THE ROYAL SOCIETY

Measuring biodiversity for conservation

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excellence in science

Foreword

Professor Peter Crane FRS

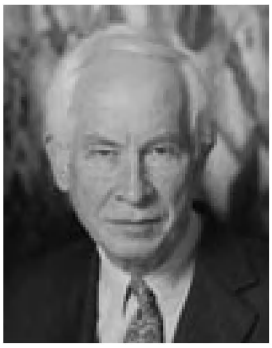
Chair of the Royal Society working group on measuring biodiversity for conservation

Nearly every week new evidence emerges of the steady erosion of life's diversity, driven by human population growth, profligate use of natural resources and the loss and degradation of habitats. Since we depend on the Earth's rich variety of life, for food, fibres, fuel, pharmaceuticals and many other goods and services – we should be concerned about what impacts these losses will have on our own species, and our prospects for the future.

This report was motivated by the recognition that science has an important role in supporting effective conservation and sustainability practices. Considerable effort is already directed toward biodiversity assessment, conservation and sustainable development. However progress is impeded by major gaps in knowledge of biodiversity. Addressing these gaps requires the scientific community to place an urgent emphasis on the synthesis of scattered data, which must also be supported by a more favourable attitude to such projects by the funding bodies. In order to better measure the loss of biodiversity, existing monitoring programmes should also be reviewed and new programmes, incorporating improved and consistent sampling methods, need to be implemented for the collection of new data. Applying the framework developed in this report would help ensure that measurements undertaken by such programmes are both scientifically sound and appropriate to the purpose to which they are being applied.

In September 2002 the World Summit on Sustainable Development in Johannesburg set down the challenge of significantly reducing the current rate of biodiversity loss by 2010. For governments charged with the responsibility to deliver against this demanding challenge, for the evolving work programme of the Millennium Ecosystem Assessment, and for the scientists, conservationists and businesses working to halt biodiversity loss, we hope that this report is a valuable contribution to the essential but difficult task of measuring the state of biodiversity.

My thanks go to all members of the working group who worked extremely hard to complete this report. We are also especially grateful to all those who contributed to the report, by submitting their views or through the consultation workshops.



Sir Patrick Bateson

Biological Secretary and Vice-President of the Royal Society

The World Summit on Sustainable Development made a commitment to a significant reduction in the rate of loss of biodiversity by 2010. How should this objective be monitored? Much work has been done in the attempt to assess the global status of biodiversity and a wide range of measures is already in use. However, debate about losses has already revealed that these measures are inadequate. Different sets of data collected over time are needed to demonstrate what is happening. Achieving this will require co-ordination and co-operation between conservation groups, academic scientists and governmental and intergovernmental agencies.

The Royal Society is keen to engage interested parties in its attempts to help monitor losses of biodiversity. A wide range of organisations and individuals are working on biodiversity measurement and we are particularly grateful to those who responded to our call for views and participated in the two consultation workshops we hosted in November 2002. I am especially indebted to Professor Peter Crane, the other members of the working group and the secretariat for the considerable effort that has gone into this report. The report provides a valuable contribution for the development of a robust and scientific foundation for the global assessment of biodiversity. It will be of use to all those involved in commissioning, funding and undertaking biodiversity measurement. I warmly commend it to policy makers, national and international conservation bodies, professional scientists and their funding bodies, including commercial, non-governmental (NGO) and governmental organizations.

Measuring biodiversity for conservation

Contents

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Preparation of this report

This report has been endorsed by the Council of the Royal Society. It has been prepared by the Royal Society working group on measuring biodiversity for conservation.

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Summary

The living world is disappearing before our eyes. Losses of biodiversity have accelerated over the last two centuries as a direct and indirect consequence of human population growth, unsustainable patterns of resource consumption and associated environmental changes. Effective methods of measuring biodiversity are needed to monitor changes in the state of nature and to measure progress towards the target, set by the World Summit on Sustainable Development, of achieving 'a significant reduction in the current rate of biodiversity loss by 2010'. No sound scientific basis currently exists for assessing global performance against this target.

Enough is already known of the distribution and drivers of biodiversity loss to indicate the scale of the problem and to provide a basis for the urgent conservation action that is needed to prevent many species from being irretrievably lost. This action must not be delayed. However without the right measures it will be impossible to determine whether rates of loss of biodiversity are declining or accelerating, and therefore impossible to demonstrate the effectiveness of mitigating actions. Good measures of rates of biodiversity loss are lacking for many parts of the world as well as for many groups of organisms. Better measures, that are cost effective and based on sound science, are crucial to help assess success in managing biodiversity and preventing further losses.

A significant impediment to the development of measures that are improved in terms of efficacy and scope is the extraordinarily limited knowledge of many aspects of biodiversity. Knowledge about the total number of species present on earth is poor, and for many of those that have been described little or nothing is known of their distribution, ecology, population size or evolutionary history. The fate of organisms that have not yet been recognised by science cannot be measured. Likewise, how ecosystems function cannot be understood until more is known about the organisms of which they are comprised. Knowledge is most limited and patchy for the very geographic areas and biomes where species diversity is greatest – principally in the tropics; and next to nothing is known of the deep sea. Understanding trends both in time and distribution of biodiversity is further hampered by the absence of reliable baseline data for most groups and habitats, as well as by inconsistencies in methodology.

Measures of biodiversity vary in scale and purpose. They extend beyond the species level to encompass entire habitats and ecosystems, and can also focus more narrowly on the details of populations and genes. No one measure is best for all purposes. A broad suite of measures is necessary to meet specific needs but the sheer multiplicity of current measures contributes to the difficulty of building public awareness and understanding. Selecting the most appropriate measure, especially at large scales, requires a careful consideration of the purpose of the assessment as well as the tradeoffs between usefulness, completeness and required effort in terms of time and other resources.

We therefore recommend that the framework, developed in this report, be applied routinely in all situations, by those commissioning, funding and undertaking biodiversity measurement. Implementation of the framework would ensure that measures are appropriate to the purpose to which they are being applied. As a result each biodiversity assessment would clearly identify: i) interested parties; ii) the attributes which those parties value and are seeking to measure; iii) the extent of existing knowledge relevant to the assessment; iv) the assumptions used in the assessment and the limitations of the measure in addressing the valued attributes; v) precisely how each measure is defined; vi) the nature of the sampling strategy used; and vii) the data gathering and analytical methods to be employed. Applying this framework would also help to identify weaknesses in current approaches, as well as highlight major science and information gaps. A series of case studies in the report demonstrates how this approach can be used in a number of circumstances, for terrestrial, freshwater and marine systems, and at the ecosystem, species and population levels.

We recommend an urgent emphasis on synthesis of existing knowledge, by those working on biodiversity. Making otherwise scattered data more readily available and more useful, for example by the use of web-based technology, requires a more favourable attitude towards such projects by funding bodies. Key gaps in knowledge, revealed by such synthesis, should be addressed by the urgent development of new programmes with realistic goals that can be completed in the next three to seven years.

Future data gathering and analytical techniques should aim to provide biodiversity information that is both relevant to interested parties and usable by other similar assessments. Enhancing the quality of baseline knowledge will facilitate the use of the framework as well as the development of more effective measures with expanded scope. Maximising the efficiency with which baseline information – including that generated by systematists – is transferred, and made useful, to conservation biologists, is especially crucial. Enhancing the level of taxonomic training, and linking such training more directly to the ongoing measurement and management of biodiversity, especially in countries where biodiversity is high, will also be essential. Combined with well-designed sampling strategies and application of new technologies, these initiatives could transform the current knowledge of changes in habitat types, patterns and

rates of delivery of ecosystem services, distributions of specific taxa and changes in population abundance.

We also recommend that new and existing programmes of biodiversity assessment focus on establishing a baseline and rate of change. Effective initiatives, that meet their goals, should be maintained and, where appropriate, expanded. Without a marked increase in funding, as well as coordination and cooperation among non-governmental organisations (NGOs), academics and governmental agencies, measuring progress towards reducing rates of biodiversity loss by 2010, the commitment of the 2002 World Summit on Sustainable Development, will be unachievable.

1 Introduction and context

1.1 The reality of ongoing biodiversity loss

The living world around us is disappearing before our eyes. Around a tenth of all the world's bird species and a quarter of its mammals are listed by the World Conservation Union (IUCN) as threatened with extinction (IUCN 2002). For less studied groups such as fish, mussels and crustacea, the proportion under threat could be as high as one or two thirds (Master *et al* 2000; IUCN 2002). Between half and one percent of the world's tropical forests are still being lost each year (FAO 2001; Achard *et al* 2002). Since the early 1980s, over one third of all mangroves have been cleared (Valiela *et al* 2001). Long-term studies indicate that wild vertebrate populations have declined in number by an average of over one-third since 1970 (Loh 2002), shark populations in the Northwest Atlantic have fallen as much as 75% since 1986 (Baum *et al* 2003), and amphibian population sizes worldwide have decreased by around 80% in 50 years (Houlahan *et al* 2000). This information is in the public domain but a systematic framework for assimilating data on the loss of biodiversity, and for assessing its impact on society, does not exist. The aim of this report is to clarify the scientific basis for measuring biodiversity in order to contribute to an international consensus on how biodiversity can be monitored.

Losses of biological diversity are being driven, primarily, by human population growth and by unsustainable patterns of resource consumption, reinforced by inappropriate economic structures and activities that maximise short-term gain, without considering long-term consequences (Raven 2002). There is broad scientific consensus that without an adequate response to the resulting pressures on natural ecosystems – loss, fragmentation and degradation of habitats, overexploitation of wild species, the introduction of non-native alien species, and climate change – biological diversity will continue to be lost at a rate that is unprecedented since the appearance of modern kinds of ecosystems more than 40 million years ago (May *et al* 1995; Pimm & Askins 1995; Wilson 1999; Myers & Knoll 2001). Action is needed now, and if conservation strategies and policies wait for perfect knowledge many species will be lost.

This section considers why these losses matter, what international and national political tools already exist to address biodiversity loss and how science must play a role in measuring change in biological diversity.

1.2 Definition

In this report we have adopted the Convention on Biological Diversity (CBD) definition of biological diversity (biodiversity), which defines it 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 (CBD Art. 2).*

Biodiversity exists as a complex web of life forms that interact with each other in an ecosystem, in a region or globally. Biodiversity drives the functioning of ecosystems through countless reciprocal interactions with the physical and chemical components of the environment.

1.3 The significance of biodiversity

Human civilisation, indeed human life on earth, is ultimately dependent upon myriads of other organisms with which we all share the planet. Our dependence on biodiversity is absolute: without it humans would not be able to survive. All food is directly or indirectly obtained from plants and other photosynthetic organisms. Apart from direct benefits of biodiversity from the harvest of domesticated or wild species for food, fibres, fuel, pharmaceuticals and many other purposes, humans also derive benefit from its influence on climate regulation, water purification, soil formation, flood prevention and nutrient cycling (i.e. ecological services); and the aesthetic and cultural impact is obvious (see Section 3, table 3.1) (Daily 1997; Balmford *et al* 2002). Biodiversity is thus fundamental for current and future social and economic livelihoods.

1.3.1 Sustainability and biodiversity conservation

A series of ethical questions is at the core of the sustainability debate – sustainability of what, for whom, for how long and why? (O'Neill 2001). For example, one approach might be to seek sustainability in the levels of well-being necessary to meet individual preferences. Another might be to seek sustainability in the options or opportunities to meet broader societal needs. The issue of equality also impinges directly on these questions. For many people greater equity in contemporary society (intragenerational equity) is an urgent priority. For others equality of opportunities between generations (intergenerational equity) lies at the heart of the sustainability debate.

In this report we take the view that, as a minimum requirement, each generation should pass on a set of opportunities no less than it itself inherited (the so-called 'justice as opportunity' proposition). Nevertheless, we recognise the fundamental tension between intergenerational equity and the humanitarian imperative of equality here and now.

Biodiversity provides substantial socio-economic, scientific, technical, and socio-cultural opportunities. These opportunities give rise to benefits that are based on diversity within and among species and ecosystems. The perspective on sustainability adopted here requires that these benefits continue to be available to future generations. Thus biodiversity conservation is essential to sustainability.

1.3.2 Direct and indirect benefits from species and ecosystems

The delivery of sustainable development objectives requires the efficient and ongoing conversion of solar energy into useful goods and services. Biodiversity fulfils this role, providing a vast range of significant use and non-use benefits, as well as essential life-support services. Examples of these benefits can be found in Section 3, table 3.1. It is estimated that 40% of the global economy is based on biological products and processes (Packer 2002). However, quantifying these benefits is not straightforward, because they are mostly not captured by conventional, market-based economic activity and analysis.

A synthesis of more than one hundred studies attempting to value ecosystem goods and services estimated their aggregated annual value to lie in the range of about \$20 trillion to \$60 trillion (10^{12}), around a rough average of about \$40 trillion (Costanza *et al* 1997, updated to 2000 US dollar value). These figures are of similar size to the total gross national product of the world (GNP). Although such estimates should be interpreted with caution, they nevertheless indicate the potential magnitude of the global ecological goods and services. At a more local level, estimates of the differences in benefit flows between relatively intact and converted versions of different biomes suggest that, despite private, often short-term, gains, the total economic value of natural systems, to society as a whole, is roughly halved following conversion to farming, forestry or aquaculture (Balmford *et al* 2002; Turner *et al* 2002).

1.3.3 Intrinsic value

It can also be argued that biodiversity has intrinsic value in and of itself. One such perspective is that all living things possess inherent worth and their interests deserve respect. From this position it is only a short, but fundamental step, to the controversial claim that all living things, individually and collectively, possess rights (see Attfield 1981; Taylor 1981; Baird Callicott 1995 for discussion).

1.4 Role of science in the conservation and sustainable use of biodiversity

In broad terms enough is already known of the distribution and drivers of biodiversity loss to indicate the scale of the problem and to guide urgent conservation action. However, there are major gaps in knowledge. For example, it is not known how much an ecosystem can be simplified but still provide the ecological services on which humans depend. Similarly, surprisingly little is known about the changing state of populations, species and ecosystems (see Section 2.1). Much of our existing knowledge has been developed opportunistically, leaving us with information that is too patchy and selective for optimal long-term planning. Improved knowledge, improved analysis and improved synthesis at regional and global levels will enhance the effectiveness of attempts to measure biodiversity for sustainability and conservation goals.

Working together with conservation practitioners, economists, lawyers and other social scientists, science has a key role to play in developing ever more effective conservation and sustainability practices.

- Scientific principles must guide the systematic and objective documentation, analysis and assessment of biodiversity as well as trends in the state of wild species, populations, habitats, and the ecological services that these organisms and systems provide.
- Both large and small-scale scientific studies are essential in establishing the causes of biodiversity losses, in identifying priority responses, and in evaluating their effectiveness.
- Scientific analyses (integrated with economic and sociological studies) are vital to developing a thorough understanding of the significance and value of biological diversity, and to the development of management protocols that enable the benefits of biodiversity to be delivered sustainably.
- New and innovative techniques, methods and discoveries from across the natural and social sciences will need to be integrated to address the complex and inter-disciplinary challenges inherent in biodiversity conservation.

1.5 International agreements and policy responses to biodiversity loss

In the late 1980s the United Nations World Commission on Environment and Development Report, *Our Common Future* (WCED 1987), introduced the concept of sustainable development as a holistic way of approaching the interrelated problems of environment and development. Subsequently, growing environmental concern culminated in the United Nations Conference on the Environment and Development (UNCED), the Earth Summit, in Rio in 1992, from which emerged the Convention on Biological Diversity (CBD). This legally binding treaty came into force on 29 December 1993 and to date has been ratified by over 186 countries. The CBD has three main objectives: i) the conservation of biological diversity; ii) the sustainable use of the components of biological diversity; and iii) the fair and equitable sharing of benefits arising from the utilisation of genetic resources (see Annex D for further detail).

Prior to the 2002 World Summit on Sustainable Development (WSSD) the CBD published the first of its periodic Global Biodiversity Outlook reports (CBD 2001). The report provides a summary of the status of global biodiversity with an analysis of progress towards the three objectives of the CBD. Much progress has been made, but the persistent challenges of implementation and development of a comparable and consistent approach to national reporting, are considerable. Uncoordinated national reporting has led to some repetition of effort and can obstruct the connection of disparate information strands into a regional or global overview.

The first Global Biodiversity Outlook report emphasised that the lack of biodiversity information was one of the major impediments, not only for reporting achievements, but also for the creation of meaningful targets against which progress could be measured. A number of initiatives have been launched in response to the lack of information, such as the Global Taxonomy Initiative (GTI) (see Annex F) and OECD's Global Biodiversity Information Facility (GBIF) (see Annex D for more detail). However inadequate focus and co-ordination of many of these global projects, combined with a lack of clearly developed and differentiated objectives, create the potential for wasteful overlap. As a result no single mechanism exists for the easy collection or synthesis of data, information and knowledge of biodiversity, or provisions for making it globally accessible.

Specific global targets for conservation (albeit for a single group of organisms) were set for the first time in April 2002, when the parties at the Conference of the Parties (COP 6) of the CBD, adopted the Global Strategy for Plant Conservation. This initiative is important, along with other new approaches such as the ecosystem approach for integrated implementation, but their goals will not be realised without adequate resources and improved co-ordination.

Taken as a whole, the situation with respect to biodiversity loss has not improved markedly since 1992. In recognition of this continuing challenge, a key outcome of the WSSD in Johannesburg in late August and early September 2002, was the commitment to:

> *Achieve by.2010 a significant reduction in the current rate of loss of biological diversity.*

The Summit implementation plan (United Nations 2002) stresses that this would need to be achieved through more efficient and coherent implementation of the three objectives of the CBD alongside the importance of supporting initiatives, such as the GTI. However, while stressing the importance of the CBD and related agreements, and despite establishing significant Government, NGO and business partnership initiatives, the WSSD did not develop explicit mechanisms to reduce the loss of biodiversity. Indeed no agreement exists on the best ways to measure the rate of biodiversity loss (Annex D).

Measurements and indicators are needed urgently to help scientists and policy makers assess whether the WSSD goal is being met. In other environmental arenas, for example in reducing the use of chlorofluorocarbons (CFCs), agreed measures and indicators have made it easier to assess the impact of global remediation strategies. Similarly, measurements of carbon emissions are the basis for international treaties and reduction commitments, based on the work of the Intergovernmental Panel on Climate Change (IPCC), an internationally recognised body comprised of the world's top scientists and economists in this field.

The Millennium Ecosystem Assessment project (MA), launched in 2001, in which the Royal Society is actively participating, will assess the ability of ecosystems to meet the needs of people through the provision of goods and services. The Assessment will seek to support environmental decisions by responding directly to requests for information from intergovernmental conventions, governments, industry and society. The status of ecosystems will be assessed at many spatial scales (local to global) through a series of assessment reports to be distributed to policy makers (Ayensu *et al* 2000). Being based on international scientific consensus, reports from the MA have the potential to provide an authoritative assessment of the status of the world's ecosystems in the same way as IPCC reports do for climate change.

Without the awareness, participation and commitment of business and society, policies developed to combat biodiversity loss and habitat decline will not be successful. Current political best practice is becoming more competent in engaging all sectors earlier in decision-making processes, and also in making better use of the breadth of resources and experience found outside of government. For example, many NGO-led initiatives in the area of biodiversity management are now taken up and used by governments.

Industry and various businesses are starting to understand the concepts of sustainable resource use and the potential commercial value of biodiversity, both as a resource and in terms of generating consumer goodwill. In some cases, business has taken the lead in creating biodiversity action plans and developing indicators to measure and limit the impact of their activities. The global coverage of many businesses means that much could be achieved by promoting conservation as an integral part of their activities, and in some countries the potential beneficial impact of such an approach may outweigh that of national governments. It is therefore vital that responsibility is taken and that partnerships are forged in these areas.

For governments charged with the responsibility to deliver the biodiversity commitment made at the WSSD, for the evolving work programme of the MA, and for the scientists, conservationists and businesses working to halt biodiversity loss, improvements in measuring the state of biodiversity are essential.

Coordination is also needed among the range of national, international, NGO and business led initiatives underway to measure and monitor biodiversity, so that practitioners have a common approach and can develop the information base needed to achieve global conservation and sustainability objectives.

1.6 Overview of the Report

The primary aim of this report is to provide a scientific contribution to the development of an international consensus on how biodiversity is assessed. Such a consensus will be vital if significant progress is to be made – and measured – by 2010. Because there are so many existing and potential ways of measuring biodiversity, commenting on them individually in this report is impractical. Instead, we propose a conceptual framework for biodiversity assessments that seeks to enhance effectiveness by clarifying goals, constraints and underlying assumptions. The framework will also help ensure that the information gathered from individual assessments can be added to the overall wealth of biodiversity knowledge. It can also be used to highlight scientific and knowledge gaps, and to identify priority areas where further research is required.

Many national and international conservation bodies, scientists, individuals, companies, governmental and non-governmental organisations (NGO) already make diverse and important contributions in the areas of biodiversity assessment, conservation and sustainable development. We are grateful to the representatives from many of these organisations who provided valuable input into this study. Our initial call for written submission was met with 52 responses. This was followed by a consultation workshop in November 2002 with UK and international academics, policy makers and representatives from conservation and NGO organisations. A further smaller meeting was held in December 2002 with representatives from the UK Statutory Conservation bodies. We are also grateful to those individuals who independently tested the framework and submitted worked case studies. A full list of the contributors can be found in Annexes A, B and C. We hope that this report will be of interest and value to all those who have contributed to its development, as well as the many other parties concerned with the sustainable utilisation and conservation of biological diversity.

In the following section, some of the challenges inherent in measuring biodiversity are discussed. We also highlight several areas in which we believe progress is necessary to provide a broader foundation of knowledge on which biodiversity assessments can be made. In Section 3 we present the framework for measuring biodiversity. This is followed in Section 4 by a series of case studies that illustrates how the framework is used. Finally, in Section 5, we offer our conclusions together with a short list of recommendations to be implemented now.

2 Progress and challenges in measuring biodiversity

2.1 Progress towards measuring biodiversity

Many countries now have National Biodiversity Strategies and Action Plans, which help monitor status and changes in biodiversity at national scales. For a few groups of organisms in some places, very good knowledge of current status and certain recent trends at the species level exist. For example, changes in distribution over time of vascular plants in Britain in 10 km^2 grids are known (Table 2.1; Preston *et al* 2002). Similarly, for many species of British birds, accurate time series of population numbers are available (Gregory *et al* 2002). Some countries also have useful measures of abundance for other taxa, such as commercially exploited fish species. These kinds of information enable the identification of threatened species and provide a basis for policy development and management action.

There has also been good progress with technical approaches that have increased the amount and utility of data relevant to biodiversity measurement. For example, satellite data have helped increase awareness among the public and policy makers of the scale and magnitude of habitat loss and transformation. Compilations of observational and specimen data and their manipulation and analysis in electronic databases have also permitted an improved understanding of current status and change in biodiversity in some countries, such as Mexico and Australia. Some progress has been made at the global level for certain well-known groups of organisms, such as mammals and birds. These assessments have helped establish large-scale priorities for conservation.

Advances in molecular biology have facilitated genetic analyses at the level of populations, which are now used routinely for a variety of conservation-related purposes. Examples include *ex situ* breeding, translocation and reintroduction programmes, assessment of diversity for difficult groups such as protozoans, bacteria and fungi, and monitoring trade and international agreements.

Considerable progress has also been made towards supplementing subjective assessments of species threat status with more quantitative assessments, where the data are sufficient. An example is the quantitative criteria being used by the World Conservation Union (IUCN) to assess global threat status of species, which have been adopted or modified by many other organisations for smaller-scale assessments. Considerable advances have also been made in developing explicit measures of uncertainty in estimates of species status and trends. A further positive development, of recent years, has been that the context of biodiversity measurement has broadened to include more consideration of ecosystem-level approaches to complement the long-standing species-level emphasis.

In addition, the ability to capture and utilise large quantities of useful information collected by non-specialists has been enhanced. Examples range from censuses of birds, butterflies and dragonflies in the UK to the use of parataxonomists to collect data in Costa Rica. In the UK and elsewhere, direct involvement of amateur naturalists in the Biodiversity Action Plan (BAP) process is becoming more widespread (for example, the British Bryological Society's Survey of the Bryophytes of Arable Lands; www.rbg-web2.rbge.org.uk/bbs/).

Good data sets have the potential to inform environmental policy. Two examples illustrate this. The first is the UK Wild Bird Index produced for Department for Environment, Food and Rural Affairs (DEFRA 2002) by the Royal Society for the Protection of Birds (RSPB) and the British Trust for Ornithology (BTO). The UK government uses this index as one of 15 headline indicators for sustainable development. Together these indicators are intended to form a barometer for 'quality of life' and measure everyday concerns about health, wealth, services and jobs, but also include wildlife. Published since 1998, the UK Wild Bird Index includes data on 139 common bird species from which regional and national data sets are derived with separate indices reported for farmland and woodland species. Farmland species show a deteriorating index, with the majority of species declining (Figure 2.1). Some woodland species are also declining, for reasons that are very poorly understood. The farmland bird index has undoubtedly been influential in the debate concerning the relationship between agriculture and environment.

A second example is the Living Planet Index, a periodic update on the state of the world's ecosystems produced by the World Wide Fund for Nature (WWF) (Loh 2002). The index is derived from trends over the last 30 years in hundreds of vertebrate species, and is calculated separately for forest, marine and freshwater species. During the period 1970–2000 the index fell by 37%. Of the three ecosystems, freshwater seems to be the most heavily impacted (Figure 2.2). The power of the Living Planet Index is potentially great since it is based on undisputed population level data. Its potential to influence decisions is limited by the availability of population data (which are especially limited in the tropics) and the speed with which the data needed for the index can be gathered and compiled. Nevertheless, this is an excellent example of how indices could and should be developed and presented (Loh 2002).

Figure 2.1 Mean population sizes of Britain's commoner breeding bird species, 1970–2000; species counts are standardized to a value of 1 for 1970, and then averaged across all species in a category (data from DEFRA 2002, re-drawn from Balmford et al 2003).

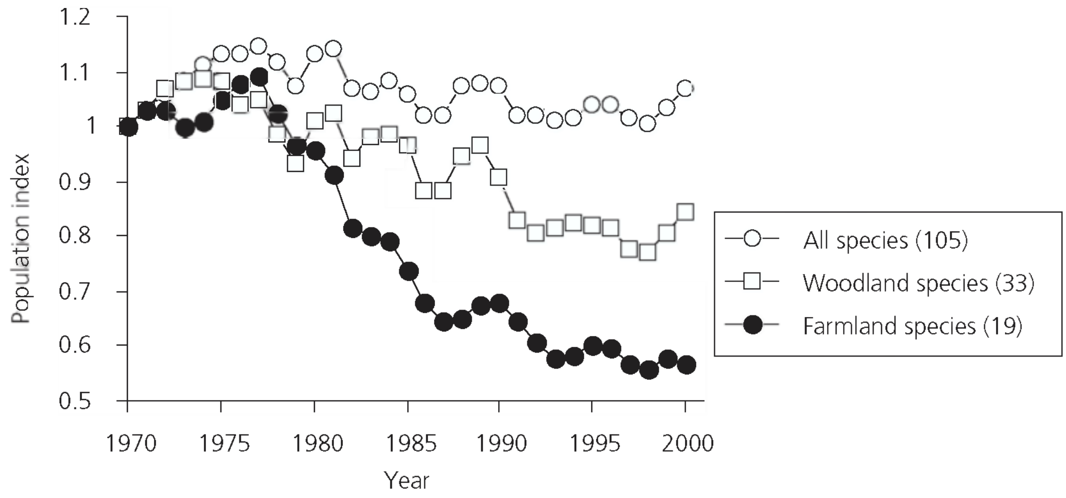
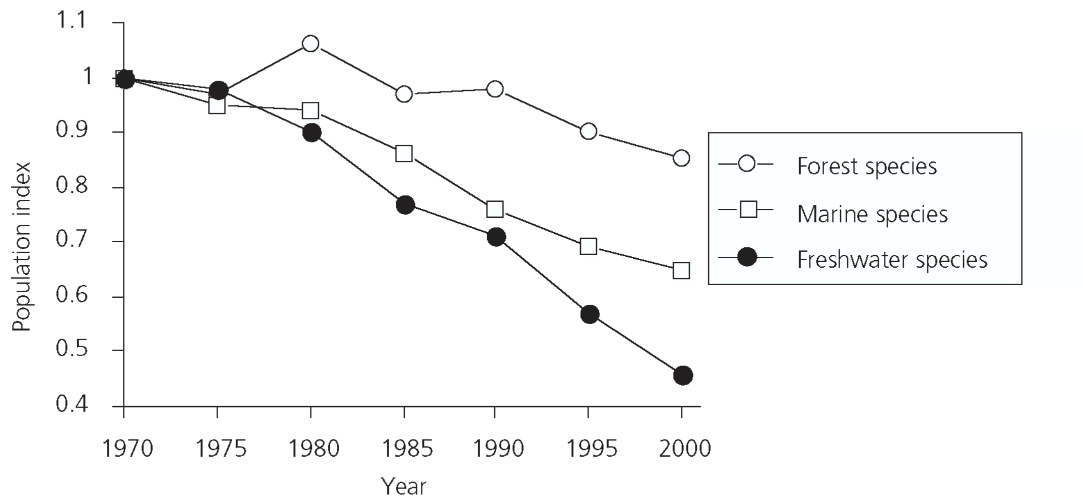


Figure 2.2 An index of vertebrate populations for forest, freshwater and marine biomes, 1970–2000; the index is based on 282, 195 and 217 populations, respectively; counts are standardized to 1.0 for 1970 and then averaged across all species in a category (data from Loh 2002, re-drawn from Balmford et al 2003).



2.2 Challenges

From the above, it may seem that the currently available data and assessments of biodiversity are adequate to underpin future management and policy development for sustainable development. Yet this is far from true. Alarming gaps remain in the data, where it is either absent, very limited or biased. Comparison between levels of detailed knowledge for vascular plants in Britain and the severe lack of information for the globally much more significant flora of Madagascar illustrates this point (Table 2.1). However, even in the UK, knowledge about the biodiversity of some groups of organisms, such as fungi, is critically inadequate. In contrast, other taxa such as birds have been well surveyed in many countries, and are relatively well known on a global basis, including in tropical regions where they are at their most diverse.

To demonstrate further the extent and nature of our ignorance, we list here five categories of information deficiency that we consider to be especially crucial.

2.2.1 Poor knowledge of biodiversity at the species level

Today the total number of living species named and recorded has been estimated at around 1.7 to 1.8 million. This number is uncertain to within 5 to 10%, because no centralised catalogue yet exists.

For some better-known groups, most notably birds and

Table 2.1. Comparison of biodiversity information available for vascular plants in the UK and Madagascar – two island nations with very different levels of biodiversity and associated knowledge.

VASCULAR PLANTS: UK	VASCULAR PLANTS: MADAGASCAR
Area: 234, 410 km^2	Area: 587,040 km^2
Total number of species: 1,403 (+1,600 non-natives)	Total number of species: 9,345–12,000
Endemic species: < 4%	Endemic species: > 80%
Biodiversity Action Plans in place for critical species	No Biodiversity Action Plans in place
Species of conservation concern identified	Most species of conservation concern still to be identified
Population genetic data available for species of particular conservation concern	Little population genetic data available for any species
Abundance at population level known for species of conservation concern	Very few species for which abundance at population level is known
Extinction rate – at national level – known	Extinction rate – at national level – unknown
Immigration rate of exotics – known in broad terms	Immigration rate of exotics – unknown
Phylogenetic relationships among species being addressed	Phylogenetic relationships among species not addressed
Ecology and physiology of some species known in some detail through Biological Flora accounts[1]	Ecology and physiology known for very few species.
Distributions of all species mapped to 10 km squares in 1960 and again in 2002	Distributions of few species mapped in detail. Herbarium specimens provide most useful data.
DNA of almost all species in DNA Banks – some sequencing of some genes for many species – DNA IDs feasible but not necessary	DNA of very few species in DNA Banks – little sequence data available – DNA IDs not feasible.
Almost all species protected *ex situ* in seed banks	Few species protected *ex situ* in seed banks
Species inventory complete – new species added only rarely – generally aliens.	Species inventory incomplete – new species discovered frequently – generally natives.
Many specimens of most species in preserved collections.	Few specimens of most species in preserved collections: many species presumed not represented

mammals, global level catalogues exist, but more than half (roughly 56%) of all known species are insects, for which few comprehensive catalogues are available. By one estimate, around 40% of all named beetle species are known only from one site, and many from only one specimen. The amount of current taxonomic effort varies very widely from group to group, with about one third of all taxonomists working on vertebrates, another third working on the roughly 10 times more numerous plant species, and the remaining third working on invertebrate animals, which outnumber vertebrate species by at least a factor of 100 (Gaston & May 1992).

Estimates of the total number of species listed are further hampered by changes in the concepts of species limits and by problems of synonyms – the same species inadvertently given different names by different people. Estimates of the proportion of synonyms have been put at about 20% (Hammond 1995; Solow *et al* 1995), but may actually be about 40% (Solow *et al* 1995). For seed plants synonyms may be as high as 56–78% (Govaerts 2001; Scotland & Wortley 2003). Deliberate accounting for the effect of synonyms would put the current global total of different eukaryotic species (including plants, animals and fungi) that have been named and recorded at around 1.5 million (May 1999).

The true total number of extant species, as distinct from those that have been named and recorded, is hugely uncertain. One recent survey of surveys – emphasising the evidence and uncertainties – gives a plausible range of 5 to 15 million extant species, with the best guess toward the lower end of the range (May 1999). Other estimates range from as low as 3 million to as high as 100 million, the uncertainty in this number being dominated by insect totals.

Knowledge of the totality of species on Earth is therefore very poor. Even using a 'low' estimate of about 7 million

[1] Biological Flora of the British Isles. Currently published in *The Journal of Ecology* by the British Ecological Society & Blackwell Science

living species, means there are between three and four undescribed species for every one currently known. For those species that have been described and recorded, knowledge is often very inadequate. For many, only a brief morphological description based on a single specimen exists, with no information on distribution, habitat, ecology or past or current population levels.

2.2.2 Poor knowledge of geographical areas and biomes

The deep sea covers two thirds of the planet yet all of our quantitative knowledge of the communities of the deep sea floor comes from samples with a combined area of a few football fields (Paterson 1993). Less than one millionth of the deep sea floor has been touched upon by biological science and every mission brings forth new discoveries, such as entirely new habitats around methane seeps, and the previously unappreciated extent of cold-water coral reefs in offshore waters of countries like Britain (Freiwald *et al* 1999).

Of approximately 500 species of carabid beetles known from southern South America, 30% are known only from one locality. Inventories in Amazonian forests still yield at least one new plant species for every 100 specimens prepared, and equivalent figures for west-central Africa may be as high as 5%.

From what is known about certain groups, the tropics contain many more species than temperate areas, but this may not be true for certain groups of invertebrates and microorganisms. Our knowledge of ecological principles and trends are very biased towards studies of relatively simple, temperate communities. Nearly 90% of forest species population trend data in WWF's Living Planet Index (see Section 2.1) derive from studies in temperate regions.

2.2.3 Poor knowledge of current status of biodiversity

Assessments of conservation status have been made for up to 10% of described species, and an uncertain percentage of all species (IUCN 2002). The extent of these conservation assessments is highly skewed across groups, ranging from close to 100% of birds and mammals to less than 0.1% of insects. The available species-level conservation assessments are also skewed geographically, with complete or near-complete coverage for some groups in temperate regions contrasting sharply with very low percentage coverage for tropical regions where biological diversity is high but scientific capacity is often not well developed. This geographic bias produces clearly anomalous results, such as the US appearing to have nearly three times as many endangered species as Peru. Conservation assessments for tropical plants are available for only a fraction of the very large number of species in tropical countries.

Even for our closest relatives, the two species of chimpanzees, current estimates of global population sizes vary by a factor of two (Butynski 2001). Global estimates of threatened plant species, extrapolated from endemism data, range from 22 to 74% (Pitman & Jørgensen 2002), two to four times as high as the figures reported by the World Conservation Union (IUCN 1997). The least thoroughly assessed group of vertebrates is the freshwater fishes, yet these appear to be among the most threatened (IUCN 2002).

Since conservation assessments depend on distributional and population information, any attempt to increase the proportion of species for which formal assessments are available is likely to be impeded by the limited knowledge of biodiversity (see Section 2.2.1). A particular concern is that in any group of organisms, common and widespread species are more likely to be discovered and described than scarcer ones. Many of the species as yet undiscovered and undescribed have very restricted distributions and are thus more likely to be vulnerable to extinction through habitat loss. Thus it is expected that the proportion of species considered as threatened will rise as our knowledge of the earth's biota increases.

2.2.4 Poor knowledge of trends in the state of biodiversity

In general, knowledge of trends in biodiversity loss is hampered by the absence of reliable baseline data for most groups of organisms as well as habitats. For example, global assessments of changes in habitat extent since the 1992 UNCED Summit have been conducted for just four out of 14 major biomes (temperate and tropical forests; mangroves; and seagrass beds). No reliable global estimates have been published of recent rates of change in the quantity of freshwater swamps, lakes and rivers, estuaries, continental shelf habitat, rock and ice habitats, grasslands, deserts or tundra (Jenkins *et al* 2003; Balmford *et al* 2003).

Despite over 20 years of data compilation, recent estimates of rates of loss of one of the biomes best studied with respect to changes in extent – tropical forests – still vary by a factor of two (FAO 2001; Matthews 2001; Stokstad 2001; Achard *et al* 2002).

Coral reefs have long been acknowledged as one of the earth's most important habitats, in terms of both species richness and the delivery of ecosystem services to people. Even so, no reliable global estimates exist of recent rates of change in their area, though assessments have been done of the levels of risk from various adverse impacts (Spalding *et al* 2001).

Of those species whose conservation status has been assessed, less than 10% are the subject of any sort of ongoing monitoring, even for birds, the best-known group of organisms globally. Good population estimates exist for less than 30% of threatened bird species (BirdLife 2000) and it proves surprisingly difficult to trace the status of individual species back through time. Routine reassessments are still dominated by changes due to new knowledge (or past errors) rather than genuine changes in status. For example, between 2000 and 2002, three of the 14 changes in conservation status of bird species, were due to genuine alteration in status of populations (IUCN 2002).

2.2.5 Poor knowledge of ecosystem services and the link to biodiversity

Services such as nutrient cycling, carbon sequestration, or stream flow can be some of the key products of biodiversity. Available data on the economic value of ecosystems and their individual components generally relate to contributions at given locations and points in time. Very little is known about the transformation of relatively pristine habitats into degraded forms and the consequent gains and losses in human welfare. Of particular importance to sustainability is the distribution of welfare changes within communities and across societies as a result of habitat change, but again information in these areas is currently deficient. Such information and analysis of the impacts are needed to guide choices about ecosystem management.

2.3 Problems with existing measures and their application

There is a vast range of biodiversity measures already in use. Such variety is inevitable, given the great breadth inherent in the concept of biodiversity (see Section 1.2), and also the range of spatial, temporal and taxonomic scales across which measurement is useful. Many existing measures are well designed and informative. But, very often, existing measures are inadequate for purposes beyond those for which they were specifically designed.

Many measures are only available for a small and often unrepresentative subset of species, habitats or areas, or span too short a time period to provide meaningful information about temporal trends in status. Groups of organisms that are especially poorly known include most species from the tropical regions and in the deep sea, invertebrates, protists (microscopic unicellular eukaryotes) and fungi.

It is often necessary to make do with data that were collected for very different purposes than biodiversity assessment. For example, in Europe most data on commercial landings of skates and rays do not distinguish between species. While this may be adequate for providing an overall picture of the health of skate and ray fisheries, it hampers attempts to monitor individual species that may be endangered (Dulvy *et al* 2000). Similarly, in using data from museum collections to assess geographic distribution, it is important to separate patterns that reflect collecting activity from those that reveal the underlying diversity distribution (Nelson *et al* 1990).

Shortcomings have in turn been compounded by a lack of clarity about exactly what particular data sets reveal. For example, attempts to assess changes in global forest cover have sometimes ignored the differences between primary (undisturbed) forest, commercial forestry and secondary (regenerating) vegetation. Similarly, catch-per-unit-effort data in fisheries sometimes provide more information about the behaviour and efficiency of fishers than about the populations of fish that they are catching.

Many aspects of biodiversity, including some of those of greatest interest to local stakeholders, are scarcely being assessed at all. Opinion about the most important aspects of biodiversity to measure also varies greatly. For example, while many stakeholders are interested in the delivery of ecosystem services, only five out of 300 recent studies into their value provide substantial data on the central question of how both direct and indirect benefits change when intact habitats are converted to other forms of land use (Balmford *et al* 2002).

Attempts to improve the quality, extent, coverage and coordination of biodiversity assessment and analysis will cost money, yet no large-scale mechanism is in place to support such initiatives. For example, many organisations hold biodiversity data relevant to assessing change, but the incentive to combine these data sets is frequently over-ridden by local concerns. Similarly, regional and global projects could be delivered through the Convention on Biological Diversity, but this depends on the political will of the Parties involved. Action through the Convention often focuses within national boundaries, making it difficult to organise global databases and overviews. The value systems in place in much of academia can also inhibit data sharing and free access, and incentives to focus on pure rather than applied research may limit the contributions from a potentially significant number of well-qualified experts in universities and research institutes.

2.4 Areas where rapid progress is possible

Gaps in the current knowledge of biodiversity status and change are enormous. In many areas large-scale biodiversity assessment exercises are hampered by lack of an overview of existing knowledge, which is often patchy and widely scattered across diverse published and unpublished sources. Synthesis is necessary, not only to make better use of the existing data, but also to pinpoint more accurately those areas where new data are most urgently required. Equally, for some areas and groups, existing data are so few that almost any new observations are likely to yield useful and worthwhile additions to the body of knowledge.

Addressing the Johannesburg commitment of significantly reducing the current rate of loss of biodiversity by 2010 will require striking a balance between synthesis of information that is already available and the collection of new data using sampling methods that are improved in efficacy and scope. This balance is important if future global biodiversity assessments are to rest on a firmer and broader foundation than current knowledge permits.

2.4.1 Potential progress at the species level

The lack of authoritative taxonomic treatments for many groups of organisms limits our ability to identify organisms, make inventories and assess change. Existing levels of knowledge differ widely, but groups for which taxonomic needs are exceptionally acute include insects, nematodes and unicellular eukaryotes. For other relatively well-known groups (e.g. Lepidoptera, aculeate Hymenoptera (ants, bees and true wasps), ciliated Protozoa), including some considered to be good indicators of overall levels of biological diversity at the species level (e.g. plants), a synthesis of existing knowledge is urgently needed to make it more accessible for purposes of conservation, measurement, monitoring and management. The results of such syntheses could initially take the form of synonymised checklists of species with information on distribution, but should evolve to be more inclusive archives of information containing taxonomic, identification, and ecological data, as well as, where feasible, preliminary assessments of conservation status. Such syntheses would provide near comprehensive baselines of current knowledge and would greatly facilitate future conservation and monitoring activities at a global scale.

Widespread dissemination of this information and its transfer to facilitate conservation action in the field is crucial (Royal Society 2002). Collections and expertise in national museums, on which determinations are based, are often away from the area of need and not readily deliverable to conservation practitioners in the field. Provision of this information in a low cost format that could be used by non-experts, such as keyed-out guides or compact discs and tapes of birdcalls, could greatly enhance conservation efforts and the collection of new data. Up-to-date lists of taxonomic experts, who are able to respond either remotely or directly, could also be helpful to support situations where advice is required. Assembling data, which at present may be scattered and very difficult to access, and supplementing it with additional data (e.g. illustrations, biological data, links to other sites), would provide a universally accessible portal for systematic information on particular groups (with safeguards to allow alternative taxonomic hypotheses to be put forward). For example through a web based 'unitary taxonomy' as proposed by Godfray (2002).

2.4.2 Potential progress at the geographic level

Knowledge of biodiversity is particularly poor in those very areas that are most biodiverse – the tropics and especially the wet tropics. Central Africa, South East Asia and northern South America are among the regions with the greatest biodiversity where even basic inventories are incomplete for most groups of organisms and completely lacking for many. Basic improvements in rudimentary baseline knowledge are needed. In addition, a complete biological inventory of a tropical forest area would strongly facilitate ecological studies aimed at understanding how these systems work. In turn this would highlight potential differences from the temperate systems on which most ecological knowledge is based. In Costa Rica, collaboration between scientists and parataxonomists within a comprehensive sampling programme makes a near-complete inventory a realistic goal. Building human capacity in the areas of biodiversity, conservation and sustainable use is also crucial in most megadiverse countries that are seeking to measure their biodiversity and meet their obligations under the Convention on Biological Diversity.

2.4.3 Potential progress at the habitat level

Reliable estimates of recent rates of change in the extent of particular habitats are lacking for several major biomes including coral reefs and grasslands. Changes in continental shelf habitats are also still relatively unknown, despite their importance for world fisheries. The stratified sampling approach recently applied to humid forests (Achard *et al* 2002) could be usefully extended to coral reefs, tropical dry forests, temperate forests and wetlands (including freshwater habitats, see worked example in Section 4.2) in order to provide reliable baseline data on extent for these important habitats. Key elements in further broadening the range of habitats being monitored are the refinement of techniques using remote-sensing data, and the establishment of networks of field sites where such applications can be calibrated and supplemented.

2.4.4 Potential progress at the ecosystem level

Rational planning for conservation actions might ask questions such as: Which has more effect on the functioning of global ecosystems – losing say 25% of all mammal species or 25% of the vastly more numerous insect species? To address questions like this, more knowledge is needed of the organisms that comprise biodiversity and a clearer understanding of how biodiversity contributes to the functioning of ecological systems. Gaps in our knowledge of ecosystem services are even more extensive. Our limited understanding of nutrient cycling, climate regulation and the delivery of freshwater are of particular importance in this respect. Data on how these services alter as ecosystems are converted for other uses, how they vary over time and how they interact are also lacking. Collation and synthesis of recent and historical data in these areas could result in substantial improvements in understanding and provide the baseline against which future changes could be monitored. The production of global and regional maps of major ecosystem services would be an important achievement.

2.4.5 Potential progress on types of data

Across all groups of organisms, geographical areas and scales of study, certain types of data that are of great potential utility, are generally scarce or completely lacking. Chief among these are time series data (systematic observations repeated at documented intervals), data on abundance and how it varies, and distribution data, especially where apparent absence and effort invested in survey are also recorded (see worked examples in Section 4). Databasing and geo-referencing the data currently held in museum collections, forestry and wildlife department archives, expedition logs, and even the notebooks of amateur naturalists, would mobilise much historic information at relatively low cost per observation and provide an important baseline and context for the interpretation of current and future observations. Synthesis of this data is essential and will quickly reveal key gaps in knowledge. These gaps should then be addressed by the development of realistic new programmes capable of delivering substantial improvements in knowledge of otherwise poorly understood geographic areas, habitats and groups of organisms. Cost-effective ways of addressing these gaps could be driven by technical advances in other fields (for example the internet, molecular biology, remote sensing), they could also include more effective deployment of amateur naturalists and other non-specialists to help document distribution, abundance and variation over time.

2.5 Refining assessments of biodiversity

Expanding and improving biodiversity assessment is essential if a clearer understanding of the changing state of ecosystems, species and populations is to be provided, and protocols put in place with which to assess whether the Johannesburg 2010 commitment is met. Assessments must be scientifically based to improve the accountability and rigour in the reporting of biodiversity trends and status. As the conservation and sustainable use of biodiversity become more prominent, nationally and internationally and in political and legal debates, data sets and methods are needed that are well founded and that will withstand intense scrutiny.

3 A framework for measuring biodiversity

3.1 Introduction

One problem in the measurement of biodiversity is that existing measures are often not well suited to the purposes of those making policy decisions, or measuring the effect of policy. To address this issue we have developed a framework (Figure 3.1) for the assessment of some aspect of biodiversity. The framework does no more than make explicit best science practice, but is intended to be used by all scientists who measure biodiversity – whether academic, industry based, governmental or NGO – as well as those who commission and use the information generated.

3.2 Structure of the framework

The framework consists of a series of linked activities that comprises the assessment of some aspect of biodiversity or ecosystem function. The framework process can be divided into three main stages: a scoping stage, a design stage and an implementation and reporting stage. A rational approach to any of the activities in the framework depends upon the outcome of at least one other activity. Sections may have to be repeated if feedback from activities downstream indicates that changes are needed.

The framework can be regarded as a conceptual process that can be applied to all levels of biodiversity. A series of case studies in the following section (Section 4) demonstrates its use for terrestrial, freshwater and marine systems, and at the ecosystem, species and population levels. It is also relevant to long-term monitoring programmes and in emergency situations, such as an oil tanker disaster. Equally, in situations where a potential disaster can be anticipated, the framework can be used to develop a damage limitation programme, where potential risk areas are assessed in advance. For example, programmes of this kind are already carried out by oil companies along important shipping lanes.

Clearly, the quality of an assessment will be enhanced as more time and effort is spent on each stage. At certain points an extra investment of time could have significant bearing on later activities and may increase the amount of information the study yields. For example, widening the range of interested parties at the scoping stage may alter what needs to be measured. Additional time spent identifying the assumptions and limitations used in the design stages, and making them explicit in the reporting, will increase the robustness of the assessment. Where a rapid response is needed some of these activities could be quite quick, such as through a phone call to a few key stakeholders, rather than a full consultation process.

Routine use of the framework, in all situations, will help ensure stakeholder involvement and that measures are fit for the purpose to which they are being applied. It would also help to identify weaknesses in current approaches, as well as highlight major science and information gaps.

3.3 The scoping stage

3.3.1 Context, stakeholders and interested parties

Biodiversity is embedded within human ecological and social systems. Those people involved with, and affected by, the biodiversity of such systems are referred to here as stakeholders. The potential effects of decisions about management of biodiversity within a system may vary among stakeholder groups. For example the health, welfare, intellectual, recreational, spiritual and financial interests of different groups of stakeholders may be affected in different kinds of ways. Scientific assessments of biodiversity occur because some subset of stakeholders (interested parties) wish to have certain information. These wishes should influence the way in which assessments are carried out. Other stakeholders, whose interests may be greatly affected by the outcome of the assessment, may not be among the initial set of interested parties. This may be because they are not interested in encouraging a scientific study of the system, they do not know about it, or because they do not have the resources or political influence to become involved.

A major objective of biodiversity assessments is to inform policies that seek to reduce the rate of biodiversity loss as part of a sustainable development strategy. However, this broad policy-driven objective has to be translated into practical activities via a decision-support mechanism. This will place the biodiversity component of a system within the broader context of relevant social, political, economic and scientific knowledge.

The Driver-Pressure-State-Impact-Response (DPSIR) approach (Turner *et al* 1998) is a tried and tested scoping procedure. It recognises that at the root of environmental change are socio-economic drivers, such as exploitation of wild natural resources, intensification of agriculture, urbanisation, and tourism development. The cumulative effect of these, together with climate change and other factors, is to exert pressure on environmental systems and cause changes in the state of the environment (biological, geochemical and physical) including changes and losses in biodiversity. In turn those changes have impacts (positive and negative) on human welfare. However, these changes in welfare affect different, often competing, stakeholders in different ways and therefore frequently stimulate debates about equity, values and ethics. These in turn can spur political systems to provide legal and management regimes that seek to control driving forces and pressures. The result is a dynamic cycle with feedback loops.

Table 3.1 Examples to illustrate the meaning of the terms interested party and valued attribute as applied to the value of biodiversity Direct use benefits are valued through the market, whereas indirect use is valued by observation.

Object	**Interested parties**	**Valued attributes**	**Type of value**
Diversity of life on Earth	Evolutionary biologists	Global species richness and the location, abundance and range of species as resources for documenting and understanding the evolutionary process	Option value i.e. conservation allows time for new science and information to be discovered
	People who like 'wild' nature	Global species richness and the abundance, range extent and viability of species	Existence value or non-consumptive use value
A forested river catchment	Local people whose health and livelihoods depend upon a reliable fresh water supply	Volume and reliability of streamflow (in part controlled by the moisture collection and retention properties of forest vegetation) as a determinant of water availability to people.	Forest vegetation – direct use value Flood protection benefits in terms of costs avoided – indirect use value
	Commercial foresters	Volume of timber that can be extracted	Direct use value
Coral reef	Local fisheries	Reliable ongoing source of protein and income	Direct use (consumptive) value
	Marine ecotourists	'Beautiful' and abundant coral and fish species	Direct use (non-consumptive, amenity) value
The world population of an arctic-temperate migratory goose species	Conservationists	Range and population size (desired state – at least maintained well above the minimum viable level)	Existence value
	Farmers in the winter range	Range and population size (desired state – below the level that results in significant damage to crops and grass by grazing)	Negative value above a given population size

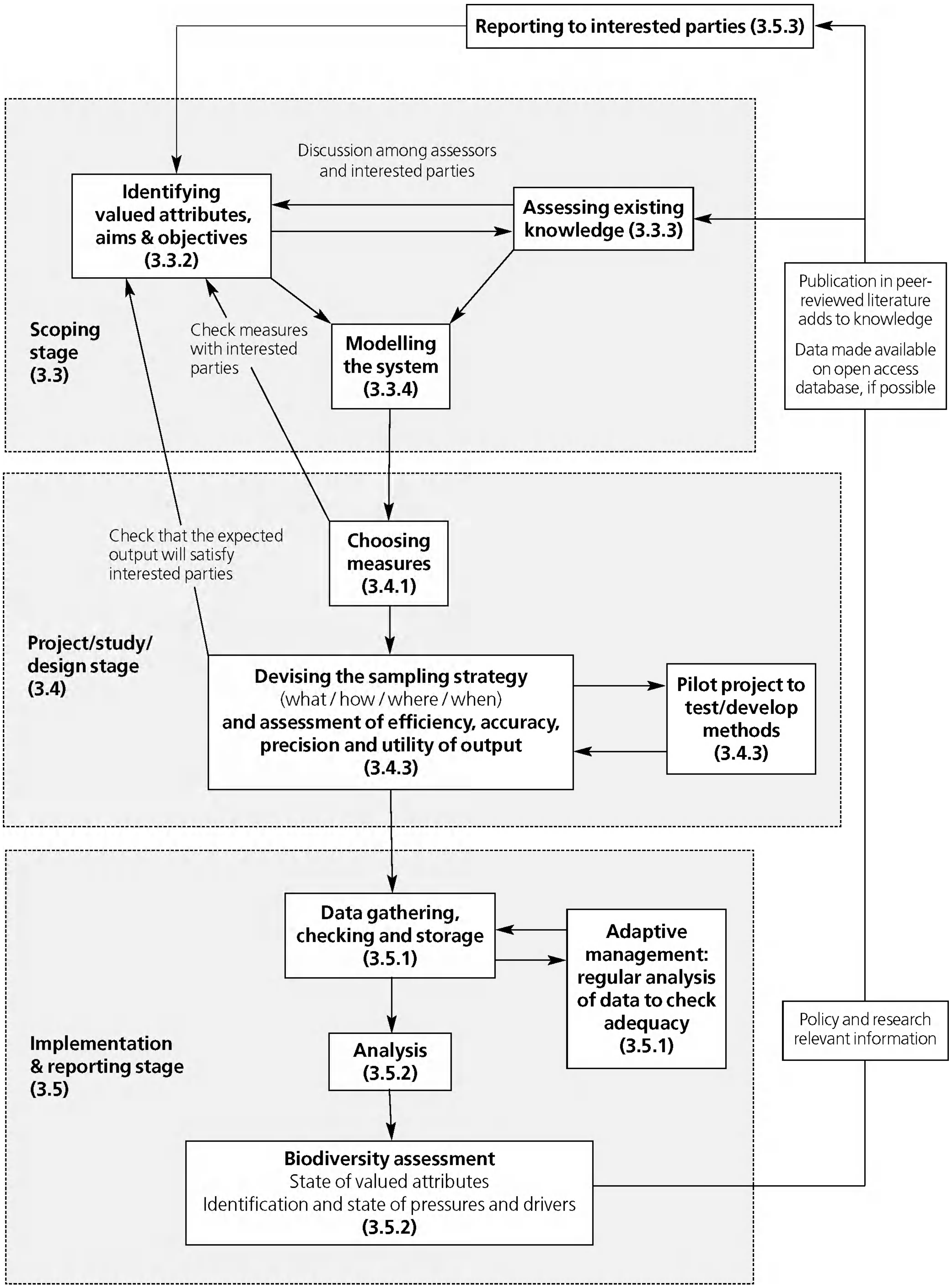
3.3.2 Identifying valued attributes, aims and objectives

At the outset, the object of the assessment, and the attributes of that object that are of interest, need to be defined, both by the interested parties and those carrying out the assessment. Differences in timescales that are inherent in the stakeholders' values will also be identified at this stage. Some examples of valued attributes and objects are provided in Table 3.1. Interested parties will often differ in the desired state of the attribute and the levels of precision and accuracy they require from the assessment. The examples in Table 3.1 illustrate some ways in which different interested parties might value the same attributes. Care is then needed in defining the measurements to be used (Section 3.4.1) and designing the sampling strategy (Section 3.4.3). It is essential that interested parties are clear about what the assessment can and cannot provide. A scientific assessment is only likely to satisfy the requirements of interested parties if it first establishes what their interests and values are.

For every attribute of interest, decisions must be made about how best to capture information about its state in a quantitative form. This involves the identification of measurements that are feasible to obtain at the spatial scale needed and within the time available. Before the measurements are defined precisely (Section 3.4) there should be consultation with interested parties, beginning with the following straightforward questions.

- What do you care about?
- What questions do you want the assessment to answer?

Figure 3.1 Framework for biodiversity assessment, showing the various conceptual stages necessary for assessing an element of biodiversity



- What are you likely to do with the results?
- When is the result of the assessment needed?
- Is it envisaged that the assessment will be repeated in order to measure change through time?

Discussion of these questions is likely to lead to more detailed queries such as the following.

- Is there a need to quantify as fully as possible the total abundance and distribution of an attribute of interest, or will a reliable estimate based upon sampling be acceptable? For example, a full census of an endangered vertebrate population may be needed in order to define and justify the designation of a protected area, but otherwise a reliable estimate based upon extrapolation from samples within the range might be adequate.
- Where the attribute of interest is difficult to measure is it acceptable to substitute measurements of an indicator? For example, changes in the species richness of a single taxon may be shown to be a good proxy for changes in species richness more widely.
- Is it necessary to have absolute measurements of the state of a particular attribute or is an index that is correlated with population size and that will allow the assessment of change over time acceptable? For example, is an estimate of the total number of breeding age adults in a fish population required, or is an index such as catch per unit effort acceptable?
- What level of precision is needed and is there asymmetry in the level of uncertainty that can be tolerated? For example, for an endangered species close to its minimum viable population size, the amount of uncertainty about current population size below the best estimate is more important to conservation managers than uncertainty above it.
- What is the desired state or set of states of the attribute of interest? Asking this may help to define the required accuracy of the estimates (see above). For example, species richness estimates for protected areas can be based on species lists derived from opportunistic sightings by tourists, but more systematic surveys with records of sampling effort will be needed to quantify changes over time.
- Is assessment of the valued attribute the only thing that the interested parties require? This is unlikely if the Driver-Pressure-State-Impact-Response (DPSIR) scoping process has been fully implemented. However the value of the assessment could be increased at modest extra cost by also measuring aspects of environmental pressures and their socio-economic, biotic and abiotic drivers. For example, in remote sensing surveys of deforestation rates it may be efficient to expand the study to include a survey of land use in the places converted from forest as part of the same research programme.

3.3.3 Assessing existing knowledge

Existing knowledge may come from a variety of sources, such as previous studies, the interested parties and from those carrying out the assessment. Where the knowledge comes from previous scientific studies of the system or from studies of other systems, if the similarities are sufficiently strong, judgements have to be made about the extent to which it can be relied upon as a guide to the present assessment. Such judgements should be identified as assumptions. Even if the information is derived from the same system, it may have become an unreliable guide because of changes over time. For example, inferences about the sustainability of a bushmeat harvest from a tropical forest may be made from current measurements of the volume of the harvest and densities of hunted species, but they may also depend critically upon pre-existing knowledge of the geographical distribution of consumers and markets and the catchment area used by hunters. If bushmeat from the study area begins to be exploited by new hunters and traded in previously unknown markets then estimates of the harvest, and conclusions about sustainability, would become unreliable.

Existing knowledge is likely to be used to make sample surveys efficient. For example, to measure changes in the threat status of species, prior knowledge of geographical range and previous assessments of specific threats can be used to design efficient surveys for multiple species simultaneously.

Interested parties frequently have some knowledge of the object to be assessed as well as being able to provide some insights about factors that affect the state of the attributes. The initial stages of an assessment of biodiversity may (and often should) involve formal review and critical testing of existing knowledge alternating with discussion with interested parties of the conclusions drawn from it. During this process of rigorous examination, interested parties may change their priorities about which attributes of a system they value.

3.3.4 Modelling the system

Consideration of existing knowledge, together with values and requirements of interested parties, provides a background to prepare a conceptual model of the system. Even a simple model will be of great value as it forces assumptions to be recognised and made explicit and can highlight defects in the reasoning that links the attributes of interest with the measurements that can be made. Without having collected any data developing a model may seem premature, but there is usually some information available from which it is possible to provide some level of quantitative or qualitative analysis.

The nature of an appropriate model will depend upon the system and the attributes to be measured. For example, suppose the object of the assessment is a measure of species diversity and the attributes to be measured concern the effects of habitat fragmentation at a global or continental scale. The underlying model might include known latitudinal trends in species numbers, range sizes and levels of endemism. This knowledge, in turn, would influence the choice of study sites and the scale of analysis required in different regions. Similarly, in the case of an animal or plant species being monitored for population size and trends over time, there may only be certain life history stages for which individuals can be counted and certain areas that can be covered by surveys. An appropriate model might be a matrix of the number of individuals in various life history stages over a period of several years. For a bird species, it may only be possible to obtain reliable counts for territorial males during the breeding season. In this case having a model of the bird population would lead to an enhanced understanding of what a feasible assessment could achieve, and what it is necessary to assume or find out in order to interpret the results. Counting only the singing territorial adult male birds either assumes that this provides an acceptable index of the total population size, or that studies must be initiated to work out the relationship between numbers of males and the size of the whole population.

If the assessment aims to measure aspects of the pressures and drivers that are thought to affect the biodiversity attributes of interest, it is important that the model of the system includes the relationships among them. These relationships can be expressed using a Driver-Pressure-State-Impact-Response (DPSIR) framework, even if this is only possible in conceptual form.

Making a model based upon whatever is known about the system forces the assessor to make explicit the links between the attributes they are interested in and the measurements that it is feasible to make. This will help to identify the limitations of the scope of the assessment.

The process of identifying valued attributes, assessing existing knowledge and developing a conceptual model of the system, comprises the Scoping Stage. This should lead to the identification of a clear set of aims and objectives for the assessment. In turn, these are likely to be modified and refined during later steps in the framework as practical constraints become apparent. However, all but the most trivial of such changes should be referred back to interested parties for discussion.

3.4 The design stage

3.4.1 Choosing measures

3.4.1.1 Advantages and disadvantages of different types of measures

With a model in place, the specifics of what to measure can be considered. The model can also be extended to include the relationship between the measurement and the true state of the valued attribute. Table 3.2 provides a simplified scheme of four broad categories that encompass many common measures.

Extent of habitat

The first category of biodiversity measurements establishes the extent of large-scale ecosystems or habitats. Knowing something about habitat area may be valuable in itself, and when linked to knowledge about rate of change in habitat area can provide an indirect measure of the loss of populations and species associated with that habitat. It may also provide a basis for estimates of certain kinds of ecosystem services.

Large-scale habitat measurements have been aided greatly by advances in remote sensing and GIS software. For example, the extent of forest fires in Southeast Asia and losses of primary forest globally have been monitored with satellite images. However, the degree of resolution of this technique is still not adequate for many purposes, such as monitoring more subtle habitat degradation or distinguishing between regenerating forest and plantations.

Ecosystem processes and changes in function

This broad category of biodiversity measures seeks to assess ecosystem processes and changes in ecosystem functioning. Often this is approached by the use of proxies. For example, key aquatic plants can be valuable indicators of eutrophication of freshwater bodies. Surveying these aquatic macrophytes may be more rapid and cheaper than full-scale monitoring of water quality and biological composition. However, measurements of indicator species may make comparisons across habitat types difficult.

Attempts to assess ecosystem processes also potentially inform improved understanding of the goods and services provided by ecosystems. For example, understanding tidal and other hydrological effects is important in understanding how saltmarsh ecosystems work, and measurements of wave heights at saltmarshes are used to provide a direct indication of the services provided by marshes in reducing the risk of sea defences being breached. Measurements of services provided by ecosystems can also be used to provide rapid and inexpensive indications of the state of habitats, though they often have low sensitivity to changes in abundance of specific taxa.

Lists and distribution mapping of taxa

Counts of species (species richness) are probably the most commonly used surrogate for overall biodiversity at both local and broader scales. The species level is an accepted standard, because species are the most familiar taxonomic unit for scientists, the public, and policy makers. Information on the presence of well-known groups of species such as birds and flowering plants is available for many areas and time periods from the records of visiting naturalists, as well as more formal surveys undertaken by governments and NGOs. The wide availability of these data has led to their common use. However, such data also have drawbacks that are not always fully appreciated.

Table 3.2 Four broad categories of biodiversity measures, with examples of advantages and disadvantages

Measure	Advantages	Disadvantages
Extent of habitat	Remote sensing can provide large-scale assessment and measurement of recent trends. Can be used to estimate rates of species endangerment based upon species-area relationships. Links to delivery of biogeochemical ecosystem services are potentially strong.	Objective delineation of boundaries of habitat or ecosystem sometimes problematic. Often difficult to identify ecologically important subdivisions of broad habitats such as forests. Degradation of habitats and loss of component taxa of ecosystems may not be detected.
Ecosystem processes and changes in functioning	Potentially strong links to ecosystem services and direct relevance to material needs of humans. May provide deeper understanding of ecosystem functioning that is helpful for management. May provide quick and efficient composite measurement of state of habitats and taxa.	Reliability may vary across habitat types. Methods require careful validation before wide application. Relation to fates of taxa often uncertain.
Listing and distribution mapping of taxa (especially species and sub-species)	Most commonly available information from existing records at a variety of scales. Provides easily understood data about diversity, especially through simple species counts. Information is often directly relevant to species protection legislation. Information frequently highly relevant to the identification of priority areas for conservation and definition of their legal status. Useful historical data may exist from distribution atlases, museum specimen collection localities and other sources.	Difficult to ensure that absence of records means that the taxon is absent. Difficult to generalise: most taxa are undescribed and known taxa may not be a representative sample. Taxonomic distinctions difficult to make or of limited validity for some groups (often a function of asexual reproduction). Sometimes difficult to factor out survey effort and methods; apparent changes in distribution may be artefacts of changes in effort or observer skill. Changes in range, even when accurately recorded, may be insensitive as an index of overall abundance.
Population size of selected species	More sensitive than measurements based upon distribution alone. Data potentially can be aggregated across species to provide a composite index. Clear relationship with some values and services.	Labour intensive and expensive to collect the data: not practical for many taxa. Methods and interpretation are taxon-specific. Limited historical information compared with distribution measurements. Some applications require expensive acquisition of separate data on abundance of age/sex/size classes.

In certain cases, levels in the hierarchy of biological diversity other than species, can be used to indicate biological diversity across sites. For example, genetic variation within species is an important component of biodiversity in its own right. Recent advances in molecular techniques are also allowing genetic assessments as a proxy for species diversity when taxa are difficult to identify individually, as is the case for many microorganisms. Other assessments consider higher taxonomic levels, such as the number of families, which are sometimes easier to identify and count than species. This may be a valuable approach if these higher taxa adequately capture phylogenetic distinctiveness.

Measurements based on mapping and listing particular taxa often categorise species according to their rarity or the extent to which they are threatened with extinction. Measurements of rarity and extinction risk are extremely useful, but measurements of actual species extinction rates are a poor way to monitor biodiversity loss. Most extinctions have a long 'tail', whereby the species may persist temporarily at low numbers with a negligible chance of recovery and a severely diminished role in the ecosystem. Measurements of extinction rates therefore provide a very crude indication of biodiversity loss, which reveal little about short-term changes in pressures and cannot provide the kind of 'early warning' that could lead to successful conservation interventions. Measurements of extinction rates at the species level also suffer from other problems, including: i) most of the world's species have yet to be described, ii) estimates of extinction rates, such as those derived from habitat loss, have significant associated uncertainties, and iii) for most groups of organisms background extinction rates for comparison with contemporary losses, are problematic to estimate.

Population size of selected species
A fourth group of measurements concerns the abundance of individuals and changes in population numbers of organisms. These measurements are often aggregated across species to produce composite indicators of changes in particular regions or habitats. Population surveys can provide sensitive indicators of the status of particular species under study, but they may also be expensive to acquire. It may also be difficult to extrapolate the conclusions to other species with different ecological requirements.

3.4.1.2 Deciding among alternative measurements

Selecting appropriate measurements depends first and foremost on the object of the assessment and the attributes of interest. Some attributes can be measured directly, but others cannot and in these cases reliance may have to be placed on indirect (proxy or surrogate) measurements that are in some way correlated with those of direct interest. In this case, the precise relationship of the indirect measures with those measurements of direct interest will need to be determined, if necessary by pilot studies. Unfortunately, such relationships are often quite variable and context dependent. The resource demands involved in establishing the usefulness of an indirect measure may sometimes be so high that they negate its benefits.

In some cases, measurement may not be currently feasible. For example, the taxonomy may be in such a state that it is impractical to estimate species diversity in the field. Similarly, there may not be enough information known to be able to effectively measure complex ecosystem functions such as nutrient cycling. Solving these problems will require a concerted effort from the scientific community.

Among the many considerations in selecting measurements two are especially important. First, alternative measurements might vary in usefulness and fitness-for-purpose. Second, alternative measurements may vary in cost and difficulty. These two factors need to be considered together; the best measurement is the one that is most useful in relation to available resources. An illustration of the decision process around these factors is shown in Box 1.

This example brings out the value of having some prior sense of the qualitative relationships between the various variables indicated in Figure 3.2, as well as considering the total amount of time and resources that will be available for the assessment and the results that have already been obtained by previous efforts. If repeat surveys to monitor change are anticipated, then the ease with which a given assessment could be exactly reproduced in future would need to be incorporated into the evaluation of the usefulness versus completeness function. In the example given here, this might reduce the advantage of the direct ground surveys (for which new staff might need to be trained) over the more automated processing of satellite imagery.

This model really does no more than formalise the decisions to use informative data sets that can most readily be gathered. Yet it is important to make this explicit. Often the temptation is to gather the easiest to obtain data despite their limited bearing on the issue (failure to consider the relationship in Fig. 3.2a), or to gather new data when strategic additions to existing data could be more efficient (failure to consider the relationship in Fig. 3.2c). A dataset that can be readily gathered or completed may or may not be the best option, depending on the circumstances.

3.4.3 Devising the sampling strategy

The next step is to use the model, imperfect as it may be, to develop a sampling strategy that specifies what to measure, when, where and how.

A fundamental decision is whether to make estimates of attributes of interest by extrapolating from measurements made upon a sample, or whether to survey or measure them in their entirety. Assessments of plant and animal populations routinely use counts made from surveys in sample areas, such as quadrats or line transects, which are then extrapolated to estimate the total population size. If characteristics of surveyed and unsurveyed areas that are correlates of population density, such as vegetation type or topography, can be obtained, then these can be used to improve the precision of the estimates and to model the distribution and abundance of the species outside the surveyed areas. Line transect methods for estimating the population of particular species and some approaches to surveying species richness extrapolate not only from the surveyed area to other areas, but also within the surveyed area to allow for incomplete detection of individuals and species within it (Buckland *et al* 1993; Boulinier *et al* 1998). These methods recognise that not all individuals or species in the surveyed area are necessarily detected by the fieldwork and use models that describe the probability of detection of individuals or species by the observer as a function of distance from the transect line, time spent searching or some other proxy for observer effort.

Extrapolations from a sample are often the only feasible way to estimate large or widespread populations or the size of large assemblages of species. The accuracy of assessments based upon extrapolation from samples is likely to depend critically upon the realism of the assessor's model of the system. Stratified random sampling, based on prior knowledge, can greatly increase the precision of the resulting estimates.

As well as deciding where to survey, the questions of when to survey and on how many occasions also need to be considered. If trends over time are to be measured careful consideration must also be given to the extent to which attributes fluctuate over short time intervals or show systematic trends over longer periods. Assumptions in the model about the causes of variation over time in the attributes being measured are important here. For example, trends in the population size of a large-bodied mammal with a high mean annual survival rate and low average fecundity would probably be revealed by sampling at intervals of several years. Much more frequent sampling will be required for a small-bodied mammal with strong intra- and inter-annual population variability.

When measurements of the attributes of interest have been identified, and a provisional sampling strategy has been developed, an attempt should be made to use the model of the system to simulate the likely outcomes of the assessment. This can be attempted based on plausible guesses about the true state of the attributes being measured. In a preliminary way, the question should be posed: is it likely that the study will yield meaningful results that will help to answer the questions posed by the interested parties? It is also essential to consider the likely confidence intervals for all the parameters used, so as to determine whether the inevitable uncertainty in the results, arising both from the model specification and the statistical analysis (or sampling), are such that the results are likely to be too vague to be useful to interested parties. Consideration should also be given to any technical aspects of the data collection methods that are in doubt. Development work on the data collection methods or a pilot survey to check that they work as envisaged might be needed.

3.5 The implementation and reporting stage

3.5.1 Data gathering, checking and storage

The collection of data is dictated by the sampling strategy. Several principles of data collection apply to a wide variety of biodiversity assessments (listed below). Guided primarily by the requirements of effective analysis and reporting (Section 3.5.2 and 3.5.3), the data will also add to existing knowledge. Data stored with details of exactly how it was collected will therefore increase its value compared to other similar data for which such information is not available.

- Ensure that people collecting data are adequately trained and follow a common protocol for collecting and recording information.
- Keep raw data for checking and re-interpretation.
- Store data in its most disaggregated form.
- Record precise locations of field study areas.
- Record sampling effort and who collected the data.
- Record both presence and apparent absence in distribution and abundance assessments.
- Ensure that checks are carried out to keep errors in recording and data storage at an acceptable level.
- Where possible, collect any additional, low cost data that may be useful later (such as simple data on drivers when collecting information on an object's state).
- Review progress regularly to check that the data being collected will address the questions originally posed. For example, do the ground truth checks confirm the accuracy of the distinction between regenerating forest and plantations in a remote sensing survey of forest extent? If not, there may still be an opportunity to revise the methods. Regular review will also allow the assessment to be adapted to respond to any unforeseen circumstances, such as the appearance of alien species.

3.5.2 Analysis, assessment and reporting

The details of the analysis and reporting of the assessment will be specific to each particular case, but we make some recommendations on issues of wide significance.

- The sensitivity of the conclusions of the assessment to the underlying model and its assumptions should be explored and reported clearly. Where appropriate, alternative conclusions arrived at from plausible variants of the model should be reported.
- The results of the assessment should be used to update and improve the underlying model of the system as a basis for future research. Defects in the model underlying the assessment should be identified clearly and remedies suggested.
- The survey design, the procedures used in sample area selection, and the fieldwork and analysis protocols should all be described in sufficient detail to allow the survey to be repeated. This is especially important for complex, semi-automated techniques such as the mapping of habitats.
- Where possible, the raw data from the assessment should be available to other researchers for alternative analyses.
- Precise survey localities should be archived so that the study could be repeated at the same localities if necessary.
- The results of the assessment should, wherever possible, be published in the peer-reviewed literature. Where this is not possible, an attempt should be made to subject the outputs to other forms of external review.

3.5.3 Reporting to interested parties

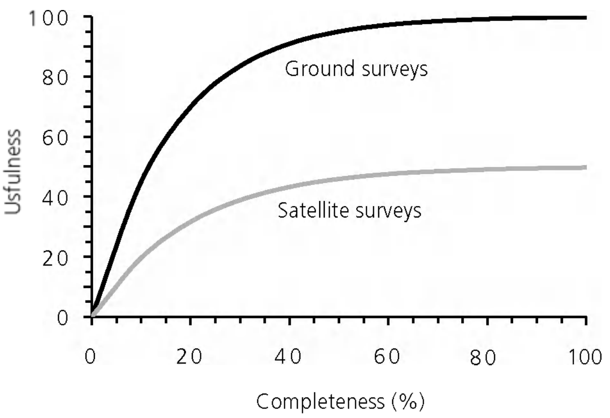
Scientific assessments of biodiversity should be reported to interested parties in ways that minimise the scope for misinterpretation of the results. Reporting results in a form accessible to scientific colleagues is important, but is unlikely to be effective in communicating to interested parties without further effort. For example, when fisheries biologists communicate with each other they refer to *F*, the

Box 1: Deciding between two measures

Suppose a team is trying to estimate the area of old-growth native forests in a region. They could either send groups of researchers out to map hundreds of sites on the ground, or use satellite imagery. But satellite imagery, though developed using some ground truth information, may not be entirely reliable in distinguishing between younger forests, native old-growth, or plantations of exotic species. If this reliability problem could not be overcome the team might assume that usefulness is determined mainly by the accuracy of the two different methods for making the estimates. But the decision may rest on other factors.

The expected usefulness of the results can be plotted against the completeness of each of the alternative research programmes (Fig 3.2a). Both methods become more accurate and therefore more useful as they become complete, though the rate of improvement declines as the task nears completion. This would be expected if both methods produce more accurate estimates based upon progressively larger samples. However, the satellite-based estimates are only half as useful as the direct ground surveys, even when complete, because of their lower reliability.

Figure 3.2a Expected usefulness of results against the completeness of alternative measurements



Similarly, the completeness of the research programme in relation to the effort (cost or person-years of effort) expended can be considered (Fig 3.2b). The advantage of the satellite-based method is that it can be accomplished with much less effort than the direct ground-based survey.

Combining these two approaches it is possible to estimate the relationship between usefulness and effort expended (Fig 3.2c). Suppose 20 units of effort were available and that neither measurement approach had yet been started. From Fig 3.2b it is clear that the satellite-based survey could be virtually completed with this level of resources, but that the same expenditure would only complete a small fraction of the direct ground survey work. In this case the complete satellite-based survey obtained with 20 effort units is more useful than the incomplete ground survey, despite the higher reliability of direct land-based survey data (Fig 3.2c).

However, had 40 units of effort been available the usefulness of the results of the direct survey would have been higher. In this example, if the effort available is small, the indirect proxy is favoured, whereas if more time and resources are available, the direct survey method is preferable. Intuition alone would not necessarily lead to this conclusion, because the answer depends on the particular functions that relate usefulness to completeness, and completeness to effort. Different outcomes can be obtained with different functions.

Figure 3.2b Completeness of the research programme in relation to the effort or money expended

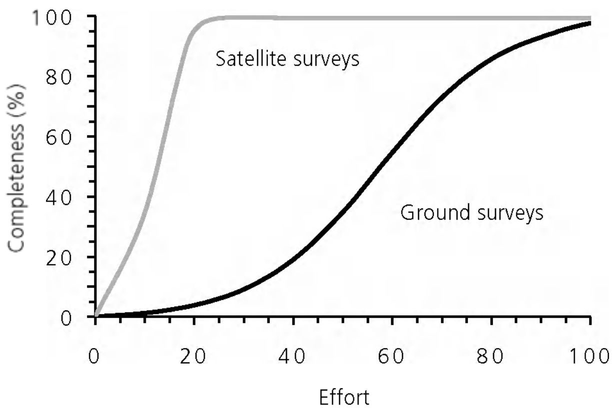
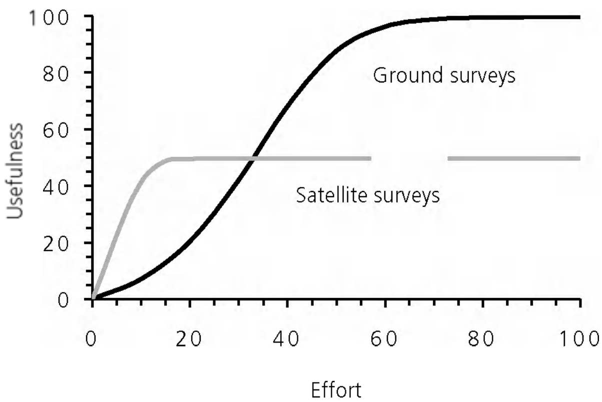


Figure 3.2c Estimated relationship between usefulness and effort expended



An additional consideration in choosing among alternative measurements is the amount of information that is already available. For example, suppose that 20 units of effort had already been spent on the direct ground survey before the option of satellite-based methods became possible, and a further 20 units of effort became available. Examination of Fig 3.2c indicates that continuing to spend the new resource on the ground survey will yield a more useful result than switching to the satellite-based method. However, if only 5 units had already been invested in the ground survey, a more useful outcome would be obtained by spending the newly available 20 units on initiating the satellite-based survey.

instantaneous rate of fishing mortality. But when they communicate with fishers and politicians, they usually convert *F* to percentage mortality, which is more meaningful to non-scientists. Reporting to interested parties should be as straightforward as possible and specifically address the possible policy responses under consideration. Interested parties should be informed of the relative strength of the evidence for and against a particular policy option, and the extent to which this could be altered if untested assumptions prove erroneous.

Reporting of the results of an assessment to interested parties will often lead to proposals to repeat the assessment or to undertake some connected piece of research. This should involve re-discussing valued attributes, aims and objectives with interested parties. The completed assessment is now part of the existing knowledge to be taken into account in designing the new study. The DPSIR framework may well be modified and new stakeholders may be identified and recruited as interested parties. With the new information it will usually be possible to identify important questions not identified when the original study was being planned. Experience may also suggest changes to methods that will improve efficiency or accuracy. Such changes in objectives and methods should be considered carefully and with great caution. If the measurement of changes over time is important it is often essential to ensure that the original design is repeated so that results can be compared directly among assessments. However, solutions are often possible in which new, more detailed recording methods yield results that can be converted into a form comparable to those derived from previous methods.

3.6 Conclusion

Routine implementation of this framework, in all situations, would ensure that measures are appropriate to the purpose to which they are being applied. As a result each biodiversity assessment would clearly identify: i) interested parties; ii) the attributes which those parties value and are seeking to measure; iii) the extent of existing knowledge relevant to the assessment; iv) the assumptions used in the assessment and the limitations of the measure in addressing the valued attributes; v) precisely how each measure is defined; vi) the nature of the sampling strategy used; and vii) the data gathering and analytical methods to be employed. Applying this framework would also help to identify weaknesses in current approaches, as well as highlight major science and information gaps.

In the following section we demonstrate, with a series of cases studies, how this framework can be used in a number of circumstances, for terrestrial, freshwater and marine systems, and at the ecosystem, species and population levels.

4 Case studies

In this section we present 11 case studies that illustrate how the framework, put forward in Section 3, can guide planning for biodiversity measurements. We have chosen examples to illustrate the widest possible kinds of biodiversity measurements, ranging from those that encompass ecosystems to others involving genetic variation within and among populations. While all of these case studies are based on real examples, in many cases we have considered hypothetical stakeholders who might be interested in different attributes of each system. Consideration of differing stakeholder priorities illustrates the importance of implementing full scoping phases, with profound impacts on the subsequent choice of sampling strategy, data gathering and analyses.

4.1 Forest cover in the Eastern Arc Mountains of Tanzania

4.1.1 Background

The forests of the Eastern Arc Mountains are priority candidates for biodiversity conservation. A key requirement is to understand how changes in habitat area relate to changes in the delivery of ecosystem services.

4.1.2 Valued attributes

Many different groups of interested parties are concerned about forest loss in this area. Here two of these groups are considered: a group concerned primarily with the maintenance of forest biodiversity and a group concerned primarily with the delivery of ecosystem services by forests to local people. Both need to measure the rate of loss of natural forest quantity and quality, now and in 2010. Those most interested in biodiversity may also want to know about numbers of species committed to extinction by habitat loss, while those most interested in services may need to know about stream flows, soil erosion, rates of harvesting wild species, and so on. Both groups probably want to collect additional information on pressures and underlying drivers of deforestation.

4.1.3 Knowledge

The Eastern Arc forests are among the most important priorities for biodiversity conservation in Africa, with exceptional levels of floral and faunal richness and endemism (Burgess *et al* 1998; Lovett 1998; Newmark 2002). Their eastern slopes intercept clouds arriving from the Indian Ocean, with the run-off from the forests providing the principal water supply to major coastal settlements, including Dar es Salaam (where 3–4 million people and most of Tanzania's industry is located). This water catchment function was the main reason for the establishment of the area's forest reserves by colonial authorities.

Since the 1950s, the Eastern Arc forests have been reduced considerably in extent, with estimated rates of loss for individual mountains running at 0.5–1.0% per year, principally in areas not covered by forest reserves (Burgess *et al* 2002). However, quantitative estimates of forest loss are patchy, and estimates of changes in forest quality are almost non-existent.

The main reasons for forest loss have been clearance for farming, both for subsistence and for sale to readily accessible urban populations in Dar es Salaam and elsewhere, as well as extraction of timber and non-timber forest products for local use (Burgess *et al* 2002; Newmark 2002). The intensity of these pressures and their underlying drivers vary with local population density, land tenure and access to roads.

Complete ground surveys of the extent of forest would be impractical, however satellite imagery and aerial photographs can be analysed to yield estimates of changes in forest cover. Studies in Brazil, Kenya and elsewhere (Pimm 1998; Brooks *et al* 1999) have shown that the biological value of forests will depend not just on their total area but on their degree of fragmentation, with species-area and other theory enabling us to predict very roughly how and when species numbers change with area and isolation. Species lists of the terrestrial vertebrates and most of the flowering plants of Eastern Arc are reasonably complete and it is known which species are endemic to individual mountains or to the Eastern Arc as a whole (Burgess *et al* 1998; Lovett 1998; Newmark 2002).

4.1.4 Model

Combining species-area theory with empirical data on the spatial extent of edge effects and on times taken for the composition of the forest biodiversity to adjust or 'relax' following habitat loss, should enable us to estimate the impact of changes in habitat area on species persistence. Far less theoretical or empirical information exists on how changes in habitat area relate to changes in the delivery of ecosystem services. However, the development of a water balance model of the region would be valuable. This should pay particular attention to modelling the relationship between the type and extent of vegetation and the amount and temporal variability of streamflow from mountain catchments. Depending on which ecosystem services are of interest, models of soil erosion and harvesting of wild species may also be necessary.

Measures of erosion and streamflow would be required, as would measures necessary to make parameter estimates for the water balance model of catchments.

4.1.5 Relevant questions identified by the scoping stage

- How has the extent of forest changed in recent decades?
- Where forest has disappeared, what other land cover types have replaced it?
- How do observed and expected changes in species distribution relate to changes in forest cover?
- How do changes in ecosystem service provision, especially water supply from stream flow, relate to changes in forest cover?

4.1.6 Sampling strategy, data gathering and analysis

The core data for both groups of interested parties will likely be time series of aerial photography or satellite imagery to characterise the extent of forest fragments – done retrospectively at intervals, depending upon image availability, in order to improve and standardise estimates of past losses. The same methods would be used to measure future habitat extent at intervals of not more than five years.

If complete coverage of all Eastern Arc forests is not possible, data collection should be carefully stratified, with disproportionate sampling effort devoted to areas expected to have higher rates of clearance, higher levels of endemism (for those interested in biodiversity), and higher likely values for service delivery (because of denser human settlement, more rivers, steeper slopes, etc – for those interested in ecosystem services) (see Achard *et al* 2002 for a worked example). Collating historical imagery may also be useful. Interpreting imagery will require consultation with local and international experts, as well as a stratified programme of ground-truthing.

Those interested in biodiversity losses may want to supplement estimates of loss of habitat quantity with ground surveys to test predictions of changes in species occurrence. These should again be stratified, focusing disproportionately on areas of high loss and endemism, and on taxa that exhibit high endemism and which are relatively easily surveyed and identified. Those interested in changes in service delivery may be able to get some information (e.g. on erosion) from aerial or satellite imagery, but will probably also need to collect a considerable amount of field data (e.g. on water flows, harvesting rates, etc.). Stratification criteria here might include proximity to villages, slope, aspect, and ground cover. Historical data on service delivery may be extremely useful too, though at present little such information is compiled in an accessible format.

Both the interpretation of remote imagery and ground surveys could be expanded at relatively low cost to provide information on pressures and drivers behind forest loss – through mapping land uses, settlement and infrastructure, and through social surveys documenting reasons for conversion, household incomes, demographic patterns, land tenure systems, and so on.

4.1.7 Science gaps

- Very little is known, either empirically or theoretically, of how estimates of changes in the delivery of ecosystem services relate to more readily assessed changes in habitat area – yet this is of crucial importance to many stakeholders, and may be far more likely to result in effective responses to pressures than will information on species losses.
- Data on historical levels of ecosystem delivery (such as streamflow) is very limited – yet, in many cases such information is likely to have been gathered by organisations such as museums and colonial administrations. A major effort to collate these data and make them accessible may be very worthwhile.

4.2 Global extent of open freshwater habitats

4.2.1 Background

Most freshwater ecosystems support substantial levels of biological diversity. Natural processes and human demand for water for drinking and irrigation threaten these ecosystems. A fundamental requirement is for a dynamic, descriptive model of the quantity, quality and diversity of freshwater ecosystems worldwide.

4.2.2 Valued attributes

No substitute is known for freshwater; it is an absolute necessity for all non-marine life. Freshwater ecosystems provide a range of services, including the provision of reliable water supplies for human consumption, irrigation, sustainable freshwater fisheries, nutrient cycling, detoxification of wastes, recreational pursuits, and aesthetic pleasure. All of these are products of healthy ecosystem functioning, which is driven and sustained by the activities of a great diversity of aquatic life forms. Stakeholders include all individuals of the human species, whether in rural or metropolitan areas.

Ponds, lakes and swamps in particular tend to be biologically productive, and this productivity is usually associated with substantial biological diversity. Thus a large aquatic biodiversity is typically supported within a relatively small geographical area. Freshwater ecosystems also support species such as dragonflies, hippopotamus, coarse fish, and bulrushes that do not exist in other ecosystem types, and many lake ecosystems are home to endemic species. It is self-evident that the persistence globally of numerous unpolluted freshwater ecosystems of diverse types is necessary for the conservation of freshwater biodiversity worldwide.

4.2.3 Knowledge

More than 99% of the fresh water in the biosphere is locked up in polar ice and glaciers, or hidden from view below ground, but all fresh waters, whether still or flowing, groundwaters or bogs, are connected with each other through dynamic interactions (e.g. above and below ground exchange), so that impacts on one ecosystem type eventually filter through to other ecosystem types.

It is generally acknowledged that the world's water problems continue to worsen, but the deterioration is not always directly linked to anthropogenic factors. Lake Chad has shrunk to one twentieth of its size 40 years ago, but this may have more to do with persistent drought than with direct human impact. The causes of other threats are more obvious. Since 1950, the number of large dams worldwide has increased from about 5,000 to roughly 45,000, with a proportionate increase in the degree of ecosystem alteration and destruction. In South America, the projected multinational Hidrovia Dam will (if it goes ahead) turn the Paraná and Paraguay Rivers into a barge canal that will drain the Pantanal – one of the world's largest and most biodiverse wetlands.

Where human demand for fresh water exceeds supply, ecosystem degradation usually follows. The US (seven states including California) and Mexico, remove almost all of the water that flows down the Colorado River, leaving virtually nothing to service the deltaic ecosystem on the fringe of the Gulf of Mexico.

Problems associated with excessive irrigation are most clearly demonstrated in the Murray-Darling Basin – a watershed that accounts for one seventh of the area of Australia. Extensive irrigation has brought the soils' naturally occurring salts into the root zones and rivers, leading to basin salinisation. Most of the Basin's rivers now exceed World Health Organisations' guidelines for drinking waters. On the other side of the continent, some 450 species of plants, insects and birds have been officially recognised as being under threat in Western Australia alone. One of the biggest contemporary problems is the over-pumping of ground waters, especially across large areas of the middle and Far East, and in India, where the Ganges runs dry for part of each year.

In the UK, about 90% of the total number of standing bodies of fresh water have areas of one hectare or less, and there may be 750,000 of these in England and Wales alone. It is estimated that they are decreasing in number by several thousand per year, largely as a result of new drainage schemes and urbanisation.

4.2.4 Model

Loss of and damage to freshwater ecosystems threatens biodiversity worldwide, but quantitative data at the global scale are lacking. The fundamental requirement is for a dynamic, descriptive model of the quantity, quality and diversity of freshwater ecosystems worldwide. At the core of this model is a world map, possibly sub-divided into biogeographic regions, and, at a range of finer scales, superimposed layers of quantitative information for:

- Availability of unpolluted surface waters relative to that in undisturbed catchments at the same latitude
- Level of salinisation of surface waters
- Time required to recharge aquifers (assuming current levels of abstraction)
- Probability of catastrophic flooding, including that associated with political/military activities (e.g. the Tigris-Euphrates watershed)
- Distribution of pressures and drivers arising from human use.

With the incorporation of time-based data, the most useful products of the model will be measured rates of change in extent and quality of water in sample ecosystems.

4.2.5 Relevant questions identified by the scoping stage

The aims are to provide global time series data for the real extent, quality and diversity of freshwater ecosystems and to use these to derive rates of change in these parameters and the services they provide to stakeholders. Causes of loss of freshwater habitats would also be identified.

4.2.6 Sampling strategy data gathering and analysis

Aerial photography and remote sensing techniques are now very advanced, capable of recording with very high resolution. They can be deployed for accurate mapping of lakes, rivers and floodplains, and can measure subtle water level changes over time in all of these. A major advantage over traditional mapping is that the data are potentially available in real time. It is now possible to use data from airborne or satellite based spectrometers to estimate aquatic chlorophyll *a* concentrations. Water status can be assessed using a number of indicators including Secchi disk depth, turbidity and stream flow rates. The main problem is that coverage of the world, at an appropriate level of detail, is far from complete, although it is excellent for North America and parts of Europe. For areas of the world where data are not available or where maps are currently inadequate, remote sensing is probably the only feasible approach to gathering data for small (< one hectare), invariably ephemeral, water bodies in large continental areas.

For the Western Palaearctic, it should be possible to produce the first maps within a few years, especially if the European Union Water Framework Directive and other large-scale projects can drive the project. Of principal interest are trends over time, and it should be possible to answer the question by the year 2010, as to how the global status of freshwater ecosystems is changing.

4.2.7 Science gaps

- What will happen if some of the most extensive wetlands in the world are drained is simply not known.
- Some habitat types (e.g. farmyard ponds) are much more common globally than others (e.g. the deep rift valley lakes of East Africa). Loss or degradation of a

single major lake may result in a significant number of species extinctions, yet there is no internationally agreed hierarchical list of vulnerable freshwater ecosystems.

- Local communities often have low awareness of the freshwater ecosystems in their neighbourhoods, although voluntary organisations in the UK and other countries have raised the public profile of freshwater ponds in particular. In the USA, the scientific management and conservation of water resources is increasingly becoming the prerogative of the local community (e.g. the Catskills Watershed agreement, which involves local people, forest owners, New York City and State, the Environment Protection Agency, and environmentalists), who collectively recognise the value of ecosystem services (e.g. water purification by forested catchment) and are supporting an enhanced watershed protection programme for New York City's drinking water supply.

4.3 Trophic integrity of marine ecosystems

4.3.1 Background

Marine ecosystems have been exploited for hundreds of years. Fisheries tend to target the largest and most valuable species. But intensification of the industry and depletion of the large bodied and higher trophic level species has led to the targeting of increasingly smaller species, further down the food chain.

4.3.2 Valued attributes

Intact, pristine ecosystems often support high levels of biomass of large-bodied and higher trophic level species (Odum 1969; Christensen & Pauly 1998). By contrast, disturbed, exploited and polluted ecosystems can be characterised by the absence or rarity of such species, and by dominance of small-bodied species with high rates of population turnover, usually from lower trophic levels (Odum 1969; Christensen & Pauly 1998). Compared to undisturbed ecosystems, they may have simplified food webs and can be prone to blooms of algae, microbes and plankton (Jackson *et al* 2001). Relatively intact marine ecosystems may be able to sustain a level of exploitation of their animal populations and can act as sources of recruits for fisheries in other areas. Stakeholders include those who depend upon fishing for their livelihoods and those who value marine biodiversity.

4.3.3 Knowledge

Recent analyses of fisheries and historical data suggest that over the last 500 years, marine ecosystems have undergone major losses in biomass of larger-bodied and higher trophic level species (Jackson 1997; Jackson *et al* 2001). In parts of the world where large-scale exploitation extends far back in time, such losses occurred so long ago that few people today appreciate that the species were ever common in these places. For example, at the time of Columbus' discovery of the Caribbean, there might have been as many as 33 million turtles there (Jackson 1997). Early explorers and settlers killed many of these and other large-bodied animals to supply their food, and for commodities such as oil and fur. Throughout the world, other organisms including sea otters, seals, manatees, dugongs, and cetaceans have met similar fates.

The intensification of fishing has continued the process of ecological extinction of species from marine food webs. Fisheries tend to target the largest and most valuable species first and as each is depleted they then move on to others that are smaller and less desirable. Pauly *et al* (1998) call this phenomenon 'fishing down marine food webs' and have used world catch statistics from the Food and Agriculture Organisation of the United Nations to quantify the phenomenon.

4.3.4 Model

The model is based upon a simplified description of the trophic relationships among marine animals and plants. It also includes relationships between the level of human exploitation of a given species and the abundance of other species at higher trophic levels.

4.3.5 Relevant questions identified by the scoping stage

The main aim is to quantify changes over time in the average trophic level of marine animals being exploited by fisheries.

4.3.6 Sampling strategy, data gathering and analysis

The relevant data concern time series of landings of fish taken by fisheries in defined areas. Pauly *et al* (1998) assigned an integer value to the trophic level of each species in landings, based on the fraction of its diet that comes from each trophic level. For example, if 50% of an omnivorous species' diet consists of algae and 50% comes from species that are exclusively herbivorous, it will have a trophic level of 1.5 [0.5 x 1 (algae) + 0.5 x 2 (herbivores)]. This approach deals effectively with the problem that most species have diets that consist of foods taken from a variety of trophic levels. Using this information, it is possible to estimate the average trophic level of animals in fishery landings by multiplying the proportion in the catch by the trophic level of the species. Changes in this measure over time could then be examined.

Trophic levels of landings have been declining in nearly all regions of the world since the 1950s (Pauly *et al* 1998). In some areas, such as the North Atlantic, declines have been steep while in others they have been less pronounced, such as the Mediterranean. Slower declines in the Mediterranean reflect a more extended history of exploitation, where mean trophic levels of catches were already low by the 1950s. Globally, the trend has been a loss of 0.1 trophic levels per decade.

Pauly *et al*'s (1998) approach has been criticised on several grounds. First, the analyses involved some necessary approximations since catches are often reported in aggregate units, such as 'mixed groundfish'. Trophic levels had to be assigned to these units on the basis of probable rather than actual species composition. Second, some argue that changes in trophic composition of landings may have more to do with changing tastes than change in availability of species. In the 1950s, few people ate shrimp, which are debris eaters, but these detritivores are now considered among the most desirable of seafood. Third, reported landings are not the same as catches, since they do not account for species caught but discarded as unwanted bycatch, or if fishermen have gone over their quota.

More recent analyses have attempted to deal with some of these problems. For example, Pinnegar *et al* (2002) estimated trends of decline in mean trophic level in the North Sea since 1982. They used fishery survey data, so removing the problem of unreported catches and reducing the problem of aggregation of species into broader categories. Like Pauly *et al* (1998), they found a clear trend of decline in mean trophic level. They also examined price trends for species in relation to trophic level, and found that high trophic level species had experienced faster increases in price than those from lower down food webs, indicating that demand for these species remains high. This suggests that the view that lower trophic level species are being caught today only because of changing tastes is false. While consumers have clearly developed tastes for species like shrimp and lobster in recent years, high trophic level species remain highly desirable.

Few scientists now doubt that 'fishing down marine food webs' is real, and most consider that Pauly *et al*'s (1998) measure represents a robust indicator of underlying trends of species depletion. It provides a valuable proxy measure of loss of biodiversity and its ecosystem level effects.

4.3.7 Science gaps

- The quantitative relationship between landings and catches is relatively poorly known for most parts of the world.

At regional and global scales, applying the measure to Food and Agriculture Organisation (FAO) data will continue to provide a credible and useful synoptic picture of regional and global trends. However, at a smaller scale, countries could adopt approaches similar to that employed by Pinnegar *et al* (2002) and use fishery survey data directly to calculate year-on-year measures of trophic level of catches. The ecosystem level effects of fishery management approaches designed to rebuild depleted stocks should soon become apparent through systematic application of this measure.

4.4 Meiofaunal indicators of pollution

4.4.1 Background

Many inshore coastal and estuarine sites are vulnerable to industrial pollution. Meiofauna (mud- and sand-living organisms including nematodes, arthropods, and annelids) are especially sensitive, but their local biodiversity is often difficult to characterise because of a lack of available specialist taxonomic knowledge. Modern DNA-based methods offer the prospect of simple and unambiguous surveys of biodiverse but taxonomically difficult groups.

4.4.2 Valued attributes

Inshore habitats support a large animal diversity, notably wading birds and meiofauna. They also provide the resources required for a range of recreational pursuits. Monitoring of pollutant impact on coastal sites is therefore important for maintenance and protection, and also for assessing remediation and recovery processes.

Many large industrial concerns use tidal rivers as part of their waste management strategy. While current discharges are carefully monitored and controlled, historical discharge, and also accidental discharge, can result in unknown effects on ecosystems under threat. For example, in the Firth of Forth, there are several large industrial/marine establishments (Grangemouth, Rosyth Docks and Europarc), as well as significant inputs from cities and towns and associated domestic and lighter industrial activity. Confounding this pattern of anthropogenic pollutant input are several 'natural' sources of coal-measure derived material, in the form of gas seeps and oil-shale seeps. Monitoring the health of the Firth's shores requires measurement of biological responses and recoveries from both sources of disturbance.

4.4.3 Knowledge

Meiofauna are very sensitive to disturbance, and after a major pollution event, may take years to recover completely. On the other hand, their short life cycles and ability to colonise, means that individual species' responses may be relatively rapid. One barrier to the use of meiofaunal organisms in monitoring is their sheer abundance and diversity: it is rare to find a worker capable in the many different phyla involved, and rarer to find one with time on his/her hands. Nematodes in particular are often neglected in meiofaunal surveys owing to the small size of each individual, the relative paucity of easy morphological characters and the difficulty in identifying juvenile and other stages.

Meiofaunal taxa occur in many phyla, including, among others, the nematodes, arthropods, tardigrades and annelids. For each of these groups, at least some DNA sequence data is in a publicly accessible database

(GenBank www.ncbi.nlm.nih.gov/Genbank/Genbank Overview.html), having been provided by researchers worldwide working on phylogenetic or population genetic questions. These data can be used to develop potentially unique markers for species. DNA sequencing is becoming a common technique and its cost is dropping significantly. In addition, the technology for isolation of sequenceable DNA from small specimens has been developed to a stage where it is possible to implement it on a large-throughput scale.

Molecular bar-coding methods involve isolating an informative segment of the genome and sequencing it for each specimen, then using the sequence to place an individual in a molecular taxonomic unit (Floyd *et al* 2002). These methods may be both sensitive, in that they can distinguish between closely related 'species', and universal, insofar as they are applicable across the range of biological diversity. The resulting data consist of DNA sequences with associated ecological and other metadata. These data can be archived and shared between sites by the use of Internet-available databases.

4.4.4 Model

The meiofaunal assemblage of a particular site is an integrated response to both current and historical conditions, overlaid with stochastic and seasonal/climatic metapatterns. It is assumed that the distribution and abundance of individual molecular taxonomic units are influenced by the abundance of food, predators and the chemical composition of water and sediment.

4.4.5 Relevant questions identified by the scoping stage

The main aim is to build up a spatial-temporal map of meiofaunal species diversity and the relative dominance of individual molecular taxonomic units in the area of interest, in this case the shores of the Firth of Forth. These data can also be used retrospectively to describe changes over time and relate them to external pressures and drivers.

4.4.6 Sampling strategy, data gathering and analysis

The survey requires a dedicated sample acquisition and processing team. Small sediment samples are taken at sites distributed along the tidal shore, based on a sampling strategy that takes into account height above low water and substrate diversity as well as geographical spread. Samples are sieved for meiofauna and a subsample taken for individual molecular analysis. The remainder of the sample is archived, part as a standard fixed 'museum' deposition, and part as a total meiofaunal preparation. These permit future morphological surveys or DNA-chip based surveys. Individual meiofauna DNA is extracted, and a segment amplified and sequenced. Sequences are stored in a relational, online database.

Each sample can be assessed for taxon diversity (i.e. the number of different molecular sequences), taxon relative abundance, taxon biology, and thus ecology. Biological identifiers are added to sequences by comparing them with a database of sequences from well-identified specimens. Identity allows attribution of the known taxon's biology to the sequenced specimen, while close similarity will permit less robust annotation. Over time, with integration of the space and time-mapped sequence biodiversity data with known abiotic factors (particularly the point sources of pollutants) a map of meiofaunal response to the environment can be established. Re-assessment of diversity at intervals permits seasonal as well as longer term (e.g. associated with global warming, or the release from pollutant pressure) trends to be established. The data also allow simple comparison with other sites sampled in a similar manner.

Data analysis tools developed for molecular bar-code surveys of terrestrial species (Floyd *et al* 2002), incorporating sensitive discriminators for sequencing error and taxon identification can be adapted to the survey. All data and analyses can be readily shared between sites as raw sequence, or as annotated molecular taxonomic unit measures.

4.4.7 Science gaps

- Very few DNA sequences currently exist from properly identified meiofaunal specimens, in public databases. These are essential to establish the relationship between historical knowledge based on morphology and Linnaean taxonomy, and the new molecular taxonomy.
- The isolation of meiofauna individuals and the generation of molecular sequence are currently labour-intensive, but could be robotically automated, perhaps in one (or a few) environmental genomic taxonomy centres.
- To simplify the process, once a large database of relevant sequences is available, it would be possible to design a DNA oligonucleotide microchip that represented all relevant taxa. The chip could be produced in large quantities, and samples screened from bulk meiofaunal DNA samples by hybridisation for a fraction of the already small sequencing cost.
- A long-term goal is the development of methods that can be universally applied to all inshore habitats. A universal protocol would yield congruent datasets, permitting analyses of ecological patterns on a large scale.

4.5 Global state of plant biodiversity at the species level

4.5.1 Background

Completing a global assessment of the conservation status of plant species diversity by 2010 is one of the achievable goals identified as priorities for action on a global scale (NRC 1980; Ehrlich 2002). Its completion is also highlighted in the Global Strategy for Plant

Conservation, adopted by the Conference of the Parties to the CBD in 2002. Such an assessment will enable us to obtain a clear picture of those plants under threat (currently estimated as 22–47% of species), and to develop action plans to safeguard the most threatened of those species (Pitman *et al* 2002; Pitman & Jørgensen 2002).

4.5.2 Valued attributes

Plants are the primary producers and key structural elements of most ecosystems on land. Total plant diversity is often correlated with diversity of other groups of organisms (Williams *et al* 1998). The valued attribute is global plant species richness. Many different groups of interested parties wish to know about the state of plant diversity at the global level, ranging from those interested in maintaining the use value of many thousands of species to conservationists wishing to maintain overall levels of diversity. Plant diversity is relatively well known and thus a global synthesis represents a more achievable global target for plants than for other larger and less well-studied groups, such as beetles or fungi (Erhlich 2002). Making this information usable by non-specialists and transferring it to the field is an important goal, particularly for areas of high biodiversity where expertise may be lacking.

4.5.3 Knowledge

Progress towards a global overview of the state of plant diversity has been relatively rapid. In 1980 no South American country had complete Floras or checklists. Today, checklists have been compiled for Ecuador (Jørgensen & León-Yánez 1999), Peru (Brako & Zarucchi 1993) and Argentina (Zuloaga *et al* 1994; Zuloaga & Morrone 1999), demonstrating that such syntheses are possible and can be completed in a timely manner. Species level treatments like these are the starting point for more formal and detailed conservation assessments (Valencia *et al* 2000), which are lacking for the majority of the world's plant species.

Despite this progress and given that vascular/seed plants are one of the better-known major groups of organisms current knowledge is surprisingly patchy. As no comprehensive checklist of plants of the world exists there can be no agreed figure for total species number. Estimates range from 270,000 (Prance 2000; Scotland & Wortley 2003) to 420,000 (Govaerts 2001; Bramwell 2002). Complete species level checklists with full synonymy and formal conservation assessments for each accepted species are available for only a tiny proportion of plant species, for example the conifers (c. 600 species.), the cacti (c. 900 species) and some groups of orchids (c. 500 species). For other groups, published checklists have been made with synonymy and geographical information at country level (e.g. the International Legume Database and Information Service (ILDIS) www.ildis.org), but the information is generally not sufficiently detailed to serve as the basis for formal species level conservation assessments. For groups such as Sapotaceae, Euphorbiaceae, Magnoliaceae, and Fagales, information is only available on the numbers of species and in which countries they occur, but not which are most threatened and in need of immediate action to conserve them. An estimated 30% of plant species are included in global synonymised checklists of this sort. For the vast majority of plant species there is no comprehensive list of accepted names and synonymy. Instead, users rely on the International Plant Names Index (www.ipni.org), which lists all published names including many which should correctly be placed in synonymy. The database maintained at the Missouri Botanic Garden (TROPICOS; http://mobot.mobot.org/W3T/Search/vast) presents synonymy information for many taxa, but this is patchy and reflects areas of current staff and project interest (i.e. Mesoamerica, Ecuador, Bolivia, Iridaceae, Poaceae etc.).

4.5.4 Model

The model assumes that an informed collation of nomenclatural information from authoritative published sources (Floras and monographs) will result in a listing that approximates to a globally comprehensive survey of plant species. It further assumes that a large proportion (80–90%) of the taxonomic and nomenclatural information published in the recent literature is congruent and can be presented as a consensus listing with relative ease. Specialist taxonomic input is assumed to be a very limited resource that is best directed in a targeted fashion towards i) refining and correcting draft listings and ii) presenting defensible resolutions of taxonomically controversial groups.

With respect to the utility of the eventual product, the model assumes that the majority of plant species are already known to science so that, once synonymy is taken into account, known diversity is a reasonable proxy for total diversity for most plant groups and (to a lesser extent) areas. This assumption is more likely to hold true for groups where the baseline taxonomic information is quite good, for example Fabaceae (legumes). It should be tested for groups for which the available taxonomy is patchy and dated, for example Celastraceae.

Implicit in the whole undertaking is the key assumption that the results based on those plant species that are known will be representative of the true status of all plant species, whether known to science or not. Some synonymy will remain undetected indefinitely and tens of thousands of plant species remain to be described. Thus a fully complete and definitive checklist is not attainable within a timescale consistent with the urgency of the need to protect as many plant species as possible, whether known to science or not.

4.5.5 Relevant questions identified by the scoping stage

- How many plant species are known only from one country/state?

- Which plant species should be considered as priorities for conservation assessment and action?
- How can the rate at which the conservation status of individual plant species is assessed be increased one hundred fold, so as to focus attention on the most threatened species before they become extinct?
- This plant has been referred to by at least two different names – which is correct?
- This plant appears to have changed name more than once over the past few years – how will this affect the accessing of all the relevant literature for planning research or a conservation strategy?
- How can a meaningful comparison of these species lists be made from adjacent reserves in neighbouring countries?
- How many plant species are there?

4.5.6 Sampling strategy, data gathering and analysis

Sampling for a global checklist should be conducted on a taxonomic rather than a regional basis and based on knowledge already in the published literature. Herbarium collections should be used where available, particularly for poorly known groups and at local scales (Funk *et al* 1999). Decisions must be attributed; it will be necessary to trace synonyms by contributor if not from the literature (see examples in W^{3}FM – *Flora Mesoamericana;* www.mobot.org/mobot/FM).

Step 1: Create a searchable database for dissemination via the Web. The result would be a 'first pass' list with accepted names and place of publication; synonyms with place of publication (and attribution of taxonomic decision); geographical distribution by country (Taxonomic Databases Working Group (TDWG) level 3, with literature or herbarium specimen 'vouchering'); and a preliminary assessment of conservation status for each accepted species. These assessments would be: i) not assessed – assumed not threatened, ii) assessed and no apparent threat, iii) preliminary assessment indicates some level of threat, iv) data deficient, v) formal IUCN assessment completed.

Step 2: (in the specialist community) Send lists to taxonomically focussed referees; add links to on-line specimen databases (many of which exist, but are not linked up). Make revisions and add herbarium data as advised by referees.

Step 3: Make the global checklist available on-line in a format that can be annotated and checked by users of the information and accessible to non-specialists.

4.5.7 Science gaps

- The effect of synonymy remains one of the most difficult factors to assess. Estimates of overall rates of synonymy for vascular plants vary widely (see Section 2.2.1) (Govaerts 2001; Bramwell 2002; Scotland & Wortley 2003). Evidence from recent monographs may shed some light on the problem but a large proportion of the total diversity is accounted for by large genera that tend to be neglected by monographers.
- Distribution data compiled from the literature and from herbarium vouchers, are unlikely to prove an adequate basis for a preliminary assessment of conservation status in certain groups that tend to be under collected (such as palms and cacti). For these groups robust alternative means of documenting distribution must be established.

4.6 Genetic diversity in wild lentils

4.6.1 Background

In 30 years time, the world's human population will have grown significantly to 8.5 billion according to some estimates and substantial, sustainable increases in food supply will be needed. Conservation and sustainable use of plant genetic resources should form a foundation upon which improvements in sustainable agricultural productivity can be built. (Hawkes *et al* 2000; Maxted *et al* 1997).

4.6.2 Valued attributes

Wild species are an important component of agricultural biodiversity. Species that are relatives of crop plants contain valuable genes for crop improvement, and wild species of plants may be important nutritionally and culturally to people in many parts of the world, where they serve as food in times of famine, provide vitamins, minerals and nutrients, and provide income for cash-poor households (Hawkes *et al* 2000; Maxted *et al* 1997). In the case of wild species of lentils, it will be necessary to breed better adapted crop varieties in the future (Ferguson *et al* 1998*c*). Natural populations of lentil species conserved in regions of greatest diversity will be particularly valuable when their genetic diversity results from adaptation to changing abiotic factors. Wild species of lentil form an important component of ecosystems that are vulnerable to climate change, and to reduced rainfall in particular (Ferguson *et al* 1998*a*). Wild lentil germplasm is represented in *ex situ* seed bank collections but the diversity conserved does not accurately reflect the genetic diversity found in nature (Ferguson *et al* 1998*a*).

4.6.3 Knowledge

The genus *Lens* consists of 6 wild taxa that are relatives of the cultivated lentil – *L. culinaris* (Ferguson *et al* 2000). Their distribution is the Mediterranean basin, with one species spreading into Central Asia. All species exist in small, disjunct populations, predominantly in undisturbed rocky or pine forest habitats. These factors make these species vulnerable to genetic erosion unless effective conservation in protected areas can be achieved. Approximately 800 seed accessions are conserved in gene banks – the majority at the International Center for Agricultural Research in the Dry Areas (ICARDA www.icarda.cgiar.org/) where 'passport data' are maintained. Other data are available from herbarium specimens. Together these data sets are sufficient to determine accurate geographical distributions and ecological preferences for all species. Each species is highly inbreeding; heterozygotes are extremely rare. On average, 89% of genetic diversity within the species occurs among (as opposed to within) populations, but within-population variation is significantly different for different populations, and is therefore an important consideration for conservation (Ferguson 1998*b*).

4.6.4 Model

The model assumes that there is genetic variation within the wild species of lentils and that it may vary within and among populations in different parts of the geographical range. It further assumes that measures of genetic distance obtained from a sample of molecular markers can represent this variation in a quantitative and reliable way.

4.6.5 Relevant questions identified by the scoping stage

The main aim is to map the geographical distribution of *Lens* species and the genetic variation within these species. It is feasible to do this for four of the six wild taxa of lentils (*L. culinaris* subspecies *orientalis*, subspecies *odemensis, L. ervoides, L. nigricans*). From the map it should be possible to identify the most important wild populations for the conservation of genetic resources (Ferguson *et al* 1998a).

4.6.6 Sampling strategy, data gathering and analysis

An assessment of the distribution of the genetic diversity of each species both within and among populations was made using molecular markers (RAPD). This approach was chosen because RAPD markers are easily applicable to species where little or no genomic information is available, and they are relatively simple and inexpensive.

Geographical distribution of the genetic variation in the four taxa was assessed by calculating genetic distance between population samples, cluster analysis, then calculating gene diversity as well as 'number of clusters per sub-region' (NCSR). Further analysis was undertaken to determine whether diversity was directly associated with ecological and geographic range, so that areas where further sampling or collection should be undertaken, in a recurrent biodiversity assessment, could be identified.

Seed samples of each species were obtained from the gene bank accessions held at ICARDA (141 in total). Exploration and seed collection activities provided a dataset and material for assessing the correlation between genetic diversity and ecogeographic range to highlight future conservation priorities. While seed collection from each population was randomised, the locations of these populations was not, but was guided by ecogeographic information from various sources. Sampling (by ICARDA) was concentrated in the Fertile Crescent of the Middle East, but samples were also collected throughout the total geographical range of wild lentils from Portugal to Uzbekistan. It was not possible to determine the likely total number of populations in existence for each species, although previous pilot studies gave indications that the Fertile Crescent had the highest numbers of populations. For every sample, geographical co-ordinates of the collection site were available. Both assessments of diversity were undertaken on all samples.

The two measures of diversity (gene diversity and NCSR) sometimes gave conflicting results. To meet the objective of maximising conserved variation, the use of NCSR was used. Some areas of high diversity coincide with high plant population densities and are therefore good targets for reserve establishment and *in situ* conservation (listed below). In one case (*L. culinaris* subspecies *odemensis*) however, genetic diversity is distributed widely and will be more problematic to conserve *in situ*.

- *Lens culinaris* subspecies *orientalis*: two centres of diversity are identified (west and north Jordan and southern Syria; southeast Turkey and northwest Syria) and should be prioritised for *in situ* conservation.
- *Lens culinaris* subspecies *odemensis*: genetic diversity is localised in small pockets of distinct germplasm, and six of the eight subregions studied exhibited unique germplasm. For adequate conservation, many small reserves throughout the distributional range would need to be established.
- *Lens ervoides*: a centre of diversity associated with high population numbers (density) is found on the coast of Syria and is a good target for reserve establishment.
- *Lens nigricans*: a clear centre of diversity with a high population density exists in western Turkey that should be a target for *in situ* conservation.

Areas of high and unique genetic diversity are located for each taxon in Turkey, Syria and Jordan; outside of these countries, much less genetic diversity, total and unique, is found. This indicates that although the majority of existing *ex situ* conserved material has been sampled from Turkey, Syria and Jordan, it still under-represents the genetic diversity from these countries. Conversely the diversity found in peripheral countries is already well represented in existing collections.

4.6.7 Science gaps

- New data are needed for two taxa (not included in the study) – *Lens culinaris* subspecies *tomentosus* was only recently separated taxonomically from subspecies *orientalis*, so populations and samples with definitive identification were not included. *Lens lamottei* is regarded as a cytotype of *L. nigricans*, and insufficient populations/material could be identified for the study.
- Although the majority of existing *ex situ* conserved material has been sampled from Turkey, Syria and Jordan, it still under-represents the genetic diversity from these countries.

- *In situ* genetic reserves have recently been established for wild lentils in Turkey, Syria, Lebanon, Palestine and Jordan, but even these multiple reserves cannot represent the total genetic diversity found in nature. ICARDA continues to routinely sample genetic diversity for wild lentils at the geographical centre of their diversity.
- Other molecular markers such as SSRs, AFLPs or SNPs could provide much more transferable information, and could be developed as specific indicators of biodiversity loss for future assessments in this group of species.

4.7 Freshwater fish of conservation concern in the UK and Mexico

4.7.1 Background

Around 40% of the 25,000+ species of fish are found in freshwater habitats. This figure is all the more impressive given that available fresh water, in lakes and rivers, accounts for less than 0.01% of water on the Earth (Nelson 1994).

4.7.2 Valued attributes

Freshwater fish are of significant value to a wide variety of interested groups. Some species, for example the bony-tongued pirarucu, *Arapaima gigas*, and the herring-like *Limnothrissa miodon*, support substantial fisheries. Others, including the Atlantic salmon, *Salmo salar*, are iconic game species and are associated with a significant recreational industry. Freshwater species are important in fish farming and underpin the valuable home aquarist trade. In addition, they have been extensively used for investigations of behaviour, ecology, physiology, genetics and evolution. Finally, freshwater fish are useful indicators of pollution and have come to symbolise a healthy ecosystem. The return of salmonids to the Thames in London was hailed as a breakthrough in environmental management.

4.7.3 Knowledge

Although freshwater fish have been the focus of a large body of scientific research and are well documented in temperate regions it is estimated that Amazonia and other large tropical systems contain significant numbers of unrecorded species. What is certain is that the threats facing freshwater fish species worldwide are disproportionately higher than those for terrestrial vertebrates. More than 20 percent of the world's known 10,000 freshwater fish species have become extinct or endangered in recent decades. In the United States 343 fish species (36% percent of the fauna) are at risk of extinction and 27 species have already been lost (Moyle & Leidy 1992).

Two examples are used to highlight the issue. In the UK relict populations of whitefish (genus *Coregonus*) are found in the English Lake District, Scotland, North Wales and Northern Ireland (Winfield *et al* 1996). The pollan, *C. autumnalis*, is still fished commercially in Lough Neagh but the population is at risk from poor water quality and competition from non-native roach, *Rutilus rutilus*. The vendace (*C. albula*) and whitefish (or schelly, powan or gwyniad) (*C. lavaretus*) are already protected under the Wildlife & Countryside Act 1981. Both surviving UK vendace populations and four of seven whitefish populations occur in stillwaters of the English Lake District, where they and their habitats have been subject to considerable conservation research and management over the last few years.

The second example, the Goodeidae, are an endemic group of livebearing Mexican fish. Thirty-five species are currently recognised. Of these 19 species are endangered (eight critically) and two are already extinct in the wild (though the possibility of reintroduction exists as some stocks are maintained in culture). Habitat loss and fragmentation – a result of the increasing urbanisation of Central Mexico – invasive species and pollution are the principal factors in the loss of native fish. Mexican biologists are currently quantifying these threats (De la Vega-Salazar *et al* in press *a, b*).

4.7.4 Model

A simulation model is used to carry out population viability analysis (PVA) on each of the fish species. This subdivides each population into component sub-populations where necessary. Effects on demographic rates of exploitation, predation or competition from introduced species and habitat loss and degradation are included in the model and population-level outcomes, such as probabilities of extinction are assessed.

4.7.5 Relevant questions identified by the scoping stage

- What is the probability of extinction and expected population size within a specified time period under existing and forecast conditions?
- How would specified changes to management affect the probability of extinction and expected population size?
- Would reintroductions be likely to increase population viability?
- Can a minimum viable population size be identified below which the population becomes vulnerable to stochastic extinction?
- What do local resource managers need to know to implement effective conservation programmes?

4.7.6 Sampling strategy, data gathering and analysis

In commercially exploited species (such as the pollan) sampling can be integrated with the normal fisheries activities. Where vulnerable populations and species are involved non-destructive sampling should be used wherever possible. The goal is to monitor changes in species status over time and evaluate threats. Data gathered will include population level data for as many species at as many sites as possible, habitat quality data for rivers and lakes and the presence and abundance of invasive species. Since inferences on changes in the viability of populations and species require repeated sampling it will not be possible to examine all taxa at the same degree of resolution. One approach is to focus on key groups that are already reasonably well documented. These include the Lake District whitefish and goodeids in the genera *Skiffia* and *Zoogoneticus.*

All data gathered must be appropriately archived in raw and processed form. Forced and unforced changes in sampling techniques must be taken into account during data interpretation. Since freshwater fish throughout the world are affected by the same anthropogenic impacts there is considerable scope for collaborative projects that analyse the rate of biodiversity loss and draw up common guidelines for the preservation of stocks and species (Moyle & Leidy 1992).

4.7.7 Science gaps

- Population level data such as size, structure and recruitment over all species' ranges are not uniformly available for most species of freshwater fish.
- Presence (and abundance) of invasive species coupled with field investigations (supported where possible by laboratory studies) of interactions between invasive and target species will be critical to monitoring changes in relation to the 2010 target.
- Close monitoring of environmental variables including eutrophication, siltation, pesticide spills and disturbance will allow environmental data to be correlated with biological effects.
- The performance (including behavioural and reproductive success) of hatchery or zoo-reared fish prior to any reintroduction to the wild must be evaluated.

4.8 Barndoor skate

4.8.1 Background

The barndoor skate, *Dipturus laevis*, is a large-bodied, wide-ranging marine fish found in coastal regions and deeper waters from North Carolina to the Grand Banks off Newfoundland. It was abundant up until the 1950s, but since then has undergone severe declines to the point where it was considered vulnerable to extinction (Casey & Myers 1998). Fisheries have been the clear driver of its decline, and its recovery is probably hampered by mortality when it is caught as unwanted bycatch of commercial fisheries aimed at other species.

4.8.2 Valued attributes

Two different communities of people are considered in this example. The first is concerned with species conservation. They include the people who proposed that the species should be listed under the US Endangered Species Act. Their primary value is a reduced risk of extinction, though of course they will probably also be concerned about any negative consequences of recovery programmes for local fisheries. The goal would be for the species to attain a large enough population size to make it unlikely to become extinct within a time period of centuries. This value has two implications for an assessment. First, it implies a risk-averse attitude to assessment whereby an over-estimate of population size and viability is clearly unacceptable, whereas some under-estimate would not be as bad. Second, precise estimates of population size and extinction risk would be ideal, but it might also be acceptable to have sampling strategy that involves monitoring a small part of the range so long as this could be representative.

The second community is involved in fisheries. They might be less concerned about extinction risk *per se*, but want the species to show sufficient recovery to avoid harsh measures being imposed on their fishing activities as a result of concerns about skates being taken in bycatches. Ultimately they might like there to be a sufficient number that a barndoor skate fishery could be opened. In contrast to species conservationists, they may not mind over-estimates of population size. However, they would be very concerned about over-estimates of extinction risk, which could lead to unnecessary curtailment of their fishing. People who manage the local fisheries on their behalf might therefore be content with index or a sample, but the level of accuracy required would be greater if the results started to suggest a need for reduced fishing.

4.8.3 Knowledge

Barndoor skates are known to inhabit shallow waters as well as deeper regions that are currently beyond the reach of fishing boats. Little is known about the biology of this species, though educated guesses are possible based on related species. Thus, it probably matures at about age 11, and it may produce about 50 eggs per year.

4.8.4 Model

A simulation model of the population could be developed and used to produce a population viability forecast. Ideally an age- or stage-structured model would be used. This should also have a spatial component, to reflect spatial variation in densities and to inform decisions about potential area closures. It would be important to model the effects drivers and pressures, such as habitat alteration, fishing pressure, and bycatches on demographic rates. There might be a specific need to look at size and age structure in bycatch alongside information on size-related breeding structure.

4.8.5 Relevant questions identified by the scoping stage

- What is the current population size and recent population trend of the barndoor skate?
- What is the probability of extinction and expected population size within a specified time period under existing and forecast conditions?

Figure 4.1 Abundance of the barndoor skate from the Gulf of Maine to southern New England (Dulvy et al 2003)

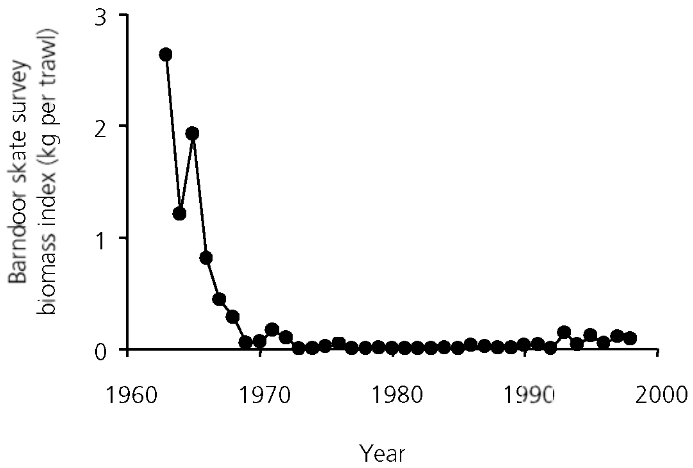
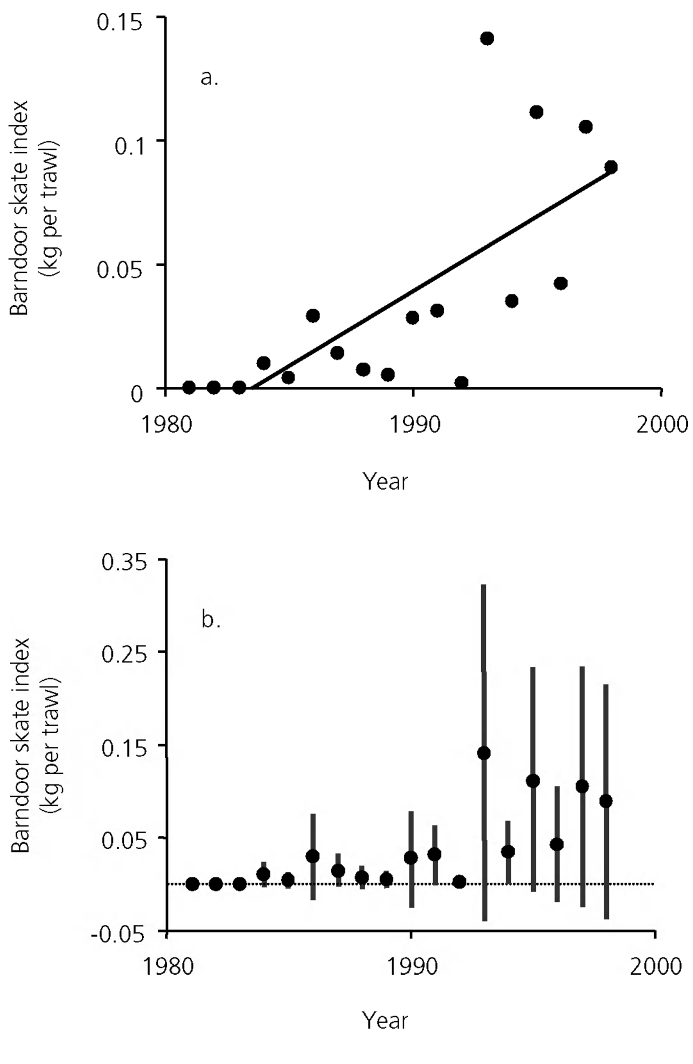


Figure 4.2 Same time series as in Figure 4.1, restricted to the period 1980–2000 to clarify recent trends in abundance of the barndoor skate. a) Statistically significant increase in mean abundance (regression: P = 0.002). b) Same data as in a) but with 95% confidence intervals, showing an overlap with zero abundance in most years



- How would specified changes to management affect the probability of extinction and expected population size?

4.8.6 Sampling strategy, data gathering and analysis

This case requires estimates of population sizes and trends. These may need to be quite precise to satisfy those who wish to estimate risk of extinction, whereas less precise indices may suffice for those concerned mainly with overall trends. This species illustrates the typical difficulties of sampling rare organisms, especially in the sea, where surveys can be very expensive, and it is difficult to stratify surveys according to habitats because habitats are not well known.

Dedicated surveys using trawlers can be used to estimate abundance if catches per unit effort can be scaled up to population sizes by estimating catchability. Observers on fishing boats can help estimate bycatches in commercial fisheries. Habitat surveys and environmental monitoring can be used to match fish survey data to habitats, and thereby scale up to regional estimates. Note that the long-lived nature of this species means that fish surveys can be repeated over longer time periods than would be necessary with species that have shorter generation times.

The recent data in Figure 4.1 seem to indicate a slight upward trend in the numbers of this species, based on surveys. This is brought out more clearly by a reanalysis in Figure 4.2a. Based partly on this increase, it was concluded that there was 'no evidence that they were in danger of extinction or likely to become endangered within the foreseeable future' (NEFSC 2000). This interpretation of the data as well as the discovery of the fish in deeper waters than previously considered led to the denial of a proposal to list this species under the US Endangered Species Act. However, consideration of the variation around the estimates from the surveys suggests a less optimistic interpretation (Figure 4.2b). The 95% confidence intervals include zero abundance in most of the last 15 years (Dulvy *et al* 2003). Furthermore, these data include adults and juveniles combined, whereas it would be more informative to examine population trends within age classes, especially adults.

These results show how difficult it can be to give clear answers about trends in biodiversity when individuals are rare. Unless a massive and expensive survey programme is launched, it is unlikely that biologists will be able to say with any certainty whether or not this species is recovering by 2010.

4.8.7 Science gaps

- Existing survey data is severely lacking in precision. This is inevitable for marine surveys of rare fish species.
- It is very difficult to forecast population trends of species like the Barndoor Skate, when little basic information about life histories and behaviour is known, especially if the data do not distinguish between adults and juveniles.
- A frequent problem with marine species is lack of information about habitat requirements.

4.9 Trinidadian Guppy

4.9.1 Background

The Trinidadian Guppy, *Poecilia reticulata*, has become a model system for testing theories in evolutionary biology (Houde 1997). The species is native to Trinidad and Tobago and NE South America and is widely distributed among freshwater habitats there. Caryl Haskins, working in the 1940s and 1950s, was the first person to observe that populations of guppies differed in a predictable manner and that this variation is correlated with the severity of the predation risk (Haskins *et al* 1961). Subsequent researchers have shown that a shift in the intensity of predation leads to heritable changes in a range of traits. In other words the system can be used to demonstrate evolution in action over tractable timescales. For example, when a population is released from severe predation males become more colourful, females have fewer but larger offspring and the intensity of schooling behaviour declines within 10 to 100 generations (Endler 1995; Magurran 1998; Reznick *et al* 1990). Moreover, recent work has revealed that the degree of heritable variation in populations is correlated with molecular variation. This variation is superimposed upon marked genetic divergence amongst populations, itself a legacy of geological events.

4.9.2 Valued attributes

The primary value of this system lies in the opportunities it offers to evolutionary biologists. At present more than 20 different groups of scientists (from North America and Europe) use the species to answer questions in natural and sexual selection. Over 250 papers have been published on the system since 1981. However, the guppy system is also of value to Trinidadians since income is generated through scientific research and because it is a vehicle for knowledge transfer from visiting to local biologists. Finally, the wild fish provide genetic material for the ornamental fish trade.

4.9.3 Knowledge

The guppy is not an endangered species in the conventional sense – population sizes may be large and the species is found in every freshwater habitat from clear mountain streams to turbid brackish pools. However, the rich diversity of populations is threatened. One of the great strengths of the guppy system is that contrasts between predation regimes (and other ecological variables) are replicated across rivers and between guppy clades or subspecies. This greatly enhances the power of the system in hypothesis testing. But, like many other freshwater systems, Trinidadian Rivers are subject to pollution – including industrial, domestic and agricultural effluent, disturbance, water abstraction, exotic introductions and periodic flooding (exacerbated by forest clearance). Furthermore, scientists can impact the very biological diversity they come to study by over-collecting at key sites, and moving fish between localities. Artificial transplants have proved to be an important tool for deducing evolutionary rates but at the same time lead to irreversible changes to guppy population genetics and to the ecology of the manipulated streams.

4.9.4 Model

A simulation model of the fish population is used to carry out population viability analysis (PVA). This approach is especially relevant since researchers are primarily interested in the small, low-fecundity populations found near the upper altitudinal range of the species. Such populations typically experience large fluctuations in size and sex ratio. The guppy system can thus be used to model the consequences of various biotic and abiotic factors on vulnerable populations. The model can also be expanded to include the effects of gene flow on heritable local adaptation.

4.9.5 Relevant questions identified by the scoping stage

- How do biotic and abiotic factors affect the size and distribution of the guppy population and its long-term viability?
- How does gene flow among sub-populations affect demographic and evolutionary processes?
- How do fates of populations experiencing different rates of immigration vary? Since the balance between female choice and sexual coercion varies amongst populations models of gene flow must in turn be informed by models of sexual selection and sperm competition and information on individual mating tactics.
- Does molecular variation reflect heritable variation? The guppy system provides important opportunities for further testing this.

4.9.6 Sampling strategy, data gathering and analysis

The goal must be to collect consistent information on a wide range of populations. As many as possible of the following items should be recorded on each occasion. Ideally there should be a stratified sampling programme to cover the diversity of guppy habitats but in practice samples are likely to be restricted to the sites that guppy biologists habitually visit. Sampling should also be replicated over time so that the temporal dynamics of populations can be assessed.

- Grid reference of site
- Population size
- Sex ratio
- Age/size structure of population
- Presence (and if possible abundance) of other fish species and key invertebrates
- Basic habitat descriptors – river width, depth, temperature, cover
- Water quality descriptors – pH, turbidity, biochemical oxygen demand (BOD), nutrients, productivity, pollutants
- Description of any impacts such as quarrying, sewage outfall, pesticide use
- Mark-recapture studies to estimate mortality risk, migration rate.
- Molecular analysis to include nuclear and mitochondrial DNA markers
- Record of precise number of fish collected from and/or introduced to each site.

Many of these data are already routinely collected but are stored in field notebooks and individual computers. The challenge therefore is to ensure that they are entered in a single database and that all researchers collect and deposit information in a standard manner. The database, as described above, would provide rich opportunities for comparative analyses of populations using standard approaches in ecology and evolution. Its main purpose however would be to generate guidelines for the conservation of guppy populations in Trinidad. These guidelines would be developed through consultation with Trinidadian biologists and international researchers.

4.9.7 Science gaps

- To date few studies have been able to disentangle genetic diversity and population size when assessing population viability. This system could be used to address this important science gap.

4.10 Brown argus butterfly

4.10.1 Background

Brown argus butterflies (*Aricia*) are members of a small group of related European butterflies whose taxonomic status in Britain is still a matter of controversy. Genetic and ecological work has investigated fragmented populations of this group in order to understand their taxonomic status and the role of adaptive evolution in maintaining genetic diversity at the species boundary.

4.10.2 Valued attributes

Brown argus butterflies are locally distributed and strongly associated with chalk downlands and limestone grasslands, where one of the main larval food-plants, the rockrose *Helianthemum nummularium*, grows abundantly (Thomas & Lewington 1991). High species diversity of these calcareous grasslands is maintained under traditional grazing regimes: knowledge of the ecology of brown argus and other butterfly species is critical for grassland management that is designed to conserve both plant and animal species.

Approximately 30–40% of so-called 'species-level' diversity of European butterflies consists of closely related sister species that are either partially (parapatric) or fully (allopatric) geographically separated. These sister species either do or potentially could interbreed. For conservationists, this leads to the question of how distinct forms are maintained in areas of contact between related species.

4.10.3 Knowledge

Originally, *Aricia* from Scotland and northern England was classified as the only endemic British butterfly species, *Aricia artaxerxes*. Later, northern and southern British forms were amalgamated as subspecies within the European *Aricia agestis*. However, most recent treatments separate them again (e.g. Thomas & Lewington 1991). Based on genetic data from mitochondrial DNA, both species as currently envisaged have wide distributions in Europe (Aagaard *et al* 2002), so that the northern British *A. artaxerxes* is no longer viewed as an endemic British species, in spite of some differences in colour pattern from the European forms.

The two species differ mainly in ecology: northern *A. artaxerxes* is single-brooded, flying in June and July, while southern *A. agestis* is typically double-brooded, flying in May and early June, with a second brood in August (Thomas & Lewington 1991). The number of broods is an adaptation to prevailing temperature: two broods are achieved in the south, but only one brood is possible in the shorter northern growing season.

In North Wales, both single-brooded and double-brooded forms occur across a patchwork, or 'metapopulation', of different limestone grassland sites. Recent mitochondrial DNA studies have shown that both brood types have southern mitochondrial DNA haplotypes, suggesting that all forms in north Wales belong to *Aricia agestis* (Aagaard *et al* 2002; Wynne *et al* submitted). However, it may be that the area represents an ancient hybrid zone between the two taxa, and the northern mitochondrial haplotype has been simply lost by genetic drift. Thus genetic and ecological studies in this area would be of great interest to understand both the taxonomic status of a potentially endemic British taxon, and also the adaptive evolution that may have led to their divergence.

4.10.4 Model

Consideration of how genetic diversity is maintained and can be conserved in this system requires identification of:

- Whether single- and double-brooded forms differ genetically.
- Whether the forms are 'adaptive', in the sense of occurring in habitats where the number of broods per year matches the local microclimate.
- The extent to which genetic differences between different populations depend on their connectedness to other populations.
- How landscape-scale patterns of genetic variation reflect metapopulation dynamics.
- How a species achieves distinct adaptations (one or two generations per year) in the face of continuous environmental variation (temperature).

4.10.5 Relevant questions generated by the scoping stage

A key need is to characterise and understand climatic adaptation of *Aricia* butterflies in terms of the numbers of generations per year. The taxonomic status of the two forms is also of interest, because two nominal species occurring in the UK have previously been recognised on the basis of whether they have one or two generations per year. Understanding this system will show how distinct forms are maintained in areas of contact between related taxa, and how extinction/colonisation events affect this adaptive response in a taxonomically relevant character.

4.10.6 Sampling strategy, data gathering and analysis

All *Aricia* populations across mainland North Wales are mapped and visited repeatedly, and population densities are assessed. Populations are always either single-brooded or double-brooded; no population included individuals from both brood types (Wilson *et al* 2002; Wynne *et al* submitted). Population sizes and distances between populations are recorded to give an estimate of how connected populations are to other populations and groups of populations. Temperature is monitored continuously, and these data are used to develop a statistical model that provides an estimate of the thermal environment for each patch suitable for the butterflies. Samples of key populations are studied genetically using seven enzyme loci.

Double-brooded populations are typically found in the warmer habitat patches, while single-brooded populations are found in cooler habitats, as expected. Genetically, populations of the two brood types are not clearly differentiated in enzyme alleles; instead there is an overall effect of physical distance on genetic distance. Caterpillars from single- and double-brooded populations differ in their responses to day length in captivity: the caterpillars of single-brooded populations enter an over-wintering diapause when exposed mid-summer day lengths, whereas double-brooded caterpillars continue to grow.

However, the match between the number of broods and the thermal environment is not perfect. Populations near to large populations of a particular brood structure tend to show the brood structure of those populations, rather than the optimal brood structure for the particular thermal microenvironment in which they were found. These mismatched populations also have generally lower densities, as expected if poorly adapted to the local climate (Wynne *et al* submitted). These maladaptive populations are almost certainly a result of extinction/recolonisation turnover, which, according to simulations, is expected to be much faster than local adaptation. The likelihood of rapid population turnover is also suggested by genetic results: isolated populations are more differentiated genetically than populations near to large networks of populations, suggestive of drift caused by colonisation bottlenecks. Perhaps surprisingly, local connectivity of populations acts to prevent local adaptation over distances of tens of kilometres, versus typical individual movements of much less than 1km (Wynne *et al* submitted). This appears to be due to the importance of rare long-distance movements in recolonising extinction-prone populations.

4.10.7 Science gaps

- Long-term monitoring (say 20 years or more) of very large numbers of populations is required to test and refine estimates of colonisations and extinctions based on simulations. Such data are rare, but essential for understanding the population biology and adaptability of such species.
- As well as documenting newly colonised habitat patches, it would also be extremely useful to know from which source populations successful colonisations originated. Genetic studies will hardly help in this matter, since the populations studied here were only weakly differentiated, and colonization may cause a bottleneck in population size that can radically change gene frequencies.
- New molecular markers characteristic of *A. artaxerxes* and *A. agestis* will be needed to assess haplotypes across the species range, focusing on N. Wales. Recently a sex-linked marker has been found which has characteristic haplotypes in these two forms (Wynne *et al* submitted). Polymorphism in some N. England single-brooded populations suggests that ancient hybrid zones may indeed exist.
- To clinch understanding of climatic adaptation by *Aricia* in N. Wales would require finding the genes responsible for switching from single to double-brooded phenology. Independent evolution of single-broodedness in N. Wales and in *A. artaxerxes* in N. England and Scotland should be detectable via sequence differences at these loci. Because of the difficulty of isolating such genes, it will be a long time before this particular science gap is filled.

4.11 The tiger in India

4.11.1 Background

During the 1970s, the Indian government made a commitment to protect the tiger in India. 'Project Tiger' was launched, and focussed on the management of the species in 27 Project Tiger Reserves distributed across the country. Thirty years on the programme has been a national success; over 50% of the world's tigers still live in India, one of the most densely populated counties on Earth with almost a billion people inhabiting a deeply fragmented habitat and facing high levels of poverty.

4.11.2 Valued attributes

Project Tiger is a continuing commitment with a budget approved every five years by the Indian Federal Government. The main objective of the project is to ensure maintenance of a viable population of tigers in India for scientific, economic, aesthetic, cultural and ecological values. As one of the main threats to tigers is habitat loss a second objective of the project is to protect areas of national biological importance that will also be of benefit, education and enjoyment of the people. The government and Indian biologists therefore wish to know whether, and where, the population of tigers is increasing, stable or declining.

4.11.3 Knowledge

Tigers continue to face a variety of threats, even within the reserves. Habitat deterioration, prey depletion, poaching for trade, and direct persecution by people are all continuing problems. However, tigers have relatively high fecundity, and the potential to recover from depletion as long as there is adequate prey and suitable habitat. Political will and commitment for Project Tiger have declined over time (Thapar 1999). Some biologists now question the methods used to monitor tigers across their range (Karanth 1999; Karanth *et al* 2003).

Over the last 30 years the status of the tiger has been assessed by a regular nation-wide 'pugmark census'. Over a period of no more than a couple of weeks, thousands of government staff search tiger habitats and gather plaster cast imprints from the left hind foot pugmark of each tiger track located. A central database, individual recognition from the pugmarks and reconciliation across geographical areas result in an estimate of the tiger population number for the country as a whole. This method is therefore an attempt to census the entire population in India. The variation in numbers between each census forms the basis for future management and funding of the programme.

Field studies on wild tigers, in recent years, have generated new knowledge about their ecology and behaviour, and methods for population estimation have become more sophisticated. These advances can inform the choice of methods used in the Indian national tiger census.

Tigers may be quite polygynous with overlap in the ranges of breeding females within male territories, common routes followed by adjacent breeding males, and both female and male transient individuals that move across breeding territories. In the census therefore, not only must tracks from each individual tiger be located, regardless of the accessibility of the area, but trackers must also be able to distinguish between different individuals who may be following the same tracks. This must pose difficulties in all habitats but will be especially problematic in areas where the substrate is inappropriate, and be almost impossible in areas that are especially remote or inaccessible. Hence, is it appropriate to undertake the full census and to estimate the size of the entire tiger population when there are so many uncertainties, especially as the method used does not allow any estimate of the uncertainty associated with the resulting population number? (Karanth *et al* 2003).

4.11.4 Model

The tiger is widely distributed across India, but depends on local reserves for its persistence. Local extinction within reserves, the loss of migration routes and the fragmentation of the habitat could all lead to its rapid decline. Absolute measures of population numbers are therefore less informative for responsive conservation planning than effective monitoring of the range extent, and of the trends in population size in key reserves.

4.11.5 Relevant questions identified at the scoping stage

Three goals for tiger monitoring have therefore been stated (Karanth & Nichols 2002; Karanth *et al* 2003):

- How is the countrywide distribution of the species changing over time? This can help to assess the negative effects of habitat fragmentation and local extinction versus the positive outcomes of conservation actions leading to range expansion.
- What are the observed trends in local abundance in individual reserves? This will help managers to assess whether the status locally is improving, deteriorating or stable. This measure allows conservation actions, and where necessary, more detailed monitoring to be appropriate targeted.
- What is the absolute abundance of tigers, especially at priority sites?

4.11.6 Sampling strategy, data gathering and analysis

At the national level (>300,000 km^2 of tiger habitat), the presence or absence of tigers could be recorded annually by geo-referenced, statistically rigorous sampling surveys recording presence or absence of tiger tracks and other signs. This would be substantially less effort than the pugmark census but yield annually a map of the extent of tiger populations with associated uncertainly levels.

Within reserves, managers need to monitor local populations to assess the effectiveness of conservation measures. But estimating population density may be prohibitively difficult and expensive, especially on the annual basis that is recommended for management (Karanth *et al* 2003). Instead, an index of relative density could be developed, which might not be easily translated to population abundance measures but would be relatively cheap, objective and replicable, and provide useful information for managers. The index might be derived from standardised encounter rates of sign, such as the number of tiger track sets or tiger scats encountered per 10km walked, or the proportion of 1km long trail sections in which tiger sign was detected.

Where resources allow, or where the low-intensity methods above suggest more knowledge is required, absolute numbers of tigers, and their age and sex ratios may need to be estimated. Land transect surveys and camera trap capture-recapture surveys are possible methods to use here.

4.11.7 Science gaps

This example highlights the importance of choosing the appropriate monitoring method for the context. Limited financial and skill resources can be used to better effect when information on the species and relevant statistical techniques are incorporated into the design of the monitoring programme.

Further information on the breeding and ranging behaviour of different age and sex individuals, an improved understanding of predator-prey relationships, and better techniques for monitoring prey abundance are all needed to improve tiger monitoring and thereby its conservation management (Seidensticker *et al* 1999).

4.12 Case study conclusions

The 11 case studies presented above show that the framework presented in Section 3 can be used to guide a wide variety of biodiversity measurements. It does no more than represent best science practice but its value is that it helps promote careful dialogue between scientists and stakeholders during the preliminary scoping phase, it helps uncover assumptions about the nature of the system (the initial ‘model’), and this information, in turn, informs the sampling strategy, data gathering and analysis. All of the case studies found major science gaps that ideally, would be filled in order to provide complete pictures of the state of biodiversity in each study. However, in summarising prior knowledge and articulating conceptual models of the system, it often becomes apparent that a great deal is known about each case, which could usefully inform practical decisions about what to sample, where to sample, and how often. Use of the biodiversity measurement framework would therefore help those engaged in biodiversity assessment make the best use of the time and resources available in seeking to provide answers to the questions being asked by the interested parties.

5 Conclusions and recommendations

Clear evidence and widespread scientific consensus indicate that losses of biodiversity have accelerated over the last two centuries as a direct and indirect consequence of human population growth, unsustainable patterns of resource consumption and associated environmental changes, such as eutrophication and the effects of alien invasive species. Effective methods of measuring biodiversity are needed to monitor its condition and to measure progress toward the target established at the World Summit on Sustainable Development in 2002 of achieving 'a significant reduction in the current rate of biodiversity loss by 2010'. Despite data insufficiencies, substantial progress has been achieved in developing and implementing conservation techniques and policies to protect biodiversity. However, no sound basis currently exists for assessing performance against the WSSD objectives. Without internationally agreed measures it will be impossible to determine whether losses of biodiversity are declining or accelerating. It will therefore be impossible to assess the success of mitigating actions.

A broad suite of measures is necessary to monitor changes in biodiversity through time, and to assess the success of conservation and sustainability initiatives. Such measures need to be implemented cost-effectively and must be scientifically sound. However, a significant impediment to assessing the overall state of nature, now and in the future, is the extraordinarily limited knowledge of many aspects of the biodiversity with which we share the planet, and upon which we all depend for critical goods and services. Most significantly, of all the species present on earth, possibly only one in ten are known to science. The fates of organisms that have not yet been scientifically described cannot be measured. Likewise, how ecosystems function cannot be understood until more is known about the organisms of which they are comprised. Several key deficiencies in knowledge exist:

- For most species that have been described little or nothing is known of their distribution, ecology, population sizes or evolutionary history.
- Knowledge of biodiversity is most limited and patchy for the very geographic areas and biomes where species diversity is greatest – principally in the tropics, and next to nothing is known of the biodiversity of the deep sea.
- Reliable estimates of current conservation status are available for only a tiny proportion of species and are biased toward certain groups (birds and mammals) and certain parts of the world (temperate regions).
- Understanding of trends in the state of biodiversity is hampered by the absence of reliable baseline data for most groups and habitats as well as inconsistencies in methodology over space and time.
- Knowledge of the benefits to people from biodiversity remains limited, especially in terms of the value of economic services.
- Analyses are needed of the gains and losses incurred as relatively pristine habitats are transformed and biodiversity is lost.

Measures of biodiversity vary in scale and purpose and can extend beyond the species level to encompass entire habitats and ecosystems or focus on details of populations and genes. No one measure is best for all purposes. A broad suite of measures is necessary to meet particular needs but the sheer multiplicity of current measures contributes to the difficulty of building public awareness and understanding. Selecting appropriate measures requires a careful consideration of the purpose of the assessment as well as the tradeoffs between usefulness, completeness and required effort in terms of time and resources. Although commonly used, measurements of extinction rates for species are an inherently poor way to monitor biodiversity loss. Population data, although expensive to collect, can provide a more sensitive measure of a particular species over the short term and, depending on the species chosen, can often have considerable resonance with the policy-makers and the public.

Detailed measures of many key aspects of biodiversity are limited by resources, but effective sampling strategies and application of new technologies could transform the current knowledge of changes in habitat types, patterns and rates of delivery of ecosystem services, distributions of specific taxa and changes in population abundance.

For many geographic areas, important information on historical status of habitats, species and ecosystems resides in museums, libraries and informal records. Making this information available as a basis for assessing trends and establishing time series would greatly increase the value of data being collected now. Transferring taxonomic information into an accessible form, for example through the use of the Internet, appropriate information technology or as user-friendly guides, will greatly enhance conservation efforts. A list of taxonomic experts, who are able to respond either remotely or directly, could also support situations where advice is required urgently.

Despite the difficulties of measuring biodiversity, and current inadequacies, enough is known about the state of global biodiversity to say with confidence that unprecedented rapid losses of biodiversity are occurring. What are needed are better measures of rates of loss together with information on the geographic areas, habitats and groups of organisms where these losses are concentrated. Better measures, based on sound science, will help assess success in managing biodiversity and preventing further losses.

We therefore make the following recommendations:

- The framework for biodiversity assessment presented in this report should be applied routinely by those commissioning, funding and undertaking biodiversity measurements. As the case studies presented in this report (Section 4) demonstrate, the framework can be used for terrestrial, freshwater and marine systems, and at the ecosystem, species and population levels. We also believe it is applicable to situations ranging from large, long-term studies to instances where a rapid response is required, and can accommodate differences in the timescales of stakeholder interests. Application of the framework would help ensure stakeholder involvement and that measures are fit for the purpose to which they are being applied. It would also help to identify weaknesses in some current approaches as well as major science and information gaps.

- Urgent emphasis on synthesis is needed by the scientific community to make otherwise scattered data more readily available and more useful. This needs to be accompanied by a more favourable attitude towards such projects by funding bodies and more widespread use of web-based technology for more effective dissemination of information. Synthesis will quickly reveal key gaps in knowledge, which should then be addressed by the development of realistic new programmes capable of delivering substantial improvements in knowledge of otherwise poorly understood geographic areas, habitats and groups of organisms. Such programmes must be implemented urgently with realistic goals for completion. It is crucial that they are completed in the course of the next three to seven years.

- The scientific community should focus on the development of data gathering and analytical techniques to provide biodiversity information that is both relevant and organised for efficiency. This will involve: consideration of sampling strategies (both sample sizes and appropriate stratification); assessment and integration of the relevant drivers of change, including input from the social sciences; better information on the values ascribed to biodiversity by different stakeholders; effective deployment of new techniques from molecular genetics, bioinformatics, remote sensing and e-science; as well as consideration of the role of volunteers and informal methods of data gathering.

- We recommend enhancing levels of taxonomic training and linking such training more directly to the ongoing measurement and management of biodiversity. Increasing scientific and technical capacity in countries with high biodiversity is crucial. It is especially important to increase the number of professional taxonomists for key groups of organisms, and to ease the problems of identifying a broad range of organisms in the field by the more effective use of appropriate information technology. Low cost approaches to facilitate identification can also be extremely effective. Maximising the efficiency with which the information generated by systematists is transferred and made useful to biologists in the field is crucial.

- The international community and intergovernmental organisations should undertake a review of current programmes for biodiversity status assessment, especially at a global level. Existing monitoring programmes that are already contributing to, or delivering, robust, global assessments of biodiversity must continue. Where possible they should be enhanced and extended. Across both new and existing programmes, there should be a particular focus on establishing a baseline and rates of change so that progress towards reducing rates of biodiversity loss by 2010 can be measured. Expanding existing monitoring programmes and developing new assessments will require a marked increase in funding as well as a degree of co-ordination and co-operation among NGOs, academics, and governmental and intergovernmental agencies.

Annex A List of submissions to call for views

The working group sought the views from a variety of organisations and individuals. The working group is grateful to all who responded; they are identified below.

Name of submitter	Organisation
Dr Tundi Agardy	Sound Seas USA
Dr Mark Avery	Royal Society for the Protection of Birds (RSPB)
Dr Harald Beck	University of Miami
Dr Andrea Belgrano	University of New Mexico
Dr Colin Bibby	Birdlife International, Biodiversity Conservation Information System (BCIS)
Mr David Brackett	Species Survival Commission
Dr Ben ten Brink	Research for Man and Environment (RIVM)
Dr Colin Catto	Bat Conservation Trust
Dr Geoffrey Chapman	Personal submission
Professor Andrew Clarke	British Antarctic Survey
Dame Barbara Clayton	University of Southampton
Mr Jonathan Cowie	Institute of Biology
Dr Ben Delbaere	European Centre for Nature Conservation (ECNC)
Dr Keith Duff	English Nature
Dr Nicholas Dulvy	The Centre for Environment, Fisheries and Aquaculture Science (CEFAS)
Dr Sam Fanshawe	Marine Conservation Society (MCS)
Dr Alan Feest	Bristol University
Dr Gustavo Fonseca	Center for Applied Biodiversity Science (CABS) – Conservation International (CI)
Dr Ron Fraser	Society of General Microbiology
Dr Nick Gotelli	University of Vermont
Professor Jeremy Greenwood	British Trust for Ornithology (BTO)
Dr Richard Gregory	Royal Society for the Protection of Birds (RSPB)
Ms Melanie Heath	Birdlife International
Mr Colin Hedley	Country Landowners Association
Professor Mac Hunter	Society of Conservation Biology
Ms Janet Hurst	Society of General Microbiology
Mr John Jackson	Natural History Museum
Mr David Mansell-Moullin	International Petroleum Industry Environmental Conservation Association (IPIECA) – Energy and Biodiversity Initiative
Ms Rebecca May	World Wide Fund for Nature (WWF)
Dr Dorian Moss	Centre for Ecology and Hydrology (CEH) – Monks Wood
Mr Kalemani Mulongoy	Principal Officer, Secretariat of the Convention on Biological Diversity, Scientific, Technical and Technological Matters
Professor Norman Myers	Personal submission
Ms Louisa Ogry Nakanuku	Environmental Information Service (EIS) Namibia
Dr Adrian Newton	United Nations Environment Programme – World Conservation and Monitoring Centre (UNEP–WCMC)
Professor Aharon Oren	International Committee on Systematics of Prokaryotes
Dr Kent Redford	Wildlife Conservation Institute
Mr Nick Reeves	Chartered Institution of Water and Environmental Management
Professor John Richards	University of Newcastle
Dr Paul Rose	Joint Nature Conservancy Commission (JNCC)
Dr Bernhard Schmid	Institut fuer Umweltwissenschaften
Dr Martin Sharman	European Commission
Dr Mark Shaw	National Museums of Scotland
Dr Phil Shaw	Scottish Natural Heritage (SNH)
Dr Andrew Sier	UK Environmental Change Network (UK ECN)
Sir David Smith FRS	Linnean Society
Dr Malcom Smith	Countryside Council for Wales (CCW)
Mr Richard Smithers	Woodland Trust
Dr Jorge Soberon	Conabio

Dr Bruce Stein	NatureServe
Dr Simon Stuart	IUCN Species Survival Commission
Professor Albert van Jaarsveld	Centre for Environmental Studies, University of Pretoria
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Annex B List of participants in the consultation meetings

To inform the study and discuss initial findings, the working group hosted two workshops, 25 November and 13 December 2003, inviting UK and international academics, policy makers and representatives from industry, conservation and non-governmental organisations (NGO). The working group are grateful to all those who attended; they are listed below.

Name of submitter	**Organisation**
Professor Michael Akam FRS	Zoology Museum, Cambridge
Mr Jonathan Bass	Centre for Ecology and Hydrology (CEH) Dorset
Professor Richard Bateman	Natural History Museum
Dr Harald Beck	University of Miami
Dr Colin Bibby	BirdLife International, Biodiversity Conservation Information System (BCIS)
Professor Ian Boyd	University of St Andrews
Mr David Brackett	Species Survival Commission
Dr Ben ten Brink	Research for Man and Environment (RIVM)
Dr Thomas Brooks	Conservation International (CI)
Mr Neil Burgess	World Wide Fund for Nature – US (WWF)
Mr Martin Capstick	Department for the Environment Food and Rural Affairs (DEFRA)
Dr Kevin Charman	English Nature
Mr Mark Collins	United Nations Environment Programme – World Conservation and Monitoring Centre (UNEP–WCMC)
Ms Mireille de Heer	UK Permanent Representation to the European Union
Mr Mark Diamond	Environment Agency
Dr Keith Duff	English Nature
Dr Nick Dulvy	The Centre for Environment, Fisheries and Aquaculture Science (CEFAS)
Dr Mark Eaton	Royal Society for the Protection of Birds (RSPB)
Professor Dianne Edwards FRS	Cardiff University
Dr Alan Feest	Bristol University
Dr Brian Ford-Lloyd	University of Birmingham
Dr Ed Green	United Nations Environment Programme (UNEP)
Dr Michael Green	Norfolk Broads Authority
Professor Jeremy Greenwood	British Trust for Ornithology (BTO)
Dr Andy Hector	Imperial College
Dr Colin Hindmarch	Institute of Biology
Professor Chris Humphries	Natural History Museum
Mr John Jackson	Natural History Museum
Dr K A Joysey	Linnean Society
Dr Val Kapos	United Nations Environment Programme – World Conservation and Monitoring Centre (UNEP–WCMC)
Dr Terry Langford	Linnean Society
Professor Nigel Leader-Williams	The University of Kent at Canterbury
Dr Kyrre Lekve	University of Oslo
Mr Jonathan Loh	World Wide Fund for Nature – UK (WWF)
Dr Nigel Maxted	University of Birmingham
Dr Dave Roberts	Natural History Museum
Dr E J Milner-Gulland	Imperial College
Dr Dorian Moss	Centre for Ecology and Hydrology (CEH) Monks Wood
Professor Norman Myers	Fellow of Oxford University
Dr Adrian Newton	World Conservation Monitoring Centre (WCMC)
Dr Mark O'Connell	Wildfowl and Wetlands Trust (WWT)
Dr Andy Purvis	Imperial College
Professor Paul Raffaelli	University of York
Dr Paul Raven	Environment Agency
Professor John Richards	University of Newcastle
Dr Paul Rose	Joint Nature Conservancy Society (JNCC)
Dr Jane Sears	Royal Society for the Protection of Birds (RSPB)
Dr Mark Shaw	National Museums of Scotland

Dr Andrew Sier	UK Environmental Change Network (UK ECN)
Dr Malcolm Smith	Countryside Council for Wales
Mr Richard Smithers	Woodland Trust
Dr Jorge Soberon	Conabio
Dr Jean-Luc Solanot	Marine Conservation Society (MCS)
Dr Alistair Taylor	Natural History Museum
Dr Kate Trumper	House of Commons, Committee Specialist
Dr Paul Williams	Natural History Museum

Annex C Contributors of additional case studies

We are very grateful to the following people who provided invaluable assistance in utilising and developing the framework through authoring specific case studies for the report.

Professor Nigel Maxted and Professor Brian Ford-Lloyd University of Birmingham	Genetic diversity at the species level in wild lentils
Professor James Mallet – UCL and Professor Chris Thomas – University of Leeds	Brown argus butterfly
Dr Mark Blaxter University of Edinburgh	Meiofaunal indicators of pollution

Annex D International agreements: policy responses to biodiversity loss

Over the past several decades the fate of biodiversity has become an important political issue that has been addressed in a variety of ways including through the development of international and national policy. This Annex provides an overview of the policy situation internationally, and in the UK, along with a brief consideration of its relation to the NGO community and industry.

D.1 International agreements and the Convention on Biological Diversity

A gradual increase in environmental awareness through the 1950s and 1960s resulted in the Stockholm Declaration at the United Nations Conference on the human environment, which outlined the need for a healthy natural environment to ensure the well-being of humanity (United Nations 1972). In parallel, important early steps toward global protection of certain aspects of biodiversity were enshrined in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 1973, which led from the World Conservation Union (IUCN) resolution in 1963 to protect certain species from the threats of unregulated trade.

In the following decades it became clear that species conservation needed to be integrated into a broader ecological and social context. This was emphasised in the World Conservation Strategy (IUCN 1980) and the World Charter for Nature (United Nations 1982). Most significantly this broader view culminated in the Brundtland report (World Commission on Environment and Development 1987), which introduced the concept of 'Sustainable Development'.

Subsequently the Convention on Biological Diversity (CBD) emerged from the Earth Summit, in Rio in 1992. The CBD went beyond existing conventions, such as the Ramsar Convention on Wetlands (Ramsar 1971) and CITES, by emphasising the importance of protecting biological diversity within the paradigm of sustainable development. The CBD has three main objectives: i) the conservation of biological diversity; ii) the sustainable use of the components of biological diversity; and iii) the fair and equitable sharing of benefits arising from the utilisation of genetic resources.

The CBD is designed to accommodate change and evolution. Scientific assessments, to assist this process, are provided by the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA), which reports back to the decision making biannual Conference of the Parties (COP). Regular assessments of the CBD, incorporating expert scientific advice, enable the Parties to set priorities for international work and strengthen national implementation.

Two international mechanisms support the work of the CBD. The Global Environment Facility (GEF) facilitates the distribution of financial aid to biodiversity and conservation projects in developing countries, and the Clearing House Mechanism (CHM) provides a virtual meeting place for the exchange of information and knowledge, along with advising on the development of standards, formats and protocols.

The objectives of the CBD in relation to biodiversity conservation and monitoring are set out in Articles 6 and 7 of the Convention. In recognition of the different conditions and capabilities of the Parties, the objectives are broad, requiring each country to develop their own strategy for implementation.

In 2001, a review of the current status of global biodiversity was published in the first edition of the Global Biodiversity Outlook (CBD 2001). Requested by the COP of the CBD, the report also analysed progress towards the three objectives of the CBD. It highlighted that the absence of clear objectives for the CBD, such as having defined targets, specific sites for conservation or lists of protected species, has generated problems in developing reporting standards for national achievements. Problems of coordination have also frustrated efforts to set and monitor global targets. The report emphasised that the lack of biodiversity information was one of the major impediments not only for reporting achievements but also for the creation of meaningful targets against which progress could be measured. At COP 6 in April 2002, the parties adopted the Global Strategy for Plant Conservation, thereby agreeing specific global targets for conservation (albeit for a single group of organisms) for the first time.

One response to insufficiencies in the quantity and quality of global biodiversity information was the endorsement of a programme of work for The Global Taxonomy Initiative (GTI) at COP 6 in 2002. The GTI specifies that each Party should set up National Focal Points. In the UK this role has been taken by the Natural History Museum. National Focal Points are responsible for linking with regional centres of taxonomic expertise around the country and where appropriate sharing their information with other countries. Similarly, in response to the Earth Summit in 1992, the OECD introduced the Global Biodiversity Information Facility (GBIF), which aims to provide the infrastructure for an international mechanism to make biodiversity data and information universally accessible. Various other initiatives are working towards web-based inventories of life on earth, for example, the Catalogue of Life by Species 2000, All Species and CODATA (Annex F).

D.2 At the European Union level

Responding to concerns about the loss of biodiversity, a pan-European agreement, the Bern Convention on the Conservation of European Wildlife and Natural Habitats, came into force in 1979. Since the adoption of the CBD, Europe has also introduced two strategies to help its implementation at a Member State level. They are the Pan-European Biological and Landscape Diversity Strategy (PEBLDS) which strengthens existing European conventions and the European Community Biodiversity Strategy (EC 1998), which introduces four sectoral Action Plans, namely Conservation of Natural Resources, Agriculture, Fisheries, and Economic Co-operation and Development. In addition, the Natura 2000 programme, which is supported legislatively by the European Birds (EEC 1979) and Habitats Directives (EEC 1992), outlines habitats and species for protection and has been an important guide in creating priority conservation areas within Europe. As these Special Areas of Conservation (SACs) have been identified and designated by Member States, a successful programme will require the co-ordination and exchange of a high level of information between countries.

A limitation to the potential success of a pan-European strategy is that an over-arching framework does not exist for the production of formal and regular reports of the trends and state of European biodiversity. The European Biodiversity Monitoring and Indicator Framework (EBMI-F) potentially provides a good basis for monitoring within the framework of the PEBLDS, but the European Environment Action Programme (EEAP), in its sixth action plan for the period until 2010, highlights the need for extra funding and research for basic data collection. Without data on trends and the state of biodiversity, the EEAP stresses that the major environmental institutions would be restricted in carrying out their work (EC 2001).

D.3 The United Kingdom

The UK ratified the CBD in 1992 and published its own biodiversity strategy in *Biodiversity: the UK Action Plan* (DoE 1994). The 59 objectives in the plan cover four main areas: i) the development of action plans for key species and habitats; ii) monitoring systems; iii) access to information through biodiversity databases; and iv) public awareness and involvement in contributing to conservation efforts.

Progress towards the targets for conservation and recovery of both species and habitats was outlined in a review of the UK Biodiversity Strategy and Action Plan (UK Biodiversity Group 2001). However, this found that there were still declines in some of the identified priority species and one of the priority habitats. There was also a concern that biodiversity issues and policy were not fully integrated into central and local government practices or fully factored into decisions throughout the business and industrial sectors. The difficulty of assessing biodiversity status without access to sufficient information to make informed decisions was also noted.

In part, information shortages derive from a lack of resources (both skills and finance) for the identification, description and classification of species. A decline in support for systematic biology research within the UK was first highlighted in the House of Lords Select Committee inquiry into Systematic Biology Research (House of Lords 1992), which expressed concern over its decline in the UK. It proposed a number of measures to rectify the situation such as increased funding and further help to the relevant institutions. Ten years later a similar study by the House of Lords (House of Lords 2002) found that, despite several subsequent initiatives, the number of scientists involved with systematic biology, in particular taxonomy, had continued to decline. It stressed that improvement would only arise through a collaboration of government and scientists determined to address, prioritise and fund taxonomy.

More positively, recognition of the broad responsibility and potential international contribution of UK science and conservation activities overseas has come through the Darwin Initiative. Established in 1992, this programme draws on UK expertise in biodiversity and provides funds for projects that create partnerships with organisations and scientists in less developed countries to conserve biodiversity and promote the sustainable use of natural resources. The Prime Minister, Tony Blair, announced at the World Summit on Sustainable Development in 2002 that the UK intended to increase funding for the Darwin Initiative to £7 million per annum by 2005. This new funding will be used to enhance project programmes, while also developing the capacity of host countries to be able to continue the projects themselves. To this end, it will also fund scholarships to broaden the professional knowledge and experience in overseas participants.

D.4 NGOs and industry

Without the awareness, participation and commitment of business and society, policies developed to combat biodiversity loss and habitat decline will not be successful. Current political best practice is becoming more competent in involving all sectors earlier in decisions, and also in making use of the breadth of resources and experience found outside of government. For example, many NGO-led initiatives in the area of biodiversity management are now taken up and used by governments.

Industry and business are starting to understand the concepts of sustainable resource use and the potential commercial value of biodiversity, both as a resource and in terms of generating consumer goodwill. In some cases, business has taken the lead in creating biodiversity action plans and developing indicators to measure and limit the impact of their activities. Such action plans have a two-fold effect, both making business practice more sustainable, and encouraging stakeholder participation in the company's activities. The global coverage of many businesses means that much could be achieved by promoting conservation within their activities. In some countries the scope for business to undertake concerted conservation action may far outweigh that of national governments. It is therefore vital that responsibility is taken and that partnerships are forged in these areas.

For the activities of business and NGOs to be successful, baseline measurements and appropriate means for measuring and monitoring biodiversity are essential. These will facilitate refinement of strategies and tactics, and the international co-ordination of conservation efforts. They will also facilitate the ongoing monitoring of biodiversity and provide a basis for recognising where success has been achieved.

Annex E Abbreviations and glossary

Aquatic Macrophytes	A plant that grows or has part of its life cycle in an aquatic system
BAP	Biodiversity Action Plan
Biome	The classification of certain physical and chemical characteristics of an environment. Often characterised by the dominant forms of plant life and the prevailing climate. Examples include temperate forests and deserts
BOD	Biochemical Oxygen Demand
BTO	British Trust for Ornithology
CBD	Convention on Biological Diversity
CEFAS	The Centre for Environment, Fisheries and Aquaculture Science
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
COP	Conference of the Parties
Cytotype	Exhibiting identical cytological features (i.e. chromosomes) as those originally described for the taxon
DEFRA	Department for Environment, Food and Rural Affairs
DPSIR	Driver-Pressure-State-Impact-Response Framework
EBMI-F	The European Biodiversity Monitoring and Indicator Framework
Eco-geographic	Involving both the entire ecological and geographic range of a species.
Eutrophication	The process whereby water bodies become severely oxygen deficient as a result of decomposing organic matter. Increased organic matter levels are often caused by pollution
FAO	Food and Agriculture Organisation
GBIF	Global Biodiversity Information System
GEF	Global Environmental Facility
Gene bank	A centre or institution that manages genetic resources, in particular, maintaining *ex situ* or *in situ* collections
Germplasm	Often synonymous with 'genetic material', it is the name given to the total genetic variability, represented by germ cells or seeds, available to a particular population of organisms
Germplasm, *ex situ* conservation	Maintaining the genetic variability of a population in a different environment or geographic location than where it evolved i.e. botanical gardens, breeding orchards, cold storage of seed or pollen (seed banks)
Germplasm, *in situ* conservation	Maintaining the genetic variability of a population in approximately the same geographic and ecological conditions under which it evolved
Geo-referencing	The task of establishing the relationship between page coordinates on a planar map and known real world coordinates
GIS	Geographic Information System
GTI	Global Taxonomy Initiative
Haplotype	A set of closely linked genetic markers present on one chromosome which tend to be inherited together
ICARDA	Centre for Agricultural Research in the Dry Areas
IPNI	International Plant Names Index
IUCN	World Conservation Union
MA	Millennium Ecosystem Assessment
NCSR	Number of Clusters per Sub Region
NERC	Natural Environment Research Council
NGO	Non-Governmental Organisation
Nomenclature	Assignment of names to taxa
OECD	Organisation for Economic Co-operation and Development
Oligonucleotide	A sequence of nucleotides. Nucleotides being organic molecules that constitute the building blocks of genetic material such as DNA.
PEBLDS	Pan-European Biological and Landscape Strategy
Phylogeny	The relationship between groups of organisms that share a common ancestry
Protists	Microscopic, unicellular eukaryotes. As distinct from prokaryotes they have a membrane-bound nucleus.
PVA	Population Viability Analysis
RSPB	Royal Society for the Protection of Birds
SAC	Special Areas of Conservation

SBSTTA	Subsidiary body on Scientific, Technical and Technological Advice (SBSTTA) for the CBD
Synonyms	The same taxa or species inadvertently given different names by different people
Systematics	The organisation of biological information using the combination of taxonomic science and nomenclature
Taxa	Groups of organisms distinguished through the science of taxonomy. A species is the primary taxonomic unit (singular taxon)
Taxonomy	The science of classifying organisms into groups using information that reflects their natural and evolutionary relationships
Trophic level	The level in the food chain at which an organism feeds. Primary producers such as phytoplankton or grass, using photosynthesis to convert sunlight into biomass, are on the first trophic level.
TDWG	Taxonomic Database Working Group
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme
WEHAB	Water, Energy, Health, Agriculture and Biodiversity – 5 key thematic areas raised by Kofi Annan for WSSD 2002
WSSD	World Summit on Sustainable Development Johannesburg 2002.
WWF	World Wide Fund for Nature

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(CITES) Convention on International Trade on Endangered Species of Wild Fauna and Flora
www.cites.org/

(CBD) Convention on Biological Diversity
www.biodiv.org

(CODATA) – Committee on Data for Science and Technology – International Council for Science (ICSU)
www.codata.org

Global Taxonomy Initiative
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