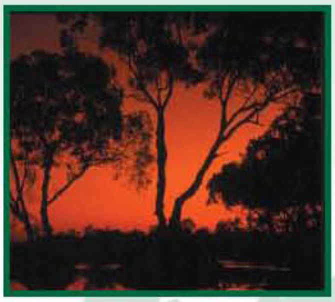
SPECIAL REPORT

Environmental Crisis: Climate Change and Terrestrial Biodiversity in Queensland

Edited by A.K. Krockenberger, R.L. Kitching and S.M. Turton



Rainforest CRC

Cooperative Research Centre for Tropical Rainforest Ecology and Management

ENVIRONMENTAL CRISIS:
CLIMATE CHANGE AND TERRESTRIAL BIODIVERSITY IN QUEENSLAND

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PREFACE

The Cooperative Research Centres program was established in Australia in 1990 to ensure that research undertaken by Australian scientists led to real outcomes, both commercial and public good, for Australia. One of the challenges for CRCs such as the Rainforest CRC which carries out largely public good research is how to produce research products that are of relevance to, and influence, government policy. Australia faces some of the world's most challenging environmental problems. Our research must provide a real understanding of Australia's biodiversity and ecosystems and give warning signs of when these are threatened. We must also provide some solutions as to how to tackle these threats - but without straying in to the policy arena. It is important that as scientists we remain independent of government policy, but try to inform it.

This document arose through the provision of a grant from the Queensland Premier's Department to the Rainforest CRC to participate in the newly established Global Canopy Program (www.globalcanopy.org). The Global Canopy Program seeks to link existing and new projects studying the world's forest canopies into one integrated global program of research, education and conservation. One of the conditions of that grant was that we should hold a forum to inform Queensland policy makers about forest canopy research and what the implications were for government environmental policies. In the last twelve months a number of critical research findings led us to decide to focus this workshop more broadly on the impacts of climate change on terrestrial biodiversity in Queensland. Australia is one of the leading countries looking at forest canopies and was the first in the southern hemisphere to establish an industrial crane in our Daintree rainforest. Several of us using that crane to understand forest canopies were co-authors on a review paper (*Science* 301: 183-186) which looked at the critical issues in canopy research and the role of the canopy in climate change was one of the key foci for this paper.

Our rainforests in North Queensland are arguably the best understood of all rainforests around the world and this means that we often provide new insights into rainforest biodiversity and ecology that others have followed. For example, previous studies by our researchers have changed scientists' views of the structure and distributions of rainforests with past and future climates. Forests are far more dynamic than we once thought. At the same time this has had a remarkable influence on the genetic structure of animal and plant populations. Two of those who participated in the workshop that led to this paper, Steve Williams and Dave Hilbert, have built on this legacy and have recently published cutting edge papers looking at the impacts of future climates on vertebrates and vegetation of the Wet Tropics, respectively. A recent article (*Nature* 427: 145-148), discussing global extinction risk from global warming, includes Williams as a significant contributing co-author. Both Williams and Hilbert are now in high demand to present at international conferences.

The focus of our workshop was the impacts of climate change on Queensland's terrestrial biodiversity, with a special interest in tropical forests. In preparing the resulting report, we were strongly influenced by the style of the 'Wentworth' report but have chosen to provide more references to key areas of scientific debate. One thing we learn as scientists is that nothing is ever fully proven – all we can do is to provide more evidence. Right now the evidence for climate change impacting on our precious biodiversity is increasing all the time. We hope that our governments will take the necessary actions to help reduce the severity of those impacts. We are especially grateful to the strong support provided by the Queensland Departments of Premier and Cabinet and Environmental Protection Agency in the production of this report.

Prof Nigel Stork
CEO, Rainforest CRC

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GCP
Global Canopy Programme

EXECUTIVE SUMMARY

It is now widely accepted by the scientific community that anthropogenically-induced climate change is occurring, and is the greatest threat to global biodiversity, surpassing that attributed to habitat loss. The average temperature of the globe has risen by around 0.6^{o}C over the last century and is predicted to rise a further 1.4 to 5.8^{o}C before the turn of the next century. In Queensland, the rate of warming is predicted to be similar to the rest of the globe. Along with the increase in average temperatures, scenario's predict that the severity and frequency of occurrence of extreme temperatures will rise, heat waves will become more frequent, and evaporation and, hence, effective "dryness" will increase. Modelling indicates that rainfall is likely to become more variable, with more wet spells, but also more droughts with greater impacts due to the higher temperatures.

Climate change today differs from past climatic variability in two ways that suggest it may have more serious effects on biodiversity. First, the rate of temperature change recorded in the late twentieth century and predicted to continue, is considered by many scientists to be unprecedented in the past 10,000 years. Second, these changes are impacting on ecosystems already stressed by other human impacts, such as land clearing and the consequent fragmentation of natural vegetation.

The impact of such changes on biodiversity in Queensland is likely to be very serious and could be catastrophic under some scenarios. Even moderate levels of warming, well within the envelope defined by the Intergovernmental Panel on Climate Change have the potential to pose serious threats to biodiversity.

Our protected area estate and the biodiversity it contains is not protected from global climate change and is just as vulnerable as the rest of the landscape.

Climate change, resulting from human impacts, has been a phenomenon of concern to the scientific community for many years. However, the ability to engage governments and the wider population has been hampered, until now, by a lack of scientific certainty and the by size of the task. Recent trends in temperature and modelling of future climates have reduced this uncertainty to the point where it would be foolish, indeed irresponsible, if knowledge of climate change impacts were not incorporated into future conservation planning.

Research, based on current models, shows that many species of animals and plants are at highly increased risk of extinction as a result of climate change, even under the least extreme of scenarios. This is predicted to be particularly acute for regions with many local endemic species (such as the Wet Tropics) because the current climatic ranges of local endemics are generally restricted. Modelling shows that high elevation species especially may become progressively restricted as their already limited habitat shrinks or even disappears. For example, the climatic habitat of the Bellenden Ker Nursery frog, *Cophixalus neglectus*, is predicted to disappear entirely with 1^{o}C average annual warming. It is also important to note that endemic species have been important in the designation of parts of the protected area estate, such as the Wet Tropics World Heritage Area, so the loss or decline of these species has important ramifications for the ongoing heritage values of these areas.

The ecosystems we currently recognise will be redistributed across a landscape affected by climate change. In addition the actual structure and/or composition of ecosystems is likely to change, creating new ecosystem types, derived from but different to existing types. The expansion, or new introduction, of many weed species may also have a significant impact on ecosystem composition.

A range of ecosystem types are at relatively high risk. They include arid and semi-arid rangelands, rainforests and vine thickets, montane areas, wetlands, rivers and riparian systems. These ecosystems will be strongly affected by the increases in temperature and changes in rainfall predicted by climate change models. Some, such as montane areas, may even cease to exist, as their bioclimatic environments could disappear entirely.

Queensland should respond immediately to the threat climate change poses to its biodiversity. Actions to minimise the effects of climate change on biodiversity must be strategically designed and carefully considered, and they will take time to implement and become effective. It is essential to reinforce the aspects of current conservation policy that make species, communities and ecosystems more resilient or adaptable or better able to absorb or adjust to the pressures of climate change.

Any strategy for mitigating the effects of climate change in Queensland must be supported by two fundamental principles.

> **First**, no strategy for the amelioration of climate change impacts can work in the long-term without effective global and local emission control. However,
>
> **Second**, minimising the impacts of climate change on biodiversity must begin with the cessation of widespread clearing of vegetation.

A set of additional actions is now clearly required. These actions are as follows:

- An assessment of the effectiveness of the current protected areas estate and its likely response to climate change should be undertaken. This should be followed by a strategic land acquisition program to increase the comprehensiveness and resilience of the estate to the impacts of climate change.
- There should be increased emphasis on off-reserve conservation to improve connectivity of reserves, allow movement of species and communities across the landscape in response to altered climates, and maximise the resilience of the whole landscape to altered climates. As part of this a tender system for conservation of biodiversity on private land should be introduced after trials within a region of Queensland.
- The biodiversity values of regrowth vegetation should be recognised. The protection of regrowth vegetation should be considered in areas that are important for maintenance of connectivity of natural vegetation in the landscape, in the light of planning for climate change.
- Decisions on land, water and biodiversity allocation and use should become more precautionary. Consideration of climate change should be incorporated in all levels of community-based natural resource management and environmental planning in Queensland. This should include incorporation of climate change issues in development of water resource plans.
- Recovery planning for endangered species should include consideration of the effects of predicted climate change. In particular, the relative importance and likely effectiveness of both *in situ* and *ex situ* approaches need to be considered. The establishment of a DNA/germ plasm/seed bank is recommended for the ‘most-at-risk’ species.
- There should be a review of the distribution and impacts of weeds, feral animals and diseases/pathogens in Queensland, or which could easily enter Queensland, in the light of climate change predictions.
- Fire management strategies and plans should be revised to take account of the predicted future changes to climate and biodiversity.
- A Climate Change Commission managed by an independent group of commissioners with expertise in greenhouse science and policy, sustainability, resource and biodiversity management, resource economics, and public administration should be established to

oversee and facilitate the changes required to minimise the effects of climate change on biodiversity in Queensland.

- Government investment in subsidies should be reviewed to identify any that exacerbate the impact of climate change. Reduction or removal of subsidies identified in this way could be considered to generate funds to pay for the measures outlined in this report. We believe that drought relief schemes are one type of subsidy that can have perverse outcomes. Whilst intended to help struggling farmers, they can exacerbate the land degradation and consequent impacts on biodiversity associated with drought. It is time to make fundamental changes to the way we provide drought relief so that farmers are assisted to relieve pressure on the land. This is about changing the nature of the subsidies, not withdrawing assistance from farmers when they most need it.
- Water management should be revised in the light of predicted increases in variability and decreases in total river flow, to ensure that environmental flows are maintained in waterways and wetlands.
- A public education campaign to inform and educate the public about the nature and consequences of climate change on biodiversity and effects on landscape function and ecosystem services is essential.
- A strategic on-ground biodiversity monitoring system should be established to assess the progress of impacts of climate change across the landscape as well as responses to management interventions.
- It is crucial that management of the impacts of climate change on biodiversity in Queensland be informed by an on-going, comprehensive and strategically prioritised program of research.

INTRODUCTION

It is now widely accepted by the scientific community that anthropogenically induced climate change is ocurring[1,2]. The average temperature of the globe has risen by around 0.6°C over the last century[2] (Figure 1) and is predicted to rise further, between 1.4-5.8°C before the turn of the next century[3]. Further, some recent models predict that there is a 40% chance that warming may exceed the maximum 5.8°C increase predicted by the Intergovernmental Panel on Climate Change[4].

In Queensland, the rate of warming is predicted to be similar to the rest of the planet (from 0.9°C/°C of global temperature rise on the coast to 1.1°C/°C for the inland[5]). Along with the increase in average temperatures, models' predict that extreme temperatures will rise, heat waves will become more frequent, and evaporation and, hence, effective "dryness" will increase. Modelling indicates that rainfall is likely to become more variable[6], with more wet spells, but also more droughts with greater impacts due to the higher temperatures[5]. It is also predicted that climate change could lead to more intense tropical and temperate storms.[3,5,6]

In the past, climate change has been associated with massive changes in natural ecosystems and losses of biodiversity. For example, the transformation of Australia from a continent with a substantial cover of Gondwanan rainforests to the driest continent on earth where spinifex grassland is the single most common vegetation type has been as a result of natural climate change over millions of years. More recently Australia has experienced climatic fluctuations that had substantial effects on the distribution and abundance of flora and fauna[7,8].

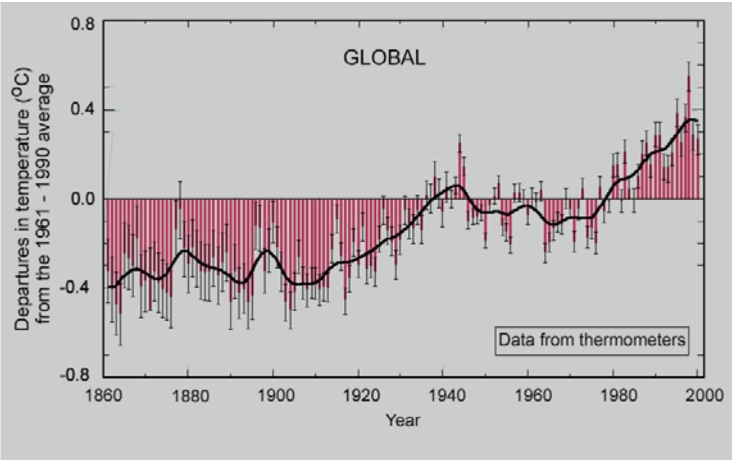

Figure 1: The 1990s was the warmest decade ever recorded instrumentally. The last 100 years were the warmest of the millennium, with 1998 the hottest year on record and 2002 the second hottest[3].

Climate change today differs from past climatic variability in two ways that mean it may have more serious effects on biodiversity. First, the rate of temperature change recorded in the late twentieth century (Figure 1) and predicted to continue is considered by many scientists to be unprecedented in the past 10,000 years[9] and second, many of the earth's ecosystems are already stressed by other human impacts, such as land clearing and the consequent fragmentation of natural vegetation[10].

The impact of such changes on biodiversity in Queensland is likely to be very serious and could be catastrophic under some scenarios. Even moderate levels of warming, well within the envelope defined by the IPCC have the potential for serious threats to biodiversity[11,12,13,14].

Policy responses to climate change should enhance the resilience of our landscapes, their ability to adjust to or absorb the impacts of change, and to minimise the detrimental effects on biodiversity and the functioning of the entire landscape.

CLIMATE CHANGE RESPONSIBILITIES

HOW CERTAIN ARE CLIMATE PREDICTIONS?

Climate change, resulting from human impacts, has been a phenomenon of concern to the scientific community for many years. The ability to engage governments and the wider population has been hampered, until now, by a lack of scientific certainty and the size of the task.

Detractors have argued that global warming is a natural phenomenon resulting only partially from human activity. There is also a view that change is inherent in climate and that the extent of natural variation is not known[15]. Recent trends in temperature and modelling of future climates have reduced this uncertainty[1,2,12] to the point where it would be foolish, indeed irresponsible, if climate change were not incorporated into future conservation planning[16,17,18].

Predicting future climatic conditions is a probabilistic science and it is impossible to be absolute in predictions. Furthermore, the ability to model different types of climatic parameters varies, and consequently the different predictions of climate models vary in their robustness and level of acceptance[6]. However, it is clear from historical data, and generally accepted that average temperatures have risen, and will rise further[1-6,12]. Predictions of rises in extreme temperatures (both maximum and minimums) are similarly robust[5,6]. Predictions for Queensland suggest that average maximum temperatures may rise around 0.4-2.2^{o}C and "hot" winter/spring days become 30-400% more common by 2070[5]. Trends in precipitation are far more difficult to accurately predict, especially in Queensland where precipitation is strongly influenced by the El Nino-Southern Oscillation (ENSO) phenomenon, which has generally not been well modelled in General Circulation Models (GCMs)[5]. However, there is an increasing acceptance that "… the balance of evidence … suggests a trend towards more El Nino-like (low rainfall) conditions…"[5]. It is also likely, but less robustly predicted than for temperature rises, that rainfall will become more variable, with prolonged dry periods and intense wet periods[6].The CSIRO Darlam-60 climate model predicts slight (0-5%) decreases in winter and spring precipitation over much of Queensland[5]. The consequences of such decreases (or even just a lack of increase in precipitation), coupled with higher temperatures and possibly more common El Nino-like conditions (usually associated with prolonged dry periods[5]), suggest that Queensland may experience more frequent drought conditions and lowered average soil moisture due to the enhanced evaporation associated with higher temperatures[5]. The CSIRO's climate models suggest that annual water balance (precipitation less evaporation) may decline by around 40-100% (for each degree of global temperature rise) over much of Queensland[19].

Initial impacts of climate change are already apparent in Australia and around the world[10,11,17]. In 2003 alone, the hottest days on record in the UK claimed 900 lives in just the first two weeks of August; thousands died in a similar French heatwave and pre-monsoon temperatures in India reached 49^{o}C and killed 1500[20]. While attribution of any particular extreme event to anthropogenic climate change can and will always be debated and disputed, an increase in the frequency and severity of temperature extremes is a robust prediction of most climate models[6]. Climate change is also impacting natural ecosystems. Worldwide, coral reefs (including the Great Barrier Reef) are afflicted by coral bleaching caused by rising sea-surface temperatures[21]. There have also been extinctions of amphibians from cloud forests[22] as well as changes in the distribution and abundance of a variety of organisms[10,11,17]. These effects are predicted to continue for the foreseeable future because of the long-term effects of the greenhouse gases already in our atmosphere[3,23,24].

Even though some degree of climate change is now extremely likely, effective global control of greenhouse gas emissions is vital to limit the magnitude of climate change that we ultimately experience[24]. No management of the impacts of climate change on biodiversity can be effective in the face of uncontrolled emissions. Queensland and Australia overall should play a role in that emissions control.

Queensland has taken up the challenge to develop policy and initiatives aimed at the management of emissions and climate change and has produced the Queensland Greenhouse Policy Framework *A Climate of Change.* That framework will guide further action to address greenhouse and climate change issues. Consultation and development of both national and Queensland policy addressing the effects of climate change on biodiversity have begun[25]. It is the intent of this document to inform those considerations.

IMPACTS OF CLIMATE CHANGE ON TERRESTRIAL BIODIVERSITY IN QUEENSLAND

Climate changes are predicted to impact on the distributions of species - either native to Queensland or invading forms, as well as the distribution and functioning of ecosystems[11].

IMPACTS AT THE SPECIES LEVEL

Research, based on current models, shows that many species of animals and plants are at highly increased risk of extinction as a result of climate change, even under the least extreme of scenarios. This is predicted to be particularly acute for regions with many local endemic species (such as the Wet Tropics) because the current climatic ranges of local endemics are generally restricted. Modelling shows that high elevation species especially may become progressively more restricted as their already restricted habitat shrinks or even disappears[12] (Table 1).

For example, the climatic habitat of the Bellenden Ker nursery frog, *Cophixalus neglectus*, is predicted to disappear entirely with 1^{o}C average annual warming[12]. It is also important to note that endemic species have been important in the designation of parts of the protected area estate, such as the Wet Tropics World Heritage Area[26], so the loss or decline of these species has important ramifications for the ongoing heritage values of these areas.

The ability of species to adjust to climate change by moving to more climatically suitable areas (eg. to higher altitudes or more southern latitudes) will be hampered by existing geographical barriers as well as new barriers created by the widespread human modification of the landscape[10].

If species distributions change, so too will the intensity of population level processes change.

Table 1: List of species most affected by climate change. This lists the most vulnerable species of endemic vertebrates, those that are predicted to lose greater than 50% of their current area of core environment with only a 1^{o}C increase in temperature[12].

FROGS	
Thornton Peak nursery-frog	*Cophixalus* sp. Thornton Peak
Magnificent broodfrog	*Pseudophryne covacevichae*
Pipping nursery-frog	*Cophixalus hosmeri*
Northern barred frog	*Mixophyes* sp. Nov.
Tangerine nursery-frog	*Cophixalus neglectus*
Bloomfield nursery-frog	*Cophixalus exiguus*
Mountain top nursery-frog	*Cophixalus rheophilus*
Northern tinkerfrog	*Taudactylus rheophilus*
MAMMALS	
Atherton Antechimus	*Antechinus godmani*
Mahogany glider	*Petaurus gracilis*
Daintree River ringtail possum	*Pseudochirulus cinereus*
Lemuroid ringtail possum	*Hemibelideus lemuroids*
Herbert River ringtail possum	*Pseudochirulus herbetensis*
Spotted-tail quoll	*Dasyurus maculatus*
BIRDS	
Golden Bowerbird	*Prionodura newtoniana*
Atherton scrubwren	*Sericornis keri*
Mountain thornbill	*Acanthiza katherina*
SKINKS	
Thornton Peak skink	*Calyptotis thorntonensis*
Bartle Frere skink	*Techmarscincus jigurru*
Czechura's litter skink	*Saproscincus czechurai*
	Saproscincus lewisi
	Lampropholis robertsi
	Eulamprus frerei
	Glaphyromorphus mjobergi

Predator-prey disruptions, or shifts in the distribution of competitors are predicted to create or exacerbate impacts of threatening processes on endangered species. As part of this process invasion pressures from weeds and exotic animal pests are likely to increase, because invasive species tend to be generalists that can extend their ranges rapidly and tolerate a wide range of climatic conditions[27].

On a very practical level, shifts in species and ecosystem distributions, and resulting shifts in ecosystem or community composition will create difficulties in implementing legislation that is designed to protect or manage significant geographic areas (such as the Protected Area Estate), rare and threatened species[28] and endangered ecosystems or communities (such as Regional Ecosystems[29]), because those pieces of legislation tend to define areas, communities or ecosystems that may not be relevant in a changing landscape.

IMPACTS AT THE ECOSYSTEM LEVEL

The ecosystems we currently recognise will be redistributed across a landscape affected by climate change. In addition the actual structure and/or composition of ecosystems is likely to change, creating new ecosystem types, derived from but different to existing types.

Our protected area estate and the biodiversity it contains is not protected from global climate change and is just as vulnerable as the rest of the landscape[11,12,13]. Changes in the distributions and nature of ecosystems and species as a result of climate change are predicted to fundamentally change our current reserve estate.

Deterioration of Ecosystem Function

Ecosystem function is the sum total of all processes at the ecosystem level, including interactions among species and between organisms and their physical environment such as nutrient cycling, water availability and soil development[30]. The outcomes of ecosystem functions include ecosystem services, the wide array of benefits humans derive from ecosystems, including life-support functions and production of goods[31].

Ecosystem function is likely to be disrupted by climate change, with changes in primary productivity, carbon stocks in natural and managed systems, water relations (ecosystem use, yield and flows) and hence the ecosystem goods and services contributed to the human economy as well as integrity of natural systems. One likely change is an increase in weed/invasive species able to exploit opportunities opened up as a consequence of climate changes[27].

Ecosystem services that we currently take for granted (related to the maintenance of air, soil and water quality, and the provision of products directly from ecosystems) may change in nature, magnitude and distribution. For example, towns and cities are dependent on the ecological function of their reservoir catchments for provision of good quality water. Changing catchment dynamics (see below) as a result of climatic changes could have important effects on the ability of those catchments to continue to provide that water supply. For example, a recent study of the effect of climate change on one of the catchments for New York's water supply suggests that catchment output may decrease by 13-30%[32].

Changes in the timing of biological processes due to changing climate are already evident[10,11,17], and could disrupt ecosystem function by causing mismatches in:

- pollination services to agro-ecosystems as well as natural systems - as pollinators and plants react differentially to changes
- predator-prey relationships- which may create or exacerbate effects of herbivores or pressure on endangered species and pests in agricultural environments.

Deterioration of Water Availability and Quality

Australia is the driest inhabited continent in the world with the least reliable water resources [33,34]. Predictions of the effects of climate change indicate that the hydrological cycle will become increasingly destabilised. Extreme events such as droughts or floods are likely to become more severe, frequent and prolonged[5,6] resulting in increased variability of river flows and water availability[33,34,35]. This variability along with increased evaporation due to elevated temperatures[5] leads to predictions of less water in our rivers and wetlands as well as more frequent water shortages in our urban and agricultural areas[32-36]. These changes will impact on river and wetland ecosystems and cause the decline of aquatic and riparian biodiversity[36].

Reduced runoff in small headwater streams results in loss of aquatic habitats and associated rare and restricted freshwater species, including fish and crustaceans[37]. Reduced in-stream flows and deterioration of water quality also result in more toxic blue-green algal blooms[38,39].

Another hydrological effect attributed to climate change is a rise in the altitude of the cloud base[40]. This rise is predicted to retard the “cloud stripping” ability of north Queensland’s highland tropical forests, which derive up to 30% of their total annual precipitation from intercepting the cloud layer[41], thus reducing the input of water and hence the functions of our catchments, with serious impacts on hydrology, ecosystem processes and biodiversity.

Greater variability of rainfall, with increases in extreme events, would make flows from the land difficult to predict and/or manage, effecting water availability to agro-ecosystems. Furthermore, increased runoff from cropping systems may deliver large nutrient and sediment pulses into estuarine and marine systems such as the Great Barrier Reef, exacerbating the water management problems already in existence in Queensland[21,42].

Predicted rises in sea level[5] will impact the estuarine and wetland systems that form the interface between terrestrial and marine systems, important in controlling nutrient and sediment flows from the land, and providing fish habitat and spawning grounds[43]. Lowland and littoral rainforests will also be threatened by these increasing salt water incursions.

Changes in water relations will necessitate a major reassessment of water use and a further need to manage water resources and environmental water flows. New water management policies, practices and markets are being developed in a period of climate change, and will need to be adaptive to this change.

Invasions of pest species

Changes in climatic conditions may create new or modified ecological niches (disturbed environments) that will favour the expansion of weeds, feral animals and diseases[44].

These disturbed landscapes may become increasingly dominated by a few invasive or opportunistic species because disturbance and shifts in the distribution of vegetation types tend to open opportunities for weeds which colonise faster than the natural vegetation[27].

Greater fire frequency or other disturbances that break up the forest canopy is also predicted to increase the likelihood of invasion by alien species[27].

Although the majority of our current weeds are invasive species from temperate zones, others that originate in tropical and subtropical regions may represent a greater threat as temperatures increase.

Increased occurrence of extreme events

Extreme weather conditions, heat waves, frosts, floods, droughts and severe storms are predicted to increase as a result of global warming[3]. Together with increased summer drying, it is predicted that livestock and wildlife will experience greater heat stress, that there will be a greater potential for more forest fires[45,46], and more pressure on water supplies. Impacts on the biodiversity of moister ecosystems, such as rainforests of all kinds, are likely to be greatest under such regimes.

Increases in duration and severity of heat waves are likely to lead to the death of many species as temperatures exceed tolerable levels. Mountain-top endemic vertebrates in Queensland's Wet Tropics rainforests[12], such as the endemic rainforest ringtail possums[47] may be particularly sensitive to these changes.

Increased frequency, length and extent of drought coupled with high winds and exposed soils are likely to increase dust storms with subsequent top soil loss across the State. Apart from effects on agricultural production there are likely to be impacts on biodiversity associated with such soil degradation. Increase in frequency of fires is also likely to lead to opportunities for weed and feral animal invasion and changes in ecosystem structure, exacerbating other effects of climate change on species distribution and ecosystem function, particularly for ecosystems vulnerable to damage from fires such as rainforest and vine-forest. Increases in fire frequency, even small low-intensity leaf litter fires, may be catastrophic in rainforests where none of the species are adapted to fire.

More intense rainfall events may lead to greater flooding in some regions[5,48]. Global warming is expected to accelerate the hydrological cycle and thus raise the percentage of precipitation that falls in violent bursts. Biodiversity impacts of such changes would be mediated through flooding, landslides and erosion.

The intensity of tropical cyclones is likely to worsen over some areas[49]. The risks include direct threats to human life, coastal erosion, and destruction of ecosystems such as tropical forests, coral reefs and mangroves.

TERRESTRIAL ECOSYSTEMS AT HIGH RISK

ARID AND SEMI-ARID RANGELANDS

Semi-arid and arid environments are closely driven by climate patterns, and climate change scenarios predict more severe and extended droughts, thereby threatening general catchment vegetation and aquatic systems (including indirect impacts such as increasing frequency of blooms of toxic algae)[50].

These are marginal habitats with extensive primary industry, meaning that social impacts of perturbations will be high. A high proportion of the enterprises in rangelands are already economically marginal and much of the rangelands have only small positive, or even negative terms of trade once public inputs and land degradation are considered[51,52]. Increases in evaporation and variability of rainfall will further marginalise primary industry in these regions, initially forcing managers to respond by working their land harder. This will exacerbate the effects of climate change on the landscape and biodiversity, leading to a cycle of deterioration.

Many of these impacts could be based on critical thresholds, following altered fire regimes, CO_2 levels or rainfall patterns, rather than gradual change. For example increases in atmospheric CO_2 and changes in fire regime can cause a rapid shift from grassland to shrubland, or shrubland to woodland[53]. Fauna and flora in arid areas are strongly dependent on frequency and magnitude of extreme precipitation events. Altering these will open arid habitats up to further colonisation by weeds and other pests and further threaten habitats that have borne the brunt of contemporary extinctions in Australia[54]. The relative densities of trees and grasses may also shift[52], altering the structure and productivity of rangelands.

Elevated CO_2 has been shown to improve plant water-use-efficiency, and may partially counteract the effects of prolonged dry periods and increased evaporation[55].

RAINFORESTS AND VINE THICKETS

Vine thickets in seasonally dry environments such as the Wet-Dry Tropics, maintain a unique suite of species and require a low fire frequency if they are to survive[56]. They are likely to be particularly susceptible to changes in rainfall patterns and fire regime because they are surrounded by highly flammable sclerophyll woodlands. Vine thickets are generally associated with specific physical features of the habitat, such as rock outcrops, or specific soil types, therefore they have a low potential to respond to changes by migrating across the landscape.

The Wet Tropics rainforests contain the greatest density of regional endemic species in Queensland[57]. Impacts of climate change are predicted to be disproportionately high in these forests due to the high number of endemic species restricted to upland forests whose bioclimates will contract or disappear under many climate change scenarios. The environments of over half these regionally endemic vertebrates are predicted to disappear under even moderate temperature rises[12].

Lowland and littoral rainforests are likely to be adversely impacted by sea level rise, salination of the water table and increases in storm intensity.

MONTANE AREAS

Mountainous habitats are predicted to be among the most seriously affected areas because they are often refugia for cool-adapted endemic species. Temperature rises will push current climatic envelopes higher up mountains, decreasing the area of habitat (Figure 2). The bioclimates of some montane species are predicted to disappear entirely with even moderate temperature rises (Figure 3).

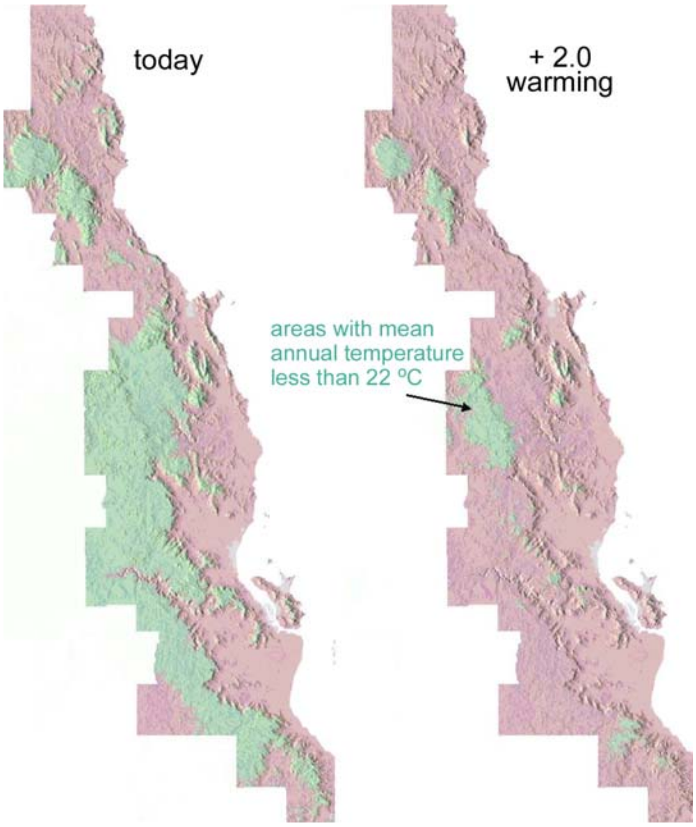

Figure 2. Areas in the Wet Tropics with mean annual temperatures less than 22 ^{o}C (green) in today's climate (left) and after 2^{o}C warming[58].

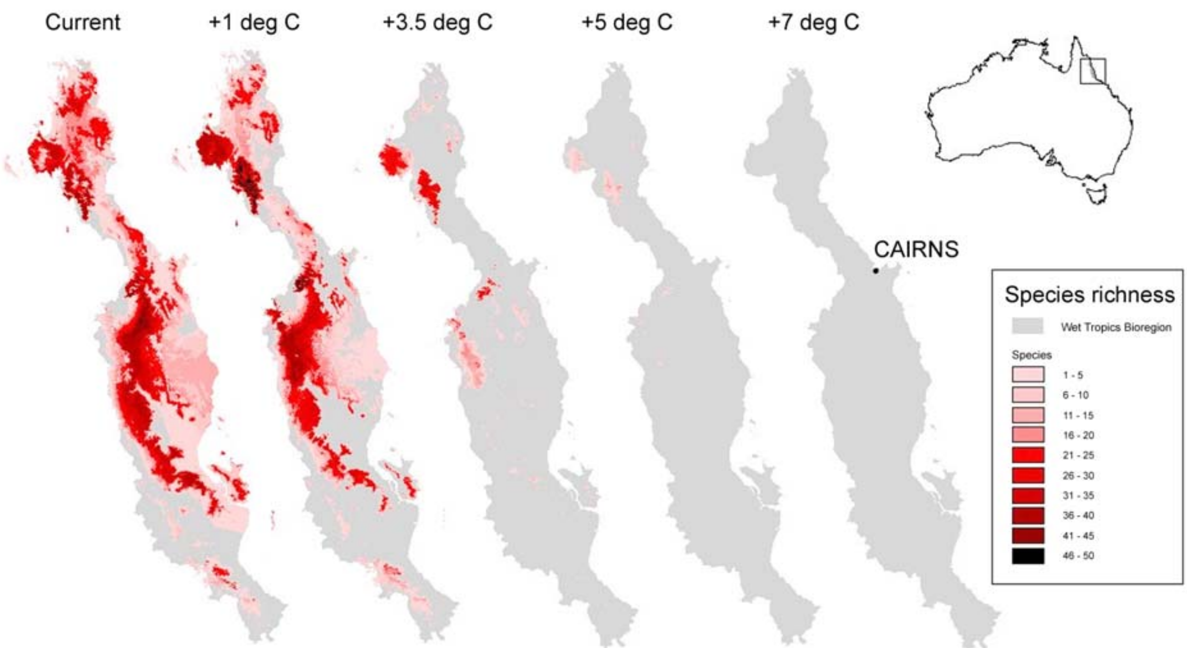

Figure 3. Indicates the decline in distribution of species richness of regionally endemic terrestrial vertebrates with increasing temperature[12].

The Wet Tropics and Border Ranges montane ecosystems are particularly at risk, because they currently act as refugia for cool-adapted upland rainforest species[12]. Low, dry geographic barriers mean that there is little potential for Wet Tropics' species or ecosystems to migrate southward but elements of the Border Ranges montane ecosystems may be able to migrate south.

Extreme events will have a strong impact on these areas. Research into vertebrates in north Queensland mountain habitats suggests strongly that high temperature extreme events will lead to mortality of individuals and, possibly extinction of populations of some sensitive species such as rainforest possums[12,47,58].

WETLANDS, RIVERS AND RIPARIAN SYSTEMS

These systems are dependent on volume, seasonal timing and variability of freshwater flows and will be strongly affected by changes in rainfall pattern. Because they are often the major refuges of natural habitat in the landscape, deterioration of wetlands, rivers and riparian habitats will have a disproportionately high effect on biodiversity.

Deterioration in these systems is predicted to also affect water quality and availability, providing a clear link between biodiversity values, ecosystem services and the economy[59].

ACTIONS TO MINIMISE THE EFFECTS OF CLIMATE CHANGE ON TERRESTRIAL BIODIVERSITY

Queensland should respond immediately to the threat of climate change. Any actions designed to minimise the effects of climate change on biodiversity must be strategic and considered, and will take time to be effective. Consequently, by acting now, rather than waiting for the effects of climate change to become even more evident or more serious, we have a better chance that our actions will be successful.

TWO POINTS AS PREFACE TO THESE PROPOSALS

First, no strategy for the amelioration of climate change impacts can work in the long-term unless there is emission control. There are many effective strategies that will lead to reduction in emissions of greenhouse gases, from more fuel-efficient engines, to alternative energy sources and reduced dependency on motor vehicles. It is not our intention to explore these here, but we do re-iterate that without such emission control catastrophic impacts of climate change on biodiversity are only a matter of time. Any strategy to minimise the effects of climate change on biodiversity should be accompanied by long-term effective global control of greenhouse gas emissions[18]. While most of those emissions are beyond the control of Queensland policy-makers, Queensland and Australia should play a role in global emissions control.

Second, clearing of natural vegetation exacerbates greenhouse gas build-up and reduces the resilience of the landscape to effects of climate change. Minimising the impact of climate change on biodiversity should begin with the cessation of widespread clearing of vegetation. We welcome the current efforts of the Queensland Government to control or end broadscale clearing of remnant vegetation[60].

INTEGRATED NATURAL RESOURCE MANAGEMENT

It is essential to reinforce the aspects of current conservation policy that make species/ communities/ ecosystems more resilient or adaptable ie. best able to absorb or adjust to the pressures of climate change.

Integration of reserves in the landscape

As climate changes, the distribution of species across the landscape is predicted to also change. This means that the relationship between reserves and the rest of the landscape will become even more important. In terms of current policy this reinforces the requirement for both on- and off-reserve conservation, possibly in consultation with the Natural Resource Management Planning processes occurring across the State.

We should further promote off-reserve conservation to improve connectivity of reserves and allow movement of species and communities across the landscape in response to altered climates. Current land management across tenures should be re-examined, and possibly modified, to maximise the resilience of the whole landscape to the effects of climate change. As part of this the State needs to promote the important role of primary production lands for biodiversity conservation more vigorously, by increasing resources for the negotiation of nature refuge agreements. We should also ensure that mechanisms that assist to build ecosystem resilience are included in leasehold land management requirements.

Land clearing

We congratulate the Queensland government for the draft agreement to phase out remnant native vegetation clearing by 2006 and for the current moratorium on the issuing of clearing permits[60]. However, given the massive threat presented by climate change to Queensland's biodiversity, we believe that regrowth clearing should also be tackled.

Broadscale regrowth clearing effectively removes options for ecosystem recovery and options for restoring large-scale species or ecosystem migration corridors. We understand the huge challenge this presents the government. However, climate change presents an unprecedented challenge to all the governments of the world, and an unprecedented scale of solutions will be required, if we are to stem the loss of biodiversity.

Regrowth vegetation should be protected where it is determined to be in an area that is important for connectivity, in the light of planning for climate change.

Natural Resource Management and environmental planning

Climate change necessitates that land, water and biodiversity allocation and use decisions by government, industry and the community become more precautionary from now on. We simply cannot use the same level of resources that we have used in the past without magnifying the already negative current and future impacts of climate change.

Consideration of climate change should be incorporated into all levels of community-based natural resource management and environmental planning in Queensland. The plans should demonstrate integrated planning for climate change for both on- and off-reserve conservation efforts.

Groups preparing these plans should be equipped with information from research institutions to enable them to make precautionary decisions.

Water planning

Water planning and management deserve particular mention. The Australian continent already has the world's least reliable and most variable surface water resources[33]. Water is predicted to become scarcer and less predictable in some parts of the landscape due to increases in evaporation rates and variability of rainfall[3,5,19,36,41]. If we remove more than two-thirds of the natural flow of a river, we may cause obvious and significant damage to river health[61] and loss of biodiversity. Flow regimes of less than half the natural discharge will mean that it is highly unlikely that a river will be capable of remaining healthy in the long-term[62,63]. Altered flow volumes and seasonal patterns of river flow will have significant impacts on in-stream biodiversity[36,37,61-63]. Altered freshwater flows to coastal systems will affect fish spawning and result in reductions in the productivity of important coastal fisheries[43].

It is crucial that any Queensland government plans to manage water resources factor in future scenarios of climate change and use the best available scientific advice to determine the most likely scenarios on which to base each plan, and hence water allocation decisions during the life of the plan.

Weeds and Pests

Invasive species are likely to profit from climate change due to disruption of natural systems[27]. We believe that the government should undertake a review of weeds, feral animals and diseases/pathogens in Queensland or that could easily enter Queensland, in the light of climate change predictions. This review is essential to ensure that funding priorities are aligned with our changing world.

Fire Management

Bushfires are predicted to become more frequent and severe due to an increase in the occurrence of “El Nino-like” conditions[5,45,46]. Again, this necessitates a review of fire management in Queensland. For example, fire sensitive ecosystems or communities (for example, vine thickets) may need specific protection measures in the future to guard against their loss. A specific public education campaign is essential to explain the implications of increased fire risk from climate change and the increased need for caution.

CONSERVING OUR NATURAL SYSTEMS IN PROTECTED AREAS

The prevention of environmental damage is vastly cheaper than trying to restore or repair it[64]. The best way to conserve biodiversity is through a well-managed protected areas estate. Currently Queensland has only about 4% of its natural ecosystems in protected areas. This is well below international and national standards. It is essential that this percentage be increased. However, many of the impacts of climate change will need to be addressed in off-reserve conservation also.

All further changes in the protected area network should be designed to take into account the future impacts of climate change and maximise the diversity of future climates represented within that estate.

The government should undertake an urgent assessment of the current protected areas estate in the light of climate change and produce climate change predictions for important or specific ecosystems, communities and species, under a range of likely scenarios. This includes development of a planning program that assesses the spatial organisation of the current ecosystems and protected areas and examines this in light of climate change predictions for important ecosystems, communities and species. This program needs to identify:

- useful indicators for monitoring;
- potential and future refugia/hotspots;
- potential migration corridors (e.g. Riparian);
- areas and species of high vulnerability;
- land areas required to improve connectivity and increase heterogeneity of reserved habitats both current and future;
- possible places for translocation.

The outcomes of the assessment should be used to undertake a major strategic land acquisition program to improve dramatically the resilience of the reserve network. This would:

- involve strategic land acquisition to improve connectivity and increase heterogeneity of reserved habitats, both current and future;
- identify non-reserved areas where alternative land management (including rehabilitation) could improve connectivity/resilience;
- identify needs for active intervention for particular species (through, eg, translocation);
- identify buffer zones into which species may move naturally;
- link protected riverine and riparian habitats to other protected areas, thereby ensuring whole-of-catchment gains for biodiversity and water quality.

The upgraded protected areas estate should be managed in harmony with off-reserve biodiversity, in a way that maximises the resilience of the entire landscape.

The Queensland component of the national Biodiversity Hotspots Assessment prepared for the Federal Environment Minister[65] should be reviewed. Among other anomalies, this assessment ranks the Wet Tropics as the lowest priority in Australia for biodiversity conservation, despite its undisputed, unequalled biodiversity values and their strong sensitivity to climate change.

THREATENED SPECIES AND ECOSYSTEMS

The number of threatened species in Queensland is predicted to increase due to climate change[11,12,14,44]. For example, in the Wet Tropics, distributions of 30 of 65 regional endemic vertebrates are predicted to disappear and the remainder decline to 11% of their current range with a 3.5^{o}C temperature rise[12], and highland rainforests decline by 50% with only a 1^{o}C temperature rise[13] (Figure 3). Threatened species and ecosystems are particularly vulnerable to climate change, due to their already restricted or fragmented ranges. Threatened species recovery plans are the key policy tool used by the EPA/QPWS to halt and reverse the decline of species. We urge the government to incorporate the effects of climate change into threatened species recovery planning, both for current existing and all future plans. For example, bioclimatic modelling may show the habitat of a threatened species is likely to seriously contract or even disappear in the future. Serious questions will need to be considered, as a result of the modelling, about the current direction of recovery planning and conservation priorities will need to be reviewed.

We believe that the best form of conservation is and will always remain *in-situ* conservation. We must enhance the resilience of threatened species by improving *in-situ* conservation and minimising human impacts.

Unfortunately, consideration of climate change may show that *ex-situ* conservation is the only realistic tool for some of the most at-risk species, at least before other strategies to maximise the resilience of ecosystems have had time to be effective. *Ex-situ* conservation should be considered subordinate to maintaining viable populations of these species *in-situ*, but needs to be considered as part of integrated management of threatened species.

Translocation has been suggested as an *ex-situ* option for species especially sensitive to the effects of climate change. Translocation is not a panacea for species conservation. The Environmental Protection Agency should review how satisfactory translocation programs are for current threatened species and examine the cost in light of the high number of species that are likely to become threatened. This feasibility study will show the real costs and potential benefits of translocation. The report should be publicly released so that the people of Queensland can have a say on this controversial subject.

Should such high cost/high risk programs of intervention be deemed inappropriate or too expensive then such policy decisions should be clear and transparent to the public as well as environmental managers. This should be recognised as a clear decision to allow certain sensitive species to become extinct after an explicit consideration by managers and the community of the costs and benefits of that decision.

We do believe, however, that a DNA/germ plasm/seed bank should be established for the ‘most-at-risk’ species in Queensland, where other management options have a low likelihood of success.

INSTITUTIONAL ARRANGEMENTS

Climate Change Commission

Climate change presents a challenge to every section of society and Government. Consideration of climate change should form an integral component of all natural resource management within the Queensland environment. Advice should be consistently and regularly obtained to ensure that the most recent information on climate change impacts is integrated into all planning. We believe a Climate Change Commission is essential to oversee and facilitate the changes required by government. The Commission should:

- Provide advice to government on climate change impacts and responses
- Audit implementation of State greenhouse policy framework
- Undertake an assessment of all legislation, policies and programs of the Queensland Government in the light of climate change, in the same way that a review of all Queensland Government legislation is being carried out with respect to the National Competition Policy
- Raise emerging issues
- Report directly to the Parliament.

Independent commissioners should be appointed to the Commission with expertise in greenhouse science and policy, sustainability, resource and biodiversity management, resource economics, and public administration.

INVESTING IN PROTECTING OUR BIODIVERSITY

As a statement of principle, all governments would agree that perverse subsidies (those with side effects that are contrary to the public good) should be removed. We suggest that Government investment in subsidies should be reviewed to identify any that exacerbate the impact of climate change. Reduction or removal of subsidies identified in this way could be considered to generate funds to pay for the measures outlined in this report.

Drought Relief

A report on the recent Australian drought[66] demonstrated that the drought was exacerbated by human-induced climate change, and that these events are likely to become more frequent and severe, as evaporation rates increase due to higher temperatures. It was well recognised during this last drought that we cannot drought-proof Australia. We have to learn to live with drought**.**

We believe that drought relief schemes can have perverse outcomes. Whilst intended to help struggling farmers, they can exacerbate the land degradation effects of drought[51]. It is time to make fundamental changes to the way we provide drought relief.

We recommend that a scientifically-based committee review the Scheme and associated subsidies and report directly to the Premier. We believe the Scheme should be altered so that farmers are assisted to relieve pressure on the land. This is about changing the nature of the subsidies, not withdrawing assistance from farmers when they most need it.

Establishing a Pilot Wet Tropics Bush Tender Scheme

The Queensland Government needs to take an innovative and cost-effective approach to assist primary producers and the community to preserve and maintain critical bushland areas. For example a tender system for preservation of biodiversity on private land could be trialled in Queensland. Cap and trade markets similar to those used for managing SO_2 and Nitrogen oxides in the United States EPA Clear Sky Initiative[67] may prove useful models.

Such a system would need to account for high non-linearity of processes, complexity, irreversibility and interdependencies in Queensland ecosystems. Once established and performing successfully, this scheme could be replicated in other regions of Queensland deemed critical for maintaining biodiversity under climate change predictions.

Developing markets to manage environmental flows in rivers and creeks

Water management will need to be revised in the light of climate change predictions because simply setting aside volumes of water for environmental use will not necessarily provide suitable flow regimes throughout the year as rainfall regimes become more irregular and less predictable.

Investing in people

We believe that **a public education campaign** to inform and educate the public about the nature and consequences of climate change on biodiversity and the effects on landscape function and ecosystem services is crucial, if the Government is to take the community along a difficult and challenging path of change. If the community understands the full consequences of the threats we face, we are confident the Queensland public will have a greater acceptance of the need for change.

STRATEGIC RESEARCH NEEDS FOR UNDERSTANDING THE IMPACTS OF CLIMATE CHANGE ON THE TERRESTRIAL BIODIVERSITY OF QUEENSLAND

Investing in knowledge

Our understanding of climate change impacts is increasing but is still far behind many other developed counties, such as the UK. Yet Australia is the only mega-diverse developed country in the world. We have a big task ahead of us to find out what is already happening to our biodiversity as a result of climate change and predict accurately what will happen in future. We cannot do this without a comprehensive on-ground biodiversity monitoring program[68] throughout Queensland. This is essential for adaptive management. In addition, in order to continue to inform management, we should initiate a strategic research program to support management of the impacts of climate change across Queensland and build on the research being carried out by a number of agencies including QDRM, CSIRO, Queensland universities and several CRCs.

Several major reports examining in detail research needs for climate change have been produced in Australia and overseas[69,70]. Research needs in Queensland do not differ significantly from those described in more detailed reports. The research needs identified surround three major questions:

- What are the actual consequences of climate change for Queensland ecosystems?
- What are the potential consequences of global change for Queensland ecosystems?
- What are the options for sustaining and improving the resilience of ecological systems and related goods and services, given projected global changes?

There is no doubt that we have sufficient scientific information and certainty about actual and impending climate change to warrant immediate policy responses. However in many areas further detailed scientific analyses are still required to maximise the effectiveness of on-going policy development and management.

It is crucial that management of the impacts of climate change on biodiversity in Queensland be informed by an on-going, comprehensive and strategically prioritised program of research with clearly identified funding and links that trigger management actions. In this way, the best management will be founded on the best scientific knowledge. At present research into the impacts of climate change on biodiversity in Queensland is not co-ordinated across research providers. Now is an opportune time to develop a clear program of priorities for research into the impacts of climate change on biodiversity, across the entire range of government and non-government research providers in Queensland.

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