ASSESSING THE IMPACTS OF CLIMATE CHANGE ON ECOSYSTEM SERVICES IN SOUTH-EAST QUEENSLAND

REPORT PREPARED BY

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INTRODUCTION

Background

Work has been progressing within SEQ Catchments, in collaboration with agencies of the Queensland Government, research organizations, universities and individual researchers, to develop and apply an ecosystem services framework for South East Queensland (SEQ). The initiative is described as the SEQ Ecosystem Services Project.

The SEQ Ecosystem Services Framework (SEQ Framework) is based on the Millennium Ecosystem Assessment (MA 2005). The Framework identifies ecosystems within the region, classified as Ecosystem Reporting Categories; the functions performed by those ecosystems; and the ecosystem services that those functions provide. The benefits associated with ecosystem services are interpreted as benefits to humans, in terms of constituents of well-being. The Framework is being developed to support the preparation of ecosystem service maps of the SEQ Region, with the potential to apply it in a range of planning and natural resource management contexts.

To construct the SEQ Framework, an in-depth process has been conducted, involving a Steering Group, Expert Panels and Technical Working Groups. To date, more than 140 individuals from government and non-government organisations have participated in its development. Methodologies applied in the process include spatial data compilation, systems modeling, computer software development, GIS technology and mapping techniques. A summary description of the Project has been prepared by SEQ Catchments (2008) shown in Appendix A.

Financial support for the Project has been received from the Federal Government (through NHT funding), Queensland Government agencies (Department of Infrastructure and Planning and Environmental Protection Agency) and Brisbane City Council. Technical support has been provided by Brisbane Regional Environment Council (BREC) and the University of the Sunshine Coast (USC).

As noted, an important objective of the Project has been to produce maps that identify spatially where various ecosystems and ecosystem functions occur in SEQ. Work is proceeding on a connected set of maps that indicate the spatial distribution of ecosystem services in the SEQ region. Preliminary versions of the ecosystem service maps have been produced but these require further review and improvement where warranted. Peer review and validation of the GIS layers underlying all maps and their relationships with the Framework have yet to be carried out and fully documented.

Other work under way is an attempt to identify and determine, in qualitative terms, the extent to which the various ecosystem services in the Framework contribute to human wellbeing in the region. Once this work has been completed, it will be possible to determine the relative importance of different ecosystem services within the region, as well as produce maps that identify the spatial distribution of ecosystem functions and/or services and their corresponding “values” where they occur.

Terms of Reference for Study

The present study is part of a three-component initiative in the Climate Change Adaptation Demonstration Project Stage 2, undertaken by USC for SEQ Catchments. As part of this initiative, USC has been contracted to undertake a preliminary consideration of how climate change will affect the ecosystem functions and services in South-East Queensland and how SEQ Catchments may invest to mitigate and adapt for effective natural resource management in the region.

The study brings together two key innovative projects of national significance, on which SEQ Catchments and USC have been collaborating - namely, the Climate Change Adaptation Demonstration Project and the SEQ Ecosystem Services Project.

The methodology at this stage of the project has not been pre-determined due to its novel approach. An important aim of the study has been to find the most effective path.

Assessments have focused on the following key Ecosystem Functions:

- Gas regulation
- Climate regulation
- Disturbance regulation
- Water regulation
- Supporting habitats
- Food

The above ecosystem functions, as well as all others in the SEQ Framework, have already been mapped by SEQ Catchments.

Projections of climate change will be facilitated by means of the SIMCLIM model, applied to the SEQ region. The projections are to be assessed with an agreed risk assessment protocol.

The expected outcomes of the study are the following:

- A written report with maps that will provide an overview of the risk to these functions over time and the implications this will have for the region.
- Possibly a report on one or two case studies if time permits.
- Recommendations for investment in regional natural resource management in the next round of federal funding.
- Recommendations for the next stage in this research, incorporating key ecosystem services.

Aims of Study

The future wellbeing of the SEQ population will depend significantly on the quality of the environment and productivity of the natural resources that the region contains.

Identifying threats to ecosystem services and their consequences for community wellbeing is an important precursor to designing effective programs for investments in environmental protection and improvement throughout the region.

Thus far, the SEQ Ecosystem Services Project has produced *profile* information – namely, status maps of ecosystem functions for the SEQ region. The present study aims to apply the Framework to assess the effects of climate change in terms of potential *change*s in ecosystem functions and services in SEQ in future years.

As indicated in the Terms of Reference, an important aim of the study has been to extend and improve the assessment methodology, using selected ecosystem functions as examples. As such, it is a pilot study.

Research Team

The study has been coordinated by Dr David James (Adjunct Professor in the Faculty of Science, Health and Education, USC). GIS techniques and mapping have been the responsibility of Mik Petter (BREC) and Shannon Mooney (SEQ Catchments). Advice on the application of SIMCLIM has been provided by Mr Greg Laves and Professor Richard Warrick from the Faculty of Science, Health and Education, USC. Ila Horosak acted as Research Assistant. Full credit is due to Simone Maynard (SEQ Catchments) who has coordinated construction of the SEQ Ecosystem Services Framework and has provided valuable data and advice.

THE SEQ ECOSYSTEM SERVICES FRAMEWORK

Study Region

The SEQ region, for the purpose of the present study, is a synthesis of the areas covered by the SEQ Regional Plan, the Natural Resource Management Plan and catchments for which SEQ Catchments is responsible. A buffer zone has been added to these boundaries, including near-shore marine areas to fully cover ecosystems that provide ecosystem services to the SEQ Region.

Description of SEQ Framework

The SEQ Framework is based on the Millennium Ecosystem Assessment (MA 2005). Ecosystems are assumed to perform certain ecosystem functions that in turn provide ecosystem services that provide various benefits to the community in terms of constituents of wellbeing.

Ecosystems within the SEQ region have been grouped according to the general Reporting Categories used in the Millennium Ecosystem Assessment framework. However, within the Framework a further sub-division and grouping of ecosystems has been defined, described as Ecosystem Reporting Categories (ERCs). The relationships between MA Reporting Categories and the SEQ ERCs are shown in Table 1 below. Areas occupied by the different ecosystems in the region are shown in Table 2.

MEA Reporting Categories		SEQ Ecosystem Reporting Categories
Marine	-	Deep Ocean
Coastal	Open Water	Pelagic
		Benthic
	Marine Wetlands	Coral Reefs
		Seagrass
		Rocky Shores
		Beaches
		Dunes
	-	Coastal Zone Wetlands
Inland Water	-	Palustrine Wetlands
		Lacustrine Wetlands
		Riverine Wetlands
Forest	-	Rainforests
	-	Schlerophyll Forests
	Plantation	Native Plantations
		Exotic Plantations
	-	Regrowth Forests

MEA Reporting Categories		SEQ Ecosystem Reporting Categories
Dryland	-	Native and Improved Grasslands
	-	Shrubland/ Woodland
Island (Vegetation)	-	Moreton Island
	-	Bribie Island
	-	North Stradbroke Island
	-	South Stradbroke Island and Other Bay Islands
Mountain	-	Montane
Cultivated	-	Sugar Cane
	-	Horticulture: small crops
	-	Horticulture: tree crops
	-	Other Irrigated Crops
Urban	-	Dams
	-	Hard Surfaces
	-	Parks and Gardens
	-	Residential Gardens

Table 1. MA Reporting Categories and SEQ Ecosystem Reporting Categories

Ecosystem Category	Ha	%
Unclassified	74,043	1.90
Beaches	11,461	0.29
Coastal Zone Wetlands	56,161	1.44
Coral Reefs	2,015	0.05
Dams	18,597	0.48
Dunes	40,562	1.04
Hard Surfaces	21,711	0.56
Lacustrine Wetlands	1,571	0.04
Miscellaneous	13,794	0.35
Montane	2,169	0.06
Native and Improved Grassland	1,002,392	25.77
Other Irrigated Crops	62,655	1.61
Palustrine Wetlands	30,556	0.79
Parks and Gardens	18,952	0.49
Pelagic	1,345,957	34.60
Plantation Exotic	53,594	1.38
Plantation Native	30,502	0.78
Rainforests	126,731	3.26
Regrowth	47,693	1.23
Residential Gardens	209,910	5.40
Riverine Wetlands	50,360	1.29
Rocky Shores	609	0.02
Schlerophyll Forest	458,152	11.78
Seagrass	21,009	0.54
Shrubland_Woodland	146,697	3.77
Small Crops	19,345	0.50
Sugar Cane	19,247	0.49
Tree Crops	3,846	0.10
Total ERC Calculated	**3,890,292**	100.00

Table 2. Areas of Ecosystems in South East Queensland

Unlike the MA Framework, the SEQ Framework distinguishes between ecosystem *services* and ecosystem *functions*, along the lines recommended by de Groot et al (2002) among others.

Ecosystem functions are defined in the SEQ Framework as the biological, geochemical and physical processes and components that take place or occur within an ecosystem. Ecosystem functions or processes are recognized as having value for sustaining ecosystems and for providing benefits to humans. Ecosystem services are therefore conceived as the “outputs” of ecosystem functions that people value.

Definitions Adopted in SEQ Framework

The following definitions have been adopted in the SEQ Framework.

Reporting Category

Reporting Categories in the SEQ Framework correspond to those in the Millennium Ecosystem Assessment (MA 2005) to report on the status of ecosystem services.

Ecosystem Reporting Category (ERC)

Ecosystem Reporting Categories in the SEQ Framework refer to groups of ecosystems within each MA Reporting Category specifically in relation to SEQ. Consistent with the MA, each ERC regardless of size, location and condition, has similar “climatic conditions, geophysical condition, dominant use by humans, surface cover, species composition and resource management systems and institutions” (MA 2005, p. 53). In general, broad vegetation groups have been used as a surrogate for different types of terrestrial natural ecosystems.

Ecosystem Function

Ecosystem Functions are defined in the SEQ Framework as the biological, geochemical and physical processes and components that take place or occur within an ecosystem. Four general categories of ecosystem functions are identified:

- Regulating Functions – maintenance of essential ecological processes and life support systems.
- Provisioning Functions – provision of natural resources.
- Cultural Functions – providing life fulfilment opportunities and cognitive development through exposure to life processes and natural systems.
- Supporting Functions – maintenance of biota through provision of healthy habitats.

Ecosystem Services

The definition of Ecosystem Services in the SEQ Framework is the same as in the Millennium Ecosystem Assessment – namely, the benefits people obtain from ecosystems (MA 2005).

Three broad categories of Ecosystem Services are distinguished:

- Regulating Services – benefits obtained from regulation of ecosystem processes.
- Provisioning Services – products obtained from ecosystems.
- Cultural Services – nonmaterial benefits obtained from ecosystems.

Structure of the SEQ Ecosystem Services Framework

The SEQ Framework has four distinct components, as shown in Figure 1. A complete listing of the ERCs, ecosystem functions and ecosystem services in the SEQ Framework is shown in Appendix B.

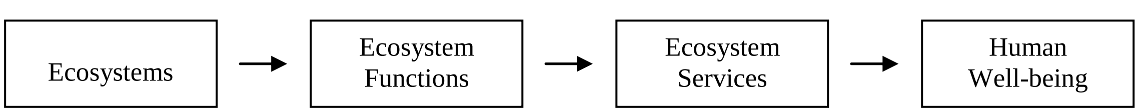

Figure 1. Components of SEQ Ecosystem Services Framework

Two key matrices lie at the core of the Framework. The first contains scores between 0 and 5 indicating the relative magnitudes of the ecosystem functions that each ERC performs. The second matrix contains scores between 0 and 5 indicating the relative magnitudes of the ecosystem services that each ecosystem function provides. The scoring system is based on the presumption that each ecosystem function, regardless of which ERC performs it, is comparable across the SEQ region. Both matrices were constructed by Expert Panels, through an extensive process of discussion and consensus.

These two matrices, when multiplied together, produce a third matrix that produces scores representing the relative magnitudes of each ecosystem service provided by each ERC wherever it occurs within the SEQ region. The scores represent *potential* rather than actual supplies of services.

The overall supplies of ecosystem services provided within the SEQ Region depend on the various ERCs within the region, their areas, their spatial allocation, the extent to which the ERCs perform the ecosystem functions, and hence indirectly the ecosystem services they provide as defined in the SEQ Framework. A description of these interconnections is presented in Appendix C.

Other components of the Framework, still under development, relate to constituents of wellbeing and the relative values of ecosystem services provided in the SEQ region. Further work is continuing on defining appropriate indicators of community wellbeing in SEQ to determine relative values or importance weights for the ecosystem services provided in the SEQ region. Methods such as ratings, the expected value method (Rietveld 1980) or the Analytical Hierarchy Process (Saaty 1980) are under consideration for this purpose.

In spatial terms, data underlying the relevant ERCs have been drawn from detailed GIS layers for the SEQ region. With all information available, either in raw form or generated by expert judgment, it has been possible to produce maps for each ecosystem function in SEQ. A map has also been produced that depicts the summation of all ecosystem functions occurring at each location or sub-area within the region. Such maps provide valuable profile information on sub-areas that are rich in ecosystem functions and those that are ecologically less dominant.

The relative values or importance of different sub-areas depends on the ecosystem services that are provided in each sub-area and the benefits that such services generate in terms of community wellbeing. As noted, these last steps in the analytical process have yet to be completed.

Applications of the Framework

It is expected that development of the SEQ Framework and the capability for mapping ERCs, ecosystem functions and ecosystem services in SEQ will assist planners and decision-makers in various ways. The range of potential applications includes the following:

- Assessing the natural assets of SEQ.

- Assisting natural resource and land managers to maintain ecosystem service provision over time.
- Assessing the sustainability of current and future regional plans.
- Identifying potential alternative land uses with multiple values in non-urban areas.
- Informing the review of the SEQ Regional Plan.
- Identifying threats to ecosystems, their functions and services in the SEQ region, including threats associated with climate change.
- Assessing potential damage or losses in ecosystem services in the region.
- Identifying strategic locations for offsets, rehabilitation and restoration, and climate change mitigation sites.
- Establishing priorities for investments or management actions that can prevent or alleviate environmental damage or enhance the natural assets of the region.
- Guiding the regional application of federally funded ecosystem services and natural resource management schemes.

The interim approach adopted in the SEQ Ecosystem Services Project has been endorsed by the Regional Landscape and Open Space Advisory Committee, which provides specialist advice to the Minister for Regional Planning.

For the present study, attention is focused on developing a methodology for assessing the impacts of climate change on ERCs, ecosystem functions and ecosystem services in SEQ.

SCENARIOS OF CLIMATE CHANGE IN SEQ

Stressors of Climate Change

Climate change involves a number of stressors that can affect ecosystem structure and function and hence the provision of ecosystem services. Key stressors on ecosystems associated with climate change include:

- Temperature
- Rainfall
- Atmospheric CO_2 concentration
- Extreme storm events
- Floods
- Droughts
- Sea level rise
- Saline intrusion
- Acidification of oceans
- Sediment and nutrient transport
- Bushfires

For the purpose of the present study, given the information available for SEQ, only two key stressors have been modeled: temperature and rainfall.

Climate Change Scenarios and Risk Assessments

Future scenarios of climate change will be based on the SIMCLIM model. To conduct realistic and meaningful scenarios, it will be necessary to specify rainfall and temperature characteristics that are of particular importance for ecosystem responses, especially high and low extremes, timing both seasonally and daily, and spatial incidence.

Preliminary maps for rainfall and temperature have been produced for year 2030. The SIMCLIM simulations indicate that changes in rainfall and temperature are not delivered uniformly throughout the SEQ Region and that their spatial distribution is important. SIMCLIM can be used to produce rainfall and temperature maps for year 2100. However, further more detailed applications of SIMCLIM have yet to be conducted.

One reason for a delay in proceeding with more intensive work on climate change projections and risk assessments is that a new version of SIMCLIM is due to be released in the near future that incorporates improvements made in climate change modeling capabilities that have recently been achieved.

ASSESSING IMPACTS OF CLIMATE CHANGE - METHODOLOGY

Ecological Impact Assessments

The complex relationships between biodiversity and ecosystem structure and function have been studied by many professionals, including Loreau et al (2004) and Gilbert (2006) among others.

Assessing changes in the structure and function of ecosystems is an extensive and complex task, beyond the scope of the present study. Ecological impacts of climate change depend on a range of factors including: which climate change stressors are involved; their timing and frequency; the range within which they vary; where they occur geographically; how they act in combination; which ecosystems or components of ecosystems are affected; and the sensitivity of different ecosystems to the changes in environmental conditions. It is widely accepted that ecological response functions are often (even most frequently) nonlinear with thresholds and complex response dynamics (Fischlin et al 2007; Australian Centre for Biodiversity 2008).

Methodologies for predicting ecological responses to climate change are discussed by Fischlin et al (2007, pp218-219) in the IPCC Working Group II Report, among others, who note that basically three approaches can be adopted:

- Correlative – this approach derives functions or algorithms based on knowledge of the past spatial distributions of species that relate the probability of occurrence to climatic and other factors.
- Mechanistic – this approach involves developing models of ecosystem structure and function based on current understanding of energy, biomass, carbon, nutrient and water relations and their interactions with species. Such models produce projections of future vegetation structure and associated ecosystem characteristics and

functions. At the global scale, these models are described as Dynamic Global Vegetation Models (DGVMs).

- Ecosystems- and species-based systems models that are developed and applied at a finer scale, such as regional or sub-regional.

Difficulties in predicting and dealing with the impacts of climate change, according to Fischlin et al (2007, p 215) are:

- Ecosystems are adaptable and will in many cases continue to exist in some form or other.
- Ecosystems are subject increasingly to other human-induced pressures, resulting in increased fragmentation and degradation of natural habitats.
- Ecosystem impacts often involve critical thresholds that trigger non-linear responses with feedbacks that are poorly understood.
- There is limited understanding of time lags in ecosystem responses in terms of biospheric changes or shifts in the geographic distribution of species.
- The conditions causing species extinctions are of particular concern, particularly where extinction are global and not just local. Global extinctions represent an irreversible change and are critical in terms of required adaptation responses.

The Australian Centre for Biodiversity (2008), in a paper prepared for the Garnaut Climate Change Review, identified the following ways in which climate change may affect biological systems (Garnaut 2008, p141):

- Physiology (individual organisms).
- Phenology (timing of life cycles).
- Population processes, such as birth and death rates.
- Shifts and changes in distribution (dispersal and shifts in geographical range).
- Potential for adaptation (rapid evolutionary change).

According to the Australian Centre for Biodiversity (2008) species can respond in three ways: Stay and adapt; Move to other areas; and/or Die, either as declining populations or, in the extreme, become extinct.

In relation to predicting the impacts of climate change on ecosystems, the Garnaut report (2008 p144) states that:

"The disruption of ecosystems, species populations and assemblages will also affect ecosystem services – the transformation of a set of natural assets (soil, plants, animals, air and water) into things we value. These include clean air, clean water and fertile soil, all of which contribute directly to human health and wellbeing. The productivity of some of our natural resource-based industries, including agriculture and tourism, depends on them."

"The vast majority of ecosystem services are far too complex to produce through engineering, even with the most advanced technologies. Their benefits are poorly understood but seem to be large. Human-induced environmental change has already disrupted ecosystem processes. Climate change will further degrade the services provided. The complex biotic machinery that provides ecosystem services is being disrupted and degraded. The consequences are impossible to predict accurately."

An additional complication for the present study is that the only direct ecosystem stressors available from SIMCLIM for the SEQ region are temperature and rainfall. In reality, it is the coincidence of a range of climate change stressors that poses a threat to the ongoing viability of ecosystems and their functions. For example, the impact of higher temperatures on horticultural crops will depend simultaneously on the carbon dioxide fertilization effect, rainfall patterns, hydrological processes, soil characteristics and crop physiology. In coastal areas, changes in temperature and rainfall may affect fisheries and aquaculture via sea level rise, warming of surface waters, saline intrusion, increased acidification, habitat destruction, changes in stratification of the water column, increased storm frequency and changes in patterns of sedimentation and nutrient discharge.

The review of literature on response functions carried out for the study indicates that there are major gaps in information relating to the predicted impacts on ecosystems of climate change. Some studies focus on ecosystem structure and function, while others deal only with the "outputs" of ecosystem functions (ecosystem services) such as water, crops, fish and timber. Where information is available, the level of confidence for much of the predictive work typically varies significantly.

The present study recommends that, despite all of the difficulties of prediction documented above, a highly simplified approach should be used.

Approach to Assessments

Figure 2 indicates that assessing the causal relationships between climate change stressors and ecosystems can be analysed via three different but inter-connected pathways:

- Impacts on Ecosystem Reporting Categories.
- Impacts on Ecosystem Functions.
- Impacts on Ecosystem Services.

In principle, changes in any one of the three pathways can be translated into changes in the other two by making use of the matrices of scores compiled by technical experts that participated in construction of the SEQ Framework.

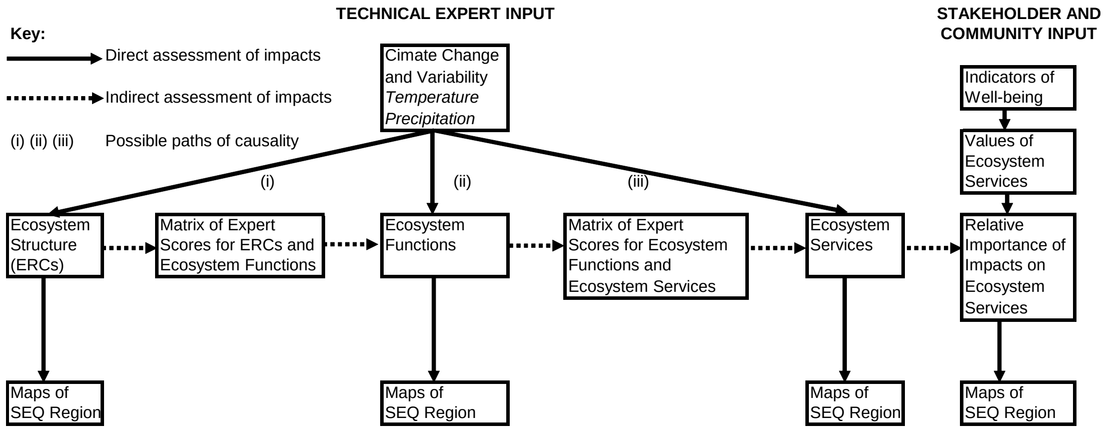

Figure 2. Framework for Assessment of Impacts of Climate Change on Ecosystem Services in South East Queensland

Ideally, assessing the impacts of climate change in terms of the SEQ Ecosystem Services Framework should focus on making appropriate alterations to the individual scores contained in the matrix relating ecosystem functions to ERCs. Such a process would require engaging a group of scientific experts with comprehensive knowledge of the predicted impacts of climate change on ecosystems and their functions, similar to the Expert Panels that constructed the basic matrices of the SEQ Framework, and seek their judgments about the way in which the scores might change.

Under the simplest assumptions, the potential impacts of climate change on ecosystems in SEQ may be represented as a set of impact factors, each of which indicates the severity of adverse impact on each ERC in terms of a projected combination of changed climate stressors in year 2030 or 2100 depending on the time horizon adopted. For each year – 2030 or 2100 - the key data required comprises a set of impact factors, each of which indicates the proportional reduction or diminution in the functioning of each ERC as a consequence of climate change in the respective year. A separate set of impact factors is required for year 2030 and year 2100.

For each ERC, application of the relevant impact factor will determine changes in the scores for the ecosystem functions performed by the ERC. The changes in the scores represent the extent to which ecosystem functions – and via calculation, the associated supplies of ecosystem services – will be diminished or enhanced as a consequence of climate change.

Letting β_i be the impact factor for the *i*th ERC in year 2030 or 2100, depending on which year is under consideration, the effect of each impact factor can be interpreted in the following way:

If $\beta_i = 0$ there is no impact on the *i*th ERC or its ecosystem functions.

If $\beta_i = 1$ the *i*th ERC and its ecosystem functions are completely extinguished.

If $0 < \beta_i < 1$ there is an adverse impact on the *i*th ERC and its ecosystem functions but the *i*th ERC and its functions survive.

If $\beta_i < 0$ the ecosystem functions of the *i*th ERC are enhanced by climate change.

It follows that $(1 - \beta_i)$ represents the proportional "survival" of the *i*th ERC in response to climate change.

Once the changes in ecosystem functions have been determined, it should be possible to translate them into predicted changes in ecosystem services, making use of the third matrix in the SEQ Framework (ecosystem services provided by each ERC). As previously explained, this matrix can be sourced from the matrices initially developed by the Expert Panels that participated in the SEQ Ecosystem Services Project.

The approach has distinct limitations. Impacts are assessed as *potential* impacts, assuming an absence of any autonomous adaptation (see below). It makes the rather restrictive assumption that the impact of climate change on any ERC has the same proportional impact on all functions performed by that ERC. In other words, linear relationships are assumed. Further, it presumes that ERCs remain in the same locations, without migrating in response to climate change, such that predicted impacts (at source) also are confined to their initial pattern of spatial distribution.

Despite these limitations, the approach does offer the scope for conducting rough subjective assessments of the ways in which climate change may impact on ERCs, their functions and the ecosystems they provide in the SEQ Region. As such, the results should indicate which ERCs and functions are most affected and hence the likely need for adaptive responses, including the kinds and scale of interventions or investments that could counter predicted adverse effects.

Empirical Evidence of Ecological Impacts

In the present study, an attempt was made to assess the potential impacts of climate change on ecosystems in SEQ in terms of expected effects on each ERC and the functions it performs. A review of relevant scientific literature was conducted in the hope that indicative impact factors might be determined (see below). However, even for just the six functions specified in the Terms of Reference, the available information proved to be inadequate for this purpose.

One of the key tasks in any follow-up research is accordingly to seek more useful and reliable empirical data on the relationships between climate change and the various kinds of ecosystems in the SEQ Ecosystem Services Framework.

Specification of Baseline

An important consideration in conducting any assessment of change is specification of the baseline against which change is measured. Options include:

- Present conditions.
- Projected trajectories assuming no autonomous adaptation.
- Projected trajectories assuming that autonomous adaptive processes take place.

Detailed investigations, beyond the scope of the present study, are required to specify likely autonomous adaptive responses and the related projections of the residual impacts of climate change. Accordingly, all impacts in the present study are assessed as *potential* impacts, relative to the present situation, excluding autonomous adaptation.

Vulnerability Assessments

An important issue from a management perspective is the vulnerability of different ecosystems within the study region. Adverse impacts on ecosystems are a threat to the natural assets and wellbeing of the SEQ region.

Figure 3 is an extended version of a diagram of vulnerability presented in the Garnaut report (Garnaut 2008, p125). It shows the role of climate change stressors in assessments of vulnerability and conveys the principle that prospective investments or other actions designed to protect or enhance ecosystems and their functions enter the system mainly by influencing adaptive capacity.

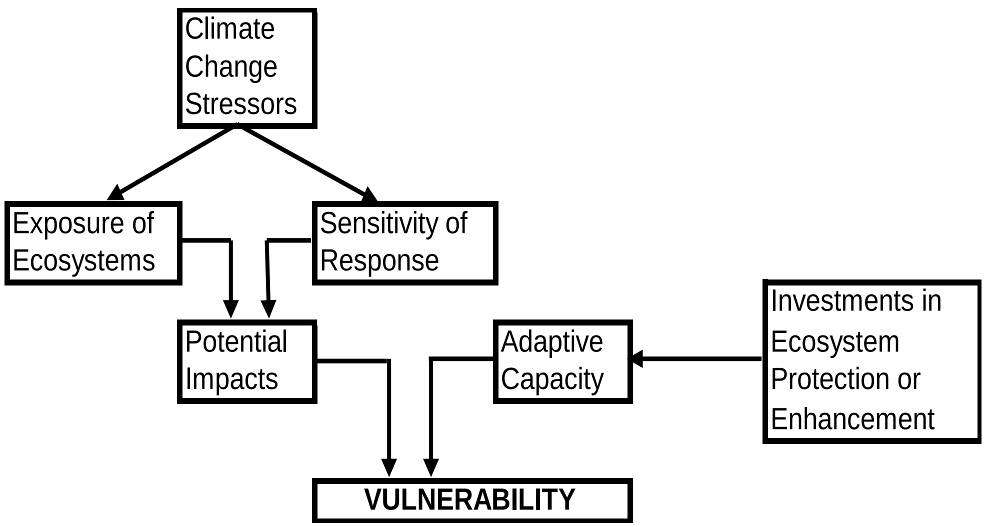

Figure 3. Factors Affecting Vulnerability of Ecosystems

The vulnerability of ecosystems in the SEQ region depends on the potential impacts of climate change stressors, tempered by the offsetting effects of autonomous adaptation. Autonomous adaptation to climate change may take two forms:

- Adaptations by natural systems and species, such as the movement by threatened species to different areas, or changes in their characteristics and/or behaviour.
- Adaptive behaviour by humans, such as deliberately changing the composition of crops in agricultural regions.

In some cases, autonomous adaptation may offset potential impacts. In other cases, the potential impacts may be so serious that adaptive measures are incapable of countering adverse effects.

The severity of ecological impacts that actually occur will depend on the variety and strength of climate change stressors that are responsible for impacts, the sensitivity of ecosystems to changes in climate change stressors and the effectiveness of any adaptive responses that take place.

Autonomous adaptation must be distinguished from policy initiatives or management strategies that are aimed specifically at responding to the impacts of climate change. Investments and other resource commitments are typically required to implement relevant policies and management plans. From a policy and planning perspective, the key issue is how to prioritise options for undertaking remedial or preventive actions.

Risk Profiles and Assessments

In the environmental management literature, a distinction is usually drawn between risk and uncertainty (Dixon et al 1988). Risk is defined in terms of known probability distributions for the factors that influence the system as well as the probability distributions for predicted responses. In the case of uncertainty, probability distributions are unknown.

Assessments of the impacts of climate change on ecosystem functions, of the kind addressed in the present study, are characterized by high levels of uncertainty. Scenarios of future changes in climate stressors are dependent on the assumptions adopted, and assessments of ecological responses are confounded by large gaps in information, especially in quantitative form.

Accordingly, the potential ecological impacts of climate change can be assessed only by conducting sensitivity analyses, specifying upper and lower bounds of key climate change stressors, and possible responses by ecosystems affected.

For the purpose of environmental and natural resource management, the key information required is which particular ecosystems and ecosystem functions are subject to the greatest threat from climate change, and where the greatest potential impacts are likely to occur within the region.

CLIMATE CHANGE AND SELECTED ECOSYSTEM FUNCTIONS

Ecosystem Functions Selected for Study

As indicated in the Terms of Reference, the Ecosystem Functions selected for the present study are the following:

- Gas regulation
- Climate regulation
- Disturbance regulation
- Water regulation
- Supporting habitats
- Food

Descriptions provided by the Expert Panels involved in the SEQ ES Project for each of these functions are detailed below.

Gas Regulation Function

The Gas Regulation Function is described as relating to the influence of natural and managed systems in relation to biogeochemical processes including greenhouse gases, photo-chemical smog and volatile organic compounds (VOCs).

Climate Regulation Function

The Climate Regulation Function is defined as the influence of land cover and biological mediated processes that regenerate atmospheric processes and weather patterns which in turn create the microclimate in which different plants and animals (including humans) live and function.

Disturbance Regulation Function

The Disturbance Regulation Function is described as the capacity of the soil, regolith and vegetation to buffer the effects of wind, water and waves through water and energy storage capacity and surface resistance. The soil profile stores water and reduces runoff. Vegetation enhances infiltration and provides surface resistance. Degraded soils and landscapes have a reduced capacity. Soil properties (eg depth, surface texture) and vegetation are important.

Water Regulation Function

The Water Regulation Function is described as the influence of land cover, topography, soils, hydrological conditions in the spatial and temporal distribution of water through atmosphere, soils, aquifers, rivers, lakes and wetlands.

Supporting Habitats Function

The Supporting Habitats Function is described as preservation of natural and semi natural ecosystems as suitable living space for wild biotic communities and individual species. Natural ecosystems are a storehouse of genetic information generated through evolutionary process. This function also includes the provision of suitable breeding, reproduction, nursery and refugia and corridors (connectivity) for species that are harvested or otherwise valued.

Food Function

The Food Function is defined as biomass that sustains living organisms; material that can be converted to provide energy and nutrition; mostly derived from photosynthesis. A broad definition of food has been adopted, reflecting primary production by ecosystems generally and not necessarily food for consumption by humans.

ERCs Performing Selected Ecosystem Functions

The ERCs that perform mostly the six ecosystem functions selected for the study can be identified from the matrix of scores allocated by the Expert Panels that indicate the extent to which each ERC performs each of the six selected ecosystem functions. The relevant data are shown in Appendix D. Using this data, the ERCs have been ranked according to the extent to which they perform the selected ecosystem functions.

In general, the ranking process indicates that the ERCs with the greatest potential to perform the six functions are, in descending order: Rainforests, Lacustrine Wetlands, Coastal Zone Wetlands, Riverine Wetlands, Palustrine Wetlands and Schlerophyll Forests. The least supportive ERCs are Rocky Shores, Other Irrigated Crops, Residential Gardens, Sugar Cane and Hard Surfaces.

When ERCs are ranked for each of the Ecosystem Functions individually, as shown in Appendix D, the order depends on the function under consideration. Taking the top five ERCs for each function, the following rankings were obtained:

- Gas Regulation: Rainforests, Regrowth Forests, Shrubland/Woodland, Moreton Island and Deep Ocean;
- Climate Regulation: Coastal Zone Wetlands, Rainforests, Schlerophyll Forests, Moreton Island and Bribie Island;
- Disturbance Regulation: Beaches, Dunes, Coastal Zone Wetlands, Palustrine Wetlands and Lacustrine Wetlands;
- Water Regulation: Lacustrine Wetlands, Riverine Wetlands, Dams, Palustrine Wetlands and Rainforests;
- Supporting Habitats: Deep Ocean, Pelagic, Benthic, Coral Reefs and Seagrass;
- Food: Rainforests, Pelagic, Benthic, Coral Reefs, Seagrass and Beaches.

For the six selected functions Hard Surfaces is the least supportive ERC.

Impacts of Climate Change on ERCs

The literature dealing with the impacts of climate change on ecosystems, ecosystem functions and ecosystem services does not mesh well with the classification of ERCs in the SEQ Framework. Much of the information is global in scope rather than specific to SEQ. In addition, many of the impacts are discussed only in terms of particular species or representative areas. Often a combination of climate change stressors is considered simultaneously rather than temperature and precipitation alone.

The IPCC Working Group II Report on *Impacts, Adaptation and Vulnerability* is a key source of information (IPCC 2007). The Garnaut Review report (Garnaut 2008) and various papers commissioned by the Review provide useful information at a national scale. There are also several reports that relate to SEQ, but these deal mainly with impacts on biodiversity or individual species rather than ecosystems as such (Low 2007, Queensland Government 2003). Production data are available for food production in SEQ for human consumption (Queensland Government 2008, Australian Bureau of Statistics 2008) but this relates to only one of the six ecosystem functions selected for the study. Information required to identify specifically the impacts on ERCs in SEQ and produce credible results is a major gap in research.

Accordingly, the following sections discuss the impacts of climate change on ecosystems mainly terms of the Reporting Categories in the Millennium Ecosystem Assessment.

Marine

According to Fischlin et al (2007, p 213) impacts of projected climate change on marine and aquatic ecosystems will be serious. They state:

"Substantial changes in structure and functioning of marine and other aquatic ecosystems are very likely to occur with a mean global warming of more than 2 to 3^o C above pre-industrial levels and the associated increased atmospheric CO_2 levels (high confidence)."

Fischlin et al highlight adverse impacts of high temperatures, in conjunction with increased acidification of the ocean, on a wide range of planktonic and shallow benthic marine organisms, particularly corals. Terrestrial tropical and sub-tropical aquatic systems are also considered to be at risk, with declining water quality.

Coral reef ecosystems are considered to be at high risk as a result of climate change. Coral reefs provide habitat for about a quarter of marine species and a range of important ecosystem functions that support tourism, commercial and recreational fishing and shoreline protection. Fischlin et al (2007, p 234-235) state that the warming of surface waters and increased CO_2 concentrations are predicted to lead to decreased calcification, weakening of reef structures and reduced coral cover.

The Garnaut report (Garnaut 2008, p143) also expresses concern over damage to coral reefs due to climate change, presenting a case study of predicted impacts on the Great Barrier Reef resulting from higher temperatures and increased acidity of the ocean. Mass bleaching is expected under these conditions, with associated impacts on a wide range of marine organisms including turtles, seabirds, marine mammals, coral species, mollusks and fish species.

Coastal

In coastal and shallow marine areas, higher temperatures can be expected to result in increased thermal stratification, lower levels of dissolved oxygen, loss of habitats, reductions in biodiversity and adverse impacts on whole ecosystems (Fischlin et al 2007, p 235).

Maximum tropical cyclone wind speeds are likely to increase by 5% to 10% by 2050, accompanied by an increase in tropical cyclone precipitation rates of 20% to 30%. However, the frequency and location of cyclones is not expected to change. (Walsh et al 2001)

The Garnaut report (Garnaut 2008, p142) states that sea level rise will threaten coastal freshwater wetlands through inundation and increased salination. The only example provided is the Kakadu National Park wetland, which supports more than 60 species of water birds and are important nursery areas for barramundi, prawns and mud crabs and are important breeding areas for crocodiles, turtles, crayfish, water snakes and frogs. In the absence of mitigation, and with a projected sea level rise of 59 cm, the report contends that by year 2100 climate change would adversely affect 90% of the Kakadu wetland system.

Inland Water

According to Fischlin et al (2007, p 223) adverse impacts on inland aquatic systems, such as lacustrine, palustrine and riverine wetlands will be associated with the direct effects of higher temperatures and CO_2 concentrations, and indirectly through changes in hydrological regimes.

Reduced runoff is expected to result in a reduction in soil moisture. Soil moisture will decrease even if rainfall increases slightly, due to the effects of higher temperatures. Based on predictions for the Macquarie Catchment in NSW, environmental flows could decrease by between 15% by 2030 and 35% by 2070 (Jones and Page 2001 quoted by Walsh et al). There is a higher degree of confidence for projected temperature changes, compared with projections of rainfall changes. (Walsh et al 2001)

Fischlin et al (2007) note that wetlands are often biodiversity “hotspots” that provide a wide range of ecosystem services. Adverse impacts include terrestrialisation of wetland areas with consequent reductions in biodiversity and ecosystem function.
In lacustrine wetlands, rising temperatures are predicted to lower water quality by reducing dissolved oxygen concentrations, releasing phosphorus from sediments, and changing mixing patterns. For lacustrine and riverine wetlands in tropical monsoonal areas, increased climate variability is expected to result in a decline in net primary productivity, reductions in species diversity and declining fish yields.

Forest

According to Walsh et al (2001) tropical forests are highly sensitive to climate change. A change of only 1^oC was predicted to result in significant changes in the distribution of forest environments even with rainfall variations ranging from -10% to +20%. The most pronounced effects are applicable on the boundaries between rainforest and open woodland. Highland rainforests are particularly susceptible.

Based on an extensive review of the scientific literature, Fischlin et al (2007, p 213) conclude that:

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

These impacts are predicted in particular for forest and woodlands in mid- to high latitudes and in the tropics, especially in association with changing disturbance regimes such as wildfire and insects.

Fischlin et al (2007, p 228) consider that climate change could have beneficial effects on forests through CO_2 fertilisation, increased precipitation where it occurs and warming in cold climates. However, these effects apply mainly to boreal forests and are not relevant to conditions in SEQ. It is meaningful that the authors also state that forests will be adversely affected by droughts, although there are uncertainties about the processes involved. Adverse impacts include reduced net productivity, reduced resilience and mortality. Additional stresses are associated with disturbances such as wildfire, insects and disease.

Dryland

Climate change is expected to have various kinds of impacts in grassland areas. Fischlin et al (2007, p 225) note that impacts on ecosystem function and species composition in temperate regions will depend mainly on changes in temperature and precipitation, but in tropical systems CO_2 fertilisation and disturbances such as wildfires will be important stressors.

Walsh et al (2001) and Howden et al (1999) maintain that the carbon fertilisation effect would lead to an increase in native pastures. Howden et al (2001b) predict increases in growth rates for trees in woodlands in SW Queensland with higher CO_2 concentrations accompanied by higher temperatures. The CO_2 fertilisation effect is also predicted to result in an increase in wheat yields with a 20% decrease in rainfall and temperature increases up to 1^oC but would decrease for temperature increases greater than 1^oC (Howden et al 2001a). Higher temperatures can be expected to result in an increased frequency of fires. These studies, however, focus on ecosystems in semi-arid rangeland environments.

Most of the research conducted into impacts on livestock production in the Australian situation has focused on rain-fed rangelands, where beef and sheep are the dominant species. The main impact occurs indirectly through reduced pasture growth, stocking rates and liveweight response (Crimp et al 2002).

Increases in temperature may adversely affect livestock in SEQ through heat stress. If water is supplied to livestock from storages, changes in rainfall generally will not have significant direct impacts. However, livestock will be adversely affected by any decrease in rainfall where there is a dependence on rain-fed pasture.

In SEQ, beef fattening is an important activity. Dairying is also important. The region produces approximately 78% of milk in Queensland (DPI&F 2008). SEQ has also large numbers of pigs and poultry (ABS 2008).

Mountain

Fischlin et al (2007, p 232) note that montane ecosystems perform important ecosystem functions such as water supply, water purification and climate regulation. Increased evapotranspiration can be expected from higher temperatures, with consequent impacts on montane vegetation and water supply.

According to Fischlin et al (2007) higher temperatures will affect the distribution of species at different gradients in montane areas. They note that even in humid tropical regions, plants and animals are sensitive to water stress. If species are unable to adapt, then significant reductions in biodiversity can be expected.

The Garnaut report (Garnaut 2008, p 142) notes that Australia's high altitude species are at risk, with some species facing complete extinction with only a 1^{o}C rise in temperature. Studies are quoted that predict that a 1^{o} C rise in temperature will result in 50% decrease in the area of highland rainforests in tropical Queensland, and a 2^{o}C increase would cause complete extinction of all endemic Australian tropical rainforest vertebrates.

The relevance of these predictions to SEQ, however, must be questioned, as the elevations of "mountains" in the region are not high. In addition, the areas of high land in SEQ are expected to experience modest increases in rainfall rather than decreases.

Cultivated

In the SEQ Framework, the relevant ERCs are Horticulture - small crops (brassicas, lettuce, onions, potato, capsicum, curcurbits, sweet corn, tomatoes); and Horticulture - tree crops (fruit trees, nuts), sugar cane and other irrigated crops. Statistics provided by the Queensland Department of Primary Industries and Fisheries (DPI&F 2008) and the Australian Bureau of Statistics (ABS 2008) indicate that production of these crops are important in SEQ.

According to Deuter (2008) all horticultural crops are sensitive to temperature and have specific requirements for yield and quality. Rainfall is not as important as temperature, as most horticultural activities rely on irrigation. Higher temperatures and increased incidence of drought, however, may indirectly affect horticulture if increased requirements for offsetting irrigation cannot be met because of restricted water availability.

Deuter predicts that in tropical and sub-tropical regions with winter crops, a rise in temperature of 1^{o}C can affect horticulture by shortening of the production period. For example, in SEQ, the winter season for brassica and lettuce production (mid-April to October) will be shortened by several weeks to only one month.

There will also be adverse effects on product quality. Deuter lists the following effects of higher temperatures on horticultural crops in SEQ:

- Adverse effects on fruit size, quality and retention of avocados.
- Quality reduction in tomatoes with temperatures over 35^{o}C
- Lettuce tipburn with high temperatures and low humidity
- Increased incidence of brown fleck disorder in potatoes
- Poor pollination of sweet corn, curcurbits, tomatoes and avocados.

- Floral abortion of capsicums with temperatures over 30°C
- Reduced tuber initiation in potatoes
- Poor pollination in crops grown for seed
- Premature seedhead production in lettuce and celery

Deuter points out that higher temperatures will lead to increased activity of pests and diseases and may reduce the effectiveness of certain types of biological pest controls. Increased CO2 concentrations tend to boost the productivity of horticulture through the CO2 fertilisation effect, but this is likely to be offset by the adverse impacts of higher temperatures.

Urban

Urban areas are typically not important in supporting ecosystem functions in terms of either diversity or level. The main ecosystem functions are associated with parks and residential gardens. In this respect, the impacts of climate change are similar to those affecting vegetation more generally, such as the effects of higher temperatures on evapotranspiration, species composition and species survival. Changes in precipitation are unlikely to be significant, because water for trees, shrubs, flowers, vegetables and lawns may be obtained from dams, rainwater tanks, aquifers and recycled effluent.

Islands

Islands are not treated separately as a Reporting Category in the Millennium Ecosystem Assessment. However, islands in SEQ can be considered as distinct areas of high ecological significance. Each island in the SEQ Framework comprises a combination of separate MA Reporting Categories. A particular combination of Reporting Categories defines the ‘island’ system in each case. For example, North Stradbroke Island contains Urban Ecosystems, Forest Ecosystems and Inland Water and Coastal Ecosystems. The impacts of climate change stressors on each island system will determine the overall impact, including any cumulative or synergistic effects.

Role of Investments in Ecosystem Protection and Enhancement

As indicated in Figure 3, investments in the protection or enhancement of ecosystems take effect mainly by improving the capacity to respond to climate change.

Under the “ideal” approach, an expert panel could be engaged to indicate, by changing scores in the matrix of ERCs and ecosystem functions, in what ways and to what extent investments or changes in management regimes might counter the anticipated adverse impacts of climate change. Indeed, more generally, with or without climate change, this is how management interventions could be simulated. Using the matrices in the framework, it is relatively straightforward to calculate the implied changes in the supplies of ecosystem services at each location and for the region as a whole.

Using the "simple" approach outlined previously – of applying ecological impact factors – expert judgments could be made about the extent to which investments or interventions might change the ecological impact factors. It is presumed that investments would reduce adverse impacts, producing higher levels of ecosystem functions and services in the SEQ Region, compared with the impacted case.

Investments are also capable of enhancing ecosystem functions and the provision of ecosystem services, as would be relevant in identifying opportunities for environmental offsets to counter adverse impacts elsewhere in the region. Such investments would involve applying impact factors with negative values: that is, $\beta_i < 0$.

Assessing the *benefits* of investments in ecosystem protection and enhancement has not been attempted in the present study. The required approach involves deriving scores, rankings or values that reflect community preferences or priorities regarding the effects of investments on constituents of wellbeing. Such a task involves information, time and resources beyond the scope of the study. Further work is required to operationalise this aspect of the assessment process.

CONCLUSIONS AND RECOMMENDATIONS

Main Findings

The main findings of the present study are that a framework and methodology has been developed that is capable of modeling ecosystem functions and services in SE Queensland. The available GIS data held by SEQ Catchments allows maps to be produced indicating their spatial distribution.

The SIMCLIM model is a useful tool for conducting scenarios of climate change to the year 2100, based on the latest results from a range of climate change models. The reliability of scenario construction will be enhanced when the latest version of SIMCLIM is released.

The SEQ Ecosystem Services Framework can be manipulated, on the basis of expert judgment, to simulate the effects of climate change on ecosystems, ecosystem functions and ecosystem services in the region, using expert scores as the yardstick of measurement. Such impacts can be mapped spatially, at source and according to their potential magnitudes, again measured in terms of expert scores.

Implications for Investment Strategies

Similar manipulations, conducted within the Framework, should provide a basis for assessing the extent to which investments in environmental protection and natural resource management might be expected to reduce or avoid adverse impacts and indeed create the potential for enhanced ecosystem functions throughout the region. Evaluating the benefits of such actions requires further information on the role of ecosystem services in relation to community wellbeing and the ways in which wellbeing might be enhanced through carefully targeted investments and management programs.

Limitations

The main limitation of the methodology recommended in the study is that a comprehensive data set – even though primarily of qualitative rather than quantitative in nature – is required. Empirical data indicating the impacts of climate change on different ecosystems, ecosystem functions and ecosystem services is at best patchy, so there is virtually no option other than relying on facilitated workshops designed to elicit scores from relevant experts. Subjectivity of one form or another is unavoidable in such procedures.

Other limitations are the assumptions of linearity and additivity in the matrix calculations, and the comparative statics approach in conducting model simulations.

Future Directions for Research

There is an urgent need for documenting in detail the GIS layers that underlie the profile maps of ERCs and ecosystem functions in the SEQ region and especially how the different GIS layers have been translated into the various categories of ecosystem functions in the SEQ Ecosystem Services Framework.

To progress research on the projected impacts of climate change on ecosystem functions in SEQ, a significant effort is needed to determine more comprehensively the relationships between climate change stressors and ecosystem functions in the region. Initially, ecosystem responses could be investigated for key ecosystem functions in SEQ, expanding the database over time as an ongoing process.

The provision of ecosystem services can be calculated from the matrix of expert scores relating ecosystem services to ecosystem functions. If warranted, a reality check with subsequent modifications should be made to establish the soundness of the Framework and confidence in its many potential applications.

In constructing future scenarios of climate change for the region, SIMCLIM should be a useful tool. Rainfall and temperature as the variables of greatest concern, but other climate change stressors could be modeled in due course. The ways these climate variables are defined and simulated - in terms of averages, upper or lower bounds, timing and spatial distribution – will bear critically on results that might be anticipated. The newer version of SIMCLIM should provide more up-to-date and reliable scenarios of future climate change.

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