Ref.: CBD/STTM/JPLD/dh 7 June 2001

NOTIFICATION

Dear Madam/Sir,

Subject: Peer Review of a document on Climate Change and Forest Biological Diversity

At its fifth meeting held in Nairobi, Kenya from 15 to 26 May 2000, the Conference of the Parties (COP) to the Convention on Biological Diversity adopted decision V/4 on forest biological diversity.

In paragraph 11 of the decision, the COP requested the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) to consider the impact of climate change on forest biological diversity. In order to assist SBSTTA in its work, the Secretariat of the Convention on Biological Diversity commissioned a study by Dr. A.N. Gillison.

The document is open for comments by the scientific community at large as part of a peer review process. The purpose of this peer review is to obtain comments regarding the accuracy and completeness of the scientific/technical/socio-economic content and overall balance of this study.

Please note that the peer review process needs to be completed by **30 June 2001**.

Yours sincerely,

[signed]

Hamdallah Zedan
Executive Secretary

To: Experts concerned by Forest Biological Diversity and Climate Change issues
CBD National focal points

Attachment: A Review of the Impact of Climate Change on Forest Biological Diversity

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A Review of the Impact of Climate Change on Forest Biological Diversity

CONTENTS

I. Executive Summary

The potential impact of climate change on FBD (FBD) is overshadowed by the overwhelming effect of human-induced modifications of terrestrial ecosystems that are responsible for major losses in biodiversity habitat in a great number of forested ecosystems. This has created difficulties in being able to discriminate between the more immediate effects of natural resource modification by humans and the longer-term and in many cases, more subtle effects of climate change. Despite conflicting accounts about the nature and extent of the impact of climate change on biodiversity there is general agreement that biodiversity will decline worldwide under most climate change and global change scenarios. Significant factors that influence the impact of climate change on FBD are:

1. **Loss of natural forest habitat:** continues unabated although this has slowed in some countries. The FAO Forest Resources Assessment 2000 (FRA 2000) released online in March 21 2001 (http://www.fao.org/forestry/fo/fra/index.jsp) reports that net deforestation was 9 Mha yr^{-1} in the 1990's. FAO claims a slowdown of 20 percent compared with the deforestation rate estimated in the first half of the decade. This is disputed by an WRI report (Matthews, 2001) that argues the FRA 2000 may be misleading and that confusion arises because FAO focuses on a net rate of global forest change in which destruction of forest habitat is offset by plantation establishment. Natural forest loss in the the tropics appears to have accelerated (Matthews, 2001). Using the IGBP definition WRI *et al.,* (2000) estimate global forest cover at 29 million km^2 or 22 percent of the world's land surface excluding Greenland and Antarctica. (FAO, 1997 estimated about 37 million km^2 or 27 percent of total land surface). Of these approximately 57% were in developing countries where greatest loss of native forests has occurred. Earlier, according to FAO (1996) in 1990-1995 this slowed with overall loss of about 65 million ha (FAO 1996). Mainly due to human activities forests decreased by about 5% between 1980-1995 (FAO 1997). The 1990 baseline has been revised upward to 3.95 billion hectares – an increase of 15% according to FRA2000. These and other estimates may be misleading as few reliable data are available due to inconsistencies in forest classification and widespread fragmentation at varying levels of intensity. Plantation forests were estimated at about 81m ha in developing countries and between 80-100 million ha in developed countries (FAO, 1997). Global forest cover has been reduced by at least 20 and possibly 50 percent since pre-agricultural times. Since 1980 forests have increased marginally in industrial countries and declined by about 10 percent in developing countries. Tropical deforestation probably exceeds 130,000 km^2 annually.

2. **Threats to FBD:**. The greatest threats to FBD in the present day are conversion to other forms of land use including agriculture, pastoralism, logging and road construction. Less than 40 percent of forests are relatively undisturbed by humans although there are wide differences between countries. Trends in the Brazilian Amazon basin suggest wildfire and intensive heavy logging cause massive losses in the order of one million ha yr^{-1} . Together with climate change, these pressures are likely to increase the threat of invasive, exotic species into both pristine and disturbed forest habitats with a concomitant reduction in native species.

3. **Impact on genotypes:** There are few accounts of climate change impact on genotypes although it is known that within-species variation seems lower at higher latitudes. Climatic warming could rapidly produce important phenotypic changes in some forest species such as birch trees (e.g. reduced root/shoot ratio, reduced growth

in alpine populations). On a longer time scale, warming could also result in genetic changes as natural selection favours valley genotypes in alpine sites where they are presently rare. Forest fragmentation induced under global warming may lead initially to a loss in genetic variability that may recover if and when patches coalesce. Much needed baseline data are relatively rare as collection is frequently resource-limiting.

4. **Impact on species:**
   a. *Plants:* Changes in atmospheric CO_2 may change the competitive balance between species that differ in rooting depth , photosynthetic pathway or woodiness as well as associated organisms below-ground. Elevated CO_2 is likely to have the most notable effect on species composition in the presence of nitrogen deposition (interaction of CO_2 and nitrogen deposition). Synergistic interactions may decrease in importance at extreme values of individual drivers of biodiversity change. For example under conditions of extreme land use change further damage by other climate change drivers may be inconsequential. Under climate change the differential response of species will affect interaction and competition leading to changes in their spatial and temporal distribution. Most scenarios indicate that as plant hosts are decoupled from pollinators, the resulting loss in population viability will lead to species decline. A plant's ability to move under pressure from changing climate will vary according to species and FT. Shoreline plants and plants capable of wide dispersal are likely to be less affected than poor dispersers in old growth forests. Relative migration rates are critical (see ecosystems). Although there will be regional differences in the nature and extent of plant species response to climate change a general consensus is that plant species diversity will decline overall.

   b. *Plant functional types:* Shifts in species composition will be largely determined by the adpative strategies defined in the functional type. For example, such features as capacity to fix atmospheric nitrogen, resist and tolerate dessication and low nutrients or disperse rapidly will play a major role in vegetation response to climate change. Increased ecological niche opportunites in changing environments may lead to a relative increase in PFT richness s relative to species. Apart from C_3 and C_4 photosynthetic pathways common among grasses, many tropical forests contain upper-storey, succulent epiphytes and some ferns that exhibit a specific metabolism (CAM) that is more typical of terrestrial plants in seasonal to hot arid habitats. While many CAM plants are known in cool, moist, upland forests (e.g. in upland Andean habitats) as well as tropical lowland, seasonal forests, their range and incidence may increase with global warming.

   c. *Invertebrates:* Climate change impact on insects is likely to differ markedly between temperate and tropical regions. Plant/herbivore interaction in the tropics may be more susceptible to climate change than in the temperate region and insect outbreaks increase and herbivory rates rise 2-4 fold where increased CO_2 is combined with drying. A predicted increase in the number of herbivores may lower the relative abundance of species and result in overall biodiversity decline. Other, evolutionary chnages such as butterfly flight, morphology and dispersal rate may be important determinants of range expansion, and may affect responses to future climate change. In several countries although impacts of climate change will vary regionally, climate change is expected to increase the range of many arthropods and thus enhance the pest status of many.

   d. *Birds:* Impacts on birds may already be underway with a trend detected in the movement of ranges towards higher latitudes in Antarctica, Australia and North America. Increased forest fragmentation under global warming may lead to variable responses in bird species richness depending on forest type and local climate. Whereas bird species richness may increase temporarily under initial disturbance, in the long term loss of habitat will lead to species decline. Migration patterns are almost certain to change for many species under a global warming scenario.

e. *Amphibians and reptiles:* Because many are adapted to very cryptic forest habitats and are susceptible to dessication, any change leading to a drying out of habitat, for example with increasing seasonality, is very likely to lead to a decline in species number.

f. *Mammals:* As mammals ultimately depend largely on plants as a food and shelter resource, a significant change in the range distribution of a key plant species under climate change can have a critical impact on mammal distribution.

g. *Ecosystems and biomes*: Earlier models that forecasted shifts in forest biomes or ecosystems as intact entities as a response to climate change are now no longer considered useful. The reason is due to the differential response of species and functional types (FTs) to changing environment in which biomes and ecosystems are likely to lose ecological integrity. For this reason forest ecotones are likely to become blurred as the range distributions of species and FTs readjust to new environments. Migration rates between different plant and animal groups differ regionally with barriers to certain groups arising through increased habitat fragmentation. Most models suggest that increases in invasive weedy species, especially exotics, associated with regional shifts in pests of forest and agricultural crops may accompany biodiversity decline in the scenarios presented by the IPCC. Regional differences in ecosystem response restrict generalisation about the invasive potential of species.

5. **Carbon storage:** Few scientific studies show direct linkages between above-ground carbon storage and biodiversity although some recent tropical, ecoregional baseline studies show these are significantly correlated. The carbon pools in the world's forests are estimated at 348 Gt C in vegetation and 148 Gt C in soil to 1m with the highest in tropical forests (60% and 45% of total respectively). The question of which forests are sources or sinks is related to forest type and climatic region. Some boreal forests may be sinks and others sources (0.5 to 2.5 t C ha^{-1} yr^{-1}). Temperate forests appear to be sinks (1.4 to 2.0 t C ha^{-1} yr^{-1}). Tropical forests are generally regarded as net source due to widespread land clearing and fire although there is limited evidence that some may be carbon sinks. Although the source output in tropical forests appears to have decreased slightly by about 0.1 Gt C yr^{-1} between 1980's and the early 1990's, under climate change with increasing seasonality tropical forests are likely to become more vulnerable to fire and thus an increased carbon source. Above-ground to below-ground carbon (root:shoot) ratios tend to decrease towards the humid tropics.

6. **The Kyoto Protocol:**

a. *Control of carbon emissions (Articles 3,6,10a,17):* The KP requires monitoring of greenhouse gas removals and emissions from human-induced, deforestation, afforestation and reforestation since 1990. While the need to redress this by slowing forest destruction and by tree planting is recognised, the COP may allow other, as yet unspecified, harvesting and management activities. Assessment of emissions and of climate impacts, especially on carbon sinks and sources, requires clearer definition of deforestation and reassessment of the fate of carbon in such systems. For example, recent studies show that, whereas in temperate and boreal forests below-ground carbon is highly significant relative to above-ground carbon this now appears less likely in many tropical forested lands apart from freshwater and mangrove swamp forests on deep peats. It is also now realised that most unmanaged forests have more biodiversity and carbon than managed (e.g. plantation) forests.

b. *The Clean Development Mechanism (Article 12):* The CDM provides for industrialized countries to undertake emission-reduction projects in developing countries. But the CDM does not specify what land use change and forest projects will be allowed leaving the way open for largely uncontrolled impacts on FBD. A closer study of potential impacts is therefore needed in order to better define the CDM implementation.

7. **An operational definition of biodiversity:** The need for this has been aired by the CBD and by many practitioners who argue this is necessary for the quantification of biological diversity and to facilitate input to climate models especially dynamic global vegetation models. The continued use of species as the sole currency for biodiversity is changing. The increasing popularity of functional types (FTs) in particular plant functional types (PFTs) is gaining credence among life scientists as a complement to species-based data. Both species and FTs appear to be needed in characterising biodiversity and facilitating generic, comparative studies between taxonomically variable regions e.g. where vegetation response to environmental change may be otherwise similar.

8. **The use of state-pressure-response models:** As applied by SBSTTA to characterise biodiversity response to climate change these may need review. Case studies concerning the selection of biodiversity indicators presented by SBSTTA confuse relationships between 'state' and 'response' of biodiversity conservation at national level and biodiversity dynamics at ecosystem level. Many assumptions about ecosystem 'state' are questionable due to unknown, unmeasureable and ongoing environmental lag effects. Such assumptions may be unnecessary and could be largely avoided by considering directly, more specific, response-based studies along known land use intensity and natural resource gradients including climate.

9. **Biodiversity assessment methods:**. For biodiversity response to environmental change to be effectively understood, range distributions of species and functional types must be included to provide an adquate biological and ecological context. In recognising this factor, many practitioners are increasingly moving away from single, large-plots (e.g. 50 ha) to multiple small plots along land use intensity and climate gradients. Contextual data of this kind are needed to provide an adequate basis for regional extrapolation. Most recent reviews of FBD highlight a paucity of data especially in the tropics where biodiversity is greatest. This reflects an urgent need for to establish regional and globally networked baseline studies to better understand the dynamic between land use change, climate change and biodiversity. Methods of biodiversity assessment may need to be revisited by SBSTTA.

10. **Socioeconomic factors and policy development:** Most global institutions concerned with biodiversity conservation are actively seeking closer links between FBD and socioeconomic factors and policy development. Many research agencies are exploring evidence for dynamic linkages for example between biodiversity and profitability. This critical dynamic has been little studied as yet and may need to be included by SBSTTA as either a new or restated research priority.

11. **Institutional cooperation:** Widespread concern about biodiversity conservation and the likely impact of climate change indicates a need for closer cooperation and coordination at global level. Several international institutions are planning for a

global network of sites for monitoring FBD and ecosystem response to environment change (Conservation International; Millenium Ecosystem Assessment). It would be logical for such bodies to coordinate with the IGBP/GCTE global transect programme where wide-ranging environmental data are being collected that are of potential value for modelling biodiversity response to climate change. As the GCTE transects have no current mandate for collecting biodiversity data it would seem eminently reasonable to coordinate joint activity in this area.

12. **Future activities and options for FBD conservation and management:** With respect to UNFCCC provisions this should include a review of methods and mechanisms to help establish linkages between biodiversity and policy development. This should include investigations into linkages between biodiversity and profitability to help attach a measureable, economic value to biodiversity. By this means it may be possible to develop incentives for alternative methods that will help sustain biodiversity and mitigate effects of climate change through the enhancement of carbon sinks. More attention should be given to establishing commercial forests with a mix of native species and corridors of natural forest contained in the forest mosaic. Most plantations can be managed to include sufficient variation in standing crop to sustain a great deal of biodiversity. In these activities it is important to ensure land owner participation and equitability are taken into account.

13. **Implementation of an effective strategy for biodiversity conservation**: A key limiting factor in the is the capacity of in-country personnel to carry out research. There is a clear need for capacity building and mentoring in countries that require such assistance. To that end a consistent training programme should be undertaken, preferably using uniform methods of survey design, data collection, data storage and analysis. This would help contribute a sense of ownership and a capacity to undertake activities that result in enhancing capacity for adaptive management at the local and national level as well as being able to contribute significantly to help solve a global problem.

II. BACKGROUND AND KEY ISSUES

1. At its fifth meeting, COP adopted decision V/4 on biological diversity (Appendix I). With respect to climate change and forest biological diversity, the decision requests the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) to, *inter alia*, (i) Consider before the sixth meeting of the Conference of the Parties the impact of climate change on forest biological diversity (paragraph 11); and (ii) prepare scientific advice, where appropriate and feasible in collaboration with the appropriate bodies of UNFCCC and IPCC, in order to integrate biodiversity considerations, including biodiversity conservation, in the implementation of UNFCCC and its Kyoto Protocol (paragraph 18).

2. The decision also requested the Executive Secretary to assemble, in collaboration with the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC), existing information relating to the integration of [forest] biodiversity considerations, including [forest] biodiversity conservation, in the implementation of the UNFCCC and its Kyoto Protocol (KP) (paragraph 17).

3. The provisional agenda of the sixth meeting of SBSTTA provides that, in response to COP request, the Executive Secretary will prepare a note on "Biological diversity and climate change: cooperation with the United Nations Framework Convention on Climate Change". A more recent note by the Executive Secretary [CBD/SBSTTA/6/11] suggests *inter alia*, that SBSTT may wish to:

a. Take note of the discussion of the interlinkages between biological diversity and climate change, contained in the discussion note by the Executive Secretary submitted to the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) at its sixth session and the UNFCCC Subsidiary Body on Scientific and Technological Advice at the second part of its thirteenth session, held in The Hague, from 13 to 24 November 2000 (annex I to the present note);
b. Welcome the agreement of the UNFCCC SBSTA to consider this matter at its fourteenth session, scheduled for May/June 2001, and its invitation to UNFCCC Parties to submit their views on the issues identified;
c. Elaborate a preliminary assessment of the interlinkages between biological diversity and climate change, drawing upon sections III C. and III D of annex I, and annex II, to the present note, and offer this as an additional input to the fourteenth session of SBSTA;
d. Promote a wider assessment of the interlinkages between biological diversity and climate change, in order to develop more comprehensive scientific advice to integrate biodiversity considerations into the implementation of the UNFCCC and its Kyoto Protocol, including:
    i. *The impacts of climate change on biological diversity;*
    ii. *The potential impact on biological diversity of mitigation measures that may be carried out under the UNFCCC and its Kyoto Protocol, and identification of potential mitigation measures that also contribute to the conservation and sustainable use of biological diversity;*
    iii. *The potential for the conservation and sustainable use of biological diversity to contribute to adaptation measures taken under the UNFCCC and its Kyoto Protocol;*

[Other, more detailed provisions of the UNFCCC and to the Kyoto Protocol relevant to this review are referred to to in CBD/SBSTTA/6/11]

4. *Forest definition:* Any consideration of Forest Biological Diversity (FBD) will be influenced by how forest and forest area are defined. Definitions are many and varied and the topic is treated in considerable detail by the Food and Agriculture Organization (FAO). The World Resources Institute (WRI) adopts the International Geosphere-Biosphere Programme (IGBP) definition of forest ecosystem as: "*the area dominated by trees forming a closed or partially closed canopy*". FAO defines forests to be all areas having a minimum crown cover of 10 percent and minimum tree height of 5m whereas in Australia forest is commonly defined as having a minimum canopy cover of 40 percent. In Indonesia, the definition of forest and 'forested land' includes any land with a *potential* to support forest and may include both plantations and natural forest. For this reason comparative estimates of forest and forested area will vary widely from country to country and should be treated with caution.

5. *Forest area:* Using the IGBP definition WRI *et al.,* (2000) estimate global forest cover at 29 million km^2 or 22 percent of the world's ice-free land surface. (FAO, 1997 estimates about 37 million km^2 or 26.6 percent of total land surface). Of this approximately 57% is in developing countries where greatest loss of native forests has occurred. In 1990-1995 this slowed with overall loss of about 65 million ha (FAO 1996). Mainly due to human activities forests decreased by about 5% between 1980-1995 (FAO 1997a). The 1990 baseline (FRA 1990) has been revised upward to 3.95 billion hectares according to FRA 2000 – an increase of 15% (Table 1). However these and other estimates may be misleading as few reliable data are available due to inconsistencies in forest classification and widespread fragmentation at varying levels of intensity. A new Australian baseline and definition of forests for Australia has resulted in a statistic al increase in forest area from 40 Mha in the 1990 assessment to 158 Mha in FRA 2000. This accounts for >40 percent of the net increase in forest vover reported for developed countries (Matthews, 2001). Plantation forests were estimated at about 81 million ha in developing countries and between 80-100 million ha in developed countries (FAO, 1997a).

6. *Forest loss:* Global forest cover has been reduced by at least 20 and possibly 50 percent since pre-agricultural times. Since 1980 forests have increased marginally in industrial countries and declined by about 10 percent in developing countries. Tropical deforestation probably exceeds 130,000 km^2 annually. The FAO Forest Resources Assessment 2000 (FRA 2000) released online in March 21 2001 (http://www.fao.org/forestry/fo/fra/index.jsp) reports that net deforestation was 9 Mha yr^{-1} in the 1990's. FAO claims a slowdown of 20 percent compared with the deforestation rate estimated in the first half of the decade. This has been disputed by an WRI report (Matthews, 2001) that argues the FRA 2000 report may be misleading and that confusion arises because FAO focuses on a net rate of global forest change in which destruction of forest habitat is offset by plantation establishment. The greatest threats to forests in the present day are are conversion to other forms of land use including agriculture, pastoralism, logging and road construction. Less than 40 percent of forests are relatively undisturbed by humans. However this varies markedly by country. Trends in the Brazilian Amazon basin suggest that wildfire and intensive heavy logging are responsible for massive losses in the order of one million ha yr^{-1} (Cochrane *et al.* 1999; Nepstad, *et al.* 1999).

7. *Forest biodiversity:* The great majority of forests in industrial countries are reportedly heavily managed and semi-natural. Forests which harbour about two-thirds of the known terrestrial species, have the highest species richness and endemism of any terrestrial ecosystem as well as the highest number of species. Many forest-dwelling mammals, half the large primates, and nearly 9 percent of all known tree species are at some risk of extinction. At current rates of tropical deforestation, the numbers of forest species could be reduced by 4-8 percent. Forest ecosystems provide enormous benefits through their ecosystem services (food, fibre, medicines, water, fuelwood, fodder for animals and animal habitat) much of it undervalued. Together with the biodiversity they support, these services are under increasing threat due to rapidly rising land clearing due in may cases to increased population pressure.

8. *Key issues concerning FBD:* With respect to the provisions of the KP these are listed in Box 1 (below). Chief concerns are the reduction of greenhouse gases that involves in part, the sustainable management of carbon sinks. Although some linkages have been established between carbon stocks, biodiversity and greenhouse gases, many unanswered questions remain. These can best be solved via carefully structured, multidisciplinary research programmes, framed within a global context that includes measurement of the key drivers of biodiversity and related carbon. A fundamental problem facing all researchers and managers alike is the lack of benchmark data. According to the latest report on World Resources (WRI *et al.*, 2000, p. 89), '*global biodiversity data sets are few and evidence is often anecdotal. Forests with high conservation value and global centers of plant diversity are based on field observation and expert opinion'*. The majority of baseline studies have been conducted in high latitudes, mainly in the northern hemispehere where impacts of climate change are considered by many to be most acute. But lessons learnt in boreal forest may not necessarily apply in warm, humid tropical forests and *vice versa*. Coupled with the biophysical aspects are highly significant, socioeconomic factors.

Table 1 Estimates of Forest Cover in FRA 1990 and FRA 2000 ('000 ha)

Region	**Total Forest Cover, 1990 Baseline**			**Total Forest Cover, 2000**
	FRA 1990	FRA 2000	Differerence (%)	FRA 2000
Africa	545,085	702,502	29	649,866
Asia	489,530	551,457	13	547,744
Oceania	88,254	201,992	129	201,164
Europe	895,295	1,030,780	15	1,039,514
North America	456,737	466,684	2	470,564
Central America & Caribbean	74,539	88,318	23	78,740
South America	892,930	910,478	2	874,194
World	**3,442,370**	**3,952,211**	**15**	**3,861,786**

Note: Countries in regional groupings in FRA 1990 have been adjusted to match those of FRA 2000, with one exception. The Caucasian countries of the Former Soviet Union could not be disaggregated from FRA 1990 regional groupings, where they are included in Europe. In FRA 2000 they are included in Asia. Total forest area in these countries in 1990, according to FRA 2000, was less than 20 million hectares.

Sources: Table from WRI: (Matthews, 2001)
Forest Resources Assessment 1990: Global Synthesis. FAO Forestry Paper 124, Table 6.
Forest Resources Assessment 2000 (2000). Table 4. Available online at http://www.fao.org/forestry/fo/fra/index.jsp. Last accessed 6 March 2001.

9. Biodiversity and related carbon stocks will continue to decline while they remain undervalued. One of the more urgent issues therefore is to obtain a clearer understanding of the dynamic relationship between biodiversity and profitability (total factor productivity). Although habitat loss through land clearing is currently more serious in its impact than foreseeable climate change, the combination of the two will continue to impact the way in which the natural resource is managed. Part of the challenge therefore will be to develop cost effective methods of inventory that will provide land managers and policy makers with the incentive and the capacity to make decisions for adaptive and sustainable management of the natural resource.

Box 1: Key issues relating biodiversity to the Kyoto Protocol

a) *Global FBD and carbon stocks continue to decline with increasing fragmentation of forested lands and loss of habitat.*
b) *FBD continues to be lost while it remains undervalued, so that a means of attaching a value is a major challenge.*
c) *The differential response of forested lands to both human-induced and natural factors including climate change may be difficult to detect and to quantify.*
d) *Ground-based biodiversity data at global and regional level are insufficient to formulate effective, science-based, models of biodiversity response to environmental impact*
e) *Lack of information about the dynamic linkages between climate and vegetation at the ecosystem level constrains the development of options for sustainable, adaptive management of biodiversity under varying climate change scenarios.*
f) *There is, as yet, no operational definition of biodiversity that facilitates cost effective, comparative assessment and monitoring under present climate and under future climate change scenarios*
g) *Methods of quantifying and aggregating biodiversity information for developing appropriate policy interventions for sustainable forest management remain elusive.*
h) *A lack of understanding of the dynamic linkages between the biosphere/atmosphere interface creates problems in sampling, analysing and extrapolating response patterns at gene, species and ecosystem levels under different environmental scenarios.*
i) *Mechanisms do not yet exist at international and national scale for the effective planning and coordination of research into the problems facing FBD and climate change and its integration into forest management, conservation and mitigation of climate change impact*

III. OVERVIEW OF CLIMATE CHANGE PHENOMENA

A. Climate change and global change:

10. Global change or 'global warming' has come to be synonymous with 'climate warming' or 'climate change'. Yet, as Walker and Steffen (1999) point out, there is much more to global change than just change in climate. From the point of view of impact on biodiversity, climate change has relatively less impact than other agencies, in particular the human conversion of terrestrial ecosystems and the alteration of the chemical composition of the atmosphere. (see also Dale, 1997). Walker *et al.,* (1999) produced a valuable synthesis of current knowledge and in have focussed the expertise of a wide range of specialists in this general area as part of the GCTE contribution to the IGBP. Of concern to most life scientists, policy planners and managers, remains the question of how to discriminate between the influence of climate change alone and the myriad factors of human-induced resource modification. Against this background Sala *et al.,* (2000) have attempted to identify the potential driving forces behind a series of global biodiversity scenarios for the year 2100.

B. The main drivers of climate change and their components

11. Sala *et al.,* (2000) explored scenarios of changes in biodiversity based on scenarios of changes in CO_2 , climate, vegetation and land use and the known sensitivity of these changes. They ranked the importance of drivers of change, biomes with respect to expected changes and major sources of uncertainty. Sala *et al.,* (2000) suggest the greatest relative change will occur in Mediterranean climate and grassland ecosystems with northern temperate ecosystems undergoing least change. Plausible changes in biodiversity in other biomes depend on interactions among the causes of biodiversity change. It is these interactions that represent one of the largest uncertainties in projections of biodiversity response. In their study Sala *et al.,* (2000) include in their definition of biodiversity all terrestrial and freshwater organisms at scales from within-population genetic diversity to community diversity across landscapes. They exclude introduced exotic organisms and highly modified communities such as regularly cultivated agricultural fields. Marine organisms are excluded. The study examines in detail likely interactions between different drivers and impacts on organisms especially plants. For example changes in atmospheric CO_2 may change the competitive balance between species that differ in rooting depth , photosynthetic pathway or woodiness as well as associated organisms below-ground (see also Jackson *et al.,* 2000).

12. The relative effect of major drivers of changes on biodiversity are summarised in Tables 2 and 3 and Figure 1. below. Among the greatest uncertainties elevated CO_2 has the most notable effect on species composition in the presence of nitrogen deposition (interaction of CO_2 and nitrogen deposition). Synergistic interactions may decrease in importance at extreme values of individual drivers of biodiversity change. For example under conditions of extreme land use change further damage by other drivers may be inconsequential. Sala *et al.,* (2000) also identify uncertainties in policy development as a key unknown and emphasize that for this reason they have presented scenarios rather than predictions of biodiversity change.

13. Vitousek *et al.,* (1997). Argue that based on a review of available scientific evidence, human alterations of the nitrogen cycle have:….

1. *approximately doubled the rate of nitrogen input into the terrestrial nitrogen cycle, with these rates still increasing;*
2. *increased concentrations of the potent greenhouse gas N_2O globally, and increased concentrations of other oxides of nitrogen that drive the formation of photochemical smog over large regions of Earth;*

3. *caused losses of soil nutrients, such as calcium and potassium, that are essential for the long-term maintenance of soil fertility;*
4. *contributed substantially to the acidification of soils, streams, and lakes in several regions; and*
5. *greatly increased the transfer of nitrogen through rivers to estuaries and coastal oceans.*
6. *increased the quantity of organic carbon stored within terrestrial ecosystems;*
7. *accelerated losses of biological diversity, especially losses of plants adapted to efficient use of nitrogen, and losses of the animals and microorganisms that depend on them; and*
8. *caused changes in the composition and functioning of estuarine and nearshore ecosystems, and contributed to long-term declines in coastal marine fisheries.*

14. The focus of debate on climate change has shifted from questions about its existence to a concern with estimates of degrees of change and the nature and intensity of impact. It is accepted that planet earth has experienced massive environmental changes in the past such as glaciations and polar magnetic reversals – each influencing the distribution and survival of the world's biota and frequently associated with climate change. Global climate may be subject to naturally occurring perturbations such as volcanic activity (decades to centuries) or meteoric impacts (tens of millions of years) but in general it is driven by two fundamental process: heating by shortwave solar radiation and cooling by longwave radiation to space.

15. Strong variations in the heating and the cooling between the tropics and and the poles results in temperature differences of some 40K on average. This is enough to drive atmospheric circulation that in turn plays a major role in the spatial and temporal distribution of clouds and water vapour in the troposphere (Garratt *et al.*1996). Factors that influence surface radiation include oceanic circulation, sea-ice and land-atmosphere interactions. Terrestrial vegetation interaction with atmosphere includes vegetation uptake and release by assimilation and respiration and changes in nutrient status and ecological composition. There is increasing evidence that carbon assimilation and leaf are closely coupled. Stomatal leaf conductance can be related to the individual and thus to the canopy and ultimately to vegetation formation depending on the operational levels of heterogeneity. The extent to which this is realistic rests on the particular assumptions about the scaling dynamics and the transfer equations used (Woodward and Smith, 1994; Leuning, 1995; Kelliher *et al.,* 1995; Lloyd and Farquhar, 1996; Mooney *et al.,*1999).

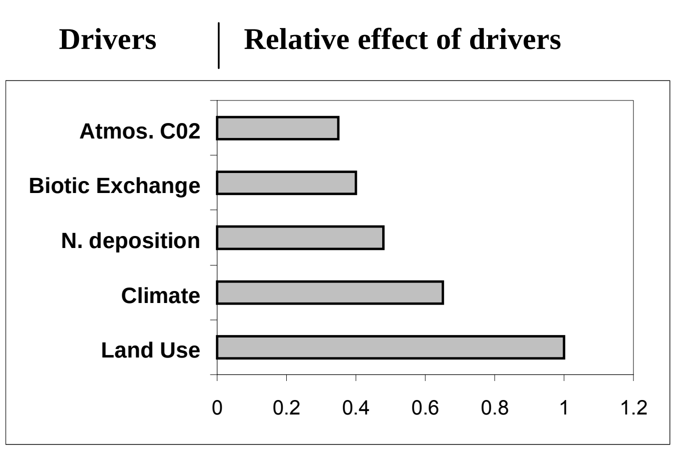
16. Trace gas records from ice cores reveal past variations in atmospheric carbon dioxide and methane concentrations that parallel climate fluctuations. While palaeorecords of climate change provide no close parallel with greenhouse warming as the primary forcing and its spatial distribution differs, they do indicate how biotic and physical systems respond to change (McGlone *et al.,* 1996). These changes are concerned not only with greenhouse emissions but also with widespread modifications of land cover and destruction of forested habitat resulting in a serious loss of the world's biological diversity. Although greenhouse gas changes may account for up to 50% of the late Quaternary temperature shifts, (Lorius *et al.* , 1990, quoted by McGlone *et al.*, 1996) there may have been prolonged periods when greenhouse gas concentrations remained high but global temperatures declined. And while widespread evidence for historical shifts in global climate has been detected in fossil pollen, marine deposits and coral, these lines of evidence provide no clear or consistent agreeement with the patterns of climate forcing under present day climate.

17. The past century and in particular the past few decades have seen major changes in greenhouse gas concentrations in the atmosphere that are closely associated with the industrial use of fossil fuels. In the last decade evidence of rapidly escalating levels of greenhouse gases suggests the major difference between historical swings in climate and the present day is

reflected not so much in degree but in the rate of change (*cf*. Weigel, 1997). These changes are concerned not only with greenhouse emissions but also with widespread modifications of land cover and destruction of forested habitat resulting in a serious loss of the world's biological diversity. The clearing of forests for agricultural land also undoubtedly contributed to increasingly cold temperatures in the eastern and central United states (Bolan, 1999). . The major greenhouse gases carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) ('NOX'), chlorofluorcarbons (CFCs) and ozone (O_3) constitute less than 0.04% of dry air. Nonetheless they play a major role in climate because they absorb radiant heat emitted from the earth's surface of the earth. In addition to these, atmospheric water vapour contributes significantly to the greenhouse effect

18. The predominant greenhouse gases have a residence time of 10 years or more (Manning *et al.,* 1996). When combined with their variable composition and interaction this creates complex lag effects with subsequent difficulties in forecasting specific greenhouse scenarios (Cramer *et al.,* 1999). The multiplicative effects of human-generated emissions, especially carbon dioxide, mainly from burning fossil fuels, have become global, and now average more than 7 billion metric tons of carbon per year (WRI *et al.,* 1998, p.170). Implications for FBD are significant as these levels are now rising annually at about 1.5 ppm from human activities alone (Houghton *et al.,* 1996). If this rate remains constant we can expect a doubling of CO_2 from preindustrial levels by the end of the 21st century. Consequences for global warming are such that the Intergovernmental Panel on Climate Change (IPCC) forecasts an increase in global atmospheric temperature 1˚C to 3.5˚C by 2100 accompanied by a rise in sea level from 15cm to 95cm. While acknowledging uncertainty in the outcomes of these forecasts, IPCC argues that increasing scientific support for this model reinforces the need for policy intervention to help mitigate these effects

Figure 1. Relative effect of key drivers of changes on biodiversity



Expected biodiversity change for each biome for the year 2100 was calculated as the product of the expected change in drivers times the impact of each driver on biodiversity for each biome. Values are averages of the estimates for each biome and they are made relative to the maximum change, which resulted from change in land use. [*Source*: after Sala *et al.,* (2000)]

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19. The atmospheric temperature profile of the present day has come to match that predicted by computer models for varying latitudes and elevations. While there is some doubt about the extent to which temperature increase is due to human influence it is unlikely that it can be attributed solely to natural background variability. The fate of other greenhouse gases, notably the ozone-destroying Chlorofluorocarbons (CFCs) has also received close attention. Earlier findings of increases in CFCs from human sources led ultimately to the Montreal protocol that resulted in sharp falls in production (unfortunately offset by a growth in black market production of these substances). Hydrofluorocarbons (HCFCs) used as substitutes for CFCs and some other man-made gases are rapidly increasing in the atmosphere (Manning *et al.,* 1996). Whereas emissions of CFCs have depleted ozone in the atmosphere possibly leading to expanding and contracting, so-called tropospheric 'holes' as in the antarctic, northern hemisphere emissions of nitrous oxides and volatile organic compounds have led to increased ozone in the troposphere. According to Manning *et al.,* (1996) global atmospheric chemistry models indicate changes in ozone levels in the past 200 years have probably contributed more to the enhanced greenhouse effect than changes in nitrous oxide or CFCs. Depletion of ozone in turn leads to increased UV-B radiation with potentially harmful impacts on biota (*cf.* Hansell *et al.,* 1998).

20. Linkages between the terrestrial biosphere and the atmosphere, particularly the lower atmosphere have been shown to be critical in modelling climate especially with respect to changes in albedo, roughness and soil moisture availability. Comparisons of climate model simulations reveal deficiencies in the land surface radiation and energy budgets as simulated. These are mainly reflected in model biases in annual net radiation and individual radiation components and a large range of variation in monthly and annual evaporation and sensible heat flux. Such deficiencies reflect a lack of understanding in (i) surface radiation and energy budgets and the lack of long-term observations; (ii) soil hydrology where there is an inability to quantify soil-water holding capacity and differences with averaging over heterogeneous landscapes; (iii) vegetation, and the need for closer links between leaf stomatal conductance , and its control of evaporation, and photosynthetic uptake and (iv) surface heterogeneity (Garratt *et al.*, 1996). Global Circulation Models (GCMs) are sensitive to assumptions about the properties of the terrestrial biosphere; areas of greatest sensitivity in land-atmosphere exchanges of energy, water and momentum are connected with measures of albedo, roughness, vegetation stomatal conductance, leaf area index, soil moisture storage capacity and availability (Garratt, 1993; Henderson-Sellers, 1993,1996; Garratt *et al.*, 1996).

21. In addition to findings by the IPCC, other lines of evidence continue to support an argument for human-induced climate change (e.g. Kaufman and Stearn, 1997). These have been sufficient to promote support for the Kyoto Protocol for signatory countries to reduce human-induced greenhous emissions by 5% according to an agreed time-table by 2012. Despite uncertainties in predictive models of climate change, there is some consensus about indication of future shifts, in particular a gradual change towards earlier springs and later winters. (Monatersky, 1996; Fung, 1997). Inter- and intra-annual variation is likely to be influenced by global warming with subsequent variable impact on forests (Kirschbaum *et al*., 1996; Foley *et al*, 1998). The consequences of these changes for the world's biota are discussed below.

22. Other climate-related phenomena such as El Niño and La Niña depend jointly on oceanic and atmospheric processes. While their impact is regional, their 'footprint' is global (Webster and Palmer, 1997). The El Niño Southern Oscillation (ENSO) process is driven by a cyclic change in ocean temperatures between east and west 'pools' of the Pacific Ocean. Normally the west Pacific is characterised by warm surface water (29-30ºC) (and high rainfall) with cooler surface water (22-24ºC) in the east with reduce precipitation. This quasi-equilibrium breaks down every three to seven years resulting in gradient reversal of east-west sea surface temperature and associated precipitation pattern. The regional consequences for forests and associated biota can be catastrophic with intense droughts occurring in regions

normally associated with high rainfall. The increasing incidence of droughts has led some authors (*e.g.* Salafsky, 1998) to suggest there may be a link between recurring ENSOs and climate change.

C. The uncertainty factor

23. There are some close parallels between our general understanding of the processes of climate change and the fossil record and present day knowledge about the deterministic role of the physical environment on the distribution and behaviour of biota. Despite these similarities there is no guarantee that the actual dynamics of past climate impacts represent those of the present day. There is little historical evidence to indicate the same coupling of both degree and rate of change in greenhouse gases is enhanced by present-day human intervention. Many land-based parameters of biosphere change that are known to be critical drivers of GCMs are questionable in terms of accuracy, repeatability and extrapolability.

24. One key uncertainty surrounds the fate of water in the hydrosphere as well as the atmosphere. An understanding of the passage of water in a forest is important when modelling vegetation-atmosphere interaction. To model water balance or soil moisture availability requires knowledge of root distribution and dynamics, soil hydraulic properties and the evapotranspiration potential of the individuals that make up a forest. These data are rarely available in relatively simple, temperate forests and almost completely absent for the great majority of the world's complex tropical forests. Changes in precipitation are also uncertain and difficult to generalise at the biome level (Sala *et al.,* 2000). Elevated CO_2 has the greatest effect on species composition in the presence of nitrogen deposition (interaction of CO_2 and nitrogen deposition) (Sala *et al.,* 2000; see also Walker and Steffen, 1997a,b for discsussion on interaction).

25. In forecasting climate change the degree of uncertainty will be influenced by assumptions about the relationships of parameters used to generate forcing functions. The highly complex nature of GCMs and underlying stochasticity each contribute to uncertainty. While physico-chemical interactions by themselves are problematic, important land use and socio-economic factors add yet another dimension of uncertainty. Model development and testing usually requires an estimate of uncertainty. By itself uncertainty eludes ready estimation due to the nature of most climate models and because the scale of experimentation needed to test outcomes is currently beyond our grasp. In an attempt to deal with this problem, Allen *et al.,* (2000) have estimated uncertainty by focussing on measurements of anthropogenic factors in climate change.

26. Variation in global land cover and land use change will, in the majority of cases exert a more immediate impact on FBD than climate *per se*. Whether the kinds of models that predict such impacts are parameterised by biome or plant life form (or neither), use single or multiple soil layers, or include N and water limitation will all affect predicted outcomes (Jackson *et al.,* 2000).

Table 2

Expected changes for the year 2100 in the five major drivers of biodiversity change (land use, climate, nitrogen deposition, biotic exchange and atmospheric CO_2) for the principal terrestrial biomes of the earth (arctic tundra, alpine tundra, boreal forest, grasslands, savannas, Mediterranean ecosystems, deserts, northern temperate forests, southern temperate forests and tropical forests). #

Driver	Arctic	Alpine	Boreal	Grass-land	Sav-anna	Medi	Desert	N temp	S temp	Tropic
Land use	1.0	1.0	2.0	3.0	3.0	3.0	2.0	1.0	4.0	5.0
Climate	5.0	3.0	4.0	2.0	2.0	2.0	2.0	2.0	2.0	1.0
Nitrogen deposition	1.0	3.0	3.0	2.0	2.0	3.0	2.0	5.0	1.0	2.0
Biotic exchange	1.0	1.0	2.0	3.0	3.0	5.0	3.0	3.0	2.0	2.0
Atmospheric CO_2	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5

Table 3

Impact of a large change in each driver on the biodiversity of each biome. Here a unit change of the driver was defined for land use as a conversion of 50% of land area to agriculture, for CO_2 as a 2.5-fold increase in elevated CO_2 as projected by 2100, for nitrogen deposition as 20 kg ha^{-1} yr^{-1}, for climate as a 4º C change or 30% change in precipitation, and for biotic exchange as the arrival of 200 new plant or animal species by 2100. (ref. text by Sala *et al.*, 2000, for additional detail)

Driver	Arctic	Alpine	Boreal	Grass-land	Sav-anna	Medi	Desert	N temp	S temp	Tropic
Land use	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Climate	4.0	4.0	3.5	3.0	3.0	3.0	4.0	2.0	2.0	3.0
Nitrogen deposition	3.0	3.0	3.0	2.0	2.0	2.0	1.0	3.0	3.0	1.0
Biotic exchange	1.0	1.0	1.0	2.0	2.0	3.0	2.0	1.5	3.0	1.5
Atmospheric CO_2	1.0	1.0	1.0	3.0	3.0	2.0	2.0	1.5	1.5	1.0

#Source: Sala, O. E., Chapin III, F.S., Armesto, J.J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E.,Huenneke, L.F., Jackson, R.B., Kinzig, A., Leemans, R., Lodge, D.M., Mooney, H.A., Oesterheld, M., Poff, N.L., Sykes, M.T., Walker, B.H., Walker, M. and Wall, D.H. (2000). Global Biodiversity Scenarios for the Year 2100. *Science*, **287**: 1770-1774.

27. Goudriann *et al.,* (1999) describe a progression of global models of terrestrial biospheric functioning that has moved from essentially 'mapped' static descriptions (such as $BIOME_1$ (Prentice *et al.,* 1992) to more recent models such as DOLY (Woodward *et al.,*1995) or $BIOME_3$ (Haxeltine and Prentice, 1996; Haxeltine *et al.,* 1996) that incorporate simulations of ecosystem state. However these models are essentially static given that the structure of the world's vegetation is undergoing continual change. This has led to a new class of global biosphere models known as Dynamic Global Vegetation Models or DGVMs. Goudriaan *et al.,* (1999) point out that DGVMs are designed to overcome two fundamental problems of earlier global biosphere models namely: (i) the lack of explicit integration between biophysical, ecophysiological, biogeochemical and biogeographical processes within models and (ii) the absence of explicit vegetation dynamics mechanisms that lead to state transitions in ecosystem structure and ecosystem functioning.

28. More realistic forest-dynamics models will also depend on evaluations of growth characteristics in many tree species, in diverse tropical rain forests. Such models are greatly needed, both for designing management for this biome and for predicting its responses to changing climate and atmospheric conditions (Clark and Clark, 1999). Combinatorial DVM and GCM approaches such as those used by Daly *et al.,* (2000) have been used to model tree-grass interactions which showed that tree rooting configurations ovewhelmed changes in biogeochemical pools. In both historical and future scenarios fire was required for the coexistence of trees and grasses when deep soil water was available to trees. Such models indicate that an absence of data on rooting systems may add significant uncertainty in forecasting tree reponse to climate change.

29. Current uncertainties with DGVMs lie in their limited ability to simulate disturbance such as fire, strong winds and pest attacks, factors that can have a massive influence on vegetation dynamics. Schulze *et al.,* (2000) report considerable uncertainties in estimates of the anthropogenic contribution to the terrestrial carbon sink at scales ranging from plots to continents. Continental-scale carbon fluxes estimated from forest inventories, eddy flux measurements, and atmospheric inverse model studies led to conflicting results when compared for the same region….for example sink estimates range between 0.2 and 1.3 Gt/year for the continental United States, between 0.01 and 1.3 Gt/year for Siberia , and between 0.2 and 0.4 Gt/year for Europe. These uncertainties arise because the methods used measure different fluxes of the terrestrial carbon cycle at different temporal and spatial scales.

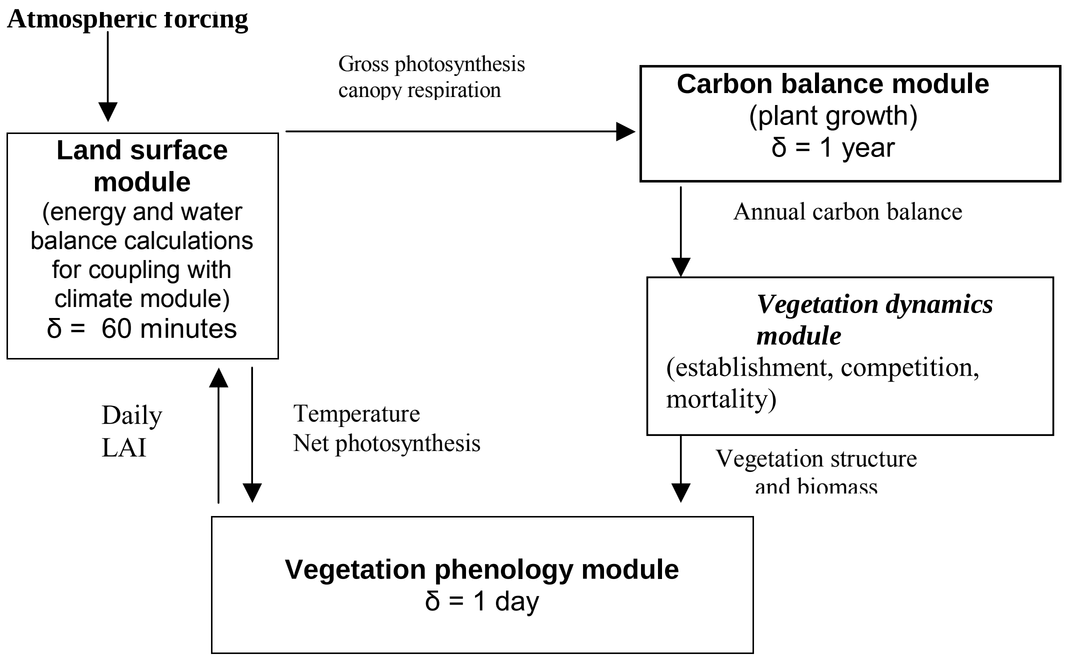
[Fig.2 here].

IV. IMPACT OF CLIMATE CHANGE ON FOREST BIOLOGICAL DIVERSITY

A. Defining biodiversity

30. The term 'biodiversity' was first used apparently by Norse and McManus (1980) and Lovejoy (1980a,b) in an attempt to encompass the variety of life in managed systems. Since then biodiversity has come to be defined as the 'Variety of life on earth" usually described in terms of gene, species and ecosystem (*cf.* Heywood and Baste, 1995). More recently, in a re-definition of biodiversity for their 'global biodiversity scenario for the year 2100' Sala *et al.,* (2000) specifically excluded "exotic organisms that have been introduced and communities such as agricultural fields that are maintained by regular intervention". While these approaches are conceptually useful at the broad level they are of no use in an operational context where quantification is vital.

Figure 2. Basic modules in a Dynamic Global Vegetation Model (IBIS, Adapted from Foley *et al.*, 1996; Goudriaan *et al.*, 1999)



31. The lack of an operational definition, possibly more than any other single factor, appears to have curtailed progress by world conventions and conservation bodies in seeking international agreement in methods of assessing and conserving biodiversity. To assess, monitor and communicate impacts of climate change on biodiversity requires a cost effective mechanism to quantify representative elements of biotic complexes as represented by gene, species and ecosystem. In turn this must be supported by readily observable, quantitative descriptors of their response to change. Finally, logistic, scientific and management need to be able to identify and locate indicators of otherwise overwhelmingly complex sets of biota and to do this using methods that are cost efficient, logical and repeatable by different observers. In an ideal world a cost efficient, generic approach would be used to assess and compare biodiversity in a uniform way at different spatio-temporal scales and within and between regions and continents. Unfortunately the 'ideal' is far from reality and much debate centers on the use and non-use of indicators in deciding how biodiversity might be defined and measured.

32. *The importance of environmental context in monitoring impact:* The move from plot-based measurements to ecosystems is compatible with the ecological concept that organisms do not exist in isolation, rather their survival depends on their relative position as a functioning unit within an interacting and integrated set of biotic and abiotic elements. To

adequately understand how plants and animals respond to environmental change requires a knowledge of the key environmental determinants of their distribution and performance. Traditional approaches to assessing biodiversity in tropical forests usually involve sampling within the closed-canopy forest istelf. Because the habitat ranges of many taxa exist outside as well as inside forests, sampling the forest interior alone leads inevitably to databases with truncated distributions of certain taxa. Models of plant and animal performance built on such databases will ultimately mislead. This may include water bodies, open plains or successional forest patches or even agriculturally modifed lands.

33. Forest edges are particularly diverse in ecological niches and correspondingly rich in species and functional types. In many developing countries where shifting agriculture is the norm, a change to permanent, intensive farming systems or a significant reduction in fallow periods can have a dramatic effect on forest-dwelling taxa if their habitat range is reduced to levels that will not support viable populations. Alternatively, emigration of people from a forested area can reduce patchiness and biodiversity especially if intermediate levels of so-called disturbance are not maintained. This concept is well understood among Australian Aboriginal and other savanna-dwelling people who practise seasonal patch-burning to maximise habitat variability and their food resource.

34. In order to provide an effective knowledge base to facilitate adaptive it is necessary to be able to forecast the impact of environmental change on taxa that are important to land owners and other stakeholders in forested lands. This will requires *a priori* knowledge of the actual range distributions of these key taxa in many cases involving land use intensity and natural resource gradients.

35. *Genetic characterisation of biodiversity:* Various institutional approaches to biodiversity assessment underscore the need to include assessement of genetic variability in examining FBD (DIVERSITAS, 1996; CIFOR, 1997). While this is desirable and methods for characterising genetic variability are becoming faster (*cf*. Templeton, 1996) the present reality is that, at least for some of the more species-rich forests, measuring genetic variability is not yet feasible (Watt *et al.,* 1998). Nonetheless questions remain about the need to assess population viability. Most species populations are genetically diverse (*cf*. Turok, 1997) and intraspecific genetic diversity is influenced by migration, selection and genetic drift (Hamrick *et al.,* 1993; Libby *et al.,* 1997; Watt *et al.,* 1998).

36. While direct methods of genetic characterisation may be impractical, indirect methods can provide insights into genetic diversity via taxonomic inventory. Although the species is the most commonly recorded unit an analysis of species in relation to lower and higher taxonomic ranks can give a measure of phylogenetic or 'taxic' richness (Vane-Wright *et al.,*1991). Various measures of phylogenetic diversity are available (Farris, 1972; Faith, 1992,1993,1994,1995). Additional characterisation of life history and adaptive traits can provide other indirect measures of gene flow (Körner *et al.,*1989; Martinez 1996; Gillison and Carpenter, 1997). Phylogenetic approaches conducted at intraspecific level can also help shed light on genetic characteristics that may be important for biotechnology (Taberlet, 1998) and in some cases such as insects can be used to detect morphologically unrecognized species among widespread, more easily recognizeable 'species' (Packer and Taylor, 1997). Congruent phylogenies between hosts and their parasites can also be used to interpret evolutionary trends as well as their ecological interrelationships and genetic diversity (Near *et al.,* 1998).

37. *The Linnean species*: Most life scientists and paractitioners regard the Linnean species as the common currency of biodiversity and this creates considerable problems for impact assessment. First, species usually differ from region to region and their names carry little if any, useful comparative information in terms of measuring response to environmental impact. Second, because a user may prefer to switch instead to species 'diversity' (commonly

termed within-site or 'alpha diversity' expressed as richness or number of species per unit area) a present trend is to regard species richness as the key operational unit or comparator of biodiversity. This has the unfortunate effect that sites low in richness (such as a unique, naturally occurring savanna on lateritic soils) may be valued less than sites with high richness. Possibly because most present-day ecology has eurocentric roots in environments with relatively few species, there is a reluctance to embrace new approaches needed to deal with the immense richness of tropical, lowland forests where species sampling and identification are frequently a major problem.

38. Where species identification is difficult, observers tend to use progressively higher taxonomic rank (typically genus and/or family) which carries information of varying utility (Dale and Clifford, 1976). Van Jaarsveld *et al.,* (1998) examined species and higher taxon data for South African plants and animals and found complementary species sets did not coincide with and only marginally overlapped higher taxon sets. In the complete absence of taxonomic identity, non-systematic, 'morphospecies' names are commonly used. While locally useful, this practice has the dual disadvantage of frequently eluding formal identification and thus limiting uniform, comparative assessment between sets of species data from other locations.

39. At progressively finer organismic scales, species tend to be replaced by functional groups that are detected by features such as enzymic pathways and molecular characterisation. At microbial level taxonomic diversity may be characterised by diagnostic procedures such as phospholipid fatty acid determination and ribosomal DNA sequencing (Aragno and Uhlelova, 1997). Similar methods of molecular detection have been used to characterise diversity among functional groups of soil and marine bacteria (Stephen *et al.,* 1996).

40. *Functional Types*: *Functional Types (FTs) are sets of organisms showing similar responses to environmental conditions and having similar effects on the dominant ecosystem processes* (Diaz, 1998) see also Cramer, (1996), Cramer *et al.,* (1999). This is an extension of an earlier definition (Shugart, 1996) who used Plant Functional Types (PFTs) *to connote species or groups of species that have similar responses to a suit of environmental conditions*.. FTs can be used to help reduce complex species groups to more manageable entities and to compare responses of individuals, for example, between geographically remote locations where environments and adaptive morphologies are simlar but where species differ. While functional phenomena apply within a 'gene-species-ecosystem' hierarchy, there is increasing debate about the role of species diversity in maintaining ecosystem function and whether or not species designations best distinguish functional groupings (Johnson *et al.,* 1996). In this sense the perception of species 'guilds' as functional assemblages (Schimper, 1903; Johnson, 1981) may need re-examination.

41. Species richness and abundance used alone and in the absence of other attributes of behaviour and performance can seriously mislead and impede biodiversity assessment. In addition, parity in species richness between different sites does not guarantee equivalence in either genetic variability or response to environment. PFTs are now widely considered a necessary and appropriate simplification of species diversity, and they have the advantage that ecosystem types often result more or less naturally from PFT assemblages (Cramer *et al.,* 1999). A global key of plant functional types has been considered by IGBP/GCTE (Steffen and Craner, 1997). A formal systematic approach using PFTs (1981,1988, 2000a; Gillison and Carpenter, 1997) builds on earlier classifications of plants into 'life form' for example that of Raunkiaer (1934) (see also Schimper, 1903 for related guilds or 'synusiae' and Fekete and Szujkó-Lacza, 1972 and other, more complex systems based on survival mechanisms and adaptive reponse to environment (Ellenberg and Mueller-Dombois, 1967; Grime, 1979; Noble and Slatyer, 1980; Box, 1981a,b, 1996; Bahr, 1982; Orshan, 1983; Lavorel *et al.,* 1997, 1999;

Gitay *et al.,*1999). Of these the modelling approach of Box (1981a,b, 1996) was among the first to successfully explore linkages between plant form and climate.

42. Recent findings indicate measurement of biodiversity impact should include functional features or functional types as well as species. (Fosberg, 1967; Box, 1981a,b; Gillison, 1981, 1988; Nix and Gillison, 1985; Cowling *et al.,* 1994a,b,c; Huston, 1994; Collins and Benning, 1996; Martinez, 1996; Woodward *et al.,* 1996). Definitions of functional types vary but are most commonly associated with 'guilds' (Bahr, 1982; Gillison, 1981; Huston, 1994; Gitay and Noble, 1996; Mooney 1996; Shugart, 1996; Smith, 1996; Smith *et al*., 1996; Gillison and Carpenter, 1997; Gitay *et al.,* 1999). Their application under wide-ranging climates indciates some promise in monitoring and forecasting the impacts of climate change on vegetation (Gillison, 1981, 1988; McJannet *et al.,* 1995; Bugmann and Fischlin, 1996; Kelly, 1996; Brovkin *et al.,* 1997; Paruelo and Lauenroth, 1997; Breshears and Barnes, 1999; Campbell *et al.,* 1999; Diaz, *et al.,*1999; Garcia-Mora *et al.,* 1999; Hodgkinson *et al.,* 1999; Kleyer, 1999; McIntyre *et al.,* 1999; de Pillar, 1999; Skov, 2000).

43. Jobbágy and Jackson (2000) suggest that plant functional types, through differences in allocation, help to control soil organic carbon (SOC) distributions with depth in the soil. Various workers have experimented with different sets of PFTs for widely different purposes and with varying success: for example, remote sensing (Nemani and Running, 1996; van den Berg *et al.,* 1999); reconstructing global vegetation patterns from palaeoecological records (Prentice and Webb, 1999) or at ecosystem level, particularly with respect to global change (Bugmann and Fischlin, 1996; Nemani and Running, 1996; Diaz and Cabido, 1997).

44. *Ecosystems:* As outlined in COP V/6 Annex A (see Annex III in this document) and provided in Article 2 of the CBD, ecosystem is defined as : "*..a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit*". The CBD applies this definition without constraints of scale and within the context of sustainable management to ensure a balance of the three objectives of the Convention: namely, conservation; sustainable use; and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources. The CBD has outlined 12 principles for the ecosystem approach (COP V/6 Annex B) together with operational guidelines for their application (COP V/6 Annex C). *The term 'ecosystem' in this review is applied within the above context.*

45. The CBD approach to ecosystems is consistent with more recent developments in conservation ecology where it is asserted that efforts to preserve biological diversity must focus increasingly at the ecosystem level and that the landscape matrix is important to maintaining biodiversity (*cf*. Franklin, 1993; Perry, 1994; Arnup and Perera, 1995; LaFrankie, 1995; Fjeldsa and Kessler, 1996; Mills *et al.,* 1996; Trofymow *et al.,* 1997; Weber and Flannigan, 1997; Carey, 1998; Feng *et al.,* 1998; Gattuso *et al.,*1998; Hodgson *et al.,*1998; Richardson, 1998; Wardle *et al.,*1998; Baker and Noble, 1999; Carey *et al.,*1999; Cramer *et al.,*1999; Mooney *et al.,*1999; Evans and Johansen, 1999; Gondard, 1999; Shi and Li, 1999; Schulze *et al.,*1999; Sala *et al.,* 1999, 2000; Williams, 2000).

46. The role of soil and soil organisms in ecosystems is also gaining more attention (Loumeto and Bernhard-Reversat, 1997; Bridges and Oldeman, 1999) while studies of biodiversity and productivity in agroecosystems has taken on an ecosystem management approach (Kevan *et al.,*1995; Inthavong *et al.*1996; Ruuska and Helenius, 1996; Chou, 1999; Groppali, 1999; Ramakrishnan, 1999; Loranger *et al.,*1999). Interactions between agricultural intensification, soil biodiversity and agroecosytem function identified by Giller *et al.,* (1997) are summarised in Table 5. Batjes (1999) maintains that the most appropriate management practices to increase soil C reserves are site specific. Available best management practices

will require evaluation and adaptation with reference to soil type and land use system, and this preferably by agro-ecological region.

Table 5. Range of below-ground biological functions, functional groups and management practices that provide a gradient-based framework for sampling biodiversity#

Biological function	**Biological/ functional group**	**Management practices** [that impact function]
Residue comminut/ decomposition	Residue-borne microorganisms, meso/macrofauna	Burning, soil tillage,pesticide applications
Carbon sequestration	Microbial biomass (esp. fungi) macrofauna building compact structures	Burning, shortening of fallow in slash and burn and soil tillage
Nitrogen fixation	Free and symbiotic nitrogen-fixers	Reduction in crop diversity, fertilization;
Organic matter/ nutrient redistribution	Roots, mycorrhizas, soil macrofauna	Reduction in crop diversity, soil tillage, fertilization
Nutrient cycling, mineralization/ immobilization	Soil microorganisms, soil microfauna	Soil tillage, irrigation, fertilization, pesticide applications, burning
Bioturbation	Roots, soil macrofauna	Soil tillage, irrigation, pesticide applications
Soil aggregation	Roots, fungal hyphae, soil macrofauna, soil mesofauna	Soil tillage, burning, reduction in crop diversity, irrigation
Population control	Predators/ grazers, parasites, pathogens	Fertilization, pesticide applications, reduction in crop diversity, soil tillage

Source: Giller, K.E., Beare, M.H., Lavelle, P., Izac, A.-M.N. and Swift, M.J. (1997). Agricultural intensification, soil biodiversity and agroecosystem function. *Appied Soil Ecology,* **6**, 3-16.

B. Impact on genotypes

47. Genetic differentiation in evolutionarily young boreal plants suggests relatively high intraspecific value with decreasing species richness as latitude increases. The species groups form evolutionary and demographically separate units and this must be taken into account when considering conservation under changing environments e.g. from cold to warm conditions (*cf.* Pamilo and Savolainen, 1999). In a study conducted across continent-wide surveys in North America and Europe, Taberlet (1998) found that intraspecific polymorphism appeared to be lower at higher latitude, particularly in areas glaciated during Pleistocene cold periods, and that most of the variation lay in areas that corresponded to refugia during range contractions. This trend may be offset if plant growth in the northern high latitudes increases due to climate change (*cf.* Myneni *et al.*, (1997). Forest fragmentation may lead an initial drift towards homozygous conditions among some species but may return to a more heterozygous condition with forest restoration or where fragments coalesce. The degree to

which fragmentation also affects pollen dispersal will also be influenced by the type of species and the pollen vector (Nason and Hamrick, 1997; Nason *et al.,* 1998).

48. Neefjes (1996) argues a case for *ex situ* conservation of genetic stocks as a guard against environmental change such as climate change. Rosenberg (1988) asserts there is a need to maintain genetic stocks and natural biodiversity as a buffer against climate change. Ruel and Ayres (1996) suggested climatic warming could rapidly produce important phenotypic changes in birch trees (e.g. reduced root/shoot ratio, reduced growth in alpine populations). On a longer time scale, warming could also result in genetic changes as natural selection favours valley genotypes in alpine sites where they are presently rare. Collection of baseline data is frequently resource-limiting; Halloy (1995) for example, reviewed New Zealand's only marginally documented genetic resources and found total investment in biodiversity research less than 0.04% GDP, with only another 0.1% spent on conservation.

C. Impact on forest species

49. *Migration potential of organisms:* Many climate change scenarios forecast changes in biome structure and position on the earth's surface. Differing dispersal and establishment characteristics between species suggest that migration rates will differ and that biomes as a result are very unlikely to move as a discrete unit (although see Kohlmaier *et al*.,1995 who forecast a northern movement of the Taiga boundary).

50. In the Swiss Central Alps Hattenschwiler and Körner (1995) contend that the montane *Pinus sylvestris-Pinus cembra* ecocline may be stabilized by species interactions and not directly responsive to moderate climatic change. Shifts in sea level may open migratory corridors between large land masses; Trojan (1997) suggests the disappearance of the sea barrier between Europe and Asia in the Quaternary, ecological corridors served as migration pathways between Europe and the Far East. Leishman *et al*., (1992) maintain past migrations of species under climate change have been an order of magnitude slower than the rate of predicted climate change for the next century. Boundaries created by fragmented landscapes will also influence species migrations (Iverson and Prasad, 1998).

51. Rates of movement needed to keep up with hypothetical biome boundary shifts may be in the order of 1 to 2 km yr^{-1} (Ritchie and MacDonald, 1986). Malcolm and Markham (2000) calculated Required Migration Rates (RMRs) for forest species under scenarios where CO_2 doubling occurred over 100 years and over 200 years. They found RMRs for all model combinations were very high ($\geq$ 1,000 m yr^{-1}) comprising on average 17 and 21% of the earth's surface; RMRs for plant species due to global warming appeared to be 10 times greater than those recorded for the last glacial retreat; high migration rates were found in the the northern hemisphere with the highest in the taiga/tundra, temperate evergreen forest, temperate mixed forest and boreal coniferous forest indicating that species that depend on these systems may be among the most vulnerable to change.

52. Malcolm and Markham (2000) concluded rapid rates of global warming have the potential to radically increase species loss and reduce biodiversity especially in the higher latitudes of the northern hemisphere. This is consistent with the trend that species have a range of minimum temperature tolerances which is much greater than the range of maximum temperature tolerances (Woodward, 1987). Other workers have reached similar conclusions for biodiversity loss based on relative lag times in species migration (Sykes and Prentice, 1996; Kirilenko and Solomon, 1998). Others (Solomon and Kirilenko, 1997) have considered scenarios where trees do not migrate. Various models of tree species distributions under climate change have been put forward (Sykes *et al.,* 1996; Woodward, 2001). However, for modelling species distribution, Halpin (1997) has pointed out that direct extrapolation of observed species distributions in relation to present climate as a means for projecting future

responses is inappropriate; such projections must include consideration of physiological tolerances, competition, and dispersal mechanisms. Davis *et al.,* (1998) also highlight uncretainties associated with predicting shifts in species range in response to global warming.

53. Mitchell and Williams (1996) suggest that species may not transfer naturally fast enough to newly suitable climates . The possibility that species may need to be relocated raises serious issues for management and conservation. Barriers to migration of certain species and functional types may be created by complex interactions affecting imigration and extinction of species within and between forest “islands” (Lomolino and Davis, 1997) and through climate-induced fragmentation of forested lands. At least in the tropics, most butterfly species for example, tend to follow forest edges (Wood and Samways, 1991) and many forest-dependent animals including birds may rely on forested corridors for access to critical habitat (Bentley and Caterall, 1997).

54. In the European alps Gottfried *et al.,* (1999) found that with global warming, mountain plant species are migrating upwards and that species inhabiting the present nival zone are threatened by competitors which move from the alpine zone towards the summits, their rate of movement being modified by local microrelief. Present-day, anomalous cooling in the eastern Arctic, primarily in late winter and early spring, has interrupted northern migration of wild fowl and led to increased damage to vegetation in southern arctic salt marshes as a result of foraging (Hansell *et al.*,1998).

55. Interaction between climate change and fire regime has the potential to overshadow the importance of the direct effects of global warming on species migration (Weber and Flanningan, 1997). Small parks and naure reserves may have a critical future role in serving as stepping-stones for fauna (Falkner and Stohlgren, 1997). Migration of plants may depend on species interaction with dispersal vectors; for example, Dyer (1994, 1995) concluded migrations of bird-dispersed tree species lagged behind forecast shifts in global warming by at least an order of magnitude (see also Leishman *et al.*, 1992) for comments of comparative rates.

56. The differential capacity of species to match the rate of change of a climate ‘front’ is likely to lead to corresponding changes in biome and ecosystem composition, assuming the change is sufficiently large (e.g. a doubling of CO_2 in 100 years). Migration rates through non-random landscapes highly modifed by human activities are usually slower than those based on predictions based on studies on randomly fragmented landscapes (Cramer *et al.*,1999). A sieving out and re-ordering of species niches is likely to favour the more vagile or weedy functional types (*cf.* Beerling, 1993). While this may not necessarily lead to a reduction in biodiversity in terms of species richness it may have drastic effects on composition and degradation with consequences for serious disruption of ecosystem processes, reduction of net ecosystem productivity (NEP) and species extinctions (Davis, 1989a,b, Overpeck *et al.,* 1991; Cramer *et al.*,1999).

57. While change of this order assumes an overall decline in biodiversity not all changes may be negative. There exist, for example, naturally occurring plant assemblages such as shoreline flora and those in so-called forest-grassland ecotones or ‘edge’ communities. Such groups have the potential to respond quickly to change and have evolved under such conditions as prograding or retrograding shorelines, recurrent wildfire, unusually extreme temperature or soil moisture fluctuations and so on. Forest ecotones are likely to become blurred as the range distributions of species and FTs readjust to new environments. (*cf.* Neilsen, 1993). Much of the seasonally dry tropics contain suites of such taxa and functional types (Gillison, 1988), many of them pantropical and capable of dispersal by water.

58. There is historical evidence for major shifts in the position of continental shorelines (e.g. the Late Miocene and Cretaceous shoreline regressions in inland Australia (Burbidge,

1960). These may leave behind refugic shoreline elements that serve as gene pools for subsequent speciation. Because shorelines are themselves receptive to incoming diaspores from other continental and island sources they also serve as a vehicle for gene exchange and evolution. On the other hand certain island floras may disappear entirely if they suffer immersion due to sea rise as in certain low-lying atolls and low-profile, volcanic islands.

59. *Invertebrates:* Under global warming the disturbance patterns caused by insects may change substantially, especially for those insects whose distributions depend largely on climate. Climate warming may already be influencing some insect life cycles (Fleming, 1996). Fleming and Candau (1998) considered how a major insect outbreak system in Canadian forests, of the spruce budworm (*Choristoneura fumiferana*), a pest of *Picea* spp. (especially *P. glauca*) and *Abies balsamea*, might react to global warming. They highlight the possible importance of natural selection, extreme weather, phenological relationships (between the pest life cycle, host phenology and natural enemies), complex feedbacks, historical conditions, and threshold behaviour. They also argue that a species-level, preservationist approach may have unwanted side-effects, be cost-ineffective, and ecologically unsustainable. The European pine sawfly (*Neodiprion sertifer*) is one of the most serious defoliators of Scots pine (*Pinus sylvestris*) in northern Europe. Virtanen *et al*., (1996) predict that in Finland, climate change (increased winter temperatures) may increase the frequency of sawfly outbreaks in eastern and northern Finland in the future. Whittaker and Tribe (1996) studied a population of the spittlebug *Neophilaenus lineatus* (Auchenorrhyncha: Cercopidae) for 10 years on a transect from 20 m to 974 m on Ben Lomond, Scotland. They found a significant relationship between the weather and the maximum altitude at which larvae are found in the same year. The study suggests that insects with a similar life cycle to N. lineatus will respond to a 2 deg C rise in mean temperature by extending their range and completing the life cycle 2 to 3 weeks earlier.

60. Farrow *et al*., (1993) explored the possible effects of climate change on insect pests in Australia and expect the range of wingless grasshopper (*Phaulacridium vittatum*) to contract southwards because of temperature increases but that it may increase in density through drier southern climates. The red-legged earth mite (*Halotydeus destructor)* is likely to contract southwords and become less of a pest while aphids and pasture scarabs may increase in number (Farrow *et al*., 1993). The rate of development of the common army worm (*Mythimna convecta*), a major pest in eastern Australia, is expected to increase southward together with cattle ticks (*Boophilus microplus*), Queensland fruit fly (*Bactrocera tryoni*), buffalo fly (*Haematobia irritans exigua*) and *Culicoides waadia* the midge vector of blue tongue virus in Australia (Sutherst, 1990; Sutherst *et al.,*1996).

61. To the extent that climate change is likely to affect insect host-plants there will be an associated impact on insects. Gerber (1989) found host plant abundance may be the main factor preventing eastward extension of the range of the red turnip beetle, *Entomoscelis americana* and climate and host plant abundance together appear to limit its occurrence to low-altitude locations north of 60 deg N latitude. In conditions where forests may undergo transitional stages a temporary destabilization of forests may provoke excessive damage by insects and reintroduction of admixed or alternative tree species may be accompanied by new tree-specific pest problems (Fuhrer, 1996). Camp *et al*., (1997) noted that in the inland west of the USA, current management goals for increasing amounts and connectivity of old, refugia-like forests for the benefit of species associated with late-successional habitat increase the risk of insect and pathogen outbreaks and catastrophic wildfires.

62. Climate change impact on insects is likely to differ markedly between temperate and tropical regions. According to Coley (1998), in contrast to the temperate zone, most herbivory in the tropics occurs on ephemeral young leaves (>70%) (see also Janzen, 1970). As a consequence plant/herbivore interaction in the tropics may be more susceptible to climate change and insect outbreaks increase and herbivory rates rise 2-4 fold where increased CO_2 is

combined with drying. The predicted increase in the number of herbivores may be primarily due to relaxed pressure from predators and parasitoids and under these circumstances relative abundance of species could change and overall biodiversity decline (Coley, 1998). . In New Zealand, although the impacts of climate change will vary throughout the country, climate change is expected to increase the range of many arthropods and enhance their pest status (Sutherst *et al*.,1996; Prestidge and Pottinger, 1990).

63. In butterflies evolutionary changes in flight morphology and dispersal rate may be important determinants of range expansion, and may affect responses to future climate change Hill *et al.,* (1999). However Fleishman *et al.,* (1998) examined the response of butterflies to a 1300m elevational gradient in the Toiyabe Range in the Central Great Basin of the USA and found indications that few butterfly taxa will be lost from the Toiyabe Range in the face of climate change.

64. Impacts of forest fragmentation on rarities may differ between forest types. In a temperate Australian eucalypt forest for example Davies *et al.,* (2000) found that rare beetle species are more likely to decline than abundant species under fragmentation. Didham *et al.,* (1998) on the other hand found that in tropical forest fragmentation rarer beetle species are predicted to be better dispersers and better at persisting.

65. *Amphibians and reptiles:* Because many are adapted to very cryptic forest habitats and are susceptible to dessication, any change leading to a drying out of habitat, for example with increasing seasonality, is very likely to lead to a decline in species number. Forest fragmentation in particular is likely to have both an immediate and long-term effect in creating a barrier for species migration in the event of climate change.

66. *Birds:* Bird species richness appears to increase with patchiness or intermediate levels of disturbance both in the tropics (Makuloluwa *et al*., 1997) and in temperate zones (Merrill *et al*.,1998). On the other hand Krementz and Christie (1999) argue that for long-leaf pine – wire grass savannas in South Carolina USA, even-aged forestry is an important management practice for maintaining and increasing avian biodiversity on public lands. In southeastern Australia there are broad trends in bird species distribution along gradients of elevation and soil moisture (Neave *et al*.,1996). In Minas Gerais, Brazil, D'Angelo *et al.,* (1998) recorded a loss of 48% of forest bird species, probably due to habitat loss resulting in very small sizes of forest fragments. They maintain there is a need to preserve larger fragments in order to retain more specialized forest bird species.

67. *Mammals:* Size of area, degree of isolation and immigration filters appear to influence mammal survival. These factors may be significantly influenced by climate change. According to Lomolino and Davis (1997), community structure of non-volant mammals of the Great Basin in in the north west montane forests of the USA appears to have been strongly influenced by extinction. Species richness and community nestedness of these mammals were significantly associated with area but not with isolation. At finer scales these communities may also be influenced by immigration. In the north of the Great Basin, where immigration filters are less severe, richness tended to decline with isolation, and community nestedness was as strongly associated with isolation as it was with area. (Lomolino and Davis, 1997).

68. In southeastern Australian forests present-day mammalian fauna has been influenced strongly by the effects of urbanization, land clearing, forestry and fire on forest structural complexity and nutrient dynamics as well as by predation by introduced carnivores (Cork and Catling, 1996). While modelling with broadly defined climatic and terrain variables might be useful for broad-scale spatial prediction of faunal distributions, such models may not provide descriptions of habitat requirements or predict impacts of forest management at the scale needed to sustain faunal biodiversity (Cork and Catling, 1996).

69. Climate-induced shifts in fire regimes may significantly influence mammal distribution and performance. In the northern boreal forest zone in Quebec, Crete *et al*., (1995) found that fire creates a mosaic of forest stands through periodic killing of trees, which helps to maintain regional wildlife diversity and that its suppression would reduce biodiversity. In highly seasonal northern Australia fire is also one the main determinants of mammal distribution in lancewood (*Acacia shirleyi*) thickets and woodlands although there is a correlation with latitude (Woinarski and Fisher, 1995). Density in small rodent species increases with latitude in Scandinavia where animal densities are slightly greater in clearcuts than in forests (Hansson, 1992). In Indomalesia widespread fire coupled with El Niño-induced drought can have a drastic effect on mammal distribution (Maryanto *et al*., 2000).

D. Impact on functional types

70. In the tallgrass prairies of the northeastern USA Smith *et al*., (1999) found that removal of the two dominant C_4 grass species altered the community structure, increased plant species richness, diversity, and evenness, and increased abundance of subdominant graminoid and forb species where the abundance of those with a highly mycorrhizal response decreased and less mycorrhizal responsive species increased. Burning strongly influenced the outcome of these interactions. Temperature is likely to be a dominant factor in controlling the distribution and abundance of plants with C_3 and C_4 carboxylation pathways (Henderson, 1993; Mooney *et al.,* 1999). Under scenarios of enhanced CO_2 and increased temperatures C_4 species may replace many C_3 functional types. While there are relatively few C_4 woody plants, in temperate forests and forest mosaics containing many C_3 herbaceous species the compositional pendulum is likely to swing towards dominant C_4 types especially Andropogonoid grasses.

71. To the extent that higher temperatures would favour C_4 weeds, this may be offset by increased rainfall and sub-soil moisture that is likely to suit C_3 woody weeds. Sequences of rainy years may also favour the development of thickets by allowing seedlings to grow high enough to escape pressure by grazing animals (Sutherst *et al.,*1996). There appears to be a naturally occurring change in C_3:C_4 ratio that varies along both elevational as well as latitudinal gradients. Along elevational gradients in the tropics there is a recognized "C_3/C_4" equilibrium point where the number of C_4 species approximates the number of C_3 species (*cf.* Rundel, 1980; Gillison, 1993). With the response scenarios presented by different authors this equilibrium point is like to increase in elevation especially in tropical montane regions.

72. Nonetheless to forecast shifts in species composition and FTs will be difficult. Lin (1998) found that under controlled CO_2 doubling, carbon assimilation rates varied between C_3 species suggesting that overall vegetation response is likely to be more complex than is generally considered. In that study stomatal conductance in most species decreased significantly when CO_2 increased from 350 to 700 micro mol mol^{-1}, but did not change with further CO_2 increase. Water Use Efficiency (WUE) also increased linearly from 350 to 2000 micro mol mol^{-1} CO_2 in some species but not others that increased WUE only when CO_2 increased to about 1000 micro mol mol^{-1}. Variations of this magnitude are likely to result in decreased biodiversity in the Pacific as CO_2 continues to rise (Lin, 1998). Effects of carbon saturation were detected by Körner *et al.,* (1997) in studies where alpine grassland at 2,470 m altitude in the Swiss Central Alps was exposed to elevated CO_2 by using open top chambers. Despite low CO_2 responsiveness at ecosystem level, species responses differed in terms of nitrogen, carbohydrates, tillering and flowering, suggesting the possibility for long-term changes in community structure. Since responses to elevated CO_2 were absent in both warm and cold growing seasons, Körner *et al.,* (1997) concluded that this late successional plant community is carbon saturated at current atmospheric CO_2 concentrations for reasons not directly related to nutrient supply and climate.

73. Apart from C_3 and C_4 photosynthetic pathways, many tropical forests contain upper-storey, succulent epiphytes (within Asclepiadaceae, Bromeliaceae, Cactaceae, Orchidaceae) and some ferns (e.g. *Pyrrhosia* spp.) that exhibit Crassulacean Acid Metabolism (CAM) that is more typical of terrestrial plants in seasonal to hot arid habitats. While many CAM plants are known in cool, moist, upland forests (e.g. in upland Andean habitats) as well as tropical lowland, seasonal forests, their range and incidence may increase with global warming. Leishman *et al.,* (1992) examined the likely distribution response of many plant species to global climate change, with respect to their ability to disperse into, and establish in, new communities. They questioned whether plant functional types based on vegetative attributes (used to model the response of adult plants) were correlated with functional types based on seed and seedling attributes. Their evidence suggested the two sets of attributes were not strongly correlated and that models of vegetation dynamics will need to incorporate seed biology explicitly.

74. Changes in species richness may not correspond directly with richness in functional types (Hodgson *et al.,* 1998; Gillison, 2000b). Changes in ratios of plant species richness to PFT richness can vary with land use intensity and successional stage with ratios decreasing with an increase in the variety of ecological niches due to disturbance. This is consistent with findings that biodiversity increases with intermediate levels of disturbance and suggests that where fragmentation is associated with global warming there may be increases in plant-based biodiversity in both species and PFTs at least in initial stages. According to Hobbs (1997) there is some evidence to suggest that the set of (functional) groups recognized in a particular vegetation will respond in a similar way to different types of impact.

75. Based on current understanding of functional responses such groupings may be useful in assessing the likely impacts of future environmental changes although these may not capture the dynamics of community or ecosystem change. Evidence from an intensive baseline biodiversity survey in lowland Sumatra along a range of land use types and intensities from rain forest to degraded grasslands showed that PFTs generally reflected an intuitive understanding of ecosystem dynamics in transitions across land use types for a range of taxa (Bignell *et al.,*2000; Jones *et al.,* 2000; Gillison 2000b,c; Jepson and Djarwadi, 2000; Maryanto *et al.,* 2000; Watt and Zborowski, 2000).

E. Impact on ecosystems and biomes

76. The integrated nature of gene-species-ecosystem-biome renders separation of these entities a relatively artificial process for many purposes. Malcolm and Markham (2000) note that the same sorts of physiological variables that the vegetation models used to map biome distributions are also relevant in mapping the distributions of the individual species (especially plant species) (*cf.* Sykes and Prentice, 1996). In this sense, the biome "*climate envelopes*" that the vegetation models simulate can be thought of as proxies for "*species climate envelopes*". While this may be so for broad vegetation structure (trees, shrubs, grass) more recent developments using finer scale PFTs may greatly improve the sensitivity of such models to give a closer correspondence between global environmental gradients (solar radiation, temperature, rainfall, evapotranspiration etc) and PFTs and by association, species. At the broad scale, 'Ecosystem functional types' can be regarded as aggregate components of ecosystems whose interactions with one another and with the environment produce differences in patterns of ecosystem structure and dynamics. However, because ecosystems are abstractions, these functional types are themselves abstractions (Shugart, 1996).

77. According to Cramer *et al.,* (1999) past evidence shows biomes are unlikely to be displaced as homogeneous entities. This is because differences in species' fundamental ecological niches and their different abilities to migrate, will result in quite different assemblages over a long period. As with biomes, ecosystems are likely to suffer change in composition and structure. The rate at which change is likely to occur and the nature of this

change remain uncertain as we do not yet know how to model processes of gradual ecosystem adjustment. Landsberg (1996) has pointed out that there is strong experimental evidence from studies on young trees that growth increases with atmospheric CO_2 but that most models do not account for processes of acclimation and biological interactions within forests stands – the latter creating uncertainties in forecasting the effects of climate change on forests.

78. Across species and ecosystems physiological and developmental processes of plants are affected by UV-B radiation (290-315 nm) and plant growth can be affected directly and indirectly (Tevini, 1994; Caldwell *et al.,* 1995). Response to UV-B also varies considerably among species and their cultivars. In forests and grasslands, this will most likely result in changes in species composition and thus there are implications for biodiversity in different ecosystems. These can have important implications for plant competitive balance, herbivory, plant pathogens, and biogeochemical cycles. The ecosystem-level effects can be anticipated, but not easily predicted or evaluated. Research at the ecosystem level for solar UV-B is barely beginning (Caldwell *et al.,* 1995).

F. Impact on ecosytem-based goods and services related to biodiversity

79. There is general acceptance that biodiversity in itself confers essential goods and services at the ecosystem level. Among the most notable of these are enhancement of water quality and supply, soil nutrients and soil physical quality, erosion control and maintenance of ecosystem 'engineers' such as ants, termites and other beneficial soil macrofauna detritivores (*cf*. Black and Okwakol, 1997). In addition, important tangible, non-timber forest products include food, fibre fuel and medicines. Among the intangible benefits are cultural and spiritual values for forest-dwelling people. Loss of biodiversity is likely to detract from these goods and services, many of which are difficult to quantify in terms of their value to local people. With fragmentation and habitat erosion, invasion by exotic weed species will diminish certain values such as food, fibre and fuel. Other aspects such as soil protection and soil nutrients may actually be enhanced. There is some evidence to suggest this may occur under certain so-called 'daisy fallows' with tropical weeds such as *Chromolaena odorata* and *Tithonia diversifolia* (Gillison, 2000a).

V. CARBON STOCKS, BIODIVERSITY CONSERVATION AND THE KYOTO PROTOCOL

80. *The carbon cycle:* The carbon cycle can be classified into the following fluxes (see Fig. 3): gross primary production (GPP; carbon assimilation by photosynthesis ignoring photorespiration), net primary production (NPP; the fraction of GPP resulting in growth when plant respiration, R_a, is taken into account), net ecosystem production (NEP; taking the annual budget of heterotrophic respiration of soil organisms, R_h, into account), and net biome production (NBP; taking nonrespiratory losses such as fire and harvest into account) Schulze et al., (2000). It is generally assumed forest biomass production will increase as CO_2 levels rise. But up to 60% of the carbon assimilated by photosynthesis is released to the atmpsphere by plant respiration. Thus a shift in the balance between photosynthesis and respiration can have a major impact on the net carbon balance (Gregory *et al.,* 1999).The extent to which forests can perform as either a carbon sink or a source depends on the interaction between climate modifed CO_2 and regional variations in rainfall and temperature. For example, Tian *et al*., (1998) showed that during dry, hot El Niño years the Amazon basin was a net source of carbon while in non El Niño years it performed as a sink. Dry, hot El Niño events predispose to widespread fire caused mainly by human intervention (Cochrane *et al*., 1999; Nepstad, *et al*.,1999). In themselves these exert a major impact on both biodiversity and carbon stocks. It seems certain the same can be said of the seasonal, indomalesian forests especially in the

islands of Borneo and Sumatra (cf. Davies and Unam, 1999) that are among the world's richest and most rapidly disappearing forest resources and epicentres of biodiversity.

81. *The distribution of carbon sinks:* across the world's forests and woodlands varies with climate. The ratio of above- to below-ground carbon also appears to vary with latitude and elevation there being a higher ratios in cooler climates. Bird *et al*., (1996) have shown that there is currently a latitudinal gradient in the signature of 13C and 14C in C_3 biomes, with low-altitude soils being relatively depleted in 13C. The 14C signatures indicated that the present gradient is due to a latitudinal gradient in the residence time of the soil organic carbon, coupled with anthropogenic modifications to the 13C:12C ratio of atmospheric CO_2 (e.g. by fossil-fuel burning). Ciais *et al.,* (1995) also present evidence for a large northern hemisphere CO_2 sink indicated by the $^{13}C/^{12}C$ ratio of atmospheric CO_2. Dixon *et al*., (1994) claim that over two-thirds of the carbon in forest ecosystems is contained in soils and associated peat deposits. While this may be the case in some tropical lowland swamp forests and mangroves, recent data from Palm *et al*., (1999) suggest that in the lowland tropics below-ground carbon may be of limited relevance as either sink or source as by far the major carbon stocks appear to be above-ground in forested mosaics.

82. *Carbon and biodiversity:* Despite developing concern about the fate of these, there is little of substance that actually links the two in a dynamic relationship. In a study across a range of land use intensity gradients in Gillison (2000a) developed a vegetation index based on mean canopy height, mean basal area, plant species richness, PFT richness and species:PFT ratio. These were matched with estimates of above-ground carbon acquired by C. Palm and others (see also Palm *et al*., 1999). The results (Figure 4) indicate a generally predictable relationship between the vegetation index (expressed as a plant biodiversity index) and above-ground carbon across all land use types. The study was completed by an international consortium of scientists as part of a systemwide initiative of the CGIAR coordinated by ICRAF in the Alternatives to Slash and Burn (ASB) project (see Gillison, 1999; Palm et al.,1999). Although the relationship between ecosystem carbon and biodiversity is mainly correlative, net primary productivity (NPP) and net ecosystem productivity (NEP) appear to be related to biodiversity in forests.

83. Carbon lost through deforestation may return if successional sequences are facilitated. Rhoades *et al.,* (2000) found, for example, that under second growth forest soil C increased by 1.9 Mg ha^{-1} yr^{-1} and the total soil C pool returned to pre-clearing levels within 20 years., the result of a 3Mg ha^{-1} l increase in C_3 carbon and a 1.1 Mg ha-1 annual loss of C_4 carbon. Cannell (1999) (Box 3) has shown that compared with managed (plantation) forests, unmanaged forests sequester more carbon and are associated with higher biodiversity (see also Cannell, 1996).

84. *Management conflict:*
Conflicts between forests managed for timber versus those managed for biodiversity and as a carbon sink may increase. Pruitt (1997) considers that commercial exploitation of the taiga and conservation of woodland caribou are incompatible since loss of habitat directly reduces the carrying capacity of the taiga for caribou, and that the forests are of more value as a carbon sink than for their timber because growth is too slow for the carbon sink function to be replaced before clear felling is repeated. In France, Dupouey *et al*., (1999) maintain the forests are accumulating 10.5 Mt C/year in biomass, i.e., 10% of national fossil fuel emissions. The main causes of this net carbon uptake are the rapid increase in forest area (currently +40 000 ha/year), increasing productivity due to environmental changes, ageing or more intensive silvicultural practices. These carbon sinks are not compensated for by the rate of harvesting, which remains low on average (61% of the 81 million m3/year in annual volume increment). Dupouey *et al*., (1999) stress the need for global economic and ecological budgets (including carbon storage capacity, soil fertility and biodiversity) for possible management alternatives.

Box 2. Impacts on ecosystem composition and structure

- The structure of terrestrial ecosystems influences their responsiveness to most drivers of global change: for example, growth responses to enhanced CO_2 are less at higher levels of organization and over longer periods of observation
- The future structure and composition of terrestrial ecosystems will be affected by responses at the patch, landscape and global scales. Direct extrapolation from the patch to the globe is unlikely to yield realistic projections of ecosystem change; landscsape processes must be taken into account.
- A general finding from patch model studies is that many forests appear to be sensitive to global change on the time scale of centuries. On shorter time scales, e.g. for the next few decades, many forests will show little response due to the lag effects in demographic processes. However in systems where intense disturbance are more common, or become more common under global change, there will be opportunities for mortality and replacement of existing trees, and changes in forest structure and composition may be more rapid.
- The interaction of global change and landscape phenomena can greatly modify both the magnitude and rate of change in community composition and structure. The importance of self-organization in landscape dynamics implies that change will not be incremental and smooth, but instead, punctuated and lumpy.
- Migration plays a critical role in the process of ecosystem adaptation to climate change; human modification of landscapes affects the possible velocity of migration. Migration rates through the markedly non-random landscapes created by human activities are usually slower than those based on predictions derived from theoretical studies based on randomly fragmented landscapes. Many species face a ‘double bind’ in which they need to migrate in response to climate change, but have few places to go and too much hostile territory to cross.

Source: Cramer *et al.,* (1999).

85. *Tradeoff strategies:* Boscolo and Buongiorno (1997 present a tradeoff strategy for Peninsular Malaysia in which natural tropical forests can provide income, serve as carbon sinks, and be reservoirs of biological diversity. Their optimization for a lowland tropical rain forest in Peninsular Malaysia show that to maximize sustainable income all commercial trees $\geq$ 30 cm diameter and above would be felled every 20 years. All remaining non-commercial trees would thus contribute to diversity and carbon storage. Results suggest that increasing carbon storage and tree diversity can be attained only at significant costs to foregone income. These findings are consistent with general perceptions of tropical forest management that suggest a mosaic management approach with forest stands of mixed natural species or of a monoculture/polyculture mosaic with natural forest corrridors is preferable to only monoculture. (see Box 3 below).

Box 3: Some environmental comparisons between managed and unmanaged forests

1. Evapotranspiration from planted forest monocultures is greater than from short vegetation, as a result of greater interception loss. Water loss from coniferous forests is usually greater than from deciduous hardwoods, but evapotranspiration from *Eucalyptus* in the dry tropics is often no greater than from native hardwoods.
2. Compared with short vegetation, forests can significantly increase the transfer of acidifying pollutants from the air to the soil and surface waters, and conifers are more likely to enhance acidification than are hardwoods.
3. There are normally sufficient plantation management options available to make most plantation landscapes the homes of a rich diversity of flora and fauna.
4. An area covered with a plantation managed for maximum volume yield will normally contain substantially less carbon than the same area of unmanaged forest.

Source: Cannell, (1999). Environmental impacts of forest monocultures: water use, acidification, wildlife conservation, and carbon storage. *New Forests,* **17**: 239-262.

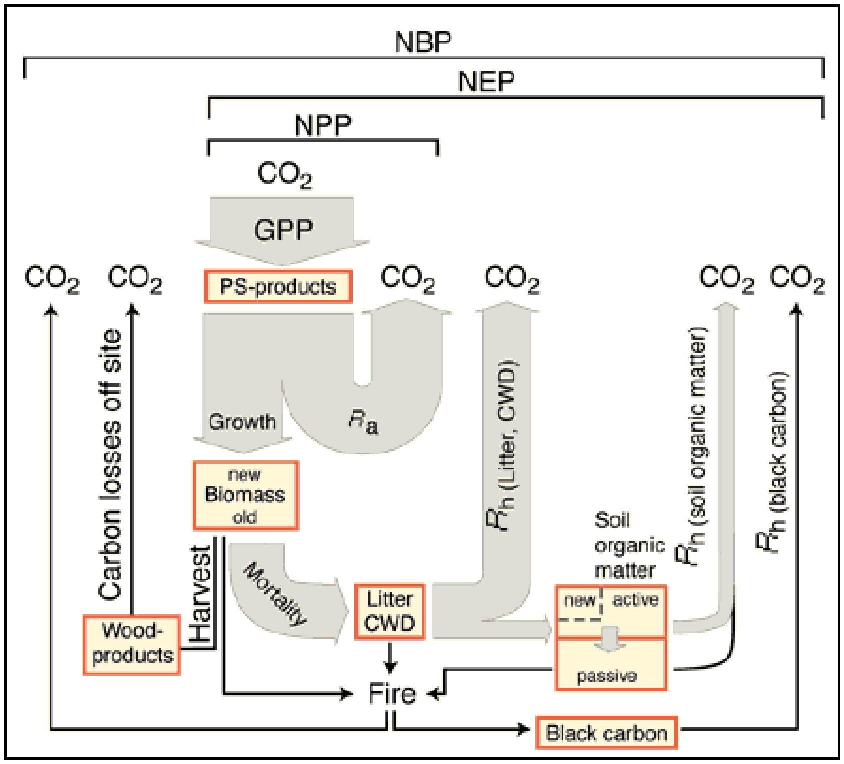


Figure 3. Schematic representation of the terrestrial carbon cycle. Arrows indicate fluxes; boxes indicate pools. The size of the boxes represents differences in carbon distribution in terrestrial ecosystems. CWD, coarse woody debris; Ra is plant respiration; Rh, heterotrophic respiration by soil organisms; PS, photosynthesis. **Source:** Schulze, E.-D., Wirth, C. and Heimann, M. (2000). Managing forests after Kyoto. *Science*, **289**: 2058-2059.

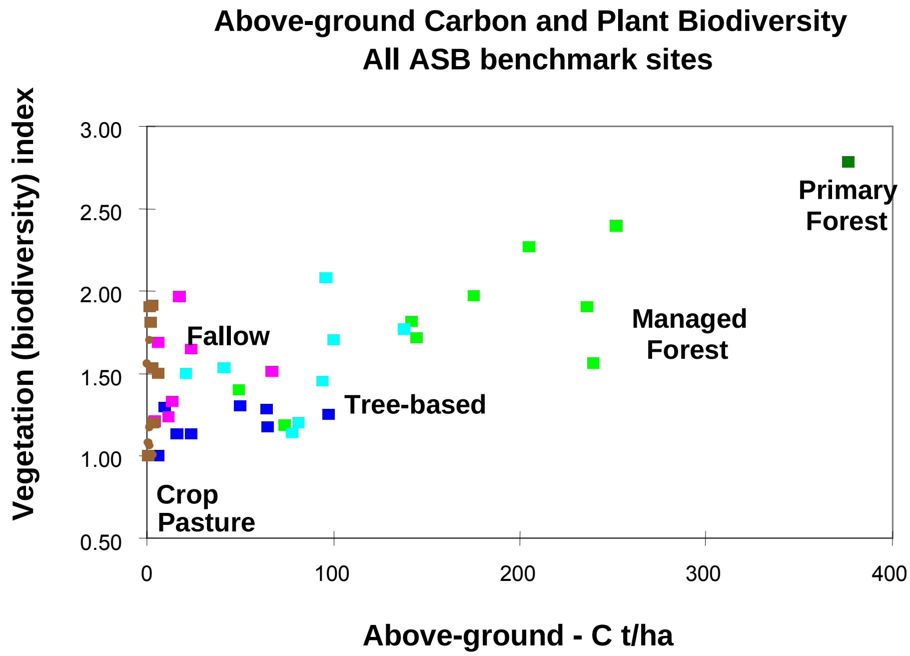


Figure 4. Relationships between a composite vegetation index (as a surrogate for plant biodiversity) and above-ground carbon in a range of global ecoregional sites.

86. *Relevance of the Kyoto Protocol to biodiversity and carbon stocks:*

a. *Articles 2 and 3:* Although the Kyoto Protocol (KP) does not refer specifically to FBD, by implication it is included in references to "*..protection of management and sinks..*" (Article 2 (a) (ii)); the "*The net changes in greenhouse gas emissions by sources and removals by sinks resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation and deforestation since 1990, measured as verifiable changes in carbon stocks in each commitment period..*" (Article 3 (3)); "*..each Party included in Annex I shall provide, for consideration by the Subsidiary Body for Scientific and Technological Advice, data to establish its level of carbon stocks in 1990 and to enable an estimate to be made of its changes in carbon stocks in subsequent years...*" (Article 3 (4)). (see also Box 4, below).

b. *Control of carbon emissions (Articles 3,6,10b,17):* The KP requires monitoring of greenhouse gas removals and emissions from human-induced, deforestation, afforestation and reforestation since 1990. While the need to redress this by slowing forest destruction and by tree planting is recognised, the COP may allow other, as yet unspecified, harvesting and management activities. Assessment of emissions and of climate impacts, especially on carbon sinks and sources, requires clearer definition of deforestation and reassessment of the fate of carbon in such systems. For example, recent studies show that, whereas in temperate and boreal forests below-ground carbon is highly significant relative to above-ground carbon this now appears less likely in many tropical forested lands apart from freshwater and mangrove swamp forests on deep peats. It is also now realised that most unmanaged forests have more biodiversity and carbon than managed (e.g. plantation) forests.

c. *The Clean Development Mechanism (Article 12):* The CDM provides for industrialized countries to undertake emission-reduction projects in developing countries. But the CDM does not specify what land use change and forest projects. Unless stricter protocols are defined, this lack of specification leaves the way open for largely uncontrolled impacts on FBD. A closer study of potential impacts is therefore needed in order to better define the CDM implementation.

[Box 4 here]

Box 4: Kyoto Protocol articles relevant to biodiversity

Article 2 (a) ii

(ii) Protection and enhancement of sinks and reservoirs of greenhouse gases not controlled by the Montreal Protocol, taking into account its commitments under relevant international environmental agreements; promotion of sustainable forest management practices, afforestation and reforestation;

Article 3 (3&4)

3. The net changes in greenhouse gas emissions by sources and removals by sinks resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation and deforestation since 1990, measured as verifiable changes in carbon stocks in each commitment period, shall be used to meet the commitments under this Article of each Party included in Annex I. The greenhouse gas emissions by sources and removals by sinks associated with those activities shall be reported in a transparent and verifiable manner and reviewed in accordance with Articles 7 and 8.
4. Prior to the first session of the Conference of the Parties serving as the meeting of the Parties to this Protocol, each Party included in Annex I shall provide, for consideration by the Subsidiary Body for Scientific and Technological Advice, data to establish its level of carbon stocks in 1990 and to enable an estimate to be made of its changes in carbon stocks in subsequent years. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session or as soon as practicable thereafter, decide upon modalities, rules and guidelines as to how, and which, additional human-induced activities related to changes in greenhouse gas emissions by sources and removals by sinks in the agricultural soils and the land-use change and forestry categories shall be added to, or subtracted from, the assigned amounts for Parties included in Annex I, taking into account uncertainties, transparency in reporting, verifiability, the methodological work of the Intergovernmental Panel on Climate Change, the advice provided by the Subsidiary Body for Scientific and Technological Advice in accordance with Article 5 and the decisions of the Conference of the Parties. Such a decision shall apply in the second and subsequent commitment periods. A Party may choose to apply such a decision on these additional human-induced activities for its first commitment period, provided that these activities have taken place since 1990.

Article 10(b)

b) Formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change and measures to facilitate adequate adaptation to climate change: (i) Such programmes would, *inter alia*, concern the energy, transport and industry sectors as well as agriculture, forestry and waste management. Furthermore, adaptation technologies and methods for improving spatial planning would improve adaptation to climate change;

Note: See also Articles 6, 12 and 17 re: emission controls via tree planting and reduction in forest removal.

VI. CRITERIA FOR IMPROVING THE ASSESSMENT OF IMPACTS OF CLIMATE CHANGE ON FOREST BIOLOGICAL DIVERSITY

A. Generic criteria

87. Superimposed above the more detailed criteria in this section are generic criteria that apply across the board. These have been compiled with the three objectives of the CBD goal in mind and are listed in Box 5.

Box 5. Key criteria for improving the assessment of impacts of climate change on forest biological diversity

- *Goals must be identifiable*
- *Impacts should be definable and measureable*
- *Assessment requires an operational definition for BD*
- *Methods and outcomes should be scale and purpose specific*
- *Survey design should be gradient-based and context specific*
- *Methods should be repeatable by different observers*
- *Data should be relevant to climate change models and facilitate forecasting of impacts under defined global change scenarios*
- *Data, databases and analytical models should aim at uniformity*
- *Limitations to scaling up and down should be identifiable*
- *There should be identifiable linkages between socioeconomic and biophysical variables (e.g. to assist policy development)*
- *Indicators should be calibrated against a global reference set of ecoregional, biophysical gradients including intact and disturbed habitats*
- *Readily observable indicators should be derived for monitoring biodiversity change*
- *Indicators should be readily adaptable by landowners and policy planners for decision support and to provide incentives for sustainable forest conservation and management*

B. Purpose, scale and context

86. *Purpose*: The goals of the Convention are to " ensure the conservation of biological diversity, the sustainable use of biological resources and the equitable sharing of the benefits arising from the utilization of genetic resources". Given this is the main purpose, the sheer magnitude and complexity of the issues surrounding climate change and biodiversity require reduction to some manageable scale. Equally demanding is the need for a science-based approach that can produce a logical hierarchy of manageable compartments to facilitate understanding of biodiversity pattern and process including the key biophysical and social drivers.

87. *Scale:* Considerable debate surrounds the issue of appropriate scales for addressing the impact of climate change on biological diversity. Within the bioecological range of gene-species-ecosystem, for practical purposes the CBD has opted for operational units based mainly on species and ecosystem. There are, as yet no established criteria for the selection of plot size or for vegetation unit. Nonetheless patch-scale and individual plant models are are vital in understanding the response of important crop and forest species to global change (Cramer *et al.,* 1999). Such models incorporate functioning at the scale of leaf stomate aggregating to individual, canopy and formation (*cf.* Section 3.2).

88. For global biospheric modelling Cramer *et al.,* (1999) point out that the practical limits to spatial resolution in globally comprehensive models are set by both data availability and computational resources. For remote sensing Marceau *et al.,* (1994) have shown that neglecting the scale and aggregation level when classifying remote sensing images can produce haphazard results having little correspondence with the objects of the scene. Kenny *et al.,* (1995) used a computer-based system (CLIMPACTS) an integrated model to assess the effects of climate change on the New Zealand environment. The projections from the model are used to scale regional patterns of climate change, as derived from GCMs and palaeoclimatic data, to give locally relevant scenarios of changes in primary climate variables for New Zealand on a 0.05 deg latitude x 0.05 deg longitude grid. Li (1995) has maintained that in addition to climate other environmental components, such as topography and soil parent materials, also play important roles in vegetation classification when scaling down biogeographic models relating to global change to simulate vegetation response.

89. Important ecosystem processes, such as biogeochemical cycles, disturbance regimes and demographics, take place at scales much larger than the typical experimental plot of a few hectares. These large-scale processes are only partially manifested at the smaller scale. (Schulze *et al.,*1999). Inevitably, such limitations lead to loss of sensitivity in predicting change along gradients of scale. Various techniques are being developed to facilitate cross-scale applications; for example, Harrison and Harkness (1993) suggest that 14C techniques might be used to partially validate computer models of carbon dynamics in forest ecosystems and at different scales of resolution (process, ecosystem, and landscape) in environmental studies.

90. Models that attempt to integrate input from variables at a range of scales to facilitate a 'top-down – bottom-up' in order to forecast impacts as both fine and global scale will succeed insofar as the variables concerned carry predictive weight across varying spatial and temporal scales. Wickham *et al.,* (1995) showed that for the conterminous USA vegetation richness and vegetation clustering showed a scale-dependent relationship to altitude across the range of quadrat sizes from 500 to 50 000 miles^2 . In a global assessment of land vulnerability to water erosion on a 1/2 deg by 1/2 deg grid, Batjes (1996) found that whereas a qualitative model serves to raise awareness on issues of soil degradation by water at the global level by identifying regions at risk, it provides no information on the actual rate of erosion at the field scale, nor on associated decrease in crop productivity and biodiversity.

91. There is increasing evidence to suggest that while certain patterns and processes are best considered at specific spatial and temporal scales, response patterns may be more efficiently investigated along hierarchical, biophysical gradients. Plant species richness at global, regional and local scales was examined by Austin (1999) who found that at all scales, direct and resource environmental gradients needed to be incorporated into the analysis rather than indirect gradients e.g. latitude which have no direct physiological influence on biota. Evidence indicated species richness at the regional scale is sensitive to environment, confounding current studies on local/regional species richness relationships.

92. According to Conroy and Noon (1996) Biodiversity mapping (e.g., the Gap Analysis Program [GAP], (Scott *et al.,* 1990)), in which vegetative features and categories of land use are mapped at coarse spatial scales, has been proposed as a reliable tool for land use decisions (e.g., reserve identification, selection, and design). This implicitly assumes that species richness data collected at coarse spatio-temporal scales provide a first-order approximation to community and ecosystem representation and persistence. This assumption may be false because (1) species abundance distributions and species richness are poor surrogates for community/ ecosystem processes, and are scale dependent; (2) species abundance and richness data are unreliable because of unequal and unknown sampling probabilities and species-habitat models of doubtful reliability; (3) mapped species richness data may be inherently resistant to scaling up or scaling down .

93. Austin (1999) argues that plant community experiments require designs based on environmental gradients rather than dependent biological properties such as productivity or species richness to avoid confounding the biotic components and that the exclusion of climatic and other environmental gradients and the concentration on the collective properties of species assemblages has limited recent biodiversity studies. He concludes conservation evaluation could benefit from greater use of the continuum concepts and statistical modelling techniques of vegetation ecology. Hodkinson and Wookey (1999) compare two data gathering approaches in studying soil organisms; one experimental, the other a gradient approach that makes use of measurements taken along geographical/ecological transects as analogues for climate change

100. Further evidence of the need for gradient-based approaches is described by Mistry (1998) who examined large-scale patterns of seed dispersal in a coastal evergreen forest in southern India. Mistry (1998) used three examples (natural disturbance, human disturbance and dispersal modes in a deciduous teak (*Tectona*) forest in western India, and seed dispersal modes across latitudinal and moisture gradients) to illustrate seed dispersal modes at large scales in a coastal evergreen forest in southern India. Striganova (1996) has also argued a case for a gradient-based, multiscale transect method to assess the differential diversity of soil animal communities using three gradient types: latitudinal gradients, meso-relief gradients, and microclimatic gradients. Rebertus *et al.,* (1993) studied gap formation and dieback processes in natural forests of *Nothofagus* spp. in Patagonia and Tierro del Fuego (Argentina and Chile) between 40 deg and 55 deg S. They give two examples that demonstrate how the regeneration response of *Nothofagus* spp. in fine-scale gaps varies over gradients of precipitation, latitude and altitude, as the vegetation associated with *Nothofagus* forests changes. Preliminary results suggest that coarse-scale gaps associated with dieback usually favour self-replacement by *Nothofagus.*

101. *Context:* Questions of aggregation and scale surround the assessment of biodiversity and impacts on it by various phenomena. In assessing the biodiversity of a particular forested landscape therefore, careful attention must be given to the purpose, scale and sampling context of the question being asked. In order to satisfy the need to identify linkages between biodiversity and socioeconomic factors for example such as profitability, the research criteria must include parameters relevant to both.

C. Sampling and extrapolation

102. These are closely integrated with ‘context’ to the extent that in order to derive an effective model of species and FTs for an area under study the sample design should include as far as possible the range distributions that are of concern to biodiversity management. Plot-based biodiversity data obtained within a single rain forest patch do not necessarily explain the primary range distributions of the taxa under study. Many plants and animals access areas outside closed canopy forest including urban areas and agricultural landscapes as part of their normal habitat range. If samples are restricted solely to closed-canopy forest then there is the risk of acquiring data sets with truncated range distributions. Such data can give misleading outcomes if subsequently used in models that aim to forecast the impact of environmental change on specific plant and animal groups. An example of a data set with typical elevational (representing temperature and moisture gradients) range distributions in a forested landscape (Table 6) shows how, if samples are taken only from restricted elevations, valuable range distribution data are excluded. The same principle can be applied to other sets of environmental variables.

Table 6. Elevational range distributions of some key plant and animal taxa - Mae Chaem Watershed, Northern Thailand#

Species	**Elevation (m)**										
	500	**700**	**900**	**1100**	**1300**	**1500**	**1700**	**1900**	**2100**	**2300**	**2500**
Plants											
Dipterocarpus tuberculatus											
Shorea obtusa											
Castanopsis sp.											
Chromolaena odorata											
Imperata cylindrica											
Smilax sp.											
Melastoma malabathrica											
Arisaema sp.											
Birds											
Collared Falconet											
Sooty-headed Bulbul											
Red Jungle Fowl											
Scarlet Minivet											
Striped Tit-babbler											
Grey-throated Babbler											
Arctic Warbler											

Source: Gillison and Liswanti (1999).

103. *Gradient-based sampling:* Because plants and animals tend not be distributed at random but, instead, respond to biophysical gradients, it is useful to sample along such gradients. Typical key gradients might be rainfall seasonality, soil nutrient availability, soil moisture and land use intensity. In the majority of cases these can be located within a nested

hierarchy from climate variables to local soil catenas. A sampling strategy that takes advantage of this phenomenon employs gradient-oriented transects or 'gradsects' (Gillison, 1984; Gillison and Brewer, 1985; Austin and Heyligers, 1991; Wessels *et al.,* 1998). Results using this approach have already been reported by Green and Gunawardena (1993) referred to in COP/3/13 paragraph 23e (1996) under the topic '*Existing methodologies for assessments of biological diversity'.* Gradsects have the advantage over transects located by purely random or systematic procedures and have been shown to be logistically more cost efficient in recovering range distributions of plants and animals. By more efficiently sampling key environmental gradients using spatially-referenced sites they are more likely to improve the chances of locating rarities as well as the capacity for subsequent extrapolation of specific plant and animal groups thoroughout the study area.

104. *Ecoregional baseline studies:* The ICRAF-led consortium on Alternatives to Slash and Burn project has established a series of global, ecoregional gradients in Brazil, Perú, Cameroon, Thailand and Indonesia. These have been investigated for greenhouse gas fluxes, above and below-ground carbon, soil nutrient availability and above and below-ground biodiversity. In particular intensive, multi-taxa baseline studies along land use intensity and other environmental gradients in Sumatra and Thailand has provided valuable data for identifying biodiversity indicators (Gillison, 2000a,b and others) and has paved the way for comparison of indicators and land use types within and between countries. In Thailand and Sumatra indicators of profitability are also being acquired from sites co-located with the biodiversity investigations in order to seek connectivity with socioeconomic determinants of resource use. WRI *et al.,* (2000) point out that global data sets for biodiversity in tropical forests are extremely limited and to a large extent information about the significance of biodiversity in such areas is anecdotal. The establishment of gradsect-based, baseline study sites in representative environments may be one way of seeking to redress this issue. Other, regional baseline studies have been conducted by Conservation International (Parker and Carr, 1992; Parker and Bailey, 1991; Parker *et al.,* 1993) in Bolivia and Ecuador using (non-gradient-based) rapid appraisal (RAP) techniques involving detailed aerial and ground reconnaissance.

105. In summary, sampling criteria should aim to:

- ♦ Provide cost efficient, uniform methods of survey design and data acquisition.
- ♦ Be readily transferable via training to persons with relatively limited field experience.
- ♦ Provide data that have maximum relevance to adaptive management.
- ♦ Ensure that the data collected can facilitate the development of models for forecasting the impact of climate change on biodiversity under a range of environmental and resource use scenarios.
- ♦ Facilitate the establishment of linkages between biodiversity and key socioeconomic variables such as profitability for use in policy development.
- ♦ Provide a platform for multidisciplinary investigation and facilitiate correlative models that can be used to identify readily observable and efficient indicators of biodiversity for assessment and monitoring.
- ♦ Operate across a minimum range of environmental spatial and temporal scales to be relevant to climate models.
- ♦ Acquire sufficient range distribution data for key plant and animal groups and environmental gradients to facilitate modelling of actual and potential distributions of such groups under different management and policy planning scenarios.

D. Biodiversity indicators

106. *Usage in the CBD:* In order to track the progress of the stated goals of the Convention (see 6.2.1 above) SBSTTA (5/12 paragraph 6.) points out that this effectively calls for indicators that contribute to all three objectives of those goals. Accordingly the development of biodiversity indicators has been a continuing topic in the CBD that decided to establish a '*core set of indicators'* to be used in National Reporting and in the Thematic Areas of the Convention (*cf*. SBSTTA/Inf.13 and COP3 III/10, paragraph 2, 1996). Further development was considered at the Sixth Global Biodiversity Forum (1997) and the third SBSTTA meeting (1997). SBSTTA-5-12 paragraph 2. (1999) defines biodiversity indcators as "…*a set of tools that summarize data on complex environmental issues and serve to indicate the overall status and trends of biodiversity as well as being a means to assess national performance and to signal key issues to be addressed through policy interventions and other actions*. (see also Markham, 1996). The CBD *via* SBSTTA has taken the pragmatic view that for biodiversity to be sustainably managed it must have social and economic relevance. It has also accepted that the operational plarform for applying biodiversity indicators should be at the ecosystem level. Cost-efficient biodiversity indicators within the CBD framework have been discussed by Larsson and Esteban (2000). With this in mind SBSTTA has developed a core set (described in SBSTTA-5-12, here listed in Appendix IV) based on the *state-pressure-response* principle employed by the OECD. Paragraph 6. (5/12) states that the following model is the one thought most appropriate by the Conference of the Parties:

i. *The first track for immediate implementation considers existing and tested state and pressure indicators related to the conservation of biological diversity and to the sustainable use of its components*
ii. *The second track, for longer-term implementation, should consider not only the state and pressure indicators, but also the identification, development and testing of response indicators for the three objectives of the Convention. The second track should also aim at continuous improvement of the state and pressure indicators for the first two objectives of the Convention*

107. Paragraph 41. (5/12) states that in accordance with decision III/10, a limited number of biodiversity indicators would be identified as elements of a core set that all Parties to the Convention would apply and report upon periodically. Also, to comply with such decision, indicators for the first and second track should:

i. *Quantify information so that its significance is apparent,*
ii. *Be user-driven (to help summarize information of interest to the intended audience)*
iii. *Be scientifically credible*
iv. *Be responsive to changes in time and/or space*
v. *Be simple and easily understood by the target audience*
vi. *Be based on information that can be collected within realistic capacity and time limits*
vii. *Be linkable to socio-economic developments and indicators of sustainable use and response*

108. This core set reflects several ecosystem processes in response to human pressure and economic activities. As such it is considered to be a link between biodiversity loss and socio-economic implications and thereby appropriate for policy makers (5/12, Paragraph 52). SBSTTA (paragraph 48) recognises that pressure indicators may be easier to develop and measure but their relationship to biodiversity is less easy to interpret. State indicators which are directly linked to biodiversity may be more difficult to establish and several indicators might be more applicable at site rather than national level. SBSTTA 5/12 includes a useful overview of developments in indicators by various sectors and development agencies

including OECD, UNEP's Global Environment Outlook, WRI, CSD, FAO, IUCN, WWF, World Bank, GEF, GTOS, CIAT, CIFOR, ITTO, WCMC and IIED.

109. *The utility of state-pressure-response models*: Despite the pragmatic thrust of the SBSTTA approach, there are frequent cases where distinguishing between *'state'* and *'response'* is non-feasible; for example, in discriminating between the confounded effects of a mid to long-term impacts of a 'natural' El Niño drought and logging in a 20 year old Bornean rain forest. While there is clearly heuristic value in considering *a priori* a hypothetical '*state-pressure-response'* approach, it may be more practical and realistic in the short term to focus instead, on an operational protocol for establishing a regional baseline study of changes in biodiversity along land use intensity gradients in forested landscapes. By this means it becomes possible to identify correlates between biodiversity change at both landscape and ecosystem level and, subsequently, to model and test predictive correlates between what is perceived as natural *'state'* and human *versus* natural *'pressure'*. Again, locally specific conditions will dictate perceptions of what is 'natural'. In parts of the highlands of Papua New Guinea, thousands of years of slash and burn farming have evolved as a 'natural' condition where, if humans were suddenly removed, there would be major changes in the biodiversity dynamic, thus constituting a *'pressure'*.

110. The concept of *'pressure'* is easily confused with 'disturbance' and can mislead interpretation if not considered carefully. Firing in savannas for example may be considered a *'pressure'* or a 'disturbance' but because fire is essential to the maintenance of the savanna ecosystem, a real *'pressure'* might be a significant change in the frequency and intensity of fire. Equally, it is widely known that intermediate levels of disturbance in a tropical forest contribute to transient peaks in biodiversity. This is due in part to the sudden expansion of available ecological niches and will tend to subside as successional stages return to conditions approaching so-called climax forest. Depending on whether species richness is considered a positive indicator of biodiversity or not, *'pressure'* may be considered to exert either a positive or negative impact. Either way perception must be carefully evaluated in the light of overall changes in biodiversity within the longer-term gap-phase replacement cycles in forested mosaics. The degree to which it is possible to detect the extent to which successional recovery of logged-over forest is either natural or a response to human intervention is as yet an unresolved issue. One way of discriminating between these impacts is to compare responses in successional cycles in forests where human intervention is absent and under a series of known disturbance (e.g. logging) intensities. Such a procedure would provide a scientific basis for testing hypothetical *state-pressure-response* models and at the same time gather essential baseline data for evaluating and calibrating indicators.

111. The use of the term 'response' by SBSTTA (Appendix IV) appears to differ from the ecological norm. The general ecological use of a response indicator might be for example, the development of epicormic shoots following a forest fire or subsequent changes in tree form and loss of species under a more frequent than normal fire regime. As listed in Appendix IV, SBSTTA's usage is geared to reflect response by human intervention such as the extent to which an area is protected or trends in conservation status. While this is entirely logical in the context of a management model the distinction between this use and ecological indicators of biodiversity response should be clearly explained.

112. *Ecological indicators of biodiversity:* The overwhelming complexity of biological diversity requires a means of reducing it to manageable parts for both assessment and monitoring. One logical approach is to seek and apply surrogate measures or indicators of key biodiversity elements. The search for acceptable biological indicators (bioindicators) continues with mixed results. There is no "best surrogate" (Margules and Pressey, 2000). Bioindicators may be used as surrogates for estimating both the type and distribution of organisms in time and space or, conversely, use subsets of the organisms or aspects of their functional characteristics to indicate certain features about the abiotic environment such as

soil quality, potential productivity, profitability or the state of ecosystem health (e.g. level of pollution or degradation). Bakkes *et al*., (1994) have reviewed the use of environmental indices, composite environmental indices and socio-economic indicators.

113. A useful and very comprehensive review of the use of indicators in rapid biodiversity assessment is contained in Watt *et al*., (1998). Also in a review of indicators, Noss (1999) concluded that although there is a wealth of indicators to choose from, most have been poorly tested and require rigorous validation in order to be interpreted with confidence. Nonetheless there have been many specific applications that include a variety of measures of different variables: Emberton (1996) used two landsnail genera in eastern and southeastern Madagascar as indicator/target taxa for 64 species because they are endemic, species-rich, well defined clades, sensitive to environmental degradation, with species readily identifiable by shells alone. Emberton (1996) used these to construct indices of diversity and endemism to rank 12 bioclimate-latitude regions by priority for conservation/collection.

114. There is abundant evidence for the use of biodiversity indicators from a wide range of taxa from varying ranks and phyla. These include *Banksia* spp. in southwestern Australia (Lamont and Connell, 1996); *Begonia* spp. as a bioindicator of the localities of former forest refugia in Africa (Sosef, 1994); Aspen (*Populus tremuloides*) in the Rocky Mountain parks of North America (White *et al*., 1998);); Calicaloid lichens in old oak forests in Sodermanland, Sweden (Rydberg, 1997); Aphyllophoroid fungi in North Karelia (Bondartseva *et al*.,1998).

115. Aside from using 'continuity indicator species' Ohlson *et al*., (1997) found that for boreal old-growth forests in Sweden the most important variable explaining biodiversity was the amount of dead wood present. The volume or mass of dead wood together with the amount of timber removed was also found to be a significant indicator of biodiversity in Norway (Framstad, 1999). Because they tend to be easily recordable and their taxonomy relatively well known, birds are popular as indicators of biodiversity e.g in *Eucalyptus* forests of southeast Australia (Neave *et al*., 1996); in old-growth white spruce and balsom poplar forests in Canada (Timoney and Robinson, 1996); Lemurs in Madagascan monsoon forests (Smith *et al*., 1997); longhorn and stag beetles beech (*Fagus sylvatica*) forests in Westphalia, Germany (Kleinevoss *et al*.,1996). Patel *et al*., (1999) used composite ecological indicators (species richness, species density, species cover, proportion of native species, height and foliar damage by insect herbivory) to determine which were sensitive to environmental impact in Pinery Provincial Park, Ontario.

116. Multivariate approaches to the use of composite species sets as indicators commonly include indicator species analysis as in Canadian grasslands (Schwartz and Wein, 1997; coastal tall-grass prairie along the coastal plain of the Gulf of Mexico (Grace *et al*., 2000); bird communities in boreal mixedwood forest in Alberta, Canada (Hobson and Schieck, 1999). Plant species tend to be the most commonly used of all taxa as bioindicators. But because the identification of species can be problematical some workers use higher taxa (genera and familes). This has been discussed by various practitioners (*cf*. Prance, 1995) and the results vary with the situation. Jaarsveld *et al*., (1998) for example, found in a South African study that the use of higher taxa contributed little to the complementarity of sets of taxa for conservation purposes.

117. Fine-scale attributes of plants may carry considerable indicator value of both biodiversity habitat and as indicators of effects of climate change. Halloy and Mark (1996) argue that leaf morphology of native vegetation is a sensitive indicator of environmental conditions presumably as a result of natural selection. They found that variations in leaf morphology of native vegetation in New Zealand, the Andes and the European Alps across a fixed latitudinal and elevational range corresponded with a 2-3 deg. C change in mean annual temperature, 10% in mean relative humidity and 7% in CO_2 partial pressure. As an indicator of past climatic influences, leaf anatomical features have also been used by Kurschner (1997)

who found that stomatal density with its high variability should only be used as a bioindicator of palaeoatmospheric CO_2 levels in large data sets or from one particular leaf morphotype, preferably from sun leaves. In the case of small sample sets Kurschner (1997) recommends application of the stomatal index. (*cf*. Larcher, 1973).

118. Bioindicators are also being used increasingly to characterise the state of the physical environment. For example, (Feijoo and Knapp, 1998) used macrofauna density, biomass and species diversity of earthworms expressed as a macrofauna index to indicate soil quality; species sets to indicate chronosequences and site physical conditions in old-growth forests of Brisish Columbia (Trofymow *et al*.,1997). Yin (1993) studied the variation in foliar nitrogen concentration by forest type and climatic gradients in North America and found deciduous forests nearly always had higher foliar concentrations of N than coniferous forests for given climates but these differences diminished in warmer climates. Also at broad structural level, Domingos *et al*., (1998) found that pollution accounted for a change in vegetation structure from a well-developed primary and secondary forest to low forests and shrub vegetation in the Cubatao area in Brazil.

119. Soil ecological functions including effective rooting depth, structural support for plants, biodiversity, nutrient cycling and pollutant retention were used to study the impact of carbon sequestration on soil quality as influenced by management in sustainable agriculture and found to be sensitive to to farming practices (Monreal *et al*.,1998). A classification of soil functional types is potentially useful as it has been argued that faulty estimation of the number and identity of species has serious consequences for biodiversity studies.

120. The concept of indicator groups that allow inference of total community diversity was assessed by Cranston and Hillman (1992) and found to be poorly substantiated. They maintain the term should be replaced by 'selected groups', pending further study. Howard *et al.,* (1996, 1997) applied five sets of biological indicator taxa ((woody plants, birds, small mammals (five families), butterflies and large moths (two families, Saturniidae, Sphingidae)) in a wide-ranging study of biodiversity conservation in Ugandan forests . They concluded that while there is still debate over the value of indicators and their ability to provide an accurate assessment of biodiversity within a particular site, practical factors compel their use, and thus much importance is placed on the selection of appropriate indicators groups. Their criteria for selecting indicators involve ease of sampling, and availability of resources available for their study. (selected woody plants, five families of small mammals, birds, butterflies and two families of large moths). This has been explored as well by Kremen (1992). Miller *et al*., (1995) maintain that, ironically, biodiversity has benefitted agriculture and this in turn has contributed to its loss.

121. Miller *et al.,* (1995) state that "*..indicators should, at a minimum, reflect the status of key pollinators and seed dispersers. However, since so little is known about the role of most species, it would be better to broadly monitor the status of a cross-section of biodiversity (plants, mammals, birds, invertebrates)"*. (see also Noss, 1990; Pearson, 1995). Reid *et al*., (1993) point out that policy makers and managers also require indicators for biodiversity management.

122. The compelling need for indicators is to some extent offset by lack of scientific support for the use of one taxon to predict the occurrence of another. This was made plain from a study reported by Lawton *et al.,* (1998) who found no reason for optimism from a field study of mainly insect groups in a forested mosaic in Mbalmayo, Cameroon. Nonetheless that study may not have been sufficiently comprehensive as, rather surprisingly, it excluded plant species – a critical dependent variable for many animals. Gillison (2000b) found good statistical evidence to support the use of plant functional types in combination with vascular plant species as indicators of certain groups of insects and especially termites and birds along a lowland, tropical, forested land use intensity gradient in Sumatra (see also Bignell et al.,

1999; Jepson and Djarwadi, 1999; Jones *et al.,* 1999). In the Sumatran lowlands the use of PFTs and plant species has also been shown to be usefully correlated with soil nutrient availability, above-ground carbon and land use intensity (Gillison and Liswanti, 1999; Gillison *et al.,* unpubl., 2000).

E. Input to climate models

123. Foregoing sections have already indicated which variables are likely to be of use in climate models. The challenge facing assessment of both biodiversity and related climate parameters is to develop methods that meet the following criteria:

- Acquire ecoregional data that can be used to characterise ecosystem response to environmental change that make it possible to detect differences due to climate, other naturally occurring environmental determinants and human-induced impacts.
- Provide a scientific basis for the design of cost efficient, rapid biodiversity survey design that provides co-located, key physical environmental data such as above- and below-ground carbon, soil moisture and soil nutrient availability of relevance to climate.
- Generate global, ecoregional, gradient-based baseline data sets that enable the development and testing of models of climate impact on biodiversity at sub-global and local site level.
- Provide a scientific basis for framing process-based studies within the broad ecoregional baseline to develop and test the use of indicators for upscaling and downscaling.

F. Complementarity and representativeness

124. Biodiversity assessment is but one important element of a broader suite of elements in conservation management. The concept of complementarity is now widely accepted as one important parameter in deciding which areas are sufficiently representative of the biodiversity within an area of concern. Complementarity is a measure of the degree to which a site contributes additional new information (e.g. unique species) to the total set of sites under consideration. The concept together with a series of algorithms has been developed to assist in determining complementarity for conservation purposes. (Austin and Margules, 1986; Margules *et al.,* 1988; Pressey and Nicholls, 1989; Bedward *et al.,* 1992; Csuti *et al.,* 1997; Pressey *et al.,* 1993, 1996a,b, 1997, 1999; Howard *et al.,* 1998; Pressey and Logan, 1998)

G. Socioeconomic linkages and policy development

125. As discussed above there is a need to establish an understanding of the dynamic linkages between biodiversity and socioeconomic factors. Criteria that could be used might include appropriate sets of readily recordable variables that contribute to this understanding. A major impediment at present is the lack of an analytical approach that enables the aggregation of biodiversity plot-based data to levels that are meaningful for policy analysts and socioeconomists (e.g. landscapes and land use mosaics at village level). Recent, as yet unpublished studies by ICRAF/ASB have shown a close correspondence between field plot measures of biodiversity in both Sumatra and northern Thailand, and measures of profitability expressed in terms of return to labour , return to land and employment. Such studies open the way to defining a baseline for assessing tradeoffs between biodiversity and profitability.

H. Databases

126. Harmonisation of data and efficient methods of data access and data sharing are critical to improving the quality of data used in the analysis of impacts of climate change on biodiversity. This is a very specialized topic that cannot be easily dealt with here. Internationally there is a strong move in the area of bioinformatics to assist with interoperability of data within and between countries (Bisby, 2000; Edwards *et al.,* 2000).

I. Technology and capacity building

127. One of the major limitations to implementing and sustaining effective biodiversity conservation and management is lack of expertise and institutional capacity in developing countries. One criterion for improving the assessment of impacts would be the instigation of rapid and efficient training courses with follow-up mentoring and assistance with data handling and data analysis. Other criteria might involve a need for capacity building in other areas such as enhancing computer facilities including basic GIS platforms. Such assistance should be directed towards eventual ownership and a sense of independence in initiating and completing assessment and monitoring programs. In this respect access to database networking via international consortia should be considered.

VII. PROPOSED SET OF ACTIVITIES AND OPTIONS FOR FBD CONSERVATION AND MANAGEMENT WITH RESPECT TO UNFCCC PROVISIONS

A. International

128. *The scope of the problem:* associated with mitigating the effects of climate change on biodiversity demands that there be close coordination at international level. The greatest single impediment to understanding the effects of climate change within the framework of overall global change is the lack of key data. It would seem appropriate therefore that activities should focus on establishing integrated baseline studies that contribute to such understanding at global, national and regional scales. To do this requires a logical framework preferably based on an existing platform that can be expanded in a cost efficient way to meet the end goal of gaining sufficient data to effectively model and test outcomes of likely change scenarios. The following is suggested as one way in which these goals may be achieved. Several platforms are already in existence:

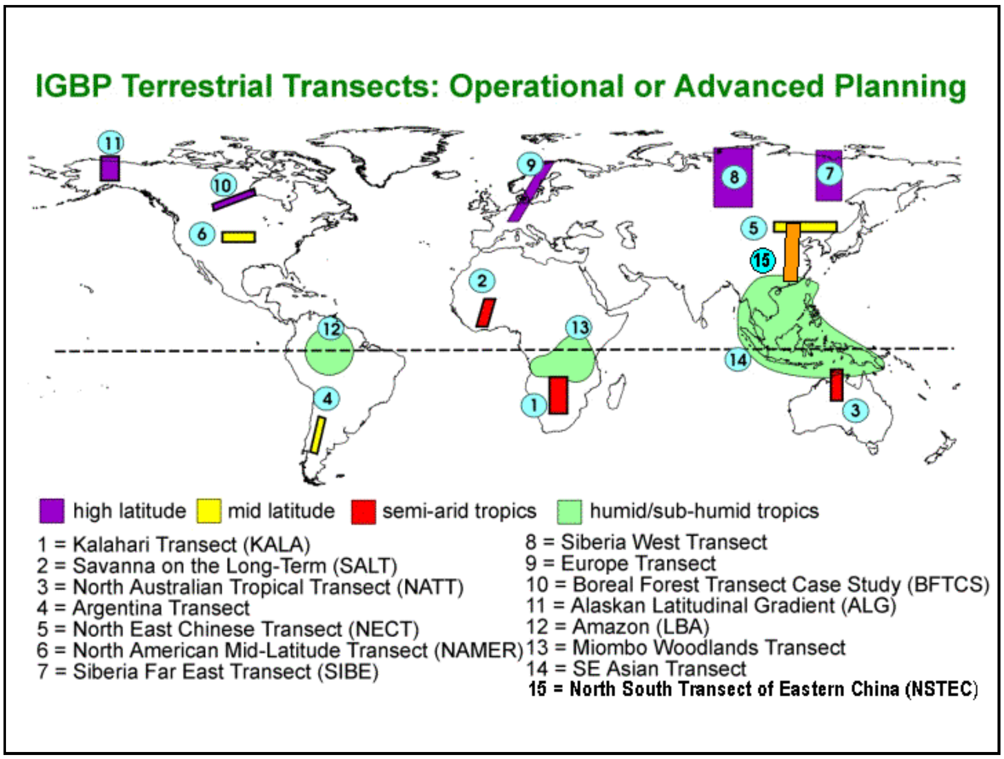
129. *The IGBP/GCTE (International Geosphere-Biosphere Programme/ Global Change and Terrestrial Ecosystems) global transect study:* This is already in place and is being developed as a tool for global change research. (Steffen *et al.,* 1999). The transects consist of a set of study sites of the order of 1000 km in length and wide enough to encompass the dimensions of remote sensing images and several grid cells of global models (DVGMs and GCMs). Each transect has been designed to sample variation of a major environmental factor as it influences terrestrial ecosystem structure and functioning (e.g. carbon and nutrient cycling, biosphere-atmosphere gas ecahange and hydrologic cycling). In all fifteen transects have been established so far (Figure 5.)

130. Of these approximately half are actively being used to acquire data along ecoregional gradients. One of these is located in Jambi, Sumatra, Indonesia where a co-located site established under the ICRAF-led consortium for Alternatives to Slash and Burn programme has also been highly productive in suplying key biodiversity data. Both the ASB site and the IGBP/GCTE site have been designed to cover a range of primary land use intensity gradients as well as naturally occurring environmental gradients. Land use types range from relatively intact forest to logged forest, plantations of rubber and softwood, home gardens and degraded

grasslands. The socioeconomic background is also well documented and comprehensive GIS databases are available to assist researchers with the spatial analysis of spatially referenced data.

131. This type of baseline study is ideally suited to collaborative work from different institutions. Within IGBP, other core projects such as Biospheric Aspects of the Hydrological Cycle (BAHC), International Human Dimensions Programme (IHDP), Global Change System for Analysis, research and Training (START) and Land Use and Cover Change (LUCC) have the capacity to interact using these transects as a common platform. A comprehensive description of networks and other consortia connected with the GCTE core project is described by Ingram *et al.*, (1999) in the synthesis volume on terrestrial biosphere and global change (Walker *et al.,* 1999). From the perspective of the UNFCCC provisions it would seem eminently logical to consider a programme of activities that could be combined with those of the IGBP transects. Such a joint programme would add enormous synergy to global, international studies on the impact of climate change on biodiversity. In addition to which the data acquired would greatly assist in the further development of models such as the DGVMs and GCMs. Such an approach would be consistent with the goals and objectives of the CBD and the UNFCCC. Clearly careful thought would need to be directed to considerations of transect representativeness for the purposes of CBD and it is likely that additional transects or modifications of existing IGBP transects could be envisaged. This may be a potential role for SBSTTA.

Figure 5 IGBP Global terrestrial transects: operational and planned



132. *The Millennium Ecosystem Assessment*[1]*:* In 1998 WRI, the UN Environment Programme (UNEP), UN Development Programme (UNDP), and World Bank established a steering committee to explore whether a process could be developed to to bring better scientific information on ecosystem goods and services to bear on public policy and management decisions. The Proposed Millennium Ecosystem Assessment (MA) would be a four-year initiative to (1) use the findings of leading-edge natural and social research on ecosystem goods and services to help make regional and global policy and management decisions, and (2) build capacity at all levels to undertake similar assessments and act on their findings. In particular the MA would address:

- Current ecosystem extents, trends, pressures, conditions and value
- Ecosystem scenarios and tradeoffs (including impacts from climate change)
- Response options

As a start the MA steering committee has decided to focus initially in two sub-global regions that include SE Asia and South Africa. “Outliers” such as boreal sites or oceanic islands will also be considered.

The Steering Committee that undertook the initial design of the MA also helped shape two related processes to help set the stage for and build support for the launch of the Millennium Ecosystem Assessment:

- A "Pilot Analysis of Global Ecosystems" to demonstrate the utility of an integrated ecosystem assessment, provide a technical foundation for *World Resources 2000*, and assemble core data that would be used in the full Millennium Assessment;

- Preparation of *World Resources 2000 – People and Ecosystems: The Fraying Web of Life,* a joint publication of UNEP, UNDP, World Bank, and World Resources Institute.

133. As with the IGBP programme, the MA approach is consistent in many ways with the need to integrate both biophysical and socioeconomic aspects of biodiversity management. As such it is highly relevant to the kinds of measures being explored by SBSTTA and, in the present context is well suited to provide complementary ecoregional baseline studies to the IGBP/GCTE global transects. Closer collaboration between IGBP, MA and the CBD would appear to be warranted.

B. National

134. Within the framework of the global transects national activities could be directed to solving issues of national as well as global concern with biodiversity conservation in accordance with commitments to reduce greenhouse gas emissions as well as commitments to national conservation strategies. The strategy of employing common research baselines would directly assist biodiversity managers, land holders and policy makers alike in helping to establish a conjoint contribution to bioregional planning. In addition to the value of the data acquired in such a programme the activity could be used to help facilitate in-country capacity building via training programmes. Training activities are already in place in Indonesia via the IGBP promoted START and IC-SEA projects. These have been effectively coupled with training programmes initiated by CIFOR in rapid biodiversity assessment. Working in the

[1] Extracted from Reid, Walter (2000) ‘Ecosystem data to guide hard choices’ Issues in Science and Technology, Spring 2000 http://www.nap.edu/issues/16.3/reid.htm

same region, ICRAF ASB has also initiated training in valuation studies and field programmes aimed at gathering data that will be fed into a Policy Analysis Matrix (PAM). These data will be used to examine potential linkages between biodiversity, profitability and above-ground carbon as well as greenhouse gas fluxes at subsets of certain common sites. Being nested within an overarching international program should greatly enhance National capacity for communciation with international colleagues operating across similar sites.

C. Project

135. Project activities would be framed to support both national and international programmes. Individual projects would be designed to complement both biophyscial and socioeconomic interests. In an ideal world, methodology should be harmonised so that results from different areas are comparable. For biodiversity this would involve the use, for example, of a common field proforma and software for data entry and analysis. Such a procedure has been developed recently by CIFOR and training workshops have been implmented successfully in several countries. A CD-ROM is currently being prepared for dissemination to intersted stakeholders and the same material will be made available shortly on the CIFOR web page. Of concern to all involved in an activity of this kind are issues of database harmonisation and intellectual property rights governing data ownership and dispersal.

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Appendix I

V/4. Progress report on the implementation of the programme of work for forest biological diversity

The Conference of the Parties

Stressing that, in the implementation of the programme of work for forest biological diversity, due consideration should be given to the role of all types of forests, including planted forests, and the restoration of forest ecosystems,

Noting the importance of supporting work on taxonomic, ecological and socio-economic issues for the restoration of forest ecosystems and conservation and sustainable use of forest biological diversity,

Noting the importance of forest ecosystems and forest resources (including wood and non-wood forest products and services) to indigenous and local communities and the need to ensure their participation in the assessment of status and trends of FBD for the conservation and sustainable use of forest biological diversity,

Noting the proposed establishment and coordinating role of the United Nations Forum on Forests,

Noting the potential impact of afforestation, reforestation, forest degradation and deforestation on forest biological diversity and on other ecosystems,

1. Urges the Parties, Governments and relevant organizations to advance the implementation of the work programme for forest biological diversity, as contained in decision IV/7;
2. Decides to consider expanding the focus of the work programme from research to practical action at its sixth meeting;
3. Decides to call upon Parties, Governments and organizations to take practical actions within the scope of the existing programme of work in order to address urgently the conservation and sustainable use of forest biological diversity, applying the ecosystem approach and taking into consideration the outcome of the fourth session of the Intergovernmental Forum on Forests (UNEP/CBD/COP/5/INF/16), and also contributing to the future work of the United Nations Forum on Forests;
4. Decides to establish an ad hoc technical expert group on forest biological diversity to assist the Subsidiary Body on Scientific, Technical and Technological Advice, on the basis of the terms specified in the annex, in its work on forest biological diversity;
5. Requests the Executive Secretary to nominate scientific and technical experts, including expertise in policy matters and traditional knowledge, to the ad hoc technical expert group mentioned in paragraph 4 above, with due regard to geographical representation;
6. Requests the Executive Secretary to prepare for the work of the ad hoc technical expert group by inviting various international organizations and institutions to contribute data and information relevant to the terms of reference;
7. Invites Parties, countries, international organizations, institutions and processes and other relevant bodies, as well as indigenous and local communities and non-governmental organizations to provide relevant information on the implementation of the work programme through, inter alia, case-studies, entries in national reports and other means, as appropriate;
8. Encourages Parties and other Governments to promote the integration of national forest programmes with national biodiversity strategies, applying the ecosystem approach and sustainable forest management;

9. Further encourages Parties and other Governments to ensure participation by the forest sector, private sector, indigenous and local communities and non-governmental organizations in the implementation of the programme of work;
10. Recognizes past efforts by different organizations and encourages Parties and other Governments to strengthen national capacities, including local capacities, to enhance the effectiveness and functions of forest protected area networks, as well as national and local capacities for implementation of sustainable forest management, including restoration, when needed;
11. Requests the Subsidiary Body on Scientific, Technical and Technological Advice to consider before the sixth meeting of the Conference of the Parties, where appropriate and feasible in collaboration with the appropriate bodies of the United Nations Framework Convention on Climate Change and the Intergovernmental Panel on Climate Change, the impact of climate change on forest biological diversity;
12. Requests the Subsidiary Body on Scientific, Technical and Technological Advice to consider the causes and effects of human induced uncontrolled forest fires on forest biological diversity and propose possible approaches to address negative impacts;
13. Urges Parties to consider without delay the proposals for action of the Intergovernmental Forum on Forests and the Intergovernmental Panel on Forests on programme element II.d (v), on valuation of forest goods and services;
14. Requests the Subsidiary Body on Scientific, Technical and Technological Advice to consider the impact of, and propose sustainable practices for, the harvesting of non-timber forest resources, including bush meat and living botanical resources;
15. Requests the Executive Secretary to invite relevant organizations and forest-related bodies, institutions and processes, including criteria and indicator processes, as well as indigenous and local communities, non-governmental organizations, and other relevant stakeholders to contribute to the assessment of status and trends, including gaps and priority actions needed to address threats to forest biological diversity;
16. Urges the United Nations Framework Convention on Climate Change, including its Kyoto Protocol, to ensure that future activities of the United Nations Framework Convention on Climate Change, including forest and carbon sequestration, are consistent with and supportive of the conservation and sustainable use of biological diversity;
17. Requests the Executive Secretary to assemble, in collaboration with the United Nations Framework Convention on Climate Change and the Intergovernmental Panel on Climate Change, existing information relating to the integration of biodiversity considerations, including biodiversity conservation, in the implementation of the United Nations Framework Convention on Climate Change and its Kyoto Protocol;
18. Requests the Subsidiary Body on Scientific, Technical and Technological Advice, prior to the sixth meeting of the Conference of Parties, to prepare scientific advice, where appropriate and feasible in collaboration with the appropriate bodies of the United Nations Framework Convention on Climate Change and the Intergovernmental Panel on Climate Change, in order to integrate biodiversity considerations, including biodiversity conservation, in the implementation of the United Nations Framework Convention on Climate Change and its Kyoto Protocol;
19. Requests the President of the fifth meeting of the Conference of the Parties of the Convention on Biological Diversity to transmit the present decision to the meeting of the Conference of the Parties of the United Nations Framework Convention on Climate Change at its sixth meeting;
20. Invites the Executive Secretary to strengthen cooperation with the United Nations Framework Convention on Climate Change, including its Kyoto Protocol, the United Nations Convention to Combat Desertification, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), and the Ramsar Convention on Wetlands especially on issues relevant to forest biological diversity, taking into account the role of the United Nations Forum on Forests.

Annex

AD HOC TECHNICAL EXPERT GROUP ON FOREST BIOLOGICAL DIVERSITY

Terms of reference

Taking into account the ecosystem approach and sustainable forest management, decisions of the Conference of the Parties on thematic and cross-cutting issues, in particular Article 8(j), proposals for action agreed by the Intergovernmental Panel on Forests (IPF) and the Intergovernmental Forum on Forests (IFF), as well as the work of other relevant international processes and organizations including the Food and Agricultural Organization of the United Nations (FAO), processes related to criteria and indicators, the International Tropical Timber Organization (ITTO), and the Centre for International Forestry Research (CIFOR), the outcome of the Commission on Sustainable Development at its eighth meeting, and contributing to the future work of the United Nations Forum on Forests (UNFF) in the context of and in support of the programme of work for forest biological diversity, and making use of the information contained in available case-studies,

1. Provide advice on scientific programmes and international cooperation in research and development related to conservation and sustainable use of forest biological diversity in the context of the programme of work for forest biological diversity (decisions IV/7 and V/4);

2. (a) Carry out a review of available information on the status and trends of, and major threats to, forest biological biodiversity, to identify significant gaps in that information;

(b) Identify options and suggest priority actions, timeframes and relevant actors for the conservation and sustainable use of forest biological diversity for their implementation through activities such as:

(i) Identifying new measures and ways to improve the conservation of forest biological diversity in and outside existing protected areas;

(ii) Identifying practical measures to mitigate the direct and underlying causes of FBD loss;

(iii) Identifying tools and mechanisms to implement the identified measures and actions;

(iv) Identifying measures for the restoration of degraded forest; and

(v) Identifying strategies for enhancement of collaborative management with local and indigenous communities;

(c) To identify innovative, efficient and state-of-the-art technologies and know-how relating to assessment, planning, valuation, conservation and sustainable use of FBD and provide advice on ways and means of promoting the development and transfer of such technologies.

Duration of work

The work of the ad hoc technical expert group on FBD should be initiated immediately after approval by the Conference of the Parties at its fifth meeting of the terms of reference, and the nomination of experts, and completed not later than the seventh meeting of the Subsidiary Body on Scientific, Technical and Technological Advice, in time for the sixth meeting of the Conference of the Parties, which will consider FBD as one of the main priority issues.

Appendix II

Terms of Reference for consultant

[Insert electronic copy – only fax available]

Appendix III

COP V/6 Annex

A. Description of the ecosystem approach

1. The ecosystem approach is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. Thus, the application of the ecosystem approach will help to reach a balance of the three objectives of the Convention: conservation; sustainable use; and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources.

2. An ecosystem approach is based on the application of appropriate scientific methodologies focused on levels of biological organization, which encompass the essential structure, processes, functions and interactions among organisms and their environment. It recognizes that humans, with their cultural diversity, are an integral component of many ecosystems.

3. This focus on structure, processes, functions and interactions is consistent with the definition of "ecosystem" provided in Article 2 of the Convention on Biological Diversity:

> "'Ecosystem' means a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit."

This definition does not specify any particular spatial unit or scale, in contrast to the Convention definition of "habitat". Thus, the term "ecosystem" does not, necessarily, correspond to the terms "biome" or "ecological zone", but can refer to any functioning unit at any scale. Indeed, the scale of analysis and action should be determined by the problem being addressed. It could, for example, be a grain of soil, a pond, a forest, a biome or the entire biosphere.

4. The ecosystem approach requires adaptive management to deal with the complex and dynamic nature of ecosystems and the absence of complete knowledge or understanding of their functioning. Ecosystem processes are often non-linear, and the outcome of such processes often shows time-lags. The result is discontinuities, leading to surprise and uncertainty. Management must be adaptive in order to be able to respond to such uncertainties and contain elements of "learning-by-doing" or research feedback. Measures may need to be taken even when some cause-and-effect relationships are not yet fully established scientifically.

5. The ecosystem approach does not preclude other management and conservation approaches, such as biosphere reserves, protected areas, and single-species conservation programmes, as well as other approaches carried out under existing national policy and legislative frameworks, but could, rather, integrate all these approaches and other methodologies to deal with complex situations. There is no single way to implement the ecosystem approach, as it depends on local, provincial, national, regional or global conditions. Indeed, there are many ways in which ecosystem approaches may be used as the framework for delivering the objectives of the Convention in practice.

B. Principles of the ecosystem approach

6. The following 12 principles are complementary and interlinked:

Principle 1: **The objectives of management of land, water and living resources are a matter of societal choice.**

Rationale: Different sectors of society view ecosystems in terms of their own economic, cultural and societal needs. Indigenous peoples and other local communities living on the land are important stakeholders and their rights and interests should be recognized. Both cultural and biological diversity are central components of the ecosystem approach, and management should take this into account. Societal choices should be expressed as clearly as possible. Ecosystems should be managed for their intrinsic values and for the tangible or intangible benefits for humans, in a fair and equitable way.

Principle 2: **Management should be decentralized to the lowest appropriate level.**

Rationale: Decentralized systems may lead to greater efficiency, effectiveness and equity. Management should involve all stakeholders and balance local interests with the wider public interest. The closer management is to the ecosystem, the greater the responsibility, ownership, accountability, participation, and use of local knowledge.

Principle 3: **Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems.**

Rationale: Management interventions in ecosystems often have unknown or unpredictable effects on other ecosystems; therefore, possible impacts need careful consideration and analysis. This may require new arrangements or ways of organization for institutions involved in decision-making to make, if necessary, appropriate compromises.

Principle 4: **Recognizing potential gains from management, there is usually a need to understand and manage the ecosystem in an economic context. Any such ecosystem-management programme should:**

(a) **Reduce those market distortions that adversely affect biological diversity;**

(b) **Align incentives to promote biodiversity conservation and sustainable use;**

(c) **Internalize costs and benefits in the given ecosystem to the extent feasible.**

Rationale: The greatest threat to biological diversity lies in its replacement by alternative systems of land use. This often arises through market distortions, which undervalue natural systems and populations and provide perverse incentives and subsidies to favour the conversion of land to less diverse systems.

Often those who benefit from conservation do not pay the costs associated with conservation and, similarly, those who generate environmental costs (e.g. pollution) escape responsibility. Alignment of incentives allows those who control the resource to benefit and ensures that those who generate environmental costs will pay.

Principle 5: **Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach.**

Rationale: Ecosystem functioning and resilience depends on a dynamic relationship within species, among species and between species and their abiotic environment, as well as the physical and chemical interactions within the environment. The conservation and, where appropriate, restoration of these interactions and processes is of greater significance for the long-term maintenance of biological diversity than simply protection of species.

Principle 6: **Ecosystems must be managed within the limits of their functioning.**

Rationale: In considering the likelihood or ease of attaining the management objectives, attention should be given to the environmental conditions that limit natural productivity, ecosystem structure, functioning and diversity. The limits to ecosystem functioning may be affected to different degrees by temporary, unpredictable or artificially maintained conditions and, accordingly, management should be appropriately cautious.

Principle 7: **The ecosystem approach should be undertaken at the appropriate spatial and temporal scales.**

Rationale: The approach should be bounded by spatial and temporal scales that are appropriate to the objectives. Boundaries for management will be defined operationally by users, managers, scientists and indigenous and local peoples. Connectivity between areas should be promoted where necessary. The ecosystem approach is based upon the hierarchical nature of biological diversity characterized by the interaction and integration of genes, species and ecosystems.

Principle 8: **Recognizing the varying temporal scales and lag-effects that characterize ecosystem processes, objectives for ecosystem management should be set for the long term.**

Rationale: Ecosystem processes are characterized by varying temporal scales and lag-effects. This inherently conflicts with the tendency of humans to favour short-term gains and immediate benefits over future ones.

Principle 9: **Management must recognize that change is inevitable.**

Rationale: Ecosystems change, including species composition and population abundance. Hence, management should adapt to the changes. Apart from their inherent dynamics of change, ecosystems are beset by a complex of uncertainties and potential "surprises" in the human, biological and environmental realms. Traditional disturbance regimes may be important for ecosystem structure and functioning, and may need to be maintained or restored. The ecosystem approach must utilize adaptive management in order to anticipate and cater for such changes and events and should be cautious in making any decision that may foreclose options, but, at the same time, consider mitigating actions to cope with long-term changes such as climate change.

Principle 10: **The ecosystem approach should seek the appropriate balance between, and integration of, conservation and use of biological diversity.**

Rationale: Biological diversity is critical both for its intrinsic value and because of the key role it plays in providing the ecosystem and other services upon which we all ultimately depend. There has been a tendency in the past to manage components of biological diversity either as protected or non-protected. There is a need for a shift to more flexible situations, where conservation and use are seen in context and the full range of measures is applied in a continuum from strictly protected to human-made ecosystems.

Principle 11: **The ecosystem approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practices.**

Rationale: Information from all sources is critical to arriving at effective ecosystem management strategies. A much better knowledge of ecosystem functions and the impact of human use is desirable. All relevant information from any concerned area should be shared with all stakeholders and actors, taking into account, inter alia, any decision to be taken under Article 8(j) of the Convention on Biological Diversity. Assumptions behind proposed management decisions should be made explicit and checked against available knowledge and views of stakeholders.

Principle 12: The ecosystem approach should involve all relevant sectors of society and scientific disciplines.

Rationale: Most problems of biological-diversity management are complex, with many interactions, side-effects and implications, and therefore should involve the necessary expertise and stakeholders at the local, national, regional and international level, as appropriate.

C. Operational guidance for application of the ecosystem approach

7. In applying the 12 principles of the ecosystem approach, the following five points are proposed as operational guidance.

1. Focus on the functional relationships and processes within ecosystems

8. The many components of biodiversity control the stores and flows of energy, water and nutrients within ecosystems, and provide resistance to major perturbations. A much better knowledge of ecosystem functions and structure, and the roles of the components of biological diversity in ecosystems, is required, especially to understand: (i) ecosystem resilience and the effects of biodiversity loss (species and genetic levels) and habitat fragmentation; (ii) underlying causes of biodiversity loss; and (iii) determinants of local biological diversity in management decisions. Functional biodiversity in ecosystems provides many goods and services of economic and social importance. While there is a need to accelerate efforts to gain new knowledge about functional biodiversity, ecosystem management has to be carried out even in the absence of such knowledge. The ecosystem approach can facilitate practical management by ecosystem managers (whether local communities or national policy makers).

2. Enhance benefit-sharing

9. Benefits that flow from the array of functions provided by biological diversity at the ecosystem level provide the basis of human environmental security and sustainability. The ecosystem approach

seeks that the benefits derived from these functions are maintained or restored. In particular, these functions should benefit the stakeholders responsible for their production and management. This requires, inter alia: capacity-building, especially at the level of local communities managing biological diversity in ecosystems; the proper valuation of ecosystem goods and services; the removal of perverse incentives that devalue ecosystem goods and services; and, consistent with the provisions of the Convention on Biological Diversity, where appropriate, their replacement with local incentives for good management practices.

3. Use adaptive management practices

10. Ecosystem processes and functions are complex and variable. Their level of uncertainty is increased by the interaction with social constructs, which need to be better understood. Therefore, ecosystem management must involve a learning process, which helps to adapt methodologies and practices to the ways in which these systems are being managed and monitored. Implementation programmes should be designed to adjust to the unexpected, rather than to act on the basis of a belief in certainties. Ecosystem management needs to recognize the diversity of social and cultural factors affecting natural-resource use. Similarly, there is a need for flexibility in policy-making and implementation. Long-term, inflexible decisions are likely to be inadequate or even destructive. Ecosystem management should be envisaged as a long-term experiment that builds on its results as it progresses. This "learning-by-doing" will also serve as an important source of information to gain knowledge of how best to monitor the results of management and evaluate whether established goals are being attained. In this respect, it would be desirable to establish or strengthen capacities of Parties for monitoring.

4. Carry out management actions at the scale appropriate for the issue being addressed, with decentralization to lowest level, as appropriate

11. As noted in section A above, an ecosystem is a functioning unit that can operate at any scale, depending upon the problem or issue being addressed. This understanding should define the appropriate level for management decisions and actions. Often, this approach will imply decentralization to the level of local communities. Effective decentralization requires proper empowerment, which implies that the stakeholder both has the opportunity to assume responsibility and the capacity to carry out the appropriate action, and needs to be supported by enabling policy and legislative frameworks. Where common property resources are involved, the most appropriate scale for management decisions and actions would necessarily be large enough to encompass the effects of practices by all the relevant stakeholders. Appropriate institutions would be required for such decision-making and, where necessary, for conflict resolution. Some problems and issues may require action at still higher levels, through, for example, transboundary cooperation, or even cooperation at global levels.

5. Ensure intersectoral cooperation

12. As the primary framework of action to be taken under the Convention, the ecosystem approach should be fully taken into account in developing and reviewing national biodiversity strategies and action plans. There is also a need to integrate the ecosystem approach into agriculture, fisheries, forestry and other production systems that have an effect on biodiversity. Management of natural resources, according to the ecosystem approach, calls for increased intersectoral communication and cooperation at a range of levels (government ministries, management agencies, etc.). This might be promoted through, for example, the formation of inter-ministerial bodies within the Government or the creation of networks for sharing information and experience.

Appendix IV

PROPOSED CORE SET OF BIODIVERSITY INDICATORS

State Indicator			Thematic areas [1]						Data Sets	Methods	Comments
			F	M/C	IW	D[2]	M	Ag[3]			
• **ECOSYSTEM QUANTITY**		**1. Habitat** 1.1 Self-regenerating 1.2 Man-made	* *	*	* *	* *	* *	*	Remote sensing data, vegetation maps, national forest cover inventories, coastal zone maps, wetland and freshwater inventories	Overlay maps, GIS, Aerial surveys, Ground truthing	Measured as % area/total land. Shows the extent of the area and whether habitat is being gained or lost in recent times
• **ECOSYSTEM QUALITY**	• **ECOSYSTEM**	**2. Habitat Fragmentation/Conversion** 2.1 Native vegetation fragmentation 2.2 Wetland drainage and filling 2.3 Conversion of coastal areas 2.4 Erosion 2.5 Irrigation	* * *	* * * *	* * * *	* * * *	* *	* *	Land use plans, remote sensing data, surveys FAO data	GIS, overlay maps	Shows trends in significant habitat disturbance
		3. Species Richness	*	*	*	*	*	*	National biodiversity data base. Surveys, transect, sampling reports	Monitoring and research programs, Inventories	Species richness data is being collected widely (at different taxonomic levels) but its use as indicator is limited by the uncertainty of the total number of species present and taxonomical difficulties
	• **SPECIES**	**4. Change in abundance and/or distribution of a selected core set of species**	*	*	*	*	*	*	Wide area, transect, sample results	Surveys and monitoring programs depending on the species involved	Can provide information on ecological changes and early warning signals regarding ecosystem processes. Species in the set to be included based on country-specific conditions (e.g. rare, endemic, key stone, flagship, e onomi . invasive.

											pests, livestock/grazers, scientific interest, ecosystem functions. etc.)
		5. Threatened species 5.1 % of total species or certain taxonomic groups 5.2 % endemic species threatened 5.3 Threatened species in protected areas	* * *	* * *	* * *	* * *	* * *	* * *	Endangered and threatened species data sets	Surveys and monitoring	Indicate species for which most urgent actions are needed
	• **GENETICS**	6.1 Replacement of indigenous crops 6.2 Replacement of land races with few imported one	*		* *	* *	* *	* *	Allelic diversity, karyotype variants	Morphological analysis, offspring parent regression, DNA sequencing, electrophoresis, karyotypic analysis	Will provide information on inbreeding depression, out-breeding rate, rate of genetic drift, genetic flow, etc.

Appendix IV (cont.)

Pressure and Response Indicators		Thematic areas						Data Sets	Methods	Comments
		F	M/C	IW	D	M	Ag			
• **PRESSURE INDICATORS**	**7. Population density** 7.1 -In/adjacent to key habitats 7.2 In/adjacent to Protected Areas	* *	* *	* *	* *	* *	* *	National or local statistical data or surveys	Existing administrative data, translated to habitat level, socio-economic surveys, census	Rapid growth likely to indicate negative impact on biodiversity. Increase inside or adjacent to protected areas might suggest illegal incursion
	8. Harvesting/use 8.1 Production totals 8.2 Export totals 8.3 Imports total 8.4 Local processing capacity 8.5 Domestic consumption 8.6 Catch/effort 8.7 Changes in proportion of commercial species	* * * * * *	* * *	* * *	* * * * * *	* * * * * *	* * * * * *	National statistics, commercial production records, records by community groups	Record keeping and monitoring of selected data	Trends in amount harvested, changes in harvest/effort can give early warning signals on over-harvesting. The data is most useful when compared as a set of several indicators
	9. Infrastructure 9.1 Road and transportation networks 9.2 Dams 9.3 Rate of housing development	* *		*	* * *	* * *		National statistics, commercial records, remote sensing, surveys, records by community groups	Record keeping, overlaying maps, field reports,	Trends associated with increased human pressure, extraction, habitat destruction, etc.
	10. Pollution 10.1 Soil quality 10.2 Water quality 10.3 Air quality	* * *	*	*	* * *	* *	* * *	Import, production, sale records, Emission records, monitoring data	Record keeping, emissions and field monitoring	Indicator set to be developed on country-specific needs. Can be based on data regarding production, import, sale, use, emissions, contaminant load, or levels in the environment of salinity, dust, agrochemicals and harmful substances.
	11. Alien/Invasive species 11.1 % habitat colonized by invasive species 11.2 % protected areas colonized by invasive species	* *	* *	* *	* *	* *	* *	Surveys, transects or sample results, patrol reports or reports from local communities	Monitoring of trends in distribution	
	12 Climatic change	*	*	*	*	*	*	National statistics, records	Monitoring of trends	Several variables to be selected based on country-specific issues to be monitored and data availability (droughts, sea-level, temperature, storm frequency, etc.)

• **RESPONSE** **INDICATORS**	**13. Habitat Management** 13.1 % protected (IUCN 1-3) 13.2 % protected (IUCN 4-5) 13.3 % managed for production 13.4 No. of fires/area burned/yr	* * * *	* * *	* * *	* * * *	* * * *	* * *	Spatial plans, national statistics, remote sensing	GIS, overlay maps	Shows changes in conservation status and land-use
	14. Special habitat 14.1 % remaining 14.2 % protected	* *	* *	* *	* *	* *	* *	Spatial plans, national statistics, remote sensing, surveys	GIS, overlay maps,	Shows trends and conservation status of fragile, threatened, biodiversity-rich habitats (e.g. Mangroves, peat-swamps, coral reefs)

1 F- FBD; M/C- Marine and coastal biodiversity; IW- Inland water biodiversity; D- Dryland biodiversity; M- Mountain biodiversity; Ag- Agrobiodiversity.

2 Also reviewed by the liaison group on drylands.

3 Not discussed by the liaison group on biodiversity indicators.