correlated variability of deep-sea tropical biodiversity of benthic microfauna during the last four glacial–interglacial cycles with orbital-scale oscillations in global climate. This type of studies remain rare, so that reformatting of such data must be considered as a relatively new activity depending on local and regional funding.

GEO BON's task is to stimulate such funding and to strategically follow the same approach as sketched for the historical data, including the surfacing of hidden data at archaeological and geological institutes and organisations and to provide a common platform to search for and analyse historical and fossil data sources.

5.3.3.3 Existing data, data accessibility, and key data gaps

Ad hoc and ongoing long-term observations of marine biodiversity are on average much better scientifically and logistically organized nowadays than in the past. More attention is being paid to national and international protocols related to sampling, sample processing, sample storage and data handling partly due to large international programmes such as JGOFS, CoML, MARBEF, HERMES, organisations such as ICES and requirements of funding agencies. Also, there is an abundance of catch data, as well as stock assessments, made in conjunction with fishery management.

Nevertheless, it is still a difficult task to make a comprehensive inventory of all present-day marine biodiversity programmes and activities worldwide. Such an inventory is crucial for reasons mentioned above and is one of the priorities of the Marine WG. This inventory can be made by the stepwise approach mentioned above and should therefore be combined with the efforts to map the historical data using, amongst others, existing databases of all institutions and programmes which have contributed or are contributing to marine databases. Several portals aim at capturing information on the available data (e.g., FGDC, GCMD, SeaDataNet); many of these systems are converging on the ISO 19115 standard, and will be or are already interoperable. For marine sciences, the recently established global database http://www.oceandataportal.org of IODE, a portal through which the data of 66 National Ocean Data Centres (NODCs) is playing a key role. A detailed discussion of metadata systems and their interoperability is left to the Data Interoperability WG. When the inventories of historical and actual data are mapped and tabled a global overview will be obtained per zone, ecosystem, and sub-ecosystem, including species distributions together with their contextual and metadata, protocols relating to sampling, processing, storage, data handling, etc.

Based on such an inventory geographical and (micro)biological gaps will become clear so that focused actions can be taken to fill those gaps. It is the Marine WG's task to facilitate filling these gaps and to stimulate all activities necessary to help scientists worldwide to obtain funding to start long term observations, to digitalize data, to submit data, to optimize protocols, to fill the gaps and, above all, to make all data freely accessible through well-established databases (e.g., OBIS, GBIF, LifeWatch, Barcode of Life (BoL), Encyclopedia of Life (EoL), ICES, and the IUCN Red List). Such an inventory will aid in identifying unique or highly diverse ecosystems and those supporting migratory, restricted range or globally threatened species, as well as those whose biodiversity is of socioeconomic importance and in developing a strategy for assessing biodiversity at the gene, species and ecosystem levels.

5.3.4 Detect and monitor invasive species and harmful algal blooms

A large part of major marine biodiversity changes now and in the recent past are due to economically triggered human activities such as deliberate or accidental introductions of invasive species, by shipping (fouling and ballast water), by aquaculture and by removal of endemic species directly by hunting (e.g., fisheries).

One of the major challenges in current biodiversity research is to monitor the past and present distribution of invasive species as a prerequisite for understanding their role in changing ecosystem properties such as productivity, stability and resilience. For detecting new invasions and monitoring extension of known benign and non-benign invasions, a monitoring network based on marine field stations is indispensable. For macro-species, this is an ideal area to make use of the efforts of amateur or citizen science, including schools, that are prepared to execute regular sustained surveys of particular stretches of coast under supervision of a scientific station or institute in the region. For microbial species, a regular survey of genetic diversity will be developed using modern sequencing technology (see above), amongst others to detect pollution of gene pools, a problem associated with fish farming escapes.

Harmful algal blooms (HABs) are becoming increasingly common, particularly in coastal waters where they cause massive fish kills, contaminate seafood with toxins, and alter ecosystems in ways that humans perceive as harmful. Although much is known about HABs, the factors controlling the dynamics of individual species is poor. The challenge is to understand the critical mechanisms underlying the population dynamics of HAB species in a variety of oceanographic regimes. Effective monitoring is a prerequisite for this and required as a basis for modelling and thus predicting the occurrence, movement, toxicity, and environmental effects of HABs.

5.3.5 Model and predict marine biodiversity

Data inventories and better access to data must support different modelling techniques, in some cases coupled to Climate Change and economic scenarios, that need to be developed to better describe and predict biodiversity change and its consequences for ecosystems. Marine biodiversity modelling is still in its infancy and an assessment of existing models—mostly from the literature on terrestrial biodiversity—and future modelling needs is necessary. Models are needed for a wide range of applications, e.g., to forecast spread and impact of invasive species, to forecast algal blooms and HABs and their movements, to describe food web structure and the effects of top predator removal, and to support marine protection and conservation in general. A review of existing models and a strategy for developing new ones must be developed and partnerships need to be developed.

5.3.6 Build capacity

Capacity building is crucial when it comes to comprehensive and sustained observations and monitoring of the oceans, the more so if it is realized that two thirds of the oceans are in the southern hemisphere and that funding for ocean observations and monitoring is mostly related to the northern hemisphere. Capacity building programs such as established by IOC, POGO and SCOR (fellowships and the Centre of Excellence in Bermuda at the Bermuda Institute of Ocean Sciences (BIOS) funded by the Nippon Foundation) are excellent examples of sustained capacity building and should be extended to ultimately fill key gaps in ocean observations and monitoring, especially in the southern hemisphere. The Marine WG will work with a variety of organisations to coordinate existing activities where needed, and to facilitate the creation of new ones where they are missing. The first step in this process will be to identify some of the most relevant potential partners.

5.3.7 Strengthen the knowledge base on taxonomy

Biodiversity research depends critically upon accurate identification of organisms or populations. This may be by conventional visualisation or by molecular taxonomic analyses. Yet the state of taxonomic and systematics training at universities is generally poor. There is a strong need to ensure that taxonomic skills are not lost and that specialist training courses are given. In the marine sciences there is a strong need for this and the few specialised courses that are run are often oversubscribed. Courses should cover phylogenetics, revisionary taxonomy as well as identification, and address both living and fossil organisms.

In the UK, the poor state of taxonomy and systematics is considered a threat to national capability across a wide user community and a national review is being commissioned (http://www.uktaxonomy.co.uk). This review will cover training, sample curation, support to environmental and biological sciences and the role of the volunteer community in taxonomy.

The European Distributed Institute of Taxonomy (EDIT) (http://www.e-taxonomy.eu) is the collective answer of 29 leading European, North American and Russian institutions to a call of the European Commission, issued in 2004, for a network in "Taxonomy for Biodiversity and Ecosystem Research". The EDIT consortium agreement has started on the 1 March 2006 and will last 5 years.

Among the members of EDIT are the premier natural history collections-based institutions worldwide, which have both the management capacity and the will to progress toward EDIT's objectives. Their collections are global in coverage and are supported by complementary expertise. More than half of the world's natural history specimens, which constitute the large scale infrastructure for taxonomic research, are held in the repositories of EDIT's membership. The inclusion in the consortium of network institutions devoted to management of biodiversity data, and of a research organisation directly related to users of taxonomy for agriculture and environment, in addition to the links or inclusion of many partners with universities, will facilitate dissemination of EDIT taxonomic research and training toward a wide audience.

The Marine WG will strongly support these and other educational activities.

5.4 Deliverables

Adoption of the monitoring approaches identified above will generate the data requirements to address key drivers such as ecosystem performance and development; extent of habitat changes; trends in the status of threatened species; trends in the impacts of specific pressures such as impact of fisheries on fish stocks; and coverage and extent of protected areas.

5.4.1 Pilot study on marine ecosystem classification with associated biological data series

This study will be based on ongoing developments of two marine ecosystem classifications—one for the open ocean and one for the coastal regions—and it will integrate and refine these ecosystem classifications for a selected region. The study will be the basis of an attempt to implement a global ecosystem classification that will integrate biodiversity and physico-chemical information.

5.4.2 Inventory of past and present sustained observation programs and associated data series

This will be an exhaustive database of past and present observations and databases, based on existing inventories of sustained observation programs and associated databases. The database will help to identify gaps in marine observations, to promote future observation programs and to standardize observations and databases.

5.4.3 Inventory of historical, anecdotal, archaeological and fossil biological data series

This will be a database of inventories of biodiversity-related data of the last centuries and millennia. It will help to define the state of biodiversity before human impact and thus improve understanding of the present state of biodiversity and assist with predictions of future biodiversity changes. This inventory has two main components:

1) An inventory of past and present marine organisations, including research institutes, marine stations, university departments, museums, governmental bodies, international and national programs, etc.

2) An inventory of existing databases of cruise summary reports related to biological activities, identifying responsible PI's and their host organisations

5.4.4 List of data providers regarding invasive species

This list is a complete overview of data providers pertinent to invasive species. Such a list is considered as a first and crucial step in creating a worldwide comprehensive inventory of past and present invasive species events.

5.4.5 Review of modelling needs for marine biodiversity

This review will provide (1) an inventory of past and present modelling exercises related to biodiversity change and (2) a discussion of modelling needs for marine biodiversity. Modelling marine biodiversity as well as biodiversity processes is needed to better predict the consequences of biodiversity change. However, such modelling is challenging, and this deliverable is intended to help address that challenge.

5.4.6 Report on strengthening capacity building and taxonomy training

This report will suggest paths to increase capacity, particularly for marine taxonomy and with a focus on less developed countries. Such capacity building is critical for extending comprehensive and sustained biological observations of the coastal and open oceans from the photic zone to the deep sea and the surface sediments. Less developed countries will need to play a very significant role because two thirds of the oceans are in the southern hemisphere.

5.5 Data

The data required for effective implementation of GEO BON's activities are extremely diverse and range from molecular and genetic information, which is stored systematically in data banks, to species information in many different formats and data bases, and to habitat maps obtained by acoustic methods. Most biodiversity information is at the species level and the main challenges for the coming years will be to inventory the existing historical, anecdotal, archaeological, fossil and modern data and the data bases from which they can be retrieved, and to make this information known and easily accessible. Besides identifying existing data, key data gaps will have to be identified and efforts will be made to eliminate these gaps.

5.6 Implementation Partners

The activities required to create a global partnership will be developed gradually from existing partnerships at the national and regional level. This can be done by using informal networks of willing scientists on the one hand and obtaining support through non-governmental and governmental mechanisms at the other.

The starting point for organizing a partnership for coastal ocean observation will be the networks of marine stations and institutes such as MARS (European Network of Marine Research Institutes and Stations), NAML (North American Association of Marine Laboratories) and CHONE (Canadian Healthy Oceans Network). These organisations have existing relationships with each other that can be formalized, e.g., through a Memorandum of Understanding to be developed at an inaugural meeting in 2011. A recent initiative to build a group called the World Association of Marine Stations together with IOC may support this (see below).

Regional networks of marine stations exist in several other places in the world, e.g., in East Africa, Australia, New Zealand and Japan, and the Marine WG will identify these networks. This is a topic of discussion with the Intergovernmental Oceanographic Commission, and the Marine WG will request assistance from the National and Regional Implementation Committees of the Census of Marine Life to achieve an up-to-date inventory of existing networks and to identify the individual scientists who are willing and capable to support the development of marine biodiversity observation.

For the open ocean observations SAHFOS as well as the Partnership for the Observation of the Ocean (POGO) and GOOS can be addressed. POGO has already committed to participation in GEO. The Global Ocean Biodiversity Initiative (GOBI, http://www.gobi.org) is an IUCN-led initiative that seeks to illustrate how scientific data (both remote sensing and *in situ* data) can contribute to the decision making processes of the Convention on Biological Diversity. Several illustrations of how science can contribute to the identification of Ecologically and Biologically Significant Areas (EBSAs) in the open ocean were compiled, and made public through the GOBI web site. These illustrations can also be used in the framework of GEO BON. Furthermore BirdLife International has made important progress in identifying and monitoring marine Important Bird Areas, and by extension, under the auspices of IUCN, this methodology is being adopted to identify key biodiversity sites in the marine environment.

The marine biodiversity community in Europe is well-organized through several organisations such as MARS (European Network of Marine Research Institutes and Stations), the very recent MarBEF+ (European Institute for the Study of Marine Biodiversity and Ecosystem Functioning) and its sister networks MGE (Marine Genomics Europe) and Euroceans. Several initiatives and projects funded by the European Commission are relevant to the marine component of GEO BON. These include the integrated projects HERMES, HERMIONE and SESAME, the network of deep sea observatories ESONET and its scientific component VISO, EMODNET (data acquisition), etc. One of the early activities of the Marine WG will be to inform these networks and projects, as well as the European Commission, of GEO BON and its Marine WG activities.

The 120 members of the National Association of Marine Laboratories (NAML) in the US represent most of the research infrastructure for coastal oceanography in the US. A few of these laboratories have open ocean vessels and all have vessels capable of oceanographic observations and sampling of the continental shelf. NAML has regional meetings and an annual meeting to exchange ideas on issues associated with operation. Marine field stations have helped develop the use of autonomous underwater vehicles such as REMUS which are pre-programmed for each underwater mission, and gliders that take measurements on long glides to the bottom.

A special place in the process of creating a marine biodiversity observation community can be occupied by the International Council for the Exploration of the Sea (ICES), with governmental membership from many European countries, the US, Canada and Russia. ICES has been collecting information on fisheries and on the marine environment since the beginning of the previous century and has an extremely valuable and well-kept data archive.

The Marine WG will also contact IOC/IODE to help identify organisations and people in developing countries. Through its regional networks, and capacity building within these networks, IOC has created a vast global network of potential collaborators. It is especially important to have representation of all continents and a major effort will be made to identify relevant partners worldwide.

The outcome of these activities may be an international network of marine research institutes and stations devoted to organize the observation of the marine environment.

5.7 Coordination

The coordination of the Marine WG will remain the responsibility of the NIOZ Royal Netherlands Institute for Sea Research for a period of three years, starting March 1st 2010 or until the formation of a formal international organisation capable of running the program. The composition of the Marine WG reflects different expertises and the global distribution of participants.

5.8 Schedule

Activity/Deliverable	2010	2011	2012	2013	2014	2015	2016	2017	2018
5.4.1. Contribution to GEO BON assessments			X					X	
5.4.2. Contribution to GEO BON outreach	X	X	X	X	X	X	X	X	X
5.4.3. Pilot study ecosystem classification		X							
5.4.4. Inventory sustained observations			X				X		
5.4.5.1. Inventory marine organisations			X						X
5.4.5.2. Inventory cruise reports			X						
5.4.6. List data providers invasive species		X					X		
5,4,7, Review of modelling needs		X							
5.4.8. Report Capacity building/training		X					X		
5.6.1. Establish liaisons with data holders of commercial species (ICES, etc.)	X								
5.6.2. Create partnerships through joint meetings of MARS/NAML/CHONE/POGO in conjunction with regular annual meetings	X	X	X						
5.6.3. Discussion of implementation plan with IOC and COML-NRIC's	X	X							
Create "proof of concept" products based on existing expertise and datasets to advance understanding of biodiversity change			X						

5.9 Barriers and their Implications

The major barriers to progress for this WG are:

- Developing partner relationships, gaining partner participation, and allocating responsibilities;
- Obtaining funding;
- Determining which data to focus on, where it comes from, and gaining access;
- Defining the components of the observation network.

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6 Ecosystem Services (Working Group 6)

6.1 Introduction

Ecosystems provide benefits to society through the production of ecosystem services. It is vital that society keep track of the capacity of those systems, upon which they depend, to sustainably provide these services. This calls for mapping of service delivery over time at a scale relevant to users. Mapping of services can be done at all scales from global to local.

In order to accomplish this goal the Ecosystem Service WG focuses on the explicit linkage between ecosystem functioning and ecosystem services (Figure 6.1). The linkage between biodiversity and ecosystem functioning is not covered since this is still an emerging research area being investigated by the International Council for Science programs (DIVERSITAS and PECS) as well as the research community at large. Further, the plan only focuses on certain components of the human well-being and ecosystem service axis.

GEO BON proposes an accounting of ecosystem service delivery at a national resolution. National level reporting affords a global view of the status of ecosystem service delivery worldwide, and provides a pivotal point to scale up to the globe and downward to major local watersheds and administrative units. The Convention on Biological Diversity is built on national reporting and the emerging Intergovernmental Platform on Biodiversity and Ecosystem Services will most likely have a bottom-up approach, in contrast to the IPCC which was more of a global top-down effort.

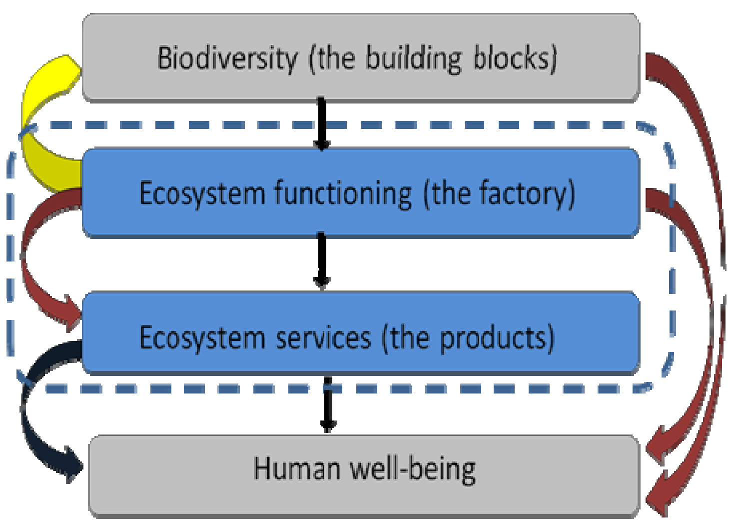

Figure 6.1. The chain of interaction among biodiversity elements, ecosystem functioning, ecosystem services and human well-being. One can enter anywhere along this chain for analyses of relationships. Ecosystem processes (supporting services) feed back to biodiversity composition and structure. GEO BON's Ecosystem Services WG focuses primarily on the dashed-encompassed relationships—ecosystem functioning and ecosystem services—although some components of human well-being are evaluated.

In addition, data on the status of physical, natural and social stocks and flows are generally available at the national level and provide the platform to scale up or down for integrated evaluations of their interactive products, in terms of ecosystem services. Many of the relevant data streams are reported at the country level but are based on available subnational level political units that are also accessible.

The national level, however, does not address many of the important cultural and other services that are important at the more local geographic entities (villages, states, etc.) and that often have crucial non-economic values for the resident population. GEO BON will focus its work at the subnational scale in the provision of standards and recommendations in order to accommodate a longer term "bottom-up" analysis of service delivery and valuation.

GEO BON is not a direct observational program but is a derivative and integrating mechanism based on observations taken for many different purposes (Scholes et al. 2008).

This plan has four primary interrelated activities:

1) Monitoring and evaluating global ecosystem service change at subnational and local resolutions;
2) Monitoring and evaluating global ecosystem service change at national resolution;
3) Reporting changes in bundles of ecosystem services;
4) Providing a database and toolbox for multiscale ecosystem service assessments.

6.2 Concepts to be Implemented

6.2.1 Ecosystem services—what GEO BON is measuring

Ecosystem services flow from the environment to people through a suite of steps. Each can be represented by a separate set of metrics. GEO BON will assess and track the condition of the underlying ecosystem (supply), the amount of service actually used or enjoyed by people (service), and/or society's preference for that level of service (value) (Figure 6.2).

Consider food from wild fisheries as an example. The total number of individuals or biomass of a harvested species is a measure of supply. The number or biomass of fish actually caught is a service metric. Finally, the market value of landed fish is a value metric, representing how much society prefers consuming one species over another. For example, Atlantic cod and Atlantic croaker provided a similar amount of service in the United States in 2008 (8,652 metric tons and 8,513 metric tons landed, respectively), but cod had a much higher value than croaker ($30,635,000 and $8,695,000, respectively; Pritchard 2008). This example uses economic value, but non-monetary values, such as preferences for service delivery to indigenous groups or the poor, can also be represented in value metrics. Information about each step in ecosystem service delivery can be informative to different types of research, assessment or decision making. GEO BON will monitor as many points in the supply chain as possible for each ecosystem service.

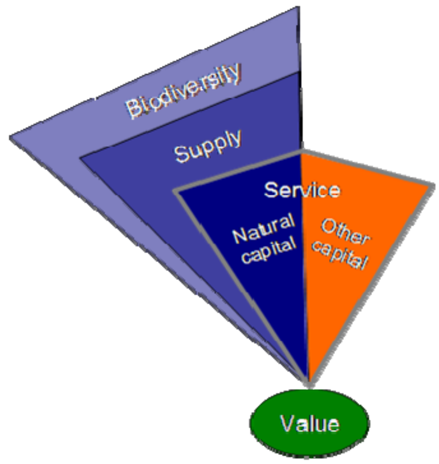

Figure 6.2. Ecosystem services can be measured at several points in the supply chain. Supply metrics represent the total amount of ecosystem process or elements that can lead to services. Service metrics represent the amount of supply that is enjoyed by society.

The additional distinction that needs to be made among possible ecosystem service measures is between the contribution of natural capital and other types of capital to the delivery of services (Figure 6.2). Some ecosystem services are the product of both natural and other types of capital, such as built, human or social capital. For example, food from agricultural production is an ecosystem service that relies on natural capital components such as fertile soil, ample water, pollination (sometimes by wild pollinators), which would constitute the blue wedge in the service portion of Figure 6.2. But crops do not rely on these inputs alone. They also require other capital inputs such as technology, fertilizer and labour (the orange wedge in Figure 6.2). In cases like this, GEO BON would like to report only the contribution of natural capital, often called the marginal contribution, but these values are harder to derive. Metrics of the overall service (both natural and other capital components) are often reported in national statistics (yield by crop species). In other cases, the natural capital contribution, such as the marginal crop yield attributable to wild pollinators, can be extracted.

Other services are simpler to track because they are derived entirely from natural capital, such as climate regulation via carbon sequestration. Growing vegetation captures carbon dioxide from the atmosphere, which is well-mixed, so vegetation growing anywhere provides a service to people. This carbon capture happens without the help of any human infrastructure, knowledge or intervention (e.g., built, human or social capital). GEO BON will attempt to report the natural capital contribution to ecosystem services as often as possible, but rely on several metrics that reflect both natural and other capital contributions to service provision.

6.2.2 Monitoring change at national, subnational and local scales

Finding or implementing consistent measures of ecosystem services globally for any point in the supply change is still a major challenge. In the absence of such consistent global measures across all services, GEO BON will rely on four major types of information to track ecosystem service change; global datasets, national statistics, models and field-based measures (Figure 6.3).

Global datasets and national statistics can give us direct information on several commercially-important services (e.g., agriculture, timber, water, etc.) and carbon storage. Beyond the services already traded in markets, GEO BON needs to turn to models to estimate levels of production, delivery, value and change because they are not directly monitored by any existing system. Several models exist that could be used to map a subset of ecosystem services globally. Most of

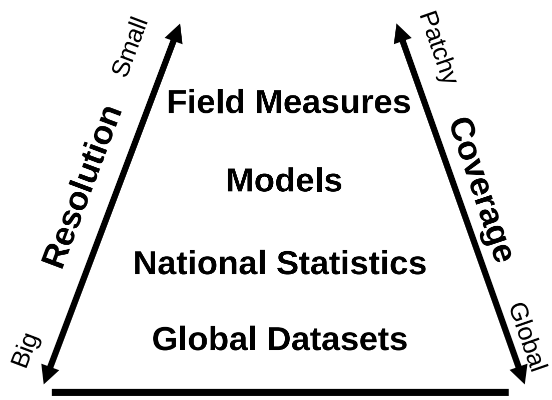

Figure 6.3. Sources of information on ecosystem services to be integrated by GEO BON.

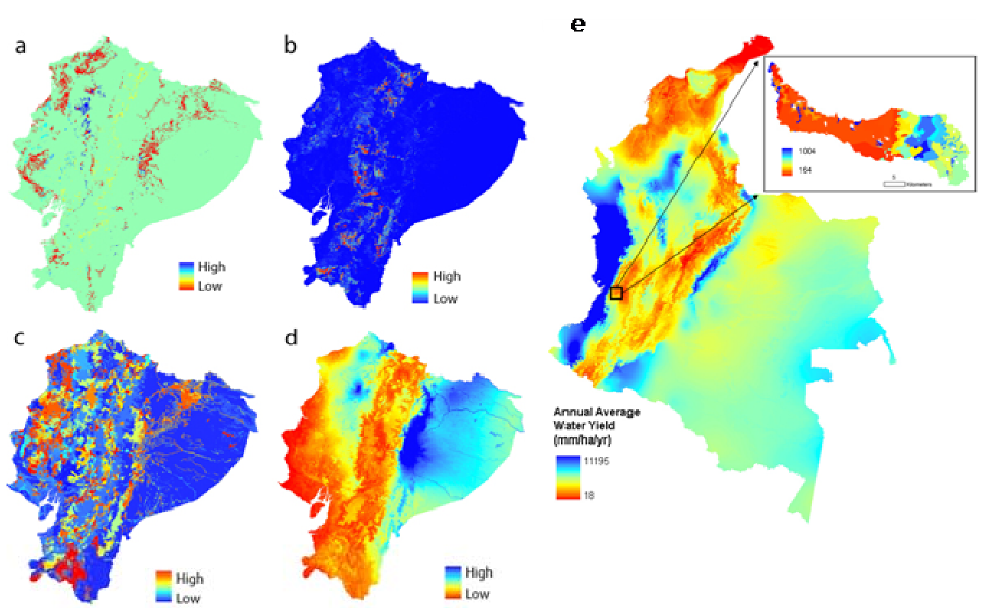

Figure 6.4. Subnational to local scale ecosystem service patterns. Models using readily available data can provide patterns of multiple services such as a) carbon sequestration (service metric, metric tons C ha-1), b) annual average erosion rate (inverse supply metric, tons ha-1 yr-1), c) pollination index (service metric, unitless index) and d) annual average water yield (supply metric, mm ha -1 yr-1) in Ecuador. The same models can provide maps of ecosystem service patterns at multiple scales, as shown for annual average water supply in Colombia (e). (Natural Capital Project and The Nature Conservancy).

these models give outputs at subnational resolution, allowing scaling up and down as desired (Figure 6.4). However, many of these rely on an input of land use and cover. Land use and land cover maps are not currently updated reliably and frequently enough for our needs. Therefore, GEO BON needs to explore the development of new methods that will draw from readily provided remotely sensed data. Remotely sensed data are available at increasingly finer levels of resolution, but they infer limited characteristics of an ecosystem, and none of the current data streams represent ecosystem services directly. However, several existing, regularly updated global datasets measure important processes or elements that might be useful in modelling ecosystem services. These datasets include: spectral vegetation indices, such as NDVI, landcover maps of simple biome class (forest vs. grassland), leaf area index, and net primary production (Figure 6.5).

In the long term these “top-down” approximations of ecosystem services must be complemented with information generated from local scale sources. Such a “nutcracker approach”, combining top-down with bottom-up data approaches, verifies global trends and highlights areas of disagreement (Figure 6.6). Bottom-up approaches can report on groups of services using data often not available at global scales (e.g., cultural services) and also provide engagement with

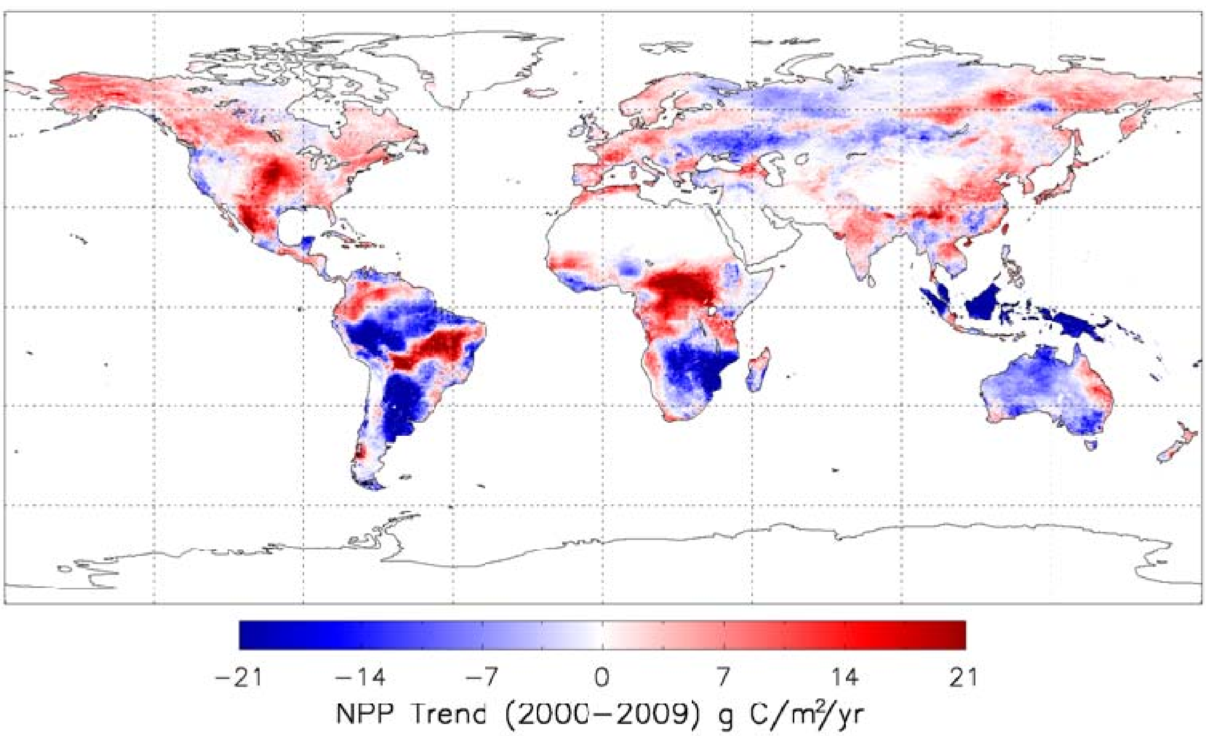

Figure 6.5. A global map at 1km of the trends in annual NPP relative to the average of 2000–2009, based on methodology in Running et al. (2004). By representing the annual anomaly of NPP, a dimensionless index showing positive or negative trends can be created and then applied to a variety of ecosystem services related to carbon cycle based processes (from Zhao and Running 2010).

national and local scale decision makers. This engagement will help GEO BON foster local to global decision making as well as related capacity-building.

Policy decisions typically consider multiple ecosystem services and the relationships among them. For example, provisioning services such as agricultural production may be increasing over time, while other services such as water purification or carbon storage decline. Managing these common tradeoffs among services requires information on bundles of ecosystem services. While the relationships are often complex, finding ways to communicate in clear and simple terms about this complexity is most urgently needed.

To facilitate this more synthetic view, GEO BON will develop an approach for expressing bundles of ecosystem services. One promising way of depicting bundles of ecosystem services is via a "spider diagram," that expresses on multiple axes the quantity of each service (Figure 6.7). Comparing spider diagrams among spatial units or through time can help clarify the aggregate benefits from or changes to ecosystem services. Other analyses can borrow from biodiversity theory, analyzing evenness of service delivery and dominant services. Declining evenness in service delivery could signal growing instability in a country's aggregate supply of natural capital.

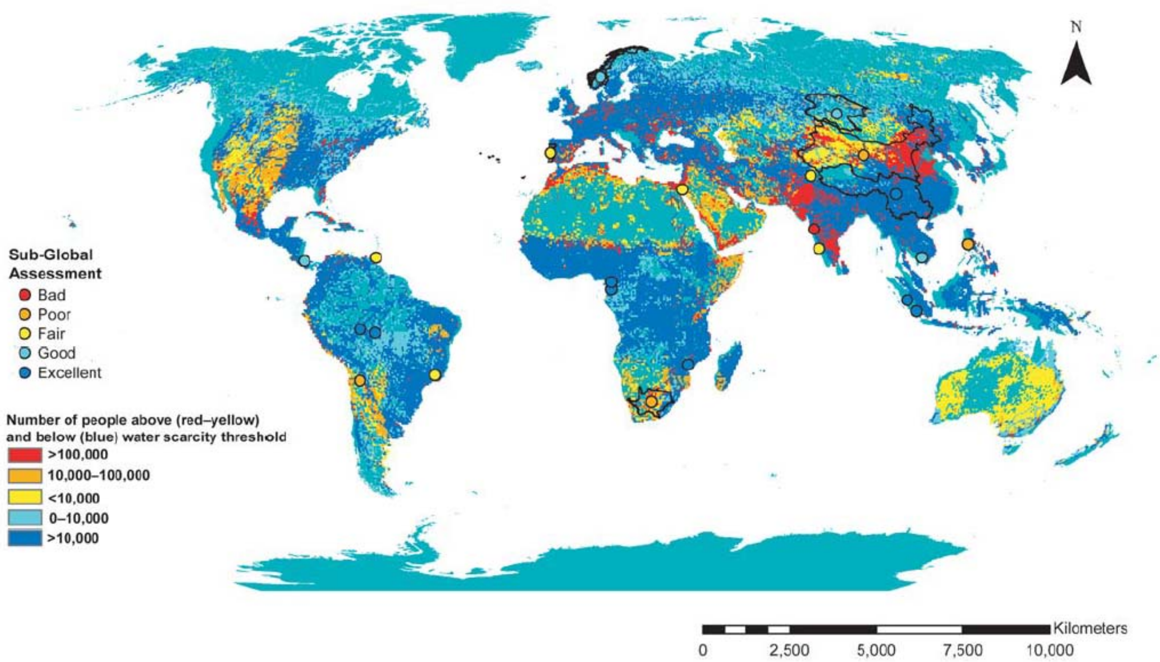

Figure 6.6. Comparison between the subglobal assessments of freshwater condition and the global distribution of population in 1985 relative to a threshold of severe water scarcity. The threshold corresponds to a ratio of 40% of water use or withdrawal to discharge. Extracted from Pereira et al. 2005.

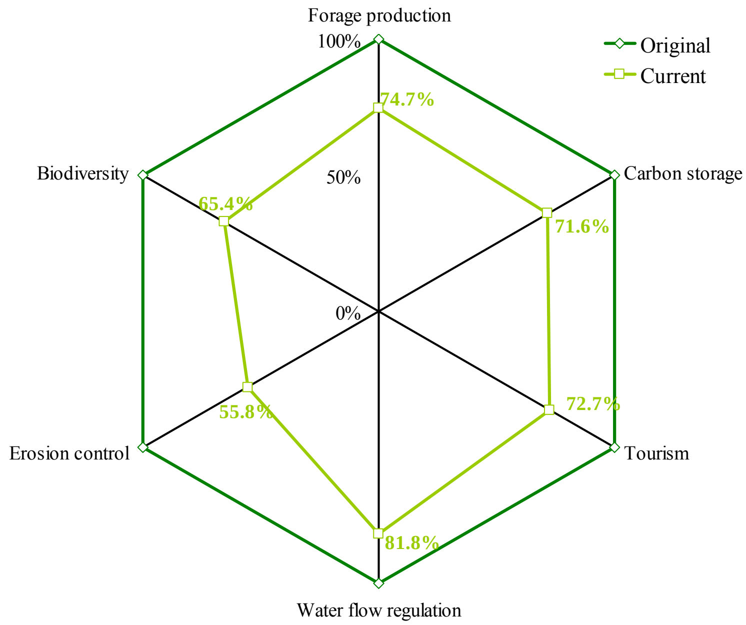

Figure 6.7. "Spider diagram" illustrating the bundle of ecosystem services currently provided by the Little Karoo landscape in South Africa relative to pre-colonial conditions (original). Each of the six axes represents a different ecosystem service; light green line depicts the amount of each service currently provided, relative to an historical baseline (outer dark green line).

6.3 Activities

6.3.1 Monitoring and evaluating global ecosystem service change at subnational and local resolutions

This bottom-up activity will rely on strong partnerships (Network of Networks) with many programs working at the local scale. These programs include the MA subglobal assessment process, the Natural Capital Project (Stanford University, The Nature Conservancy and World Wildlife Fund), the integrated TEAM Network observational program of Conservation International, the US National Ecological Observatory Network (NEON), the DIVERSITAS ecoSERVICES core project, the ILTER (International Long Term Ecological Research) Network and the closely associated ICSU Program on Ecosystem Change and Society (PECS). In order to optimise the value of these bottom-up data and approaches, GEO BON must help to ensure some consistency, standards and recommendations to inform these approaches and ensure their data are useful to the global monitoring and observation systems.

The major steps for this Activity are:

- Develop links with partners;
- Review existing standards and programs;
- Organize group and develop standards;

- Organize group and develop recommendations to partner programs.

6.3.1.1 *Standards and guidelines for collecting ecosystem service data at the local scale*

Some services have emerging sets of standards for field-based measurement that will allow credible interpretation at local scales, as well as integration across scales for interpretation at larger scales (subnational, national, etc.). For example, there are several available protocols for making field measurements of carbon storage (e.g., IPCC, Winrock). The focus here will be on services which do not already have such standards. For example, a working group on cultural ecosystem services (National Center for Ecological Analysis and Synthesis) is developing standards for assessing a suite of cultural services at the local scale. GEO BON will compile such emerging standards and develop new standards for services that will be best measured at the local scale. GEO BON will also provide metadata standards for field-based and subnational scale data collection.

6.3.1.2 *Recommendations for additional data streams to be collected*

Several ongoing subnational, national and international efforts collect consistent streams of data that could be expanded slightly to acquire extremely useful data on ecosystem services and their importance to human well-being. For example, Chinese researchers recently expanded local census questions to include information on household reliance on natural capital. Similar expansions could be made to national censuses, and World Bank data collection efforts such as those summarized in the Little Green Data Book and the World Development Report. GEO BON will make recommendations for which new data streams could be added in the short and long term to provide regularly collected, standardized data on ecosystem services.

As these standards and recommendations become implemented in ongoing subnational and local research within partner monitoring initiatives, such data will be incorporated into the synthesis products produced by GEO BON.

6.3.2 Monitoring and evaluating global ecosystem service change at national resolution

GEO BON has identified key services to track, along with key beneficiaries and temporal resolution for each. There is an extensive list of ecosystem services that should be monitored globally. Given the state of data, capacity and fundamental science, GEO BON has selected a subset of services as the initial focus. However, as more is learned about the fundamental nature of ecosystem service behaviour and our ability to measure and model additional services improves, they will be added to the observing system. GEO BON has selected the initial set of services based on the following criteria:

- Economic or social significance; prioritizing services with greater economic or social relevance;
- Rate of change; prioritizing services that are declining most precipitously;
- Marginal role of service in affecting well-being; prioritizing services that account for the majority of a social benefit. For example, flood mitigation is a very popular service, but the natural environment can only mitigate the impacts of relatively small-scale floods, so this service would not be of top priority. Carbon stocks and water quality are examples of clear contributions from ecosystems to well-being;
- Data or model availability; prioritizing services that can be tracked with available data or available validated models.

The major steps for this Activity are:

- Develop links with partners;
- Compile data;
- Define and develop models;
- Organize analysis group;
- Develop models and maps.

6.3.2.1 Initial service set (reported every two years)

GEO BON will track an initial set of services on a two year update cycle, and provide maps and reports summarizing these services. It will not be possible to monitor all services at all points along the chain of ecosystem service delivery (Figure 6.2). GEO BON has identified the services, beneficiaries, and points along the supply chain that can be monitored with existing data and models (Figure 6.8). This list will be expanded as additional information and methods become available, working towards a monitoring system that tracks the supply, demand and value of all ecosystem services, and considering that service valuation will vary with region.

Global maps of essential ecosystem services, aggregated at the level of individual countries, will be based on a combination of available national statistics and the outputs of models linking basic processes of ecosystem dynamics that are driven by biophysical data. The national statistics (e.g., FAO crop yields) have the advantage of being a direct estimate of ecosystem services at the desired scale, but they do not permit attribution of the specific quantities to the state of the country's ecosystems under the given climatic conditions of the reporting year. Process-based models of the dynamics in managed ecosystems, on the other hand, will only approximate the reported quantities of crop or water yields—but they allow for an integrated assessment of major ecosystems and their tradeoffs, for example with respect to water use for crops (rain-fed or irrigated) versus other uses of water.

Most available process-based models require a land use and land cover input. Given the shortage of regularly (2 yrs or less) updated, highly-resolved land use and land cover maps, GEO BON proposes to use a remote sensing approach as an input for models of ecosystem services. The current remote sensing products GEO BON might draw on include the MODIS Global Disturbance Index (MGDI), developed by Mildrexler, Zhao et al. (2009), that accounts for long term perturbations in the energy balance of the land surface driven by such events as wildfire, hurricanes, ice storms, and deforestation. Future work linking changes in this index with changes in NPP and a base land cover map will produce an ecosystem state index (Figure 6.9) that may be useful in modelling change in both the basic and extended sets of ecosystem services

Another new, similar approach that is being considered combines available land use and land cover data, disturbance, NPP seasonality and key characteristics of land cover patterns to develop a quantitative indicator of structural and functional ecosystem change at every 1-km pixel on the global land surface. These areas of change can then be assigned a new land cover class, which when linked to existing models of ecosystem services can be used to update ecosystem service status estimates regularly and consistently across the globe.

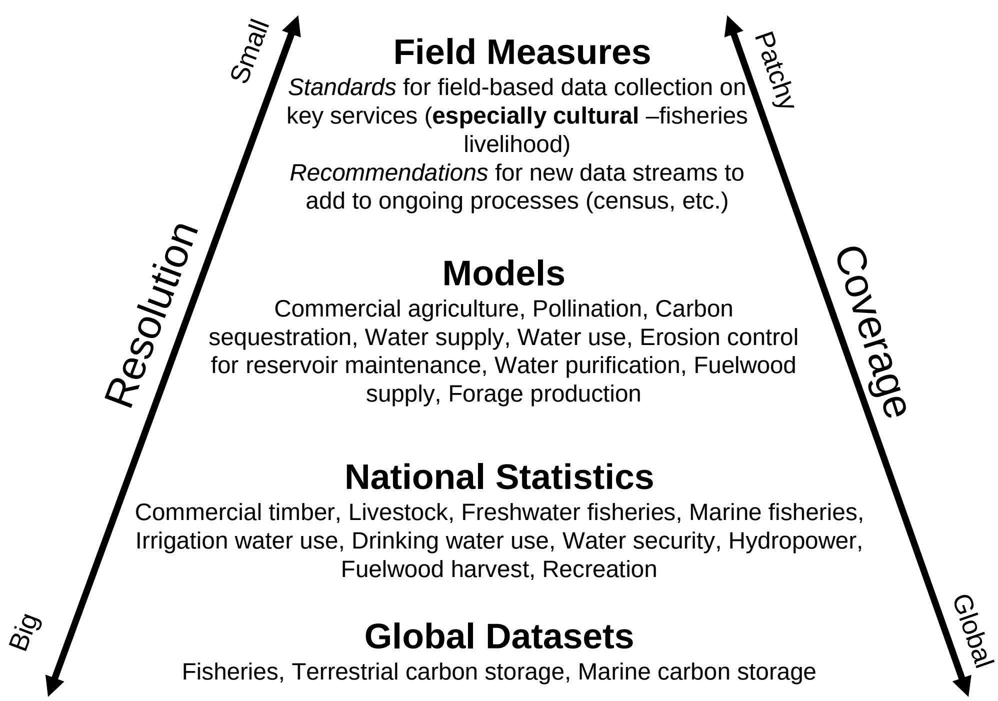

Figure 6.8. Initial set of ecosystem services to be reported at national resolution every 2 years.

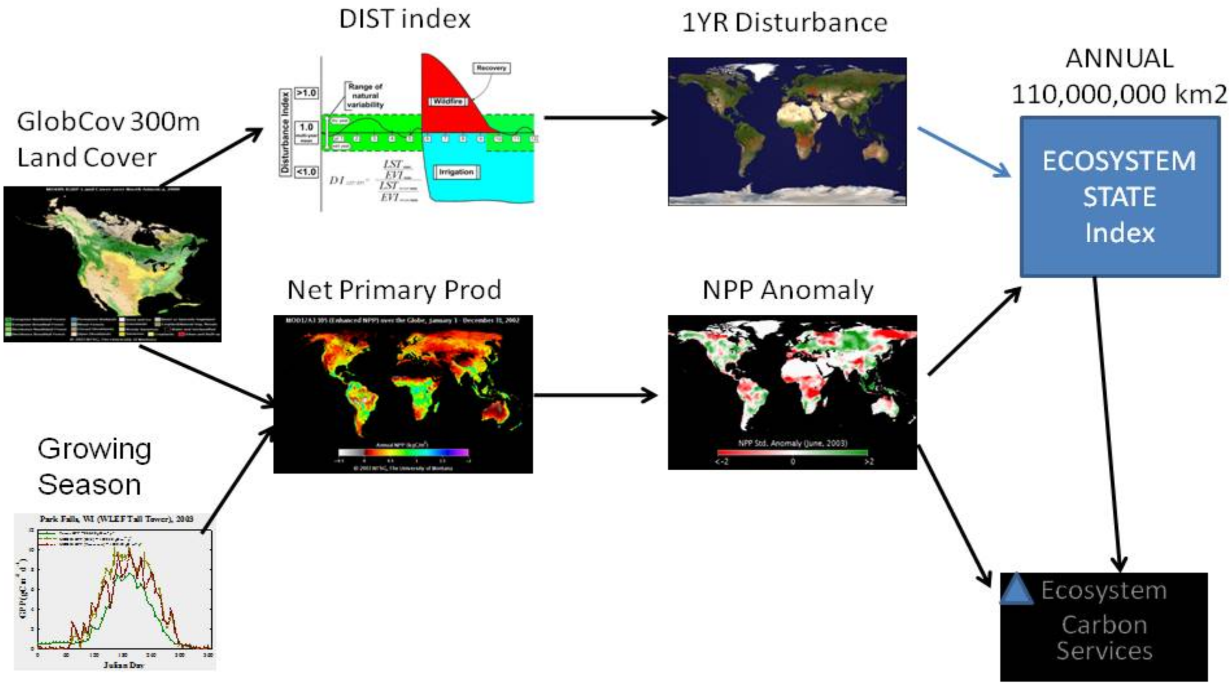

Figure 6.9. Possible framework for combining existing remotely sensed data products into an index that can be used for biodiversity and ecosystem service modelling.

6.3.2.2 Extended service set (reported every 2 years)

GEO BON will monitor an additional set of services as science and methodologies advance, allowing us to fold in new data streams and models (Figure 6.10). These additional services will be integrated into the same synthesis and reporting framework as the services noted above. Whenever refinements are made, analyses will be re-run on previous time steps to allow rigorous comparisons over time.

6.3.3 **Monitoring changes in bundles of ecosystem services**

Our core, national-scale activities in section 6.3.1 will provide information on the status and trends of individual services useful in global monitoring and reporting programs. The tools developed will be used to analyse and communicate (1) the bundle of services for any country, (2) the changes in this bundle over time, and (3) the differences in the bundle of services among spatial units.

The major steps for this Activity are:

- Review approaches for reporting bundles and changes in bundles;
- Select approaches;
- Identify and organise group for bundle reporting;
- Develop reports.

6.3.3.1 Produce national-resolution summaries of service bundles

Accompanying each update of national-resolution maps (see section 6.3.2.1) this task will produce a set of simple but defensible summaries of ecosystem service bundles. These analyses may include:

- Spider diagrams displaying bundles of ecosystem services for sampled countries;
- National estimates of evenness among services and changes in that evenness;
- Maps of evenness.

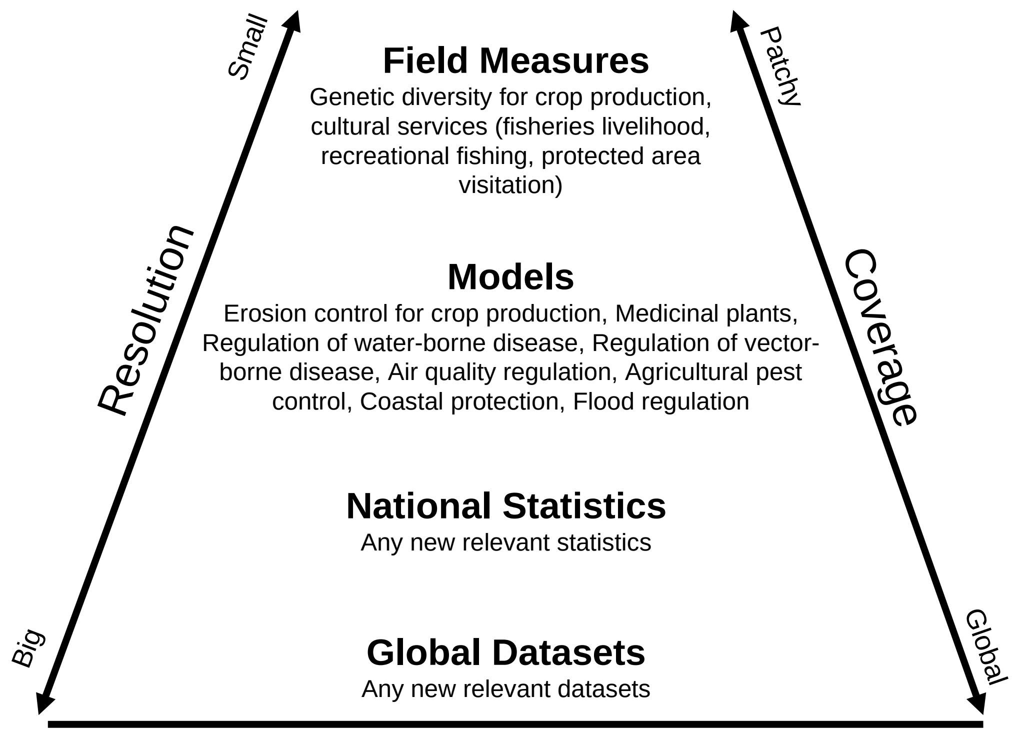

Figure 6.10. Expanded set of ecosystem services to be reported as science, data and methodologies advance.

6.3.4 **Providing a database and toolbox for multiscale ecosystem service assessments**

Spatially explicit ecosystem service (ES) assessments need to be based on a consistent and traceable framework for the collection and management of data (from inventories, statistics or models), their analysis, their interpretation and for the communication / mapping of changes (including risks). Data layers exist for the biophysical environment (e.g., topography / bathymetry, climate, land cover, etc., at local to global scales, gridded or polygon-based) and for services delivered by managed systems (agriculture, forestry, fisheries, etc.), but there is no generally accepted standard for a coherent data management structure in ES assessments. An Ecosystem Service Assessment Toolbox could provide the platform for management and processing of observations. Ideally, the Toolbox would be implemented in such a way that ES modelling and valuation approaches could be performed within the same computational environment. The Toolbox will also help assessments to move between scales with consistent approaches and take advantage of best available data.

Several frameworks for ES assessments exist (e.g., the ATEAM Mapping Tool,[6] the InVEST modelling toolbox,[7] and others). A review of these approaches and an evaluation of their applicability to ES analysis for a broader range of problems, data quality conditions, and stakeholders will be carried out. Following the review, a plan will be developed for a versatile, open-source protocol which could be applied to a wide range of conditions.

Several discipline-oriented databases are available, including agricultural databases (FAO), national, social databases, and climate databases (NASA, UEA-CRU). However, there is no international ecological database, and no links among existing repositories that would assist in the use of multiple, diverse datasets for ecosystem service analysis.

The major steps for this Activity are:

- Identify partners in database and toolbox development;
- Organise groups for development;
- Organise group for documentation and capacity building.

6.3.4.1 Database and toolbox development

GEO BON will develop the means to allow for (possibly decentralized) Internet-based data upload, storage and retrieval (e.g., hosted by national and international agencies or major research laboratories). Implementing the protocol implies substantial development of software structures (based on open source tools, e.g., R) which allow coupling of models and data on different computer platforms. In parallel, actual geospatial databases with global or local focus are developed in different locations, allowing fully open access for ES assessments over the internet.

6.3.5 **Document the state of ecosystem service science and toolbox development**

The science of ecosystem service observation and analysis is a rapidly developing field. The

[6] http://www.pik-potsdam.de/ateam
[7] http://www.naturalcapitalproject.org/toolbox.html

utilisation of the products of this research is being employed to an ever greater extent in quests to account for the status and trends of natural capital in land- and seascapes at all levels. Periodic comprehensive syntheses of the latest state of knowledge and applications of concepts, models, scenarios and analytical tools would promote the progress and utility of the vast sea of activity in ecosystem service concepts and analysis. These syntheses will draw extensively from the scientific literature as well as reports of the outputs of ecosystem service evaluations produced by the global community (including but not limited to GEO BON).

6.3.6 Capacity building in ecosystem service science and toolbox application

As the above toolboxes develop and become available within the global community, there will be a need to provide training in their use in the monitoring and assessment of ecosystem services at multiple scales. Securing funding and collaboration with training bodies (e.g., GEF and START) will form an essential component of this activity to develop and produce workshops, training courses and training manuals in ecosystem service science. The capacity building program will link to the bottom-up Network of Networks developed within this working group.

6.4 Deliverables

6.4.1 Standards for local and subnational scale methods

This one-time report will present standard methods for collecting data on locally and regionally provided ecosystem services that are not well-tracked by satellite data or national statistics approaches.

6.4.2 Recommendations for new data streams in ongoing local and sub-national processes

This one-time report will suggest new types of ecosystem service data that could be collected through standard, existing programs such as national censuses and sub-global assessments. We will focus on recommending data streams that will be most useful to advancing ecosystem science and policy making.

6.4.3 Global maps of initial service set every two years

This will include two sets of maps. One will portray the spatial distribution of individual ecosystem services at national resolution in the year two years prior to reporting. The other will portray the change in individual ecosystem services, at the national scale, since the period of last reporting. The services included in these maps will be those that we can currently map today.

6.4.4 Global maps of extended service set every two years, as available

As science and technology advance, it will become possible to map more and more services regularly. We will continually add maps of ecosystem service condition and change as possible.

6.4.5 Ecosystem service bundle maps of initial service set every 2 years

These maps will show spider diagrams (or other representations) for each country, identifying the relative provision of multiple ecosystem services in one map. This set of maps will represent the services we can map today.

6.4.6 Ecosystem service bundle maps of extended service set every 2 years

As services are added in Deliverable 1.1.4, we will include them in national bundles and report on them in this set of maps.

6.4.7 Concept document for open database and modelling toolbox structure

This document will include specification of database protocols, data layers for minimal ES assessments, and coupling interfaces to models (internally coded or external).

6.4.8 (Initial) release of distributed database and modelling toolbox

This database will provide access to all streams of national statistics that we can secure free access to. The modelling toolbox will provide access to a set of biophysical and socio-economic models that allow modelling and mapping of ecosystem services that are not included (or are not included reliably) in national statistics.

6.4.9 Regular report on state of ecosystem service modelling and data sources

This report, released every 2 years, will provide a literature review to inform and update models and data used in global maps.

6.5 Data

There are two activities of our work that will involve data compilation. The other activities will draw from the information gathered and produced by these two activities.

6.5.1 National statistics

Service	Output	Data Source	Reporting Cycle	Lag Time	Coverage
Commercial Fisheries					
	supply per species				
	landings per species	FAO FishSTAT	annual	3 years	Global
	value per species	FAO FishSTAT	annual	3 years	Global
Commercial aquaculture					
	harvest per species	FAO FishSTAT	annual	3 years	Global
	value per species	FAO FishSTAT	annual	3 years	Global
Commercial food production from agriculture					
	yield by crop	FAOSTAT	annual	2 years	Global
	value by crop	FAOSTAT	annual	5 years	Global
	food security metrics	FAO food security stats progress to MDG hunger reduction targets	annual	5 years	Spotty
Commercial Legal Timber Production					
	production quantity by wood type or product	FAOSTAT	annual	2 years	Global
	production value by wood type or product	FAOSTAT	annual	2 years	Global
Livestock					
	stock numbers by species	FAOSTAT	annual	2 years	Global
	Livestock production index per species and livestock value per species	FAOSTAT	annual	3 years	Global
	list of species	FAOSTAT	annual	2 years	Global
Health					
	population affected by waterborn diseases	WHO	1990, 2000, 2006	NA	Spotty
Water					
	total supply	World Bank Little Green Book	annual	1 year	Global
	total consumption	World Bank Little Green Book	annual	1 year	Global
	for hydropower production	FAO Aquastat	Every 4 years and sporadic	NA	Spotty
	for irrigation	World Bank Little Green Book	annual	1 year	Global
	groundwater use	FAO Aquastat	Every 4 years and sporadic	NA	Spotty
Clean Water					
	avoided treatment costs	World Bank Little Green Book	annual	1 year	Global
	access to safe drinking water	worldwater.org	Rougly Every 5 years	Until 2004	Global

6.5.2 Data required for ecosystem service modelling

Ecosystem services lie at the interface of biophysical and social systems. The GEO BON effort will draw from extensive data sources compiled by diverse fields including hydrology, biogeochemistry, ecology, ecosystem science, economics, conservation science and others.

6.6 Implementation Partners

Developing the list of actual partners is an incremental exercise. For example, initially one or more appropriate organisations will be suggested as possible candidates to do the development.

These organisations will then be contacted and the possibilities discussed. Once an agreement is reached, this can be indicated (and the activities and other information updated as appropriate, since the implementing organisation may not be able to do exactly what was originally proposed). A preliminary list of partners follows:

SWAT or some other modelling group

DIVERSITAS

FAO (Food and Agriculture Organisation)

IUCN (International Union for Conservation of Nature)

UNEP (United Nations Environment Programme)

UNEP-WCMC (UNEP-World Conservation Monitoring Centre)

WRI (World Resources Institute)

Millennium Ecosystem Assessment Sub Global follow up process (Co chairs D Capistrano and A van Jaarsveld) and corresponding partners around the world

Natural Capital Project and corresponding partners around the world

ILTER (International Long Term Ecological Research)

PECS (ICSU Programme on Ecosystem Change and Society)

TEAM (Tropical Ecology Assessment and Monitoring Network)

Advanced ecosystem service mapping and assessment groups

National environment agencies

Space agencies

Existing research laboratories and collaborative projects (e.g., Greg Asner, Carnegie Institute, Stanford University; Charles Vörösmarty, City College of New York)

START (Global Change System for Analysis, Research, and Training)

6.7 Coordination

6.7.1 With other GEO BON topical working groups and partners

As a derivative working group there will be a substantial reliance on coordination with all other working groups in directing data collected and in developing the above-listed products. Early topics of collaboration identified include data on commercially important terrestrial, freshwater and marine species (the Terrestrial Species, Freshwater, and Marine WGs); regular updates of land cover and use data (Terrestrial Species, Terrestrial Ecosystems, and *In Situ*/Remote Sensing Integration WGs); and coastal and estuarine processes related to coastal protection. The alignment of data inputs will be a key collaboration with the *In Situ*/Remote Sensing Integration WG. The Data Integration WG is also a key group.

6.7.2 With other GEO areas

Tasks in the Agriculture, Water and Ecosystems SBA's hold direct relevance especially in the collection of data on hydrology, ecosystem change and agricultural statistics. The Ecosystem Services WG envisages close alignment on tasks: EC-09-01a; Subtask Title: Ecosystem Classification and Mapping and WA-07-02: Satellite Water Quantity Measurements and Integration with *In Situ* Data. The identification of partners, progress and future plans in these tasks will be an important first step.

6.8 Schedule

An initial schedule is provided below, and should be considered preliminary. It will be updated as discussions with partners move forward.

Activity/Deliverable	2011	2012	2013	2014	2015	2016	2017	2018
Global ecosystem service maps			X		X		X	
Pilot tradeoff maps	X	X						
Global trade-off maps			X		X		X	
6.4.6 Toolbox and database concept document		X						
6.4.7 Toolbox and database			X	X	X	X	X	X

6.9 Barriers and their Implications

	Strengths	Weaknesses	Opportunities	Threats
A1. Identify key services	Multidisciplinary team with experience in several socio-ecological settings	Different cultures hold different values for different services, making it difficult to pick one representative set of services	Represent broad set of benefits important to society	
A2. Identify key data sources or models	Key data processers and modellers are on team	Limited by available data and models	Will facilitate compilation and standardisation of disparate data sources and model approaches	Translating among many models and data types may be difficult

	Strengths	Weaknesses	Opportunities	Threats
A3. Produce global maps	Team includes members of MA and subglobal assessments	Ability to establish group to consistently produce maps	Improve public and decision-maker awareness of ecosystem service change	
A4. Produce summaries of ecosystem service change	Team includes members who regularly communicate ecosystem service change to decision-makers	Ability to establish group to consistently produce reports	Help decision-makers interpret importance of ecosystem service change	
1. Pilot tradeoff maps	Four experienced teams under different socio-ecological conditions and perspectives		Synthesis of existing experiences	
2. Global tradeoff maps 5-year interval	Connections to other GEO BON components	Dependent on number of services that can be actually mapped globally	Communicating about complex interactions among services, and sustainability challenges, in clear ways relevant to decision makers	
Toolbox and database	Open structure, permitting assessments being made from many locations and by many different experts	Limitations in terms of people's ability to acquire new skills in use of software	Standardized new framework with broad applicability	Ability of research community to acquire new data handling and modelling skills (even for user-friendly and more versatile toolboxes)
State of Science Report	Ability to consolidate and synthesize disparate advances in ecosystem service science	Ability to establish group to consistently produce reports	Improve uptake of ecosystem service knowledge by decision-makers	

6.10 References

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7 *In Situ* / Remote Sensing Integration Through Modelling (Working Group 7)

7.1 Introduction

To enable effective detection and monitoring of biodiversity change GEO BON will give particular emphasis to the integration of *in situ* and remote-sensing observations. The *In Situ*/Remote Sensing WG is focusing on the analytical and modelling approaches needed to achieve such integration across a range of spatial scales (local to global).

The work of this group cuts across that of a number of other working groups, as the group has an interest in techniques of relevance to multiple levels of biodiversity (genetic, species, ecosystem) and across multiple environments (terrestrial, freshwater, marine). In many cases these other groups are themselves exploring, planning and facilitating implementation of methodologies that involve integration and modelling of *in situ* and remotely sensed observations. The *In Situ*/Remote Sensing WG is supporting and complementing, rather than duplicating or competing with, these activities.

At a broader level, and in keeping with the overall philosophy of GEO BON, it is also crucial that the *In Situ*/Remote Sensing WG complements, builds on, and adds value to existing and emerging initiatives in global biodiversity modelling and indicator development outside GEO. In many cases the most important contribution that GEO BON can make in this area will be to facilitate stronger linkage and integration of disparate datasets, models and indicators generated by other such initiatives.

7.2 Concepts to be Implemented

The concepts to be implemented by this group are basically those outlined in section 2.5 of the GEO BON Concept Document—"Adding value: integrated modelling and assessment". However, the envisaged focus of this GEO BON component has narrowed somewhat since the release of the Concept Document. At the June 2009 GEO BON Steering Committee meeting it was agreed that integrated modelling of *in situ* and remotely sensed data within GEO BON should focus, at least initially, on observing and monitoring biodiversity change (past to present), rather than on forecasting future scenarios for biodiversity. GEO BON should nevertheless actively strive for compatibility and, wherever possible, close collaborative linkage of the models and indicators it employs for biodiversity monitoring with those employed for future scenario analysis by other international initiatives and organisations (and possibly, in the longer term, by GEO BON itself).

The *In Situ*/Remote Sensing WG is focusing on strategies and techniques for using modelling to link, and thereby add value to, *in situ* biodiversity observations and remote sensing data. The term "remote sensing data" is here used in a broad sense to include any layer of spatial information derived remotely (not through field-based observation) and therefore providing complete geographical coverage of a given study domain (typically the entire planet). Layers of most relevance and value to the types of modelling considered in this document will often be themselves products of prior interpretation or modelling of raw remotely-sensed data—e.g., layers relating to land cover, land use, climate, soils, terrain, vegetation structure, biomass, net primary productivity, ocean colour and temperature. Our interest here is not in the analytical techniques used to derive these layers (many of which are already being addressed by other GEO tasks), but rather in how best to further link this information to *in situ* biodiversity observations through additional forms of modelling.

7.3 Activities

Two parallel streams of activities are planned. The first of these (consisting of a single activity, 7.3.1 below) will undertake a comprehensive review of needs, capabilities, opportunities, and priorities for using model-based integration of *in situ* and remote-sensing data to assess biodiversity change across scales. This review will help to inform and guide future modelling initiatives within GEO BON and beyond. The second stream of activities (7.3.2 to 7.3.8 below) will facilitate collaborative establishment and testing of an approach to modelling change in compositional diversity that the group feels is particularly suitable for early commencement.

7.3.1 Review model-based integration needs, capabilities, opportunities and priorities

This activity will develop a detailed, overarching conceptual and operational framework within which it will then review existing initiatives, evaluate current gaps in addressing user needs, and prioritise future directions for integrated modelling of *in situ* and remote-sensing data in the global assessment of biodiversity change across scales. This will require strong and extensive interaction with other GEO BON working groups, other GEO areas, and various organisations and initiatives beyond GEO. The framework will need to address and encompass a wide range of issues and factors including, for example:

Multiple biodiversity levels (genes, species, ecosystems) and dimensions (compositional, structural, functional), multiple ecological realms (terrestrial, freshwater, marine) and multiple spatial scales (local, regional, global—including consideration of cross-scale issues);

Synergies, and therefore potential for stronger collaboration and sharing of components, between existing modelling efforts (within and beyond GEO BON);

Opportunities to add value to existing, and emerging, global indicators of biodiversity change—e.g., Living Planet Index (LPI), Red List Index (RLI), Mean Species Abundance (MSA)—through integrated modelling;

Opportunities for provision of integrated indicators to high-level biodiversity policy and assessment processes, e.g., the Convention on Biological Diversity's (CBD) post-2010 targets, the emerging Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES);

Potential links between initiatives in change-observation modelling and future-scenario modelling;

Gaps in the existing coverage / completeness of *in situ* sampling sites;

Opportunities for taking advantage of new and emerging developments in *in situ* monitoring techniques, and in Earth observation technologies (e.g., new sensors) and analytical products (e.g., seasonality change indices);

Recommendations for (1) prioritising and promoting the use of a common set of *in situ* measurements which, when combined with remote sensing data, have the maximum value for global biodiversity assessments; and (2) enabling the biodiversity community to specify requirements and lobby for future sensor and satellite platform developments (desirable characteristics of remote-sensing products).

7.3.2 Facilitate establishment of a collaborative approach to modelling global change in compositional diversity

This activity will facilitate establishment and testing of an approach to using modelling to estimate global change in compositional diversity, involving three main components (numbered in Figure 7.1):

1) Derivation of spatial surrogates for the baseline distribution of biodiversity entities and/or attributes by modelling and interpolating relationships between point observations (e.g., species location records) and relevant environmental layers (using either species-level or community-level modelling techniques);
2) Inference of large-scaled biodiversity change via interpretation of remotely-sensed (time series) change in ecosystem use/condition and abiotic environmental attributes (e.g., climate, water chemistry) through the filter or "lens" of modelled patterns in biodiversity distribution (from 1 above);
3) Use of *in situ* (time series) monitoring of biodiversity change at local scale to test and calibrate assessments of change at regional and global scales inferred through remote sensing (from 2 above).

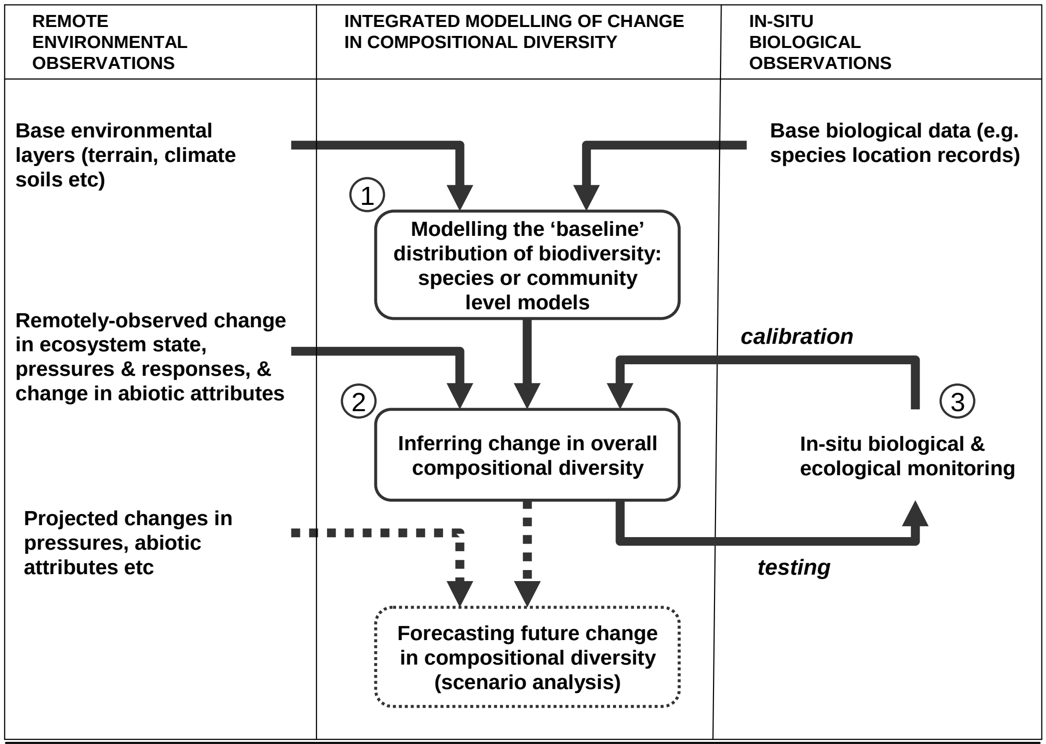

Figure 7.1. General framework for integrated modelling of global change in compositional diversity

This activity will develop an overall methodological framework detailing approaches and options for implementing each of the components introduced above, and for establishing necessary linkages between these components. It will also identify existing global initiatives, or communities of practice, already addressing components of the framework, and will seek to establish collaborative links or partnerships between these initiatives. Potential examples include GBIF for the provision of base biological data, the NCEAS "Environment and Organisms" working group for preparation and provision of base environmental layers, and the emerging "Map of Life" initiative (and associated BioSync working group) for derivation and management of global species distribution maps and models.

Activities 7.3.3 and 7.3.4 (below) will address key technical challenges in implementing the methodological framework that are not already being well-addressed by existing initiatives or communities of practice. Activities 7.3.5 to 7.3.8 (below) will trial applications of the methodological framework in a wide range of environments.

7.3.3 Derive terrestrial ecosystem state/intactness from remote sensing

The ability to reliably map ecosystem state, intactness, naturalness or condition from remote sensing is an essential component of the above methodological framework. While significant advances continue to be made in satellite-based mapping of land cover, and monitoring of changes in land cover, major challenges remain in using this information to derive effective measures of state or intactness from a biodiversity perspective (Ellis and Ramankutty 2008, Alkemade et al. 2009)—e.g., being able to distinguish whether an area classified as open savannah woodland in Madagascar is really a natural savannah or instead a cleared tropical forest.

This activity will investigate, and where necessary test, state-of-the-art techniques for addressing these challenges through global integration of land cover mapping with other information sources and analytical techniques, leading initially to recommendation of a solution, followed by facilitation of the implementation of this solution.

7.3.4 Use networks of *in situ* sites to validate and calibrate models of change

This second key technical challenge relates to the use of *in situ* ecological monitoring sites for validating and calibrating remotely derived measures of biodiversity change. The activity will address this challenge by:

1) Creating a global directory of existing *in situ* monitoring sites of relevance in this context, enabling discovery of sites, and access to data;
2) Developing an agreed set of field-based measurements of biodiversity and ecosystem condition that can be used by the GEO BON community to calibrate and validate models incorporating remotely sensed observations;
3) Conducting a test of an integrated (*in situ*/RS) observation-based modelling approach in a pilot study investigating the use of MODIS derived Net Primary Productivity (NPP) products (Running et al. 2004). Global products of NPP are now available with time-series back to 2000. There are also well-established relationships between NPP and species diversity that occur within ecosystems or through changes between ecosystems (e.g., through land use change) which might enable NPP to be used to model changes in biodiversity on regional to global scales. To test this, a set of field sites will be used to develop relationships between MODIS/NPP and field derived measures of biodiversity and habitat condition. A key objective of this work will be to establish the community of practice required to agree on standard methods of measuring and/or reporting on biodiversity change that can be applied across a broad spectrum of field sites for calibration/validation of RS data;
4) Developing and testing global measures of change in biodiversity through the use of integrated models incorporating a wider range of field sites, RS data sources and contextual data.

7.3.5 Facilitate trial applications: a) terrestrial—global implementation

The first, and most extensive, trial application of the methodological framework (from 7.3.2 above) will facilitate development and implementation of a new suite of global measures of change in compositional diversity of the terrestrial realm (reportable at any desired level of spatial aggregation). These measures will make use of two contrasting approaches to modelling the baseline distribution of biodiversity:

1) Species distribution modelling (Elith and Leathwick 2009), or ecological niche modelling, of large numbers of species in better-known biological groups—e.g., all terrestrial vertebrates. Wherever possible GEO BON will link with, and make use of distributions generated by, other global species modelling initiatives already underway, or in the pipeline. An emerging initiative of particular relevance in this regard is the "Map of Life", being developed by Walter Jetz (Yale University), Robert Guralnick (University of Colorado) et al., and currently the focus of a collaborative BioSynC working group. The Map of Life will generate, and make available, best estimates of global species distributions through rigorous integration of modelling with other major sources of information including range maps;
2) Community-level modelling and extrapolation of patterns in the spatial distribution of emergent biodiversity attributes (compositional turnover, richness) for a wide range of biological groups, by linking best-available location records for all species in these groups (from GBIF, IUCN, etc.) to best-available global environmental surfaces (terrain, climate, soils, ecoregions, etc.) using various analytical techniques such as, for example, generalised dissimilarity modelling (GDM, Ferrier et al. 2007). Particular emphasis will be placed on lesser known, highly diverse, biological groups for which species-by-species modelling is most problematic (e.g., invertebrates).

Distributional models derived using these two approaches will then be used as filters or lenses through which to interpret remotely-sensed change in habitat condition (intactness) and abiotic environmental attributes (e.g., climate), thereby inferring change in overall compositional diversity (e.g., collective species richness) retained in any specified spatial domain. This inference will be achieved using analytical methodologies such as those described by Jetz et al. (2007) in the case of individual species distributions, and by Ferrier et al. (2004) and Faith et al. (2008) in the case of community-level modelling.

7.3.6 Facilitate trial applications: b) marine—scoping exercise and regional test cases

This activity will conduct a scoping exercise exploring the potential applicability of the general framework described above to the marine realm, using test cases in regions with availability of suitable data and expertise (possibly the Great Barrier Reef and the Gulf of Maine). The work will evaluate alternative data sources and analytical approaches, and will use the test cases to promote the value of this approach (and GEO BON generally) to the marine science and planning community, with a view to scaling up for broader global implementation.

7.3.7 Facilitate trial applications: c) freshwater—proof-of-concept

The Freshwater WG is planning to trial application of the general approach to modelling change in compositional diversity (introduced above) in 12 selected freshwater spatial units from around the world (Activity 4.3.5), with a view to then extending this to the entire planet (Activity 4.3.7). The *In Situ*/Remote Sensing WG has agreed to provide ongoing modelling advice in relation to these activities.

7.3.8 Facilitate trial applications: d) microbial 16S metagenomics—proof-of-concept

The Genetics WG is also planning to trial application of the same general approach using microbial metagenomic data in place of traditional species-locality data (Activity 1.3.7). The *In Situ*/Remote Sensing WG has agreed to provide ongoing modelling advice in relation to this activity.

7.4 Deliverables

7.4.1 Review of model-based integration needs, capabilities, opportunities and priorities

A comprehensive GEO BON report reviewing existing initiatives, evaluating emerging needs, capabilities and opportunities, and prioritising future directions for using model-based integration of *in situ* and remote-sensing data to assess biodiversity change across scales. This report will also form the basis for a major position paper in a high-profile scientific journal.

7.4.2 Collaborative framework for modelling global change in compositional diversity

A report and published paper describing and promoting the overall methodological framework. Collaborative links or partnerships established with relevant global initiatives and communities of practice addressing components of this framework.

7.4.3 Implemented solution for deriving ecosystem intactness from remote sensing

An operational methodology for repeated derivation of ecosystem intactness from remote sensing, and a report and/or published paper describing this approach.

7.4.4 Global directory of suitable *in situ* monitoring sites, and agreed field measurements, for validation and calibration

A global directory of *in situ* monitoring sites suitable for use in validation and calibration of remotely-sensed (or inferred) biodiversity measures, and a set of agreed field-based measurements for validation and calibration purposes.

7.4.5 Results of *in situ* testing of MODIS-derived NPP and relationship with species richness

A report and/or published paper presenting results of this testing.

7.4.6 Operational system for assessing change in compositional diversity of terrestrial ecosystems

A working system for ongoing (repeated) derivation of the new suite of measures (reportable at any desired level of spatial aggregation—regional to global) of change in compositional diversity of terrestrial ecosystems, along with supporting documentation, and a published paper describing the approach.

7.4.7 Results of marine case studies, and strategy for scaling up to global implementation

Published paper(s) and conference presentation(s) describing and promoting the marine case studies, and a strategy for scaling up to broader global implementation within the marine realm.

7.5 Data

7.5.1 Review model-based integration needs, capabilities, opportunities and priorities

No data are required for this activity, although the activity will need to consider the existing, and potential, availability of both *in situ* and remote-sensing data to support current and future modelling initiatives.

7.5.2 Facilitate establishment of a collaborative approach to modelling global change in compositional diversity

No data are required to conduct this activity, but consideration will need to be given to availability of data for future implementation of various components of the methodological framework.

7.5.3 Derive terrestrial ecosystem state/intactness from remote sensing

Global land-cover datasets, and other global layers of potential utility for translating land cover into ecosystem intactness. These will be identified, and accessed, through close collaboration with the Terrestrial Ecosystem WG and the GEO Ecosystems and Agriculture SBAs.

7.5.4 Use networks of *in-situ* sites to validate and calibrate models of biodiversity change

- *In-situ* ecological site networks, globally (e.g., ILTER, Smithsonian)
- MODIS-derived NPP layers

7.5.5 Facilitate trial applications: a) terrestrial—global implementation

- Location records for all species (globally) in selected groups of plants and animals (e.g., beetles, birds, vascular plants). Main data source will be GBIF, but data may require careful filtering and/or cleaning, and possible supplementation with other sources of biological observations where available. For example, Birdlife International maintain occurrence data for threatened, restricted-range, congregatory, and biome-restricted birds for ~10,000 sites globally, and this initiative has since expanded to include other taxa under a set of guidelines developed under the auspices of IUCN for identifying Key Biodiversity Areas.
- Best-available global environmental layers for terrain, climate, soils and vegetation types.
- Best-available global spatial data on change in ecosystem intactness.

7.5.6 Facilitate trial applications: b) marine—scoping exercise and regional test cases

Appropriate biological and environmental data for the two case-study regions.

7.5.7 Facilitate trial applications: c) freshwater—proof-of-concept

Data needs for this activity covered by the Freshwater WG.

7.5.8 Facilitate trial applications: d) microbial 16S metagenomics—proof-of-concept

Data needs for this activity covered by the Genetics WG.

7.6 Implementation Partners

7.6.1 Review model-based integration needs, capabilities, opportunities and priorities

Will require extensive interaction and networking with numerous external organisations and initiatives—e.g., DIVERSITAS BioDiscovery program, IUCN, UNEP-WCMC, etc.

7.6.2 Facilitate establishment of a collaborative approach to modelling global change in compositional diversity

Will need to identify existing global initiatives, or communities of practice, already addressing components of the framework, and establish collaborative links or partnerships with these. Potential examples include GBIF and IUCN for the provision of base biological data, the NCEAS "Environment and Organisms" working group for preparation and provision of base environmental layers, and the emerging "Map of Life" initiative (and associated BioSync working group) for derivation and management of global species distribution maps.

7.6.3 Derive terrestrial ecosystem state/intactness from remote sensing

To be determined, but probably various research groups from the Earth observation and ecological science communities.

7.6.4 Use networks of *in situ* sites to validate and calibrate models of change

ILTER, University of Montana, Smithsonian, and various other site networks.

7.6.5 Facilitate trial applications: a) terrestrial—global implementation

GBIF, IUCN, NCEAS "Environment and Organisms" working group, CSIRO, other relevant national institutions, etc.

7.6.6 Facilitate trial applications: b) marine—scoping exercise and regional test cases

CoML, institutions involved in test cases (e.g., CSIRO Marine & Atmospheric Research, University of Southern Maine, Center for Marine Biodiversity)

7.6.7 Facilitate trial applications: c) freshwater—proof-of-concept

Partners covered by the Freshwater WG

7.6.8 Facilitate trial applications: d) microbial 16S metagenomics—proof-of-concept

(Partners covered by the Genetics WG)

7.7 Coordination

7.7.1 Review model-based integration needs, capabilities, opportunities and priorities

This activity will require extensive interaction and consultation with all other GEO BON working groups, but particularly Genetics, Terrestrial Species, Terrestrial Ecosystems, Freshwater, Marine, and Ecosystem Services, to gain a better understanding of: 1) the needs of these groups for integrated modelling of *in situ* and remote-sensing data; 2) modelling activities already being undertaken by these groups; and 3) opportunities for collaborative development of new modelling initiatives.

The activity will also benefit from interaction and consultation with all other GEO SBAs, but particularly Ecosystems and Agriculture, to gain a better understanding of how these themes are using modelling to integrate *in situ* and remote-sensing data.

7.7.2 Facilitate establishment of a collaborative approach to modelling global change in compositional diversity

Will require extensive collaboration with the Genetics, Terrestrial Species, Terrestrial Ecosystem, Freshwater, and Marine WGs, and very strong links with the Data Integration WG regarding data integration and system architecture issues.

7.7.3 Derive terrestrial ecosystem state/intactness from remote sensing

Links to the Terrestrial Species and Terrestrial Ecosystem WGs—both have expressed a strong interest in this issue, and to the GEO Ecosystems and Agriculture SBAs.

7.7.4 Use networks of *in-situ* sites to validate and calibrate models of biodiversity change

Strong link to the Data Integration WG regarding development of global site directory, and potential links to other working groups and GEO SBAs.

7.7.5 Facilitate trial applications: a) terrestrial—global implementation

This activity will require interaction with the Terrestrial Ecosystem WG regarding remotely-derived data on change in habitat intactness or condition, with the Data Integration WG regarding access to required biological data (GBIF, etc.) and establishment of a system for ongoing derivation of the new indicator, and the Terrestrial Species WG regarding potential for testing and calibration of the new measure through ongoing *in situ* monitoring programs.

The activity may also require interaction with three other GEO SBAs—Ecosystems, Agriculture and Climate—regarding remotely-derived data on land use / land cover change, and remotely-observed climate change.

7.7.6 Facilitate trial applications: b) marine—scoping exercise and regional test cases

Need to establish links to Marine WG.

7.7.7 Facilitate trial applications: c) freshwater—proof-of-concept

This Activity is directly linked to Activity 4.3.5 for the Freshwater WG.

7.7.8 Facilitate trial applications: d) microbial 16S metagenomics—proof-of-concept

This Activity is directly linked to Activity 1.3.7 for the Genetics WG.

7.8 Schedule

Activity	2010	2011	2012	2013	2014	2015	2016	2017	2018
7.3.1 Comprehensively review model-based integration needs, capabilities, opportunities and priorities	X	X							
7.3.2 Facilitate establishment of a collaborative approach to modelling global change in compositional diversity	X	X	X						
7.3.3 Derive terrestrial ecosystem state/intactness from remote sensing	X	X	X	X					
7.3.4 Use networks of *in situ* sites to validate and calibrate models of biodiversity change	X	X	X	X	X	X			
7.3.5 Facilitate trial applications: a) terrestrial—global implementation	X	X	X	X					
7.3.6 Facilitate trial applications: b) marine—scoping exercise and regional test cases	X	X	X						
7.3.7 Facilitate trial applications: c) freshwater—proof-of-concept	X	X	X						
7.3.8 Facilitate trial applications: d) microbial 16S metagenomics—proof-of-concept	X	X	X						

7.9 Barriers and their Implications

The major barriers to progress for this WG are:

- Access to funding. This is likely the primary barrier.
- Gaining the necessary acceptance, engagement and buy-in from external partners. While this is less challenging than funding, it nevertheless requires careful management, particularly for those initiatives and communities of practice with whom collaborative links need to be established in Activity 7.3.2.

7.10 References

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8 Data Integration and Interoperability (Working Group 8)

8.1 Introduction

GEO BON will leverage the work of other organizations by facilitating their connection and supporting their work so that integrated and novel products can be efficiently produced. The Data Integration WG focuses on data integration and interoperability to help coordinate, standardize and manage data collected by a variety of disparate institutions and individuals for many different purposes. The WG has a mandate that is somewhat different from other GEO BON Working Groups. It is not directly aimed at generating certain products about biodiversity, rather, it will focus on building permanent structures and linkages that will support the delivery of such products.

The GEO BON Concept Document covers data integration and interoperability only in very general terms. Alone, it is not a sufficient basis for that part of the implementation plan that the Data Integration WG is concerned with. More extensive guidance can be found in the documentation from the GEOSS Architecture & Data Committee (ADC) and in existing interoperability pilot projects that have been prototyping the GEOSS information system (Khalsa et al. 2009; Nativi et al. 2009). The Data Integration WG has therefore taken as its goal to introduce these concepts into the design of GEO BON. This calls for explaining the potential uses and meaning of many new concepts and technologies. For this purpose the Data Integration WG has prepared a companion document to the Implementation Plan entitled "Principles of the GEO BON Information Architecture" which is available at the GEO documents page (http://www.earthobservations.org/geobon_docs.shtml). That document is henceforth referred to in this report as the "companion document".

8.2 Concepts to be Implemented

According to the Concept Document, the GEO BON network should make use of existing resources, including data, data systems and catalogues; it should be comprehensive, dealing with all aspects of biodiversity on a global scale; it should provide a framework that is scientifically robust, that enables priority setting and gap analyses, and facilitates modelling of biodiversity change in a changing environment. The GEO BON system will largely be built from contributing systems that have their primary responsibility at regional, national or subnational scales. GEO BON will add value by connecting such networks together. At the global level, GEO BON will build on the experience of GBIF, LTER/ILTER, OBIS, IODE, and others, but fill gaps in data and extend the coverage to other types of data such as genetic and ecosystem levels. Data sources will encompass field observations (including those by volunteer networks of citizen observers), specimen and image collections, and remote sensing imagery. Work will be needed to harmonise observation standards, to promote use of standards, and to define and update interoperability arrangements.

GEO BON will help to promote data publication principles in support of full and open availability of data and information, recognizing relevant international instruments and national policies and legislation.

8.2.1 Introduction to the information architecture

In keeping with the GEOSS conceptual approach, the informatics infrastructure for GEO BON will be based on a decentralised and distributed architecture based on the Service Oriented Architecture (SOA) model. For interoperability within GEOSS, the GEO BON infrastructure must implement the SOA international standards and Earth system science multidisciplinary best practices (e.g., the GEOSS Standards & Interoperability Forum (SIF) interoperability arrangements). However, the SOA pattern presumes that any service producer and consumer share both a distributed computing protocol and a semantic domain which is comprised of a data and metadata model. In heterogeneous and complex systems (like a system of systems), this is generally not the case. Thus, the introduction of broker components implementing mediation services, is a proven solution to implementing interoperability for a number of issues including discovery services. The GEOSS Common Infrastructure (GCI), based on SOA, consists of web-based portals, clearinghouses for searching data, information and services, and registries containing information about GEOSS components, standards, best practices and requirements. GEO BON will contribute to the GCI by registering resources (e.g., web sites, services, data, and portals) and implementing interoperability solutions mediated via the GCI Web Portal, Clearinghouse Catalogue and registries. Whether GEO BON will need a portal or portals (i.e., Community Portal) needs to be investigated, as well as how such components would relate to existing ones (e.g., the GEO Portal and GBIF Data Portal). GEO BON will build on, not duplicate, existing systems.

8.2.2 Networks and their information resources

8.2.2.1 Data types and data content

GEO BON will need to support a rich observation information model such as that described in the OGC Observations and Measurements specification[8] and cover such data types as species occurrences based on points (e.g., point locations), lines (e.g., transects), polygons (e.g., range distributions); images/gridded data (remote sensing, coverages); population and time series data (e.g., density, abundance, age stratification, trends). Strategies for traversing across data from the different levels of organisation of biodiversity (genes → species → ecosystem) are of interest to GEO BON with spatial and taxonomic referencing acting as two key ways for linking across levels and enabling integration. For example, documenting genetic sequences with a georeference and the environmental parameters of the extraction environment using the

[8] http://www.opengeospatial.org/standards/om

appropriate standards will support integration. Because of the diversity of data types across levels of organisation, GEO BON will need to adopt a broker model architecture (see 8.2.1).

8.2.2.2 Existing global networks

GEO BON will build on existing networks. Table 1 in the companion document lists major examples of the existing global networks that carry biodiversity data. Each network is categorised by ecosystem coverage, taxonomic or topical coverage, data or information types, data and metadata standards, architecture, access and protocols. Not all existing networks are based on a similar architecture. Some operate centralised databases while others follow the SOA model. Some kind of open access principle is common but standards-based discovery (via metadata catalogues) and access mechanisms have not been implemented widely.

8.2.2.3 National and regional networks

Because there is a multitude of national and regional networks, listing them all is not practical. Table 2 in the companion document lists some examples of the most advanced or largest networks using the same categories as for the global networks. These networks can be incorporated into GEO BON if they adhere to the data exchange standards and protocols that will be adopted by GEO BON and provide open access at least to their metadata. Some of these networks are quite advanced in their development, so mapping all of their specialized functions to the global level may not be possible, although adherence to, or adoption of, common standards for data and metadata should allow access to the data they share. Harmonisation or mediation and ensuring compatibility of approaches will be fundamental to the successful development of GEO BON across regions.

8.2.3 Discovery services and registries

GEO BON, as part of the wider GEOSS, can exploit the functionality provided by the GEOSS Clearinghouse — this functionality will make GEO BON easier to implement. It is expected that all components, services, and standards contributing to GEO BON will be discoverable through the GEOSS Clearinghouse and should therefore be entered in the appropriate registry (Components Registry, Services Registry, Standards and Special Arrangement Registry—http://geossregistries.info/). Although not preferred, also so-called *special interoperability arrangements* can be supported because the GEOSS registry offers a mechanism for registering services that are not based on a recognised standard type but are nonetheless widely used within a community of practice. The GEOSS portal provides web-based entry forms for populating the registries. One of the main tasks for GEO BON is thus to identify the main components contributing to the network, list the services that they provide and the standards or special interoperability arrangements used by those services. Metadata catalogues and registries are two particular types of service fundamental for resource discovery and will normally be maintained by individual communities of practice. It is not yet clear how much integration is envisaged between such community registries and the GEOSS Registries but any GEOSS-equivalent components, services and standards should certainly be registered. The companion document lists some of the existing metadata catalogues and registries that are expected to play a role in GEO BON. These include (1) GBIF UDDI, GBRDS, and metadata catalogue, (2) ILTER network metadata catalogue, (3) KNB metadata catalogue, (4) NASA GCMD metadata catalogue, and (5) NBII metadata catalogue. It is envisaged that these catalogues will connect to the GEOSS Clearinghouse by implementing the required interface based on OGC Catalogue Services for the Web (CSW).

8.2.4 Interoperability and information management services

Developing interoperability arrangements for sharing varied and complex data types is a demanding process. Not all can be implemented in the short term and therefore some priorities will need to be agreed on. What these priorities are will depend on the kinds of early product that GEO BON is aiming for. Here, two categories of data for GEO BON are recognized which ideally will be combined: (1) data required for the delivery of the specific products identified by the thematic Working Groups, and (2) data for supporting the vision of GEOSS as an informatics network, i.e., integration of existing biodiversity observation networks for long-term benefits. Several standards are available to aid interoperability arrangements. These are listed in Table 3 of the companion document and include standards for metadata, data exchange and transfer protocols.

8.2.5 Ontologies, thesauri, dictionaries, semantic mediation

The growth of the Internet, along with formal standards for the exchange of metadata through the Web, have provided new opportunities for enhancing collaborative research in biodiversity through the development of consistent ways of expressing the observations and measurements that constitute the basic data informing scientific researchers' models and analyses. Ontologies, thesauri and dictionaries are no longer simply lists of terms (words, or concepts) to be read by humans, to help them understand the meaning and relationships among the values contained in some dataset. These modern variations of "controlled vocabularies" are now constructed in standardized syntaxes that allow for computers to rapidly exchange, search, manipulate, and make decisions with these constructs. GEO BON will benefit greatly from the application of these approaches in the service of data integration and interoperability.

While it is beneficial for the distinct thematic GEO BON Working Groups to try to standardize their protocols and datasets through discussion and agreement to the greatest extent possible, there will undoubtedly still remain a large number of variations in the way data are collected due to specific research or logistical motivations, and this will lead to significant challenges in attaining optimal interoperability of the data for integrated analysis. Furthermore, when GEO BON groups (and others) attempt to pass beyond the boundaries of the data collected using their own internally well-conceived design, data integration becomes even more challenging.

Thus, efforts to develop a unified approach to ontology construction and deployment should provide immediate advantages with regards to data interoperability and integration within GEO BON. These approaches are discussed further in the companion document.

8.2.6 Organism names and habitat classifications

There are numerous taxonomic names databases and several notable initiatives to organize the naming systems in use by custodians worldwide. These will need to be accessible by the various networks that make up GEO BON and therefore registered as part of the GCI. These are described in the companion document and include (1) the Integrated Taxonomic Information System (ITIS), (2) Species 2000, (3) The Catalogue of Life, (4) the World Register of Marine Species, and (5) the Global Names Index (GNI), which is the first component of a semantic environment for biology called the Global Names Architecture (GNA). GNI itself is a fairly simple list of names, with reference to who holds the names, and links back to the sources of the names. See http://www.globalnames.org/data_sources for a list of participating scientific names repositories. GNI has been developed by GBIF and the Encyclopedia of Life (EOL). GBIF is currently extending the basic scope of the GNI to create a dynamic index of taxonomic catalogues and annotated species checklists. It serves as a global name service broker capable of serving multiple taxonomic resources through a single and consistent access point (see http://names.gbif.org/). It should be noted that observations of biodiversity in the field are made of biological concepts—not names. Hence the ability to uniquely identify the concept is paramount. Scientific names alone, unfortunately, are not sufficient for this purpose, but need to be accompanied by additional information about the sense in which the name or classification has been used. Synonym lists that map historical names to current concepts are also needed. Such semantic information can best be attached to a persistent identifier, such as LSID or URI, that is shareable between the various networks. Taxonomic services are increasingly offering such identifiers and GEO BON needs to promote their use. Data integration, in particular, can benefit when datasets can automatically be united using shared identifiers.

Numerous habitat classification systems exist covering terrestrial, marine, freshwater ecosystems. The major classifications are listed in the companion document.

8.2.7 Workflow of services and integration of applications

Between the acquisition and integration of data into a useful product, there usually is a long chain of transformations and analytical steps. In keeping with GEO interoperability experiments (see Nativi et al. 2009), a "system of systems" such as GEO BON needs to support such processes, managing and serving more than measurements and data: it must support modelling resources, allowing ad hoc, on-demand service chaining. The main architectural patterns suitable for service chaining, and to be supported by GEO BON, are described in the companion document. The Data Integration WG will consider the needs of the other Working Groups to find out what kind of service chains are required, identifying suitable networks such as GBIF, and integrating plans for modelling developed by the *In Situ*/Remote Sensing WG.

8.2.8 Portals, search engines, querying and harvesting

The GEO Portal provides a web-based interface for searching and accessing the data, information, imagery, services and applications available throughout GEOSS. The search facilities of KNB, LTER/ILTER, NBII, and NASA GCMD work similarly. Datasets can be located based on metadata keywords. Thousands of datasets are available for download, but as they have thousands of different data models, data have not been integrated in any of these networks; only metadata have been integrated. The GBIF Data Portal and its thematic subnetworks such as OBIS and VertNet work differently as they use a unified information model onto which data from various resources are mapped. It harvests and integrates selected information from about 300 data publishers and their 7000 datasets. A metadata catalogue for searching across datasets is currently being implemented. Various services providing aggregated information based on these integrated data systems are emerging, e.g., integration of GBIF occurrence data with IUCN / UNEP-WCMC Protected Areas (http://www.wdpa.org/) and the Global Register of Migratory Species (http://groms.gbif.org/); predictive maps of distribution (LifeMapper, http://specify5.specifysoftware.org/Informatics/informaticslifemapper.html; AquaMaps, http://www.aquamaps.org); predicting distribution of crop wild relatives (http://www2.gbif.org/PosterCCC31low-res.pdf). The companion document outlines how GEO BON can build on these experiences.

At a minimum, GEO BON will need a place for inventorying and discovering the products and their underlying data from all thematic work groups. To demonstrate GEO BON's utility and its role as a permanent informatics infrastructure, it would be useful to document the underlying chain (workflow) of data management, from data generation through analysis to reporting, so that it can be repeated in future monitoring activities. Using the main GEO Portal for this would be the preferred alternative. Specific scenarios of use for each working group will help to scope this. The main function would not be a toolbox for analysis, at least in the beginning, but discovery of datasets should be supported.

8.2.9 Open access issues

The GEOSS 10-Year Implementation Plan explicitly acknowledges the importance of data sharing in achieving the GEOSS vision and anticipated societal benefits. The GEOSS-commissioned white paper on data sharing principles[9] calls for the full and open exchange of data, metadata, and products shared within GEOSS, recognizing relevant international instruments and national policies and legislation. However, there is evidence that lack of

[9] http://www.earthobservations.org/geoss_dsp.shtml

scientific credit for data sharing activities is still hampering actual implementation of the open access principles. To encourage sharing, GEO BON should promote formal "publication" of datasets such as occurs through the GenBank model, and also a mechanism for citation of datasets. These and related data use issues are discussed further in the companion document. The decision on whether or not to allow restricted data into GEO BON goes beyond the mandate of the Data Integration WG but has clear implications for the development of the data and information infrastructure.

8.3 Activities

The following activities will be carried out in the timeframe of Q3/2010–2013 in order to actually build the GEO BON network.

8.3.1 Establish a working group and coordinating unit for technical implementation

It will be hard to establish any permanent informatics network or similar functions for GEO BON unless there is a technical coordination and support unit of some kind. Beyond pilot projects, these functions cannot rely entirely on the voluntary contributions of the current Data Integration WG. Establishing this unit is the purpose of the first activity.

A group of interested participants will need to apply for funding and in-kind contributions to establish this unit or team. This will be a joint activity with all Working Groups.

8.3.2 Review existing data provider networks and establish partnerships

It will be necessary to complete the inventory presented in section 8.2 and the companion document. This work includes an inventory and review of existing data processing services, registries, and portals, and a review of their data exchange standards and interoperability protocols. A gap analysis is also necessary, including consideration of how existing networks and services could be adjusted in order to work more coherently to integrate a wider range of data coming from disparate networks. Results will be made available on the GEO BON website and will be continually updated as required.

While the foregoing analysis is underway, the Data Integration WG will communicate with the relevant and interested networks and establish partnerships such that they agree to become part of GEO BON. The criteria for selection are that data from these networks are actually needed for some of the early products planned by the various thematic work groups, or otherwise contribute to GEO BON goals. Once such partnerships are agreed, the necessary interoperability arrangements will be made (see Activity 8.3.6).

8.3.3 Review of data processing needs of other WGs

Preliminary interviews were held with the other Working Groups at the Asilomar meeting, February 22–25, 2010 to ascertain existing infrastructures and additional requirements, and subsequent to this, a questionnaire was circulated. Working groups were requested to report on each of their deliverables/products including:

- Data types: list each data type required for concept
- Metadata: list metadata type
- Services: list all services required—metadata catalogue, transformation, modelling, mapping, etc. List inputs and outputs of services.
- List agents/organisations

The first version of this review will be available in late 2010, and will be updated as the other Working Groups proceed with their plans. Based on this material and further interviews, 1–3 use scenarios will be built with each of the Working Groups

8.3.4 Design the information architecture of GEO BON

This work entails identifying priorities in building selected informatics infrastructure elements listed above in 8.2 (Concepts to be implemented). It will be based on formalising the use scenarios into use cases, but also by examining the logical construction order of needed components, and examining architectures of related networks such as LIFEWATCH (Hernandez-Ernst et al. 2009). The work includes identifying data needs, potential gaps, and data processing components, and assessing the time and cost implications; it also includes design of selected workflows (value chains) from data through services to products. The outcome will be a roadmap—a rough design document. This will be reviewed publicly in a workshop, followed by refinement of the design. Thereafter, a call for contributions to put the missing pieces in place will be launched.

8.3.5 Build the components such as portal, registry, ontologies

It is too early to state here which components will actually be prioritised and built, and which ones will be adopted from existing networks. In either case, however, a portal is very likely to be needed. So is a facility to support standardisation and semantic mediation between the various networks, i.e., a registry and ontology service. Because it is not yet clear what needs to be built, and what kind of funding to support this might be available, giving exact time frames and cost estimates is not possible.

In order to keep the possibilities open at this stage, Section 8.2 and the companion document include a very large selection of data providers, standards, protocols, metadata and discovery services, etc. At a minimum, recommendations will need to be provided on which will be required for GEO BON. Integration of the contributed components into GEO BON infrastructure will be managed by the coordinating unit.

8.3.6 Register data and services and provide helpdesk

Regardless of whether new components are built or adopted, data and services of the existing networks will have to be registered in the GEO Clearinghouse. New interoperability arrangements will have to be made and interfaces installed. Links will need to be established from the GEO BON web site to the GEOSS Registry with encouragement to participate. This ongoing activity will be performed with the assistance of the coordinating unit by the participating networks themselves.

8.3.7 Outreach and capacity building

There is still limited understanding among the GEO BON Working Groups and other stakeholders as to what it means to build an informatics network for GEO BON. Because GEO BON will build upon existing facilities, the focus must be on making arrangements for interoperability and integration, only building new components where necessary to support this goal. Many networks, in particular at national level, are not yet aware of all the available standards, requirements and possibilities of interoperability nor have practical experience with them. Outreach, as well as capacity building are thus necessary. Naturally, this should be undertaken in coordination with related activities of the participating networks.

This activity would consist of workshops and training events that will be carried out on a worldwide basis. They could probably be best organised in conjunction with regional GEO BON meetings, a series of continual activities commencing in 2011. The capacity building aspect could cover site visits where the GEO BON coordinating unit will work for a limited time with sites and networks to enable their interoperability functions.

8.4 Deliverables

8.4.1 Document on user needs

A document on user needs will be based on the analysis of the requirements put forward by other working groups, their scenarios and use cases (Activity 8.3.3). “Users” refers to the scientists and analysts who will use the system to produce reports, etc. for their clients (policymakers and such).

8.4.2 Gap analysis document

The gap analysis document will be based on outputs of Activity 8.2.2. and will cover descriptions of missing data, missing services, lack of knowledge and research to be done, priority evaluation, timeline and budget considerations.

8.4.3 Design document

The existing companion document "Architectural Principles for GEO BON Informatics Network" will act as precursor of a more complete design document. This is based on outputs of Activities 8.3.2, 8.3.3, and 8.3.4.

8.4.4 Organisation of a workshop

A workshop will be organised to review the information architecture design of GEO BON. This is based on outputs of Activities 8.3.4 and 8.3.7.

8.4.5 Text for a call for proposals/contributions

The text for a call for proposals and contribution of components and services to GEO BON will be produced in Activity 8.3.4.

8.4.6 Portal, registry and ontology service

Prototypes of those GEO BON portal, registry and ontology service components which will be deemed necessary and prioritised will be developed as outputs of Activity 8.3.5. Content for the portal will include GEO BON Early Products and products developed under the GEOSS Architecture Implementation Pilot (AIP-3) call.

8.4.7 Registration service and help desk

GEO BON Working Groups will need assistance in registering their data and services in the GEOSS Clearinghouse or compatible registries. It is foreseen that this is a permanent service that GEO BON will need to provide. There will be a need for a helpdesk, training, and capacity building worldwide. Without these services, it is difficult to see how the integration and interoperability foreseen in this plan can be achieved. Each connection of a network to the GEO BON interoperability scheme should lead to pilot projects that provide demonstrations and explanatory documents. This Deliverable results from Activity 8.3.6.

8.4.8 Training and outreach programme

A training and outreach programme with details of training events will be created based on outputs of Activity 8.3.7.

8.5 Data

The topic of data requirements for GEO BON has already been covered in general terms in Section 8.2 about data types and networks. Here, only some aspects of their integration, analysis of gaps, and data needed by the other Working Groups for specific products will be covered.

8.5.1 Data needed to support use cases

According to the interviews with the other GEO BON Working Groups, which have been documented in the companion document, standardisation of data access is the most often mentioned need. As GEO BON is a network of networks, standardisation and harmonisation cannot be easily achieved, because a network's own design has typically been driven by specific needs without reference to other networks. Therefore cross-mappings, i.e., developing semantic mediation layers which leave underlying networks intact, are likely to be a most desired feature. Improvement to data discovery and access is another repeatedly mentioned need. Further details will be captured through the templates that the other Working Groups are completing subsequent to the Asilomar interviews.

8.5.2 Gaps between networks and data access problems

The GBIF report "Global Strategy and Action Plan for Digitization" (GBIF 2009) documented gaps in data provision. It lists three main obstacles to increasing the rate of digitisation and the impact of specimen data. First, digitisation is a costly and labour-intensive process. Second, although innovative ideas abound, there is a marked lack of coordination, coherence and encouragement for the ongoing digitisation efforts in collection institutions. Third, there is no mechanism to globally request information about relevant holdings of collection institutions nor to answer such requests, and the purpose of specimen digitisation is thus not widely appreciated by the wider user community. Furthermore, there are also access problems. Even major museums with technical capabilities are providing access to only a small percentage of their complete data holdings. In addition, monitoring and natural resource survey data is largely not available openly. It is hidden in PDFs, reports, maps, etc., but raw data is not shared. Projects operating monitoring networks often have the view that they can perform all the analyses that can be made of their data, that there is not a great demand for data sharing. The data can usually be made available through personal contacts, but such an approach is not scalable to global cooperation levels.

An approach to build stronger thematic networks which also understand their role in larger contexts such as GEO BON may work here. Data providers have their own conditions and may require recognition. A data publishing framework that gives credit to data publishers and involves them better in end products needs to be developed.

Many national and thematic networks are sharing data among themselves but not yet globally.

For instance, Russian and Brazilian data are available through Herpnet (http://www.herpnet.org) and MaNIS (http://www.manisnet.org), but not to global networks. Arctic data are available to the CBMP (http://cbmp.arcticportal.org/) through various thematic networks, but are not publicly available. GEO BON will emphasize the role of the various thematic networks, and include them in GEO BON in visible roles. These "intermediate institutions" i.e., thematic networks, seem to be able to bypass political barriers more easily than a country-based approach.

Other missing components have been identified by Scholes (2009). These include (1) a global database of interaction observations, i.e., food webs, pollinators, hosts and pathogens/ parasites, symbionts, mutualists; (2) a community/plot/site database, i.e., species that co-occur, their relative or absolute abundances, community attributes such as functional type profile (broadleaf, needleleaf, grass, etc.), structure (height, crown cover, biomass, leaf area, etc.), and function (NPP, albedo, bulk conductance, etc.); and (3) uses of biodiversity (societal benefits), i.e., nature of use (food, fibre, medicinal, cultural, etc.), use intensity, and value. GEO BON will promote setting up of these data sources as they are needed for the various GEO BON products.

8.5.3 Approaches for integration of existing networks

Integration of existing networks has been covered partly in the section about portals. The approach is to:

- Promote emergence of value-adding services that combine data from various networks, and encourage registration of these services in the GEOSS Clearinghouse.
- Harmonise metadata across the networks.
- Adopt and build ontologies, and with them build a semantic mediation layer between the networks. This is somewhat similar to what is called Semantic Enterprise Architecture.
- Build portals that aggregate selected data. Through pilot projects that link with the output of other GEO BON Working Groups, explore functions of semantic portals that are based on RDF databases. Make these functions available through the GEO Portal.

8.6 Implementation Partners

The Data Integration WG cannot achieve its goals without extensive interactions with all the other GEO BON Working Groups. The user needs for information systems come from those groups.

All the networks referred to in Section 8.2 and the companion document are potential partners. They will be asked to consider harmonising their metadata and service interfaces. They will need to register their services in the GEOSS Clearinghouse for which support from the coordinating unit will be available. Pilot and demonstration projects should result from each such exercise. Coordination meetings between all the participating networks to support such integration activities are foreseen when full implementation commences.

Establishing the technical coordination unit is open for contributions by a coalition of willing partners who will identify the funding sources and secure the resources for these activities.

Interactions are also foreseen between the Data Integration WG and the GEOSS Architecture & Data Committee (ADC). In particular, the mechanism by which the GEOSS Clearinghouse and Portal might support the needs of GEO BON will be reviewed together with the ADC. The GEOSS Architecture Implementation Pilot projects that have already been carried out on biodiversity issues together with the ADC (Nativi et al. 2007, 2009; Khalsa et al. 2009) can inform development of the GEO BON architecture.

8.7 Coordination

The Data Integration WG is a crosscutting Working Group and so coordinates with all the other GEO BON Working Groups, as well as with some of the GEOSS entities, particularly the ADC.

8.8 Schedule

Activity/Deliverable	Q3/ 2010	Q4/ 2010	Q1/ 2011	Q2/ 2011	Q3/ 2011	Q4/ 2011	2012	2013
8.3.1 Establish a working group and coordinating unit for technical implementation	X	X						
8.3.2 Review of existing data provider networks; establish partnerships	X	X	X	X	X	X	X	X
8.3.3 Review of data processing needs of other Working Groups	X	X						
8.3.4 Design the information architecture of GEO BON		X	X	X				
8.3.4 Public review of the proposed architecture, symposium			X	X	X			
8.3.5. Call for contributions					X			
8.3.5 Build the components such as portal, registry, ontologies						X	X	X
8.3.6 Helpdesk and registration of components and networks				X	X	X	X	X
8.3.7 Training and capacity building events				X	X	X	X	X

8.9 Barriers and their Implications

The major barriers to progress for this WG are:

- Lack of key data in a usable format, in particular, monitoring data
- Certain data, like that of organism interactions, is sparse or does not exist
- Integration of data is still technically very hard to do
- Data sharing does not yet bring scientific recognition directly, constraining data availability
- Lack of time of key people: it is hard to pull things together and provide a service to assist the various networks with technical issues on a voluntary basis only
- Lack of funding resources
- Trying to operate permanent infrastructure on temporary project funding
- Too many isolated initiatives that do not communicate with each other; hinders funding opportunities due to perceived duplication of effort
- Governments do not want to invest when hit by recession

8.10 References

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Appendices

A Acronyms and Glossary

ADC: GEO Architecture & Data Committee

AIP: GEO Architecture Implementation Pilot

ArcOD: Arctic Ocean Diversity. URL: http://www.arcodiv.org/

AUV: Autonomous Underwater vehicle

BATS: Bermuda Atlantic Time-Series Study. URL: http://bats.bios.edu/

Biodiversity: variation in the composition, structure and function at the ecosystem, species and genetic levels of biological organisation.

BioFresh: A four-year project funded through the European Commission to examine status, trends, pressures, and conservation priorities for freshwater biodiversity URL: http://www.iucn.org/about/work/programmes/species/our_work/about_freshwater/what_we_do_freshwater/bio_fresh/

BIOS: Bermuda Institute of Ocean Sciences. URL: http://www.bios.edu/

BioSynC: Biodiversity Synthesis Center. URL: http://synthesis.eol.org/

BoL: Barcode of Life

CAML: Census of Antarctic Life. URL: http://www.caml.aq/

CBD: Convention on Biological Diversity. URL: http://www.cbd.int/

CBMP: Circumpolar Biodiversity Monitoring Programme. URL: http://cbmp.arcticportal.org/

CeDAMar: Census of Diversity of Abyssal Marine Life. URL: http://www.cedamar.org/

Censean: Global Census of Marine Life on Seamounts

CheSS: Biogeography of Deep-Water Chemosynthetic Ecosystems. URL: http://www.noc.soton.ac.uk/chess/

CHONE: Canadian Healthy Oceans Network. URL: http://www.marinebiodiversity.ca/CHONe

Clade: A branch of the tree of life.

CMarZ: Census of Marine Zooplankton. URL: http://www.cmarz.org/

COMARGE: Continental Margin Ecosystems. URL: http://www.ifremer.fr/comarge/en/index.html

Community of Practice: An voluntary and self-organising group of people or organisations, who agree to cooperate for a given purpose, and share skills, techniques and information in order to do so.

Community-Level Modelling: modelling and mapping spatial pattern in the distribution of biodiversity by simultaneously linking data for large numbers of species to remotely-derived environmental surfaces

Compositional Diversity: the variety (number) of different biological elements or entities (e.g., genes, species, or communities) within a given system or region

CPR: Continuous Plankton Recorder

CReefs: Census of Coral Reefs. URL: http://www.creefs.org/

CSIR: Council of Scientific and Industrial Research, South Africa. URL: http://www.csir.co.za/

CSIRO: Commonwealth Scientific and Industrial Research Organization (Australia). URL: http://www.csiro.au/

CSW: Catalogue Services for the Web

DECCW: NSW Department of Environment, Climate Change and Water. URL: http://www.environment.nsw.gov.au/

DIVERSITAS: An international programme of biodiversity science. URL: http://www.diversitas-international.org/

Ecological Niche Modelling: See Species Distribution Modelling

Ecosystem Services: The benefits that people derive from nature, including provisioning services such as food, fibre and water; cultural services such as ecotourism and recreation; and regulating services such as climate and flood control; all underpinned by supporting activities such as nutrient cycling.

Ecosystem: a natural unit consisting of interdependent organisms that share the same habitat and function together with all abiotic factors of the environment. They are mapped (on land) by their major structural elements.

eFlowNet: Global Environmental Flows Network. URL: http://www.eflownet.org/index.cfm?linkcategoryid=1&siteid=1&FuseAction=main

EO: Earth Observation, most often referring to remote sensing of Earth from space

EOL: Encyclopedia of Life. URL: http://www.eol.org/

ESONET: European Seas Observatory Network. URL: http://www.esonet-emso.org/

EU: European Union

FADA: Freshwater Animal Diversity Assessment. URL: http://fada.biodiversity.be/

GBDC: GEO BON Concept Document. URL : http://www.earthobservations.org/geobon_docs.shtml

GBIF: Global Biodiversity Information Facility. URL: http://www.gbif.org/

GBRDS: Global Biodiversity Resources Discovery System

GCI: GEOSS Common Infrastructure

GCMD: NASA Global Change Master Directory. URL: http://gcmd.nasa.gov/

GEOSS: Global Earth Observation System of Systems. URL: http://www.earthobservations.org/

GFBA: Global Freshwater Biodiversity Assessment

GNA: Global Names Architecture

GNI: Global Names Index

GoMA: Gulf of Maine Program

GOODS: Global Open Ocean and Deep Sea-habitats

G-WOS: Global Wetlands Observation System

GWSP: Global Water Systems Project. URL: http://www.gwsp.org/

HERMES: Hotspot Ecosystem Research on the Margins of European Seas. URL: http://www.eu-hermes.net/

HMAP: History of Marine Animal Populations. URL: http://www.hmapcoml.org/

HOT: Hawaii Ocean Time-series. URL: http://hahana.soest.hawaii.edu/hot/

HydroSHEDS: Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales. URL: http://hydrosheds.cr.usgs.gov/

IBAT: Integrated Biodiversity Assessment Tool. URL: http://www.ibatforbusiness.org/

ICES: International Council for the Exploration of the Sea. URL: http://www.ices.dk/

ICoMM: International Census of Marine Microbes. URL: http://icomm.mbl.edu/

ILTER: International Long Term Ecological Research network. URL: http://www.ilternet.edu/

IOC: Intergovernmental Oceanographic Commission. URL: http://ioc-unesco.org/

IODE: International Oceanographic Data and Information Exchange. URL: http://www.iode.org/

IODP: Integrated Ocean Drilling Program. URL: http://www.iodp.org/

IPBES: Intergovernmental Platform for Biodiversity and Ecosystem Services. URL: http://www.ipbes.net/

IUCN: International Union for Conservation of Nature. URL: http://www.iucn.org/

IWC: International Water Birds Census. URL: http://www.wetlands.org/Whatwedo/Biodiversitywaterbirds/InternationalWaterbirdCensusIWC/tabid/773/Default.aspx

JERICO: Joint European Research Infrastructure for Coastal Observation

JGOFS: Joint Global Ocean Flux Study

KNB: Knowledge Network for Biocomplexity. URL: http://knb.ecoinformatics.org/index.jsp

Lentic: Standing waters

Lotic: Running waters

LPI: Living Planet Index

LSID: Life Science Identifiers

LTER: Long Term Ecological Research sites. Places or networks of places where ecological processes are studied, at landscape scale and over a period of decades. URL: http://www.lternet.edu/

MARBEF: Marine Biodiversity and Ecosystem Functioning. URL: http://www.marbef.org/

MAR-ECO: Mid-Atlantic Ridge Ecosystem Project. URL: http://www.mar-eco.no/

MARS: Marine Research Institutions and Stations. URL: http://www.marsnetwork.org/

MEOW: Marine Ecoregions of the World

Metagenomics: The study of genetic material recovered directly from environmental samples. The broad field may also be referred to as environmental genomics, ecogenomics or community genomics

MSA: Mean Species Abundance index

NADW: North Atlantic Deep Water

NaGISa: Natural Geography In Shore Areas. URL: http://www.nagisa.coml.org/

NAML: (US) National Association of Marine Laboratories. URL: http://www.mbl.edu/naml/

NBII: National Biological Information Infrastructure. URL: http://www.nbii.gov

NCEAS: National Center for Ecological Analysis and Synthesis. URL: http://www.nceas.ucsb.edu/

NODC: National Ocean Data Centre. URL: http://www.nodc.noaa.gov/

NPP: Net Primary Production

NRIC: National and Regional Implementation Committees (of CoML)

OBIS: Ocean Biogeographic Information System. URL: http://www.iobis.org/

OGC: Open Geospatial Consortium, a source of open-access standards for geospatial data. URL: http://www.opengeospatial.org/

Ontology: A defined vocabulary that allows concepts to be shared between databases.

Phylogeny: Study of the shape and development of the tree of life

POGO: Partnership for Observation of the Global Ocean. URL: http://www.ocean-partners.org/

POST: Pacific Ocean Shelf Tracking Project. URL: http://www.postcoml.org/

Ramsar: The convention of Wetlands of International Importance. URL: http://www.ramsar.org/

Red List: The world's most comprehensive inventory of the global conservation status of plant and animal species. URL: http://www.iucnredlist.org/

RLI: Red List Index; see Red List

ROV: Remotely Operated (Underwater) Vehicle

RS: Remote Sensing

SAHFOS: Sir Alister Hardy Foundation for Ocean Science. URL: http://www.sahfos.ac.uk/

SBA: Societal Benefit Area

SCOR: Scientific Committee on Ocean Research. URL: http://www.scor-int.org/

SIF: GEO Standards & Interoperability Forum

SOA: Service Oriented Architecture

Societal Benefit Area: The nine areas that GEOSS has chosen to focus on in its first ten years of implementation.

Species Distribution Modelling: Modelling and mapping the potential distribution of individual species by linking known occurrences to remotely-derived environmental surfaces

START: Global Change System for Analysis, Research, and Training. URL: http://start.org/

TNC: The Nature Conservancy. URL: http://www.nature.org/

TOPP: Tagging of Pacific Predators. URL: http://www.topp.org/

UDDI: Universal Description Discovery and Integration

UNEP: United Nations Environment Programme. URL: http://www.unep.org/

UNEP-WCMC: United Nations Environment Programme—World Conservation Monitoring Centre. URL: http://www.unep-wcmc.org/

URI: Uniform Resource Identifier

USGS: United States Geological Survey. URL: http://www.usgs.gov/

Working Groups: Groups of experts drawn from many partner organisations for a particular GEO BON task. Typically they have about 10 members, and last a few years.

WWF: World Wide Fund for Nature. URL: http://www.panda.org/

B GEO BON Activities

C GEO BON Deliverables