GROUP ON EARTH OBSERVATIONS

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GEO BON Concept Document

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This document is submitted to GEO-V for information.

GROUP ON EARTH OBSERVATIONS

Biodiversity
Observation
Network

The GEO Biodiversity Observation Network

Concept Document

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EXECUTIVE SUMMARY

The Group on Earth Observations (GEO, www.earthobservations.org) is a partnership of over 70 member countries and more than 50 participating organisations, working to improve the coordination of existing Earth observation data sets, implement new observations and promote the generation of Earth observation products. GEO oversees a Global Earth Observation System of Systems (GEOSS) as the mechanism to achieve these goals. Biodiversity is one of nine Societal Benefit Areas that GEO is mandated to address. A Biodiversity Observation Network, or GEO BON, is one of the first systems GEO proposes for the emerging GEOSS. This Concept Document presents the case for GEO BON, describes the overall vision, and suggests a framework for its implementation. Stakeholders reviewed earlier drafts of this document at a meeting in Potsdam, Germany in April 2008, and provided final comments in October 2008.

By facilitating and linking efforts of countries, international organizations and individuals, GEO BON will contribute to the efficient and effective collection, management, sharing, and analysis of data on the status and trends of the world's biodiversity. It will also identify gaps in existing observation systems and promote mechanisms to fill them.

Consistent with the Convention on Biological Diversity (CBD) the GEO BON definition of biodiversity includes variation in composition, structure and function at the ecosystem, species and genetic levels of biological organisation. The scope of GEO BON includes biodiversity in the terrestrial, freshwater, coastal, and open ocean marine domains. In addition to collecting time series of observations on the presence, abundance and condition of elements of biodiversity at all of these levels and across these domains, it will also ultimately collect information on interactions between organisms, their use by people, and supporting data on the abiotic environment, taxonomic status, drivers of biodiversity change and measures taken to protect biodiversity. GEO BON will conduct limited analyses, such as change detection, trend recognition, forward projections, range interpolations and model-based estimations of the supply of ecosystem services. Models will play a key role for changes that are hard to measure directly, as well as for predicting change, using readily available data such as that from remote sensing. GEO BON will support more detailed assessments undertaken by biodiversity and ecosystem assessment bodies.

The Ecosystems component of 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. The drivers of these changes and their consequences are of particular interest, as are linkages between different ecosystems. The GEOSS Global Ecosystem Mapping Task, from the Ecosystems Societal Benefit Area, will be an important input to this work.

The Species component will focus on several critical aspects of species. The first is how species distribution and abundance are changing, and this will be assessed using a careful global sampling scheme, utilizing representative species. The second is to facilitate access to, and creation of, distribution maps for a large number of species; this will augment work already underway by a variety of organizations. Species-level and community-level modelling will be integrated with remotely sensed time series data to help assess the consequences of observed changes in terms of impacts on biological distributions.

Genetic diversity will be monitored using a combination of remote sensing and in situ approaches and combined with work at the ecosystem and species levels. Several observational strategies will be used. The first is direct observation of specific genetic components in selected target species. The second is observation of other biodiversity components, such as range extents for a representative set of species, that are then integrated with models to infer genetic diversity. And the third is observations of ecosystem condition – for example, inferred using remote sensing – integrated with spatial genetic variation models that support large scale inferences about changes at the genetic level that are difficult to obtain directly.

In addition to the work on ecosystems, species, and genes, GEO BON will also focus on several other areas. For example, GEO BON will integrate ecosystem observations to help assess the state of ecosystem goods, services, and functioning. Modelling will be a primary tool to help integrate observations across space and time, across taxa, and to make forecasts of future change. And a capacity building effort will strengthen the capability, particularly of developing countries, to collect and use Earth observations and so contribute to GEO BON.

GEO BON will provide to users information documenting and interpreting changes in biodiversity. This information will form the basis for future assessments by the envisaged IPBES (Intergovernmental Platform for science-policy on Biodiversity and Ecosystem Services). Its systems will be designed with this intent. The main users of GEO BON will be countries (especially in relation to their obligations under biodiversity-related conventions) and their 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 environmental and scientific research organisations both in and out of academia.

1 INTRODUCTION

1.1 Document purpose

This Concept Document describes the GEO Biodiversity Observation Network as currently envisioned, the result of a process that began more than two years ago. In October, 2006 stakeholders met in Geneva to discuss user requirements, then, using these and other sources of inputs, an initial concept for GEO BON was assembled. This was distributed to more than 100 stakeholders, who met in Potsdam, Germany in April 2008 to discuss and update the concept. The Potsdam meeting led to an overall consensus that the concept was sound, as well as a set of comments to improve the concept and increase the clarity of the document. After incorporating those comments the updated document was sent out again, comments were received and incorporated, and this version created.

The GEO BON Concept Document lays out a vision for a Biodiversity Observation Network focused on changes in biodiversity at all levels. This vision is the endpoint that the stakeholders hope can gradually be converged upon by developing a network of existing networks, and by filling in gaps where needed data or capabilities do not yet exist. Although there are no plans to periodically update this document it is recognized that as GEO BON is implemented some parts of the concept will change. Both the concept and its implementation are expected to be dynamic, changing in response to new user needs, technology, resources, and constraints.

1.2 Why a Biodiversity Observation Network?

It is well-established that biological diversity is being lost in the current era at a far greater rate than can be sustained by the processes that generate new diversity. For human well-being, this is important because the continued supply of ecosystem services – those things provided by nature from which humans derive benefit – depends to a large degree on the maintenance of adequate levels of biodiversity (Figure 1). The drivers of biodiversity loss, the distribution of species and habitats, and the processes by which biodiversity supports the delivery of ecosystem services all operate at many geographical scales. Hence, it is in the collective interest of all countries to cooperate in understanding changes in biodiversity by monitoring its state and trends, as a basis for collaborative actions to stem its decline. An effective and comprehensive mechanism for gathering and sharing observations regarding biodiversity and how it is changing, and interpreting these changes, is an essential element of any international and inter-organisational strategy to combat biodiversity loss. The Group on Earth Observations Biodiversity Observation Network (GEO BON) is proposed as the mechanism to build on the national investments into and achievements to date of the Global Biodiversity Information Facility (GBIF), an inter-governmentally mandated and sponsored initiative, and other biodiversity information organisations, and serve the information needs of both the Biodiversity and Ecosystems components of GEO.

Recognising the need for gathering, sharing and interpreting observations in this domain, the nations and organisations that together form the Group on Earth Observations (GEO) designated Biodiversity and Ecosystems as two of its nine Societal Benefit Areas. GEO BON is a key mechanism for realising the GEO targets for Biodiversity and Ecosystems. The structure of GEO is suited to implement a global biodiversity observation network because it is:

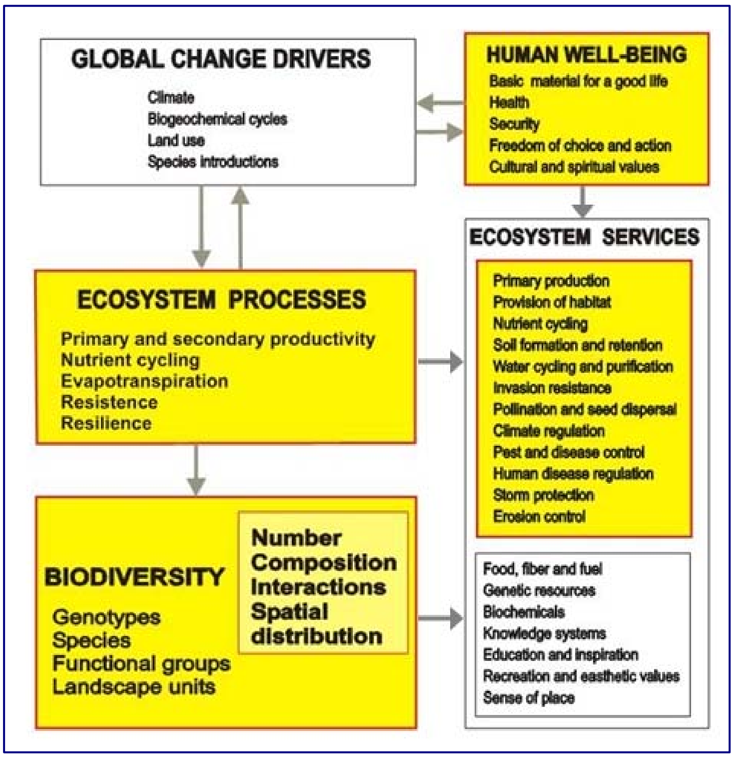

Figure 1: How biodiversity, ecosystem services and human wellbeing interact

- Intergovernmental and multi-stakeholder in nature, thus ensuring the involvement and commitment of national governments and major multinational organisations
- An open and international collaborative system linked to policy needs for societal benefits; it will thus be able to take a broader and longer term view drawing observations and other data from multiple kinds of data providers including governmental, private, and scientific bodies.

Article 2 of the Convention on Biological Diversity (CBD) defines biodiversity as “the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems." Biodiversity exists at several levels of biological organization, each with characteristic geographical and temporal scales (Boxes 1 to 3). The three main levels are ecosystems, species, and genes, and GEO BON will deal with information at all three levels. Furthermore, GEO BON recognises that biodiversity includes, at each of these levels, variation in *composition* (the entities that are present), *structure* (how they are organised in physical space), *function* (how they interact to perform particular roles), and *evolutionary history* (their relatedness and uniqueness).

Biodiversity data are generally collected locally by many different organizations (such as research, administrative, management, private and public) for multiple initial purposes (such as science, monitoring, environmental impact, management, recreation). As such, the data are diverse, incomplete, and patchy. GBIF has shown that we can use these data for many additional analyses beyond the initial intent of the collector, however, the recent Millennium Ecosystem Assessment demonstrated that there are gaps in both coverage and content which make our understanding of global, regional, and local processes imperfect. While GEO BON cannot mandate the collection of coherent data sets, it can provide the rationale and encouragement for governments and organizations to restructure their data collections to provide more and more coherent data for society’s need to understand biodiversity patterns and processes at the global, regional and local levels.

BOX 1 – Ecosystems

An ecosystem is a community of organisms and their physical environment, existing within a defined a habitat, and the interactions among them. Ecosystems occupy a more-or-less defined area, and can be nested within other ecosystems. The largest ecosystem of all is the biosphere. At the next level down, most authorities recognize on the order of 20 global terrestrial 'biomes' (major ecosystem types, such as forest, grassland, etc.). Concepts similar to the biome can be applied to marine and freshwater ecosystems as well.

BOX 2 – Species

An estimated 1.7 million species have been described (Table below), including about 230,000 marine species. In 2007, the 'Catalogue of Life', a register of all known species collectively compiled by the taxonomic community, listed over 1 million species. Predicting the total number of species on Earth is difficult because up to 90% of species in less studied areas and taxa have not been described. It is possible that 10 million or more species exist.

Taxon	Common names	Number of species known at present
Prokaryotes	Bacteria and archaea	Unknown, probably very large
Insecta	Insects	950,000
Plantae	Plants (excluding algae)	275,000
Mollusca	Snails, clams, octopi, squid, chitons	100,000
Protista	Algae, fungi, protozoans	80,000
Chelicerata (Arachnida)	Spiders, mites, sea spiders	70,000
Crustacea	Shrimp, crabs, lobsters	70,000
Chordata	Fish, mammals, birds, reptiles, amphibians	50,000
Nematoda	Round worms	25,000
Platyhelminthes	Flat worms, flukes	20,000
Annelida	Earthworms	20,000
Myriapoda	Centipedes, millipedes	12,000
Cnidaria	Anemones, corals, hydroids, jellyfish	10,000
Echinodermata	Starfish, sea urchins, sea cucumbers	7,000
Bryozoa	Mat animals	6,000
Porifera	Sponges	6,000
Other taxa		10,000

BOX 3 – Genes

Every organism contains up to tens of millions of nucleotide base-pairs, which encode for several tens of thousands of functional units called genes. Despite the high degree to which genes are shared, the variation in gene composition between individuals within a population, between populations in a species, and between species, is the foundation on which all biodiversity is built. *Phenotypic variation* (what an organism looks like) is partly due to *genotypic variation*, but is also influenced by environment. Important characteristics of a species may vary between populations and races. This may occur as a result of selection for agriculture and aquaculture, in response to harvesting pressure (e.g., earlier age of maturity in a fish stock), or reflect local environment conditions.

Thus the unique niche and added value of GEO BON will be:

- To provide a global, scientifically-robust framework for observations designed to detect biodiversity change
- To coordinate the data gathering and delivery of biodiversity change information
- To ensure the long term continuity of data supply (i.e., operational observations) related to biodiversity
- To integrate *in situ* and remote global observation systems related to biodiversity
- To provide, and be known for, a set of innovative products relevant to biodiversity change, based on the integration of data sets (e.g., global maps of ecosystem service delivery; predicted areas of rapid degradation; identification of key biodiversity sites facing rapid climate change)
- To provide assessments and forecasts, based on observations and models, of biodiversity change by performing integrative data analysis.

The scientific landscape in relation to global and complex problems is increasingly organising itself into three interconnected spheres – observations, research and assessment. GEO BON is located within the observations sphere. Its global mandate is to provide, in an operational way, biodiversity observation data, which will be used as a basis for periodic assessments (e.g., the Millennium Ecosystem Assessment and its proposed successor, the Intergovernmental Platform for science-policy on Biodiversity and Ecosystem Services, IPBES); to inform policy decisions, particularly at the national level and in support of the CBD and other biodiversity-related conventions; and to support research activities. Consistent with this, the GEO BON short- and long-term Vision and Goals are listed in Appendix 1.

1.3 GEO and GEOSS

Earth observations, comprising space-based, airborne, ground-based, ship-borne and underwater systems, are increasingly recognized as critical for monitoring and managing the Earth system. The 2002 World Summit on Sustainable Development stated the need "to promote the development and wider use of Earth-observation technologies." That vision built on a number of landmark environmental summits, including the 1972 United Nations Conference on the Human Environment (Stockholm), the 1992 United Nations Conference on Environment and Development (the Rio Earth Summit), and the conventions on climate change and biodiversity. Many of the environmental treaties concluded over the past 30 years explicitly reference the need for Earth observations to fulfil their commitments.

GEO (Group on Earth Observations; www.earthobservations.org) is the result of a series of three ministerial-level summits. It currently includes over 70 member countries, the European Commission, and more than 50 participating organizations having mandates for Earth observation or activities in related fields. Together, these partners have committed themselves to the establishment of the Global Earth Observation System of Systems. A core tenet of GEOSS is that it does not duplicate or replace existing systems, but seeks to make them more effective and efficient by linking them together and thus enabling synergies to emerge. This is why it is designated as a 'system of systems'. A principle objective of GEOSS is that data, services, analytical tools and modelling capabilities relating to Earth observation can be freely and easily accessed through the GEO Portal (www.geoportal.org).

The GEOSS 10-Year Implementation Plan Reference Document (GEO 2005) identifies nine Societal Benefits Areas (SBAs): Disasters, Human Health, Energy, Climate, Water, Weather, Ecosystems, Agriculture, and Biodiversity. Most stakeholders involved in biodiversity protection advocate an 'ecosystem approach' to their task, because ecosystems capture the underlying species and genetic diversity, even when they are unknown. For these reasons GEO BON proposes a unified approach to the Ecosystems and Biodiversity SBAs, through a single network. For example, the ecosystems component of GEO BON will incorporate an ongoing GEOSS Ecosystems task (EC-06-02) to develop a robust, standardized, and practical classification and map of terrestrial, freshwater, and marine (coastal and offshore) ecosystems. GEO BON will also build upon tasks in other GEO SBAs that are developing observing systems of relevance to biodiversity (Figure 2) such as to address major gaps in the coverage of biodiversity observations.

GEOSS will coordinate across many previously disparate biodiversity observing systems to create a platform that integrates biodiversity with other geospatial data. This effort will support monitoring of the condition and extent of ecosystems, the distribution and status of species and levels of genetic variability, and improve understanding of drivers and impacts of change in these biodiversity elements. GEOSS will connect biodiversity monitoring systems to other Earth observation networks that generate relevant data, such as climate, land use, and pollution data. It will also help fill gaps in taxonomic and biological information, support updated assessments of global biodiversity trends, track the spread and retreat of invasive alien species, and monitor how biodiversity responds to climate change (GEO 2005).

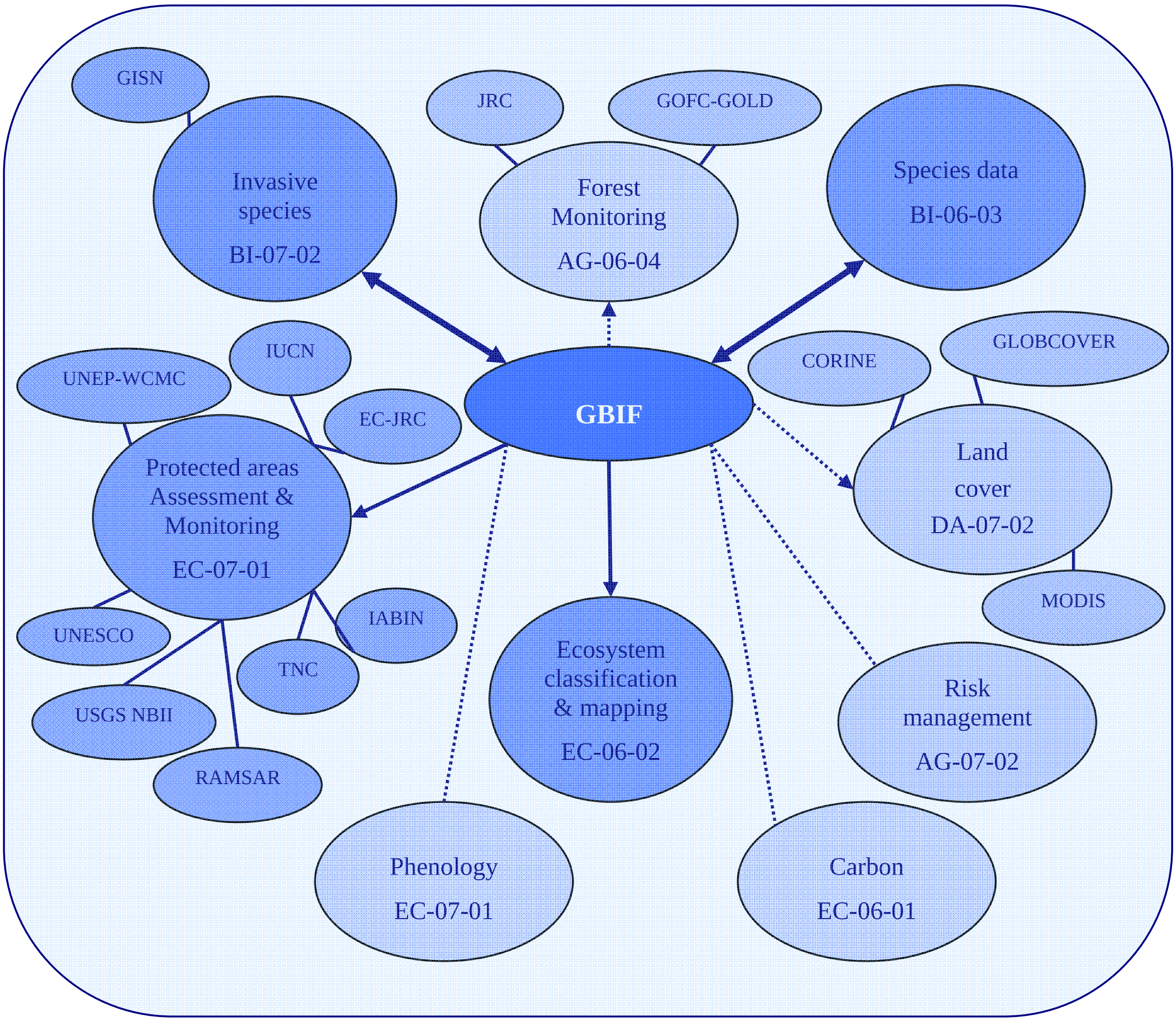

Figure 2 – GEO BON – a network of networks provides a framework for the observation of biodiversity and its changes over time. This figure presents a number of different GEO tasks (indicated by their XX-XX-XX identifiers) that are both relevant to and supportive of the development of GEO BON. Many GEO Societal Benefit Areas, associated tasks, and other elements are cross-cutting in nature.

1.4 What is the GEO Biodiversity Observation Network?

Under each of the nine SBAs, the GEO 2007-2009 Work Plan calls for the completion of specific tasks. One of the tasks within the GEO Biodiversity SBA is designated BI-07-01, which calls for the development and implementation of a Biodiversity Observation Network. The BI-07-01 task reads as follows:

"Develop and implement a biodiversity observation network that is spatially and topically prioritized, based on analysis of existing information, identifying unique or highly diverse ecosystems and those supporting migratory, endemic or globally threatened species, those whose biodiversity is of socio-economic importance, and which can support the 2010 CBD target. Develop a strategy for assessing biodiversity at both the species and ecosystems level. Facilitate the establishment of monitoring systems that enable frequent, repeated, globally coordinated assessment of trends and distributions of species and ecosystems of special conservation merit. Facilitate consensus on data collection protocols and the coordination of the development of interoperability among monitoring programs."

Of course, numerous efforts are already in place to observe and monitor various aspects of biodiversity across multiple taxa, levels of biological organization, and spatial scales. What can GEO BON add to this activity? It is not our aim to replace or inhibit efforts already underway or planned, but to make them more effective. What seems needed is a coordinated framework that allows for information exchange and access at all levels of biodiversity, and seeks to identify and help fill important gaps in observations. Such a coordinated biodiversity observation network will enable new and synthetic understanding of biodiversity and its role in maintaining the Earth system and humanity's place in it (Figure 3). It will facilitate the efforts of governments and the global community to address biodiversity loss by improving our ability to monitor trends in biodiversity and to develop and test response scenarios. One can perhaps find a physical science analogue in the enhanced understanding within climatology and other physical sciences arising over the past two decades from the coordination of Earth science observations under the relatively new discipline of Earth System Science. It is now time for similar coordination and corresponding advances in the biological sciences.

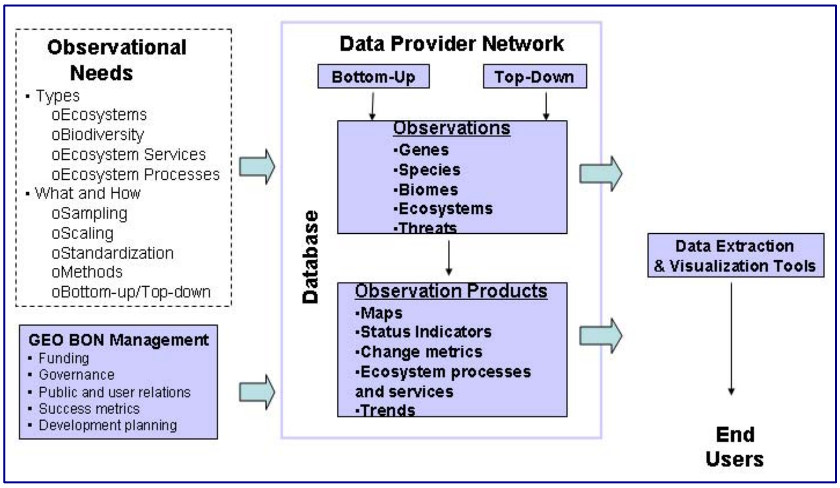

Figure 3: GEO BON end-to-end concept

As biodiversity represents perhaps the ultimate public good in terms of its provision of ecosystem services, it follows that an overarching biodiversity observation network should exist under the auspices of national governments as they are responsible for the maintenance of such public goods. Thus, the network's existence within the context of GEO, an entity comprising government ministries and agencies from around the world, is entirely appropriate. We envision an operational international network with enabling government support but open to all sectors: public, private, academia, and non-profit.

Through its network of networks GEO BON will support the integration of biodiversity data from land, freshwater, and marine environments and distribution to all interested parties. It will focus on: a) quantifying and mapping the drivers of biodiversity change, including threats; b) recording the impacts of biodiversity change with a focus on vital ecosystem functions and resulting services; and c) reporting the current state and changes in biodiversity over time. Data sources will encompass field observations (including those by volunteer networks of lay observers), specimen and image collections, and remote sensing imagery. Model products will also be a key component of GEO BON in that they serve to identify gaps among observations and also demonstrate knowledge of processes that may enable a predictive biodiversity science. GEO BON will provide access to distributed data sources by helping to integrate and build upon existing initiatives that continue to develop components of a global biodiversity informatics infrastructure.

1.4.1 GEO BON Guiding Principles

Information sharing. The GEO BON Data Sharing Principles will follow on the GEO Data Sharing Principles, laid out in the 2005 GEOSS 10-Year Implementation Plan. These call for the full and open exchange of data, metadata, and products shared within GEOSS while recognizing relevant international instruments and national policies and legislation that allow for the appropriate protection of sensitive data, for instance on the precise location of endangered species.

Architecture, data systems, standards and interoperability. GEO BON, as a part of GEO and working in accord with its Architecture and Data Committee, and building on existing systems and initiatives such as GBIF, ILTER, and the Conservation Commons, will

- Define the necessary elements of a system of systems to satisfy societal needs in the areas relating to biodiversity and ecosystems
- Work towards the convergence and harmonisation of observation methods
- Promote the use of standards and references, inter-calibration, and data assimilation
- Define and update interoperability arrangements to which GEO Members and Participating Organizations agree to adhere, including technical specifications for collecting, processing, storing, and disseminating shared data, metadata and products
- Facilitate data rescue activities, recovering data that are now only available in paper publications or other forms that do not make them readily available for inclusion in analysis.
- Facilitate data management, information management, and common services, and 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.

Metadata contents. GEO BON data must satisfy quality control requirements, as documented in associated metadata. The key ones are:

- Traceability of data to originator and the method of collection and transformation
- Explicit location and date of collection to accompany observations
- Sufficient information to accompany observations to permit an assessment of their accuracy

User requirements and interface. The top level goals for GEO BON appear in Appendix 1. The key drivers for suitability and usability are:

- GEO BON contents and priorities will be based upon user requirements; these will evolve over time.
- The distributed, multi-system nature of GEO BON should not negatively impact on its ease of use

Earth observation requirements. Critical requirements for Earth observation data are:

- Repeatability: Measurements should be repeatable to allow for monitoring of status and trends of components of biodiversity and ecosystems. Ecological and biotic data can be useful even if they simply provide a baseline "snapshot."
- Integrative capacity: Different kinds of observations data can play different roles in an integrated system to monitor change. For example, remote sensing data may provide temporal information tracking change in condition, and biodiversity models based on other observations may then allow interpretation of these changes at various biodiversity levels.

- Data continuity: Long-term continuity of *in situ* and satellite observations are needed to support change detection and monitoring. Continuity also applies to Earth observation-derived geospatial data products such as weather, climate, land cover, and phenology. Landsat data continuity is essential to long-term monitoring because of its historic acquisition and use.
- Reprocessing: Reprocessing of historical Earth observations may be required to develop consistent long-term data records.
- Sampling frame: A global sampling frame that scales to local, national and regional scales is required to provide a statistically sound basis for repeated measurements of biodiversity and ecosystems for status and trends, and to provide a platform for the inter-comparison of multiple datasets.
- *In situ* data collection and management: While likely to be a significant challenge, it is essential to coordinate, standardize, and manage *in situ* data that are collected by disparate institutions and individuals for differing purposes. The Census of Marine Life, and OBIS, its data integration component, can serve of an example how sharing data can make the sum more than the sum of its parts.

1.5 Users and user requirements

It is possible to predict only broad categories of GEO BON users, together with the ways that they and society as a whole would benefit from a worldwide network of integrated biodiversity data linked to spatial and other data types (Box 4). Because GEO BON will be a system that continually integrates additional data sets, sources and streams into its network, it will be able to serve simple or complicated, general or specific selections of data to users, depending on their requirements. It will also integrate software applications that will make use easy, for the non-expert and expert alike.

The Parties to international treaties, and the secretariats and structures of those treaties, represent a particularly important category of users because Earth observation data are needed to fulfil the requirements of a host of international treaties and conventions. The CBD has perhaps the most direct, urgent and well-defined need for observational data on biodiversity and ecosystems (Box 5). The CBD recommends monitoring, amongst other things, trends in the extent of selected biomes, ecosystems and habitats; trends in the abundance and distribution of selected species; the coverage of protected areas; the connectivity and fragmentation of ecosystems; and the change in status of threatened species.

BOX 4 - Broad groups of GEO BON users and benefits they will derive

The biodiversity-related conventions

- Improved ability to assess and monitor the integrity of selected ecosystems and habitats, including protected areas, biological corridors, drylands and wetlands and the effectiveness of their management
- Improved ability to assess and monitor the status of selected species, including migratory, wetland-dependent species and species in trade, and pests of species and ecosystems
- Improved ability to develop indicators and communicate the information through relevant reports
- Improved ability to assess the effectiveness of the conventions in achieving desired outcomes
- Improved ability to enforce protective laws and treaties

UN organizations

- Enhanced ability to provide services to member countries through:
  - Improvement of relevant databases
  - Improved reports on biodiversity components, including ecosystem goods and services (state of forests – agriculture and livestock – fisheries and aquaculture – soil biodiversity)

National and international conservation organizations

- Improved understanding of potential genetic diversity in different populations
- Enable use of scientific research in legal actions aimed at protecting species at risk
- Improved identification and evaluation of:
  - Species and areas in need of the most immediate action
  - Threats to species, habitats or ecosystems
  - Potential distribution of invasive species

National governments and agencies

Individual governments may already have instituted many of the components of GEO BON for areas within their borders, and have agencies assigned to implement certain goals equivalent to those of GEO BON. However, because not all nations do this, there are gaps in the data being collected. At the same time, there is a need to assemble global data sets pertaining to certain issues, such as to:

- Inform decisions regarding management practices for invasive species
- Predict and plan for the impacts of climate change
- Assist anti-poaching efforts
- Control illegal natural resource extraction

Countries may have various subsets of GEO BON data types, interconnected at various levels of integration. These constitute a good start on the GEO BON system, and integrating them would represent cost-efficiency.

BOX 4 - Broad groups of GEO BON users and benefits they will derive (continued)

Research and Education

To provide the scientific knowledge necessary to predict, forecast and help manage the large-scale social, economic and environmental effects of change, the scientific community needs:

- Access to quality-assured data at local, national, and global levels with relevant metadata
- Spatial, time series, and process level data
- Data-mining for studying patterns and mechanisms across different taxa and scales
- Data to support the development and testing of process level models for making predictions
- Access to contextual and supporting data to enable interpretation of the causes of change in biodiversity
- Filling of key gaps in the observational record required to understand trends and conditions of ecosystems and the services they provide.

Across multiple user communities

Access to such a system will enable the scientific and other communities to support large-scale analysis, modelling and assessment exercises to provide:

- Process level understanding of the relationship between biodiversity and ecosystem processes across different scales
- Statistical estimates of stock and changes in key attributes of biodiversity and their levels of uncertainty
- Assessment methods for relating changes in genetic and species biodiversity to ecosystem services and their social and economic benefits
- Analysis of the key drivers and pressures affecting biodiversity and their variation in time and space
- Assessments of the risks and threats to biodiversity and the services it provides
- Evaluations of the direct and indirect effects of current and proposed policies on biodiversity, including evaluations of the effectiveness of current biodiversity policies (e.g., protected areas)
- Forecasts of biodiversity in relation to management and policy scenarios as a basis for resource management strategies and the development of biodiversity policy options

BOX 5 – Looking beyond the 2010 biodiversity target

GEO BON can support our ability to develop post-2010 biodiversity indicators and build on Biodiversity Indicators Partnership achievements. It can improve coverage, quality and reliability of a large number of indicators agreed by the CBD (Table below) and improve our ability to analyse and interpret information across individual indicators. In the long term, GEO BON will be able to refine the monitoring framework applied for assessing biodiversity loss beyond 2010.

Focal Area	Headline Indicator (those benefiting initially from GEO-BON in bold)
Status and trends of the components of biological diversity	**o Trends in extent of selected biomes, ecosystems, and habitats** **o Trends in abundance and distribution of selected species** **o Coverage of protected areas** **o Change in status of threatened species** **o Trends in genetic diversity of domesticated animals, cultivated plants, and fish species of major socioeconomic importance**
Sustainable use	o Area of forest, agricultural and aquaculture ecosystems under sustainable management o Proportion of products derived from sustainable sources **o Ecological footprint and related concepts**
Threats to biodiversity	**o Catalog threats to biodiversity and their relative risks** **o Habitat loss due to human encroachment and fragmentation** **o Habitat degradation by the introduction of pollutants (chemical, bio-active, radioactive, light, and noise)** **o Habitat instability due to changes in abundance of prey or the removal of predators or other unbalanced changes in the population of one species** **o Habitat pressure due to the introduction of invasive exotic species**
Ecosystem integrity and ecosystem goods and services	o Marine Trophic Index o Water quality of freshwater ecosystems o Trophic integrity of other ecosystems **o Connectivity / fragmentation of ecosystems** o Incidence of human-induced ecosystem failure o Health and well-being of communities who depend directly on local ecosystem goods and services o Biodiversity for food and medicine
Status of traditional knowledge, innovations and practices	o Status and trends of linguistic diversity and numbers of speakers of indigenous languages o Other indicators of the status of indigenous and traditional knowledge
Status of access and benefit-sharing	o Indicator of access and benefit-sharing
Status of resource transfers	o Official development assistance provided in support of the Convention o Indicator of technology transfer

2 OBSERVATIONS

2.1 Ecosystems

The Ecosystems component of GEO BON will provide essential global information on ecosystems: in particular, their distribution, extent and condition, the drivers of change, and the consequences of those changes. The scope of this component covers integrated multi-scale approaches (Figure 4) and includes terrestrial (including subterranean), freshwater, and coastal and open ocean ecosystems, throughout the world.

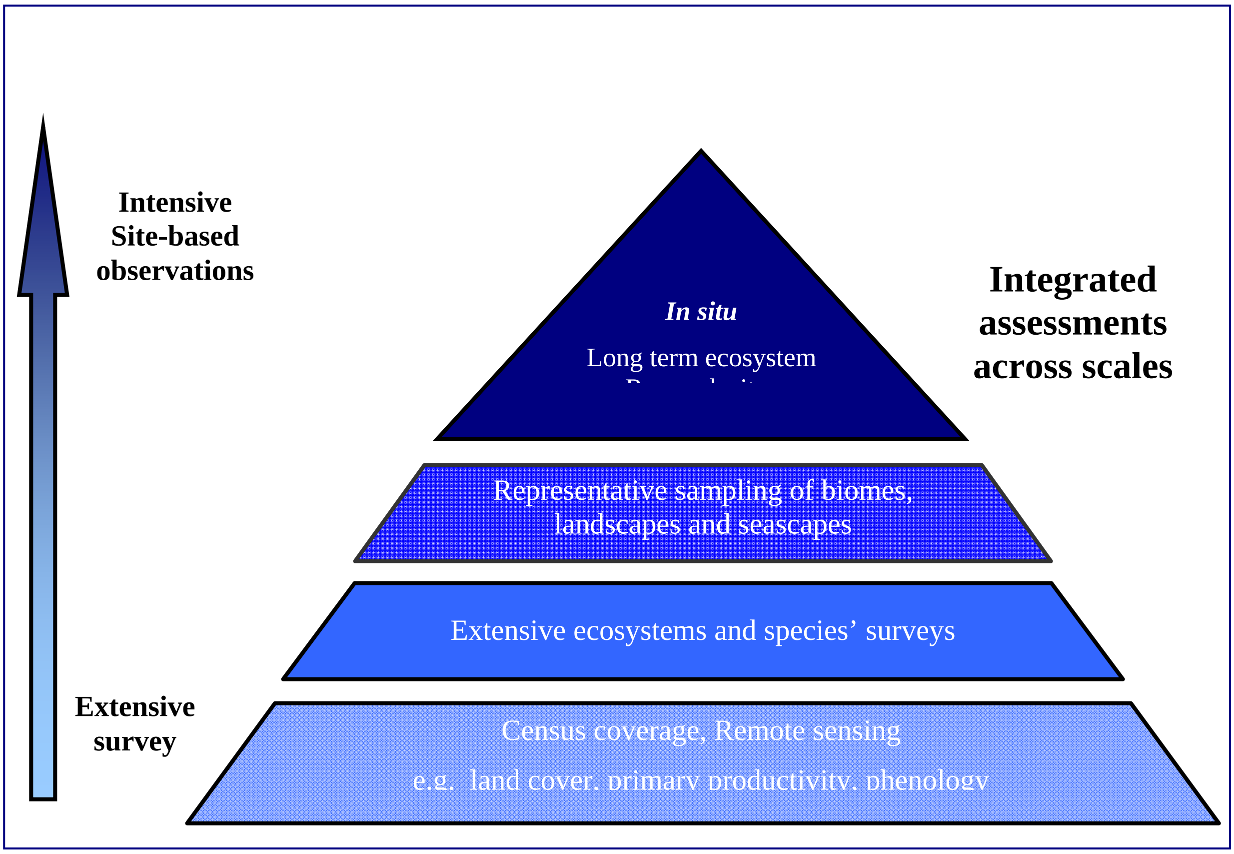

Figure 4: Example of multi-scale approaches to GEO BON observations

2.1.1 Measuring change in the extent of ecosystems

GEO BON will facilitate the global monitoring of ecosystems using a combination of remote sensing and *in situ* approaches. For remote sensing-based monitoring purposes, the most desirable imagery, and its associated resolution, frequency, and accuracy, will depend on the type of ecosystem to be monitored. For historical reconstruction, optical passive sensors provide the longest time-series of satellite-derived images with spatial resolutions in the 15 to 1000 m range (e.g. Landsat and AVHRR). For land and freshwater studies these can be augmented with more recent radar or higher resolution imagery. Remote sensing change detection products will quantify the changes in ecosystem and habitat metrics such as the presence or absence of particular ecosystems, their surface area, and degree of fragmentation. Change detection techniques are numerous, and range from photo-interpretation, simple image differences, classification and map differences, and modelling. The most suitable technique is highly dependent on the sensor, the target, and operator skills. GEO BON will seek to promote image processing and interpretation workshops to improve the calibration of ecosystem change products to specific situations and processes.

GEO BON will especially contribute to the design and the availability of image time-series. Detailed specifications for each broad ecosystem type will be compiled within GEO BON to define the best strategy for long term acquisition. This will help space agencies to define their upcoming observation programs (similar in spirit to the Long Term Acquisition Plan of the Landsat 7 mission) but will also indicate which archived or historical data needs to be released or purchased in the short term.

GEO BON will call on providers of remotely sensed imagery to make freely available archived and new data. Specifically, the release of images from the Landsat archive and other archives will be useful for change detection. GEO BON will also encourage governments to obtain very high resolution imagery according to user's specifications and for an optimised set of monitoring sites related to biodiversity change. These data should be served by long-term sustained web servers.

Note that many marine ecosystems, in particular, can be difficult to observe using remote sensing, and direct, *in situ* measurements are required. To achieve global coverage for such systems the efforts of individual institutes and countries will have to be coordinated via global programmes such as the Census of Marine Life.

2.1.2 The GEOSS Global Ecosystem Mapping task

A GEOSS task from the Ecosystems Societal Benefit Area (Task EC-06-02) is producing new, standardized, robust, and practical classifications and maps of global ecosystems, and these will be used as a primary ecosystems dataset and foundation for GEO BON. GEOSS commissioned this new global ecosystems classification and mapping effort because existing globally-applicable ecological zonations are often too coarse to be useful for local scale, on-the-ground management applications, and/or lack a basis in empirical data, which can be updated as better quality data (e.g., finer spatial resolution) becomes available.

Users will have free and ready access, through GEO BON, to all the ecosystem data products generated as inputs to the global ecosystems mapping effort. The terrestrial, freshwater, and marine ecosystems distribution maps will be produced at a finer scale than any existing ecoregionalization of the planet. The ecosystems also represent a current characterization (baseline) of the types and multi-occurrence distributions of ecosystems and their current spatial extent. Importantly, the ecosystems products can be used in national gap analyses of biodiversity at the ecosystems level, an assessment that is mandated by the CBD/COP7 agreement.

2.1.3 Measuring change in the condition of ecosystems

Surveys and long-term monitoring of ecosystems in the field provide data on the abundance of key species and community composition that are essential for quantifying changes in the condition of ecosystems. These *in situ* assessments can also be directly related to the drivers and pressures of change and loss of ecosystem services. They provide the data necessary for the development and testing of process models, risk assessments and forecasting systems. They may also provide early warning of thresholds or tipping points by indicating where a rapid change in ecosystem condition, loss of species and loss of ecosystem services may be about to occur.

Although *in situ* data are essential for GEO BON they often come from diverse sources and are usually very expensive to collect, manage and distribute to users. GEO BON will develop consistent approaches and standards for *in situ* ecosystem observations and develop integrated systems that use remotely sensed sources of data to make cost-effective use of *in situ* capacity. GEO-BON will also undertake the task of bringing together data from *in situ* sources and making them available in forms that can be used most easily with remotely sensed data. To achieve this GEO BON will build on the capacity already provided by existing long-term ecosystem research sites and observatories in, for instance, the International Long Term Ecological Research (ILTER) network, the Census of Marine Life, MAB-Biosphere Reserves, and BIOTA-Africa.

2.1.4 Linkage among terrestrial, freshwater and marine ecosystems

The highest human population densities are located along coastal and inland water systems. The interfaces between terrestrial and aquatic systems are extremely important and complex in terms of processes, the diversity of habitats and species they support, and the ecosystem services they provide, in the form of food, waste absorption, transport and recreation, among others. A GEO BON working priority is to consider explicitly the land-freshwater-marine components within a global integrated framework. Terrestrial, freshwater and marine (coastal and offshore) ecosystems are physically connected through water circulation (surface and groundwater) and through many other processes including the biogeochemical cycles for carbon, nitrogen, phosphorus, and other elements. These physical and biological interactions are multi-directional and occur at a variety of spatial and temporal scales that will be addressed using GEO BON's integrated approach to ecosystem observations.

2.1.5 The GEO BON ecosystems approach

An "ecosystem approach" is a strategy for integrated, holistic management of resources that promotes biodiversity conservation and sustainability. The GEO BON Ecosystems approach emphasises:

- Mapping the distribution of marine, freshwater, and terrestrial ecosystems
- Detecting changes in these ecosystems
- Characterizing the linkages between these ecosystems

These emphases are part of a larger aim to characterize the types and states of ecosystems and the drivers and consequences of ecosystem change. Tables 1 to 3 summarize pertinent datasets and providers for the three broad ecosystem types. Each table presents three focal areas (status and distribution, drivers of change, and ecosystem services) matrixed against associated datasets, priority (short-term vs. long-term), and data sources. For the purposes of these tables, "Short-term" under the Priority category means the datasets are either currently available or soon will be through GEOSS or other sources, while "Long-Term" refers to products requiring effort over the coming years to complete. The tables show a variety of applications that interested users may both contribute data to and draw data from using GEO BON participant networks.

2.2 Species

Species and their populations are core elements of the biosphere, each one with its independent evolutionary origins and unique suite of characteristics and adaptations. Species interact with one another in biological communities, as well as with the abiotic components of the environment. So, context is important for monitoring changes in their distribution and abundance both for the purposes of GEO BON and also for many other societal benefits areas, e.g., agriculture, health, etc. GEO BON will focus on several specific areas with regard to observations of trends in distribution and abundance of selected species.

Different methodologies will apply according to the species group of interest. The respective roles of direct observation, *in-situ* sampling, modelling, and remote sensing data will vary enormously with different ecosystems (e.g., terrestrial versus marine) and different species groups (especially micro-organisms versus other taxa).

2.2.1 Changes in distribution and abundance

GEO BON will work with partners to establish a coordinated and sustained *in situ* sampling scheme, at appropriate spatial and temporal resolution, to generate time series that inform on (1) changes in species' distributions, and (2) the direction and rate of changes in their abundances. Rather than duplicating existing or emerging *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 is a gap-filling activity, since only a tiny and non-representative percentage of all species is currently being monitored this way. GEO BON will establish a comprehensive global sampling scheme for sets of species representing key criteria (Table 4). Besides gathering baseline information on distribution and abundance, parameters that relate to important biological processes should also be determined, including drivers of change (Table 5).

At permanent observation sites, monitoring combined with experimentation (i.e., deliberate manipulation of given factors) can further strengthen the understanding of cause-effect relationships. Establishment of linkages will enable the system not only to detect rapid biodiversity change at an improved spatial and temporal resolution, but also to pinpoint the probable causes of changes.

	Category	Dataset	Priority	Data providers
Marine	**Status and distribution**	Pelagic Ecosystem map	Short-term	GEO EC06.02 (baseline+ 1st iter.)
		Habitat map	Long-term	Universities, Government Agencies, NGOs
		Benthic cover		Universities, Government Agencies, NGOs, CBD
	Drivers	Land use and changes	Short-term / Long-term	GEO
		Points of urban sewage and industrial discharge	Long-term	National Agencies
		Hurricane paths	Short-term	GEO Disasters
		Circulation (coarse and fine scale)	Long-term / Short-term	Universities, Government Agencies
		Resource extraction	Long-term / Short-term	FAO, GEO, Government Agencies, NGOs
	Ecosystem services	Fish provisioning	Short-term	
		Shore protection	Long-term	GEO, Government Agencies
		Recreation		Government Agencies

Table 1: Marine ecosystems datasets

	Category	Dataset	Priority	Data providers
Freshwater	Status and distribution	Ecosystem map (rivers, lakes, etc.)	Short-term	GEO EC06.02 (baseline+ 1^{st} iter.)
		Fine ecosystem map (e.g. small wetlands, riparian systems, etc.)	Long-term	Universities, Government Agencies, NGOs, Ramsar Convention, CBD
		Eecosystem condition and composition		ILTER and MAB Biosphere Reserves
		In-stream attributes: water depth, water velocity, slope, flow regimes and discharge, nutrient load, white water versus black water turbidity, stability of banks		Universities, Government Agencies, NGOs
	Drivers	Map of dams (size, changes in annual discharge) and water diversions	Long-term	Government Agencies, NGOs, Private sector
		Land cover in watersheds		GEO, EC
		Points of urban sewage and industrial discharge and non-point source run-off		Government Agencies
		Map of invasives (floating vegetation, molluscs, etc.)		GEO, Global Invasives Species Programme, IUCN, Govt. Agencies
		Circulation (coarse and fine scale)	Long-term / Short-term	Universities, Government Agencies
		Harmful Algal Blooms and Anoxia		
		Pollutants (including bio-active chemicals, sewage, nutrients, industrial waste, etc.)		
	Ecosystem services	Water provisioning for drinking water and irrigation	Short-term	FAO, GEO, Government Agencies, NGOs
		Flood and inundation regime	Long-term	FAO, GEO, Government Agencies
		Fish provisioning		GEO, Government Agencies

Table 2: Freshwater ecosystems datasets

	Category	Dataset	Priority	Data providers
Terrestrial	Status and distribution	Coarse Ecosystem map	Short-term	GEO EC06.02 (baseline+ 1st iter.)
		Ecosystem condition and composition	Medium-term	ILTER, BIOTA, MAB Biosphere Reserves
		Fine Ecosystem map (e.g., forest plantation map)	Long-term	GEO Land-Cover, FAO, Government Agencies, CBD
	Drivers	Land use change map (conversion to agriculture, afforestation, logging, fragmentation, urbanization)	Short-term	GEO Global Forest Task. FAO, Government Agencies, GTOS (GOFC-GOLD)
		Farmland intensification	Short-term	GEO Agriculture, GEO Ecosystems, FAO, Government Agencies
		Climate change	Short-term	GEO Climate
		Desertification	Long-term	GEO, FAO, Government Agencies, Dryland Convention
		Human Encroachment (noise, night-lighting, soil disturbance, litter, roadkill, domesticated animals, hunting, etc.)		
		Pollution (pesticides, industrial waste, radioactive material, sewage, etc.)		
		Urbanization		
	Ecosystem services	Carbon sequestration	Short-term	GEO, Universities. Global Carbon Project
		Fire regime	Short-term	GEO Disasters, Government Agencies, European Environment Agency, Universities, NGOs
		Water cycle regulation	Long-term	GEO, GCOS
		Timber provisioning and other forest products	Short-term	FAO, Government Agencies, GEO
		Crop production	Short-term	FAO, Government Agencies, GEO

Table 3: Terrestrial ecosystems datasets

To realize this ambitious undertaking, GEO BON will be guided by the following:

- A combination of top-down and bottom-up sampling schemes will be used with capacity-building for data providers, which will be an integral part of turning this sampling scheme into a global process over time.
- The sampling scheme will, through appropriate stratification, aim to provide representative coverage of geographical regions and ecosystem types. If deemed necessary, it may also direct particular sampling efforts towards global "hotspots" of current or impending biodiversity loss.
- The sampling scheme will be vetted by taxonomic and statistical experts (such as the IUCN Species Survival Commission), with special attention given to an adequate sampling of rare species and events that operate over different spatial and temporal scales. The sampling scheme will be reviewed by the various data users, including from the other GEO Societal Benefit Areas (e.g., agriculture, ecosystems, health).
- The sampling scheme will be designed around existing and potential experimentation, remote sensing, and modelling to fill sampling gaps, validate cause-effect relationships, and produce risk and early-warning assessments.

Stratum	Included groups
Provisioning species	Domesticated mammals & birds, food crops, forestry species, medicinal plants, wild-harvested mammals, freshwater fish, coastal reef fishes, marine high tropic fish, pelagic fish, demersal fish
Treaty species: Migratory, RAMSAR, CBD, etc.	Migratory passerines, migratory waterfowl, sedentary waterfowl, large marine mammals, sea turtles
Key functional groups	Pollinators, N-fixing organisms, soil nematodes, keystone food plants
Top predators	Sharks, raptors, mammalian predators, snakes, spiders
Herbivores	Bovids, caprids, camelids, antelopes, rabbits, hares (e.g., for mammals)
Primary producers	Grasses, trees, shrubs, mosses, corals, phytoplankton, seagrass
Detritivores	Crayfish, lobsters, crabs, dung beetles, earthworms, molluscs, termites
Charismatic species	Elephant, rhino, hippo, primates, large cats, wolves, bears, pandas, whales, dolphins
Indicator groups	Salamanders and newts, rainforest frogs, freshwater frogs, butterflies, moths, bats, lichens, fruit-eating birds, ants, seed-eating birds, insect-eating birds
Disease and pest species	Human disease-vector insects, ticks, small rodents, locusts, crop pest insects, crop weeds, aquatic weed plants, toxic algal bloom species
Evolutionary clade representatives	Ferns, cycads, echinoderms, ascidians, crocodiles, tortoises
Major Ecosystem types	Freshwater, coastal, marine, forest & woodland, wetland, dryland

Table 4: This list is an example of criteria to prioritize and stratify the choice of intensively monitored species, which should be drawn from a representative range of biomes, ecosystems, habitats, taxa, functional types, and other important axes of biodiversity.

Criteria	Parameters
Metrics of change	Spatial shifts: movement of species distribution areas, changing altitudinal ranges, habitat shifts
	Abundance shifts: change of numbers and density
	Community shifts: changes in endemicity and homogenization
	Migration: phenological and spatial changes
	Local and global extinction rates
	Demographic changes: standing age structure, sex ratios/recruitment intensity, trophic structure
Drivers of change and threats	Direct drivers - habitat change, climate change, pollution, invasives, overexploitation
	Indirect drivers - increasing global trade, population growth, increasing consumer demands, etc.

Table 5: A provisional list of parameters that should be measured for a selected group of species

- While maintaining a continuous sampling scheme to produce reliable time series, the scheme needs to be flexible enough to quickly incorporate new sampling methods if they promise to significantly raise the information content of the scheme (e.g., monitoring of markets by including genetic identification of species).

If feasible, GEO BON will attempt to extend time lines backwards using retrospective monitoring based on a range of different historical data (e.g., archived data, photographs, historical accounts of animal abundances). Such data would provide important information to address concerns over 'shifting baselines' whereby historical biodiversity loss is not counted in recent assessments. In particular, as leader of task B1-06-03 (Capturing Historical and New Biodiversity Data), GBIF can play an important role in continuing to drive the mobilisation and accessibility of online primary biodiversity data through its extensive network of participating institutions, countries and organisations.

The baseline data acquired will produce one or a few reliable and comprehensive indicators of global biodiversity change at the species level, which can be subdivided regionally, taxonomically and functionally according to user needs.

2.2.2 Distribution range maps for a large number of species

GEO BON will facilitate access to, and (when needed) generation of, global distributional ranges for a large and representative set of species. GEO BON will facilitate expert forums to map global species distributions for various taxonomic groups, working with and building upon the work of IUCN, whose Species Survival Commission has generated thousands of such maps, and other groups. If feasible, historical or, in some cases, new data will be made available to fill critical data gaps. Most of the data should be accessible through data providers (e.g., the GBIF network of institutions worldwide). To model distributions, niche-based modelling techniques will be applied in ensembles to generate grid-based probability ranges for each species. For example, AquaMaps (www.aquamaps.org) compares species distribution data from the Ocean Biogeographic Information System (OBIS – www.iobis.org) to environmental data to produce marine species range maps. The environmental basis for the predicted ranges will then be edited and validated by experts. Generating such species distributions will help interpret the implications of remotely-sensed change data.

For less well-studied, yet highly diverse, biological groups (e.g., invertebrates), community-level modelling approaches will be employed (e.g., Ferrier and Guisan 2006), in place of individual species modelling, to interpolate global patterns of community richness and composition from best-available locational data for species in these groups.

The products of both species-level and community-level modelling will provide a baseline or "lens" for interpreting remotely sensed cover-change data (e.g., from other GEO Societal Benefit Areas), facilitating assessment of the consequences of observed changes in terms of impacts on biodiversity.

2.2.3 Other activities

The GEO BON species-level effort has also identified several other important activities, which need further planning by panels convened for this purpose.

- Facilitate (in collaboration with other existing initiatives and organizations – e.g., GBIF) the continuing digitization of all relevant species data needed for informed research and management, with relevance being determined by expert groups. These data would then be made freely available, along with user-friendly tools for their analysis.

- Improve the early-warning function of GEO BON by developing forecasting scenarios (e.g., Millennium Ecosystem Assessment land-cover change scenarios) using a variety of models (e.g., population and habitat viability models, forecasting models, bioeconomic models on resource uses) that alert stakeholders to impending threats, such as regional or global extinctions or outbreaks of invasive species, pests, or pathogens.

- Widen and improve both the support for and the utility of local and regional capacity-building efforts on a worldwide basis, including both science-based and citizen-based observations.

Table 6 lists potential data providers and data types to generate species richness and turnover data that can be monitored for trends in time and space. These will evolve over time and also depend upon the willingness of networks to contribute and adapt their data gathering efforts. GEO BON will provide a platform for data gathering efforts in cases where data gaps and needs are identified. Note that hundreds of such institutions/organisations worldwide already collaborate to make their data available through GBIF, which provides access to 151 million primary biodiversity records as of October 2008. GEO BON will work with GBIF to grow this network of contributors.

Type	Data providers
Primary data providers	Museums, NGOs, governmental and intergovernmental agencies, inventories, taxonomic and other monographs, citizens organized through NGOs
Secondary data providers	EOL, FAO, GBIF, IUCN, UNEP-WCMC, monographs, reports, status assessments, etc.
Types of data	
Point-locality records (e.g., specimen) Polygons (e.g., range distributions) Images (e.g., remote sensing) Trends in use (e.g., harvesting levels) Population data (e.g., breeding success, age structure, etc.) Census information	

Table 6: A provisional list of data providers and data types to be gathered

2.3 Genes

The fundamental basis of biological diversity is genetic diversity. Genetic diversity has important consequences for both evolutionary and ecological processes. GEO BON will promote regional and global observations of within-species genetic diversity in order to assess trends in genetic variation and their causes and consequences. Genetic diversity includes diversity in several classes, including DNA sequences, gene number, genome structure, and genome size within and between species. Most organisms have protein-coding genes, regulatory elements of gene expression, non-functional DNA sequences and parasitic DNA sequences such as transposable elements. Protein-coding genes support various ecosystem functions. Some protein-coding genes are widely-shared, but others are restricted to some particular species or lineages of organisms. In addition, substitutions in non-coding sequences are of interest as they supply another source of genetic diversity for adaptation. Both changes in gene sequences and the evolution of new genes are key components of evolutionary changes.

In parallel with GEO BON goals for ecosystems and species, GEO BON will facilitate the global monitoring of genetic and phylogenetic diversity using a combination of remote sensing and *in situ* approaches. These approaches will often be most effective when integrated with GEO BON observation strategies at species and ecosystems levels. Three broad strategies for observations/analyses at the level of genetic and phylogenetic diversity will be addressed by GEO BON.

- Repeated observations, over time, of specific genetic components of interest, in selected target species.

- Repeated observations, over time, of other biodiversity components (e.g., range extents for a representative set of species), integrated with models that create links from these observations to genetic diversity.
- Repeated observations, over time, of changes in land/water condition (e.g., using remote sensing), integrated with spatial genetic variation models that act as the "lens" for inferences about the corresponding changes at the genetic/phylogenetic levels.

GEO BON will promote these overlapping strategies as a way to enable a range of monitoring approaches, extending from detailed observations for key species to model-based inferences of more general changes in genetic diversity. In accord with the overall GEO BON approach of integrating remote sensing and *in situ* observations, changes in genetic variation may be based on direct observations, or inferred indirectly through a combination of remote sensing and biodiversity models.

2.3.1 Observations over time of selected genetic components

GEO BON will take advantage of the rapid development of automated sequencing techniques and other new tools of genome research that now make it feasible to record aspects of genetic diversity within (and between) species at regional and global scales. Until recently, it had not been practical to probe the within-population genetic variability of more than a few species in detail (e.g., humans, laboratory model species, some key crop and domestic livestock species, and some important disease-causing organisms). This situation is changing rapidly with the widespread availability of automated instruments for reading sections of the genetic code, and the associated development of bioinformatics tools for interpreting these code fragments. As a result, the detailed genetic variability within populations of an increasing number of organisms is becoming well observed, and those data are being utilized to measure within-population diversity in various functional genes (Box 6).

BOX 6 – Observations of within-population genetic diversity - some examples

- MHC genes (Major histocompatibility complex genes) in vertebrates often show extremely high allelic diversity that is maintained under diversifying selection, probably due to the coevolution with pathogens. Loss of allelic diversity, expected under reduced population size, will constrain evolutionary potential of populations. Allelic diversity of MHC genes is now monitored in threatened wild animals. In plants, allelic diversity of self-incompatibility genes and R (resistant) genes are maintained under diversifying selection and can be used to monitor evolutionary potential of populations.
- Hybridization between native and alien relatives is on-going in various areas of the globe. It often threatens persistence of native species and drives evolution of new lineages that may be invasive. This process is now being monitored by using various genetic markers, including expression profiles of functional genes. Examples are hybridization between native and introduced tiger salamanders in California; an invasive newly-evolved species, *Spartina anglica*, of hybrid origin between native and introduced species in England; and hybridization between Japanese and introduced European dandelions (*Taraxacum*).

GEO BON will implement a process that accelerates monitoring of biodiversity changes using multiple genetic markers between species and within a given population. GEO BON will seek to establish an observational system, including sources of information, data exchange protocols, data storage and access systems, and an agreed set of indicators, in order to track changes in genetic diversity in a selected set of organisms – including species that are important in the supply of provisioning services: staple food crops, domestic livestock and aquaculture species, and wild-harvested fish populations and important forestry species.

GEO BON will support an emerging general framework for “conservation genetic monitoring”, described as “the systematic, temporal study of genetic variation within particular species/populations with the aim to detect changes that indicate compromise or loss of such diversity” (Laikre et al., 2008). This framework provides guidelines for choice of target species and for collection of information (Box 7). These categories cover a number of important monitoring strategies, including the measuring of genetic diversity in species translocation programs. Other genetic monitoring of target species can be used to derive indicators of environmental condition, and so support other monitoring tasks within GEO BON. GEO BON will support integrated approaches to monitoring of within species variation in such selected species, including providing support for standardized approaches.

A long-term priority for GEO BON is to produce broad-based observational records of genetic variation to the point where reliable indicators of genetic variability and trends ‘in the wild’, across a wide range of taxonomic groups are available. These would be of assistance in detecting the pollution of gene pools through the diffusion of genetically modified material; help to prioritize species protection efforts in situations where all species cannot be saved; and determine the minimum population sizes for the conservation of threatened species.

BOX 7 – Categories of species that may be early targets for genetic monitoring programs (after Laikre et al 2008)

- Species subject to large scale release operations
- Species subject to large scale harvesting
- Species classified as “near threatened”
- Species with small population sizes
- Species which are already subject to other types of monitoring (e.g., to detect environmental contaminants)
- Species for which extended time series of samples are already available

As a complement to efforts focused on selected target species, GEO BON also will enhance the use of existing databases. One strategy is to establish a link between georeferenced species-level datasets and DNA sequence databases. In contrast to species-level observations that need a standardized sampling scheme, we already have a widely-accepted system of DNA sequence databases in which data formats are standardized. However, most providers of DNA sequence data do not intend to monitor biodiversity changes. For DNA sequence data to be utilized to monitor biodiversity changes by integrating them with remotely sensed and in situ observed data, it is important to georeference each DNA sequence. An optional qualifier in DNA databases supports input of latitude and longitude of the locality where a DNA sample is obtained, but until now, inputs to this field have been extremely limited. GEO BON will help establish some structure by which inputs of DNA sequence data with latitude and longitude of locality are accelerated.

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. The total phylogenetic diversity or 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”.

GEO BON will address monitoring at the phylogenetic level because such monitoring may capture aspects of biodiversity not captured at the conventional species level. For example, in a "phyloclimatic" study of Cyclamen species, the potential loss of PD and evolutionary potential due to climate change was small relative to the estimated loss of species. This important perspective on climate change impacts depended on not only a phylogenetic tree, but also on corresponding geo-referenced species data and their integration with other data layers. GEO BON will promote biodiversity observations at the phylogenetic level by helping to 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.

2.3.2 Extending species level observations

Because GEO BON will be active across all levels of biodiversity, it will develop and promote methods to allow changes in genetic diversity to be inferred even when we only have observations over time at the species level (e.g., estimates of changes in species' range extent). GEO BON in this context can help to extend existing global 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). GEO BON will promote the integration of such data with appropriate models (e.g. the range size-genetic diversity curve of Rauch and Bar-Yam [2004, 2005]) that can use changes in range extent of a given species to predict corresponding changes in genetic diversity.

Monitoring of target species has been enhanced by the application of new approaches for the spatial analysis of genetic diversity. GEO BON's integration of different data sources will promote such approaches, including models using geographic separation and environmental variables as predictors of genetic distances among populations (for example, as used in the monitoring of genetic diversity of *Arabidopsis thaliana* in China). Further, GEO BON can help to extend the application of the models emerging from these approaches. For example, the observed correlation of genetic distance with geographic distance (e.g., for *Brassica* species) allows for the application of additional distance-based models that infer changes in genetic diversity based on observed changes in geographic distribution patterns of a given species. Such models may be effective for a wide variety of organisms, and GEO BON can promote standardized approaches.

In these approaches, observations over time of range extent are made at the species level, and then interpreted using models at the level of genetic diversity. Such strategies face a limiting factor in the availability of relevant specimen/observation data in electronic geo-referenced records, and leveraging on work already underway amongst the wide GBIF Participant network, GEO BON will promote ways to overcome such gaps in geo-referenced data.

GEO BON support of new technologies such as DNA barcoding (the use of a short DNA sequence from a standardized and agreed-upon position in the genome as a molecular diagnostic for species-level identification) will promote the integration of genetic monitoring with species level observations. DNA barcoding programs may expand the capacity to have repeated broad sampling of species over their geographic range.

2.3.3 Models providing a "lens" for genetic/phylogenetic interpretation of remotely-sensed changes

GEO BON will address the integration of remote sensing observations and *in situ* observations at the genetic level. GEO BON will use approaches that side-step 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). GEO BON will 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 standardization of these strategies.

2.4 Ecosystem goods, services, and function

Ecosystems, comprising communities of the living and non-living components of an environment and their interactions, deliver goods and services to society. The health or condition of the ecosystem can be defined from a human perspective as the degree to which ecosystems continue to be able to deliver these goods and services (Table 7).

State	Metric	Data providers
Goods		
Change in quality or quantity of goods (e.g., wood supply, fruit, vegetables, shellfish, sport hunting, fisheries, harvests)	Number, mass, diversity, quality and availability of products	Government and industry organisations
Services		
Change in availability of recreational space, water and/or air quality, environmental quality, waste disposal, local climate	Contaminant concentrations, availability of service, drought and flood events, pollination success rate, indicator species abundance and distribution	Environmental monitoring agencies (including meteorological, hydrological, pollution control)
Function		
Phytoplankton productivity	Chlorophyll biomass	Government and research organizations
Extent of pollination	Fruit production	
Stable nutrient cycling	Phosphorous, nitrogen concentrations	
Sediment and soil stabilization	Flood frequency and extent	
	Indicator species abundance and distribution	
Food web	Trophic index	

Table 7: Examples of the goods, services and functions of ecosystems; the metrics by which they are measured; and the types of organisations that collect such data

GEO BON will seek to integrate appropriate ecosystem metrics in space and time to provide information of value to society regarding the state of ecosystem goods, services, and functioning. For example, GEO BON could apply a metric to the geographic areas delimited in the GEO ecosystem classification, to show where the quantity of an ecosystem good is increasing, decreasing, or stable. A challenge will be measuring changes in less well quantified ecosystem services and ecosystem functioning.

GEO BON will enable comparisons of these changes to climate and human activities to aid inference of cause and effect by providing access to the best available climatic and land use data. The goal is integrated assessments derived from a variety of observations, so that an integrative view emerges which encompasses different trends and their relationships. For example, wood supply may be increasing but soil stability may decrease in relation to poor forestry practices. Or a shellfish harvest may increase due to increasing seawater temperature, but shellfish quality may be compromised by toxic algal blooms stimulated by sewage discharges from an increasing urban population.

2.5 Adding value: Integrated modelling and assessment

The primary focus of GEO BON is observations of change, of two broad types:

- *In situ* (direct) observations of change in biodiversity at all three levels of biodiversity – ecosystems, species, and genes
- Remote sensing observations of change in ecosystem extent and condition

Many of these observations depend to some degree on embedded models, so there is often no clear distinction between a model and an observation. For instance, the automated classification of ecosystems using remotely-sensed data depends on a model-based interpretation of the spectral radiation received by a satellite. However, beyond this direct use of models, GEO BON offers considerable potential to further extend the utility of primary observations through additional levels of integrated modelling and assessment.. These activities will not only increase the extent and efficiency of GEO BON itself, but also add enormous value to its products. The system will be designed to allow the realization of these synergies whenever possible.

Making effective use of primary change observations through modelling and assessment is likely to involve integration of these observations with at least three major types of additional information (Figure 5).

- Baseline spatial data on distributional patterns in biodiversity, at the species level (e.g., GBIF location records), and genetic level (e.g., emerging DNA barcoding datasets).
- Information on spatial and temporal patterns of threats (e.g., climate change, population growth, agriculture) and management responses (e.g., protected areas from the World Database on Protected Areas) using data from other GEO Societal Benefit Area activities, and related initiatives.
- Understanding of ecological, evolutionary and socio-economic processes and interactions, to inform the application of process models. This information is most commonly derived from "expert opinion," supported to some extent by existing scientific research, but in the longer term should also be informed by feedback from GEO-BON site-based monitoring programs.

Major levels of modelling and assessment

As depicted in Figure 5, various levels of modelling and assessment may be used to add value to primary biodiversity-change observations. The following six levels of assessment involve a progressive increase in the amount of additional information required (in terms of spatial data as well as understanding of processes and interactions) and in the complexity of underpinning models.

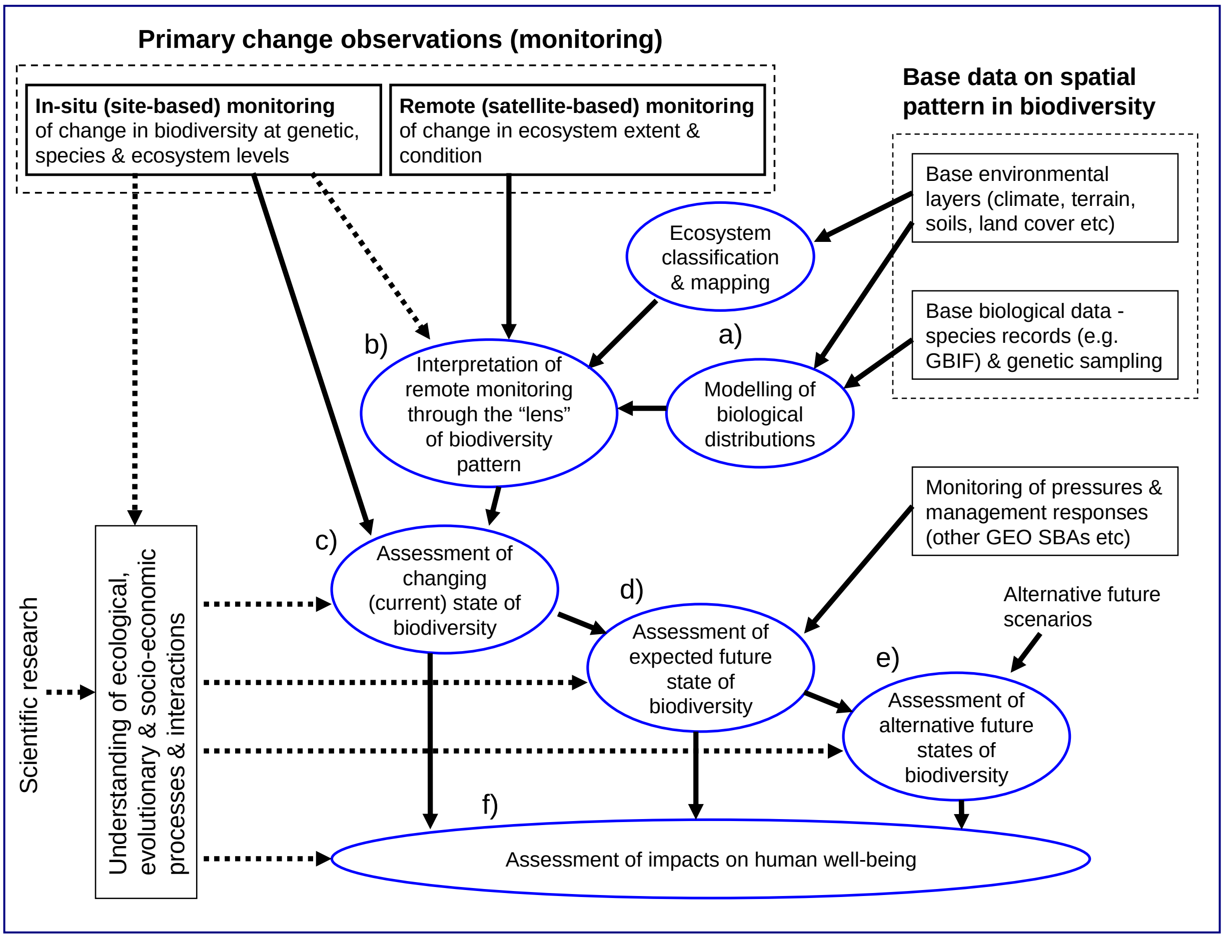

Figure 5: Broad framework indicating major types of modelling and assessment (oval-shaped components) that may be used to interpret, and add value to, primary observations of biodiversity change

- Derivation of spatial surrogates for the distribution of biodiversity, either through classification and mapping of ecosystem types, or through modelling and extrapolation of species or community distributions.
- Interpretation of remotely-sensed changes in the extent and condition of ecosystems through the "lens" of spatial patterns in biodiversity.
- Assessment of the changing (current) state of biodiversity, derived from the integration of *in situ* and remote sensing change-observations.
- Assessment of the expected future state of biodiversity, integrating information on changing pressures and management responses.
- Assessment of alternative future states of biodiversity, under alternative ecological and socio-economic scenarios.
- Assessment of the expected impacts of changes in biodiversity on human well-being.

3 IMPLEMENTATION

3.1 Building the Data Network

The construction of shared data networks involves building not only the information infrastructure that enables data flow, but also the networking of groups of people. In this regard, GEO BON is fortunate to be able to build upon the extensive expertise and experience of GBIF in biodiversity informatics, and technological and social infrastructures, developed over the past seven years.

As the GBIF experience shows, especially on the global level, this human component must allow for wide variation among countries, cultures, scientific disciplines, etc., in:

- Existing physical and technical capacity to use and contribute to data made available through the network
- Ability to upgrade hardware and software in a timely manner
- Attitudes toward the publication of research and other data
- Availability in digital form of important datasets
- Understanding of the potential of GEO BON to improve the outputs of various tasks that involve analysis and understanding of biodiversity

Governments, organizations and institutions that sign on to GEO BON will need to acknowledge and promote the principles of:

- Open access to scientific and monitoring data
- Fair use of data for educational and research purposes
- The development of international Intellectual Property Rights (IPR) laws that protect the investments of private industry but that are not so restrictive that societal benefit from scientific research on biodiversity is stifled

The development of the GEO BON network will require many workshops and a good deal of educational outreach to the various scientific, professional and agency-employee communities. Again, GEO BON is fortunate in being able to build upon all the extensive work already done in this regard with GBIF. Such outreach will help smooth the interactions that will be required to build, initiate, maintain and grow the network’s capability to deliver data and information products, and interpret them.

The key to building an engaged and enthusiastic community of network participants is to ensure that there are appropriate incentives for organizations to participate. Thus GEO BON must offer data providers and other participants a "net positive return" on their investment in time and other resources. GEO BON will do this in a variety of ways. First, GEO BON will provide, thanks to its analysis and integration capacity, new insights and interpretation on biodiversity change to GEO members, based on work performed by network members. Second, it will provide an expanded forum for discussion of needs and priorities, making it easier for network participants to work with a broader range of data and tool providers and users. Relatedly, GEO BON will facilitate meetings and other forms of communication. Third, and perhaps most important, because it has the weight and integrity of GEO and its member governments and organizations behind it, GEO BON will be able to facilitate greater funding of its network participants by making recommendations for new or extended initiatives (these initiatives, of course, would be consistent with those of the network participants). This should result in increased funding and greater forward movement towards each network participant's mission. Overall, then, one aim of GEO BON is to lessen the burden on its network members, providing a shared infrastructure to help the coordination between them, while also providing additional visibility and facilitating additional resources.

3.2 Capacity building

The GEO capacity building strategy follows the World Summit on Sustainable Development concept of a global partnership between those whose capacity needs development and those who are able to assist in the process, recognizing that activities have intertwined social, environmental, and economic impacts. The goal of capacity building within GEO BON is to strengthen the capability of all countries, and in particular developing countries, to use Earth observation data and products and to contribute observations and systems to GEOSS.

Capacity Building Objectives of GEO BON are to**:**

- Facilitate Earth observation capacity building activities at multiple levels (global, national, and regional) among GEO Members, in concert with GEO Participating Organizations.
- Build global capacity to access, retrieve, analyze, include into appropriate models, and interpret relevant data from global data systems.
- Build global capacity to collect and publish data from all around the world that can be integrated with data and information from other sources, thereby improving understanding of problems in order to identify solutions that enhance sustainability.
- Develop a coordinated capacity building strategy among GEO members and participating organizations based on the principles articulated in the GEOSS 10-Year Implementation Plan Reference Document and on already existing ongoing capacity building activities by GBIF, the Partnership for Observation of the Global Oceans, Scientific Committee on Oceanic Research, Intergovernmental Oceanographic Commission, etc.
- Recommend strategies for resource mobilization to GEO Members and Participating Organizations (e.g., e-learning approaches).
- Consider assembling an inventory of capacity building activities that have been used successfully in other contexts and upon which GEO BON can draw for inspiration.

3.3 Governance

GEO is established on a voluntary and legally non-binding basis, with voluntary contributions supporting its activities. GEO BON governance is a leadership function. Participation in governance is voluntary and non-binding. Any governing or committee body has no authority to direct participants; rather it provides guidance and recommendations to participants and contributors. GEO BON is open to all who wish to participate.

Preliminary plans call for GEO BON to be guided by a Steering Committee (SC) that reports to the GEO members at Plenary through the GEO Secretariat. A tentative structure appears in Figure 6. An Executive Subcommittee within the SC will lead tasks between meetings.

The rules to establish the GEO BON Steering Committee have not yet been determined, but a preliminary set, for discussion, are:

- The SC will be composed of a maximum of 15 people, individually appointed for a period of 3 years, renewable once.
- The SC will strive for balance in its membership between users and providers, disciplines, geographical origin, and gender.
- The SC will be responsible for nominating successor members, who will be endorsed by GEO (Plenary)
- The SC will guide the implementation of GEO BON, and report to GEO (Plenary)
- The SC will be assisted by administrative staff, who will report to GEO BON through the SC.

- The SC will establish a variable number of panels, as needed, with defined objectives and lifetimes, to oversee the development of an identified set of GEO BON products.
- The SC will meet as needed, but no less than once every two years. An executive committee (subset of the SC) may be appointed to guide implementation and the work of the secretariat between meetings and will meet on a more frequent basis.

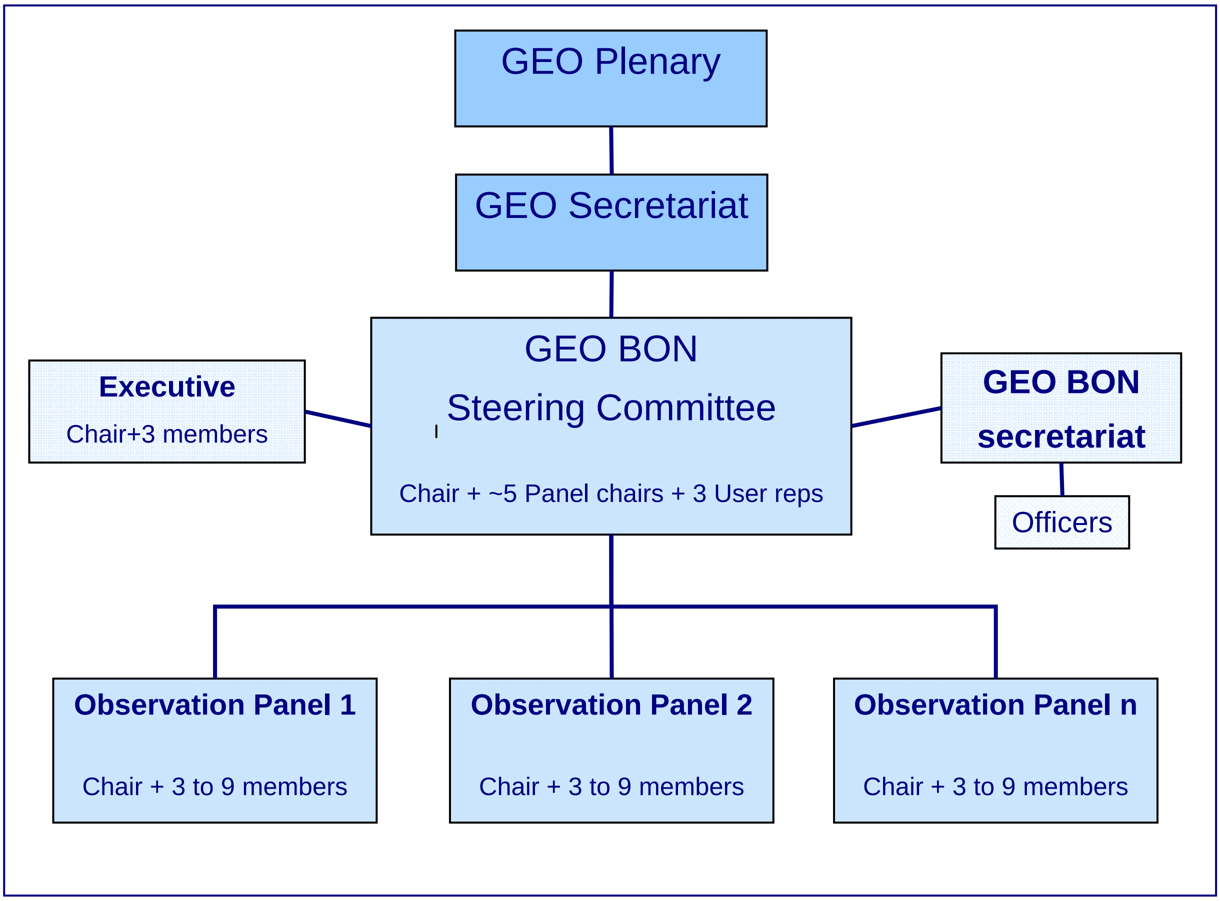

Figure 6: Tentative structure of GEO BON

3.4 Funding

GEO BON is a significant undertaking and will require significant resources over a period of years. Nearly all funds will go directly to the network participants as they continue their current activities and add new ones to help mobilize greater amounts of data, increase accessibility, and fill in gaps, gradually helping to realize the concepts described in this document. Such a distributed project (if it can be called that) does not raise or use funds in the "traditional project" manner where funds are fed into a project and project management then allocates them to the various project components. Rather, GEO BON facilitates network participants obtaining funds to support their work – which is also the work of GEO BON. In this approach participants take considerable initiative in obtaining their own funds from their current and perhaps new sponsors. However, they can use the leverage provided by the weight and integrity of GEO and its member governments and organizations to help them, with GEO BON acting as a facilitating body.

Parties to GEO are expected to be the largest contributors to GEO BON; these parties consist of governments and participating organizations, with governments playing a leading role. To start the process, GEO parties and other major organisations will be invited to a high-level commitment meeting, where they will have the opportunity to commit new resources to various network participants working on specific aspects of GEO BON. Some needed funds for the GEO BON organizing body, currently part of the GEO Secretariat with help from several organisations, can also be obtained in this way.

Recommendation

The Parties to GEO should commit to the full implementation of an integrated global observing system for biodiversity, sustained on the basis of high quality satellite and *in situ* measurements, dedicated infrastructure, and capacity building, and by working through existing biodiversity informatics and other initiatives.

3.4.1 How much will it cost?

While it is difficult to provide a detailed estimate before an implementation plan is agreed to, particularly for a dynamic and incrementally developed system such as this, the costs can be put into a useful context. Current expenditures on conservation and resource management agencies, museums and herbaria, non-governmental organisations, and local, national and international efforts only come to several hundred million US dollars per year, worldwide – a small sum compared to other large data-gathering and monitoring systems, such as climate or security. The marginal cost of implementing GEO BON – enhancing networks, increasing standardization, filling in gaps, etc – on top of these existing observation networks and initiatives would be much, much less. Furthermore, GEO BON will greatly leverage the existing investment by extracting greater societal benefits, and so provide much greater benefits relative to costs.

A. APPENDICES

A.1 GEO BON Vision and Goals

1 SHORT-TERM

1.1 Vision

The global community of biodiversity data providers and users share an open-access data resource with the best available global biodiversity data, as well as tools and resources for the integration and analysis of these data. To engage the community of data users and providers, a consultative process is underway to design, develop and implement a biodiversity observation and indicator system that meets the needs of this community.

1.2 Goals

- Agree among stakeholders on a process for the development of a global observation and indicator system, including its purpose and goals, a data and information policy, a design and validation process, and a strategy for funding and resourcing
- Integrate existing terrestrial, freshwater, and marine observation systems, using a combination of top-down and bottom-up approaches, the former drawing upon global observations and assessments and the latter upon local and regional efforts
- Identify methodological, taxonomic, regional or ecosystematic knowledge gaps and make strategic decisions about which ones to fill within the short- and long-term, using a spatially and topically prioritized and stratified sampling strategy
- Develop early products that demonstrate types of innovative products relevant to biodiversity change, based on integration of data sets
- Begin to organize the first round of global sampling of indicator taxa, ecosystems, etc. with a focus on monitoring the status of populations (abundance), species, and ecosystems through the use of a common and hierarchical reference frame
- Begin integrating modelling into monitoring to fill those gaps that cannot be filled by monitoring
- Explore the opportunities to include the monitoring of ecosystem services and drivers of change so as to establish interdependencies
- Formulate plans for the validation of observation and modelling products
- Work with the remote sensing community towards the integration of biodiversity concerns into current global and regional land cover initiatives, particularly in terms of meaningful legends for biodiversity and backward comparability
- Develop an initial strategy for global sampling of different types of indicators
- Begin integration of biodiversity concerns into current global and regional land cover initiatives, particularly in terms of meaningful legends for biodiversity and backward comparability

2 LONG-TERM

2.1 Vision

A global biodiversity observation system provides timely and relevant information on biodiversity status and functions so as to improve environmental management and human well-being. The system is open-resource, user-friendly and responsive to changing requirements, thus providing authoritative and widely respected reports and updates at appropriate intervals.

2.2 Goals

- Establish a global biodiversity observation facility and data clearinghouse, which would ensure standardized data protocols, interoperability and analyses
- Establish an independent advisory board including both data providers and users. The role of this group is to periodically review and validate the observation system, including its set of biodiversity indices. This group interacts with the management group for the system but is independent of it
- Establish a set of global biodiversity indices that are based on global, regional, national and local observation data that use modelling approaches to fill monitoring gaps, that include ecosystem services vital to human well-being, and that are widely accepted by the public, stakeholders, and decision-makers
- Develop monitoring techniques to track the paths of ecosystem services from where they are produced to where they are delivered so as to better connect ecosystem services to human well-being
- Develop techniques for using monitoring data to retrospectively evaluate the predictive performance of forecasting models, and thereby adaptively improve these models over time
- Widen the early-warning function of the system by developing forecasting scenarios that alert stakeholders to impending threats and disasters with appropriate measures of both risk and uncertainty
- Widen and improve support for local and regional capacity-building efforts on a worldwide basis, including both science-based and citizen-based observation
- Link forecasting results to decision support systems with key “tailored” products for stakeholders and partners (e.g., through the driver-pressure-state-impact-response (DPSIR) framework)
- Interact widely with governments, NGOs, media, etc. to ensure “biodiversity change” becomes recognized as a global issue in the same vein as “climate change”, with particular emphasis on making its links to changes in human well-being more visible to stakeholders and the general public

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