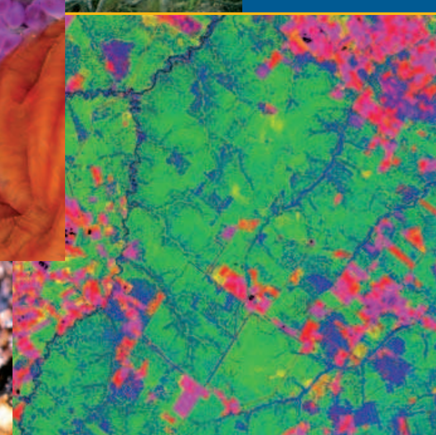
bioDISCOVERY

Assessing, monitoring and predicting biodiversity change



bioDISCOVERY Science Plan and Implementation Strategy

bioDISCOVERY

a core project of DIVERSITAS

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Approved by the Scientific Committee of DIVERSITAS

DIVERSITAS
an international programme
of biodiversity science

bioDISCOVERY
a core project of DIVERSITAS

Preface

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We are proud to have participated in the delivery of the bioDISCOVERY science plan following a long period of gestation. The initial meetings for laying the foundation for a DIVERSITAS Core Project covering the "origins and maintenance of biodiversity" were held several years ago. But what initially seemed like a reasonable piece of the overall DIVERSITAS science plan was in reality exceptionally rich and extremely ambitious. Over time, the original plan has given rise to two science plans: "bioGENESIS: providing an evolutionary framework for biodiversity science" and "bioDISCOVERY: assessing, monitoring and predicting biodiversity change". We encourage you to read them both.

Our motivation for encouraging and doing the science outlined in this document has never waned because we are convinced that the scientific community cannot continue doing business as usual if we are to slow the decline in biodiversity. We are currently faced with a very troubling situation. On one hand, the scientific community has good evidence that the decline in biodiversity is occurring at ever increasing rates, the public is sensitive to the loss of biodiversity, and decision makers have put in place national and international treaties to conserve biodiversity and ensure its sustainable use. On the other hand, there has been very limited progress in slowing the decline of biodiversity at the global scale, and in many situations the rate of decline of biodiversity is increasing. So we are confronted with several vexing questions. Can we demonstrate unequivocally that biodiversity is declining at unprecedented rates? What will be the impacts on human well-being if the erosion of biodiversity continues unabated? Why isn't science playing a more important role in decision making, and promoting stronger action for biodiversity? Putting the bioDISCOVERY science plan into action would provide a means of addressing these questions.

We hope this document speaks to the whole of the scientific community. Many scientists have participated in its conception, so we believe that this plan reflects a broad consensus concerning the steps necessary to make breakthroughs in assessing, monitoring, understanding and predicting biodiversity change. The plan of action outlined in this document is ambitious and, therefore, must rely on the mobilisation of the entire scientific community to be successful. Developing the international biodiversity science plan is the first step. But real achievement will only come from taking it forwards, and delivering on its contents. We look forward to doing so, and hope that you will join us.

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DIVERSITAS

I

DIVERSITAS is an international, non-governmental programme under the auspices of ICSU, IUBS, SCOPE and UNESCO (see side bar), that addresses the complex scientific questions posed by the loss of and change in global biodiversity. By connecting individuals across natural and social science disciplines, and across national or regional boundaries it addresses issues of global concern, thereby adding value to research projects being undertaken around the world at the national and disciplinary levels.

In accordance with the mandate developed by its sponsoring bodies, the mission of DIVERSITAS is two-fold:

- To promote an integrative biodiversity science, linking biological, ecological and social disciplines in an effort to produce socially relevant new knowledge.
- To provide the scientific basis for the conservation and sustainable use of biodiversity.

DIVERSITAS Sponsors

- International Council for Science (ICSU)
- International Union of Biological Sciences (IUBS)
- Scientific Committee on Problems of the Environment (SCOPE)
- United Nations Educational, Scientific and Cultural Organisation (UNESCO)

Scientific Core Projects

The primary means by which DIVERSITAS carries out its mission is through catalysing research aligned with its four Scientific Core Projects. Collectively, DIVERSITAS Core Projects comprise a cycle of discovery, analysis and information sharing that supports the application of socially relevant knowledge:

- bioGENESIS provides an evolutionary framework for biodiversity science, focusing on new strategies for documenting biodiversity, the causes and consequences of diversification, and evolution in relation to biodiversity conservation and human well-being.
- bioDISCOVERY focuses on developing a scientific framework to investigate the current extent of biodiversity, monitor its changes, and predict its future changes.
- ecoSERVICES explores the links between biodiversity and the ecosystem functions and services that support human well-being, and seeks to determine human responses to changes in ecosystem services.
- bioSUSTAINABILITY concerns itself with the science-policy interface, looking for ways to support the conservation and sustainable use of biological resources.

Cross-cutting Networks

DIVERSITAS also establishes Cross-cutting Networks, on specific topics or ecosystems, which embrace issues addressed in all four Core Projects:

Global Mountain Biodiversity Assessment (GMBA)

Steep terrain, extreme climates, and severe land-use pressure make mountain ecosystems among the most endangered in the world. Established in 2002, GMBA synthesises knowledge on ethical, ecological, economic and aesthetic values to tackle issues of societal relevance, including land-use management practices such as fire, grazing and erosion.

Global Invasive Species Programme (GISP)

Non-native organisms that cause, or have the potential to cause harm to the environment, economies, or human health, invasive alien species (IAS), are one of the most significant drivers of environmental change worldwide. GISP aims to conserve biodiversity and sustain human livelihoods by minimising the spread and impact of such species.

freshwaterBIODIVERSITY

Despite their critical role for basic life support, freshwater ecosystems remain poorly understood. In addition to identifying and monitoring freshwater biodiversity and its role in ecosystem functioning, this network seeks to understand how biological and social processes interact.

agroBIODIVERSITY

Examining both agricultural and plantation systems, this network promotes research on how contrasting land-use patterns affect biodiversity, ecological economics, and standard economic gains.

ecoHEALTH

This network studies the relationships between plant and animal biodiversity and (re)emergence of infectious diseases and the consequences for wild biodiversity and human societies.

Earth System Science Partnership (ESSP)

Recognising the links between biodiversity and other areas of global concern, DIVERSITAS is a founding member of the **Earth System Science Partnership** (ESSP; www.essp.org). In addition to DIVERSITAS, this partnership includes three other programmes that focus on global issues such as climate change and human impacts on the planet:

- International Geosphere-Biosphere Programme (IGBP)
- International Human Dimensions Programme on global environmental change (IHDP)
- World Climate Research Programme (WCRP)

Established in 2001, ESSP supports the integrated study of the Earth system: its structure and functioning, change occurring within the System, and the implications of change for global sustainability. ESSP currently oversees four Joint Projects.

Global Environmental Change and Food Systems (GECAFS) develops strategies to address food provision concerns while also analysing the environmental and socioeconomic consequences of adaptation and mitigation.

Global Carbon Project (GCP) investigates carbon cycles and energy systems to develop policy relevant knowledge that encompasses natural and human dimensions, as well as their interactions.

Global Water System Project (GWSP) examines how humans are altering the global water cycle, the associated biogeochemical cycles, and the biological components of the global water system, as well as human response to these changes. This project is closely aligned to freshwaterBIODIVERSITY.

Global Environmental Change and Human Health project (GECHH) investigates how environmental change worldwide affects human health and well-being, with the aim of developing policies for adaptation and mitigation. This project is developed in conjunction with ecoHEALTH.

National Committees and Regional Networks

One of DIVERSITAS' primary objectives is to create a worldwide network in support of biodiversity science that fosters integration across disciplines and establishes links at regional and international levels. Two types of bodies play important roles in the achievement of this objective: National Committees and Regional Networks.

National Committees enlarge DIVERSITAS' scientific and policy networks, thereby helping to establish crucial links between

national biodiversity programmes and international framework activities. They also make it possible to implement and, where necessary, to adapt the DIVERSITAS Science Plan to local and regional concerns. Because many issues related to biodiversity transcend national boundaries, it is often essential for several countries to collaborate in scientific research and policy development.

The knowledge and experience gained through such integrative approaches is invaluable across the DIVERSITAS network.

Capacity building

The quest to expand knowledge about biological diversity holds inherent challenges. While most species are located in tropical areas, financial resources and technical capacity are severely lacking outside the developed world. Thus, it is critically important to pursue science while also making technological advances more widely available and building the skills necessary to carry out integrative research. As far as possible, all DIVERSITAS activities will be designed to support direct involvement of scientists from all regions of the world.

II

OVERVIEW

The goal of the bioDISCOVERY Core Project of DIVERSITAS is to facilitate the development of science that addresses fundamental questions concerning current and future biodiversity[1] change:

- How and why is biodiversity changing at global, regional and local levels?
- What are future changes in biodiversity likely to be?
- How do we best communicate our understanding of biodiversity change to decision makers?
- What impacts will biodiversity change have on ecosystems and human well-being?
- How can we best conserve and sustainably use biodiversity?

This introduction provides an overview of the current status of our ability to answer these questions and outlines a strategy to improve assessment methods and to strengthen the science of observing, understanding and predicting biodiversity change. The bioDISCOVERY Science Plan focuses on providing responses to the first three questions, but also provides data and insight into the last two questions. This strategy depends on tight collaboration with the other Core Projects and Cross-Cutting Networks of DIVERSITAS, strong partnerships with all of the ESSP[2] programmes and close cooperation with new and existing bodies for assessing biodiversity (e.g., IPBES[3]) and for international decision-making (e.g., CBD[4], GEO[5]).

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What we know – The Millennium Ecosystem Assessment[6] (MA) provided strong evidence that the abundance of many species is declining, and that species distributions have been substantially altered due to habitat conversion, pollution, invasive species, overexploitation of natural resources and, more recently, climate change (99). The MA also highlighted the ways in which biodiversity is linked to ecosystem services and ultimately human-well being. Recent historical and current changes in biodiversity have been associated with a degradation of many ecosystem services, but this has often been accompanied by net gains in human well-being. There is, however, considerable concern based on current and modelled future trends that declining populations, species extinctions, shifts in species and biome distributions and the associated degradation of ecosystem services will lead to strong negative impacts on human well-being in the 21st century. There are many current situations that provide a glimpse of a future in which severe biodiversity loss and negative impacts on human well-being go hand-in-hand. For example, many coastal ecosystems are polluted and overfished to

(1) We use the term "biodiversity" in a broad sense to mean the abundance and distributions of and interactions between genotypes, species, communities, ecosystems and biomes.

(2) The Earth System Science Partnership (ESSP) is a partnership between the international science programmes on global change including the WCRP, IGBP, IHDP and DIVERSITAS as well as four cross-cutting projects on Carbon, water, food, and health.

(3) The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) is a scientific and social process to strengthen relations between knowledge holders on biodiversity and ecosystem services and actors involved in decision/policy making processes. The modalities of its functioning, funding and the location of its secretariat are still under discussion as of early 2009.

(4) The Convention on Biological Diversity (CBD) is "an international treaty to sustain the rich diversity of life on earth". It was opened for signature in 1992 in Rio de Janeiro and the secretariat is currently headquartered in Montreal, Canada.

the extent that they have shifted from relatively long, fish dominated food webs of high diversity and high value to relatively short food webs of low value. If current trends continue, the phenomenon will almost certainly become global in scale causing substantial losses of food sources and livelihoods (76).

There are large gaps in our knowledge – The MA also clearly highlighted that we do not yet have adequate data or tools to provide sound, comprehensive answers to the fundamental questions outlined above. For example, assessment methods must be improved to make them more comprehensive in their coverage and provide clearer, stronger messages to stakeholders such as decision makers, natural resource managers and the public. There are huge gaps in our knowledge of current biodiversity. Scientists estimate that only about 20% of all species have been discovered or described in any detail. The compilation of even basic information on the abundance and distribution of many species is missing. Tremendous progress has been made in developing future scenarios of biodiversity response to global change, but confidence in these scenarios must be improved through the development of more robust models, rigorous benchmarking and analyses of uncertainty.

A strategy for strengthening the science – The bioDISCOVERY Science Plan can be broken down into three foci that provide the essential elements to address the questions outlined above (Fig.1). The overarching goals of these foci are to stimulate the basic research to understand the mechanisms responsible for biodiversity change and associated modifications of ecosystem services and to provide input to policy so as to promote the conservation and sustainable use of biodiversity.

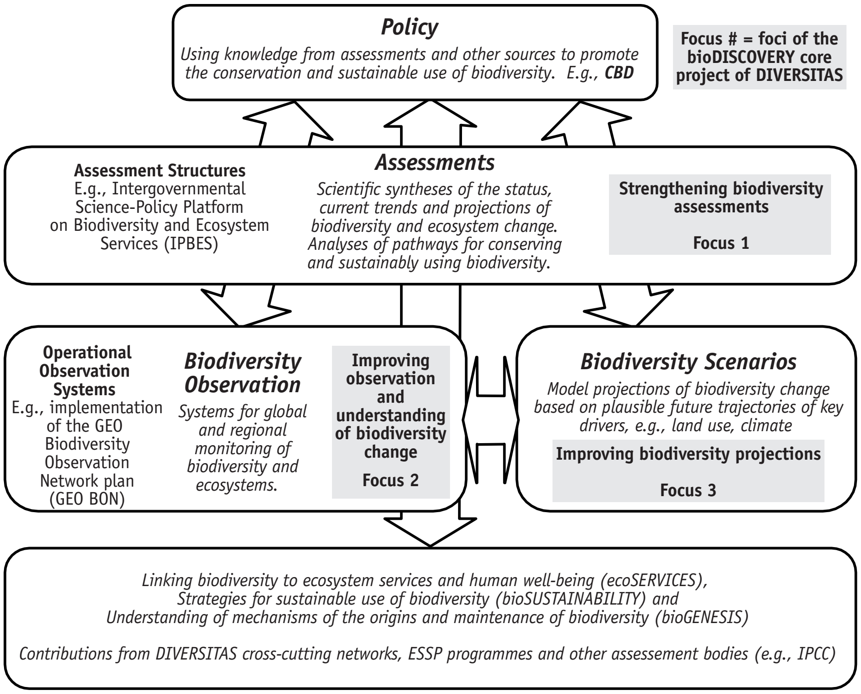

FIG. 1 Structure of the bioDISCOVERY Science Plan and its relationship to policy making, to structures for monitoring and assessing biodiversity, and to other international research programmes. The three bioDISCOVERY foci are highlighted in grey. Arrows indicate the flow of information. Note that DIVERSITAS does not pilot assessment or monitoring structures but provides the scientific foundations for their structure and operation, participates in their development, offers access to networks, etc.

[5] The Group on Earth Observations' Biodiversity Observation Network (GEO BON) aims to create a global network from local, national and regional biodiversity monitoring efforts "by linking and supporting them within a scientifically robust framework". DIVERSITAS, NASA and EBONE have "accepted the task of leading the planning phase of GEO BON, in collaboration with the GEO Secretariat".

[6] The Millennium Ecosystem Assessment (MA) was undertaken by an international consortium of scientists to synthesize the status of the world's ecosystems at the beginning of the 21st century. This assessment published in 2005 provides "a state-of-the-art scientific appraisal of the condition and trends in the world's ecosystems and the services they provide, as well as the scientific basis for action to conserve and use them sustainably".

FOCUS 1 – Strengthening biodiversity assessments. Assessments play a critical role in structuring the scientific community, synthesising research and communicating these findings to policy makers, natural resource managers, the scientific community and the public. In this context, the overall goal of Focus 1 is to promote improvements to the assessment of biodiversity across spatial and temporal scales, at different levels of biological organisation, and in terms of the various attributes, processes, and functions of biodiversity. Focus 1 also aims to further stimulate the development of relevant and robust indices of biodiversity change, and to provide a broader scientific basis for better understanding of the consequences of biodiversity change for ecosystem functioning. This work is intended to provide scientific support for a wide range of assessment initiatives, including the envisaged Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES).

FOCUS 2 – Improving observation and understanding of biodiversity change. There is a substantial amount of biodiversity data available and a large range of monitoring programmes is in operation. One of the difficulties is that these data are not readily available, are heterogeneous in terms of quality, and are incomplete in terms of spatial, temporal and taxonomic coverage. The goal of Focus 2 is to provide the scientific framework to develop systems for monitoring biodiversity change that are capable of detecting trends at various levels of biodiversity, identifying the main drivers of change, documenting the consequences for ecosystem functions and services, and pinpointing areas of greatest risk. Focus 2 will encourage the development of experiments and the comparisons between observations, experiments and models to gain greater understanding of the mechanisms of biodiversity change. Work within Focus 2 will provide scientific support for the implementation of the GEO Biodiversity Observation Network[5] (129) and regional observation networks (e.g., BIOTA AFRICA, EU LifeWatch network[7]).

FOCUS 3 – Improving biodiversity projections. Developing effective policy and adaptive management strategies in the face of global change requires that we anticipate future biodiversity change. Medium to long-range planning will depend, in part, on the use of model-based projections. The goal of Focus 3 is to increase our confidence in biodiversity projections by encouraging the development of models that better describe the mechanisms of biodiversity response to global change, by facilitating the benchmarking of model predictions using observational and experimental data, and by promoting efforts to quantify sources of uncertainty. This work will cover projections of changes in the abundance and distribution of genotypes, species, species groups and biomes, and will provide input into assessment and monitoring programmes.

Interactions between foci – All three foci depend on combinations of observations, experiments and models to achieve their goals. The three foci often rely on the same data or tools, but with slightly different objectives. For example, models play the central role in Focus 3 for projections, but


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[7] The LifeWatch network is a European Union project to construct a European platform for networking biodiversity observatories and for sharing data on-line. This project is still in the development phase. The BIOTA Africa project is described in more detail in the text of the bioDISCOVERY science plan.

these same models will be used for gap filling, understanding mechanisms underlying observed biodiversity changes, etc. in the other two foci. Particular attention will be paid to ensuring complementarity in the development and use of data and tools across the three foci.

Interactions with other DIVERSITAS projects – The work within bioDISCOVERY is designed to aid in the assessment of the impacts of biodiversity change on ecosystem services and human well-being that are the focal points of the ecoSERVICES Core Project. It will also provide knowledge that will guide policy and decision-making to implement the sustainable use and management of biodiversity that are the focus of the bioSUSTAINABILITY Core Project. The bioDISCOVERY Core Project also heavily depends on work within the bioGENESIS Core Project related to the detection and description of undiscovered species and to the development of novel methods for increasing the speed and reliability of taxonomic surveys.

This Science Plan is intended for a wide audience including the broad scientific community and stakeholders such as political and economic decision-makers, natural resource and conservation managers. Given the immense magnitude of the task, we hope this document will inspire scientists to participate in this Core Project or other projects under the DIVERSITAS umbrella.

FOCUS 1. Strengthening biodiversity assessments

Assessments play a critical role in synthesising research and communicating research findings to policy makers, natural resource managers, the scientific community and the public. In this context, the overall goal of Focus 1 is to improve the scientific basis for assessment of biodiversity research, and thereby improving how biodiversity science is brought to bear on decision-making. In doing so, Focus 1 also aims to develop more robust indices of biodiversity change, and to provide a broader scientific basis for better understanding the consequences of biodiversity change for ecosystem functioning. This work is intended to draw on, and provide scientific support for, a wide range of assessment initiatives at multiple scales, including the activities of the emerging Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES).

Focus 1 comprises four complementary research tasks that support more comprehensive and scientifically credible biodiversity assessment at multiple scales:

- Integrating heterogeneous data sources into biodiversity assessment;
- Improving the credibility with which biodiversity change is interpreted, including through the use of indicators;
- Developing scientifically rigorous novel and rapid biodiversity assessment approaches, and;
- Providing more robust evaluation of uncertainty in biodiversity assessments.


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Focus 1 will be implemented and supported by bioDISCOVERY through stimulating, guiding, and connecting multiple, small-scale assessments of biodiversity from which insightful synthesis can be drawn. This will include a balance of support provided for adopting and testing new approaches to biodiversity assessment, and encouragement for creativity in local assessment initiatives, resulting in the development of novel approaches to biodiversity assessment from which lessons learned and best practice can be derived and shared. bioDISCOVERY will also play a role in coordinating activities to develop and agree on new approaches for assessment and the presentation of uncertainty. This will include new approaches for determining priorities for assessment, and the development of representative and robust indicators and indices of biodiversity change.

RESEARCH TASKS

RESEARCH TASK 1.1 Heterogeneous data sources are integrated into biodiversity assessments

The current focus of global biodiversity assessment is on species level taxa, and within that there is a bias towards the better-known groups of vertebrates and terrestrial systems (14, 26, 95). The only taxon for which data have enabled a complete assessment of trends in the conservation status through time is birds (27). Almost nothing is known about the status of microorganisms or marine biodiversity, the global status of genetic diversity beyond a few domesticated species, or ecosystem change at global scales (31, 70, 95, 141). Despite over 40 years of satellite observation, a globally consistent land-cover change data series remains elusive. There is therefore a considerable need for improving the scope of biodiversity assessment, to integrate a wider set of data sources, and to better encompass genetic, population and ecosystem scale biodiversity. As well as a wider range of taxa, the further development of modelling approaches and scientific understanding of ecosystem functioning will support the inclusion of biodiversity interactions into assessment.

In addition to encouraging the collection and collation of further primary biodiversity data, data sets on biodiversity and environmental variables need to be better linked to enable more effective and relevant assessment. There is now considerable opportunity to connect biodiversity data through the growing number of global data clearinghouses, including the emerging GEO Biodiversity Observation Network (GEO BON) and Global Biodiversity Information Facility (GBIF) (see Focus 2), but in all cases more robust approaches are needed to ensure data are appropriately and meaningfully integrated and assessed.

RESEARCH TASK 1.2 Biodiversity change is credibly interpreted, including through the use of indicators

Biodiversity assessment would be improved significantly if a broader set of more representative indicators was available to track biodiversity change. Current global indicators of biodiversity are insufficient to provide representative measures of change – both due to the paucity of data, but also due to the methodological constraints in the use of available data. A high priority is to build on ongoing initiatives that are taking place within the context of the Convention on Biological Diversity and the European Environment Agency (32, 142) in order to develop new global and multiscale biodiversity indicators that would be useful for future international biodiversity targets, beyond 2010.

Indices are needed that are sufficiently robust, representative, and sensitive to monitor biodiversity change at global and sub-global scales, but also fulfil the requirement to communicate complex biodiversity data in an easily understandable manner to decision-makers and the public (15, 25, 103). Indicators need to be developed that monitor not just the conservation status of various taxa, but are also relevant to ecosystem functioning and services, and can easily be incorporated into biodiversity models and scenarios (see Focus 3). Further research that combines experimentation, observation, modelling, and meta-analysis of the causal links between environmental changes and changes in biodiversity, including research into the sensitivity of different taxa to change, will also lead to improvements in the capacity to develop indicators for use in early warning and integrated environmental assessment.

Despite being an extensive area of research, there are remarkably few robust generalisations about the consequences of biodiversity change for ecosystem functioning. While the need for more fundamental research remains, priority should now be given to interpreting and assessing biodiversity to be able to provide guidance to decision-makers on possible "dangerous" biodiversity changes, in an analogous manner to that assessed in climate change science (127). Considering what might constitute "dangerous" biodiversity change is a key research question that would require both consideration of the consequences of biodiversity change, and the development of robust metrics to track change.

It is likely that most biodiversity remains to be discovered, and much biodiversity is localised and rare. Determining the contributions of rare, and as yet undiscovered, biodiversity to ecosystem functioning and the resilience of ecosystems to change is also a key frontier in biodiversity research and conservation.

More comprehensive assessment of rare and local biodiversity is likely to lead to new insights into the characteristics of diverse systems, and the role of diversity in ecosystem functioning, further supporting the assessment of "dangerous" biodiversity change.

RESEARCH TASK 1.3 Scientifically rigorous, novel and rapid biodiversity assessment approaches are developed

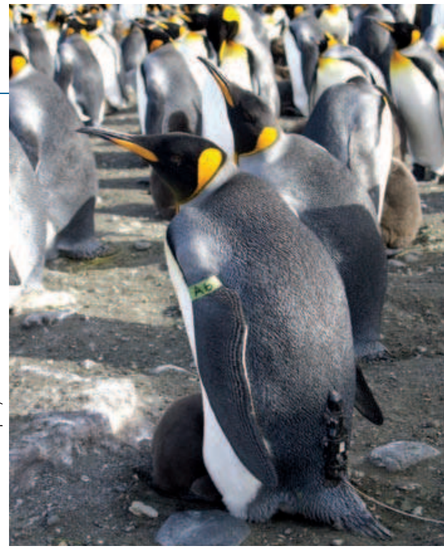
Biodiversity assessment would benefit considerably from the development, testing and validation of novel approaches. For example, there is considerable potential for developing scalable assessment approaches that would enable greater insight to be drawn from the development of networks of assessments at multiple spatial scales. This might include the development of scalable core variables and indicators, the development of common research questions, and the use of a common conceptual framework for linked networks of biodiversity assessment. There have also been recent advances in developing rapid assessment methodologies to better inform decisions in time-bound situations of high uncertainty, and in situations of resource or capacity constraints (11, 55). It is important that such approaches maintain scientific credibility if they are to be effective and useful.

To advance understanding of biodiversity and to support assessment prioritisation, a key research area is to determine how much more needs to be discovered and understood in order to better manage biodiversity. Modelling studies may contribute to both more efficient use of existing information and to identifying key gaps in knowledge. In collaboration with the assessment user community, further attention needs to be given to identifying the priorities for assessment – both in the context of global biodiversity change, and in the local values of biodiversity to people through ecosystem services.

RESEARCH TASK 1.4 Robust evaluation of uncertainty is provided in biodiversity assessments

One of the key elements of biodiversity assessment is to consider and communicate important uncertainties. There is a variety of methods by which uncertainties can be measured, allocated and communicated and these need to be applied to assessments of biodiversity status and change, as well as to biodiversity models.

New work is needed to enable the available and emerging biodiversity models to better inform biodiversity assessment. This will include assessments of uncertainties in model structure as well as data inputs and future projections and scenarios. Advancing individual techniques such as ecological niche modelling (12, 53, 67) and combining these with new mapping techniques such as gene mapping and isotope mapping (34, 35) will enable new approaches to determine the distribution and status of a wider range of taxa, and especially rare species (106). Reducing uncertainty and providing more robust measures of uncertainty will contribute considerably to strengthening the credibility and utility of future assessments of biodiversity.



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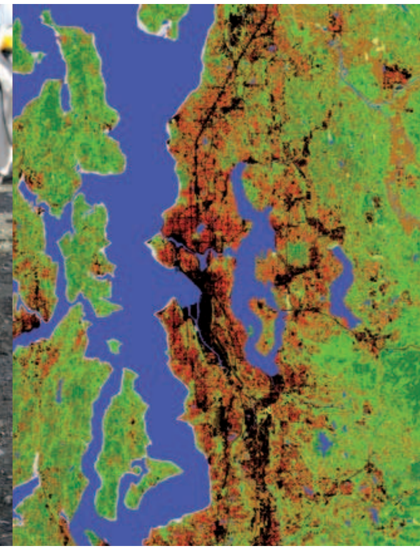

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FOCUS 2. Improving observation and understanding of biodiversity change

The goal of Focus 2 is to develop the scientific framework to enable systems for monitoring biodiversity change that are capable of:

- Measuring change of biodiversity at various scales and levels (genes, taxa, functional groups and communities, as well as structures and functions of ecosystems),
- Identifying the environmental and socioeconomic drivers of change and the consequences for ecosystem functions and services,
- Analysing the complex biotic mechanisms governing the dynamics, direction and intensity of change of biodiversity, and
- Pinpointing areas where the constellations of drivers, pressures, vulnerability, resilience, create a high risk for biodiversity loss.

One of the overarching goals of the three research tasks of Focus 2 is to improve our ability to provide robust scientific information on the change of global biodiversity by integrating existing activities and approaches in terrestrial, freshwater, and marine systems.

Various regional and global biodiversity observation schemes exist, but they are very heterogeneous in terms of what and how biodiversity is monitored and are still divided into separate terrestrial (20, 49, 66), freshwater (45, 47, 143) and marine (41, 62) systems (Box 2 .1). Focus 2 aims to bring scientists involved in these various schemes together to design strategies that integrate various monitoring activities and improve them using a combination of top-down and bottom-up approaches. For example, the top-down approach may lead to new specifications for capturing, integrating, and analysing relevant satellite observations as well as calls for new remote sensing data sets, while the possible bottom-up approach could lead to the organisation and adoption of methods for reliable 'citizen science' on a global level. Such activities will necessarily be closely linked with the activities of the global biodiversity observation network GEO BON (Box 2.2). bioDISCOVERY will play a key role in stimulating the research that feeds into the designs and methods of such global monitoring systems so as to make them operational on all levels; e.g., how to organise and analyse the vast amounts of biodiversity data that have been and will be collected. Connections to other disciplines dealing with similar data problems, e.g. health, agriculture, etc. will be made.

A second overarching goal of Focus 2 is to synthesize and interpret monitoring results in an ecosystem context. In particular, observations systems must provide more than just information on the status of biodiversity; they must place this information in an ecosystem context using extrapolations, models and expert opinions to evaluate ecosystem resilience and vulnerability and their relationships to human well-being. For example, an observation system might not just provide data showing the declining status of a fisheries stock, but could also provide data indicating possible causes (e.g., eutrophication, high fishing pressure) and documenting loss of ecosystem services. This approach will strengthen early-warning and high-risk assessments and help to ensure that data from long-term monitoring are synthesised and interpreted in ways that facilitate their use (2, 70, 74).

BOX 2.1 Examples of regional and continental biodiversity monitoring systems

For illustrative purposes, we present three different systems that are monitoring biodiversity at various levels of biological organisation.

BIOTA AFRICA: BIOdiversity Monitoring Transect Analysis in Africa

Within some of the major regions and biomes of the African continent, this project established a network of structurally comparable, standardised *in-situ* monitoring sites (Figure B.2.1) to monitor a wide variety of taxa, e.g., algae, fungi, lichens, plants, spiders, insects, and small mammals, and to combine the biodiversity monitoring with climate and soil monitoring, remote sensing, field experiments, modelling exercises, biogeographical and socio-economic studies. BIOTA AFRICA also performs capacity building, e.g., the training of local para-ecologists (18, 20, 78, 79). Data storage has been centralised, so that data are interactively available to all research groups involved in the project and made available over the internet via BioCASE (6) and GBIF (9). This international research network ultimately aims to promote sustainable use of biodiversity and conservation within Africa.

Continuous Plankton Recorder Survey

The Continuous Plankton Recorder Survey (41) based at Sir Alister Hardy Foundation for Ocean Science (SAHFOS) is a marine monitoring programme that has been collecting data mostly from the North Atlantic and the North Sea on the ecology and biogeography of phytoplankton and zooplankton since 1931. SAHFOS is unique in having comparable data on the geographical distribution, seasonal cycles and year-to-year changes in abundance of plankton over a large spatial area. Data are available in paper form back to 1931 and from January 1946 onwards in a computerised relational database, containing results from 181,262 sampled routes with more than two million taxonomic abundance entries. This unique marine biological dataset provides a wide range of environmental and climatic indicators and is used by marine scientists and policy makers to address marine environmental management issues such as harmful algal blooms, pollution, climate change and fisheries. It publishes regular reports on the status and trends of oceanic plankton as well as scientific publications on the effects of climate change, eutrophication, fisheries, non-indigenous species and weather phenomenon such as the North Atlantic Oscillation on oceanic plankton. Research is being expanded to include other oceanic regions as well.

DIWPA: DIVERSITAS in Western Pacific and Asia

Within the region of Western Pacific and Asia, DIWPA (49) maintains an international network for promoting cooperative studies and information exchange on biodiversity. Its main activities are: **(1)** promotion of international research projects, **(2)** facilitation of international citizen programmes, and **(3)** promotion of governmental and non-governmental activities for conservation and utilisation of biodiversity. Through its inventory system, DIWPA aims to improve the quality of specimens, by including DNA samples and secondary chemical compounds in addition to traditional specimens of morphology. The main inventory specimens are deposited at the core centre and duplicate specimens are stored in regional centres. Specimens and information are open to scientific research and use by industry and the public. With increasing threats to biodiversity due to global change, DIWPA is now committed to work with the major international global change programmes to understand and predict ecosystem change and biodiversity loss in the Western Pacific and Asia (including Polynesia). DIWPA also undertakes the rapid assessment of the current status and predictions of the ecosystem changes and biodiversity loss under the context of MAIRS (Monsoon Asia Integrated Regional Studies) and the ESSP (Earth System Science Partnership among IGBP, IHDP, WCRP and DIVERSITAS).

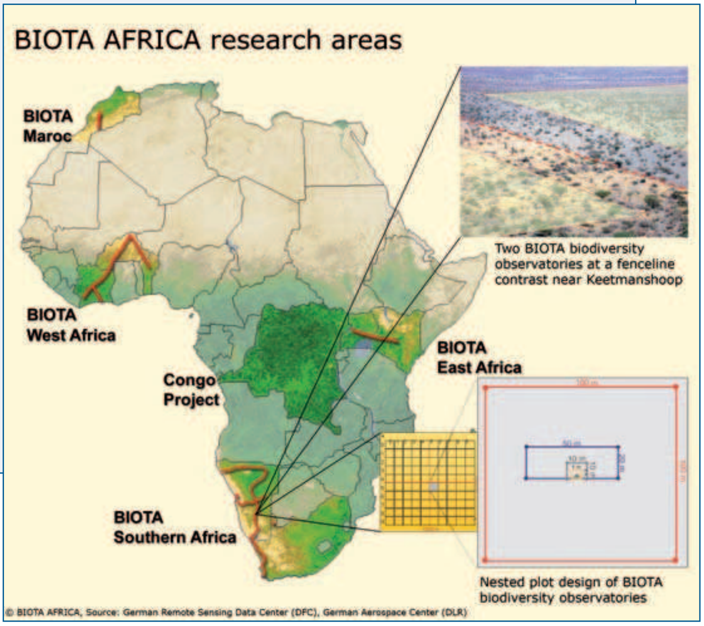

FIG. B.2.1 BIOTA AFRICA research areas: the project cooperates with about 80 universities and research institutes that form four regional networks. Each network maintains a number of monitoring sites, called biodiversity observatories, along various landscape transects. A nested plot design is maintained within each biodiversity observatory.

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bioDISCOVERY working groups will develop research tasks through various activities such as workshops and networking. bioDISCOVERY will also play an advisory role in various global monitoring institutions and programmes that are beginning to implement a vision of a global biodiversity observation system (Box 2.2 on GEO BON). Here, we focus on the science necessary to make such a system as efficient and informative as possible.

RESEARCH TASK 2.1 Biodiversity observation incorporates a broad set of measures of environmental and socio-economic drivers, biodiversity change and ecosystem services

Due to the complex role of biodiversity in the earth system, the measurement of change of biodiversity should integrate the whole cause and effect cascade starting with the causes of change, focusing on the measurement of change itself and ending up with the consequences of change for ecosystem services.

Task 2.1.1 - Environmental and socioeconomic drivers of biodiversity change are integrated into biodiversity observations

Long-term monitoring has the potential to expand its data collection to include proximate and ultimate drivers of biodiversity change, such as biogeochemical cycles, climate change, land-use change and socio-economic change (42, 52). In conjunction with two other Core Projects (ecoSERVICES and bioSUSTAINABILITY), bioDISCOVERY aims to bring together monitoring, ecosystem and sustainability scientists to link observation and monitoring to process understanding, ecosystem functioning and services, resource management and model-based projections (Focus 3). For example, a key question will be how to set up monitoring schemes that can disentangle the impacts of climate and land use change on biodiversity.

Task 2.1.2 - Biodiversity observation incorporates a broad set of measures of biodiversity

Current observation systems often provide information on a relatively limited range of levels of biodiversity. *In-situ* monitoring often focuses on taxa, morphotypes, or community types while remote sensing often focuses on functional groups or community types (often using different classifications than *in-situ* studies). One of the goals of this task is to encourage the monitoring of a broader range of levels of biodiversity in all observation systems including genetic diversity and diversity of functional traits (*i.e.*, traits of organisms that are related to their role in ecosystem function or their response to environmental change). Monitoring of genetic diversity has greatly increased over the last decade due to the development of rapid genetic and meta-genomic analysis methods. Work in close collaboration with bioGENESIS will encourage the broader adoption of these techniques in observation systems and will contribute to the development of *in-situ* barcoding instruments. Monitoring of functional traits has also greatly increased over the last decade due to standardization of methods and increased interest in linking biodiversity to ecosystem functions and services (37, 48, 88). Close collaboration between bioDISCOVERY, ecoSERVICES, the IGBP and other partners has already led to the development of a global database of plant traits for use in earth-system models (TRY network) and a generalised framework for integrating trait data for all types of organisms and linking them to ecosystem services (TraitNET, as part of the ecoSERVICES Core Project). This task will encourage the broader adoption of functional trait measurements in observation systems, and support the further development of global databases and the use of trait data in biodiversity models (Focus 3).

Task 2.1.3 - Measurement of ecosystem services are linked to biodiversity observation

Long-term monitoring has the potential to expand its data collection so that key ecosystem services are included (42, 52, 103, 108). The rationale is two-fold: to strengthen the causal link between biodiversity and ecosystem services so as to better understand the entire system, and to bolster the socio-economic arguments that biodiversity is linked to human well-being so as to inform management and policies (75, 93, 101, 132). For example, it has been shown that mapping ecosystem services can improve regional conservation planning (33, 100, 114, 123), thus protecting both biodiversity and ecosystem services. Therefore, bioDISCOVERY will foster work that combines monitoring, mapping and modelling of biodiversity and ecosystem services.

RESEARCH TASK 2.2 Interoperability between biogeographical, remote sensing, ecosystem process and population dynamics data is enhanced

Monitoring has so far embraced three conceptually different approaches: **(1)** monitoring taxa and their populations, **(2)** monitoring structures and patterns of biodiversity with remote sensing techniques and **(3)** *in-situ* monitoring of ecosystem processes. Their strengths and weaknesses are discussed in Box 2.3 . While each approach can be improved and expanded, the central scientific challenge is to integrate them by using them to reciprocally verify their results, thus strengthening the overall global monitoring effort (42, 108). The goal of this task is to foster such exchanges, particularly in the context of the development of GEO BON.

Jasper Ridge Global Change Experiment
The responses of biodiversity and ecosystem function to factorial manipulations of atmospheric CO_2 concentrations, N deposition, temperature and precipitation are being studied at the Jasper Ridge Global Change Experiment in California. This study is helping to understand the complex interactions between simultaneous global change factors **(150)**.

RESEARCH TASK 2.3 Experimental, modelling and observation data are integrated to improve understanding of the mechanisms of biodiversity change

To improve our understanding of ecosystem processes and enhance our ability to forecast biodiversity change, long-term monitoring, field experiments and ecological modelling need to be closely integrated (42, 108). One important challenge is to develop field experiments and biodiversity models (Focus 3) that will help identify those biodiversity components that are sensitive indicators or early warning systems for sudden and dramatic changes in biodiversity and ecosystem services (30, 103, 108, 135, 136). For example, early warning models for detection of population decline and extinction risk have been developed (51, 63, 81, 85, 98, 105, 113, 133), as have models of eutrophication (38), watershed deterioration (65, 80, 130), deforestation (57, 96), environmental or toxicological stress (21, 39, 59, 83), disease outbreaks (58), and species invasions (139, 147). The ability to identify negative trends and risks using models, experiments and observational data would provide substantial added value to monitoring systems.

One of the biggest gaps in our understanding of the effects of global change on biodiversity concerns the interactive influences of a broad range of natural and anthropogenic drivers. Until recently, there have been relatively few multi-factor, global change experiments that could help to disentangle these complex interactions (but see 150), but the number is rapidly increasing in terrestrial ecosystems. bioDISCOVERY will work closely with the TERACC network, the GLP and other partners to support the establishment and networking of such multifactor experiments, including in aquatic ecosystems. Such experiments will play a key role in helping to detect and disentangle the drivers of observed changes in monitoring systems.

An additional challenge is to close monitoring gaps with ecological modelling since observation systems cannot monitor everything. For example, one of the key weaknesses of remote sensing is its uncertain link to lower levels of biodiversity (Box 2.3). For example, a West African forest may still be structurally intact to the eyes of a remote sensor because it has an undisturbed canopy of healthy trees, but hunting may have completely decimated the mammalian fauna (24, 54, 145). Furthermore, forests with the most intense hunting pressures may be in zones that are very difficult to access (e.g., civil-war zones) making ground-truthing a practical impossibility. Therefore, to get a better picture of biodiversity change in such situations, we need ecological models that may use parameters such as human population, food consumption or degree of armed conflict as proxies to estimate biodiversity loss. Likewise, modelling may be needed to estimate biodiversity trends for mega-diverse taxa such as invertebrates, fungi and bacteria, where monitoring simply cannot do the job. On the other hand, models of the relationships between drivers of change, biodiversity and ecosystem services need field experiments to test the directions and strengths of causal relationships.

Biodiversity monitoring must become more inventive and encompassing, and bioDISCOVERY will foster progress by bringing together experimental, monitoring and modelling scientists. One of the crucial goals will be to integrate ecological concepts such as food webs, species interactions and community assemblage as well as conservation concepts such as metapopulation theory, minimum viable population, area selection algorithms, fragmentation and connectivity, into a spatially explicit modelling framework that draws on information gathered from all monitoring approaches (17, 63, 100, 113, 149). This effort will be coordinated with the new HEW (Humans, Ecosystem Services and Well-being) programme of ICSU, UNESCO and UNU where place-based, integrated studies will be promoted. Concepts such as ecosystem services and drivers of change need to be linked into the modelling framework to finally create an operational biodiversity model that can render regional and global biodiversity projections given various socio-economic inputs (Focus 3), thus delivering a key tool for conservation managers and policy makers (30, 108, 125).

BOX 2.2 GEO BON: A vision of a global biodiversity monitoring system

With the adoption of the international target of reducing the rate of biodiversity loss by 2010 (7, 32) and the initiation of GEOSS (10, 60), the goal of creating an internationally coordinated, globally integrated biodiversity monitoring system is supported by directly policy-relevant processes (8, 69, 92, 111, 117, 128).

DIVERSITAS and NASA are facilitating the early planning stages for the GEO Biodiversity Observation Network (GEO BON, 146). bioDISCOVERY Scientific Committee members actively support GEO BON in an advisory role. The overall vision for GEO BON includes the following processes (129):

- Technical, logistical, and institutional implementation through the long-term establishment of a global biodiversity monitoring facility and data clearinghouse, similar to the GBIF (9), which would ensure standardised data protocols, flows, interoperability and analyses (see Figure B.2.2)
- Continuous scientific research and advice by a scientific advisory committee for GEO BON that, with a mandate from both data providers and users, regularly reviews, improves, validates and endorses the actual implementation of the monitoring system, including an accepted set of biodiversity indices.

In this context, bioDISCOVERY supports that such a network combines global programmes that follow a top-down, centrally coordinated approach and regional programmes that follow a bottom-up approach (111). The bottom-up development of local and regional capacity-building enables users to monitor those aspects of biodiversity of relevance to them (19, 46, 77, 86, 121, 122, 131, 148).

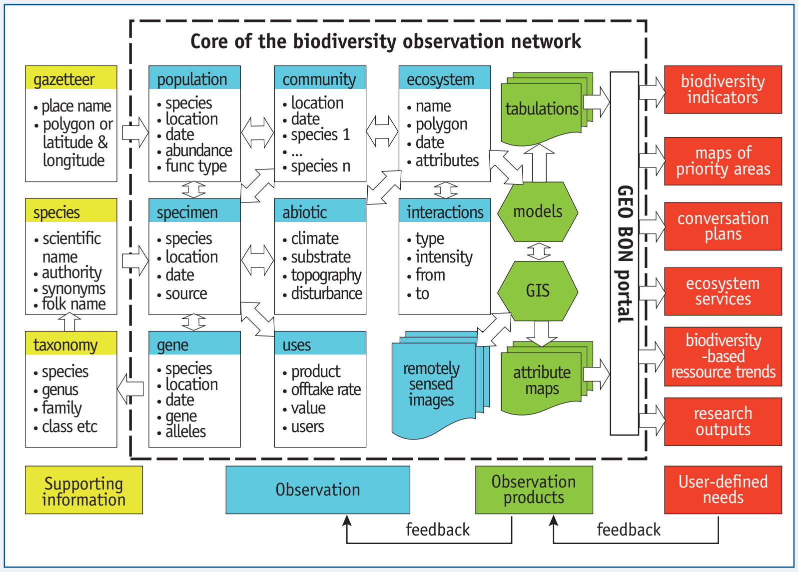

FIG. B.2.2 A schematic representation of the core set of data types, observation products and end uses of an integrated biodiversity observation system such as the envisioned GEO Biodiversity Observation Network **(129)**. Most of the elements already exist, but are incomplete or dispersed among a wide range of partners.

BOX 2.3 Three different monitoring approaches

Monitoring taxa and their populations (taxon-specific monitoring)

This approach monitors the number of individuals, populations, or species over time. Its weakness is the usually insufficient spatial and temporal resolution and the often heterogeneous quality of these data. It also provides little information on ecosystem context and drivers of change, unless such monitoring is specifically included. Moreover, most of the taxon-specific monitoring schemes are of local or regional scale, and only some of continental and a few of global scale (91, 103, 111). Its strength is the often large number of independent samples and their sometimes high temporal depth, as well as the high interest from important international stakeholders (e.g. BirdLife International, CBD, CI, IUCN, WWF, etc.) and the public in taxon-specific information, especially regarding the so-called charismatic megafauna and flagship species. Therefore, direct monitoring of these kinds of taxa will remain a high priority because they are:

- attractive to the public and thus generate more financial and political support,
- easy to monitor because they are well-known, often easy to spot and identify and therefore generate most voluntary monitoring effort, e.g., through bird watching,
- represented by relatively few species, thus require less effort than mega-diverse groups such as insects or microbes,
- amenable to monitoring even for rare species, which represent the tip of the iceberg of the extinction crisis, and
- often indicators of pristine ecosystems because of their key role in regulating food webs as top predators and/or keystone species (36).

However, mega-fauna represent a very small proportion of the world's biodiversity (102). This taxonomic imbalance should be addressed through gap analyses, and, whenever possible, monitoring should gradually expand to consider the vast diversity of invertebrate, fungal and microbial taxa that play a role in determining ecosystem services, human health and economic welfare (50).

Monitoring structures and patterns of biodiversity with remote sensing techniques over large areas

This approach uses remote sensing techniques to monitor structural properties of biodiversity or even proxy data at the level of ecosystems and/or vegetation structures. Its greatest weakness is clearly its uncertain link to lower levels of biodiversity, *i.e.* the level of genes, populations and taxa (89, 90, 112). Furthermore, remote sensing of freshwater and marine habitats is much less developed than that of terrestrial habitats. Its strengths are its almost non-existent human observer bias, its spatial resolution (down to metres) and coverage (often continuous and possibly global) and temporal resolution (conceivably down to days or even less) and length (sometimes decades). Figure B.2.3 illustrates the increasing power that new remote sensing techniques have for detecting subtle biodiversity changes in complex ecosystems. Increases in computational capacity and increasing user-friendliness of geographical information systems have facilitated their global use in making regional and global assessments of, for example, land cover and seasonal vegetation (1, 56, 57, 68, 97, 120), but successful intercomparisons over time or across systems require consistent measurement techniques and classification schemes (61, 97).

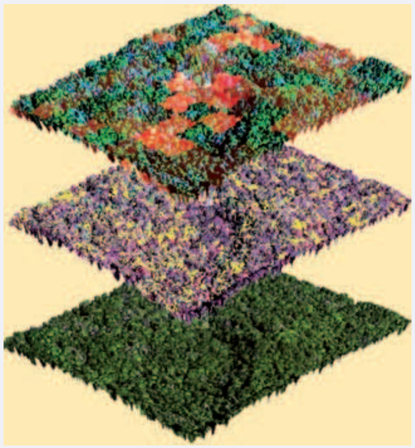

FIG. B.2.3 New "spectranomic" approaches based on advanced airborne sensor technologies, such as hybrid hyperspectral-laser systems, demonstrate that mapping of canopy species richness and abundance is possible, even in complex tropical forest ecosystems. These images were collected by the Carnegie Airborne Observatory's Spectranomics Team (http://cao.stanford.edu), showing that the 3-D chemical composition of rain forest canopies (bottom layer) reveal the presence of certain invasive species (yellow in middle layer) as well as canopy diversity hotspots (red in top layer). Reproduced with permission from G. Asner (http://asnerlab.stanford.edu/index.shtml).

***In-situ* monitoring within an ecosystem context (site-specific monitoring)**

This approach observes one or several parameters of biodiversity within an ecosystem context, usually within one or a few pre-defined sites, ranging from a small habitat patch to the size of a country. Its weakness is the often low degree of connectivity and inter-operability because sites are usually local and isolated and because a very wide variety of methods are being applied. Furthermore, high resource investment is usually required. One of the strengths of this approach is high data quality and density. Another strength is that biodiversity changes can be monitored together with ecosystem processes and services and even proximate and ultimate drivers of change. Thus *in-situ* monitoring can help answer specific research questions that are linked to conservation goals or drivers of change. Experiments used at monitoring sites can directly feed into scientific understanding of system dynamics, which in turn can be used to model biodiversity (Focus 3). Such experiments can sometimes also be used as demonstrations to illustrate to land users methods of sustainable use of biodiversity, restoration of degraded systems, etc. *In-situ* monitoring has the potential to become a powerful tool of biodiversity science as well as to expand onto the global scale, as several regional or continental monitoring systems have now demonstrated its applicability to larger spatial scales and long time periods. An example of *in-situ* monitoring, experiments and demonstrations being combined into extensive networks of sites for assessing ecosystem processes is provided by the International Long-Term Ecological Research Network (ILTER) (72, 107, 144).

A successful Global Biodiversity Observation Network will need to incorporate all three of the monitoring approaches discussed above.

FOCUS 3.
Improving biodiversity projections

The goal of Focus 3 is to enhance our understanding of future biodiversity change in response to multiple natural and anthropogenic drivers based on integrated analyses of observations, experiments and models. This understanding will be used to develop improved, quantitative projections of future changes in the abundance and distributions of genotypes, species and functional groups of plants, animals and micro-organisms as well as community and biome structure and distribution. The development of well-accepted and compelling model-based projections of the future of biodiversity will rely on:

- Developing improved mathematical models of biodiversity response to a full range of key drivers,
- Comparing observations, experiments and models to parameterise and test models (see Focus 2),
- Using well-tested models to generate quantitative scenarios of future biodiversity change that include assessment of uncertainties, and
- Coupling these scenarios to estimates of the impacts of biodiversity change on ecosystem services and economic impacts (Fig. 2).

Our efforts will focus on supporting research on the weak links in this chain of analysis, including data/model comparisons, analysis of uncertainty, and ties to ecosystem services. To address these and other issues, Focus 3 of bioDISCOVERY will promote research tasks that: 1) develop improved quantitative projections of future biodiversity change that explicitly treat multiple sources of uncertainty and 2) link projections of biodiversity change to impacts on ecosystem services and to decision making.

Monitoring fertilizer effects on wild orchids.
Counting wild orchids in a study of the long-term effects of N and P fertilizer addition on their populations in a pasture of a regional park in central France.
©P Leadley.

The development and testing of models with observations and experiments in order to provide improved confidence in projections of future biodiversity is described in Focus 2 and will require strong links will focus 1 of bioDISCOVERY and with

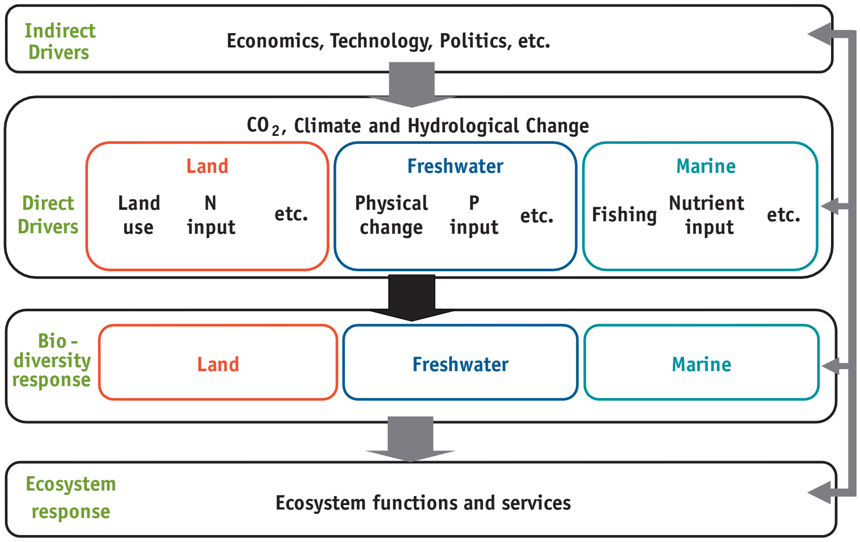

FIG. 2 Major drivers of biodiversity change and their impact on ecosystem functions and services in land, freshwater and marine systems. Research in Focus 3 of bioDISCOVERY will concentrate on studying and predicting the impact of the main direct drivers of biodiversity (black arrow). Studies of indirect drivers and of the impacts of biodiversity change on ecosystem services are dealt with in the bioSUSTAINABILITY and ecoSERVICES Core Projects of DIVERSITAS and in other ESSP programmes (grey arrows).

the bioGENESIS Core Project. The second task will require strong links with the ecoSERVICES and bioSUSTAINABILITY Core Projects.

combination with a large array of earth system models. This task outlines steps for following a similar pathway for biodiversity scenarios, while acknowledging that this is

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RESEARCH TASK 3.1 Quantitative projections of future biodiversity change are improved and explicitly treat multiple sources of uncertainty

The climate change community has been successful in generating credible climate scenarios because they have developed models that include most of the key processes influencing climate, tested their models against observed climate variation in the past and assessed uncertainty in future climate scenarios by studying a wide range of socio-economic scenarios in

an extremely challenging task because of the large number of drivers of biodiversity change and the large variety of biodiversity response models.

This task will concentrate on improving model-based scenarios of the *response* of biodiversity to natural and anthropogenic drivers (Fig. 2). Thus, the evaluation of uncertainty will require close collaboration with researchers from other Core Projects of DIVERSITAS and a number of other ESSP programmes who are working on models of the indirect and direct *drivers* of biodiversity change (Fig. 2).

Work on this task will build on several existing approaches of generating biodiversity scenarios including integrated, global scale modelling of the type done for the Millennium Ecosystem Assessment (29) or with the GLOBIO model (3), and a variety of other approaches including dynamic global vegetation models (DGVMs) (44, 84), empirical models of the impacts of habitat modification in freshwater systems (104), regional fisheries models (109), niche-based modelling (137, 138), and a variety of landscape scale approaches (40) (Box 3.1). Several tasks will be an essential part of building the next generation of biodiversity models:

Task 3.1.1 Stronger links are established with researchers developing scenarios of factors driving biodiversity change

Future scenarios of indirect and direct drivers of biodiversity change have been developed within the Millennium Assessment and the IPCC working groups, among others. The dialog with biodiversity modellers must be reinforced to ensure that the most recent scenarios of direct and indirect drivers are used in modelling biodiversity response, that guidance on the proper use of drivers is provided and that the outputs of models of drivers match the needs of biodiversity models. One example of the increased collaboration between DIVERSITAS and its partners are research projects that are currently being developed to examine the impact of extreme climatic events on biodiversity (Box 3.2).

Task 3.1.2 Emerging drivers of biodiversity such as genetically modified organisms (GMOs) and biofuels are included in projections of biodiversity change

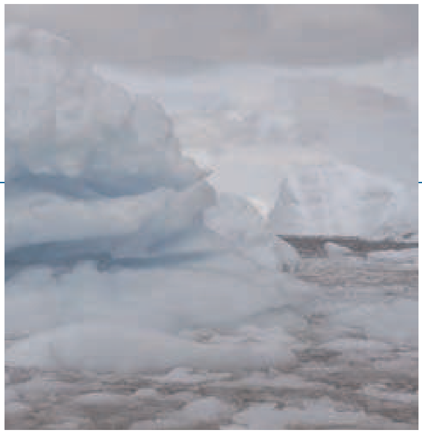
Habitat modification, nutrient loading, invasive species, exploitation and, more recently, climate and atmospheric change are generally considered to be the major direct drivers of biodiversity change (29). A number of additional factors – such as GMOs and biofuels – are emerging as potentially potent drivers of future biodiversity change. The potential positive and negative effects of these emergent drivers must be rapidly assessed and then included in biodiversity scenarios. With these goals in mind, DIVERSITAS has recently joined with its ESSP partners and SCOPE to undertake assessments of the potential impact of biofuels on biodiversity and to develop long-term research strategies.

Task 3.1.3 Treatment of uncertainty in projections is improved

Uncertainty in biodiversity scenarios has rarely been treated in a thorough manner, in part because of the difficulty in doing so. Occasionally, a wide range of scenarios of indirect drivers (e.g., greenhouse gas emissions scenarios) and direct drivers (e.g., model projections of climate change) have been explored (12, 13, 29, 110, 138). However, very few studies have focused on the sensitivity of biodiversity scenarios to the choice of biodiversity response model. Model comparison has been an essential element in improving understanding and building confidence in many areas of environmental modelling and therefore must be undertaken by the biodiversity community. A few research programmes are beginning to explore uncertainty in biodiversity scenarios using comparisons of a broad range ensemble of biodiversity response models, and bioDISCOVERY will encourage the exchange of ideas in this emerging area of research.

Task 3.1.4 Novel approaches to modelling biodiversity response are developed

No biodiversity response model currently simulates the abundance and distribution of a wide range of species or species groups to global change based on mechanisms that describe functional interactions with the environment, species interactions, mortality, migration and adaptation. All of these elements are potentially necessary to simulate the effects of global change on species loss and the impacts of changes in abundance and distribution on ecosystem services. While it is unreasonable to expect that any single model will include all of these elements in the near future, many existing models are being improved and several novel types of models are being developed (4, 82). bioDISCOVERY is currently collaborating with the GLP project to develop a new generation of DGVMs (see Box 3.1) and forest gap-dynamic models that include a broader range of species or species groups and/or improved representations of mortality and migration ("Biome Boundary Shift" initiative). This effort is strongly tied to the IGBP/DIVERSITAS Plant Functional Classification initiative, which will provide some of the key plant trait data (TRY network) necessary for the parameterisation



of these models. DIVERSITAS will also sponsor "brainstorming" workshops on novel approaches to modelling biodiversity response. In addition, coordinated efforts in Focus 3 and in the bioGENESIS Core Project aim to strengthen ties between groups working on biodiversity change at the genotype, species and functional group levels. This will include a coordinated effort with bioGENESIS to develop models that can account for rapid evolutionary responses to environmental change.

Task 3.1.5 Generalised, modular modelling frameworks are tested

A modular framework for ecosystem models that includes information about the abundance and distribution of plants or animals could substantially facilitate the development and comparison of biodiversity scenarios. As an example of such an initiative, the French ANR funded "3Worlds" project is underway with the objective of building a highly flexible, modular, spatially explicit ecosystem model with a strong ecosystem functioning and biodiversity emphasis. The fate of similar projects in the past suggests that such initiatives are high risk, but the potential gain is great, so DIVERSITAS will join with the GLP in supporting such initiatives.

RESEARCH TASK 3.2 Projections of biodiversity change will be linked to ecosystem services and to decision making

Policy makers and biodiversity managers are confronted with the task of assessing a wide range of complex tradeoffs when making decisions that may affect biodiversity: Will conservation measures for one species have positive or negative effects on others? Will the intensification of agriculture have a net negative impact on biodiversity, or will it leave more space for "natural" habitats as marginal lands are abandoned (16, 28, 64, 126)? Will increasing the use of biofuels negatively affect biodiversity at the global scale by competing for land, or will it brighten the future for biodiversity by limiting climate change (5, 36, 71, 87, 115, 116, 118, 124, 140)? Our current tools for assessing these types of tradeoffs are rudimentary. But rapid improvement in biodiversity response models will allow them to become an important aide to decision making.

Task 3.2.1 Biodiversity projections are broadened to include more emphasis on ecosystem services

Much of the recent emphasis of biodiversity scenarios has been on predicting the effects of global change on species presence or absence, species richness or the risk of species extinctions. These scenarios can be of considerable use, but explicitly linking biodiversity change to ecosystem services and human well-being will be of considerable help in guiding the development of policy and biodiversity management strategies. There is substantial work being done on modelling changes in the abundance and the distribution of species that can often be readily tied to ecosystem services. In collaboration with the ecoSERVICES Core Project, our objective is to increase the visibility of such examples via high-profile syntheses and support the broader development of such approaches.

Task 3.2.2 Stronger dialogs are established with stakeholders, especially natural resource managers

Many natural resource managers are now acutely aware of the dangers that global change may pose for ecosystem services via changes in the abundance and distribution of species. Biodiversity modellers have a broad range of models that can be used to help develop adaptive management strategies in the face of global change. However, modellers must be very careful to explain the full scope of uncertainty in their scenarios and managers should be given greater opportunity to use their expertise to identify key strengths and weaknesses in current modelling approaches. bioDISCOVERY is currently exploring funding opportunities for a series of workshops that would bring together researchers and natural resource managers from terrestrial, freshwater and marine ecosystems to share insights into the use of biodiversity scenarios as an aide in guiding decision making. This research will be at the heart of a long-term collaboration with the bioSUSTAINABILITY Core Project to develop decision tools for biodiversity protection and management.

BOX 3.1 Lexicon of models of biodiversity response to global change

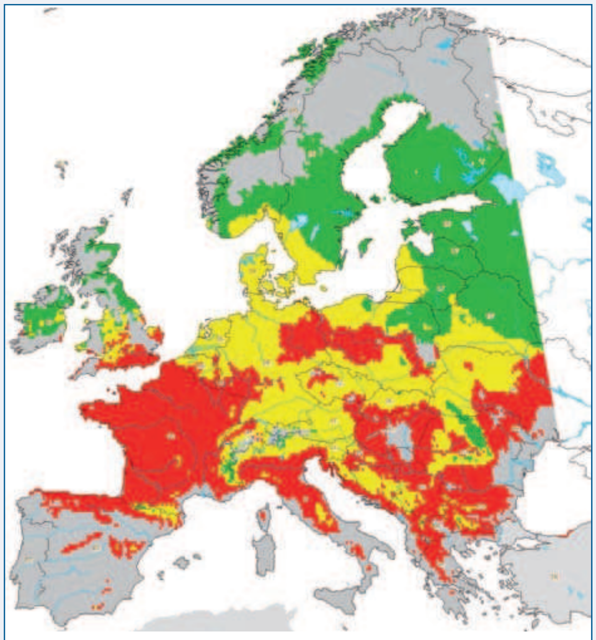
Models of the response of biodiversity to global change differ radically in their basic assumptions, their spatial and temporal scale, and the types of biodiversity that they treat (e.g., plants vs. animals, terrestrial vs. aquatic, genotypic vs. species vs. functional groups). Descriptions of a few examples of these models are given below.

Gene flow models simulate the flow of genes within and among populations (see 134 for review). These models can be combined with models of population demography to simulate the long-term viability of populations in response to human disturbances such as habitat fragmentation. More recently these models have been adapted to explore the genetic and phenotypic adaptation of species to climate change (A. Kramer, pers. comm.). Few other types of models account for the possible adaptation of plants and animals to a changing environment. These models are, however, difficult to parameterise and test for more than a few species and generally have very limited representations of the functional response of plants or animals to their environment.

Niche-based models are based on statistical relationships between spatial distributions, usually of species, and key environmental factors controlling their distribution such as temperature, rainfall, soil type, etc. (12, 53, 67, 94). The resulting model of the environmental niche can be used to simulate past or future distributions of plants or animals when combined with models of environmental drivers. This approach is powerful because it can be used for any species (or genotype, functional group, etc.) for which there are maps of their distribution and corresponding environmental drivers. Limitations of these models generally include the lack of species migration, interspecific interactions, key environmental factors controlling distributions (such as atmospheric CO_2 concentrations for plants), or adaptation.

Forest gap-dynamic models simulate the dynamics of species succession in forests using empirical relationships describing the growth and regeneration of tree species in gaps created by the death or removal of trees. These models have been relatively successfully used to reproduce past and current species composition of temperate forests and therefore are powerful tools for simulating the effects of global change on temperate tree species. They have been less successful in describing species dynamics in tropical forests where a variety of other models including "neutral" models have been applied. There are currently a variety of efforts to improve the representation of the functional response of trees to global change and to simulate mortality and migration in gap-dynamic models (119).

Dynamic Global Vegetation Models (DGVMs) are used to simulate the distribution of plant functional groups at the scales from large regions to the globe (43, 44, 84). They are based on mechanistic descriptions of plant and ecosystem functioning (physiology, competition, disturbance, mortality). The strength of this approach is that it simulates the distribution of major plant types and the functioning of plants and ecosystems, including major agricultural crops, as a function of relevant climatic variables as well as of atmospheric CO_2 and human land use. The very small number of plant functional types (often less than 10 for the entire planet) and absence of animals currently prohibits their use for directly modelling distributions of species or species richness. DGVMs have, however, been used in combination with empirical dose-response models (3) or relationships between species number and biome area to estimate changes in species richness or abundance at large spatial scales (29), and are more recently being used to provide "habitat" models for animal distributions.



Niche-based model projections of climate change impacts on European beech

Projected response of European beech *(Fagus sylvatica)* to 21st century climate change using Hadley climate model projections for the IPCC A1 emissions scenario and the BIOMOD niche-based model **(139)**.

Red = current portion of range where climate becomes unsuitable by 2080, Green = new areas where climate becomes suitable, Yellow = climate suitable now and in 2080.

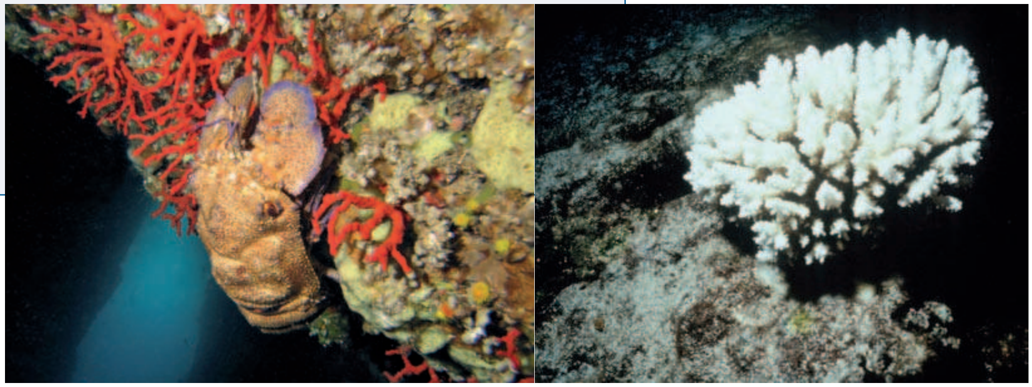
Graphics courtesy of Wilfried Thuiller.

BOX 3.2 Biodiversity and extreme climatic events

The vast majority of models of the impacts of climate change on biodiversity have focused on the effects of long-term climatic trends. There is growing concern that the occurrence of extreme climatic events such as drought, extreme ocean temperatures and hurricanes may increase in the future and that these events will play an important role in driving mortality. Examples of this include the recent episodes of severe coral reef bleaching due to extreme sea surface temperature anomalies (73) or forest dieback in temperate forests due to extreme heat and drought (22, 23). Extreme climatic events pose two challenges for biodiversity modellers.

First, extreme climatic events are difficult to model because of their very nature of being rare events in space or in time. The simulation of extreme events is an area of active research within the climate community, but much of the most recent work has not yet been used by the biodiversity modelling community. Progress in simulating the response of genotypes, species or functional groups to extreme events depends on strengthening the dialog between climate and biodiversity modellers, especially since an in-depth understanding of the uncertainties associated with models of extreme climatic events is necessary to use and interpret them correctly.

Second, many biodiversity models are not designed to handle extreme events. In particular, the statistical relationships between distribution and climate in niche-based models are typically based on long-term averages of climate and distribution making them difficult to apply to extreme climatic events. Models such as forest gap-dynamic models or DGVMs contain the mechanisms to account for some types of extreme events on trees or plant functional groups, but have very limited applications for predicting biodiversity responses outside a relatively limited number of tree species or plant functional groups. Several novel types of models are now under development that would provide the mechanisms to simulate the response of a large number of species or functional groups to extreme events.



Left: "healthy" red coral and Mediterranean slipper lobster in the Mediterranean Sea.
Right: bleached coral near the island of Moorea, Polynesia, following an extreme sea surface temperature anomaly,

III

Management Structure

The activities of the bioDISCOVERY Core Project are overseen by a Scientific Committee (SC), the SC-bioDISCOVERY, appointed by the DIVERSITAS Scientific Committee. Duties of the SC-bioDISCOVERY include:

- Engaging the international community worldwide in embracing the goals of bioDISCOVERY, and implementing them,
- Providing scientific guidance in the development and implementation of bioDISCOVERY, especially in stimulating the development of research networks and activities centred around the focal areas and tasks outlined in this Science Plan,
- Linking bioDISCOVERY activities to the other Core Projects and Cross-cutting Networks of DIVERSITAS and to other relevant national and international programmes,
- Encouraging governments, regional funding agencies and other donors to support bioDISCOVERY related research at national, regional, and international levels,
- Providing expert advice on the formulation of biodiversity policy and conservation management.

International Project Office

The activities of bioDISCOVERY are supported through the bioDISCOVERY International Project Office (IPO), currently hosted by the DIVERSITAS Secretariat in Paris, France. Along with the SC-bioDISCOVERY members, the IPO is responsible for engaging the international community in bioDISCOVERY, establish networks, coordinate activities, and monitor progress in the implementation of bioDISCOVERY worldwide. The results of bioDISCOVERY activities are communicated through reports, publications, and the DIVERSITAS website (www.diversitas-international.org).

bioDISCOVERY Activities

In its start-up phase (2007-2008), bioDISCOVERY has initiated a number of activities to start implementation.

Work on “Strengthening biodiversity assessments” **(Focus 1)** has been initiated with the preparation of a white paper by SC-bioDISCOVERY and SC-DIVERSITAS members on “biodiversity targets after 2010”. The paper will contribute to the preparation of documentation for CBD meetings planned for 2010, including COP10. In addition, SC-bioDISCOVERY members have been closely associated with the development of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES).

Work on “Improving observation and understanding of biodiversity change” **(Focus 2)** has been initiated with activities guided by SC-bioDISCOVERY members in the context of GEO BON. These have included participation in GEO BON interim steering committee meetings, in production of the

GEO BON concept document and GEO BON overview implementation document (accepted by GEO V plenary, Nov 2008), and in leading the publication of a vision article on GEO BON (129). The role of bioDISCOVERY in GEO BON is to ensure that it develops within a robust scientific framework, and that the science necessary for its implementation gets produced.

Work on "Improving biodiversity projections" **(Focus 3)** has been initiated for several of the tasks:

- SC-bioDISCOVERY members have been selected by the Secretariat of the Convention on Biological Diversity to perform a synthesis and critical analysis of existing global and regional biodiversity scenarios as a contribution to GBO-3 (3rd Global Biodiversity Outlook). The synthesis will focus on biodiversity at the biome, functional group and species levels (Research Task 3.1).
- bioDISCOVERY is contributing to an assessment of the impacts of biofuels on biodiversity in initiatives led by SCOPE and ESSP partners (Task 3.1.2).
- bioDISCOVERY is currently collaborating with the Global Land Project of IGBP and IHDP, to develop a new generation of vegetation models that include a broader range of species or species groups and/or improved representations of mortality and migration ("Biome Boundary Shift" initiative). This effort is strongly tied to the IGBP/DIVERSITAS Plant Functional Classification initiative, which will provide some of the key plant trait data (TRY network) necessary for the parameterisation of these models (Task 3.1.4).
- bioDISCOVERY will also sponsor "brainstorming" workshops on novel approaches to modelling biodiversity response. In addition, coordinated efforts with the bioGENESIS Core Project aim to strengthen ties between groups working on models that can account for rapid evolutionary responses to global change (Task 3.1.4).

In its current phase, SC-bioDISCOVERY members are committed to leading a variety of activities associated to the focal areas and specific tasks described in the Science Plan. However, the bulk of the work will be performed by scientists around the world inspired by this document.

Getting involved

There are many ways to participate in DIVERSITAS and to support the activities of the bioDISCOVERY Core Project, as an individual scientist, through the establishment or participation in a National Committee, or as a funder.

The activities highlighted above are meant only to provide examples of projects that might be carried out in connection with bioDISCOVERY. We encourage scientists to propose additional activities that support the goals outlined in the bioDISCOVERY Science Plan including:

- Proposals for collaborative research or educational initiatives,
- Meetings, symposia, and workshops, and
- Synthetic activities and products, including databases and web resources.

bioDISCOVERY also welcomes requests for the endorsement of activities that embrace its goals. Such proposals should be submitted in the early planning stages of the event or initiative. We welcome your involvement in fulfilling the mission of bioDISCOVERY!

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IV

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List of acronyms

VI

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BioCASE	The Biological Collection Access Service for Europe
CBD	UN Convention on Biological Diversity
CI	Conservation International
DGVM	Dynamic Global Vegetation Model
DIWPA	DIVERSITAS in Western Pacific and Asia
EBONE	European Biodiversity Observation Network
ESSP	Earth System Science Partnership (DIVERSITAS, IGBP, IHDP, WCRP)
GBIF	Global Biodiversity Information Facility
GEO	Group on Earth Observations
GEO BON	Group on Earth Observations Biodiversity Observation Network
GEOSS	Global Earth Observation System of Systems
GISP	Global Invasive Species Programme
GLP	Global Land Project (IGBP, IHDP)
GMO	Genetically Modified Organism
ICSU	International Council for Science
IGBP	International Geosphere-Biosphere Programme
IHDP	International Human Dimensions Programme on Global Environmental Change
ILTER	International Long-Term Ecological Research Network
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IUBS	International Union of Biological Sciences
IUCN	International Union for Conservation of Nature
MA	Millennium Ecosystem Assessment
MAIRS	Monsoon Asia Integrated Regional Studies
NASA	National Aeronautics and Space Administration
SAHFOS	Sir Alister Hardy Foundation for Ocean Science
SCOPE	Scientific Committee on Problems of the Environment
TERACC	Terrestrial Ecosystem Response to Atmospheric and Climatic Change
UNU	United Nations University
UNESCO	United Nations Educational, Scientific and Cultural Organisation
WCRP	World Climate Research Programme
WWF	World Wide Fund for Nature

Getting involved...


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The success of DIVERSITAS is directly related to the voluntary involvement of scientists and organisations from around the world. The following paragraphs briefly describe the primary means of contributing to this dynamic network of integrated biodiversity science. More detailed information is available in the **Getting involved** section of our web site: www.diversitas-international.org

as a Scientist

DIVERSITAS invites individual scientists to make the Secretariat aware of their ongoing research and to suggest ways to integrate local and international initiatives. The DIVERSITAS Secretariat, as well as the Core Project and Cross-cutting Network offices, welcome proposals for collaborative activities (research projects, workshops, syntheses, etc.) that support the implementation of the DIVERSITAS Science Plan.

as a National Committee

DIVERSITAS encourages the establishment of National Committees as a means of building a truly international network to support integrated biodiversity science. These Committees play an important role in linking national and international programmes, as well as interacting with policy makers and other stakeholders in their home countries.

as a Funder

Funding DIVERSITAS initiatives provides an excellent opportunity for individuals and organisations to demonstrate a strong commitment to conservation and sustainable use of biodiversity – issues that often have strong appeal for their own stakeholders and publics. DIVERSITAS welcomes the opportunity to collaborate with private industry, non-governmental/inter-governmental organizations, foundations and associations.

Our Mission

DIVERSITAS
is an international, non-governmental programme with a dual mission:

• To promote an integrative biodiversity science, linking biological, ecological and social disciplines in an effort to produce socially relevant new knowledge

• To provide the scientific basis for the conservation and sustainable use of biodiversity.

Collectively, DIVERSITAS Core Projects comprise a cycle of discovery, analysis and information sharing that supports the application of socially relevant knowledge. The bioDISCOVERY Science Plan complements efforts in related areas of:

bioGENESIS

Facilitating the development of new strategies and tools for documenting biodiversity, understanding the dynamics of diversification, and making use of evolutionary biology to understand anthropogenic impacts.

ecoSERVICES

Exploring the links between biodiversity and ecosystem functions and services that support human well-being; seeking to determine human responses to changes in ecosystem services.

bioSUSTAINABILITY

Looking at the science-policy interface for ways to support the conservation and sustainable use of biological resources.

ICSU
IUBS
SCOPE
UNESCO

DIVERSITAS
an international programme
of biodiversity science

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