10th Meeting of the Conference of the Parties to the Convention on Wetlands (Ramsar, Iran, 1971)

"Healthy wetlands, healthy people"

Changwon, Republic of Korea,
28 October-4 November 2008

Ramsar COP10 DOC. 25

Additional information on climate change and wetlands issues

(see COP10 DR 24 "Climate change and wetlands")

Background

1. This information paper, prepared by the Scientific & Technical Review Panel (STRP) to provide supporting information for the consideration of COP10 DR 24 on "Climate change and wetlands" provides a digest and summary of recent work undertaken by the STRP concerning a range of issues relevant to addressing wetlands and climate interactions.

2. During the 2006-2008 triennium, the STRP recognised the need to pay further attention to climate change and wetlands issues in the light of much new information and activity since the preparation of its earlier review report on wetlands and climate change provided to COP8 (2002) as an Information Paper (COP8 DOC.11, available at www.ramsar.org/ cop8/cop8_doc_11_e.htm).

3. Since COP8 there have been a range of significant developments in the understanding of climate change impacts and the roles of wetlands in climate mitigation and adaptation, including through the recent UNFCCC Bali Conference, the Intergovernmental Panel on Climate Change (IPCC)'s 4th Assessment Report, and more specific issues of the role of wetlands in climate change such as new research on the important role of peatlands, especially in Southeast Asia. Nevertheless, there still appears to be a general lack of significant attention to wetlands in the climate debates.

4. Accordingly the Panel established an additional thematic work area on climate change and wetlands, led by STRP Chair Heather MacKay, and identified a number of immediate tasks to undertake to provide further background and understanding of current issues and opportunities in relation to the role of wetlands in climate change mitigation and adaptation.

5. Immediately prior to the STRP's mid-term workshops in March 2007, the STRP and the Secretariats of Ramsar and the CBD held a joint expert workshop on "Wetlands, water, biodiversity and climate change" to review current knowledge and issues and identify future priorities for attention. The draft report of this workshop was launched jointly by the CBD Executive Secretary and Ramsar Secretary General on the occasion of World Biodiversity Day in June 2007, and it is available at www.biodiv.org/doc/case-

studies/wtr/cs-wtr-ramsar-en.pdf. The executive summary of this meeting report is provided below. The expert meeting stressed the need for better communication and public awareness on wetlands, water and climate change.

6. This Information Paper provides further information on the results of STRP's recent and ongoing work on climate change and wetlands. The information provided below is as follows:

    A. Decisions, recommendations and key issues relevant to climate change, wetlands and the Ramsar Convention from some other recent global processes;

    B. The Executive Summary of the report of the March 2007 joint CBD-Ramsar technical workshop on "Wetlands, water, biodiversity and climate change";

    C. The Executive Summary of a review report on "The role of wetlands in the global carbon cycle", being prepared for STRP by invited expert Colin Lloyd and to be published as a *Ramsar Technical Report* – work commissioned by the STRP in recognition that there is a dearth of consolidated information on the role and importance of different types of wetlands and in different parts of the world in carbon sequestration and storage;

    D. The draft Executive Summary of a *Ramsar Technical Report* on "Wetland vulnerability assessment", prepared for the STRP by Habiba Gitay and Max Finlayson.

    E. The Summary of a report on methodologies for assessing the hydrological vulnerability of different wetland types to climate change scenarios, prepared for STRP by Mike Acreman and colleagues at UK Centre for Ecology & Hydrology and to be published as a *Ramsar Technical Report*; and

    F. A review paper on "Climate change and wetland restoration", prepared initially as a discussion paper for STRP by invited expert Kevin Erwin, and now being published in a special issue of the journal *Wetlands Ecology and Management*.

7. The STRP intends that these various reports summarised below will together form a sound basis for the further priority attention it is proposing to give to wetland mitigation and adaptation in relation to climate change in the 2009-2012 period of its next work plan (see COP10 DR 10), which will include follow-up on various aspects of the initial work undertaken and reported below.

8. Specifically, the future work proposed on climate change and wetlands in COP10 DR 10 Annex 2 is as follows (note that these proposed tasks are subject to change dependent on the final text adopted at COP10 of COP10 DR 24 "Climate change and wetlands"):

    6.1 Wetlands and climate change – further review and guidance. Develop guidance, working with the IPCC and others, on the latest knowledge of the current and potential impacts of climate change on wetlands and on appropriate policy and management responses for addressing these impacts, including *inter alia*:

i) building on initial work done in the 2006-2008 triennium, further development of methods for assessment of hydro-ecological impacts of climate change on wetlands, including the testing of such methods in data-poor areas;
ii) a review of wetland distribution in relation to land use and population distribution trends, in order to demonstrate potential effects on human health if wetlands are lost due to climate change impacts;
iii) guidance on how wetland management and restoration can contribute to improving adaptation to climate change (linking as appropriate with the other tasks on wetland restoration and rehabilitation defined separately elsewhere in the present Annex).

(STRP 14, [COP10 DR 24 on Climate change and wetlands])

HIGH PRIORITY

6.2 Climate change and wetlands mitigation and adaptation – collaborative activities. In conjunction with the Ramsar Secretariat, develop a leading role with relevant international conventions and agencies, including UNFCCC, CBD, UNCCD, IPCC, UNEP, UNDP, FAO and World Bank, in the development of a coordinated programme of work to investigate the potential contribution of wetland ecosystems to climate change mitigation and adaptation, in particular for reducing vulnerability and increasing resilience to climate change, and in addition:

i) establish ways and means of working with the UNFCCC and other relevant bodies to develop guidance for the development of mutually supportive adaptation and mitigation programmes that recognize the critical role of wetlands in relation to water and food security as well as human health;
ii) bring wetlands and climate change issues to the attention of the Chairs of the Scientific Advisory Bodies of the Biodiversity-related Conventions (CSAB) at the next available opportunity, and use this forum to encourage enhanced scientific collaboration on issues related to climate change;
iii) establish ways of collaborating with the IPCC and contributing to its future work in order to raise the awareness of the climate change community regarding the importance of wetlands, including through the preparation and publication of relevant scientific reports on wetlands and climate change.

(STRP 14, [COP10 DR 24 on Climate change and wetlands])

HIGH PRIORITY

A. Recent decisions, recommendations and key issues relevant to climate change, wetlands and the Ramsar Convention from other global processes

Decisions of the 9th meeting of the Conference of the Parties to the Convention on Biological Diversity (CBD COP9, Bonn, May 2008). Available on: http://www.cbd.int/decisions/?m=cop-09

9. Extract from CBD COP9 Decision IX/16 “Biodiversity and Climate Change: options for mutually supportive actions addressing climate change within the three Rio Conventions”:

D. Summary of the findings of the global Assessment on Peatlands, Biodiversity and Climate Change

1. *Recognizes* the importance of the conservation and sustainable use of the biodiversity of wetlands and, in particular, peatlands in addressing climate change and *noting with appreciation* the findings of the global Assessment on Peatlands, Biodiversity and Climate Change;

2. *Invites* the Global Environment Centre, subject to available resources, to translate into other United Nations languages, and further disseminate the global Assessment on Peatlands, Biodiversity and Climate Change;

3. *Encourages* Parties and other Governments to strengthen collaboration with the Ramsar Convention on Wetlands and promote the participation of interested organizations in the implementation of the Guidelines for Global Action on Peatlands and other actions, such as the ones listed in the global Assessment of Peatlands, Biodiversity and Climate Change, that could contribute to the conservation and sustainable use of peatlands;

4. *Welcomes* the initiative of the Scientific and Technical Review Panel of the Ramsar Convention to consider wetlands and climate change as an important emerging issue, *invite*s the Secretariat and the Scientific and Technical Review Panel of the Ramsar Convention, subject to available resources, to further assess the contribution of biodiversity to climate-change mitigation and adaptation in peatlands and other wetlands and *further invites* the Secretariat and the Scientific and Technical Review Panel of the Ramsar Convention to make the reports on these assessments available, for example through its website;

5. *Requests* the Subsidiary Body on Scientific, Technical and Technological Advice to explore ways to engage with the Intergovernmental Panel on Climate Change in planning and preparing its next assessment reports and *invites* the Intergovernmental Panel on Climate Change to participate in the Convention on Biological Diversity and Ramsar processes of preparing future technical studies on climate change and biodiversity, particularly on wetlands;

6. *Requests* the Executive Secretary, in collaboration with the Secretariat of the Ramsar Convention, and subject to available resources, to conduct an analysis of the potential of incentive measures and funding mechanisms under climate-change adaptation and mitigation in supporting biodiversity conservation and sustainable use in wetlands as well as in supporting local livelihoods and contributing to poverty eradication and *further requests* the Executive Secretary to explore ways to engage with those national and international research centres (e.g. CGIAR centres) addressing climate-change adaptation and mitigation in relation to wetlands biodiversity; and

7. *Invites* the Conference of the Parties to the Ramsar Convention, at its tenth meeting, to consider appropriate action in relation to wetlands, water, biodiversity and climate change in view of the importance of this subject for the conservation and sustainable use of biodiversity and human welfare.

10. Extract from CBD COP9 Decision IX/19 "Biological diversity of inland water ecosystems":

7. *Recognizing* the vulnerability of inland water ecosystems to climate change, and the consequent need to improve their management, *welcomes* the ongoing and planned work of the Ramsar Convention on wetlands and climate change and *invites* the Conference of the Parties to the Ramsar Convention, at its tenth meeting, to consider appropriate action in relation to wetlands, water, biodiversity and climate change to further improve synergy and collaboration between the Ramsar Convention and the Convention on Biological Diversity in their work on climate change.

"Biodiversity-climate interactions: adaptation, mitigation and human livelihoods". Report of an international meeting, June 2007. Pp.49. ISBN 978 0 85403 676 9. London, The Royal Society. 2008. Available at http://royalsociety.org/displaypagedoc.asp?id=29026.

11. **Extracts from "Conclusions and Recommendations"** [Note. Only sections of the conclusions and recommendations speaking directly to wetlands and/or Ramsar are provided here. Other texts in the Conclusions and Recommendations speak more broadly to biodiversity and ecosystems and could be considered inclusive of wetlands.]

Reducing emissions from deforestation clearly must play an important role in any global framework to address climate change. However, other ecosystems also provide important climate regulatory roles. The biodiversity, climate and development research communities must collaborate to identify where opportunities exist to take advantage of the climate regulatory services already being provided by ecosystems, while at the same time contributing to improving human livelihoods and meeting biodiversity goals. Peatlands and other wetlands are obvious other contenders for integration into a post-2012 framework. Their potential should be actively investigated and assessed against sustainability criteria. The UNFCCC in collaboration with the CBD, UNCCD, **Ramsar**, UNEP and the UNDP should, in the meantime, identify and report examples of cases where these win–win–wins are already being realised. [Editorial note: the emboldening of "Ramsar" is as in the published report]

Recommendation 3: Under the auspices of the UNFCCC, a programme of work should be coordinated jointly by the CBD, UNCCD, Ramsar, IPCC, UNEP, UNDP, and the World Bank, to investigate the potential contribution of other ecosystems [than forests] to climate change. This should explicitly consider the contribution of non-forest ecosystems, in addition to forest systems, to reducing vulnerability and increasing resilience to climate change. Current examples should be gathered and reported to the UNFCCC.

Recommendation 4: The UNFCCC should develop guidance for the development of mutually supportive adaptation and mitigation programmes, and sustainability criteria against which such programmes should be assessed.

Policy-makers at the international, regional, national and local levels should be encouraged to develop and implement new mechanisms for achieving adaptation and mitigation benefits at the same time. Where these mechanisms already exist and have been implemented, particularly at the local level, exchange of best practice should be facilitated and the results communicated to the UNFCCC and CBD.

Recommendation 5: The IPCC, in collaboration with the CBD, UNCCD, Ramsar and UNDP, should develop a decision-making framework, as suggested in Figure 3, to enable the assessment of appropriate land-use priorities for ecosystems (landscapes or communities), with the objective of identifying potential for delivery of co-benefits, and the transparent assessment of trade-offs.

Despite the efforts of the CBD, UNFCCC, UNCCD, Ramsar, CMS and WHC to improve integration on biodiversity and climate change at the international level, further collaboration, particularly with the international development community, is essential for capacity building, resourcing and implementation of Convention work programmes (particularly at the national level), technology transfer, and communication, financing, and research and monitoring.

Climate Change and Water. Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof (Eds.) 2008. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp.

12. This recent (June 2008) Technical Paper was requested by the Intergovernmental Panel on Climate Change (IPCC) Plenary in response to suggestions by the World Climate Programme - Water, the Dialogue on Water and other organisations concerned with the provision of water. It was prepared under the auspices of the IPCC Chair, Dr. R.K. Pachauri. The full report is downloadable from: http://www.ipcc.ch/ipccreports/tp-climate-change-water.htm.

13. The report contains much of high relevance to the future implementation of the Ramsar Convention and a number of the draft Resolutions being considered for adoption at COP10, not only directly concerning wetland ecosystems and climate change, but also on water resource and river basin management, agriculture, human health and the energy sectors.

14. Extracts of the report which are particularly relevant to understanding of the issues for wetlands of climate change and water are provided here: Executive Summary, and extracts concerning wetlands from Chapters 4 (Climate change and water resources in systems and sectors) and 8 (Gaps in knowledge and suggestions for further work).

Executive Summary

Observational records and climate projections provide abundant evidence that freshwater resources are vulnerable and have the potential to be strongly impacted by climate change, with wide-ranging consequences for human societies and ecosystems.

Observed warming over several decades has been linked to changes in the large-scale hydrological cycle such as: increasing atmospheric water vapour content; changing precipitation patterns, intensity and extremes; reduced snow cover and widespread melting of ice; and changes in soil moisture and runoff. Precipitation changes show substantial spatial and inter-decadal variability. Over the 20th century, precipitation has mostly increased over land in high northern latitudes, while decreases have dominated from 10°S to 30°N since the 1970s. The frequency of heavy precipitation events (or proportion of total rainfall from heavy falls) has increased over most areas (*likely*[1]). Globally, the area of land classified as very dry has more than doubled since the 1970s (*likely*). There have been significant decreases in water storage in mountain glaciers and Northern Hemisphere snow cover. Shifts in the amplitude and timing of runoff in glacier- and snowmelt-fed rivers, and in ice-related phenomena in rivers and lakes, have been observed (*high confidence*). [2.1[2]]

Climate model simulations for the 21st century are consistent in projecting precipitation increases in high latitudes (*very likely*) and parts of the tropics, and decreases in some subtropical and lower mid-latitude regions (*likely*). Outside these areas, the sign and magnitude of projected changes varies between models, leading to substantial uncertainty in precipitation projections.[3] Thus projections of future precipitation changes are more robust for some regions than for others. Projections become less consistent between models as spatial scales decrease. [2.3.1]

By the middle of the 21st century, annual average river runoff and water availability are projected to increase as a result of climate change[4] at high latitudes and in some wet tropical areas, and decrease over some dry regions at mid-latitudes and in the dry tropics.[5] Many semi-arid and arid areas (e.g., the Mediterranean Basin, western USA, southern Africa and northeastern Brazil) are particularly exposed to the impacts of climate change and are projected to suffer a decrease of water resources due to climate change (*high confidence*). [2.3.6]

Increased precipitation intensity and variability are projected to increase the risks of flooding and drought in many areas. The frequency of heavy precipitation events (or proportion of total rainfall from heavy falls) will be *very likely* to increase over most areas during the 21st century, with consequences for the risk of rain-generated floods. At the same time, the proportion of land surface in extreme drought at any one time is projected to increase (*likely*), in addition to a tendency for drying in continental interiors during summer, especially in the sub-tropics, low and mid-latitudes. [2.3.1, 3.2.1]

Water supplies stored in glaciers and snow cover are projected to decline in the course of the century, thus reducing water availability during warm and dry periods (through a seasonal shift in streamflow, an increase in the ratio of winter to annual flows, and reductions in low flows) in regions supplied by melt water from major mountain ranges, where more than one-sixth of the world's population currently live (*high confidence*). [2.1.2, 2.3.2, 2.3.6]

Higher water temperatures and changes in extremes, including floods and droughts, are projected to affect water quality and exacerbate many forms of water pollution – from sediments, nutrients, dissolved organic carbon, pathogens, pesticides and salt, as well as thermal pollution, with possible negative impacts on ecosystems, human health, and water system reliability and operating costs (*high confidence*). In addition, sea-level rise is projected to extend areas of salinisation of groundwater and estuaries, resulting in a decrease of freshwater availability for humans and ecosystems in coastal areas. [3.2.1.4, 4.4.3]

Globally, the negative impacts of future climate change on freshwater systems are expected to outweigh the benefits (*high confidence*). By the 2050s, the area of land subject to increasing water stress due to climate change is projected to be more than double that with decreasing water stress. Areas in which runoff is projected to decline face a clear reduction in the value of the services provided by water resources. Increased annual runoff in some areas is projected to lead to increased total water supply. However, in many regions, this benefit is likely to be counterbalanced by the negative effects of increased precipitation variability and seasonal runoff shifts in water supply, water quality and flood risks (*high confidence*). [3.2.5]

Changes in water quantity and quality due to climate change are expected to affect food vailability, stability, access and utilisation. This is expected to lead to decreased food security and increased vulnerability of poor rural farmers, especially in the arid and semi-arid tropics and Asian and African megadeltas. [4.2]

Climate change affects the function and operation of existing water infrastructure – including hydropower, structural flood defences, drainage and irrigation systems – as well as water management practices. Adverse effects of climate change on freshwater systems aggravate the impacts of other stresses, such as population growth, changing economic activity, land-use change and urbanisation (*very high confidence*). Globally, water demand will grow in the coming decades, primarily due to population growth and increasing affluence; regionally, large changes in irrigation water demand as a result of climate change are expected (*high confidence*). [1.3, 4.4, 4.5, 4.6]

Current water management practices may not be robust enough to cope with the impacts of climate change on water supply reliability, flood risk, health, agriculture, energy and aquatic ecosystems. In many locations, water management cannot satisfactorily cope even with current climate variability, so that large flood and drought damages occur. As a first step, improved incorporation of information about current climate variability into water-related management would assist adaptation to longer-term climate change impacts. Climatic and non-climatic factors, such as growth of population and damage potential, would exacerbate problems in the future (*very high confidence*). [3.3]

Climate change challenges the traditional assumption that past hydrological experience provides a good guide to future conditions. The consequences of climate change may alter the reliability of current water management systems and water-related infrastructure. While quantitative projections of changes in precipitation, river flows and water levels at the river-basin scale are uncertain, it is *very likely* that hydrological characteristics will change in the future. Adaptation procedures and risk management practices that incorporate projected hydrological changes with related uncertainties are being developed in some countries and regions. [3.3]

Adaptation options designed to ensure water supply during average and drought conditions require integrated demand-side as well as supply-side strategies. The former improve water-use efficiency, e.g., by recycling water. An expanded use of economic incentives, including metering and pricing, to encourage water conservation and development of water markets and implementation of virtual water trade, holds considerable promise for water savings and the reallocation of water to highly valued uses. Supply-side strategies generally involve increases in storage capacity, abstraction from water courses, and water transfers. Integrated water resources management provides an important framework to achieve adaptation measures across socio-economic, environmental and administrative systems. To be effective, integrated approaches must occur at the appropriate scales. [3.3]

Mitigation measures can reduce the magnitude of impacts of global warming on water resources, in turn reducing adaptation needs. However, they can have considerable negative side effects, such as increased water requirements for afforestation/reforestation activities or bio-energy crops, if projects are not sustainably located, designed and managed. On the other hand, water management policy measures, e.g., hydrodams, can influence greenhouse gas emissions. Hydrodams are a source of renewable energy. Nevertheless, they produce greenhouse gas emissions themselves. The magnitude of these emissions depends on specific circumstance and mode of operation. [Section 6]

Water resources management clearly impacts on many other policy areas, e.g., energy, health, food security and nature conservation. Thus, the appraisal of adaptation and mitigation options needs to be conducted across multiple water-dependent sectors. Low-income countries and regions are *likely* to remain vulnerable over the medium term, with fewer options than high income countries for adapting to climate change. Therefore, adaptation strategies should be designed in the context of development, environment and health policies. [Section 7]

Several gaps in knowledge exist in terms of observations and research needs related to climate change and water. Observational data and data access are prerequisites for adaptive management, yet many observational networks are shrinking. There is a need to improve understanding and modelling of climate changes related to the hydrological cycle at scales relevant to decision making. Information about the water related impacts of climate change is inadequate – especially with respect to water quality, aquatic ecosystems and groundwater – including their socio-economic dimensions. Finally, current tools to facilitate integrated appraisals of adaptation and mitigation options across multiple water-dependent sectors are inadequate. [Section 8]

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[1] See Box 1.1.

[2] Numbers inside square brackets relate to sections in the main body of the Technical Paper.

[3] Projections considered are based on the range of non-mitigation scenarios developed by the IPCC Special Report on Emissions Scenarios (SRES).

[4] This statement excludes changes in non-climatic factors, such as irrigation.

[5] These projections are based on an ensemble of climate models using the mid-range SRES A1B non-mitigation emissions scenario. Consideration of the range of climate responses across SRES scenarios in the mid-21st century suggests that this conclusion is applicable across a wider range of scenarios.

Box 1.1: Uncertainties in current knowledge: their treatment in the Technical Paper [SYR]

The IPCC Uncertainty Guidance Note[9] defines a framework for the treatment of uncertainties across all Working Groups and in this Technical Paper. This framework is broad because the Working Groups assess material from different disciplines and cover a diversity of approaches to the treatment of uncertainty drawn from the literature. The nature of data, indicators and analyses used in the natural sciences is generally different from that used in assessing technology development or in the social sciences. WGI focuses on the former, WGIII on the latter, and WGII covers aspects of both.

Three different approaches are used to describe uncertainties, each with a distinct form of language. Choices among and within these three approaches depend on both the nature of the information available and the authors' expert judgement of the correctness and completeness of current scientific understanding.

Where uncertainty is assessed qualitatively, it is characterised by providing a relative sense of the amount and quality of evidence (that is, information from theory, observations or models, indicating whether a belief or proposition is true or valid) and the degree of agreement (that is, the level of concurrence in the literature on a particular finding). This approach is used by WGIII through a series of self-explanatory terms such as: *high agreement, much evidence*; *high agreement, medium evidence*; *medium agreement, medium evidence*; etc.

Where uncertainty is assessed more quantitatively using expert judgement of the correctness of the underlying data, models or analyses, then the following scale of confidence levels is used to express the assessed chance of a finding being correct: *very high confidence* at least 9 out of 10; *high confidence* about 8 out of 10; *medium confidence* about 5 out of 10; *low confidence* about 2 out of 10; and *very low confidence* less than 1 out of 10.

Where uncertainty in specific outcomes is assessed using expert judgement and statistical analysis of a body of evidence (e.g., observations or model results), then the following likelihood ranges are used to express the assessed probability of occurrence: *virtually certain* >99%; *extremely likely* >95%; *very likely* >90%; *likely* >66%; *more likely than not* >50%; *about as likely as not* 33% to 66%; *unlikely* <33%; *very unlikely* <10%; *extremely unlikely* <5%; *exceptionally unlikely* <1%.

WGII has used a combination of confidence and likelihood assessments, and WGI has predominantly used likelihood assessments.

This Technical Paper follows the uncertainty assessment of the underlying Working Groups. Where synthesised findings are based on information from more than one Working Group, the description of uncertainty used is consistent with that for the components drawn from the respective Reports.

[9] See http://www.ipcc.ch/meetings/ar4-workshops-express-meetings/uncertainty-guidance-note.pdf.

4. Climate change and water resources in systems and sectors [extract only]

4.1.1 Context

Temperature and moisture regimes are among the key variables that determine the distribution, growth and productivity, and reproduction of plants and animals.

Changes in hydrology can influence species in a variety of ways, but the most completely understood processes are those that link moisture availability with intrinsic thresholds that govern metabolic and reproductive processes (Burkett et al., 2005). The changes in climate that are anticipated in the coming decades will have diverse effects on moisture availability, ranging from alterations in the timing and volume of streamflow to the lowering of water levels in many wetlands, the expansion of thermokarst lakes in the Arctic, and a decline in mist water availability in tropical mountain forests.

Observed global trends in precipitation, humidity, drought and runoff over the last century are summarised in WGI AR4 Chapter 3. Although changes in precipitation during the last century indicate considerable regional variation [WGI Figure 3.14], they also reveal some important and highly significant trends. Precipitation increased generally in the Northern Hemisphere from 1900 to 2005, but the tendency towards more widespread drought increased concomitantly for many large regions of the tropics and the Southern Hemisphere, notably the African Sahel and southern Africa, Central America, south Asia and eastern Australia. [WGI 3.3.5]

4.1.2 Projected changes in hydrology and implications for global biodiversity

The IPCC Fourth Assessment Report estimates of global warming vary in range from 0.5°C in the Southern Hemisphere to 2°C in the northern polar region by 2030 for SRES scenarios B1, A1 and A2, with B1 showing the highest warming. While the models simulate global mean precipitation increases, there is substantial spatial and temporal variation. General circulation models (GCMs) project an increase in precipitation at high latitudes, although the amount of that increase varies between models, and decreases in precipitation over many sub-tropical and mid-latitude areas in both hemispheres. [WGI Figures 10.8 and 10.12] Precipitation during the coming decades is projected to be more concentrated into more intense events, with longer periods of little precipitation in between. [WGI 10.3.6.1] The increase in the number of consecutive dry days is projected to be most significant in North and Central America, the Caribbean, north-eastern and south-western South America, southern Europe and the Mediterranean, southern Africa and western Australia. [WGI Figure 10.18] Impacts of warming and changes in precipitation patterns in tropical and sub-tropical regions have important implications for global biodiversity, because species diversity generally decreases with distance away from the Equator.

The changes in hydrology that are projected by WGI AR4 for the 21st century (see Section 2) will be *very likely* to impact biodiversity on every continent. Impacts on species have already been detected in most regions of the world. [WGII 1.3, 4.2] A review of 143 published studies by Root et al. (2003) indicates that animals and plants are already showing discernible changes consistent with the climatic trends of the 20th century. Approximately 80% of the changes were consistent with observed temperature change, but it should be recognised that temperature can also exert its influence on species through changes in moisture availability. [WGII 1.4.1]

Ecosystem responses to changes in hydrology often involve complex interactions of biotic and abiotic processes. The assemblages of species in ecological communities reflect the fact that these interactions and responses are often non-linear, which increases the difficulty of projecting specific ecological outcomes. Since the timing of responses is not always synchronous in species from different taxonomic groups, there may be a decoupling of species from their food sources, a disruption of symbiotic or facilitative relationships between species, and changes in competition between species. Owing to a combination of differential responses between species and interactions that could theoretically occur at any point in a food web, some of the ecological communities existing today could easily be disaggregated in the future (Root and Schneider, 2002; Burkett et al., 2005). [WGII 1.3.5.5, 4.2.2, 4.4]

Due to the combined effects of temperature and water stress, the extinction of some amphibians and other aquatic species is projected in Costa Rica, Spain and Australia (Pounds et al., 2006). [WGII Table 4.1] Drying of wetlands in the Sahel will affect the migration success of birds that use the Sahelian wetlands as stopovers in their migration to Northern Hemisphere breeding sites. In southern Africa, unprecedented levels of extinctions in both plant and animal species are envisaged. [WGII Table 9.1] In montane forests, many species depend on mist as their source of water: global warming will raise the cloud base and affect those species dependent on this resource. [WGII 13.4.1]

Of all ecosystems, however, freshwater aquatic ecosystems appear to have the highest proportion of species threatened with extinction by climate change (Millennium Ecosystem Assessment, 2005b). [WGII 3.5.1]

4.1.3 Impacts of changes in hydrology on major ecosystem types

4.1.3.1 Lakes and streams

Impacts of global warming on lakes include an extended growing period at high latitudes, intensified stratification and nutrient loss from surface waters, decreased hypolimnetic oxygen (below the thermocline) in deep, stratified lakes, and expansion in range for many invasive aquatic weeds. Water levels are expected to increase in lakes at high latitudes, where climate models indicate increased precipitation, while water levels at mid- and low latitudes are projected to decline. Endorheic (terminal or closed) lakes are most vulnerable to a change in climate because of their sensitivity to changes in the balance of inflows and evaporation. Changes in inflows to such lakes can have very substantial effects and, under some climatic conditions, they may disappear entirely. The Aral Sea, for example, has been significantly reduced by increased abstractions of irrigation water upstream; and Qinghai Lake in China has shrunk following a fall in catchment precipitation. [WGII TAR 4.3.7]

The duration of ice cover in lakes and rivers at mid- to high latitudes has decreased by approximately two weeks during the past century in the Northern Hemisphere. [WGI TAR SPM] Increases in summer water temperature can increase anoxia in stratified lakes, increase the rate of phosphorus releases from lake-bottom sediments, and cause algal blooms that restructure the aquatic food web. [WGII 4.4.8] A unit increase in temperature in tropical lakes causes a proportionately higher density differential as compared with colder temperate lakes. Thus, projected tropical temperatures [WGI Chapters 10 and 11] will lead to strong thermal stratification, causing anoxia in deep layers of lakes and nutrient depletion in shallow lake waters. Reduced oxygen concentrations will generally reduce aquatic species diversity, especially in cases where water quality is impaired by eutrophication. [CCB 4.4]

Reduced oxygen concentrations tend to alter biotic assemblages, biogeochemistry and the overall productivity of lakes and streams. The thermal optima for many mid- to high-latitude cold-water taxa are lower than 20°C. Species extinctions are expected when warm summer temperatures and anoxia eliminate deep cold-water refugia. In the southern Great Plains of the USA, water temperatures are already approaching lethal limits for many native stream fish. Organic matter decomposition rates increase with temperature, thereby shortening the period over which detritus is available to aquatic invertebrates. [CCB 6.2] Invasive alien species represent a major threat to native biodiversity in aquatic ecosystems. [WGII 4.2.2] The rise in global temperature will tend to extend polewards the ranges of many invasive aquatic plants, such as *Eichhornia* and *Salvinia*. [RICC 2.3.6]

Effects of warming on riverine systems may be strongest in humid regions, where flows are less variable and biological interactions control the abundance of organisms. Drying of stream-beds and lakes for extended periods could reduce ecosystem productivity because of the restriction on aquatic habitat, combined with lowered water quality via increased oxygen deficits and pollutant concentrations. In semi-arid parts of the world, reductions in seasonal streamflow and complete drying up of lakes (such as in the Sahel of Africa) can have profound effects on ecosystem services, including the maintenance of biodiversity. [CCB 6.7]

Currently, species richness is highest in freshwater systems in central Europe and decreases to the north and south due to periodic droughts and salinisation (Declerck et al. 2005). Ensemble GCM runs for the IPCC AR4 indicate a south–north contrast in precipitation, with increases in the north and decreases in the south. [WGI 11.3.3.2] An increase in projected runoff and lower risk of drought could benefit the fauna of aquatic systems in northern Europe, while decreased water availability in the south could have the opposite effect (Álvarez Cobelas et al., 2005). [WGII 12.4.6]

4.1.3.2 Freshwater wetlands

The high degree of variability in the structure of wetland systems is due mainly to their individual hydrology, varying from peatland bogs in high-latitude boreal forests, through tropical monsoonal wetlands (e.g., the Kakadu wetlands, Australia), to high-altitude wetlands in the Tibetan and Andean mountains. Climate change will have its most pronounced effects on inland freshwater wetlands through altered precipitation andmore frequent or intense disturbance events (droughts, storms, floods). Relatively small increases in precipitation variability can significantly affect wetland plants and animals at different stages of their life cycle (Keddy, 2000). [WGII 4.4.8] Generally, climatic warming is expected to start a drying trend in wetland ecosystems. This largely indirect influence of climate change, leading to alterations in the water level, would be the main agent in wetland ecosystem change and would overshadow the impacts of rising temperature and longer growing seasons in boreal and sub-Arctic peatlands (Gorham, 1991). Monsoonal areas are more likely to be affected by more intense rain events over shorter rainy seasons, exacerbating flooding and erosion in catchments and the wetlands themselves. [WGII TAR 5.8.3]

Most wetland processes are dependent on catchment-level hydrology, which can be altered by changes in land use as well as surface water resource management practices. [WGII TAR 5.ES] Recharge of local and regional groundwater systems, the position of the wetland relative to the local topography, and the gradient of larger regional groundwater systems are also critical factors in determining the variability and stability of moisture storage in wetlands in climatic zones where precipitation does not greatly exceed evaporation (Winter and Woo, 1990). Changes in recharge external to the wetland may be as important to the fate of the wetland under changing climatic conditions, as are the changes in direct precipitation and evaporation on the wetland itself (Woo et al., 1993). [WGII TAR 5.8.2.1] Thus, it may be very difficult, if not impossible, to adapt to the consequences of projected changes in water availability. [WGII TAR 5.8.4] Due, in part, to their limited capacity for adaptation, wetlands are considered to be among the ecosystems most vulnerable to climate change. [WGII 4.4.8]

Wetlands are often biodiversity hotspots. Many have world conservation status (Ramsar sites, World Heritage sites). Their loss could lead to significant extinctions, especially among amphibians and aquatic reptiles. [WGII 4.4.8] The TAR identified Arctic and sub-Arctic ombrotrophic ('cloud-fed') bogs and depressional wetlands with small catchments as the most vulnerable aquatic systems to climate change. [WGII TAR 5.8.5] The more recent AR4, however, suggests a very high degree of vulnerability for many additional wetland types, such as monsoonal wetlands in India and Australia, boreal peatlands, North America's prairie pothole wetlands and African Great Lake wetlands. [WGII 4.4.8, 4.4.10] The seasonal migration patterns and routes of many wetland species will have to change; otherwise some species will be threatened with extinction. [WGII 4.4.8] For key habitats, small-scale restoration may be possible, if sufficient water is available. [WGII TAR 5.8.4]

Due to changes in hydrology associated with atmospheric warming, the area of wetland habitat has increased in some regions. In the Arctic region, thawing of permafrost is giving rise to new wetlands. [WGII 1.3] Thermokarst features, which result from the melting of ground ice in a region underlain by permafrost, can displace Arctic biota through either oversaturation or drying (Hinzman et al., 2005; Walsh et al., 2005). Extensive thermokarst development has been discovered in North America near Council, Alaska (Yoshikawa and Hinzman, 2003) and in central Yakutia (Gavriliev and Efremov, 2003). [WGI 4.7.2.3] Initially, permafrost thaw forms depressions for new wetlands and ponds that are interconnected by new drainage features. As the permafrost thaws further, surface waters drain into groundwater systems, leading to losses in freshwater habitat. [WGII 15.4.1.3] Warming may have already caused the loss of wetland area as lakes on the Yukon Delta expanded during the past century (Coleman and Huh, 2004). [WGII 15.6.2]

Small increases in the variability in precipitation regimes can significantly affect wetland plants and animals (Keddy, 2000; Burkett and Kusler, 2000). Biodiversity in seasonal wetlands, such as vernal pools, can be strongly impacted by changes in precipitation and soil moisture (Bauder, 2005). In monsoonal regions, prolonged dry periods promote terrestrialisation of wetlands, as witnessed in Keoladeo National Park (Chauhan and Gopal, 2001). [WGII 4.4.8]

4.1.3.3 Coasts and estuaries

Changes in the timing and volume of freshwater runoff will affect salinity, sediment and nutrient availability, and moisture regimes in coastal ecosystems. Climate change can affect each of these variables by altering precipitation and locally driven runoff or, more importantly, runoff from watersheds that drain into the coastal zone. [WGII 6.4.1.3] Hydrology has a strong influence on the distribution of coastal wetland plant communities, which typically grade inland from salt, to brackish, to freshwater species. [WGII 6.4.1.4]

The effects of sea-level rise on coastal landforms vary among coastal regions because the rate of sea-level rise is not spatially uniform [WGI 5.5.2] and because some coastal regions experience uplift or subsidence due to processes that are independent of climate change. Such processes include groundwater withdrawals, oil and gas extraction, and isostacy (adjustment of the Earth's surface on geological timescales to changes in surface mass; e.g., due to changes in ice sheet mass following the last deglaciation). In addition to changes in elevation along the coast, factors arising inland can influence the net effect of sea-level rise on coastal ecosystems. The natural ecosystems within watersheds have been fragmented and the downstream flow of water, sediment and nutrients to the coast has been disrupted (Nilsson et al., 2005). Land-use change and hydrological modifications have had downstream impacts, in addition to localised influences, including human development on the coast. Erosion has increased the sediment load reaching the coast; for example, suspended loads in the Huanghe (Yellow) River have increased 2–10 times over the past 2,000 years (Jiongxin, 2003). In contrast, damming and channelisation have greatly reduced the supply of sediments to the coast on other rivers through the retention of sediment in dams (Syvistki et al., 2005), and this effect will probably dominate during the 21st century. [WGII 6.4]

Climate model ensemble runs by Milly et al. (2005) indicate that climate change during the next 50–100 years will increase discharges to coastal waters in the Arctic, in northern Argentina and southern Brazil, parts of the Indian sub-continent and China, while reduced discharges to coastal waters are suggested in southern Argentina and Chile, western Australia, western and southern Africa, and in the Mediterranean Basin. [WGII 6.3.2; see Figure 2.10 in this volume] If river discharge decreases, the salinity of coastal estuaries and wetlands is expected to increase and the amount of sediments and nutrients delivered to the coast to decrease. In coastal areas where streamflow decreases, salinity will tend to advance upstream, thereby altering the zonation of plant and animal species as well as the availability of freshwater for human use. The increased salinity of coastal waters since 1950 has contributed to the decline of cabbage palm forests in Florida (Williams et al., 1999) and bald cypress forests in Louisiana (Krauss et al., 2000). Increasing salinity has also played a role in the expansion of mangroves into adjacent marshes in the Florida Everglades (Ross et al., 2000) and throughout south-eastern Australia during the past 50 years (Saintilan and Williams, 1999). [WGII 6.4.1.4] Saltwater intrusion as a result of a combination of sea-level rise, decreases in river flows and increased drought frequency are expected to alter estuarine-dependent coastal fisheries during this century in parts of Africa, Australia and Asia. [WGII 6.4.1.3, 9.4.4, 10.4.1, 11.4.2]

Deltaic coasts are particularly vulnerable to changes in runoff and sediment transport, which affect the ability of a delta to cope with the physical impacts of climatic change. In Asia, where human activities have led to increased sediment loads of major rivers in the past, the construction of upstream dams is now depleting the supply of sediments to many deltas, with increased coastal erosion becoming a widespread consequence (Li et al., 2004; Syvitski et al., 2005; Ericson et al., 2006). [WGII 6.2.3, 6.4.1] In the subsiding Mississippi River deltaic plain of south-east Louisiana, sediment starvation due to human intervention in deltaic processes and concurrent increases in the salinity and water levels of coastal marshes occurred so rapidly that 1,565 km2 of intertidal coastal marshes and adjacent coastal lowlands were converted to open water between 1978 and 2000 (Barras et al., 2003). [WGII 6.4.1]

Some of the greatest potential impacts of climate change on estuaries may result from changes in physical mixing characteristics caused by changes in freshwater runoff (Scavia et al., 2002). Freshwater inflows into estuaries influence water residence time, nutrient delivery, vertical stratification, salinity, and control of phytoplankton growth rates (Moore et al., 1997). Changes in river discharges into shallow near-shore marine environments will lead to changes in turbidity, salinity, stratification and nutrient availability (Justic et al., 2005). [WGII 6.4.1.3]

8. Gaps in knowledge and suggestions for further work [extract only]

8.2 Understanding climate projections and their impacts

8.2.2 Water-related impacts [WGII 3.5.1, 3.8]

- Impacts of climate change on aquatic ecosystems (not only temperatures, but also altered flow regimes, water levels and ice cover) are not understood adequately.

8.3 Adaptation and mitigation

- Water resources management clearly impacts on many other policy areas (e.g., energy construction: An integrated approach is needed, given the diversity of interests (flood control, hydropower, irrigation, urban water supply, ecosystems, fisheries and navigation), to arrive at sustainable solutions.Methane emissions have to be estimated. Also, the net effect on the carbon-budget in the affected region has to be evaluated.

- Bio-energy: Insight is required into the water demand, and its consequences, of large-scale plantations of commercial bio-energy crops. [WGIII 4.3.3.3]

- Agriculture: Net effects of more effective irrigation on the GHG budget need to be better understood (higher carbon storage in soils through enhanced yields and residue returns and its offset by CO2 emissions from energy systems to deliver the water, or by N2O emissions from higher moisture and fertiliser inputs). [WGIII 8.4.1.1]

- Forestry: Better understanding of the effects of massive afforestation on the processes forming the hydrological cycle, such as rainfall, evapotranspiration, runoff, infiltration and groundwater recharge is needed. [WGIII 9.7.3]

- Wastewater and water reuse: Greater insight is needed into emissions from decentralised treatment processes and uncontrolled wastewater discharges in developing countries. The impact of properly reusing water on mitigation and adaptation strategies needs to be understood and quantified.

B. "Wetlands, water, biodiversity and climate change": report of the March 2007 joint CBD-Ramsar technical workshop

15. The full draft report of this technical workshop, which was held immediately prior to STRP's mid-term workshops and supported by funding from the government of Canada through the Secretariat of the Convention on Biological Diversity (CBD), was launched jointly by the CBD Executive Secretary and Ramsar Secretary General on the occasion of World Biodiversity Day in June 2007, and it is available on: www.biodiv.org/doc/case-studies/wtr/cs-wtr-ramsar-en.pdf.

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The objective of the expert meeting was to enhance the availability of scientific and technical information on the linkages between biodiversity, wetlands and climate change so as to contribute to the international debate and strengthen in-country adaptation and mitigation planning.

Specific activities of the meeting included to:

i) undertake a review of the general state of knowledge on wetlands, biodiversity and climate change linkages based upon published reviews;
ii) identify key areas where wetlands should have a higher profile in the international debate on climate change; and
iii) identify key strategic opportunities to promote the enhanced awareness of the contribution of wetlands to the mitigation of climate change and the need to adequately consider wetlands in climate change adaptation measures.

The meeting based its deliberations on scientifically based evidence and experience but focused its outputs on influencing policies and activities in the non-specialist community.

A summary of key issues, key messages and responses is provided together with an extended set of messages to form the basis of follow-up CEPA work. These are based on reviews of the subject area and are supported by technical and scientific information provided in the report, its annexes and related publications.

There is no time for delay: combating climate change is a vital need. The report addresses this major challenge and provides some solutions regarding wetlands and biodiversity. The opportunities are significant. Wetlands/biodiversity and climate change are interlinked. Climate change threatens these important ecosystems and the services they provide for human welfare. These ecosystems are already declining faster than any other biome and climate change will exacerbate this problem largely because its main impacts will be on water. Climate change affects the hydrological cycle which in turn impacts wetlands. In addition, many response measures to climate change will focus on water (e.g. increased agricultural demand for water).

Wetlands are also critical to mitigating climate change. They have an important and underestimated role in both carbon storage and the regulation of greenhouse gas emissions. Degraded wetlands are already a significant source of atmospheric carbon and the restoration/rehabilitation of wetlands offers a return on investment up to 100 times that of alternative carbon mitigation investments.

The work of the Intergovernmental Panel on Climate Change has also made us all aware that Climate Change is likely to be the main driver of biodiversity loss in the future. Biodiversity has already been affected by recent climate change and projected climate change for the 21st century is expected to affect all aspects of biodiversity. Studies show clearly that changes in distribution and behaviour of a large number of wetland species are the consequence of shifts in local or regional climate, weather patterns and resulting changes of vegetation and habitat quality. The impacts of climate change and the changes in habitat may be dramatic for certain wetland related species such as birds, fishes, reptiles, amphibians. There is likely to be a general decline in avian species richness, with the mean extent of species' potential geographical distributions likely to decrease. Species with restricted distributions and specialized species of particular biomes are likely to suffer the greatest impacts. Migrant species are likely to suffer especially large impacts as climatic change alters both their breeding and wintering areas, as well as critical stopover sites, and also potentially increases the distances they must migrate seasonally.

An overview of regional assessments shows mainly that the impacts of global warming has been most pronounced in the Arctic, that small islands are particularly vulnerable to climate change and that Africa is expected to suffer more food and water scarcity (less coastal wetlands and fish). Thus, wetlands can also mitigate another adverse effect of climate change by providing vital biodiversity resources, especially for poor people.

For general CEPA purposes it is clear that there is already enough information to produce a substantial technical document focussing on explanations of key messages identified. The short-term goal, however, might be simpler, shorter materials targeted to specific groups. The International Day for Biological Diversity (22 May, 2007) on "biodiversity and climate change", is a good opportunity for providing appropriate materials (for both Ramsar and the CBD).

It is time for the international community to fully recognize that wetlands are more important as carbon stores than other biomes and therefore efforts to protect these vital ecosystems should be expanded. It is already known that peatlands alone store twice the carbon present in forest biomass of the world and that they store this carbon for very long periods of time (thousands of years), contrary to forests. However, precise information concerning the storage-capacity of other types of wetlands is missing. One thing is sure: degradation of wetlands by drainage and fire has severe impacts on carbon emissions to the atmosphere. Therefore, reducing climate change is possible through the conservation, restoration or creation of wetlands but even more difficult if their degradation is not prevented. On this point, it is crucial to note that the Kyoto Protocol excludes the emissions from soil and degraded vegetation, allowing no consideration of peatland degradation which is a huge cause of global warming.

It is urgent that the international community recognizes the crucial importance of wetlands to mitigate climate change (reducing Greenhouse Gases). Equally, adaptation measures for wetlands (which deal with the impacts of climate change) are critically important to human welfare. Wetland services are not only vulnerable to climate change but must be maintained in order to cost-effectively reduce the impacts of climate change on human populations.

The stage is set for action at Convention level. SBSTTA 12 will consider peatlands and advise CBD COP 9. There are indications that improved emphasis on these issues will receive strong support from some Parties – particularly in Europe. CBD COP 10 will consider climate change in detail. An effective partnership between the CBD and Ramsar Secretariats offers the possibility of significant progress in these matters but an effective strategy needs to be designed which includes having a stronger influence on the IPCC and UNFCCC.

Better explanation of wetland-biodiversity-climate change issues can provide significant additional argument for improved management in a rapidly changing world.

C. "The role of wetlands in the global carbon cycle"

16. This review report, based on published and publicly available data and information, is being prepared for the STRP by invited expert Colin Lloyd and will be published as a *Ramsar Technical Report*.

17. The report reviews available information on the role in carbon storage and emission of a range of different wetland types covered by the Ramsar Convention and in different parts of the world, on the implications for future storage and emissions under a changing climate, and on gaps in knowledge. The work was commissioned by the STRP in light of its recognition that although there has been much recent discussion of greenhouse gases in relation to some wetlands such as peatlands, there has been no available summary of the overall pattern across all wetland types. It is anticipated that the findings of the report will also assist countries in identifying which wetlands play a particularly significant role in climate change mitigation and adaptation and should thus be a focus of attention for future maintenance and restoration of their ecological character.

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Wetlands, depending on the definition used, cover up to 12.8 million km^2 or 8.5% of the Earth's land surface. Whilst not all of this wetland area plays a significant role in Greenhouse Gas (GHG) exchange and carbon balances, understanding the proportion and types of wetlands that are actively involved with GHG exchange is necessary to assess the overall, under-recognised contribution that global wetlands make to the overall climate change regime.

Wetlands are different to other biomes in that they have the ability to sequester large amounts of carbon in their waterlogged soils. This is a consequence of wetlands' high primary production and the eventual deposition of dead and decaying litter in the anaerobic region of wetland soils. In such soils the normal production of carbon dioxide (CO_2) that occurs during decomposition is slowed or completely inhibited by the lack of oxygen. This process is aided by cold conditions, but is not without consequence since methane (CH_4), another GHG, is produced in these anaerobic conditions. It is the interplay between waterlogging, high plant productivity, sequestration of carbon in the soil, and production of carbon dioxide and methane that makes wetlands one of the most important terrestrial surfaces in climate change. But different wetland types have markedly different GHG and carbon balances.

Peatlands, especially temperate and northern peatlands, have received much attention since climate change predictions indicated that northern latitudes would undergo greater than average temperature rises. It has been recognised that peatlands, historically sinks for carbon to the extent that they now contain 400-700 Gt of carbon in their soils, are at risk if temperatures and rainfall patterns alter with climate change. This amount of carbon - equivalent to a third of the world's total soil carbon - would, if all converted to carbon dioxide, increase the atmospheric concentration of CO_2 by 200 ppm.

Peatland research to date has focused on assessing current carbon stocks and identifying whether the peatlands were, on balance, still sequestering carbon or were now emitting more greenhouse gases than they used to absorb. Initial short-term studies produced a confused picture, with some sites shown as carbon sinks and others as carbon sources. As the research studies lengthened, so a picture of inter-year variability has become more apparent, with year-on-year climatic and hydrological variability switching the balances.

There are now many long-term studies of overall carbon dioxide and methane exchange with the atmosphere in temperate and northern peatlands which highlight the complex nature of the interaction between the various plant and soil components at work. Figures for different peatlands vary greatly: from a carbon uptake of more than 220 g CO_2 m^{-2} yr^{-1} to carbon losses of 310 g CO_2 m^{-2} yr^{-1}. This complexity and range of variation complicates general predictions, as although better understanding of the patterns of carbon exchange in peatlands are emerging from these long-term studies, prediction of the future of peatlands through models is still problematic.

All peatlands, as they dry, are under threat from fire which rapidly converts the peat soil to CO_2. A future warmer and drier climate will increase this threat. Peat fires, largely underground and often invisible, are difficult to control especially in remote regions that account for many of the world's peatlands.

All peatlands, whether northern, temperate or tropical, are also under threat from agriculture and forestry conversion. Conversion to forestry and other crops involves drainage and mechanical disturbance, both actions that increase the conversion of peat soil to CO_2. Tropical peatlands currently exhibit the largest uptake of CO_2 - in the region of 1800 g CO_2 m^{-2} yr^{-1}. As tropical temperatures are not expected to rise as much as those in northern latitudes, this continuing loss of carbon-sequestering peatland is a particularly serious problem.

Peatland restoration and mitigation programmes are beginning in Europe and north America but it is generally recognised that mitigation is all that can probably happen in the short-term as the current plant species are largely incapable of increasing production in response to higher temperatures and atmospheric CO_2 concentrations.

Freshwater mineral soil (FWMS) wetlands. Relatively little research has specifically targeted freshwater mineral soil (FWMS) wetlands with regard to their position in global carbon balances - even though along with with peatlands such FWMS wetlands form the vast majority of wetlands. Swamps and marshes, together with seasonally flooded river edges (e.g. the "varzea" areas in the Amazon basin) comprise the main FWMS wetlands around the world.

Some FWMS wetlands rival estuarine wetlands (see also below) in their ability to rapidly sequester carbon by burying the soil organic matter in sediments. However, there is a large variability in sedimentation rates in FWMS wetlands reported. In contrastto peatlands, where most carbon sequestration is local, an often significant proportion of carbon sequestered or lost in FWMS wetlands enters or departs the wetland itself. It is rare for experiments to measure all the components of the carbon balance, and external gains and losses may often confuse conclusions regarding the GHG balance of the wetland. Riverine wetlands create greater measurement difficulties in up-scaling and representativeness that do peatlands, and this may in part be why much less attention has been paid to the carbon cycle role of such systems.

Rice Paddies. Rice paddies, which predominantly exist in the tropics north of the equator, emit around 60 Tg of methane a year, approximately 13 per cent of global methane emissions – although estimates vary by 50 per cent. Recent estimates have also shown large disparities in the estimated area of paddy. While population and global food production growth will almost certainly increase global rice paddy area, recent research has shown that different rice varieties and agricultural management practices can reduce methane production by increasing above-ground seed productivity which leads to a reduction in the storage of carbon in the wet anaerobic soils.

Other research has indicated that the sulphate component of acid rain (a particular problem in Asia where rice is largely grown), not only increases rice yields through fertilisation, but also decreases methane production through the suppression of methane-producing bacteria in the soil in a similar way to methane suppression in saline wetlands(see below). Shortage of water and agricultural practice that drains or reduces the amount of water on rice paddies may also reduce the emission of methane but will increase the production of carbon dioxide in the re-oxygenated soils – emissions that are exacerbated by the traditional practice of burning rice straw.

The investigation of GHG production through measurement and experimental manipulation of climate and biological factors presents few difficulties in rice paddies, and the normally complex interactions of wetlands have a greater chance for understanding than any other type of wetland. But while Asian governments and major rice producers are aware of research that will mitigate the GHG problem, including the use of rice husks and straw as an energy crop in power stations, traditions and cost are preventing rural farmers from adopting these new management practices.

Dams. There has been considerable attention in the literature to the role that new hydroelectric dam projects have in producing GHGs and thus exacerbating global warming, especially in tropical regions. Where hydroelectric reservoirs have inundated tropical and other heavily vegetated areas, GHG emissions of CO_2 and CH_4 will initially be large as assimilation and uptake of CO_2 by the vegetation has been largely curtailed from the drowned vegetation, and the emissions of CO_2 and CH_4 from dead and decaying vegetation and from labile carbon in the waterlogged soil, will greatly increase previous natural levels of emissions. But these elevated levels of emissions have a limited time-scale. Research indicates that new reservoirs will return to levels more in accordance with natural lakes and old reservoirs within time periods of the order of a decade.

While freshwater wetlands are second only to tropical rain forest in terms of primary productivity, the ability of wetlands to convert this primary production to soil carbon may mean that tropical reservoirs could become net CO_2 sinks, although CH_4 will be a counterbalancing problem that current tropical forests do not have. There appears to be differences between temperate and tropical reservoirs, with tropical reservoirs generally producing higher CH_4 fluxes relative to CO_2 fluxes than temperate reservoirs. With CH_4 being converted to CO_2 in deeper water columns, this may reflect the often shallow nature of tropical reservoirs.

Very few studies have assessed GHG emissions from flux measurements at the atmosphere-water interface, relying instead on dissolved gas measurements within the water or at the outflow. Although hydroelectric schemes that flood rainforest may initially produce as much CO_2 as an equivalent fossil fuel power station, the increasing need for fresh water and the decline in fossil fuel reserves make hydroelectric schemes an increasing attractive alternative. Better long term research, devoid of the current political biases, is needed to fully appreciate the current GHG balance, and future potential of dams and reservoirs.

Coastal and estuarine wetlands. Coastal saline (and brackish) wetlands have one of the highest primary productivities on earth but are relatively small in their total global area. Salt water and anaerobic conditions inhibits the decomposition of dead plant material and the tidal regime coupled to sediment input from streams and rivers allows the burial of the dead organic matter. Methane production is also inhibited (but not necessarily stopped) in saline wetlands, where sulphate reduction replaces methane production as the dominant anaerobic decay process. This inhibition increases with salinity but decreases with temperature, a pointer that global warming may increase methane from saline wetlands.

Coastal wetlands are vulnerable to sea-level rise caused by global warming, where inundation will threaten the survival of the largely intertidal wetland plants. This may diminish primary productivity and through decay increase the CO_2 emissions. However, if continued input of suspended sediment from rivers is sufficient for sediment accretion to keep pace with a rising sea-level, then CO_2 emissions could decrease as the tidally flooded coastal areas increase in area and plant population and inundated carbon pools are buried even deeper – provided, that is, that such landward movement of intertidal areas is not prevented by coastal squeeze such as the presence of hard sea-defences and other infrastructure.

Mangrove areas are reported to be highly productive. However, the wide range of conditions, including salinities and soils, in which mangroves occur, inevitably produces a wide range of productivities ranging from near-zero in very saline saltpans to values of 40 or more tonnes ha^{-1} yr^{-1} in regions of high rainfall and low to moderate salinity. Most estimations of mangrove biomass and primary production are based on allometric measurements for above-ground vegetation, although "above-ground" in tidal wetlands can be difficult to define. For this below-ground biomass, which can account for half of the total biomass, the estimation of decomposition and productivity can be almost impossible to measure. The difficulty of access and the narrowness of the mangrove ecosystem does not lend itself to modern methods of overall net ecosystem exchange(NEE – the net balance between plant production and plant and soil respiration).

There is evidence that **Coral reefs** would appear to store CO_2 and they have acted as both carbon sinks and sources over the long period of their creation. Over the shorter time-scale from pre-industrial to the immediate future climate change, coral reefs have played little part in the sequestration of CO_2. However, increasing amounts of dissolved CO_2 in seawater may now be limiting current reef growth.

General conclusions. There is strong evidence that wetlands are one of the most important, but also the most complex, biomes in relation to carbon and GHG balances. However, the role that wetlands will play in the global picture of carbon storage and methane emissions in the future is very uncertain and the processes involved are complex. It is important to recognise that wetlands have always sequestered carbon and also decomposed to produce CO_2 and CH_4; their effect upon future climate change depends on how these processes depart from historical steady-state rates of production.

Climate change scenarios that predict either warmer and drier, or warmer and wetter, future climates will significantly affect the GHG balances of wetlands. Warmer climates will accelerate the rate of production of CO_2 and CH_4 from wetland soils, but may also increase primary production. Wetter climates will increase wetland surface areas and promote carbon sequestration and increased primary production, but may increase CH_4 emissions. Drier climates, especially in peatlands, will increase the oxidation of their large carbon stores but reduce CH_4 emissions.

Sea level rises, if locally slow will tend to increase sequestering of carbon in sediments while expanding the area of highly productive salt-marshes and mangroves. If local sea levels rise rapidly and/or landward movement of intertidal systems is blocked,, the plant population may be inundated and sediments overturned leading to a shift to net CO_2 emissions.

There are significant gaps in research and knowledge that preclude full assessment of the real magnitude of the importance of wetlands globally in the carbon and GHG balance: future research should concentrate on mapping the global extent of wetland surfaces most at risk, and extending the current long-term monitoring of northern peatlands to other wetland areas particularly tidal saltmarsh, mangrove and freshwater mineral soil wetlands and reducing the uncertainty in many current estimates of the role of wetlands in the global carbon cycle.

D. "Wetland vulnerability assessment: guidance on methodologies for vulnerability assessment of wetlands to change in ecological character"

18. This report has been prepared for the STRP by Habiba Gitay, Max Finlayson and others and will be published as a *Ramsar Technical Report*. Its tools have major relevance to assessing the vulnerability of wetlands to climate change and are supplemented by the simple framework for assessing the vulnerability of wetlands to hydrological impacts of climate change, summarised in Section E below.

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Vulnerability as a term has been widely used. It refers to the relationship between exposure to a particular risk event, the impact of that event on a system and the ability of the system to cope with the impacts or the efforts needed to minimise the impacts. It has been used in various disciplines, e.g. in the context of poverty and poverty alleviation and more recently for the effects of climate change on human systems and ecosystems. The idea of the resiliency and sensitivity of the system were also included as part of vulnerability.

Vulnerability of a wetland is its ability to cope with any impacts from externally driven forces. In 1990s, methods were developed to assess the vulnerability of wetlands to climate change, especially sea level rise and changes in extreme climatic events (e.g. floods and droughts). Methods included a series of steps that identified the system (e.g. coastal wetlands and the human populations that depended on them), its present condition, the potential changes in climatic variables (e.g. sea level rise) using downscaling models to project the likely changes in climate in a particular region over the next century, the magnitude of the likely impacts on an ecosystem and the potential management options.

Early on studies included the concept of risk identification and risk management, the idea being that by managing risk, the system would become less vulnerable. Vulnerability assessment often resulted in maps or lists of areas vulnerable to climate change.

Bringing together various approaches, a framework for vulnerability assessment is suggested. It has the following components:

1. identification of the system (biophysical and social), the present and recent pressures that exist on the system, the present condition of the system, often due to data limitation drawing on the local/expert knowledge;
2. determination of the sensitivity and resiliency of the system to the present changes;
3. the plausible changes that could occur in multiple pressures on the system;

4. the likely impact of these changes on the system;
5. the responses that need to be developed and implemented, given the sensitivity and resiliency of the system;
6. the desired outcomes for the system being sought; and
7. monitoring and adaptive management during implementation to ensure the path to the desired outcomes.

Risk assessment incorporates steps 1-4 and risk management mainly on 5-7 although there has not necessarily been emphasis placed on defining the desired outcome.

This approach goes further than producing maps of vulnerable areas, emphasizing the need for developing and implementing responses that would help reduce the vulnerability of the system, given the degraded status of many wetlands of the world. The approach would incorporate the wise use concept and thus sustainable development. It builds on Ramsar's existing risk assessment framework (available as Section E of Ramsar Wise Use Handbook 16 "Managing Wetlands" (3rd edition, 2007) on: http://www.ramsar.org/lib/lib_handbooks2006_e.htm).

There are still many challenges that will remain and will have to be addressed, including:

i) The lack of spatial and temporal data, especially time series to determine the present condition of the system, the natural dynamics, the sensitivity to past and present pressures and potential thresholds, inertia or lag effects. These are components of ecological character.
ii) The challenges of dealing with multiple pressures, as is often the case for many wetlands (e.g. land use land cover change, climate change etc), and developing a metric for the system that would measure the vulnerability.
iii) The challenges of getting the information at the appropriate scale (e.g. downscaling models for future projections in pressures).

E. "A simple framework for assessing the vulnerability of wetlands to hydrological impacts of climate change, with a case study from Great Britain"

19. This paper has been prepared for the STRP by M.C. Acreman, J.R. Blake, D.J. Booker, R.J. Harding, N. Reynard, J.O. Mountford & C.J. Stratford, of the UK Centre for Ecology & Hydrology and is planned to be published as a *Ramsar Technical Report* in late 2008.

Draft Summary

It is widely accepted that the Earth's climate is changing more rapidly than it has in the past and that over the next 100 years temperatures will rise and patterns of precipitation will be altered. These predictions for the future have important implications for all ecosystems, particularly those, such as wetlands, whose ecological character is very dependent on hydrological regime. The potential impacts of climate change on wetland hydrology are of interest to a wide range of stakeholders from wetland managers to international policy makers.

Eco-hydrological models that combine climate changes, hydrological processes and ecological response provide a means of estimating what might happen to some wetland functions and species in the future. This paper presents a framework that can be used for combining models and available data at a regional scale and is appropriate for different wetlands, in different countries and for different levels of data availability.

The simple models are based on broad conceptual understanding of wetland hydrology and are intended to describe basic eco-hydrological processes within the constraints of data availability; they are thus fit for the purpose of general assessment to 'red-flag' likely vulnerable wetlands and do not pretend to provide precise results for specific wetland sites.

Data from Great Britain (GB) have been used to demonstrate each step in the framework for two temperate wetland types: rain-fed wetlands (raised mires or wet heaths) and floodplain margins. Whilst GB may be considered to be relatively data rich, we believe that sufficient information is available in many countries to apply this framework for the regional assessment of climate change impacts on wetlands. Although the models successfully represent the baseline conditions, it is not possible to test whether they accurately predict the future vulnerability of the selected areas. Results for GB suggest that predictions of reduced summer rainfall and increased summer evaporation will put stress on wetland plant communities in late summer and autumn with greater impacts in the south and east of GB than in the north and west. In addition, impacts on rain-fed wetlands will be greater than on those dominated by river inflows.

F. "Wetlands and Global Climate Change: The Role of Wetland Restoration in a Changing World"

20. This review paper was originally prepared as a discussion paper for the STRP by invited expert Kevin Erwin. A revised version is now *in press* in a special issue of the journal *Wetlands Ecology and Management*, and will be available at http://www.springerlink.com/content/0923-4861. The abstract and recommendations from the draft paper are provided here. The final published paper will subsequently be made available also in a *Ramsar Technical Report,* by kind permission of Springer SBM.

Abstract

Global climate change is recognized as a threat to species survival and the health of natural systems. Scientists worldwide are looking at the ecological and hydrological impacts resulting from climate change. These adverse impacts can be expected to be exacerbated due to ongoing pressures on wetlands such as drainage and development. Efforts to restore and manage wetlands will be more complicated by climate change. Wetland systems are vulnerable to changes in quantity and quality of their water supply and it is expected that climate change will have a pronounced effect on wetlands through alterations in hydrological regimes with great global variability. Wetland habitat responses to climate change and the implications for restoration will be realized differently on a regional and mega-watershed level, making it important to recognize that specific restoration and management plans will

require examination by habitat. Floodplains, mangroves, seagrasses, saltmarshes, arctic wetlands, peatlands, freshwater marshes and forests are very diverse habitats, with different stressors and different management and restoration techniques now complicated by climate change. The Sundarban (Bangladesh and India), Mekong River Delta (Vietnam), and southern Ontario in Canada are examples of major wetland complexes where the effects of climate change is evolving in different ways. Thus, successful long term restoration and management of these systems will hinge on how we choose to respond to the effects of climate change. How will we choose priorities for restoration and research? Will enough water be available to rehabilitate currently damaged, water starved wetland ecosystems?

Recommendations

There is no doubt that globally there is a great need to reverse certain significant human-induced stressors to ecosystems including drainage, flood control, and unsustainable development. We can do this by undertaking wetland restoration programs and implementing sustainable ecosystem management plans now as we continue to work on the task of reducing CO2 emissions and reversing existing climate change trends.

The following recommendations are offered to provide some perspective as well as a stimulus for discussion and to developing a new direction for global wetland conservation in a changing world:

1. One of our goals should be to significantly reduce non-climate stressors on ecosystems: The reduction of stressors causes by human activities will increase the resiliency of habitats and species to the effects of climate change and variability. In essence, this situation is what good management already seeks to accomplish. However, a changing climate amplifies the need for managers to minimize effects these stressors have on wildlife populations.

2. Protect coastal wetlands and accommodate sea level change. Impacts of sea level rise can be ameliorated with acquisition of inland buffer zones to provide an opportunity for habitats and wildlife to migrate inland. Setback lines for coastal development can be effective at establishing zones for natural coastal migration based on projected sea level rise. Storm surge should be considered in establishing buffer zones and setback boundaries. In other cases, restoration of natural hydrology could facilitate sediment accretion and building of deltaic coastal wetlands.

3. Monitoring is an essential element of ecosystem management, in that it is in intended to detect long-term ecosystem change, provide insights to the potential ecological consequences of the change, and help decision makers determine how management practices should be implemented. Monitoring may be used as a starting point to define baseline conditions, understand the range of current variability in certain parameters and detect desirable and undesirable changes over time within reserve areas and adjacent ecosystems.

4. We need to quickly train restoration scientists and practitioners. There will be a great need to monitor, design and implement wetland restoration and

management projects globally on a large scale. Currently we have no global plan for improving expertise in these areas.

5. Rapidly changing climates and habitats may increase opportunities for invasive species to spread because of their adaptability to disturbance. Invasive species control efforts will be essential, including extensive monitoring and targeted control to preclude larger impacts.

6. Wetland restoration and management must incorporate known climatic oscillations. Short-term periodic weather phenomena, such as El Niño, should be closely monitored and predictable. By understanding effects of periodic oscillations on habitats and wildlife, management options can be fine-tuned. For example, restoration of native plants during the wet phase of oscillations, avoiding the drought phase, could make the difference between success and failure.

7. Conduct medium- and long-range planning that incorporates climate change and variability. This planning should also apply to institutions and governments alike. If climate change and variability are not proactively taken into account, the potential for conservation plans to succeed will likely be much reduced.

8. We must develop a strategy for selecting and managing restoration areas appropriately. As wildlife and habitats have declined across North America, the establishment of refuges, parks, and reserves has been used as a conservation strategy. However, placement of conservation areas has rarely taken into account potential climate change and variability. For example, in highly fragmented habitats, the placement of conservation areas on a north-south axis may enhance movements of habitats and wildlife by in essence providing northward migration corridors. Efforts to conserve habitats for single, or small numbers of species, should be concentrated in northern portions of their range(s), where suitable climate is more likely to be sustained.

9. We need to educate the public and private sectors to redefine the way that we now think of the protection, management and restoration of wetlands around the world. The impacts of climate change will differ regionally. Within some regions a number of wetlands will disappear from the landscape, especially those drier end systems and systems that are already under stress and their resiliency has been compromised. Many wetlands may "drift" spatially within the region due to changes in precipitation and PET rates depending upon future land use, topography and hydro-patterns.

10. We must understand the nature of climatic and ecological changes that are likely to occur regionally in order to properly design wetland management and restoration plans at the mega-watershed level.