Climate Information and Capacity Needs for Ecosystem Management,
under a Changing Climate

White Paper

Prepared for the

World Climate Conference – 3

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Introduction

Rational: This White Paper is in response to the increasing need to incorporate the best available climate information in decision making for ecosystems management. This is due to the increasing climate change impacts on natural resource management, biodiversity and ecosystem services[1]. The Paper is in recognition of the fundamental need to improve ecosystems health and services they provide for human well being. Increasingly there is need to consider the trade-offs and synergies in multiple objectives from ecosystem conservation and resource use. To adequately do so requires adequate climate information to understand how ecosystem management through interactions of natural resource management, biodiversity and ecosystem services, will respond to climate change and other multiple stressors.

Definition - Ecosystems: Here we use the term "ecosystems" as the common focus of natural resource management, biodiversity conservation and the services provided by ecosystems. We broadly define ecosystems to include all terrestrial and marine systems, both natural and semi-natural (including lands used for pastoralism, agriculture and forestry[2]). By being immersed in and components of ecosystems, humans have a self-preserving interest in understanding and managing ecosystems as fundamental life-supporting systems. Ecosystems provide the habitat resources needed by species, which in turn regulate key processes. Regional climate is both a driver and constraint of ecosystem structure and functions. Climate change poses impacts on species and the functional roles they play in ecosystems. Changing climate therefore alters, directly or indirectly, ecosystem characteristics and the sustainability of life-support services. From this perspective, ecosystem-based management is both essential and urgently needed to respond to climate change.

Definition – Decision makers: These are people who directly or indirectly make decisions that influence ecosystem management. We also include those that support or contribute to the decision process, including scientists, policy and legislation advisors, NGOs and others. Land and sea management operate under a range of legal tenures including international, private, leasehold, public and customary. Decision makers can therefore span international bodies, national and local governments, co-operations, communities, and individuals. Often, these different stakeholders are acting in a highly interactive way due to legal requirements and policy overlays that exercise an influence over how humans use ecosystems.

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[1] Definition of Ecosystem Services:

[2] Here we do not consider the response of agriculture or forestry production *per se*, as this is covered elsewhere at WCC-3, but we emphasize links between changes in agricultural and forestry ecosystem management and impacts within them and external to them. We also acknowledge that agricultural and forestry management practices affect other natural resources, biodiversity and ecosystem services.

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Definition – Climate Information: For the purpose of this paper we define climate information to include baseline observed data (range of time steps), trends, variability and higher-order statistics, extremes, inter-annual variability, and inter-decadal variability, for both the past and projected future climate. It also includes the associated information and assistance to interpret and use these data.

White Paper structure

The Paper is set out in the following order: firstly we provide details to establish the aims of the paper and background to the problem, the information being at a generic level. Secondly we provide details of a set of recommendations that support the WCC-3 expected outcomes and then specific recommendations for achieving specific goals. Given that the scope of this paper is to cover all ecosystems, the information given must be interpreted as such, as it was not possible to provide details for every type of ecosystems.

Aim*:* The aim of this White Paper is to form the basis for discussion at the WCC-3 and set the foundations for a framework to provide appropriate climate information to decision makers. The Paper will serve as a precursor to the UNFCCC Conference of the Parties (COP 15) to be held in Copenhagen (7-18th December 2009)[1] with the aim of providing support for the negotiation process. Further the paper will benefit the development of the Global Climate Information Framework and of the Global Climate Change Adaptation Network [2]. The purpose is to help build climate resilience of vulnerable human systems, ecosystems and economies through increased understanding of ecosystems and the mobilisation of knowledge and technologies to support adaptation policy setting, planning and practices.

Whilst the focus here is on climate information needs for decision making we take a holistic view on the general need for better information across many subjects to better inform the decision making process for ecosystem management. We aim to provide direction in response to key questions:

- What climate information do decision makers need?

  o Recognising that decisions are made using a wider range of information types (ecological, economic, policy etc.) not just on climate.

  o What support do decision makers need in using climate information?

  o Climate information is needed in respect of the context of ecosystem

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[1] See http://en.cop15.dk/ and http://unfccc.int/2860.php

[2] See http://www.unep.org.bh/Newsroom/pdf/CC%2017%20GAN%20Strategy%20Jan09.pdf for the draft strategy and
http://www.unep.org.bh/Newsroom/pdf/CC%2017%20GAN%20Strategy%20Jan09.pdf   for an overview of objectives.

management issue and level of human involvement.

- What is the current capacity of information providers to meet the needs, and for decision makers to respond to the information?

- How to match the level of climate information detail available to issues of scale (temporal, spatial and urgency)?

- How best to provide the climate information to decision makers and facilitate the use of it for appropriate ecosystem management? Considering:

  o Need for strategic planning (multiple urgency, time and spatial scales).

  o Other drivers of change (including economics, policy, demography) which are dynamic and therefore difficult to predict.

  o Methods of communication between information providers, decision makers and other stakeholders.

- How can credibility be built between climate information providers, decision makers and society as a whole?

These and other questions are addressed within this White Paper. Further to this, we argue there is need for an approach that integrates across information types (i.e. weather, climate, socio-economic, policy and ecology) to better inform those involved in decision making for ecosystem management.

Fundamentally, the provision and consideration of climate information needs to underpin planning for the future, and must be integrated with those other factors considered in the decision making process. This approach is necessary to enable better informed decision making in planning to ensure the adequate provision of ecosystem services (water, food, air quality, shelter etc) and appropriate climate change adaptation and mitigation strategies for the well being of both people and biodiversity.

Alongside the aims for achieving sustainable natural resource management, biodiversity conservation, and protection of ecosystem services, a further aim is to ensure that climate information needs are considered in supporting the Millennium Development Goals[1] and disaster risk reduction[2].

Basis for ecosystem approach:

Climate and ecosystems are strongly interactive, particularly at the micro-scale, through water and energy cycling. Climate changes at regional to global scale can be amplified or modified by these local processes, with significant consequences to biodiversity and ecosystem functioning.

- Ecosystems form the fundamental unit of life support for humans and all other forms of life. Their functions are primarily driven by the climate.

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[1] See http://www.un.org/millenniumgoals/

[2] See http://www.unisdr.org/

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- Healthy ecosystems support human well being through the provision of ecosystem services. These include the supply of food, fresh water, clean air, fertile soil, biological diversity, and the ability to regulate the climate through energy transfer and the global biogeochemical cycles, including the carbon cycle, but also the nitrogen and phosphorous cycles.

- The ability of ecosystems to function and provide these services is determined by many factors including their biological diversity, ecological and evolutionary processes, climatic inputs of energy and water, anthropogenic impacts related to economic activities, and their interactions.

- Depending on the nature of change and the condition of the system due to human perturbation, climate variability and change can pose substantial risks to ecosystem health, the provision of ecosystem services and therefore human and biodiversity well being.

- Greater value to support ecosystem-based management decision making can be gained through the integration of multiple information types with climate and ecosystem information forming the basis for establishing the boundaries for a sustainable human society.

Decision makers and land stewards have a wide range of considerations - including economics, policy and law, ethics, self interest - in which climate information forms only part of the decision making process. Therefore we aim to raise the profile of both ecosystem management and the associated climate information needed within societal processes and systems (political, economic, and legal) so that climate information exists at the heart of the decision making process.

Challenges

The key challenge is to make it as easy as possible for decision makers to use climate information and to facilitate change in the way that natural resources and ecosystems are valued and managed. However, this is complicated as many decision makers are non-professionals who serve the vulnerable communities and groups whose subsistence livelihoods depend on traditional land use activities in remote areas with poor communication infrastructure. Furthermore, direct manipulation of ecosystem components over extensive areas is expensive and generally unfeasible even for wealthy countries. Generally, human use of ecosystem services is managed indirectly through policy incentives and innovations in management interventions, or indirectly through changes in demand for provisional ecosystem services such as food products. The latter is influenced by consumer choices, people's attitudes, and community values. Therefore, it is important to recognize the complexity of societal factors that influence ecosystem-based management in different bioregions, economies and cultures around the world.

There may be a conflict of interests in how ecosystems are managed, varying with different stakeholder goals and objectives. Climate information needs to inform all concerned as to the consequences of what the different management actions will be.

A major challenge thus becomes how to engage with stakeholders as to what information (climate and other types) they need and how best to provide it. Currently, decision-maker at various levels make only minimal use of existing climatic information.

Maintaining credibility between information providers and stakeholders, given the natural vagaries of climate and the range of uncertainty associated with projections of future climate change and variability will be an essential challenge to address.

The specific challenge of climate change and variability requires than climatic information be seamlessly integrated into risk assessment frameworks and strategic planning for adaptation.

Expected Outcomes

> *"During the course of this century the resilience of many ecosystems (their ability to adapt naturally) is likely to be exceeded by an unprecedented combination of change in climate, associated disturbances (e.g., flooding, drought, wildfire, insects, ocean acidification) and in other global change drivers (especially land-use change, pollution and over-exploitation of resources), if greenhouse gas emissions and other changes continue at or above current rates (high confidence)".* [Fischlin et al., 2007]

The major expected outcome of the Conference is an international framework facilitating efforts to reduce the risks and realize the benefits associated with current and future climate conditions by incorporating climate prediction and information services into decision-making.

This outcome will be achieved for decision-making for ecosystem management under climate change and climate variability if a plan is established for meeting the following goals:

- ❖ **Improved data-gathering networks and information management systems for both climate and ecosystem sectors; WCC-3 Goal 1**

- ❖ **Improved integration of regional and national infrastructure for the effective delivery of climate information and predictions to national governments, agencies and the private sector; WCC-3 Goal 2**

- ❖ **Strengthened scientific and technical capabilities to provide more credible and user-oriented climate information and predictions by reinforcing international, national and regional scientific mechanisms; WCC-3 Goal 3**

- ❖ **Enhanced ability of governments, societies and institutions to access and use climate prediction and information. WCC-3 Goal 4**

Specific responses to these four Goals are given in the Sections '**Error! Reference source not found.**' and '**Error! Reference source not found.**'

Background

Direct and indirect sensitivities of ecosystems to climate change

A logical starting point for evaluating sensitivities of ecosystems to climate change and climate variability is the body of materials on this topic that has been summarized in the most recent collection of reports by the Intergovernmental Panel on Climate Change Working Group II *Report on Impacts, Adaptation, and Vulnerabilities* (IPCC, 2007)[1].

Chapter 4 of this Report, *Ecosystems, their properties, goods and services* (Fischlin et al., 2007), raises numerous issues relating ecosystem sensitivities to climate change. Among their findings, the following general statements were developed and offered, each with an attending estimated level of scientific confidence:

> "Several major carbon stocks in terrestrial ecosystems are vulnerable to current climate change and/or land-use impacts and are at a high degree of risk from projected unmitigated climate and land-use changes (high confidence)."

> "Approximately 20 to 30% of plant and animal species assessed so far (in an unbiased sample) are likely to be at increasingly high risk of extinction as global mean temperatures exceed a warming of 2 to 3°C above pre-industrial levels (medium confidence)."

> "Substantial changes in structure and functioning of terrestrial ecosystems are very likely to occur with a global warming of more than 2 to 3°C above pre-industrial levels (high confidence)."

> "Ecosystems and species are very likely to show a wide range of vulnerabilities to climate change, depending on imminence of exposure to ecosystem-specific, critical thresholds (very high confidence). "

In addition, the Chapter 5 report on *Food, Fibre and Forest Products* (Easterling et al., 2007) provides a summary of research on sensitivities of managed agro-ecosystems, including managed forest ecosystems, to climate change. Among their findings, the following general statements were developed and offered, each with an attending estimated level of scientific confidence:

> "In mid- to high-latitude regions, moderate warming benefits crop and pasture

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[1] See http://www.ipcc.ch/ipccreports/ar4-wg2.htm for access to the full report.

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yields, but even slight warming decreases yields in seasonally dry and low-latitude regions (medium confidence). "

"Projected changes in the frequency and severity of extreme climate events have significant consequences for food and forestry production, and food insecurity, in addition to impacts of projected mean climate (high confidence)."

"Simulations suggest rising relative benefits of adaptation with low to moderate warming (medium confidence), although adaptation stresses water and environmental resources as warming increases (low confidence)."

"Smallholder and subsistence farmers, pastoralists and artisanal fisherfolk will suffer complex, localised impacts of climate change (high confidence)."

"Globally, commercial forestry productivity rises modestly with climate change in the short and medium term, with large regional variability around the global trend (medium confidence)."

"Local extinctions of particular fish species are expected at edges of ranges (high confidence)."

"Experimental research on crop response to elevated CO_2 confirms Third Assessment Report (TAR) findings (medium to high confidence). New Free-Air Carbon Dioxide Enrichment (FACE) results suggest lower responses for forests (medium confidence)."

From these findings we can conclude that global temperature increases above 2-3°C, with associated climate changes, likely will have high impact on a wide range of ecosystems. On the other hand, the atmospheric CO_2 levels sufficient to produce these climate changes (some far larger than global averages) are insufficient to promote enhanced growth and productivity of plants. Land-use change is frequently cited as a companion to climate change as an agent leading to changes in natural and managed ecosystems. Hence these two factors leading to ecosystem change cannot be treated separately but call for combined evaluation. Rapid species extinction and major changes in ecosystem structure and functioning are likely with global climate changes accompanying global temperature rise beyond 2°C (Richardson et al., 2009).

Changes in climatic wetness at a regional scale are difficult to predict. For many regions, climate change models disagree with even the direction of change, let along the magnitude (Bates et al 2008). However, increases or decreases in regional water balances will result in significant ecosystem responses.

Ecosystem Services and mitigation

The following definition for ecosystem services is taken from the IPCC Fourth Assessment Report Working Group 2, Chapter 4[1] (Fischlin et al 2007) (see also Costanza et al 1997):

Ecosystems provide many goods and services that are of vital importance for the functioning of the biosphere, and provide the basis for the delivery of tangible benefits to human society. Hassan et al. (2005) define these to include supporting, provisioning, regulating and cultural services. In this chapter we divide services into four categories.

  i. *Supporting services*, such as primary and secondary production, and biodiversity, a resource that is increasingly recognised to sustain many of the goods and services that humans enjoy from ecosystems. These provide a basis for three higher-level categories of services.

  ii. *Provisioning services*, such as products (cf. Gitay et al., 2001), i.e., food (including game, roots, seeds, nuts and other fruit, spices, fodder), fibre (including wood, textiles) and medicinal and cosmetic products (including aromatic plants, pigments).

  iii. *Regulating services*, which are of paramount importance for human society such as (a) carbon sequestration, (b) climate and water regulation, (c) protection from natural hazards such as floods, avalanches or rock-fall, (d) water and air purification, and (e) disease and pest regulation.

  iv. *Cultural services*, which satisfy human spiritual and aesthetic appreciation of ecosystems and their components.

Of particular interest is how ecosystems perform vital roles in climate regulation through energy transfer (e.g. albedo) and exchange of water and exchange of other gaseous substances (in particular, transpiration and carbon dioxide). Hence it is vital that ecosystem-based management and the information on which decisions draw reflect the importance of these key life support systems. Ecosystems play a vital buffering role in the global carbon cycle and currently store around 2,500 Gt C. Net ecosystem exchange fluctuates with weather conditions and human land use impacts, and can therefore function as a source or sink of greenhouse gases (hereafter, GHG). It is therefore vital that climate information is collected and utilized to inform decision making aimed at optimizing the mitigation potential of ecosystems whilst also minimizing the risks of increasing GHG emissions. In this way mitigation becomes another service provided by ecosystems, but an additional burden on ecosystem management, in that mitigation needs to be incorporated alongside other multiple objectives for an ecosystem. Whilst GHG exchange is a natural and avoidable natural dynamic, the provision of appropriate climate information will inform decision makers as to when changes in the climate and land use destabilize ecosystem dynamic equilibria resulting in reduced quality of ecosystem services and increased GHG emissions. There is therefore a need to develop methods to evaluate the trade-offs between these multiple objectives, to meet the needs of all beneficiaries of ecosystem services. Fundamentally, there is an imperative to ensure that the key ecosystem services for life support are maintained, and that climate information is gathered and used to support this goal through appropriate management.

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[1] See http://www.ipcc-wg2.org/

Potential 'win-win' opportunities arise, in that improving ecosystem health (and therefore human society wellbeing) can also increase mitigation potential.

Valuation of natural resources, biodiversity and ecosystem services

Conventionally, ecosystems and natural resources were valued only to the extent they provide useful inputs to economic activities such as agriculture, manufacturing, transportation and settlement. However, societies have always valued natural things in ways that are not traded in markets and for which an economic approach to resource management cannot be readily adopted (McKenney et al. 1999). From this conventional perspective, economic development and nature conservation were perhaps seen as mutually exclusive societal goals. However, this conventional thinking is being overturned with increasing recognition that the services provided by ecosystems and the natural capital stocks that produce them are critical to the functioning of the Earth's life-support system, and contribute to human welfare, both directly and indirectly, and therefore represent part of the total economic value of the planet (Costanza et al. 1997; Sukhdev 2008). This change in thinking means that in addition to ecosystems being an input to the manufactured capital and human designed production systems, we must consider management for sustaining the natural processes that deliver the ecosystem services they produce.

While many people hold that we should protect wildlife species and their habitats because of their intrinsic value (and this intrinsic value is recognized by the Convention on Biological Diversity; CBD 1992), the environmental services they provide humans is becoming increasing valued through their contribution to material welfare and livelihoods, security, resiliency, social relations, health, and freedom of choices and actions (MEA 2005). However, biological diversity and 'ecosystems' are not unrelated phenomena. Therefore, the relationship between biodiversity and ecosystem-based management requires some explanation.

According to the CBD, 'Biological diversity' means the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems. And, the CBD defines 'Ecosystem' as a 'dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit'. Technically, it follows that according to the CBD, ecosystems are part of biological diversity. Note that 'biodiversity' is generally used as an abbreviation of biological diversity.

Ecosystem based management is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. It is based on the application of appropriate scientific methodologies focused on levels of biological organization which encompass the essential processes, functions and interactions among organisms and their environment '.

In this paper we use the term biodiversity conservation being cognizant of the fact that ecosystems are comprised of and are made functionally operable by communities of species and that in turn all species live within ecosystems. Given by definition their unique genotype, species respond individually to climate variability and climate change. Therefore, there is utility in considering species both separately and as part of

ecosystems. However, the intimate relationship between species and ecosystems can never be ignored as biodiversity at all levels – genetic, taxonomic, functional – has been shown to be strongly correlated with ecosystem productivity and resilience (Loreau et al, 2002).

As noted by the Millenium Ecosystem Assessment (MEA 2002), the ways in which ecosystems are affected by human activities has consequences for the supply of ecosystem services - including food, fresh water, fuelwood, and fiber - as humans are altering the capability of ecosystems to continue to provide many of these services. In parallel with unsustainable use and degradation of ecosystems, ecosystems and species now face the impacts of human-forced climate change and climatic variability. It is the interaction of these two impinging factors – human land use and climate change – that will now determine the fate of Earth's species and ecosystems, and the life-support systems upon which humans depend.

How does climate influence ecosystems and species?

Ecosystem processes are driven by the space/time variability in energy, water and nutrients. Solar radiation provides the energy for photosynthesis - the biological process whereby plants (and some bacteria) convert radiant energy (sunlight) to chemical bond energy (glucose), which is the basis to the ecological food chain and the web of life. Most of the energy and water are used to obtain the CO_2 used to produce the glucose and plant biomass. The rate of biochemical reactions scales with temperature in accordance with the Arrhenius equation. Photosynthesis is measured as an instantaneous rate of CO_2 uptake (assimilation) by leaves. Gross primary productivity (GPP) is a measure of the rate (integrated over a day, month or year) of CO_2 assimilation by biota over an area of the Earth's surface. Net Primary Productivity (NPP) is equal to GPP – Ra, where Ra is autotrophic respiration, i.e. the energy consumed and the carbon dioxide respired by organisms to keep themselves alive, growing, and reproducing. Environmental factors controlling GPP:NPP include: water (climatic wetness, surface flows, soil water storage capacity); carbon dioxide (Henry's Law – the solubility of a gas is proportional to its partial pressure); availability of mineral nutrients (i.e. lithology of soil parent material, topographic position); light energy (seasonality); and oxygen (which can be inhibited by soil water logging) (Berry et al. 2005). The rate of decay of dead biomass is also temperature and moisture dependent (Law et al. 2003; Chambers et al. 2000).

In land based ecosystems, the standing stock of living and dead biomass carbon (above and below ground) is a function of Net Ecosystem Exchange; the difference between NPP and rates of heterotrophic respiration. The life history characteristics of species affect the residency time of carbon in different pools of the ecosystem, e.g. the carbon stored in the woody stem of long lived, dense hardwood trees can have residency times of decades to centuries (Roxburgh et al. 2006).. As noted above, photosynthesis places a heavy demand on plant water use. Consequently, the age (correlated with rate of growth) and kind of plant species dominating a watershed will strongly influence the amount of water leaving the catchment as transpiration versus stream discharge (Australia Government 1996). Loss of biodiversity, along with the impacts of human land use, therefore can have a significant impact on the capacity of ecosystems to provide critical ecosystems services such as carbon sequestration and regulation of water quality and flow.

Each species has a set of genetically determined environmental conditions within which

it can live and successfully reproduce – called the physiological niche (Hutchinson 1957). The subset of this physiological niche is called the ecological niche, and is defined by the set of conditions which the species occupies in the wild, given competitors, predators and pathogens, and prevailing disturbance regimes. Nix (1982) argued that full niche specification for wild species is probably impossible to define, but a subset of the physiological niche – the environmental domain - can be more readily estimate in terms of the species response to the primary environmental regimes: thermal; radiation; moisture, and mineral nutrient. The dominant inputs to a species environmental domain are climatic at the meso-scale, but the distribution and availability of radiation, temperature and moisture are modified by local topography (*sensu* Linacre 1992). The vegetation cover then further modifies these environmental conditions at a site-scale; so-called micro-habitat buffering which determines the effective 'climate' experienced by (in the case of a forest ecosystem) a sub-canopy species (Mackey and Lindenmayer 2001). Species must also be adapted to the dominant disturbance regimes, which depending on the ecosystem type can fire regimes, flooding regimes, or cyclonic storm regimes. The space/time patterns of disturbance regimes are also primarily a function of climatic conditions.

Potential responses of intensively managed ecosystems (agriculture-cropping and forestry)

Whilst the focus of this paper is on natural resource management, biodiversity and ecosystem services, it must be recognised that changes in intensely managed ecosystems such as agriculture and commercial forestry have direct consequences for natural resources, biodiversity and ecosystem services. Further to this, projected changes in food and water security for human consumption may drive additional natural resource demands and pressures on biodiversity, risking further deterioration in ecosystem services. For example, agriculture consumes about 75% of freshwater resources worldwide. Commercial logging causes emissions of GHG and drying of micro-climatic conditions. Therefore adaptations to climate change within intensively managed ecosystems will have a corresponding impact on ecosystem services[1]. There is therefore need to consider the need for climate information for agriculture and commercial forestry in order to best evaluate how changes within these sectors will affect natural resource management, biodiversity and ecosystem services.

What are the climate information needs of decision makers?

Scales of decision making and levels of decision makers

Decisions on ecosystem management are made at many spatial and temporal scales; international, national, sub-national, single ecosystem type, and by a range of decision makers; Governments, Institutions, businesses, communities and individuals. There is also a scale of urgency, depending on the threats and vulnerabilities of a particular ecosystem. This produces a wide diversity of information needs. We need to match the level of information required to the spatial and temporal scale and realm of the decision

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[1] See Session W10 – Climate and food Security at WCC-3 for further details.

maker, considering the capacity of the information providers. Increasingly climatic information is being accessed directly from the internet by stakeholders. Dialogue is therefore needed between information providers and decision makers to make providers aware of what information is needed. Conversely decision makers need to know what information is available and how to use it, and understand the constraints on providers (data and modelling limitations, uncertainties in future climate projections.

The list of stakeholders requiring information for decision-making relating to climate change and variability is both vast and diverse. While some sectors have large and relatively homogeneous climate needs, stakeholders focusing on natural and semi-natural ecosystems have needs that are as complex and diverse as the ecosystems they oversee.

Climate information is needed across a wide range of sectors beyond natural resource management and biodiversity conservation. Opportunities exist to utilise climate information needed by other sectors (i.e. industry, insurance, military). Hence there is scope for synergies across sectors. A better understanding of the benefits from co-operation in climate information sharing and application is required.

Building credibility, salience and legitimacy between climate information providers and users.

There are no single best solutions to the problems described above. Solutions need to be framed by basic understanding of how climate interacts with ecosystems and species – the ecophysiological, evolutionary, and ecological processes and responses that determine ecological system productivity and resilience; along with the productivity and resilience of the dependent social systems. Climate information systems in the field of natural resource management and biodiversity cannot be designed in ignorance of these fundamental climate-ecosystem dynamics. However, given the broad scope and diversity of decision makers involved it is also necessary to advocate a process of social co-learning between information providers, decision makers and the wider society. Ideally, the best solutions can be tailored to specific ecosystem management issues, driven by stakeholder engagement (dialogue between information providers and decision makers). This requires the identification of whom the stakeholders are, framing the problem they are dealing with and developing a process through which solutions can be found, in order to develop appropriate climate information products. Furthermore, in the context of human-forced climate change and vulnerability, it is critical that risk assessment frameworks and strategic planning for adaptation be developed in ways that also utilise this kind of participatory approach (Fig 1)
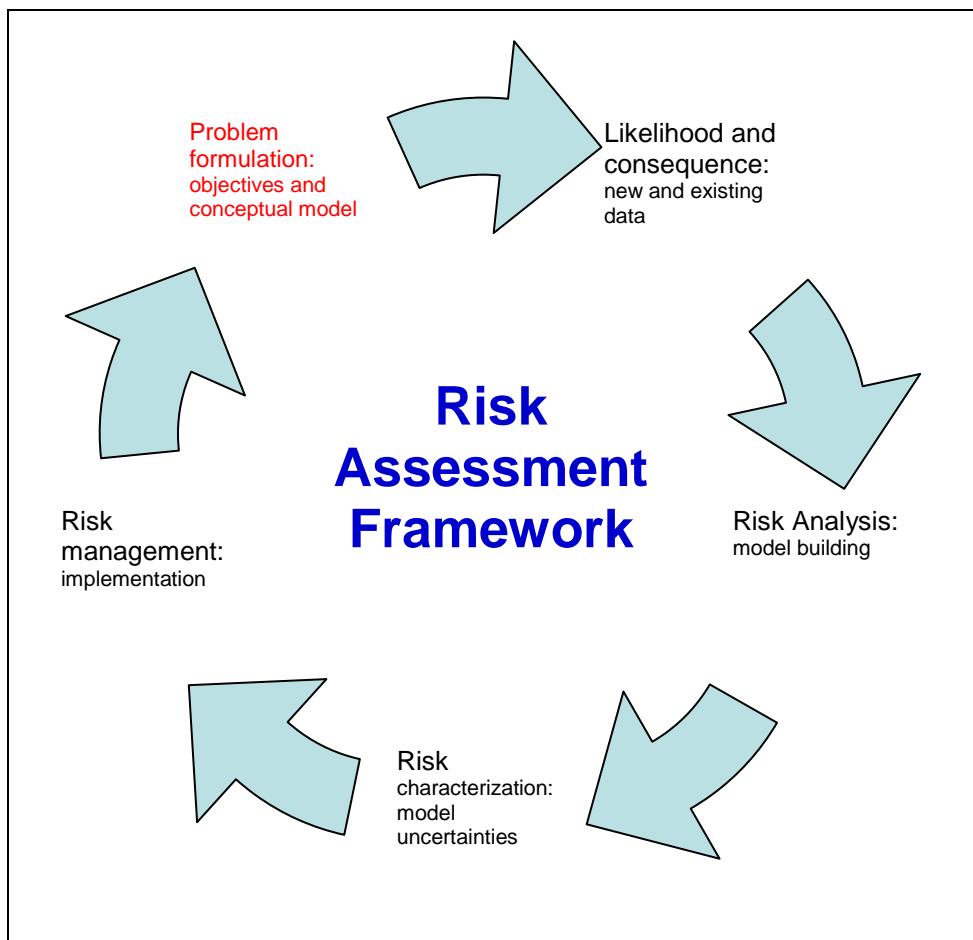
Figure 1. A generalised risk assessment framework for climatic change and vulnerability. Such analyses when undertaken as part of an iterative adaptative management approach provide a framework for coordinating the integration of climatic information with socio-economic information across sectors and jurisdictions. Modern risk assessment considers the climatic hazards, exposure, sensitivity and adaptive capacity of biophysical-socioeconomic systems, and identify adaptation responses that can minimize potential risks.

A key constraint on the use of climate information concerning future projections is the establishment of credibility, salience and relevance. Credibility can be built through effective partnerships and an understanding of the issue of uncertainty. Salience means information must be seen by stakeholders as relevant to their decision making process. Salience can be seriously compromised when information (and the research providing it) refers to geographic, temporal or organisational scales that do not match those of decision makers. Similarly, for information to be influential, it must be seen by stakeholders as legitimate, supporting or empowering decision making processes rather than dictating outcomes (Matthews et al 2008). Without addressing these issues it is less likely that appropriate climate information needs will be met, reducing the potential for viable ecosystem management solutions to be found.

There are however common considerations (or decision criteria) such as responses to risk, threats, vulnerabilities and opportunities, that can be used to structure a generic framework within which basic principles can be applied to information provision. By this

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we mean that a core approach for information provision can be developed, around which individual solutions to specific issues can evolve (see Section– specific climate information needs).

A key component of these processes is to build capacity to use information products and tools in an informed and effective way, particular in the context of risk and assessment and adaptation planning. Hence a vital part of the climate information provision process is a parallel programme of training and skills development.

Current uses of climatic information

There is a wealth of climate information available that is employed in a wide range of uses, including storm prediction, flood risk and drought warning, storm driven sea level surges, pest outbreak risks etc. There are however substantial variations globally in climate information quality and the degree to which it is available and used for ecosystem management and policy development. There is a growing trend within many countries to incorporate climate information into decision criteria, but the capacity to do so using the best available science, information and dissemination methods is more limited in developing countries.

From an ecological perspective, ecosystem processes operate at all temporal scales. In land dominated by natural and semi-natural ecosystems there is a gradient of human activity. In areas with little modern human land use activity, there has been less use of formalised climatic information, but a deep cultural history may mean a long tradition of climate understanding exists (i.e. changes in seasonality, timing of wet seasons etc).

In intensely managed areas there is a stronger history of using climatic information. Daily weather forecasts are vital for short term management decisions, whilst seasonal forecasts are used for strategic planning. The capacity to use computer generated forecasts is highly variable, being far more prevalent in developed countries. Observed weather data is an essential input to simulation models (see Text Box 2 on the AussieGRASS rangelands management simulation model) including ecosystem behaviour and response. There is now a well established body of approaches for using climatic information to model hydrological flows inclusive of watershed characteristics and land use impacts.This kind of information is more commonly being accessed by decision makers, particularly to identify changes in catchment management to improve water quality and flow, and to better allocate water between the often competing demands of environmental flows, urban consumption and agriculture. Elsewhere other forms of forecasting is used, based on observations of natural phenomena, culture and tradition.

Recently climate change projections have been used to form the basis for long term strategic planning (see Text Box 1), a trend that is likely to increase in the near future. Similarly the biodiversity extinction crisis (Wilson 1992) resulted in an explosion of research into the climatic domain of species. However, understanding how climate variability and change affects the distribution and abundance of species is complex and an area of active research. Nonetheless, biodiversity conservation both within protected areas and across the broader landscape will increasingly require climatic information in order to understand how species distributions may alter and identify possible management responses.

What is the current capacity to meet the needs?

There is considerable variability in the quality and availability of observed climate (weather) data on which to form a baseline against which we can compare potential future changes. Similarly the ability of information providers to meet the needs of decision makers for the immediate future (short range forecasts), seasonal (long range forecasts) and future projections varies considerably around the world. Some developed countries are able to deliver state of the art weather forecasts and modelled future projections of the climate at a national scale (see Text Box 1), whilst many less developed countries lack the capacity for the provision of weather and climate information, often relying on external assistance based on global scale projections that lack sufficient spatial detail for appropriate decision making.

Secondly, there is a range of capacity in the dissemination and communication of climate information to relevant people. This capacity follows the same pattern as above for forecasting and climate modelling. The provision of climate information needs to feed into existing steps to establish the capacity for adaptation, for example the 'stocktaking' exercises currently being undertaken by UNEP (i.e. UNEP 2009) and the development of National Adaptation Programmes of Action (NAPAs[1]). This disparate capacity to meet the needs of decision makers needs to be addressed.

Major gaps in data observation

Improving climatic information systems for ecosystem-based management requires, among other things, addressing current limitations in the scales and kinds of data being recorded including:

- Meteorological stations are often located near settlements and provide only a poor sample of areas dominated by natural and semi-natural lands. This means that climatic information must be spatially interpolated using statistical modelling to generate estimates at the locations of interest, with associated errors and uncertainties.

- Meteorological stations are generally located in flat, bare ground. Information is limited about topographic and vegetation shading effects on meso-scale climate and thus about the effective climatic conditions experienced by most species.

- Limited range of weather variables observed over varying time series lengths, method or archiving and process of making available.

- Lack of records for potential evaporation and net surface radiation. These two variables are key drivers of plant productivity, as well as ecosystem simulation models.

- The lack of weather data in remote, natural and semi-natural lands means there is inadequate data to calibrate satellite-based remotely sensed data; which is the main source of proxy weather data for extensive areas such as rangelands and forests.

- Integrated catchment management models require integration of stream flow records with rainfall and evaporation timer-series from the same watershed. This kind of coordinated environmental monitoring is rarely achieved.

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[1] See http://unfccc.int/national_reports/napa/items/2719.php

- These limitations apply for most developed as well as developing countries, and cannot be readily addressed by increasing the sampling density of standard weather recording instrumentation. In many developing countries, this is however a necessary first step.

Even where human activity in ecosystem management is low, there is still a need for climate information to enable researchers to understand how the ecosystem will respond to climate change. Innovative approaches should be considered that complement existing climatic information systems, including:

- Use of remotely sensed data, especially satellite-borne scanners, is one source of data that needs to be fast tracked from the research domain - where there are now decades of experience - to practical applications that can utilize spatially distributed estimates of land surface energy-water exchanges. New generation sensors provide such spatially distributed data at space/time scales appropriate for land management applications. However, these data needed to be integrated into models (Box 1) so that they can be assimilated with conventional climatic information and generate output useful to decision makers.

- Another innovation worth exploring is the use of 'iButtons' – small, cheap telemetric devices that sense temperature and humidity. So long as they are calibrated to standard, nearby weather stations, iButtons can in principle be distributed in the hundreds throughout landscape, on different topographic positions, and under vegetation, to provide a dense sampling of microclimatic conditions relevant to analysing many ecosystem processes and species habitat requirements.

The special needs of the rural poor in developing countries must be addressed and climatic data tailored to provide information appropriate to the kinds of natural resource management decisions prevalent in these situations where modern communications may be lacking and resources for management responses limited.

Infrastructural and Institutional Gaps

In many developing countries there is also a legacy of gaps in infrastructural and institutional capabilities. There has been a lack of institutional coordination to facilitate the systematic integration of relevant climate information with other pertinent information in a form that planning and operational agencies can use. Climate information is not systematically integrated into longer-term planning and investment decision making, with a tendency for Governments and other institutions to focus on short-term objectives rather than long term goals. Generally there is a lack of understanding by many policy makers of how climate variability and change might impact achievement of the Millennium Development Goals, and lack of understanding by policy makers of the utility of climate information for reducing the negative impacts of climate variability and climate change (GCOS/WMO 2006).

Specific climate information needs

Central to decision making will be perceptions of how much and when things change compared to the decision makers' experience and available information on the past.

Extreme event frequency and severity:

Climate extremes can create transient or even permanent disruption to natural systems, and even perhaps more so to managed landscapes. Some changes in extremes due to

climate change will likely become even more disruptive. Increased frequency of such events and increased opportunities for pathogens and predators afforded by such events complicate attempts to project future impacts on ecosystems and biodiversity. Dynamical climate models tend to under-estimate the magnitude of extremes, particularly in small regions, so combinations of statistical and dynamical models are needed. Dialog between ecosystem scientists and climate scientists is needed to identify specific attributes of extremes (e.g., duration, frequency, magnitude, seasonality, combinations of variables) of high impact.

Extreme events are of particular importance to ecosystems because numerous biological processes have non-linear dependence on climatic factors. Critical thresholds at both high and low temperature can lead to termination of plant functioning. Reproductive phases are particularly sensitive to extremes in both plant and animal components of ecosystems. Aquatic ecosystems, both managed and unmanaged, share much vulnerability with terrestrial ecosystems. All of these call for vastly expanded and systematically shared observations on plant, animal, and insect phenologies in relation to climate.

Timing of events:

Timing of extremes in relation to phenological stages is critically important. Reproductive stages typically are highly sensitive to climate extremes and call for special consideration. Changes in seasonality (e.g., earlier snowmelt, longer ice-free periods for lakes, drier autumns, wetter springs) that are being observed under climate change in some regions can disrupt aquatic and soil ecosystems as well as terrestrial systems.

Use of probabilistic scenarios (and how to communicate and use them):

A significant disconnection currently exists between output of climate models and input to ecosystem (and other) decision-support systems. Availability of climate change information from multi-model ensembles enables probabilistic representations to be made. Such representations, which are likely to be unique for particular ecosystem, currently are lacking. A recent example of a public release of probabilistic projections specifically to support decision making came from the United Kingdom Climate Impacts Programme[1] (see Text Box 1), with similar approaches being taken by Australia[2], Canada[3] and Finland[4].

Centralized reporting, archival, and dissemination of ecosystem impacts:

Many ecosystem vulnerabilities to climate change and climate extremes are just now being recognized due to the rapidity and magnitude of recent changes. Past peer-reviewed literature, therefore, is inadequate to determine the full range of such impacts. Rapid reporting, vetting, archiving, and disseminating newly discovered vulnerabilities

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[1] See http://ukcp09.defra.gov.uk/

[2] See http://www.climatechangeinaustralia.gov.au/

[3] See http://www.cccsn.ca/index-e.html

[4] See http://www.ymparisto.fi/default.asp?node=16118&lan=en

are needed to promote best possible management under rapid climate change. World data centres exist for climate information, but analogous facilities are needed for centralizing data on climate impacts on ecosystems. Again, integration of climate information systems with risk assessment and adaptation planning will be needed.

Downscaling:

Downscaling refers to the process of adjusting predicted information to be representative of spatial scales below which they are produced by climate models. This increases the probability that the information is relevant to decision makers working at regional scales, i.e. spatial scales smaller than that at which the climate model functions. A range of approaches exist to do this, from complex statistical to basic bias correction. The point is that the approach needs to match the capacity of the service providers and information users. Downscaling enables information to be used that stakeholders will know is more relevant to their realms of decision making. Also, researchers need future projection data that best represents site-specific conditions.

Species and the ecosystem within which they exist do not respond in isolation to a single weather variable. Instead it is the collective effect of combined environmental conditions (including response by other species) that determines species response. Therefore information on a single variable (i.e. temperature), whilst useful for indicative purposes, has limited value in terms of informing us on how a species or its habitat will respond. Greater value is gained when information is available for a set of core, biologically-relevant weather variables. However this information must be coherent in terms of its spatial and temporal synchronisation (individual weather variables must not contradict other types at the same place and time). Where single variables (i.e. temperature) are useful is in establishing the critical thresholds of tolerance of a species, information on extremes informs us of when those tolerance levels may be exceeded. The same applies to extreme rainfall events, including drought and storms.

Avoiding and reducing emissions from natural ecosystems, particularly intact systems, is now recognized as a necessary mitigation activity if we are to stabilize concentrations of atmospheric greenhouse gases at a level that avoids dangerous climate change (Cramer et al. 2001). However, mitigation policies and measure demand accurate estimates of carbon dynamics aggregated at a national level inclusive of estimating: the current stocks of ecosystem carbon on a landscape-wide basis; the emissions from land use and land use change; and the changes in flux rates due to climatic variability. A simulation modelling approach is used which integrates empirical measurements from various sources (e.g. field samples of forest biomass, sequestration rates from eddy flux towers), remotely sensed data on land cover characteristics (e.g. greenness index values), and process simulation functions which are usually driven to some degree by climatic data (e.g. radiation, rainfall, wind). An example of such an integrated modelling approach to carbon accounting is Australian Government's national accounting systems (Brac et al. 2006). As process understanding improves there will be increased demand for climatic data at space/times scales need to run such accounting models.

Recommendations that support the WCC-3 outcome

WCC-3 Goal 1:   Improve data-gathering networks and information management systems for both climate and ecosystem sectors.

Given the geographic gaps in meteorological instrumentation, it will be necessary in many regions to prioritize ecosystems for targeting investments for improving climatic information. Therefore, effective use of climate information for ecosystem management by regional and national decision-makers begins with an inventory of major ecosystems that potentially will be most impacted (the Millennium Ecosystem Assessment[1] provides a basis for this). These may range from near-pristine systems having little influence of human encroachment to ecosystems that are highly managed such as monoculture agro-ecosystems and forest plantations. Observed local and regional responses to past climatic stresses provide valuable insights on an ecosystem's sensitivity, adaptability, and vulnerability to changing climate conditions and serve as a basis for assessing possible responses these same systems may have to a future climate. There is need to identify gaps in ecosystem and socio-economic data for documenting and understanding ecosystem degradation and restoration. Future efforts should seek to maximize the value of existing data from different sources through data integration mechanisms that seek to synchronize disparate data types. Strategies should be developed to document recent trends in climate variables, environmental indicators, and relevant socio-economic indicators. There is need to ensure collection of data for monitoring the effects of climate variability and change, including extremes, with appropriate spatial and temporal resolution. High intensity monitoring of selected ecosystems or watersheds may provide "early warning" signals of climate disruption, threats to species, and ecosystem thresholds (NCSE, 2008). Environmental observing and reporting systems must be strengthened at the local-to-regional level where many adaptation decisions will be made. National mechanisms should be established to ensure that critical measurements of high quality will continue to be taken long into the future.

In Brief: inventories of major ecosystems are needed and priority ecosystems identified; observed local and regional responses to past climatic stresses should be catalogued; critical gaps in ecosystem and socio-economic data should be noted; recent trends in climate variables, environmental and socio-economic indictors should be documented; and observing and reporting systems strengthened.

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[1] See http://www.millenniumassessment.org/en/Index.aspx for details

WCC-3 Goal 2:   Improve integration of regional and national infrastructure for the effective delivery through appropriate communication of climate information and predictions to national governments, agencies and the private sector.

Given that many ecosystem processes (e.g. water flows, migrating animals) transcend political and administrative borders, and that many nations and land stewards share the same or similar ecosystem types, there is need to promote agreements that ensure international sharing of relevant ecosystem data and climate data to promote regional approaches to problems spanning national boundaries. This is achieved by building effective partnerships between relevant climate service providers and the public and private sectors, and non-governmental organizations having interests in ecosystems. Strategies that have demonstrated success in other regions, nations, or sectors should be considered for wider adoption. Partnerships between developed and developing countries can provide critical access to advanced technologies (e.g., satellite data) and infrastructure. National or regional climate services should function as an "integrated threat center," as a one-stop source of science, data, information and modelling from all branches of government and provide oversight and management to coordinate among agencies (NCSE 2008). National climate change risk assessments and associated adaptation planning can provide a framework for coordinating the integration of climatic and socio-economic information both across sectors and national borders.

In Brief: international data-sharing agreements be established; strategies having success elsewhere be adopted; technology sharing between developed and developing countries be practiced; national and regional climate services centres function as "integrated threat centres"; and risk assessment and adaptation planning provide the necessary coordinating framework.

WCC-3 Goal 3:   Strengthen scientific and technical capabilities to provide more credible and user-oriented climate information and predictions by reinforcing international, national and regional scientific mechanisms.

Best-available science must be employed to project changes in climate, including trends in means, extremes, inter-annual variability, and inter-decadal variability. Climate-ecosystem interactions and feedbacks are of particular importance for advancing models. Consideration should be given to changes and variability over the next 20 to 50 years and changes to 2100, and other possible time scales of high relevance to particular ecosystems. This also helps identify priority areas. International partnerships will facilitate access to best-available global climate information, regional climate downscaling (regional climate models and statistical downscaling), and ecosystem modelling tools. Climate scientists, in close collaboration with impacts modellers, should identify regional "hot-spot" analyses to help decision-makers and stakeholders to prioritize adaptation needs and opportunities. Decision-makers must be actively providing input to the development of climate products to ensure that decision-support tools benefit from effective flow of climate information. Consideration of the above factors will provide the basis for developing requirements for infrastructure, communication systems, education, and other forms of capacity-building.

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In Brief: international partnerships be established to ensure use of best available science; relevant time horizons for projecting changes be established; adaptation needs and opportunities be prioritized; and decision-makers should be engaged in development of climate products.

WCC-3 Goal 4:   Enhance the ability of governments, societies and institutions to access and use climate prediction and information.

Access to and effective use of climate change information requires considerable advance planning jointly by climate scientists, stakeholders, and representatives of societal groups highly impacted by ecosystem degradation. There is need to identify socio-economic drivers for and impediments to effective decision-making and to integrate information for planning, preparedness, disaster risk reduction and coping with climate variability, including extremes. Information and technology needs for facilitating adaptation to climate change at local and regional scales and over time scales of inter-annual to inter-decadal should be a basis for prioritizing strategies. Effective decision-making requires dissemination and communication of climate information in forms readily usable by stakeholders. Mechanisms built into the information flow should allow for identification of gaps between information available and services needed, rapid adoption of new information, rapid response to emergent climate product needs, and adaptive management strategies that are flexible to meet changing situations.

It also should be noted that climate information cannot be considered in isolation. Successful ecosystem management decisions in response to climate change call for a wider range of information across a broad spectrum of disciplines. These include socioeconomics, ecology, conservation management, hydrology and many others. Hence an interdisciplinary approach is required. Such data and the processes to evaluate the links between them become vital to identifying the cause, effects and roles of different drivers of change. Policy analyses and informed decisions can only be made if there is an understanding of the relationships between the climate, human society and the environment.

Climate information in conjunction with other information types needs to form the basis for the establishment of the conservation and sustainable resource use of the world's ecosystems. The utilisation of climate information to determine environmental constraints and ecological requirements will enable the human society to live within those constraints and to develop lifestyles that are sustainable.

In Brief: advanced planning be carried out jointly by climate scientists, stakeholders, and appropriate impacted groups; identify and use effective dissemination and communication forms readily accepted by stakeholders; and engage a wide range of disciplines.

Developing local, national, and regional frameworks for identifying ecosystem vulnerabilities

Here we suggest two main components for advancing the use of climate information for decision-making related to ecosystems: developing local, national and regional frameworks for identifying ecosystem vulnerabilities, and developing needs assessment for achieving specific goals. We describe the two components in the following Sections.

1.1.   Identify dominant and critical ecosystems of the target region *(Goal 1)*

A regional impact assessment begins with an inventory and development of a registry of major ecosystems of the region, which may range from near-pristine systems having little influence of human encroachment to ecosystems that are highly managed such as monoculture agro-ecosystems and forest plantations. It also is recognized that some regions may have ecosystems that should be identified as severely degraded and may require special attention in response to climate change. Ecosystems that are managed as monocultures for food, fuel, feed, or fiber by suppression of many natural species are influenced by populations of rodents, birds, and insects and are supported by complex soil ecosystems. Ecosystem services of benefit to humans include provisioning services, regulating services, supporting services, and cultural services (MEA, 2005). Whether near-pristine and multi-species or managed single-purpose monocultures, the ecosystem's numerous physical and biogeochemical processes serve valuable functions that are subject to interruption, termination, or acceleration under climate change (as broadly defined above). Changes in these processes invariably will create changes in ecosystem functioning, including resilience to changes in climate and invasion of foreign species. The ecosystem registry should identify climate-change triggered thresholds that may require particular attention. As new ecosystem threats emerge, there will be need to assess availability of current climate products to address such threats.

Agro-ecosystems that include animal agriculture call for special consideration for impacts and synergism between animals and the plant/water/soils of the region. Adaptation should ensure animal access to water, feed, and protection from heat or cold, while protecting the sustainability of grazing materials, confinement areas, and soils under changing climate (including climate variability and extremes). Ecosystem sustainability rather than economic pressure must be used to determine stocking densities. Management of waste streams from domesticated animals require special attention for cycling nutrients in harmony with sustainable soil and water ecosystem services that are subject to change under climate change.

Below-ground as well as above-ground ecosystems should be considered. Soil ecosystems, particularly in the root zone (e.g., fungi, microbial activity), are easily subject to degradation in conjunction with above-ground human activity. Its is important to better understand how climate change will impact on soil fungi and microbial activity and to identify the vulnerability of the soil biotic component. This is also vital in respect of the mitigation potential or emission risk of an ecosystem. Similarly, water ecosystems such as streams, rivers, and lakes, frequently have underground components that are impacted by land-use changes.

Local societies must be engaged in identifying and valuing ecosystem services and balancing their supply and demand. Standardized measures of ecosystem service value and demand are needed for development of models and tools for assessing impacts of

climate variability and change. Recognition is needed of the spatial extent of areas expected to provide specific ecosystem services. For instances, area needed for water purification (waste-water treatment), nutrient cycling, water retention, species diversity, etc., must be matched to the demand for such services.

Of particular note in identifying vulnerable ecosystems are those ecosystems that provide services of high societal value, either locally or in the regional or global context (e.g., rainforests, snowmelt/stream flow regions feeding urban water supply systems).

1.2. Assess threats and challenges to these ecosystems under recent past climate trends and recent past human influences (Goal 1)

Observed local and regional responses to past climatic stresses provide valuable insights on an ecosystem's sensitivity, adaptability, and vulnerability to changing climate conditions. This provides a basis for assessing possible responses these same systems may have to future climate change (CIG, 2009). Periods for which past observations are available rarely span time periods needed for capturing a full range of variability of ecosystem impacts. However scientific advances in the use of proxy information have expanded to include the periods for which past ecosystems can be observed to have responded to climate change. Alongside this, indigenous knowledge and culture can also provide supporting evidence of ecosystem changes. These serve to provide evidence of where the critical thresholds (or tipping points) of an ecosystem may be and what processes of change may trigger an irreversible decline. Observed responses to change also indicate the tolerance of a system to climatic variability. Similarly it is important to understand the sensitivity of individual components of a system to climate variability in the past in order to identify their levels of tolerance. Tolerance levels of keystone species, for example, may not have been exceeded in the past, but an understanding of their resilience (based on their interdependence with other species) will help identify what they can tolerate in the future.

The use of ecosystem modeling (or models that represent components of the system) can inform decision makers on how ecosystems have responded to a past climate and how they may respond under future climate scenarios. Such models gain utility when they are developed and used in close communication with stakeholders. Therefore climate information needs should include the provision of data suitable for ecosystem modeling gained from a wider range of sources including expert and indigenous knowledge.

1.2.1. Identifying and selecting (ecological) indicators for assessing ecosystem degradation

These need to be indicators that reflect the health and function of the ecosystem and are ones that are easily monitored. A monitoring framework (including data collection protocols) is required that is synchronized spatially and temporally with climate observations in order to detect climate related change.

1.2.2. Identify gaps in ecosystem data for documenting and understanding ecosystem degradation

In addition to insufficient length of observation records, it also is common to have inadequacies in the range of needed variables of climate and biology for assessing changes in individual ecosystem components and system performance. There is

therefore a need to fill gaps in our knowledge of ecosystems through targeted studies that are coupled with ecosystem monitoring efforts. It is also important to understand the significance of the knowledge gaps and how they influence the outcomes of decision making.

Data should include inventory of remaining fragments of native habitats and their current status. Priority should be placed on filling critical knowledge gaps in our understanding of climate change impact on predators and pathogens to native systems: effects of invasive species, vector-borne diseases, rapid evolution of pathogens, host-species movement patterns, ecosystem fragmentation, seasonality of wildlife disease events, and ecosystem dynamics.

1.2.3. *Identify gaps in socio-economic data needs for documenting and understanding human contributions to ecosystem degradation and restoration*

Baseline data on the human dimensions of ecosystem resources are limited and often difficult for decision makers to access and employ. Gaps in socio-economic and cultural information are particularly critical at the local and regional levels. Regional priority needs must be addressed in order to increase the effectiveness of efforts to plan and manage sensitive areas. The success of area-based management depends upon incorporating an understanding of the human dimension in planning, implementing, enforcing, and monitoring sites. Identifying regional research needs and developing targeted research plans for filling critical data gaps will improve ecosystem management and build regional capacity.

Continuous records should be maintained of social and economic data relating to intervention – both degrading and restoration - of natural ecosystem functioning. Data collection and archive infrastructures should be maintained across changes in governmental structures and policies. Naturally hazardous events (e.g., famine, flood, drought, earthquake, volcano, hurricane, typhoon, tsunami) that become extreme disastrous societal events should be considered as special cases calling for special collection and archive of data relating to interruption of ecosystem health and functioning. Case studies of how healthy ecosystems respond to such natural hazards provide guidance on how degraded systems should be restored (e.g., effective coastal restoration after human alterations are destroyed by tsunami or typhoon [Braatz et al, 2007]). On the one hand humans can cause ecosystem degradation (negative), but they can also maintain and restore systems (positive).

1.3. *Document recent trends in climate variables (Goal 1)*

Recent climate trends and their departure from past trends provide evidence, or lack thereof, for a climate role in change in ecosystem status. Analysis of past climate data must allow for consideration of all natural and anthropogenic contributions to climate change. This calls for assessments of trends in means and higher-order statistics, extremes, inter-annual variability (e.g., impacts of El Niño), and inter-decadal variability (e.g., impact of Pacific Decadal Oscillation (PDO)) to expose possible forcing mechanisms. Analysis employing rigorous statistical methods should explore all known forcing as a basis for such attribution studies. Information requirements include the return periods of extreme events and any change in the frequency of occurrence, changes in the timing of events (i.e. onset of wet or dry season) and other phenomena

that are important for localized human decision making (i.e. when to plant or sow crops) or natural systems (i.e. animal migrations).

Future efforts should seek to maximize the value of existing data from different sources through data integration mechanisms that seek to synchronize disparate data types into structures that allow interrogation.

1.4.   Document recent trends in environmental indicators *(Goal 1)*

Environmental indicators such as species composition, water quality, air quality, soil erosion rates, invasive species inventories, etc., are key factors to be monitored for assessing ecosystem health and ecosystem management needs under changing climate (e.g., decrease in dissolved oxygen in streams and lakes due to higher temperatures). Response of such indicators during past periods of high climate variability provide clues for future response to climate change. Evaluation of past trends informs decision makers of the possible responses under future climate scenarios. It thus becomes important to establish the links between trends in environmental indicators and climate events and trends, and separation from other drivers, such as human pressures. Through this process it becomes possible to identify the biophysical process influencing the environmental indicators and the human influences.

A wide range of data sources should be used, including literature, indigenous knowledge and proxy indicators. Environmental change networks allow wider spatial monitoring of change.

2.5.   Document trends in relevant socio-economic indicators *(Goal 1)*

Demographic indicators such as population shifts, per capita freshwater availability, land use, poverty index, household income, human health indicators, and education levels can correlate with ecosystem health indicators. Also, such variables are indicators of societal vulnerability to climate change and variability.   Documentation of trends in relevant socioeconomic indicators concurrent with ecosystem health indicators and climate factors are needed to identify optimal strategies for effective ecosystem management. Documenting and monitoring changes in societal behavior, expectations and aspirations, along with cultural norms and beliefs, also become important to relate past trends to future projections. Demands for resources previously beyond the financial reach of individuals (i.e. for meat) places additional burdens on ecosystems.

1.6.   Use best-available science to project changes in climate, including trends in means, extremes, inter-annual variability, and inter-decadal variability *(Goal 3)*

As with analysis of past climate data, consideration must be given to all known natural and anthropogenic influences for projecting future climate. The current practice for making future predictions of the climate is to use probabilistic scenarios, derived from multiple climate model ensembles (see Text Box 1). This raises many issues of climate model quality and their evaluation, and how the prediction information is to be communicated. The level of detail communicated needs to be appropriate to the issues for which decisions are being made. Climatic summaries may be appropriate at one scale, but detailed interpretations and representation in alternative forms (i.e. agro-meteorological indicators) may also be required. Decadal and longer scales of climate variability and change require assessment of slow change in (transformation of)

ecosystems (e.g., natural forest species composition) and management activities, therefore there is need for long-term ecosystem monitoring.

There is a pressing need for appropriate model testing against observed data and evaluation of uncertainty in the future projections. Also, climate models function at spatial scales considerably larger than those at which managerial decisions are made within ecosystems. Downscaling allows data from global and regional models to be estimates for finer spatial scales. There is therefore a need to utilize existing methods, or develop new ones as appropriate, to downscale climate model estimates to scales more relevant for site-specific decision making. Alongside this, there is a need for estimates made by climate models to be archived appropriately and data made available to the research community to facilitate testing.

Such a process enables confidence and credibility to be built with local stakeholders on the future projections, and hence increased utility in data use for decision making. However, some researchers argue that there is less need for accurate future projections, as adaptation planning needs to be flexible and resilient enough to tolerate a wider range of future climate possibilities, requiring robust decision making (i.e. Dessai et al 2008). There is therefore a balance required between the ability to make accurate future projections (at a range of spatial scales) and the ability to make appropriate planning decisions. These need to consider the uncertainty within not just the future climate projections, but also the future economic, social and political conditions. Decisions made on ecosystem management to adapt to climate change needs to consider all drivers of change, not just the climate.

1.6.1. Consider changes for next 20 years

Over this time period, changes in climate variability likely will dominate long and slow climate trends as factors impacting ecosystem health. Isolated record-breaking events of extreme rainfall, drought, heat wave, storm surge, etc. may be the high-impact event for planning consideration on these time scales. Over this time period it would be expected that isolated locations would experience impacts, affecting individual communities but only occasionally having impact at the national or even regional scale. Major societal response would be local. There will however be more than just changes to the climate in the next 20 years. Economies will re-adjust towards post peak oil developments for low carbon use, driven primarily by new policies and trading structures. As such it is imperative to consider these changes and their impacts alongside the biophysical changes. Major societal response would be local. However, it is likely that awareness of the climate change issue will grow to reach all sections of society, with corresponding (but as yet unknown) alterations to behavior. Short range seasonal and decadal based forecasts in conjunction with climate model projections, can help inform immediate future changes.

1.6.2. Consider changes to 2050

Changes to 2050 also will include changes in climate variability as in the short term. However, by mid-century, planning for such eventualities should be commonplace. While their occurrence will become part of the planning process, the magnitude of such extremes likely will also have a trend related to trends in global indicators. Larger regions would likely be impacted over this time scale. Regional responses are called for. Impact studies should allow for the possibility of apparent reversal of climate trends due to interaction of natural variability with anthropogenic factors (e.g., cool temperatures due

to PDO yielding to warming trend due to increased greenhouse gases). These should be considered alongside economic changes arising from reduced oil production and societal re-adjustment to alternative energy sources.

1.6.3. Consider changes to 2100

Century long changes will provide a different mean base climate from which normal weather excursions occur. Impacts may be widespread and call for national action to adaptation and coping. Caution is to be exercised in interpretation of specific variables from future climate scenarios. For instance, precipitation projections have higher uncertainty than temperature projections.

1.7. Use best-available social science to project future trends in population, urbanization, poverty, education, human health, energy needs, water consumption, etc. that would impact land-use change and hence ecosystem stresses (Goal 3)

Models and methods for projecting future trends in socioeconomic indicators should be developed that can be used compatibly and consistently with climate projections. Where possible, these models should be used interactively with climate models (e.g., land-use change and climate change as interactive drivers of future ecosystem change). Projections should account for opportunities to use renewable sources of energy, with due consideration to negative ecosystem impacts of such activities (e.g., ecosystem impact of hydropower facilities or raising bioenergy crops). The socio-economic dimensions are to be analyzed capturing the causal processes behind changing land management and land use practices. What is needed is an approach that links biophysical and socio-economic processes with land use and land management practices, which in turn would be linked to landscape or ecosystem dynamics. "Best available social science" should replace "best available practices", the latter being inadequate or inappropriate to foster agriculture and rural development in the medium term as rapid urbanization, population growth, land conversion, environmental degradation, climate change, and other factors work against increases in production and living standards.

1.8. Synchronisation of data resources across research disciplines

There is a need to better spatially and temporally synchronize available data between different research disciplines. Data for the same ecosystem may be recorded under differing research projects and kept in isolation, limiting their utility for wider research purposes. Greater value for decision-making can be gained from data that are spatially and temporally synchronized. This requires closer collaboration between research organizations through awareness of data resources, mutual co-operation through agreed data sharing and integration technologies, such as databases and the internet. It is also vital that associated meta-data are included within a synchronization process.

These points highlights the need for greater collaboration between research disciplines, to link social sciences with the physical and economic within a framework that facilitates understanding by policy makers and other decision making stakeholders.

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Developing needs assessment for achieving specific goals

Identifying ecosystem vulnerabilities will invariably uncover unmet needs in both data availability and capacity to collect, analyzes, synthesize, and interpret results. The exercise of analyzing the past exposes weaknesses in abilities to reduce the risks and realize the benefits associated with current and future climate conditions. In addition there will be new challenges that will tax our ability to achieve the specific listed goals.

2.1   *Ensure collection of data for monitoring the effects of climate variability and change, including extremes, with appropriate spatial and temporal resolution (Goal 1)*

Protection and continuation of the data collection process is of high priority. Measurements of standard meteorological and environmental variables, with regard for WMO or other international standards, are needed to detect subtle but important trends that impact ecosystems. Consideration also should be given, where appropriate, to harvest and archive indigenous knowledge of factors that indirectly give clues to past weather (e.g., crop harvest records, river transport records) that might provide valuable pieces of a very fragmented puzzle of past climate. Special attention should be given to remotely sensed data of use for monitoring ecosystem functioning and new technologies such as systems of distributed iButtons. Ecosystem scientists should be proactive in demand for and use of continuously improving remotely sensed data.

2.2   *Establish national mechanisms to ensure that critical measurements of high quality will continue to be taken long into the future (Goal 1)*

Climate scientists from all nations should be bold in seeking national-level support for infrastructure to ensure sustainable and comprehensive climate monitoring facilities. Where available, support from each country's national academy of science should be sought. An example is the report recently issued by the US National Academies report on mesoscale observing systems (Carbone et al., 2009). Regional scientific alliances that involve sharing data and analyses can help assure policy makers of good return on investment for climate, ecosystem, and socioeconomic observations.

2.3.   *Promote agreements that ensure international sharing of relevant environmental data and climate data to promote regional approaches to problems spanning national boundaries (Goal 2)*

Ecosystems do not respect political boundaries. Regional collaborations among scientists of adjacent countries promote data sharing and more efficient and effective analysis methods for understanding ecosystem status and changes. Such collaborations also enable coordination on developing and implementing adaptive strategies relating to shared problems. Therefore opportunities exist for unifying conflicting parties with shared ecosystem threats from climate change. However, it would also be wise to ensure that climate and ecosystem information does not become a device tool in places of conflict. This can be achieved by having an alternative source of information from a neutral third party.

2.4 Engage with stakeholders and representatives of societal groups that potentially will be highly impacted by ecosystem degradation in discussion on coping with climate change (Goal 4)

Effective engagement with the range of stakeholders impacted by climate change will be essential for ensuring that the science agenda meets the needs of decision-makers, including the delivery of climate science information. Recent past extreme events provide learning opportunities for identifying stakeholder groups, government agencies, and non-governmental organizations that should be engaged in discussion on coping with impact of climate change on ecosystem degradation. Dialog among these groups and with climate impact scientists promotes improvement in lines of communication, sharing ideas on data collection and more rapid and effective response to future extreme events.

2.5 Identify socio-economic drivers for and impediments to effective decision-making (Goal 4)

The degradation of ecosystem services could grow significantly worse in the future due to the growing intensity of many direct drivers of change, and the challenge of reversing the degradation of ecosystems while meeting increasing demands for their services will require significant changes in policies, institutions and practices. As every community is different, there is the need to identify a number of distinct social landscapes emerging, each with a markedly different set of economic, environmental and social opportunities and challenges.

High quality data on climate, ecosystem status and socio-economic conditions do not guarantee effective decision-making for good management of ecosystem health. Religious, cultural, or economic factors may over-ride scientific and scholarly approaches for decision-making. Assessment of past decision-making processes can provide guidance in avoiding sub-optimal future decisions. Also inquiries should concern environmental change in the social and biophysical sciences, and especially in the integration of the two. The collection of socio-economic data must count on the communities, that is, information on the attitudes of the communities towards environmental issues and on their problems and opportunities. Indigenous knowledge can provide vital information in develop and implementing adaptation strategies to climate variability and to enhance adaptive capacity for future climate change.

2.6 Integrate information for planning, preparedness, disaster risk reduction and coping with climate variability including extremes (Goal 4)

A risk conscious community may promote more integrated schemes where risk considerations are factored into development programs. The community should see the relevance of environmental management and good resource use for hazard control and reduction. Climate change and adaptation information dissemination to vulnerable communities helps for emergency preparedness measures and awareness-raising on enhanced climatic disasters. Plans for protection of ecosystems from degradation under climate change and variability should be informed by similar plans developed for protecting human societies in regions of natural hazards. For instance flood or hurricane disaster risk reduction has experienced substantial development in developed nations. Information flow for advanced planning, advanced preparation, during-event deployment of people and material and post-event analysis has enabled risk reduction despite enhanced exposure (e.g., reduction in deaths due to tornadoes). What can ecosystem

management under climate change learn from disaster risk management in hazard prone areas?

2.7   *Identify information and technology needs for facilitating adaptation to climate change (decadal and longer time scales)* (Goal 4)

Advances in technology drive human use of the environment. Technology needs to be considered very broadly to include traditional technologies, including ecosystem-based management approaches. Technology is an important part of a larger strategy to address climate change and needs to be included along with the other major components: climate science research, adaptation to climate change, and emissions mitigation. Decadal and longer scales of climate variability and change require assessment of slow change in (transformation of) ecosystems (e.g., natural forest species composition) and management activities (e.g., forest planting, thinning, cutting, burning; water management) that will facilitate provision of individual and multiple ecosystem services (soil carbon levels, nutrient cycling, water-holding capacity, water quality).

2.8   *Develop international partnerships to ensure access to best-available climate downscaling (regional climate models and statistical downscaling) and ecosystem modelling tools* (Goal 3)

Improving the spatial resolution of climate models is a high priority to be developed with international projects and climate modelling centres. It is essential that decisions made to deliver the policy agenda be based on the best possible climate science.

Organizations responsible for developing climate information for local and regional decision-making should use existing IPCC 2007 AR4 materials as a launch point for determining local climate change impacts. While these materials, including accessible archives of AR4 models, are inadequate for most specific applications, especially seasonal to decadal climate change, they do provide a basic overview of plausible climate changes determined by the largest available collection of climate models.

International partnerships should be established to provide access to best-available climate downscaling tools and, equally important, the human capacity to use these tools in an informed and effective way. Regional climate models and statistical downscaling tools required significant effort for validation on local climates before use in ecosystem modelling. Ecosystem modelling tools, such as those applicable to rangeland management, conservation management, forest use, water resource management, cropping, and specific ecosystems such as aquatic ecosystems, and coastal areas, require validation by use of recently observed local climates. International partnerships should be sought among nations/regions that have similar ecosystems for which they will be developing adaptive strategies.

International partnerships are especially important where ecosystems of high societal value (e.g., rivers, forests) span national boundaries. Long-range planning for developing adaptation strategies for internationally shared ecosystems should include coordinated and consistent measurements and coordinated training of scientists and local managers from countries sharing such ecosystems.

Coastal zones frequently are shared by multiple nations and require integrated management of development in high hazard areas, protection of natural resources, protection coastal zone water quality, provision of public access, and ensuring that the public and local governments have a role in coastal decision-making that is consistent across national boundaries that intersect the coast.   Multinational policies should be promoted that are proactive on hardening coastal areas to sea level rise, tsunamis, and land-falling tropical cyclones and hurricanes by use of managed development and strategic use of coastal ecosystems (mangroves and other natural coastal vegetation).

2.9   *Dissemination and communication of climate information in forms readily usable for decision-making (Goal 4)*

Providing the best possible scientific information supports public discussion and decision making on climate issues. Effective strategies are to be formulated and disseminated for preventing, mitigating, and adapting to the effects of climate change and to undertake periodic science assessments. Inclusion of decision makers in synthesis and assessment reports is helpful to direct the programs to produce information readily usable by policymakers.

Stakeholder engagement is a critical component for developing climate information products. Methods of presenting data (maps, tables, statistics, narrative), mode (internet, face-to-face, TV, radio, newspaper, periodicals, newsletters), terminology used (shared definitions, vernacular expressions, employing stakeholder verbiage), and timeliness of delivery (matched to decision cycles, up-to-date, available at time of day and in mode most advantageous to user) are all critical to successful use of climate information for effective decision-making. There is need to foster a change in societal culture, where esteem is associated with knowledge. In this way appropriate ecosystem management based on quality climate information (and other types detailed in the White paper) helps build social capital amongst decision makers.

2.10   *Identification of the gaps between the information and services needed, and what is available, and of areas that are weak (Goal 4)*

It is often difficult to know what is available, and what will become available and in what timeframe. Needs prioritization may call for rapid response in filling knowledge gaps.
One suggestion is to use the sequence of: issue, requirement, measurement,
observational scale, responses and feedbacks. This requires a rapid response approach to fill knowledge/information gaps through a concerted effort.
As climate-change knowledge expands, uncertainties are reduced, and new applications are developed there is need for identifying new potential user communities and deploying new tools. Similarly, as new ecosystem threats emerge there will be need to assess availability of current climate products to address such threats.   This bi-directional flow of information is best facilitated by establishment of active communication channels (websites, international forums, data exchanges, multi-national collaborations, etc.).

2.11   *Identify research and technology requirements that will improve resilience of ecosystems to changing extremes and trends of climate (Goal 3)*

Increasing scientific knowledge is essential for the informed management, use and preservation of ecosystem resources through research, exploration, education, and technology development. Enhancing resilience is tied to a basic set of initiatives such as eliminating other system stresses and early detection of severe weather.

Earth's ecosystems have developed and persisted through the glacial cycles of the Pleistocene. Time scales for these changes have been slow enough to allow soil, climate, plant, animal, and marine species to develop and in many cases co-evolve. Climate change of the next two centuries differs from past climate change in that the relatively regular glacial-interglacial cycles will be replaced with a continuously and rapidly warming climatic regime. Contemporary climate change time scales do not allow development of new species at a rate that non-adaptable species are lost. However, many other natural adaptive responses will occur including migration, local genetic adaptations, and expressions of phenotypic plasticity Mackey et al. 2008), so long as other pressures can be managed and reduced. Inventories of species likely to be threatened by loss of locally favorable environments, coupled with projections of emergence of new regions, if any, where such species will thrive can suppress species loss and promote high gross global primary production. Development of connectivity corridors (constructing natural pathways that facilitate biological permeability through the landscape) can allow plant and animal populations to more easily migrate with climate in regions where soils allow (Soulé et al. 2004).

2.12   Develop requirements for infrastructure, education, and other forms of capacity-building (Goal 3)

Adaptation of households to climate change has to be pursued through awareness-raising and capacity building on the use of renewable energy in the areas vulnerable to climate change and with ecosystems highly degraded. Capacity building should integrate climate change in planning, and designing of infrastructures, and climate change issues are to be included in curricula at educational institutions.

Ecosystem-based management under climate change and climate variability requires a reliable and predictable long-term supply of financial and human resources to achieve uninterrupted progress. Multi-national teams formed around specific ecosystems will help ensure knowledge preservation, educational opportunities and research/technology sharing that transcends variability in local financial and political support. Ongoing training and skills acquisition are essential to successful management strategies.

2.13   Develop methodologies for analysis of costs and benefits, from user perspectives (Goal 3)

Users of ecosystem services need to understand their sustainability if they expect long-term access to such services. Methodologies must be developed and employed that account for externalities and relevant time and space scales. Costs of supplying ecosystem services in alternative ways should be a basis for developing cost/benefit analyses. Economists and other social scientists are essential participants in assessing vulnerabilities and developing adaptation strategies. On a global scale there is need to develop 'full environmental costing' methods to ensure that the monetary price paid for a commodity adequately reflects the environmental cost of producing it. Therefore the flow

of revenue has to include support to ensure the sustainable supply of materials whilst maintaining ecosystem services.

2.14 *Build effective partnerships between sectors and relevant climate service providers. Adopt strategies that work in other regions, nations, or sectors* (Goal 2)

The most effective use of climate information requires that end users are fully engaged from the onset in developing climate services. New needs for climate products and developing effective decision support mechanisms calls for long-term partnerships between user groups and relevant climate service providers. Social co-learning between service providers and end users helps to refine what information is most useful and how it can best be communicated.

2.15 *Build partnerships between developed and developing countries that are of mutual benefit* (Goal 2)

Reinvention is a poor use of time and resources. Efforts that build on previous successes offer higher chances for further success. Durable and long-lasting partnerships between developed and developing countries can be highly beneficial: developing countries gain access to advanced technologies and developed countries benefit from opportunities to deploy, and thereby improve, existing methods on a wider range of climate systems.

Conclusions

The consequences of **not** using climate information and **not** valuing properly the services provided by ecosystems, is that there is a greater risk of further environmental degradation, reduction in ecosystem services and increased species extinction. Subsequently there would be increased human suffering and a higher probability of not achieving mitigation objectives. As such, the imperative is to ensure that climate and other information types are integrated into, inter alia, risk assessment frameworks and adaptation planning, to maximise the support given in decision making. What is needed is a substantial cultural shift to better recognize the importance of ecosystems as the fundamental units of life support, and the functional role of biodiversity in these systems. The scale of effort by which we study and manage these ecosystems has to reflect this increased recognition of their importance. There are however associated risks in that the future is not easily predicted, scenarios are only possibilities, and perverse outcomes are possible even given the best available information. Properly funded research and monitoring, and support for decision making, will help ensure that these risks are minimised.

The provision of climate information is a vital component to ensure that ecosystems are managed appropriately within the boundaries of environmental limits. It is imperative that human social systems (particularly resource use economics and policies) adapt to develop within the constraints of environmental limits to establish a sustainable global society. For this to occur, planning and decision making needs to be better informed about how ecosystems function now and will change in the future due to an altered climate. Therefore the climate information, when coupled with other information types

such as ecology and socio-economics, should be centralized within policy formulation and practical ecosystem management decision making process. Ecosystem management should form the basis for ensuring a sustainable provision of ecosystem services. For these reasons, human management of ecosystems under climate change and variability is both essential and urgent.

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Appendix

Box 1. Use of probabilistic scenarios

Fundamental to the UK Climate Projection 2009 (UKCP09) is that they provide probabilistic projections rather than the single "best estimate" scenarios provided by previously available climate information. The objective in providing this information is to provide users with a more transparent presentation of uncertainties that is indicative of the strength of evidence considered associated with the projected changes in climate. Rather than the single "best estimate", ranges with associated probability levels are provided. By so doing, it is believed that it will be possible for users of the information to undertake more detailed quantitative assessments of impacts, risks, and adaptation options.

In addition to the probabilistic projections, UKCP09 has a number of other enhancements compared to earlier available climate information for the UK. These enhancements are based on the climate science responses to needs identified by users. Among these are the following:

- Spatial resolution of 25 km

- Temporal resolutions of seven 30-year time periods covering the 21st century from 2010 to 2099

- Climate projections available under three SRES emissions scenarios B1 (labelled Low), A1B (labelled Medium) and A1FI (labelled High)

- Provision of analytical tools to support the use of the probabilistic projections in impacts, risk and adaptation assessments, including a weather generator which users can use to generate plausible daily and hourly time series at a 5 km resolution

- marine environment projections that include projections (not currently probabilistic) for marine variables at multiple levels

- supportive user guidance including information on how UKCP09 can and should not be used

UKCP09 is an online resource (http://ukclimateprojections.defra.gov.ul). The data sets, associated images, analytical tools, science reports and guidance are accessed through a online user interface that is also supported with a manual and online training. The use of UKCP09 will require a change in the way climate information is used. A shift from identifying possible impacts based on a "best estimate" of projected changes with an associated "optimal" adaptation response, to an approach that reflects the uncertainties associated with projections of the future that includes a risk-based approach and robust adaptation options.

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Box 2. Ecosystem-based management in rangelands

Example of an Australian rangeland landscape. Source:
http://www.anra.gov.au/topics/rangelands/pubs/tracking-changes/ris.html

This example is drawn largely from the description provided in LWA (2005). 'AussieGRASS' (Carter et al. 2000) was originally developed as a modelling framework that could contribute to drought assessments by cost effectively providing greater objectivity and accountability for deciding whether or not a region was in drought. It developed into a simulation model for predicting and monitoring grass production and land cover. By taking account of livestock numbers the model can also assess grazing pressure and therefore be used to assess degradation risk and identify opportunities for improved management. The model also provides the means to link biophysical modelling with climate forecasting. Applications include development of a national drought alert strategic information system, and research into whether seasonal climate forecasting can prevent degradation of grazing lands.

Principal inputs to the AussieGRASS model are past daily rainfall and other historical climatic data, soil type, tree density, stocking rate, and seasonal climate forecasts. A central feature of the model is the GRASP pasture production model. The model estimates surface run-off and soil moisture components, the latter being a key driver of pasture growth. Adding value to seasonal climate forecasting is an important output from AussieGRASS, as predictions of rainfall alone are more powerful if the history leading up to the present time is recognised. A modified GRASP model has been used to predict the impact of climate change (increased temperature and carbon dioxide, and changed rainfall conditions) on native pasture production and livestock carrying capacity (Crimp et al. 2002). AussieGRASS has provided the impetus to organise national climate data in a way that allows 'climate users' in the whole community to make better use of climatic data (the SILO long-term climate database). The maps produced by the model showing pasture condition in the rangelands are also shown with information on Sea Surface Temperature (SST) and the Southern Oscillation Index (SOI) to give a fuller picture of current climatic events.