

7th MEETING OF THE TECHNICAL COMMITTEE
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**ASSESSING THE IMPACT OF CLIMATE CHANGE ON WATERBIRDS AND
DEVELOPMENT OF CONSERVATION GUIDANCE FOR AEWA**

(Report by TC Working Group 8)

BACKGROUND

The third Meeting of Parties called for a range of work related to climate change and migratory waterbirds as follows:

The Meeting of the Parties:

1. *Instructs* the Technical Committee, working with the Agreement Secretariat, and taking into consideration the work of the CMS Scientific Council and others as appropriate, to give priority, resources permitting, to an assessment of current evidence of the effects of changing climate on migratory waterbirds, a review of the implications of modelled future patterns of climate change on waterbirds, and an outline of possible means of adapting to these changes, and to report conclusions to a future Meeting of the Parties;
2. *Requests* that the Technical Committee's review seeks to identify those species listed in Table 1 of the Agreement's Action Plan that current knowledge suggests are especially vulnerable to the consequences of a changing climate, and to identify measures that may help to maintain such populations;
3. *Requests also* that the Technical Committee's review identifies relevant actions that might be undertaken as part of the international implementation of the Agreement;
4. *Urges* the Secretariat, drawing on the results of the Technical Committee's review, to give priority, resources permitting, to the development of Conservation Guidelines on possible adaptation measures, and requests that these be brought to a future Meeting of the Parties following review by the Technical Committee;
5. *Urges* Parties to address climate change in so far as it is regarded as likely to bring about significant change in the ecological character of wetlands and affect the behaviour of migrating waterbirds;
6. *Stresses* the importance of including potentially beneficial adaptation measures in the development and implementation of single and multi-species action plans at both national and international scales;

This has been summarised in the TC workplan as follows:

- (a) *review current evidence of the effect of climate change on waterbirds, implications of modelled patterns of climate change on waterbirds, and an outline of possible means of adapting to these changes;*
- (b) *identify species from Table 1 that are especially vulnerable and identify measures to maintain such populations;*
- (c) *identify relevant actions to be undertaken as part of the IIP;*

- (d) *propose changes to the Action Plan to better reflect the need for action on the implications of the climate change and adaptation;*
- (e) *identify international research needs into the effect of climate change on waterbirds and their habitats;*

A POSSIBLE APPROACH

Task a: review current evidence of the effect of climate change on waterbirds

Max Finlayson and others presented a comprehensive review of likely climate change impacts on waterbirds to the Edinburgh (*Waterbirds around the world*) Conference in April 2004. This built on a review undertaken by Ramsar's STRP and others and which was reported as an information paper to Ramsar CoP8 (http://ramsar.org/cop8/cop8_doc_11_e.htm).

The paper (Annex I) is a thorough, well-written review that summarises the broad range of actual and theoretical impacts from changing climate on waterbirds. With additional work (below) it seems to go a considerable way to fulfilling Task a.

What seems a pragmatic way forward is to 'repackage' of the Edinburgh paper together with the waterbird-related elements of the DEFRA review (below) as components of an Information Paper for MoP4. The authors of the Edinburgh paper have been approached and are content with such a proposal.

This would move us forward significantly and would then mean that the work earmarked for AEWA's Technical Committee over the next year on this task might focus rather more on the development of the conservation guidelines (practical response guidance: Tasks c & d rather than essentially re-telling a story that's already been (recently) well told.

Task b: identify species that are especially vulnerable

This is potentially a larger task, but there are two major sources of information here. Last year, the UK Department of Environment, Food, and Rural Affairs commissioned a major review on the effects of climate change on migratory species for CMS CoP8 (Robinson *et al.* 2005: www.defra.gov.uk/wildlife-countryside/resprog/findings/climatechange-migratory) and which was distributed at AEWA MoP 3.

In this respect, this DEFRA review is quite complimentary to the Edinburgh paper as it is a lot more specific, and Table 11 of that review already lists potential climate impacts at the species level. Rob Robinson from the British Trust for Ornithology has kindly provided the original spreadsheet of information developed for the DEFRA review (attached). This has been edited down to include AEWA listed species only. It could be further developed by adding additional fields related to the actual or potential nature of the climate change impact, as well as primary sources of information.

In doing this, a second source of information is the Edinburgh proceedings themselves (Boere *et al.* 2006). For example, 35 papers in *Waterbirds around the world* refer to climate change and waterbirds, whilst at least 11 refer specifically to observed distributional changes, etc. There may be other sources that would help with a rapid literature review.

Attached is a spreadsheet which lists species identified the BTO/CMS review related against the list of species in AEWA's Action Plan. This is a start at summarising information which AEWA-listed species are known to be, or potentially may be, influenced by changing climate. This immediately shows (unsurprisingly) that information is better for some groups than others. Thus there seems to be more information available for Anatidae and waders than seabirds for example. A start has been made to pull together a list of published material related to each

species/population. I think it should be fairly easy to add to this, notably using other studies as noted above. With a little more work, there should be some interesting taxonomic and geographic analyses possible on these data.

It seems important to try and characterise the studies according to the strength/type of data reported. There seems to be a range of data quality ranging from:

- theoretical impacts of climate change
- to
- predictively modelled changes
- to
- observed changes that can be strongly associated with changed climate parameters.

It seems important to try and tease these apart.

Using the information gathered from this review, it should be possible to start to develop criteria for assessing which species are “especially vulnerable”. Immediate contenders would seem to be species showing some combination of the following attributes:

- specialist ecology with reliance on geographically restricted habitats, especially those predicted to be impacted by climate change;
- species dependent on highly fragmented habitats (includes populations dependent on geographically restricted staging areas);
- species with small populations; and/or
- species that are already declining.

Task c: identify relevant actions to be undertaken as part of the IIP

Task d: propose changes to the Action Plan

Both these tasks probably need most thought. Many adaptation responses are straightforward to identify - and are summarised by Finlayson *et al.*. However, others may arise from consideration of the more specific collation of information in Task b.

Task e: identify international research needs into the effect of climate change on waterbirds and their habitats

These could be readily synthesised from a range of existing material including Rehfisch 2004, Robinson *et al.* 2005 (Annex 2), Finlayson *et al.* 2006 and papers in Boere *et al.* 2006 (especially the section on climate change and waterbirds). This should not be a major task.

REFERENCES

- Boere, G.C. Galbraith, C.A. & Stroud, D.A. (eds.) 2006. *Waterbirds around the world*. TSO Scotland, Edinburgh, UK.
- Finlayson, M. Gitay, H., Bellio, M., van Dam, R. & Taylor, I. 2006. Climate variability and change and other pressures on wetlands and waterbirds: impacts and adaptation. In: *Waterbirds around the world*. (Eds. G.C. Boere, C.A. Galbraith & D.A. Stroud). TSO Scotland, Edinburgh, UK.
- Rehfisch, M.M. Feare, C.J., Jones, N.J. & Spray, C. (eds.) 2004 *Climate change and coastal birds*. Ibis 146, Supplement 1. <http://www.bou.org.uk/meetrep8.html>
- Robinson, R.A., Learmouth, J.A., Hutson, A.M. Macleod, C.D., Sparks, T.H., Leech, D.I., Pierce, G./J., Rehfisch, M.M. & Crick, H.Q.P. *Climate change and migratory species*. Report to DEFRA. BTO Research Report 414. 304 pp. www.defra.gov.uk/wildlife-countryside/resprog/findings/climatechange-migratory

Climate variability and change and other pressures on wetlands and waterbirds: impacts and adaptation

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ABSTRACT

The atmospheric concentrations of greenhouse gases have increased since the pre-industrial era due to human activities, primarily the combustion of fossil fuels and changes in land use and land cover. These, together with natural forces, have contributed to changes in the Earth's climate (both mean and variability) over the twentieth century; land and ocean surface temperatures have warmed, the spatial and temporal patterns of precipitation have changed, sea level has risen, and the frequency and intensity of El Niño events have increased. These changes have affected wetlands and their biota, especially in coastal and high latitudes, including the timing of reproduction of species, migration of animals, the length of the growing season and the frequency of pest and disease outbreaks. The Earth's mean surface temperature is projected to warm by 1.4 to 5.8°C by the end of the twenty-first century, with land areas warming more than the oceans, and high latitudes warming more than the tropics. Sea level is projected to rise by 0.09 to 0.88 m, and is expected to have further effects on wetlands and their biota either directly (e.g. through changes in sea level and/or increased temperatures) or indirectly (e.g. through changes in hydrology, fire regime and pest outbreaks). These changes will increase the risk of extinction of vulnerable species, and could drastically alter the migration patterns of many others. Populations of some species will decline, whilst some will increase in both size and distribution. The consequences of climate change and variability for waterbirds are likely to be large, but our understanding of the role of climate change versus all the other changes due to human activities (such as changes in land use and land cover, drainage, invasive species etc.) is undermined by the limited extent of our data and existing knowledge. In all but a few cases, the data are totally inadequate. As many wetland habitats and waterbird species are currently under great pressure, we propose that quantitative risk assessments of individual and multiple pressures at multiple sites along flyways and at major wetlands are undertaken as a basis for developing adaptation options for these species and ecosystems.

INTRODUCTION

We present an overview of the findings of the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report on climate change and its impacts on wetlands, in particular the information and graphics provided by IPCC (2001 & 2002). We also draw on a paper on climate change and wetlands prepared for the 8th Meeting of the Conference of the Parties of the Ramsar Convention on Wetlands (van Dam *et al.* 2002) and recent analyses of the observed and projected effects of climate change on waterbirds.

It is well recognized that at the global level, human activities have caused, and will continue to cause, a loss and/or a change in biodiversity in general. More specifically, biodiversity in wetlands has been affected by, *inter alia*, changes in land use and land cover, soil and water pollution and degradation, air pollution, diversion of water to intensively managed ecosystems and urban systems, habitat fragmentation, selective exploitation of species, introduction of non-native species, and stratospheric ozone depletion. It is also well recognized that climate change will constitute an added stress that may act synergistically or cumulatively and further adversely affect biodiversity. In turn, given that wetland biodiversity supports or provides many ecosystem services on which many humans depend (see review by Finlayson & D'Cruz 2005), changes in wetland biodiversity will undoubtedly also affect human well-being.

We therefore consider climate variability and change in the context of global change that encompasses all pressures from human activities. We specifically look at some of the impacts on waterbirds and then look at possible response options (or adaptation options) through a risk assessment framework. The paper covers:

1. climate variability and change and its impact on wetlands;
2. observed changes in the distribution of specific waterbird species in response to climate variability and change, and changes in land and water use; and
3. a risk analysis framework to develop responses that address the impacts of multiple pressures, including climate change, on wetlands.

CLIMATE CHANGE AND THE IMPACT ON WETLANDS

We summarize the following:

1. changes that have been observed in the biophysical systems (atmosphere, oceans) and the role of human activities in those changes;
2. the (observed) impacts of these changes on biological systems and especially wetlands; and
3. the role that adaptation can play in responding to these changes.

Observed changes in biophysical systems

During the period 1750-2000, the concentrations of greenhouse gases in the atmosphere increased (Fig. 1): carbon dioxide by about a third (27-35%); methane by about 150% (125-175%); and nitrous oxide by 17% (12-22%). The rates of increase over the past century are unprecedented when compared with the past 40 000 years for which a nearly continuous record exists. The increased concentrations of these gases are attributed to human activities, especially the burning of fossil fuel, leading to a release of 6.3 Gt C y⁻¹ on average during the 1990s, and changes in land use and land cover, including deforestation, releasing about 1.7 Gt C yr⁻¹. Aerosols, such as sulphur dioxide, that are relatively short-lived and have a cooling effect on the atmosphere, have also increased (Fig. 1).

Due to the increase in the atmospheric concentration of greenhouse gases and natural factors during the twentieth century, the Earth's surface has warmed by 0.4-0.8°C; land areas have warmed more than the oceans, with northern, mid-high latitudes warming more than most other parts (Fig. 2). The mean annual continental precipitation has increased by 5-10% over the twentieth century in the Northern Hemisphere and parts of Australia, although it has decreased by 3% over much of the subtropical land areas (e.g. in north and west Africa and parts of the Mediterranean). These changes may be partly due to the increasing global mean surface temperature resulting in a change in atmospheric circulation, a more active hydrologic cycle, and increases in the water-holding capacity throughout the atmosphere leading to a 2-4% increase in the frequency of heavy precipitation events in the mid- and high latitudes of the Northern Hemisphere over the latter half of the twentieth century (Fig. 3).

The severity of droughts has increased, with summer drying and an associated increased incidence of drought in a few areas. In some regions, such as parts of Asia and Africa, the frequency and intensity of droughts have been observed to increase in recent decades. El Niño events have become more frequent, persistent, and intense during the last 20 to 30 years compared to the previous 100 years. This has increased the frequency and intensity of drought and floods in the land-masses around the Pacific, especially in the Southern Hemisphere sub-tropics.

Warming has driven sea-level rise through thermal expansion of seawater and widespread loss of land ice. Based on tide gauge records, and after correcting for land movements, Mean Sea Level increased by an average of 10-20 cm during the twentieth century. A limited number of sites in Europe have nearly continuous records of sea level spanning 300 years and show that the greatest rise in sea level occurred during the twentieth century. Records from Amsterdam (The Netherlands), Brest (France) and Swinoujscie (Poland), as well as other sites, confirm that there has been an accelerated rise in sea level over the twentieth century as compared to the nineteenth century.

Observed regional changes in temperature have been associated with observed changes in physical and biophysical systems. Examples include: the retreat of non-polar glaciers; a reduction in the extent and thickness of Arctic sea ice in summer; earlier flowering and longer growing and breeding seasons for plants and animals in the Northern Hemisphere (where most long-term studies have been carried out); pole-ward and upward (altitudinal) migration of plants, birds, fish and insects; and earlier spring migration and later departure of birds in the Northern Hemisphere.

Increasing sea surface temperatures were recorded in much of the tropical oceans during the last several decades of the twentieth century. Many corals have undergone major, although often partially reversible, bleaching episodes when sea surface temperatures have risen by 1°C above the mean seasonal sea surface temperatures in any one season, and extensive mortality has occurred with a 3°C rise. Bleaching events are also associated with other stresses such as pollution and disease. Changes in the frequency and intensity of precipitation, pH, water temperature, wind, dissolved CO₂ and salinity, combined with anthropogenic pollution by nutrients and toxins, can all affect water quality in estuarine and marine waters. Some marine disease organisms and algal species, including those associated with toxic blooms, are strongly influenced by one or more of these factors. In the last few decades of the twentieth century, there was an increase in reports of diseases affecting coral reefs and sea-grasses, particularly in the Caribbean and temperate oceans.

As mentioned above, most of the warming has been attributed to human activities, particularly the emission of greenhouse gases originating from the burning of fossil fuel, and changes in land use and land cover; the evidence for this attribution has become stronger over time from the first assessment report of the IPCC in 1990 to the second in 1995 and the third in 2000. Specific conclusions from these assessments were:

1. First Assessment Report 1990: "...the observed increased [warming] could be largely due to ... natural variability; alternatively this variability and other human factors could have offset a still larger human-induced greenhouse warming".

2. Second Assessment Report 1995: “The balance of evidence suggests a discernible human influence on global climate”.
3. Third Assessment Report 2000: “Most of the observed warming in the past 50 years is attributable to human activities”.

Projected changes in the climate system and sea level

Future emissions of greenhouse gases and aerosols are determined by driving forces such as changes in human population (total number and structure), socio-economic development and technological change. The IPCC Special Report on Emission Scenarios presents six groups of scenarios or plausible futures (so called “SRES scenarios”) which are based on narrative story-lines and span a wide range of driving forces. The scenarios are used to project the future emissions of the greenhouse gases carbon dioxide, methane and nitrous oxide and the aerosol sulphur dioxide. For gases that stay in the atmosphere for a long period, such as carbon dioxide, the atmospheric concentration responds to changes in emissions relatively slowly, whereas for short-lived gases and aerosols, such as sulphate aerosols, the atmospheric concentration responds much more quickly.

Using the SRES scenarios, the IPCC has projected that carbon dioxide concentrations, temperatures and sea levels will continue to rise long after emissions of greenhouse gases are reduced. This is due to the length of the half-life of carbon dioxide in the atmosphere as well as “inertia” in the system. Even if the emissions were to be stopped today, the Earth’s surface temperature could continue to rise for a few centuries, and sea level, due to thermal expansion and melting of ice, could continue to increase for several millennia.

Projected changes for surface temperatures, precipitation and sea level are:

1. The globally averaged surface temperature is projected to increase by 1.4 to 5.8°C over the period 1990-2100. This is about two to ten times larger than the central value of observed warming over the twentieth century. The projected rate of warming is very likely to be without precedent during at least the last 10 000 years, based on long-term data on climate. For the periods 1990-2025 and 1990-2050, the projected increases are 0.4 to 1.1°C and 0.8 to 2.6°C, respectively. These results are for the full range of SRES scenarios, based on a number of climate models.
2. Some areas are projected to become wetter and others drier, with an overall increase in precipitation projected.
3. Global mean sea level is projected to rise by 0.09 to 0.88 m between the years 1990 and 2100. For the periods 1990-2025 and 1990-2050, the projected rises are 0.03 to 0.14 m and 0.05 to 0.32 m, respectively. This is due primarily to thermal expansion and loss of mass from glaciers and ice-caps.

Projections for climate-related extreme events (e.g. floods, heat waves etc.) include:

1. Higher maximum temperatures; more hot days and heat waves over nearly all land areas.
2. Higher minimum temperatures; fewer cold days, frost days and cold spells over nearly all land areas.
3. More intense precipitation events over many areas.
4. Increased summer drying over most mid-latitude continental interiors and associated risk of drought.
5. Increase in peak wind intensity and mean and peak precipitation intensities in tropical cyclones.

These projections could lead to increased heat stress in humans and livestock and decreased productivity in some regions, but could also provide some relief from extreme cold events, especially in mid-high latitudes of the Northern Hemisphere.

Impacts on wetlands

Climate change is likely to affect wetlands and their biodiversity directly (e.g. through changes in temperature) and indirectly (e.g. through affecting the hydrology). Impacts will depend on the coastal morphology and the balance between sea-level rise, deposition and erosion within catchments and the coastal zone. Wetlands play important roles in the global cycling of water and chemicals, including greenhouse gases – cycles that will be affected by climate change. The risk of impacts of climate change increases with the rate and magnitude of climate change. Specific impacts are projected to include:

1. Initially increased productivity in some mid-latitude regions and a reduction in the tropics and sub-tropics, even with warming of a few degrees.
2. Adverse affects on coastal wetlands and coastal fisheries, e.g. coral bleaching events are expected to increase and mangroves are expected to decline in many coastal zones.
3. Decreased water availability in many arid- and semi-arid regions.
4. Increased forest productivity, including that of forested wetlands, although forest management will become more difficult because of an increase in disturbances (pest outbreaks and forest fires).

Overall, it is projected that there will be more adverse than beneficial impacts on wetlands. Inland and coastal systems are likely to experience large and early impacts. These include:

1. Increased levels of inundation, storm flooding, accelerated coastal erosion, seawater intrusion into fresh groundwater, encroachment of tidal waters into estuaries and river systems, and elevated sea surface temperatures and ground temperatures.
2. Adverse impacts on marine mammal and bird species, especially migratory and nomadic bird populations that depend on coastal habitats.

Developing countries are projected to be the most vulnerable to climate change; many are already more prone to floods and droughts. Large portions of the economies of these countries are in “climate sensitive sectors”, and they have a lower capacity to adapt because of a lack of financial, institutional and technological capacity and access to knowledge.

Traditional indigenous societies that depend on inland and coastal wetlands are already vulnerable (see also McDonald et al. 1997), and would become more vulnerable as a result of these projected impacts.

Changes in climate will exert additional pressure on ecological systems. Furthermore, processes such as habitat loss, modification and fragmentation, and the introduction and spread of non-native species will affect the impacts of climate change. A realistic projection of the future state of the Earth’s ecosystems needs to take into account patterns of human land use and water use that will greatly affect the ability of organisms to respond to climate change via migration. The composition of most current ecosystems is likely to change, as the species that make up an ecosystem are unlikely to shift together. The most rapid changes are expected where they are accelerated by changes in natural and anthropogenic, non-climatic disturbance patterns.

The risk of extinction will increase for many species that are already vulnerable. Species with limited climatic ranges and/or restricted habitat requirements and/or small populations are typically the most vulnerable to extinction, such as endemic species and biota restricted to islands, peninsulas or

coastal areas. In contrast, species with extensive, non-patchy ranges, long-range dispersal mechanisms and large populations are at less risk of extinction. While there is little evidence to suggest that climate change will slow species losses, there is evidence that it may increase species losses.

Impacts on waterbirds

The general nature of the impacts of climate change on waterbirds can be identified, but the exact extent, intensity and time frames are difficult to project with certainty, as all models of global climate change are at too large a scale and the ecology of most waterbirds is insufficiently understood. Potentially, almost all aspects of their ecology could be affected, either directly or indirectly. However, the most severe effects and those most likely to occur earliest (some have already been detected) include the loss of inter-tidal habitats and increased salinity of coastal freshwater habitats caused by rising sea levels, a reduction in the extent of wetlands and duration of flooding in arid and semi-arid areas resulting from changes in climate variability, and the loss of wetland breeding habitats in Arctic and sub-Arctic areas caused by increasing temperatures, expanding boreal forests and forest fires.

The extent of loss of inter-tidal habitats and its effects on coastal waterbirds will depend on the ability of coastal environments to move inland as sea level rises. Where this is possible, either because of a lack of artificial coastal defences or by their removal, inter-tidal areas might expand and some changes in sediment characteristics, especially an increase in coarser sandy sediments, might be expected. This would benefit some species such as the Eurasian Oystercatcher *Haematopus ostralegus*. However, it is more likely that coastal defences around many areas will be strengthened, resulting in a compression of inter-tidal habitats and loss of total inter-tidal area. For the United States, Galbraith *et al.* (2002) have predicted losses of between 20% and 70% of current inter-tidal areas by 2100. This will have serious implications for the total numbers of shorebirds that can be supported (Norris & Atkinson 2000). Critically, the length of time that remaining inter-tidal areas are exposed during each tidal cycle will be reduced. The time shorebirds spend feeding during low tide depends on their body size and ambient temperatures, and is also increased when accumulating reserves prior to migration (Zwarts *et al.* 1990, Piersma & Jukema 1990). Smaller species spend almost all of the time feeding (Dann 1999) and potentially could be the most seriously affected. A reduction in the expenditure of metabolic energy through rising temperatures is unlikely to offset the loss of feeding time. Some inter-tidal areas will probably become unusable by the smaller species. In other areas, reductions in survival during winter and subsequently during migration might be expected, and lower body condition on arrival at Arctic breeding areas might reduce breeding success of migratory waders and other species such as wildfowl (Newton 1998, Pettifor *et al.* 2000).

Changes in immersion periods, sediment characteristics and also rising temperatures will cause changes in the distribution, abundance and growth of the inter-tidal invertebrate populations which constitute the prey of shorebirds (Decker & Beukema 1999, Beukema 2002), and in some cases, this might increase the availability of food. However, this relationship is not clear, as increased temperatures can also lead to a decrease in body condition of some invertebrates during winter, reducing the food value of individual prey items (Honkoop & Beukema 1997).

The effects of rising temperatures on plant communities will be particularly strong in the Arctic (Neilson & Drapek 1998), and this will lead, among other changes, to an expansion of boreal forest into current tundra areas where two thirds of all goose species and 95% of all Calidrid sandpipers breed. Losses in the breeding ranges of these tundra breeding waterbirds of between 5% and 93%, depending on the species and the degree of warming, have been predicted as a result of this forest expansion by 2070/2099 (Zöckler & Lysenko 2000). The annual breeding success of some species is correlated with spring temperatures (Zöckler & Lysenko 2000), so rising temperatures could increase productivity, which might compensate to some extent for habitat loss. Set against this, however, is a likely increase in loss of nests and chicks to predation as temperate climate predators such as the Red Fox *Vulpes vulpes* expand their range (Parmesan & Yohe 2003).

Changes in global circulation patterns will result in alterations to rainfall patterns, with some areas experiencing increases and others decreases. Included in the latter are some currently dry areas, such as Australia and parts of Asia and Africa. Wetlands and waterbird populations in these areas are already highly stressed from habitat loss to agriculture, reduced water flows caused by water abstraction for irrigation, pollution and increasing salinization (Kingsford & Johnson 1998, Kingsford 2000, Kingsford & Norman 2002). Waterbird populations in the drier continents are characterized by unpredictable and relatively infrequent breeding, high adult survival and high mobility. Successful breeding often requires exceptional flooding events that last long enough for completion of the breeding cycle (Leslie 2001, Kingsford & Norman 2002). Reduced rainfall will increase the intervals between flooding events and shorten their duration. Reduced breeding success and recruitment should be expected as a first response, followed by reduced survival of adults and then widespread population declines. Some indication of the sensitivity of such systems is provided by an analysis of the survival rates of the Sedge Warbler *Acrocephalus schoenobaenus*, a wetland passerine, breeding in Britain and wintering in West Africa. Annual survival rates are strongly correlated with rainfall in West Africa, and have varied from 2.5% to 55% (Peach *et al.* 1991).

Changes to waterbird populations should also be expected in less severely affected areas. Increased temperatures will advance breeding seasons and possibly reduce winter mortality (Crick & Sparks 1999, Winkler *et al.* 2002). The vegetation structure of wetlands can be expected to change, altering the physical aspects of habitats and plant productivity. There will almost certainly be great regional variation, with some areas experiencing increases in waterbird populations and others, decreases (Smart & Gill 2003).

THE ROLE OF ADAPTATION

Adaptation has the potential to reduce the adverse effects of climate change, but cannot prevent all impacts. Numerous adaptation options (projects and processes designed to reduce the impact of climate change) have been identified that can reduce adverse and enhance beneficial impacts of climate change, but will incur costs (see van Dam *et al.* 2002, Gitay *et al.* 2002). Adaptation is a necessary strategy to complement efforts to mitigate climate change (deliberate actions to reduce the sources or enhance the sinks of greenhouse gases). Adaptation and mitigation can contribute to sustainable development objectives for wetlands.

Adaptation activities can promote conservation and sustainable use of biodiversity and reduce the impact of changes in climate and climatic extremes on biodiversity. These activities include the establishment of a mosaic of interconnected multiple-use reserves designed to take into account projected changes in climate, and integrated land and water management activities that reduce non-climate pressures on biodiversity and hence make the systems less vulnerable to changes in climate. Some of these adaptation activities can also make people less vulnerable to climatic extremes. The effectiveness of adaptation and mitigation activities can be enhanced when they are integrated within broader strategies designed to make development paths more sustainable.

The way in which different species respond to changes caused by global warming will be determined by their individual inherent adaptive capacity and the time necessary for those adaptations to take effect. In particular, patterns of bird migration will change and be very different across species, for different latitudes and different regions of the biosphere. The most general definition of animal migration is given by Baker (1978): "Migration: the act of moving from one spatial unit to another". The classic form of bird migration is the regular seasonal movement from the breeding areas to the resting grounds (often called wintering quarters) and back (Schüz *et al.* 1971), but bird movements occur in an abundance of different forms: dispersal, irruption, partial migration, differential migration etc. (Berthold 1993).

Many studies have shown that all the main morphological, physiological and behavioural prerequisites for bird migration are under direct genetic control (Seebohm 1901, Butler & Woakes 1990, Mönkkönen 1992). Therefore, endogenous migratory patterns may not change in a time frame

sufficient to adapt to global warming, and as a consequence the species will be forced to change the extent of their migratory patterns. There is evidence that some species of migratory birds in the Mediterranean region have reduced their migratory behaviour in relation to global warming (Berthold 1988, Berthold & Terrill 1988). The predicted increased incidence of drought in sub-tropical regions could lead to an increase in dry-season migration amongst resident species causing direct competition for food between resident and migratory species. At higher latitudes, mild winters could increase the survival of resident and partially migratory species, with the consequence that long-distant migrants would find themselves at a disadvantage on their arrival on breeding grounds occupied by larger numbers of residents. On the other hand, climatic changes may also have positive effects, such as the expansion of subtropical populations to higher latitudes (Berthold 1988), and result in an unprecedented gene flow and thus a multitude of micro-evolutionary processes.

From the above considerations, it is implicit that, in the next decades, global change (including climate change) in general will play a major role in favouring the survival of certain species and will pose a disadvantage to others, if not threaten their survival. It is likely that partially migratory or less markedly migratory species would succeed in developing resident populations, but it is not clear how quickly long-distance migrants would succeed in reducing their migratory behaviour to such an extent that they would be able to stay on the breeding grounds throughout the year in the event of severe climatic changes (Berthold 1993). Migratory species with restricted ranges, restricted foraging niches (in their breeding and non-breeding areas), or under threats from other pressures such as loss and modification of habitat, pollution and weed invasion, are likely to be the most affected.

For migratory species, and in particular long-distance migrants, scientists need to devote more research effort to determine:

1. the effects of habitat alteration at stopover points and wintering areas;
2. the amounts and locations of major habitat types, through inventories, as well as the carrying capacities of these habitats; and
3. the behaviour, home range and resource needs of species most likely to be vulnerable to global warming.

On the management and conservation fronts, efforts should be devoted to:

1. maintaining population inventories of migratory birds. These inventories should form the basis for determining and designating critical habitat under various management responses, and hence encourage specific known adaptations.
2. identifying, obtaining and protecting critical stopover and wintering sites, particularly for those species whose populations tend to concentrate at few sites; and
3. addressing policies and legislation at a continental scale, or better at a flyway scale where possible.

RISK ASSESSMENT

Ecological risk assessment is not a new tool, but in recent years the usefulness of its application to wetland management has been promoted and accepted formally through the Ramsar Convention on Wetlands (van Dam *et al.* 2002). Ecological risk can be described as the likelihood of the occurrence of an adverse ecological effect of specific magnitude. Thus, ecological risk assessment attempts to quantify both the magnitude of an ecological effect and the likelihood of the effect occurring (US EPA 1998). It provides a structured, iterative approach for making rational and transparent decisions based on the best available knowledge and recognition of the associated uncertainties.

Risk assessment frameworks exist in a variety of forms (US EPA 1998, AS/NZS 1999, van Dam *et al.* 1999, US EPA 2003, Hart 2004), although they generally encompass similar steps, most

commonly *problem formulation/hazard identification, effects assessment, exposure (likelihood) assessment* and *risk characterization* (Fig. 4). Additional steps, such as risk communication, risk reduction and monitoring, are also critical in the overall decision-making process, and are necessary to complete the risk management cycle (Burgman 2004). Moreover, identification (and quantification) of the key uncertainties and gaps in knowledge enables prioritization of research and data acquisition, which, through iteration of the risk assessment, decreases uncertainty in the risk predictions and outcomes.

Applications of ecological risk assessment are numerous and include assessments that range from: screening-level (qualitative) to detailed (quantitative) or a combination of both (i.e. tiered ecological risk assessment); predictive to retrospective in temporal scale; local to global in spatial scale; and single stressor to multiple stressors (US EPA 1998, Burgman 2004). Increasingly, risk assessment is being used in a catchment or basin context to assess, prioritize and manage multiple stressors, pathways, ecological resources/assets and competing social values (Serveiss 2001, Hart *et al.* 2003). For example, catchment (or watershed) scale risk assessments have been undertaken in North America (see summaries by Serveiss 2001) and Australia (eg. Begg *et al.* 2001, Pollino *et al.* 2005) estimating relative and/or cumulative risks to aquatic ecosystems of multiple stressors including toxicants, nutrients, sediments and altered flow regimes. Further, the development of a decision support tool to prioritize and protect or restore wetlands of importance to the water quality of Australia's Great Barrier Reef includes a process that assesses and compares ecological risks across multiple wetland sites and from multiple threats (Finlayson *et al.* 2004).

Although climate change poses one of the greatest threats to wetland ecosystems (see van Dam *et al.* 2002), to date there appear to have been few, if any, applications of ecological risk assessment to this issue. Generally, vulnerability assessment has been used to help identify potential impacts of climate change and sea-level rise (IPCC & Coastal Zone Management Subgroup 1991, Waterman 1996). The vulnerability assessment process requires identification of both climatic and non-climatic (e.g. deforestation, water pollution, water extraction, over-fishing) pressures, but does not specifically involve a structured assessment of the relative risks of these pressures or the interactions between them. There are many similarities between ecological risk assessment and vulnerability assessment – a topic that is currently being addressed by the Scientific and Technical Review Panel of the Ramsar Convention on Wetlands.

It is anticipated that utilizing existing and emerging methodologies for ecological risk assessment (e.g. Bayesian and frequentist approaches; see Burgman 2004) should enhance vulnerability assessments of the impacts of climate change on wetlands by:

1. including ecological risks of existing pressures as well as projected climate change;
2. comparing ecological risks of existing and predicted/forecast pressures, including climate change;
3. assessing the impact of climate change on risks of existing/forecast pressures (e.g. invasive species, water extraction/availability); and
4. providing a structured process by which to identify explicitly the key uncertainties and associated gaps in information and research.

A catchment scale, multiple stressor ecological risk assessment underway for the Magela Creek catchment in the Alligator Rivers Region (ARR) of northern Australia (Finlayson & Bayliss 2005) provides an example of the application of risk assessment to multiple pressures on wetlands. The assessment is focusing on the relative and cumulative ecological risks of uranium mining, invasive weeds, feral animals and salt water intrusion, the latter threat being one of the major consequences for the region of projected sea-level rise due to climate change. Initial analyses have assessed the probability of adverse change occurring as a consequence of individual pressures and provide a basis for comparing the relative probability of adverse effects. The comparative analyses also provide a

basis for reassessing the results and the veracity of the information that was used, particularly if the results were unexpected. Furthermore, it is possible to link ecological models to the risk assessment models.

For the Magela analyses, it is intended to incorporate habitat suitability models for key weeds such as Paragrass *Urochloa mutica* and Mimosa *Mimosa pigra* and conceptual models for the feeding ecology of waterbird populations to assess the relative risks from various pressures including climate change projections. This provides an example of the usefulness of risk assessment in addressing multiple pressures, but it should be emphasized that the success of such assessments will only be realized through the accumulation of essential information. In addition to providing information on the relative risks, the risk assessment model provides a structured way to identify information gaps. In terms of the ongoing assessment of the consequences of climate change for wetlands and waterbirds, the various projections given above could potentially be supported through application of ecological risk assessment, particularly where multiple pressures may be involved and where probabilistic analyses could be used to identify individual responses and overcome information gaps. This is well known scientifically, but there is insufficient evidence that such approaches are being effectively incorporated into management and monitoring regimes for wetlands and waterbirds.

IDENTIFIED INFORMATION NEEDS AND GAPS

As noted above, it is widely accepted that human activities are adversely affecting ecosystems and their ability to provide ecosystem services that support humans and life on earth more generally. As climate change and other environmental pressures are inter-linked, we need to assess the effects of these multiple pressures if we are to develop programmes and actions that support sustainable development and human well-being. This assessment includes:

1. obtaining knowledge of the extent of many wetland types, their condition and their hydrology (Finlayson *et al.* 1999);
2. improved understanding of the response of wetlands and wetland species to changes in climatic factors and other pressures (van Dam *et al.* 2002);
3. development of data and models for the geographical distribution of species and their response to climate change at regional level (van Dam *et al.* 2002, IPCC 2002);
4. development of models that include patterns of human land use and water use to provide a realistic projection of the future state of wetlands; and
5. indicators to measure the effect of adaptation and mitigation options for climate change.

Increasingly, decision support systems of various complexity are being developed to assist managers make decisions about complex management scenarios, such as that presented by the pressures generated by climate change. Various technical experts have recently promoted ecological risk assessment as a means to support decision-making for wetland management (Finlayson *et al.* 2004, Hart 2004). As it is unclear what the interactions are between climate change and the many other pressures affecting wetlands, it is recommended that quantitative wetland risk assessments be undertaken as a means of addressing the uncertainty that currently characterizes many management or adaptation options for sustainable use of wetlands.

REFERENCES

- AS/NZS** 1999. Risk Management. Australian Standards, New Zealand Standards, No. 4360. Standards Australia, Canberra, Australia.
- Baker, R.R.** 1978. The Evolutionary Ecology of Animal Migration. Hodder & Stoughton, London, UK.

- Begg, G.W., van Dam, R.A., Lowry, J.B., Finlayson, C.M. & Walden, D.J.** 2001. Inventory and Risk Assessment of Water Dependent Ecosystems in the Daly Basin, Northern Territory, Australia. Supervising Scientist Report 162. Supervising Scientist, Darwin, Australia.
- Berthold, P.** 1988. Evolutionary aspects of migratory behaviour in European warblers. *Journal of Evolutionary Biology* 1: 195-209.
- Berthold, P.** 1993. *Bird Migration. A General Survey.* Oxford Ornithology Series. Oxford University Press, UK.
- Bertold, P. & Terrill, S.B.** 1988. Migratory behaviour and population growth of blackcaps wintering in Britain and Ireland: some hypotheses. *Ringed & Migration* 9: 153-9.
- Beukema, J.J.** 2002. Expected changes in the benthic fauna of Wadden Sea tidal flats as a result of sea-level rise or bottom subsidence. *Netherlands Journal of Sea Research* 47: 25-39.
- Burgman, M.A.** 2004. *Risks and Decisions for Conservation and Environmental Management.* Cambridge University Press, Cambridge, UK.
- Butler, P.J. & Woakes, A.J.** 1990. The physiology of bird flight. In: E. Gwinner (ed) *Bird migration: the physiology and ecophysiology.* Springer-Verlag, Berlin: 300-318.
- Crick, H.Q.P. & Sparks, T.H.** 1999. Climate change related to egg-laying trends. *Nature* 399: 423-424.
- Dann, P.** 1999. Feeding periods and supratidal feeding of Red-necked Stint and Curlew Sandpipers in Western Port, Victoria. *Emu* 99: 218-222.
- Decker, R. & Beukema, J.J.** 1999. Relations of summer and winter temperatures with dynamics and growth of two bivalves, *Tellina tenuis* and *Abra tenuis*, on the northern edge of their intertidal distribution. *Netherlands Journal of Sea Research* 42: 207-220.
- Finlayson, C.M. & Bayliss, P.** 2005. Landscape-scale and multiple pressure analyses of services provided by tropical floodplains, in the Alligator Rivers Region, northern Australia. Millennium Ecosystem Assessment, Volume 1, Sub-global program. In press.
- Finlayson, C.M. & D’Cruz, R.** 2005. Inland Water Systems. In: Millennium Ecosystem Assessment, Volume 1, Conditions and Trends, Millennium Ecosystem Assessment: Strengthening Capacity to Manage Ecosystem Sustainably for Human Well-being. In press.
- Finlayson, C.M., Davidson, N.C., Spiers, A.G. & Stevenson, N.J.** 1999. Global wetland inventory – Status and priorities. *Marine and Freshwater Research* 50: 717-727.
- Finlayson, C.M., van Dam, R.A., Benzaken, D. & Ingliss, R.** 2004. Towards the development of a decision support system to select wetlands for strategic intervention. Report of a technical workshop held in Townsville, 8-9 December 2003. Australian Government Department of the Environment and Heritage, Canberra, Australia. (<http://www.deh.gov.au/coasts/information/pubs/workshop.pdf>)
- Galbraith, H., Jones, R., Park, R., Clough, J., Herrod-Julius, S., Harrington, B. & Page, G.** 2002. Global climate change and sea level rise: potential losses of intertidal habitat for shorebirds. *Waterbirds* 25: 173-183.
- Gitay, H., Suarez, A., Watson, R.T. & Dokken, D.** (eds). 2002. IPCC Technical Paper V. Intergovernmental Panel on Climate Change, Geneva, Switzerland.

- Hart, B.T.** 2004. Environmental risks associated with new irrigation schemes in Northern Australia. *Ecological Management and Restoration* 5: 107-111.
- Hart, B.T., Lake, P.S., Webb, J.A. & Grace, M.R.** 2003. Ecological risk to aquatic ecosystems from salinity increases. *Australian Journal of Botany* 51: 689-702.
- Honkoop, P.J.C. & Beukema, J.J.** 1997. Loss of body mass in winter in three intertidal bivalve species: an experimental and observational study of the interacting effects of water temperature, feeding time and feeding behaviour. *Journal of Experimental Marine Biology and Ecology* 212: 277-297.
- IPCC** 2001. *Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* R.T. Watson and Core Writing Team. Cambridge University Press, Cambridge, UK, and New York, USA.
- IPCC** 2002. *Climate Change and Biodiversity.* In: H. Gitay, A. Suarez, R.T. Watson & D. Dokken (eds) IPCC Technical Paper V. Intergovernmental Panel on Climate Change, Geneva, Switzerland.
- IPCC & Coastal Zone Management Subgroup** 1991. *Common Methodology for Assessing Vulnerability to Sea Level Rise.* Ministry of Transport and Public Works, The Hague, The Netherlands.
- Kingsford, R.T.** 2000. Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. *Austral Ecology* 25: 109-127.
- Kingsford, R.T. & Johnson, W.** 1998. Impact of water diversions on colonially-nesting waterbirds in the Macquarie Marshes of arid Australia. *Colonial Waterbirds* 21: 159-170.
- Kingsford, R.T. & Norman, F.I.** 2002. Australian Waterbirds – products of the continent’s ecology. *Emu* 102: 47-69.
- Leslie, D.** 2001. Effect of river management on colonially-nesting waterbirds in the Barmah-Millewa forest, south-eastern Australia. *Regulated Rivers: Research and Management* 17: 21-36.
- McDonald, M., Arragutainaq, L. & Novalinga, Z.** 1997. *Voices from the Bay.* Canadian Arctic Resources Committee and Environmental Committee of the Municipality of Sanikiluaq, Ottawa, Canada. (Also at <http://www.isuma.net/>).
- Mönkkönen, M.** 1992. Life history traits of Palearctic and Nearctic migrant passerines. *Ornis Fennica* 69: 161-172.
- Neilson, P.R. & Drapek, R.J.** 1998. Potentially complex biosphere responses to transient global warming. *Global Change Biology* 4: 505-521.
- Newton, I.** 1998. *Population Limitation in Birds.* Academic Press, London, UK.
- Norris, K. & Atkinson, P.W.** 2000. Declining populations of coastal birds in Britain: victims of sea-level rise and climate change? *Environmental Reviews* 8: 303-323.
- Parmesan, C. & Yohe, G.** 2003. A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421: 37-42.
- Peach, W., Baillie, S. & Underhill, L.** 1991. Survival of British sedge warblers *Acrocephalus schoenobaenus* in relation to West African rainfall. *Ibis* 133: 300-305.

- Pettifor, R.A., Caldow, R.W.G., Rowcliffe, J.M., Goss-Custard, J.D., Black, J.M., Hodder, K.H., Houston, A.I., Lang, A. & Webb, J.** 2000. Spatially explicit, individual-based, behavioural models of the annual cycle of two migratory goose populations. *Journal of Applied Ecology* 37: 103-135.
- Piersma, T. & Jukema, J.** 1990. Budgeting the flight of a long-distance migrant: changes in nutrient reserve levels of Bar-tailed Godwits at successive staging sites. *Ardea* 78: 315-337.
- Pollino, C.A., Woodberry, O., Nicholson, A. & Korb, K.** 2005. Parameterising Bayesian Networks: A case study in ecological risk assessment. In: V. Kachitvichyanukul, U. Purintrapiban & P. Utayopas (eds) *Proceedings of the 2005 International Conference on Simulation and Modeling*.
- Schüz, E., Berthold, P., Gwinner, E. & Oelke, H.** 1971. *Grundriß der Vogelzugkunde*. Parey, Berlin-Hamburg, Germany.
- Seebohm, H.** 1901. *Birds of Siberia*. Murray, London.
- Serveiss, V.B.** 2001. Applying ecological risk principles to watershed assessment and management. *Environmental Management* 29: 145-154.
- Smart, J. & Gill, J.** 2003. Climate change and the potential impact on breeding waders in the U.K. *Wader Study Group Bulletin* 100: 80-85.
- US EPA (U.S. Environmental Protection Agency)** 1998. *Guidelines for Ecological Risk Assessment*. EPA/630/R-95/002F. Risk Assessment Forum, Washington, D.C.
- US EPA (U.S. Environmental Protection Agency)** 2003. *Framework for Cumulative Risk Assessment*. EPA/630/P-02/001F. Risk Assessment Forum, Washington, D.C.
- van Dam, R.A., Finlayson, C.M. & Humphrey, C.L.** 1999. Wetland risk assessment: a framework and methods for predicting and assessing change in ecological character. In: C.M. Finlayson & A.G. Spiers (eds) *Techniques for Enhanced Wetland Inventory, Assessment and Monitoring*. Supervising Scientist Report 147. Supervising Scientist, Canberra, Australia: 83-118.
- van Dam, R., Gitay, H., Finlayson, M., Davidson, N.J. & Orlando, B.** 2002. *Climate Change and Wetlands: Impacts, Adaptation and Mitigation*. Background document (DOC.SC26/COP8-4) prepared for the 26th Meeting of the Standing Committee of the Convention on Wetlands (Ramsar Convention) held in Gland, Switzerland, 3-7 December 2002.
- Waterman, P.** 1996. *Australia's coastal vulnerability report*. DEST, Canberra, ACT.
- Winkler, D.W., Dunn, P.O. & McCulloch, C.E.** 2002. Predicting the effects of climate change on avian life-history traits. *Proceedings of the National Academy of Sciences of the United States of America* 99: 13595-13599
- Zöckler, C. & Lysenko, I.** 2000. *Waterbirds on the edge*. WCMC Biodiversity Series No. 11. UNEP-World Conservation Monitoring Centre, Cambridge, UK.
- Zwarts, L., Blomert, A.M. & Hupkes, R.** 1990. Increase in feeding time in waders preparing for spring migration from the Banc D'Arguin, Mauritania. *Ardea* 78: 237-256.

Fig. 1. Observed changes in atmospheric concentrations of carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) over the past 1 000 years and sulphur dioxide (SO₂) aerosols over the last 600 years (from IPCC 2001).

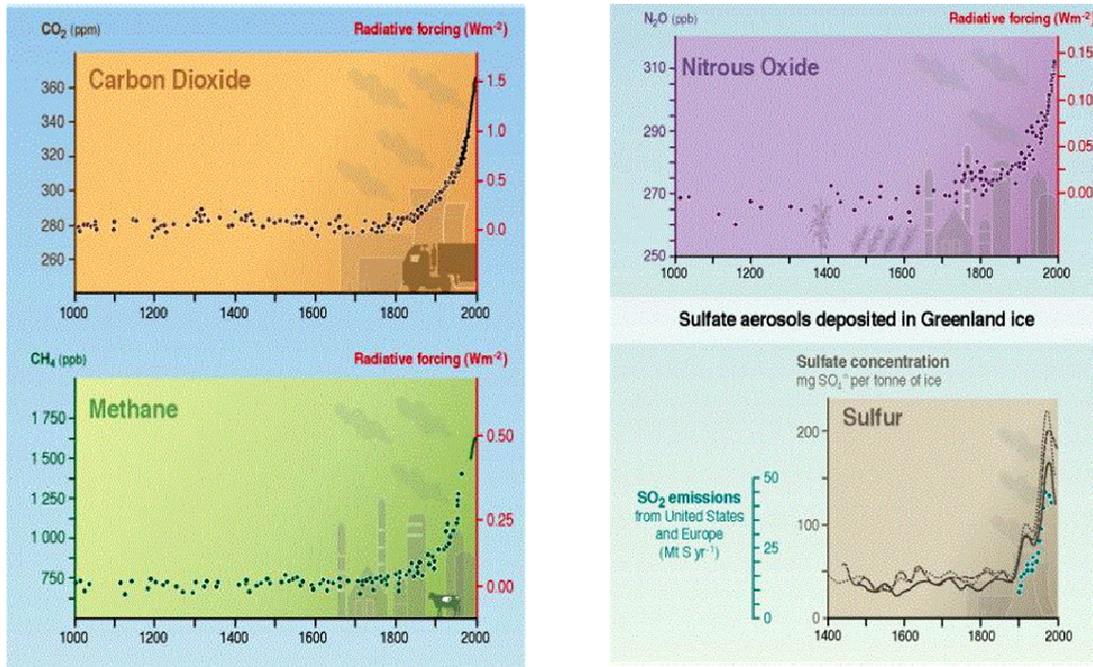


Fig. 2. Observed changes in global-average surface temperature (from IPCC 2001).

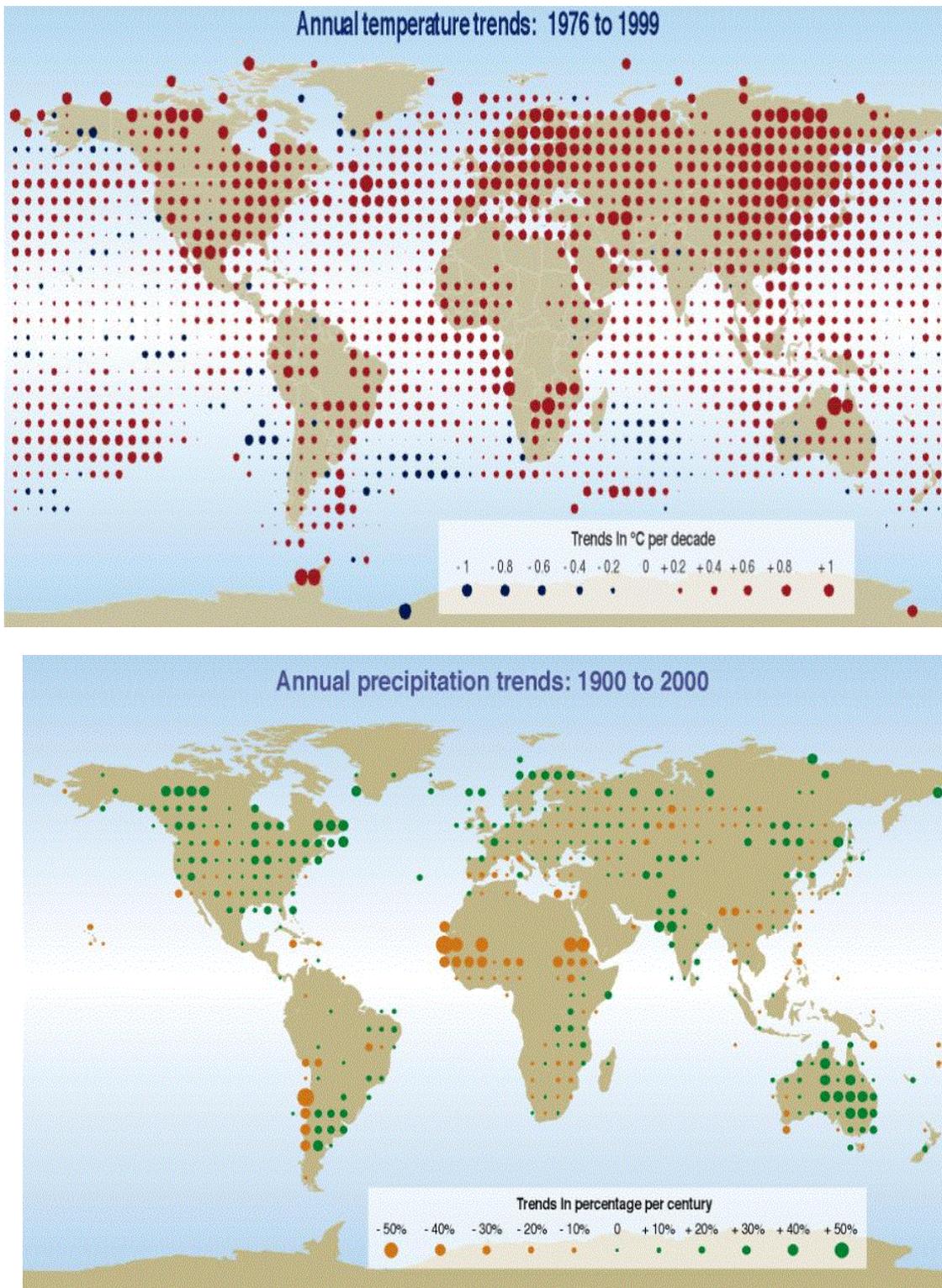
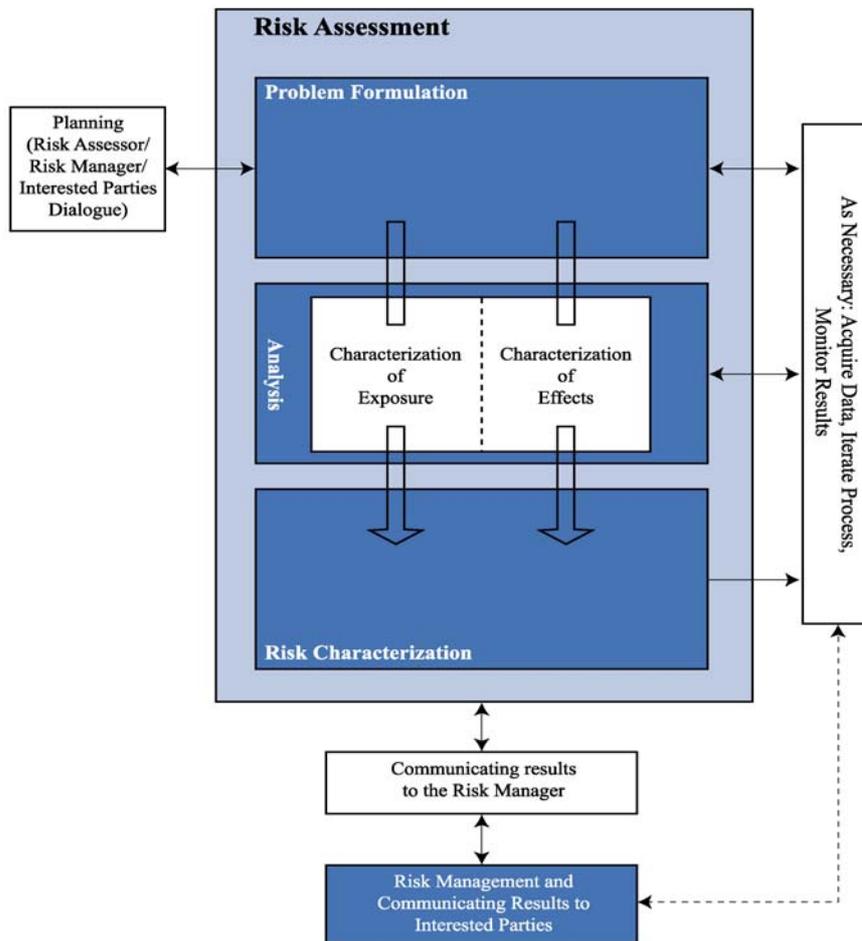


Fig. 4. Generalized framework for ecological risk assessment (modified from US EPA 1998).



Recommendations related to migratory birds from *Climate change and migratory species*¹

7.10.2. Key Conservation Priorities

Climate induced changes in habitat area, phenology and demography are likely to affect all bird species in the future, irrespective of their migratory status, but three key areas apply particular to migratory birds:

- Increase drought frequency and desertification in the Sahel making the northwards migratory journey more difficult for many passerine species (particularly migratory members of the Muscicapidae, listed on CMS Appendix II).
- Maintenance of a network of high quality wetland sites to allow many waders and waterfowl (listed on CMS Appendices I and II) to complete their migratory journeys.. These are threatened by sea-level rise and a reduction in water table level, as well as, in some cases, critical anthropogenic exploitation. In many cases this simply means making best use of existing measures. Compiling an inventory of these sites and their status for each flyway would be a useful step in assessing the coherence of the migratory network; much of this information is already available, but scattered in the literature.
- The maintenance of key long-term monitoring schemes, as these are of utmost importance for the detection of new and unexpected impacts of climate change. Birds are perhaps the best monitored of taxonomic groups, being relatively popular and thus with monitoring schemes that take advantage of extensive volunteer participation. Changes in bird populations may act as an early warning system of changes that may also impact on other parts of the food chain and other taxonomic groups.

7.10.3 Key Research Priorities

The effects and impacts of climate change on populations are best documented and best understood for birds as a whole, but more work is required to fully understand and accurately predict the impacts of a changing climate. Key research areas are:

- Understanding the mechanisms behind the observed responses to climate change to better implement adaptation measures.
- Understanding the strength and prevalence of density-dependence factors (and the role of population limiting factors more generally) in regulating population processes. This is necessary if accurate modelling and prediction of future population changes is to be achieved.
- Understanding the importance and need for genetic variability for populations to respond to climate change. Currently, very little is known in this area.

¹ Robinson, R.A., Learmouth, J.A., Hutson, A.M. Macleod, C.D., Sparks, T.H., Leech, D.I., Pierce, G/J., Rehfish, M.M. & Crick, H.Q.P. *Climate change and migratory species*. Report to DEFRA. BTO Research Report 414. 304 pp. www.defra.gov.uk/wildlife-countryside/resprog/findings/climatechange-migratory