CBD

Secretariat of the
Convention on Biological Diversity

INTERNATIONAL DAY FOR BIOLOGICAL DIVERSITY
22 May 2008
BIODIVERSITY AND AGRICULTURE

DRAFT FINDINGS OF THE FIRST MEETING OF THE SECOND AD HOC TECHNICAL EXPERT GROUP ON BIODIVERSITY AND CLIMATE CHANGE ON THE IMPACTS OF CLIMATE CHANGE ON BIODIVERSITY INCLUDING WAYS AND MEANS TO PROJECT IMPACTS[1]/

1. The following is being submitted by the Secretariat of the Convention on Biological Diversity on behalf of the Ad hoc Technical Expert Group on Biodiversity and Climate Change in response to the call for submissions on paragraph 1 of the Bali Action Plan (decision 1/CP.13).

2. This submission is made with a view to making available, to Parties, work undertaken in other international processes, particularly the second Ad Hoc Technical Expert Group (AHTEG) on Biodiversity and Climate Change, which was convened in response to paragraph 12 (b) of decision IX/16 B of the Conference of the Parties to the Convention on Biological Diversity (CBD). The AHTEG was established to provide biodiversity related information to the United Nations Framework Convention on Climate Change (UNFCCC) though the provision of scientific and technical advice and assessment on the integration of the conservation and sustainable use of biodiversity into climate change mitigation and adaptation activities, which includes:

(a) Identifying relevant tools, methodologies and best practice examples for assessing the impacts on and vulnerabilities of biodiversity as a result of climate change;

(b) Proposing ways and means to improve the integration of biodiversity considerations and traditional and local knowledge related to biodiversity within impact and vulnerability assessments with particular reference to communities and sectors vulnerable to climate change;

(c) Identifying opportunities to deliver multiple benefits for carbon sequestration, and biodiversity conservation and sustainable use in a range of ecosystems including peatlands, tundra and grasslands;

(d) Identifying opportunities for, and possible negative impacts on, biodiversity and its conservation and sustainable use, as well as livelihoods of indigenous and local communities, that may arise from reducing emissions from deforestation and forest degradation;

(e) Identifying options to ensure that possible actions for reducing emissions from deforestation and forest degradation do not run counter to the objectives of the Convention on Biological Diversity but rather support the conservation and sustainable use of biodiversity.

1/ The following document has not been peer reviewed and, as such, presents an initial summary of the findings of the second ad hoc technical expert group on biodiversity and climate change.

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COP 9 MOP 4 Bonn Germany 2008

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BIODIVERSITY-RELATED IMPACTS OF ANTHROPOGENIC CLIMATE CHANGE

Anthropogenic changes in climate and atmospheric CO2 are already having observable impacts on ecosystems and species; some species and ecosystems are demonstrating apparent capacity for natural adaptation, but others are showing negative impacts. Impacts are widespread even with the modest level of change observed thus far in comparison to some future projections. Observed signs of natural adaptation and negative impacts include:

- **Geographic distributions:** Species' geographic ranges are shifting towards higher latitudes and elevations. While this can be interpreted as natural adaptation, caution is advised, as the ranges of some species are contracting from warm boundaries, but are not expanding elsewhere; there are also geographic limits to how far some species will be able to go. Range shifts have mostly been studied in temperate zones, due to the availability of long data records; changes at tropical and sub-tropical latitudes will be more difficult to detect and attribute due to a lack of time series data and variability of precipitation.
- **Timing of life cycles (phenology):** changes to the timing of natural events have now been documented in many hundreds of studies and may signal natural adaptation by individual species. Changes include advances in spring events (e.g. leaf unfolding, flowering, and reproduction) and delays in autumn events.
- **Interactions between species:** evidence of the disruption of biotic interactions is emerging. Changes in differential responses to timing are leading to mismatches between the peak of resource demands by reproducing animals and the peak of resource availability. This is causing population declines in many species and may indicate limits to natural adaptation.
- **Photosynthetic rates, carbon uptake and productivity in response to CO_2 "fertilization" and nitrogen deposition:** models and some observations suggest that global gross primary production (GPP) has increased. Regional modelling efforts project ongoing increases in GPP for some regions, but possible declines in others. Furthermore, in some areas CO_2 fertilization is favouring fast growing species over slower growing ones and changing the composition of natural communities while not appreciably changing the GPP.
- **Community and ecosystem changes:** observed structural and functional changes in ecosystems are resulting in substantial changes in species abundance and composition. These have impacts on livelihoods and traditional knowledge including, for example, changing the timing of hunting and fishing and traditional sustainable use activities, as well as impacting upon traditional migration routes for people.

The rate of climate change has already exceeded the capacity of some species and ecosystems to adapt naturally, and is close to exceeding that of others

Many of the mass extinctions that have occurred over geologic time were tied, at least in part, to climate changes that occurred at rates much slower than those projected for the next century. These results may be seen as potentially indicative but are not analogues to the current situation, as continents were in different positions, oceanic circulation patterns were different and the overall composition of biodiversity was significantly different. It should also be kept in mind that these extinctions occurred with the temperature change taking place over tens of thousands of years – a rate at which natural adaptation should have been able to take place. This is in contrast to the much more rapid rate of temperature change observed and projected today.

Given the rapid rate of projected change, some regions and ecosystems will be more vulnerable to extinction and degradation than others. The relative vulnerability of species and ecosystems is due to a combination of individual species traits that predispose them to risk, the degree of exposure of the environment to climate change, and their capacity to adapt, either genetically or behaviourally. For example, the very nature of small island developing States, as relatively isolated territories, low-lying and surrounded by an ocean or a sea, makes their biota extremely vulnerable to climate change and related sea level rise, prolonged droughts and increases in hurricane and storm surges frequency and strength.

During the course of this century the resilience of many ecosystems (their ability to adapt naturally) is likely to be exceeded by an unprecedented combination of change in climate, associated disturbances (e.g., flooding, drought, wildfire, insects, ocean acidification) and in other global change drivers (especially land-use change, pollution and over-exploitation of resources), if greenhouse gas emissions and other changes continue at or above current rates (high confidence). [2]

Further climate change will have increasingly significant direct impacts on biodiversity. Increased rates of species extinctions are likely, with negative consequences for the provision of services these species and ecosystems provide. Poleward and elevational shifts, as well as range contractions and fragmentation, are expected to accelerate in the future. Contractions and fragmentation will be particularly severe for species with limited dispersal abilities, slower life history traits, and range restricted species such as polar and mountain top species and species restricted to freshwater habitats.

Increasing CO_2 concentrations are altering the basic physical and chemical environment underpinning all life, especially temperature, precipitation, and acidity. Atmospheric concentrations of CO_2 can themselves have important direct influences on biological systems, which can reinforce or act counter to responses to climate variables and complicate projection of future responses. The direct effects of elevated atmospheric CO_2 are especially important in marine ecosystems and in terrestrial systems that are not water-limited.

Climate change will also affect species indirectly, by affecting species interactions. Individualistic responses of species to climate and atmospheric change may result in novel species combinations and ecosystems that have no present day analogue (a finding supported by paleoecological studies). These impacts on communities may be more damaging in some regions than the direct effects of climatic changes on individual species, and may compromise sustainable development. The impacts of climate change on species will have cascading affects on community associations and ecosystems leading to non-linear responses, with thresholds or "tipping points" not yet well understood.

Climate change will interact with other pressures acting on natural systems, most notably land use and land-use change, invasive alien species and disturbance by fire. Land-use change and related habitat loss are currently major threats to biodiversity worldwide. Climate change is also very likely to facilitate the spread and establishment of invasive alien species. However, shifts in distributions of native species as an adaptive response to climate change will force a reassessment of how we define what is meant by "invasive". These pressures amplify climate change effects by causing fragmentation, degradation and drying of ecosystems, including increased incidence of fire, which is often exacerbated during climatic events like El Niño. Thus, it is vital to consider the effects of climate change in the context of interacting pressures and the influence they may exert directly on natural systems and on those systems' abilities to respond to climate change.

Extinction risks associated with climate change will increase, but projecting the rate of extinction is difficult due to lags in species' population responses, incomplete knowledge of natural adaptive capacity and the complex cascade of inter-species interactions in communities

Research shows that approximately 10% of species assessed so far are at an increasingly high risk of extinction for every 1°C rise in global mean temperature, within the range of future scenarios modeled in impacts assessments (typically <5^{0}C global temperature rise). Given the observed temperature rise, this now places approximately 6-8% of the species studied at an increasingly high risk of extinction. The current commitment to additional temperature increases (at least 0.5°C) also places an additional 5-7% of species at increasingly high risk of extinction (based on single species studies and not including losses of entire ecosystems). A recent study of global bird distributions estimated that each degree of warming will yield a nonlinear increase in bird extinctions of about 100-500 species. Temperature increases of 2°C above pre-industrial begin to put entire ecosystems at risk and the extinction rate is expected to rise accordingly.

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2 This statement is extracted verbatim from IPCC WG2 Chapter 4 conclusions.

The understanding of the characteristics that contribute to species' risks of decline or extinction has improved. Species with small ranges and tropical montane species are at particular risk as are those with naturally fragmented or isolated populations or limited dispersal ability. Areas of most concern are the arctic and Antarctic regions, centres of endemism where many species have very narrow geographic and climatic ranges, low-lying regions, wetlands, coral reefs and freshwater systems where species have limited dispersal opportunities. Vulnerability is also affected by the degree and extent of other human pressures. Recent work suggests that for birds, amphibians and warm water corals as many as 35-70% of species have life-history traits that make them vulnerable to climate change. In the absence of strong mitigation in all sectors (fossil fuel and land-use), some ecosystems, such as cloud forests and coral reefs, may cease to function in their current form within a few decades.

The negative impacts of climate change on biodiversity have significant economic and ecological costs

A key property of ecosystems that may be affected by climate change is the values and services they provide. These include provisioning services such as fisheries and timber production, where the response depends on population characteristics as well as local conditions and may include large production losses. Climate change also affects the ability of ecosystems to regulate water flows, and cycle nutrients.

There is ample evidence that warming will alter the patterns of plant and animal diseases. Current research projects increases in economically important plant pathogens with warming. There has also been considerable recent concern over the role of climate change in the expansion of disease vectors. For example, short-term local experiments have demonstrated the impacts of predicted global change on plant health including rice. Furthermore, studies of the impacts of climate change on the range of the tick-borne disease Theileriosis (East Coast fever) show increases in areas of suitability in Africa.

The impacts of climate change on biodiversity will change human disease vectors and exposure. Climate change is predicted to result in the expansion of a number of human disease vectors and/or increase the areas of exposure. For example the increased inundation of coastal wetlands by tides may result in favourable conditions for saltwater mosquito breeding and associated increased in mosquito-borne diseases such as malaria and dengue fever.

Climate change affects the ability of ecosystems to regulate water flows. Higher temperatures, changing insolation and cloud cover, and the degradation of ecosystem structure, impedes the ability of ecosystems to regulate water flow. In Asia, for example, water supplies are at risk because climate change melts the glaciers that feed Asia's largest rivers in the dry season – precisely the period when water is needed most to irrigate the crops on which hundreds of millions of people depend.

Climate change will have important impacts on agricultural biodiversity. Even slight changes are expected to decrease agricultural productivity in tropical and subtropical areas. More frequent and more extreme droughts and floods will increase the likelihood of crop failure and may result in negative livelihood impacts including forced sale of assets, out-migration and dependency on food relief. The wild relatives of crop plants – an important source of genetic diversity for crop improvement – are also potentially threatened by climate change.

Changes and shifts in the distribution of marine biodiversity resulting from climate change could have serious implications for fisheries. The livelihoods of coastal communities are threatened by the projected impacts of climate change on coral reefs and other commercially important marine and freshwater species. Fisheries may improve in the short term in boreal regions but they may decline elsewhere with projected local extinctions of particular fish species important for aquaculture production. As a result of climate change and in the absence of stringent mitigation, up to 88% of the coral reefs in Southeast Asia may be lost over the next 30 years. In addition, ocean acidification may cause pH to decrease by as much as 0.5 units by 2100 causing severe die-offs in shellfish.

Biodiversity loss and ecosystem service degradation resulting from climate change has a disproportionate impact on the poor and may increase human conflict. The areas of richest biodiversity and ecosystem services are in developing countries where billions of people directly rely on them to meet their basic needs. Competition for biodiversity resources and ecosystem services may lead to human conflict. Small Island Developing States and Least Developed Countries are particularly vulnerable to impacts such as projected sea level rise, ocean current oscillation changes and extreme weather events.

Indigenous peoples will be disproportionately impacted by climate change because their livelihoods and cultural ways of life are being undermined by changes to local ecosystems. Climate change is likely to affect the knowledge, innovations and practices of indigenous peoples and local communities and associated biodiversity-based livelihoods. However, it is difficult to give a precise projection of the scale of these impacts, as these will vary across different areas and different environments. For example, indigenous peoples and local communities in the Arctic depend heavily on cold-adapted ecosystems. While the number of species and net primary productivity may increase in the Arctic, these changes may cause conflicts between traditional livelihoods and agriculture and forestry. In the Amazon, changes to the water cycle may decrease access to native species and spread certain invasive fish species in rivers and lakes. Furthermore, climate change is having significant impacts on traditional knowledge, innovations and practices among dryland pastoral communities.

Shifts in phenology and geographic ranges of species could impact the cultural and religious lives of some indigenous peoples. Many indigenous peoples use wildlife as integral parts of their cultural and religious ceremonies. For example, birds are strongly integrated into Pueblo Indian communities where birds are viewed as messengers to the gods and a connection to the spirit realm. Among Zuni Indians, prayer sticks, using feathers from 72 different species of birds, are used as offerings to the spirit realm. Many ethnic groups in sub-Saharan Africa use animal skins and bird feathers to make dresses for cultural and religious ceremonies. For example, in Boran (Kenya) ceremonies, the selection of tribal leaders involves rituals requiring Ostrich feathers. Wildlife plays similar roles in cultures elsewhere in the world.

Novel environments and novel ecosystems are likely to emerge with potentially unexpected behaviour. Climate change is already resulting in novel climates in some microclimates within existing protected areas. This shift may render existing conservation efforts less effective.

Biodiversity can be important in ameliorating the negative impacts of some kinds of extreme climate events for human society; but certain types of extreme climate events which may be exacerbated by climate change will be damaging to biodiversity

Ecosystems play an important role in protecting infrastructure and enhancing human security. More than 1 billion people were affected by natural disasters between 1992 and 2002. During this period floods alone left more than 400 000 people homeless and caused many deaths. In response to these events many countries adopted plans and programmes recognizing the need to maintain natural ecosystems.

The value of biodiversity in ameliorating the negative impacts of some extreme events has been demonstrated. The value of mangroves for coastal protection has been estimated in some areas to be as much as US$ 300,000 per km of coast based on the cost of installing artificial coastal protection. A study of the overall value of wetlands for flood protection provided an estimated benefit of $464 per hectare. Furthermore, the conservation and sustainable use of biodiversity has a significant role to play in response to drought providing important genetic diversity in livestock and crops.

The impacts of climate change on biodiversity will reduce the ability of ecosystems to ameliorate the negative impacts of extreme events. Future predictions of the impacts of climate change on biodiversity have identified some of the ecosystems most critical for human security as being particularly vulnerable to the impacts of climate change. For example, climate change impacts are expected to result in a loss of over half the area of mangroves in 16 Pacific island States by the end of the century.

Enhancing natural adaptation by biodiversity can reduce negative impacts from climate change and contribute to climate change mitigation by preserving key functions such as carbon sequestration

Climate change will continue to alter the composition, physical and trophic structure, successional processes and community dynamics of many ecosystems, with cascading effects to the services these ecosystems provide, including carbon storage. Examples include the invasion of temperate grasslands by woody plants possibly facilitated by increasing CO_2 concentrations, and changes in the structure of reef ecosystems due to bleaching and ocean acidification. Regional modelling also projects increases in GPP for some regions as a result of longer growing seasons and higher CO_2 concentrations. However, where water balance is more important GPP is projected to either decline or to increase only slightly relative to present day conditions. Changes in productivity will result in changes in litterfall and nutrient cycling. Where litterfall increases, it may contribute to increasing respiration and loss of soil carbon.

Ecosystems are currently acting as a carbon sink to sequester 30% of anthropogenic emissions, but if no action is taken on mitigation, these sinks would slowly convert to carbon sources as temperatures rise, largely due to the increased soil respiration and regional drought. Some studies suggest that this feedback could increase CO_2 concentrations by 20 to 200 ppm, and hence increase temperatures by 0.1 to 1.5ºC in 2100. The level of global warming which would be required to trigger such a feedback is uncertain, but could lie in the range of an increase in global mean surface temperature of between 2-4ºC above pre-industrial levels according to some models. In particular:

- Local conversion of forests from sinks to sources would be exacerbated by deforestation and degradation, which increases the vulnerability of forest to climate change and reduces local precipitation encouraging drying. Some models predict that the Amazon is particularly vulnerable to such processes. Between 25-50% of rainfall is recycled from the Amazon forest, forming one of the most important regional ecosystem services. Deforestation of 35-40% of the Amazon, especially in Eastern Amazonia, could shift the forest into a permanently drier climate, increasing the risk of fire and carbon release.
- Arctic ecosystems and tropical peatlands could also become strong sources of carbon emissions in the absence of mitigation. Recent studies estimate that unmitigated climate change could lead to thawing of Arctic permafrost releasing at least 100GtC by 2100, with at least 40Gt coming from Siberia alone by 2050. Such increases will not be offset by the projected advance of the boreal forest into the tundra.
- Experimental evidence suggests that the warming climate will alter the plant species present in ecosystems that are currently based on peat soils, reducing the capacity of the peat to sequester carbon.

ASSESSING THE RELIABILITY OF THE KNOWLEDGE ON THE IMPACTS OF CLIMATE CHANGE ON BIODIVERSITY AND IDENTIFYING KNOWLEDGE GAPS

There is considerable confidence that climate models provide credible quantitative estimates of future climate change, particularly at continental scales and above. However, at finer spatial scales projections have a high level of uncertainty, particularly in tropical and subtropical regions, and in relation to projections of rainfall change.

Confidence in climate change models comes from the foundation of the models in accepted physical principles and from their ability to reproduce observed features of current climate and past climate changes. Confidence in model estimates is higher for some climate variables (e.g., temperature) than for others (e.g., precipitation). There are, however, some limitations in the models. Significant uncertainties are, for example, associated with the representation of clouds leading to uncertainties in the magnitude and timing, as well as regional details, of predicted climate change.

Despite uncertainties, models are unanimous in their prediction of substantial warming under greenhouse gas increases. This warming is of a magnitude consistent with independent estimates derived from other sources, such as from observed climate changes and past climate reconstructions. Furthermore, since confidence in the changes projected by global models decreases at smaller scales, other techniques, such as the use of regional climate models, or downscaling methods, have been specifically developed for the study of regional- and local-scale climate change.

Research needs and gaps remain. CBD Technical Series 10 outlined a number of research needs and gaps with regards to assessing the impacts of climate change and biodiversity. Some of these gaps have been filled, however many remain. For example, there is still a lack of extensive, readily available quantitative information on many species globally. While efforts to fill this need are underway (e.g., Global Biodiversity Information Facility), more work remains to be done, especially at understanding where species are not (a critical factor in performing many bioclimatic models). Human land and water use patterns are available for many parts of the world, but are not widely linked into the typical models used for looking at biodiversity impacts. This is also an impediment to using models to separate the impacts of climate change from other human activities.

Key uncertainties that limit our ability to project climate change impacts on ecosystems include projections for precipitation which carry a significantly higher uncertainty than temperature and uncertainties regarding ecological processes

Models currently contain inadequate representations of the interactive coupling between ecosystems and the climate system and of the multiple interacting drivers of global change. This prevents a fully integrated assessment of climate change impacts on ecosystem services; major biotic feedbacks to the climate system, especially through trace gases from soils in all ecosystems, and methane from labile carbon stocks such as wetlands, peatlands, permafrost and loess soils.

There is uncertainty with respect to the functional role of individual species and the functioning of complex systems. Further uncertainties are drawn from:

- the assumption of instantaneous (and often perfect) migration, which biases impact estimates;
- the net result of changing disturbance regimes (especially through fire, insects and land-use change) on biotic feedbacks to the atmosphere, ecosystem structure, function and biodiversity;
- the magnitude of the CO_2-fertilisation effect in the terrestrial biosphere and its components over time;
- the limitations of climate envelope models used to project responses of individual species to climate changes, and for deriving estimations of species extinction risks (see below);
- the synergistic role of invasive alien species in both biodiversity and ecosystem functioning;
- the effect of increasing surface ocean CO_2 and declining pH on marine productivity, biodiversity, biogeochemistry and ecosystem functioning; and
- the impacts of interactions between climate change and changes in human use and management of ecosystems as well as other drivers of global environmental change in ecosystems including more realistic estimates of lagged and threshold responses.

The complexity of ecosystems may often lead to non-linear responses that introduce uncertainty

Short-term responses within ecosystems and among species may considerably differ, and may even be the opposite of longer term responses. Ecological changes are likely to not be gradual, but stepwise, and changes may take place in the form of sudden shifts, whose timing and location is largely unpredictable. Non-linear responses include tipping points and thresholds beyond which adaptation may no longer be possible. Sudden shifts may occur as a result of the outbreaks of pests or the decrease of recovery time between extreme events.

The difficulty in predicting thresholds makes the management of biodiversity and the diversity of ecosystems an important safeguard. Landscape-scale ecosystem heterogeneity may – to some extent – buffer against moderate changes in climate. In particular, the diversity of species and interactions amongst them, as well as landscape-scale habitat heterogeneity may provide a range of natural adaptive capacity in the face of a certain level of change.

Information on extreme event impacts is difficult to gather since these occur rarely and unpredictably. A further difficulty is that climate change scenarios are limited in ability to represent their changing frequency**.** Widespread and long-duration extreme events may induce a range of damaging impacts on ecosystems and biodiversity (e.g., as observed following the 2003 European heatwave).

Investment in key areas that require scientific development would reduce uncertainty in assessments of the impacts of climate change on biodiversity and related impacts on human society

More emphasis on deriving a credible range of precipitation projections and resulting water regime effects is needed. These should emphasise interactions between vegetation and atmosphere, including CO_2-fertilisation effects, in mature forests in the Northern Hemisphere, seasonal tropical forests, and arid or semi-arid grassland and savannas.

Improved understanding of the role of disturbance regimes is needed. This includes frequency and intensity of episodic events (drought, fire, insect outbreaks, diseases, floods and wind-storms) and that of species invasions, as they interact with ecosystem responses to climate change.

Improvements in the integration of feedback mechanisms are needed in order to address differences between modelled changes and observed impacts. Such an approach could include studies on impacts of rising atmospheric CO_2 on ocean acidification, and warming on coral reefs and other marine systems, and widening the range of terrestrial ecosystems for which CO_2-fertilisation responses have been quantified.

It is important to develop a much clearer understanding of the linkages between biodiversity impacts due to climate change and their implications for human society. Significant advances have been made recently in quantifying the value of ecosystems and their biodiversity, but these are not yet widely incorporated into climate change impact assessment approaches. One of the most effective approaches has been to integrate climate change impacts on ecosystems and biodiversity in terms of the related changes in various ecosystem services.

GUIDANCE ON THE APPLICATION OF ASSESSMENT TOOLS AND METHODOLOGIES RELATED TO THE IMPACTS OF CLIMATE CHANGE ON BIODIVERSITY AT A RANGE OF SCALES

Assessments of impacts of climate change on biodiversity using currently available tools is dependent on the integration of data on the distribution of species with spatially explicit climate data for a range of climate change scenarios

Despite their limitations, the use of bioclimatic modelling techniques allows a useful, and often accurate first cut assessment of spatial distribution of exposure and vulnerability in relation to conservation efforts. Where expert knowledge on species demography is available, techniques can be applied that include consideration of climate variability and require species abundance data, but this places a higher demand on the spatial and temporal resolution of future climate data. While the use of spatially downscaled future scenario data is ideal if achievable, for robust risk and impacts assessments it may be more useful to focus on a range of future climate scenarios even if they are not downscaled, and not only on a mean or median future scenario.

Good Practice Standards and Guidelines for bioclimatic models, associating observed changes with climate, and assessing vulnerability should be developed. This could include information on how to best use the climate data, report on the results and uncertainties and perform the associations and attributions of the event with climate change. Ideally, these guidelines should be developed through an international body such as IPCC.

Observed changes and climate variability can potentially be used to assess the sensitivity of bioclimatic models. There have been a number of reviews examining how species ranges and the timing of events (e.g., arrival dates, egg laying) have been observed to be consistent with regional climate changes. These changes have occurred with a relatively small amount of global temperature change. While the number of conjoined studies (examining observed changes linked to bioclimatic models) is still small, observed changes can be used to help assess the sensitivity of some bioclimatic models – are the changes observed in the direction projected by the bioclimatic models? Other ways of assessing whether species' ranges are associated with climate, and thus would potentially move with climate changes, is whether a species' range changes in association with climate variability.

Climate change impact assessments should optimally be integrated with assessments of other stresses on ecosystems such as current and future land-use change, and changes in disturbance where applicable. The direct effects of land use and land-use change may overwhelm climate change effects on biodiversity in the short to medium term. Alternative modelling approaches that simulate changes in ecosystem structure and biome type may be more mechanistically robust in simulating, for example disturbance regimes such as fire, and should be used where possible to provide alternative or complementary insights into species and ecosystem vulnerability.

Readily available, easy to use, multiple impact stressor tools are needed. There are many different tools available to project the potential impacts of climate change on biodiversity. However, these tools are hampered in many areas and for many species by the lack of availability of distribution data. Additionally, these efforts are often undertaken in isolation from other efforts and often only look at one, or a few, climate change scenarios for only one or a few different GCMs. Efforts are now underway to link emission scenarios, multiple GCMs, and multiple species bioclimatic tools to better enable the research community to not only look at impacts using a much broader range of emission scenarios using more GCMs, but to do so in a probabilistic fashion. This will provide better estimates of uncertainty and make it easier for researchers to reanalyze their results once new emission scenarios or new climate change models become available. These same modelling tools are also being used to link the same climate and emissions data with hydrological and sea-level rise models and it is possible that, in the near future, all could be examined simultaneously.

Tools for assessing the vulnerability of species and ecosystems to climate change are available. Models are not the only way of assessing the vulnerability of species and ecosystems to climate change. Expert based systems, coupled with data where available, can be used to assess the potential vulnerability of both species and ecosystems. Some of these techniques also examine other human impacts on species and ecosystems and allows a comparison of the relative contribution of climate change versus other drivers over time.

Currently, remote sensing provides the only viable way to monitor changes at a global scale, which has serious limitations on developing a globally integrated picture of species level responses. Field monitoring efforts could be productively strengthened, harmonised and organised into a global network, especially to include the coverage of areas not studied so far. In monitoring efforts, special attention should be paid to the impacts of extreme events because they may serve as an early warning of future vulnerability.

The establishment of multi-purpose monitoring programs which include the impacts of climate change on biodiversity would be beneficial in maximizing the use of limited resources. A monitoring programme that integrates biodiversity status, within a framework that includes threat status monitoring and the recording the effectiveness of adaptation measures is also recommended.

Experimental studies on multiple pressures in various ecosystems are needed to better define causal relationships

The experimental approach can be used to establish causality and define both the nature and magnitude of cause and effect relationships. This makes this approach very valuable despite its limitations arising mainly from the limited size of experimental plots. Experiments have already been used to assess the effects of increased temperature, altered precipitation regime and increased CO_2 level on population biology, species composition, phenology and biogeochemistry in various, mostly low-stature ecosystems. More studies are needed on the combined effects of multiple pressures including temperature, precipitation, CO_2, land-use, invasive species and nitrogen deposition. Finally, broader geographic coverage is necessary to draw globally relevant conclusions, as much of this work has been conducted in temperate, northern Hemisphere ecosystems.

Observations from indigenous and local communities form an important component of impact assessments as long as they are conducted with prior informed consent and with the full participation of indigenous and local communities

Indigenous peoples and local communities are holders of relevant traditional knowledge, innovations and practices, as their livelihoods depend on ecosystems that are directly affected by climate change. This knowledge is normally of a practical nature, and covers areas such as traditional livelihoods, health, medicine, plants, animals, weather conditions, environment and climate conditions, and environmental management as the basis of indigenous wellbeing. This knowledge is based on experience based on life-long observations, traditions and interactions with nature. However, further research is needed into impact assessments that involve indigenous peoples and local communities. This will substantially enhance the understanding of local and regional impacts of climate change.

The potential impacts of climate change on biodiversity and related livelihoods and cultures of indigenous peoples and local communities remains poorly known. Furthermore, such impacts are rarely considered in academic, policy and public discourse. In particular, climate models are not well suited to providing information about changes at the local level. Even when observations are included at the species level, there is little research on, for example, impacts on traditional management systems as an important strategy to cope with change. Accordingly it is suggested that further efforts are made to ensure that traditional knowledge, innovations and practices are respected, properly interpreted and used appropriately in impact assessments through contextually relevant practices in data collection and sharing, development of indicators, assessment validation and feedback, and applications.

Tools and methodologies for monitoring the impacts of climate change on biodiversity in partnership with indigenous and local communities can benefit from a range of practices. These include utilising the results of community-based monitoring linked to decision-making, especially because indigenous communities are able to provide data and monitoring information at a system rather than individual species level.

(a) Promote documentation and validation of traditional knowledge, innovations and practices are limited. Most knowledge is not documented and has not been comprehensively studied and assessed. Therefore there is need to enhance links between traditional knowledge and scientific practices.

(b) Revitalize traditional knowledge, innovations and practices on climate change impacts on traditional biodiversity based resources and ecosystem services through education and awareness raising, including in nomadic schools.

(c) Explore uses of and opportunities for community-based monitoring linked to decision-making, recognizing that indigenous peoples and local communities are able to provide data and monitoring on a whole system rather than single sectors based on the full and effective participation of indigenous and local communities.