Climate Change and Brisbane Biodiversity

A Critique of the *Climate Change & Energy Taskforce Final Report* with Recommendations for Biodiversity added

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A report for the Brisbane City Council

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Summary

The Brisbane City Council Climate Change and Energy Taskforce report, Climate Change and Energy Taskforce Final Report (2007), depicts a scenario for Brisbane under climate change and declining oil supplies. It advocates policies to mitigate climate change and adapt to the future, but biodiversity conservation is not adequately addressed.

The present report, commissioned by the Natural Environment & Sustainability Branch of the Brisbane City Council, identifies the key threats posed by climate change to Brisbane biodiversity, identifies key actions to address inadequacies and identifies information gaps.

The major conclusions are:

> Under climate change, Brisbane Forest Park and contiguous forest offers the best prospects for conserving high biodiversity, due to the very large area embracing a large altitudinal range. Its protection should be of the utmost priority.
>
> Under climate change, Brisbane can eventually expect an explosion of weeds. As native plants become stressed from climate change, they will very often be replaced by weeds, of which more than 1,000 species are present in south-east Queensland. The BCC can best mitigate against this be eradicating scarce weeds of high invasion potential, by targeting flammable grasses and lantana, and by enlisting community support for weed control as a core element of climate change adaptation.
>
> Under climate change, the fire risk to Brisbane Bushland will rise substantially. The BCC needs to invest more in fire management. Flammable pasture grasses and lantana need controlling as a high priority.

Under climate change, the threats to biodiversity will become so great that community engagement will become essential to mitigation. The BCC will need to engage community groups, individuals and businesses in partnerships to monitor declining species, replant trees, remove weeds, and conserve threatened species.

Other possible mitigation measures include:

Conserving 'cool' sites within bushland
Enhancing habitats by increasing climate refuges
Restoring waterway habitats
Reducing other stresses to increase resilience to climate change
Identifying significant species at risk from climate change
Conserving long-range pollinators
Monitoring habitats and species to record climate-related declines
Translocation of species (as a last resort)
Conservation in captivity, Cultivation, Gene Storage
Promoting research

1. Introduction

In March 2007 the Brisbane City Council Climate Change and Energy Taskforce presented its report, Climate Change and Energy Taskforce Final Report (Losee, et al. 2007).

The Taskforce report presents a scenario for Brisbane under a future of climate change and declining oil supplies. It advocates detailed policies to mitigate and adapt to the changing circumstances. But little is said about biodiversity conservation (see section 3).

This present report has been prepared as a response to the Taskforce report to address four tasks:

1. Identify key vulnerabilities faced by the city's biodiversity, given the climate change scenario presented in the Taskforce report and other pertinent information.

2. Assess the adequacy of the current Taskforce strategy's Recommendations and Actions, in addressing biodiversity vulnerabilities.

3. Identify key actions that address any identified inadequacies;

4. Identify critical information gaps in relation to biodiversity vulnerabilities that need urgent redress to facilitate timely and informed action.

Each of these questions is addressed in turn, although the key actions (3) and information gaps (4) are first addressed within section 2.

2. Key Vulnerabilities

Climate change exposes biodiversity to many threats. The full spectrum of impacts remains very uncertain due to the large number of possible interactions under different carbon dioxide scenarios. Literature reviews often fail to take into account all the possible consequences. For example, a recent report, *Bird Species and Climate Change* (Wormworth and Mallon 2007), fails to consider that rising carbon dioxide may reduce the numbers of herbivorous insects that many birds rely on (see section 2.5).

This report does not address every possible impact and detail, but discusses key vulnerabilities relevant to the BCC under the following headings:

Rising Temperatures & Declining Rainfall
A Higher Fire Risk
Cyclones & Floods
Rising C02
Rising Sea Level

2.2 Rising Temperatures & Changing Rainfall

Climate change will eventually expose many species to climatic extremes they have not experienced before. The most recent period in time that was warmer than today was probably the last interglacial period, about 125,000 years ago, when temperatures were one or two degrees higher than today (Overpeck, et al. 2005). When temperatures rise above that level some populations, and some whole species, could face decline and extinction. In the higher latitudes of the northern hemisphere, where temperatures have recently risen more than in Australia, extinctions of montane populations of butterflies and pikas (rodents) have already occurred (Parmesan 2006). Within Australia, rising temperatures have impacted seriously on corals, but not on terrestrial organisms.

Thomas et al. (2006) modeled the future for many species around the globe and concluded that, under a rise in temperature of more than 2 degrees and increasing CO_2, 21- 32% of species would go extinct, even if migration is an option, and 38-52% of species will go extinct if it is not. This study was based on data collected from several regions, including Queensland.

In another study, Hughes et al. (1996) considered Australia's 819 *Eucalyptus* species and found that 41% have a distribution that spans less than 2°C and 25% have a range of less than 1°C. They concluded that, 'within the next few decades many eucalypt species will have their entire present day populations exposed to temperatures and rainfalls under which no individuals currently exist.'

However, species often do not occupy their full climatic range (Davis, et al. 1998, Pearson and Dawson 2003), and the Thomas paper has been criticised as an exaggeration (Botkin, et al. 2007, Lewis 2006). Botkin et al. (2007) noted that extreme climatic swings during the Quaternary did not produce the level of extinctions predicted by future climate change, with North America losing only one known tree species - although many mammals went extinct, and Europe lost 68 per cent of its tree genera during the same period. Hughes et al. (1996) acknowledged that 'the actual climatic tolerances of many species are wider than the climatic envelope they currently occupy'. The extent to which trees can be cultivated outside their native ranges demonstrates this. For example, coast tea tree (*Leptospermum laevigatum*), which is native as far north as Nambucca Heads in New South Wales, has escaped to become a weed in southern Queensland.

The problem is that the thermal tolerances and moisture requirements of most species are unknown, and biologists infer climatic limits from observed distributions. Biological interactions (for example competition) can play a large role in limiting species distributions, and these are also very poorly known. Lewis (2006) concluded that 'Any attempts to calculate the likely magnitude of future extinction inevitably have a back-of-the-envelope feel to them'. Hannah et al. 2005 lamented that 'estimating what species would find new climates suitable and how they would interact in competition with one another is well beyond our current abilities to predict.' No useful predictions can be made about the number of species Brisbane could lose under particular

climate scenarios. The best that can be done is to identify those species that appear to be especially vulnerable.

The Taskforce report points out that Brisbane in 2070 may have a climate like that of Rockhampton today. While the two cities share many plants and animals, strongly implying that many species will survive the changes, there are also substantial differences, many of which presumably reflect differing climatic tolerances. The species most likely to be at risk are those confined to high altitudes or which have a northern limit well south of Rockhampton. Each of these categories is considered in turn in the next sections.

There is a risk, under climate change, of focusing too much on what will be lost, and not enough on what will be gained. As Howden et al. (2003) explain:

> 'Many species are likely to be negatively affected by changes to mean temperature, rainfall, CO_2 concentration and disturbance regimes, and we may naturally tend to focus impact (and adaptation) assessments on those species. However, the greatest community and ecosystem impacts may come from those species that are favoured by changed conditions or disturbance and interact with other species (for instance, competitors, predators, invasive weeds, etc.). Such species could be native or exotic.'

The many species that may be lost from Brisbane will create opportunities for other species to replace them. When plants are lost the replacement species will either be other local plants, plants migrating in from further north or upslope, or weeds.

The opportunities for plants to migrate into Brisbane are severely compromised by habitat fragmentation and the rapid rate of climate change. Plants will most often be replaced by hardier local plants or by weeds. The end result will be far more weed invasion in Brisbane reserves.

This kind of scenario is predicted by various climate change experts (Dukes and Mooney 1999, Lovejoy and Hannah 2005, Zaveleta and Royval 2002). According to Lovejoy (2005a):

> 'For alien invasives, climate change may mean a world of new opportunities. Fragmentation means that when species ranges retract due to climate change, new species may not be able to disperse to fill the void. Weeds will be the exception – these rapidly dispersing pioneers may find many vacated niches, and exploit them. These and other changes have serious implications for biodiversity that will require new conservation strategies.'

A similar prediction is offered by Cox (2004):

> 'Because climatic zones are likely to shift faster than long-lived species can track through reproduction and dispersal, communities in disequilibrium may result, with conditions that indirectly favor weedy species, many of which are likely to be aliens.'

Most weeds that invade Brisbane bushland are garden plants, and changing trends in gardening will worsen the problem. As the climate keeps changing, nurseries will stock plants better suited to the new conditions. Native plants will become less and less suited to the new conditions, while at the same time the pool of introduced species able to take their place will keep growing. Climate change thus adds great urgency to the need to better control weeds.

The other implication of climate change is that today's habitats may not exist in future (Graham and Grimm 1990, Hannah, et al. 2005, Overpeck, et al. 1991). This conclusion flows from the recognition that vegetation communities during recent ice ages and interglacials were different from those today. To quote Hannah et al. (2002):

> 'The strong evidence that species move individualistically suggests that communities are not discrete entities in most cases, making community "representation" an impractical target overall.'

The same conclusion is offered by Graham and Grimm (1990):

> 'The clear palaeoecological message is that plant taxa respond differentially to changing climate: intact vegetation "zones" do not

> move in response to changing climate, but taxa reassemble into different vegetation types following a major climate change.'

The implication of this is that the bioregional ecosystems that underpin habitat conservation in Queensland today (Sattler and Williams 1999) may lose some relevance in future.

A similar shift in species composition may occur in Brisbane waterways. Warburton and Chapman (2005), after surveying fish in Brisbane streams in 2000-2005, compared their findings with those of an earlier survey from 1981: 'The most striking differences were in the strong spread of exotic species (swordtails, platies and guppies).' A decline in three native species was recorded as well. Under climate change this trend, which can be attributed to several causes, can be expected to continue, as rising temperatures disadvantage local native fish. Swordtails, platies and guppies are imported aquarium fish, most species of which prefer warm water. Climate change will increase the pool of aquarium species able to survive in Brisbane streams.

2.1.1 High Altitude

Under climate change, species confined to high altitudes face a special risk. Many of north Queensland's best-known rainforest animals are confined to mountains, and their distributions appear to be climatically determined, implying that extinction is likely if temperatures rise a few degrees (Williams, et al. 2003). The D'Aguilar Range, part of which lies within Brisbane, is also home to rainforest species confined to high altitudes. The conclusions drawn by Williams et al. (2003) drew about the Wet Tropics may apply locally as well.

But past climates can produce misleading distributions. During the various ice ages, much of the rainforest in Queensland contracted to mountain peaks where rainfall remained high. Overall rainfall is higher today, and rainforest has expanded down slope, but species with poor dispersal abilities may remain confined to peaks, creating a misleading impression about their climatic tolerances. Care is thus required when interpreting montane distributions.

The Mount Glorious spiny crayfish (*Euastacus setosus*) is one local species at very high risk from global warming. It is confined to streams on peaks around Mt Glorious above 500 metres altitude (Ryan 1995). It does not occur even in rainforest streams around Mt Nebo where the habitat appears the same. Its absence from lower altitudes strongly suggests a temperature limitation, because its larvae must often be transported down valleys by stream flow.

Other species confined to high altitudes in the Brisbane region, which are listed as rare or vulnerable under Queensland legislation, include the rare thready-barked myrtle (*Gossia inophloia*), a vulnerable sedge *Cyperus semifertilis* and the rare corky cucumber (*Nothalsomitra suberosa*). The distributions of these plants may reflect poor dispersal abilities in the face of competition from other plants, rather than climatic intolerance. Thready-barked myrtles can be grown in suburban Brisbane, although they are not necessarily capable of reproducing and competing in the lowlands. These plants may well be vulnerable to global warming, but the evidence is unclear.

There are many other species confined to higher altitudes in the Brisbane region that may be at risk from warming. They include Murray's skink (*Eulamprus murrayi*), the orange-eyed treefrog (*Litoria chloris*) and Macleay's swallowtail (*Graphium macleayanum*). Care needs to be taken in drawing conclusions. The southern rainforest dragon (*Hypsilirus spinipes*) and land mullet (*Egernia major*) are confined to montane rainforest in the Brisbane region today, but old museum records from Enoggera imply a broad temperature tolerance.

2.1.2 Northern Limits Near Brisbane

South east Queensland and northern New South Wales form the Macpherson-Macleay Overlap, a zone in which large numbers of tropical and temperate species overlap in range (Burbidge 1960). For hundreds of temperate plants and animals, their northern limit of distribution is reached in the region between Gympie and Bundaberg. Noteworthy examples are included in Table 2. Some of these species are undoubtedly climatically constrained and their future survival in Brisbane must be considered uncertain.

Table 2. Some Species Vulnerable to Climate Change

Brisbane semi-slug (*Fastosarion virens*) – Gympie
Morose woodland snail (*Meridolum morosum*) - Brisbane
Fraser's banded snail (*Sphaerospira fraseri*) - Cooloola
Illidge's ant-blue butterfly (*Acridopsis illidgei*) – Mary River
Swamp crayfish (*Tenuibranchiurus glypticus*) – Woodgate
Marjorie's hardyhead (*Craterocephalus marjoriae*) – Burnett River
Striped gudgeon (*Gobiomorphus australis*) – Woodgate
Crimson-spotted rainbowfish (*Melanotaenia duboulayi*) – Burnett River
Wallum froglet (*Crinia tinnula*) - Cooloola
Green-thighed frog (*Litoria brevipalmata*) – S.E. Qld
Bleating treefrog (*Litoria dentata*) – S.E. Qld
Elf skink (*Erotoscincus graciloides*) – Fraser Island
Bell miner (*Manorina melanophrys*) – Gympie region
Smudgee (*Angophora woodsiana*) – Noosa River area
Angle-stemmed myrtle (*Gossia gonoclada*) - Brisbane
Silky oak (*Grevillea robusta*) – Gympie

Deciding which species are most at risk is very difficult. Moreton Island is rich in specialist wallum plants and animals (for example wallum froglets *Crinia tinnula* and midyim *Austromyrtus dulcis*), most of which are not found north of Fraser Island. But this situation could reflect the distribution of large sand masses (McDonald and Elsol 1976) rather than the drop-off in rainfall that occurs north of Fraser Island. But that does not mean these plants could survive the hotter drier climate that prevails as far north as Rockhampton. Wallum heathlands occur in scattered patches as far north as Agnes Waters in central Queensland but their diversity is low north of Fraser Island. Most of these species extend southwards into New South Wales.

A worst case scenario for Brisbane would be scores of lowland species lost to climate change by the end of the 21st century. Most of these, however, might continue to survive in New South Wales. Some of them would survive by migrating up the D'Aigular Range, or by maintaining existing populations on the range. The species of greatest conservation concern to BCC would be those with very small lowland distributions, which would face a risk of

complete extinction if they could not migrate, and those that play a key role in sustaining Brisbane biodiversity.

The Swamp crayfish (*Tenuibranchiurus glypticus*), the world's second-smallest crayfish species, could be at serious risk from climate change. Endemic to shallow wetlands in southern Queensland & far northern NSW, and recorded from Brisbane, it is potentially vulnerable to rising temperatures, rising sea levels and increased drought.

An example of the former is the elf skink (*Erotoscincus graciloides*), a tiny lizard that requires humid leaf litter. It occurs only from Fraser Island to Brisbane. There is no prospect of it migrating southwards into New South Wales across farmland, housing estates and roads. Fortunately, it occurs on Mt Nebo, which is significantly cooler than the lowland sites that support it. While the lowland populations may face a high risk of extinction, the Mt Nebo population may endure.

A species that may face a higher risk of extinction is the angle-stemmed myrtle (*Gossia gonoclada*). It is an endangered tree confined to riparian zones in Brisbane and Logan City, but its thermal tolerances are unknown.

The other species that should be considered as a priority are those that play a major ecological role. Forest reserves in Brisbane are dominated either by

eucalypts (*Eucalyptus* and *Corymbia* species) or by broad-leaved paperbarks (*Melaleuca quinquenervia*) or grey mangroves (*Avicennia marina*), and table 1 lists most of the common species, and places them in risk categories, based upon their northern limits.

Table 1. Common Brisbane trees & their northern limits

Low Vulnerability	Northern Limit
Grey Mangrove (*Avicennia marina*) Spotted Gum (Corymbia citriodora)* Pink bloodwood (*C. intermedia*) Moreton Bay Ash (*C. tesselaris*) Brown Bloodwood (*E. trachyphloia*) White mahogany (Eucalyptus. acmenoides) Narrow-leaved ironbark (*E.crebra*) Gum-topped Box (*E. moluccana*) Forest Red Gum (*E. tereticornis*) Paperbark (Melaleuca quinquenervia)	Malaysia North Queensland Cape York New Guinea Atherton Cooktown Cooktown Atherton Tableland New Guinea New Guinea
Intermediate Vulnerability	Northern Limit
Broad-leaved Ironbark (*E. fibrosa*) Grey Gum (*E. major*) Grey Gum (E. propinqua) Swamp mahogany (*E. robusta*)	NW of Rockhampton Blackdown Tab., Carnarvon Gorge Gympie, Blackdown Tableland Yeppoon
High Vulnerability	Northern Limit
White mahogany (*E. carnea*) Red Bloodwood (*E. gummifera*) Tallowwood (*E. microcorys*) Grey Ironbark (*E. siderophloia*) Scribbly Gum (*E. racemosa*) Narrow-leaved red gum (*E. seeana*)	Gympie Almost Maryborough Maryborough Near Bundaberg Bundaberg Landsborough

* The southern form (subspecies *variegata*) reaches Carnarvon Gorge, the northern form extends to north Queensland

An example of an important species for biodiversity that may one day be at risk is tallowwood (*Eucalyptus microcorys*) - an important koala food tree. It favours damp sites, often on south-facing slopes, and does not grow north of Maryborough. It could be expected to survive on the D'Aigular Range, but might disappear from the lowland reserves where most koalas occur.

The forest red gum (*E. tereticornis*) is arguably the most ecologically significant tree in Brisbane, because it is abundant, and very important to nectar-feeding birds, mammals, insects and leaf-eating marsupials and insects. With a distribution that extends to New Guinea (Brooker and Kleinig 1994), it should survive climate change. The broad-leaved paperbark, spotted gum (*C. citriodora*) and pink bloodwood (*C. intermedia*), which also have special importance to nectar-feeders, should also survive. Those eucalypts that do not survive may be replaced by individuals of better adapted species, without much loss of ecosystem function.

Although species with a tropical distribution should fare better in Brisbane than those with a temperate distribution, the different climatic tolerances of different populations within each species could limit adaptation (Hughes, et al. 1996). As Botkin et al. (2007) note: 'If populations are locally adapted, climate change will cause conditions to deteriorate across the species' range, rather than just at the margins of the range.' To give an example, the thickly-furred echidnas living in the Australian Alps would be unlikely to survive in the Tanami Desert, even though echidnas of the same species occur in both places. Genetic selection may need to occur within populations towards individuals suited to the new conditions. Cox (2004) lists examples of apparent rapid evolutionary responses to climate change: larger eggs in pied flycatchers in Finland; earlier egg-laying in Holland; blackcap birds now genetically coded to overwinter in Britain which is much further north than before; smaller body size in Israeli birds; and increased stomatal density in American forest herbs. Rapid genetic selection is most likely among species with large populations and short life spans. Parmesan (2006) cautions against expecting major adaptation: 'there is little theoretical or experimental support to suggest that climate warming will cause absolute climatic tolerances of a species to evolve sufficiently to allow it to conserve its geographic distribution in the face of climate change and thereby inhabit previously unsuitable climatic regimes'.

Plunkett mallee (*Eucalyptus curtisii*) is one tree found well north of Brisbane that could fail to adapt. It occurs in small colonies scattered widely between the Brisbane region and sandstone gorges in central Queensland (Brooker and Kleinig 1994). Its unusual floral structure suggests it is a very primitive relict species. The various populations may have remained genetically isolated for many millions of years, and their thermal tolerances could differ. Bailey's stringybark (*E. baileyana*) is another relict species with a scattered distribution (Brooker and Kleinig 1994). Species are more likely to survive climate change if there is ample gene flow between populations. Birds and flying foxes that roam widely, and the trees they pollinate, are more likely to survive than species segregated into small, genetically isolated populations.

The problem today is that many species now survive as a series of disconnected populations with no genetic exchange. As Lovejoy and Hannah (2005) explain:

> 'In human-dominated landscapes, natural habitat may remain as small fragments, implying small populations of resident species which lose genetic diversity. Since the recessive traits necessary for rapid response to climate change are frequently less competitive in current climates, they may be lost in small, fragmented populations. This will reduce the pool of individuals capable of rapid response to climate change or eliminate the genetic variants for rapid response altogether.'

The implication is that any small isolated population could be at risk under substantial climate change, for example the greater gliders in Karawatha, and the rainbowfish in Brisbane streams.

2.1.3 Mitigation

The following are suggested:

- Conserve Corridors
- Plant Trees
- Conserve 'Cool' Sites
- Enhance Habitats

- Restore Waterways
- Conserve Aquatic Drought Refugia
- Reduce the Weed Threat
- Educate Fish Owners
- Reduce Other Stresses
- Identify Significant Species at Risk
- Conserve Long-Range Pollinators
- Monitor
- Promote Research
- Translocate
- Promote Captive Breeding and Cultivation
- Conserve Genetic Resources
- Engage the Community
- Educate

Conserve Corridors

The Taskforce report recommendation 13(b) calls for an increase in connectivity between bushland reserves in Brisbane. Climate change adds greatly to the rationale for conserving corridors. The BCC has a long-standing policy of conserving and strengthening corridors. The most important are those that run long distances north-south, or which capture an altitudinal gradient.

The most important corridor by far is the tract of bushland centred on Brisbane Forest Park, connecting Mt Glorious to Mt Coot-tha, Mt Crosby, Anstead and Enoggera. As the D'Aguilar Range, it continues west and well north of Brisbane. It reaches an altitude of 705 metres, by far the highest point in Brisbane. A 1ºC rise in temperature equates with a decrease of about 170 metres in altitude (Sutherst, et al. 2007), which means that Brisbane's highest point could provide a climatic envelope suitable for lowland species faced with a 4ºC rise in temperature. This forest contains far more vegetation than all other mainland reserves combined. It is the only reserve to reach a significant elevation. It is well-protected, facing few threats, and has a high interior-to-edge ratio. If climate change proves as cataclysmic as some experts predict, a fall-back position would be to protect this reserve at all costs, because it is far more likely to conserve large numbers of species than any

other reserve. Moreton Island is the only other large protected area in the city, but it lacks elevation. The greatest threats to Brisbane Forest Park (apart from climate change) would be major fires and new highways that limited migration.

Habitat loss within this forest block should be minimised, although small clearings could enhance biodiversity by providing habitat for edge specialists.

The BCC should work with other local councils to maximise protection for the vegetation of the D'Aigular Range, which extends well beyond Brisbane Forest Park.

Although Brisbane has no other corridors of comparable value, all corridors promote genetic exchange, which in turn fosters adaptation to climate change. Strengthening and extending these corridors by planting trees and shrubs will also provide a carbon sink.

Plant Trees

The Taskforce report calls for an increase in bushland reserves and increased connectivity to increase the carbon sink and 'to provide additional protection of natural areas from changing micro-climatic conditions' (Recommendation 27 b). The planting of trees can achieve several goals:
Increasing the habitat area, thereby increasing population sizes of animals and increasing their prospects of adaptation;
Reducing the fire risk by shading out tall pasture grasses;
Replacing bushland weeds;
Reducing habitat for aggressive noisy miners
Introduction of genotypes better adapted to a changing climate.

The BCC may eventually face hard decisions about whether to continue planting trees sourced locally or whether to introduce seedlings sourced from further north. For many tree species, especially those with a northern distribution and widespread pollinators (eg. *Eucalyptus tereticornis, Corymbia citriodora* and *Melaleuca quinquenervia*), local populations may survive substantial climate change. But if trees start dying *en masse* during heatwaves or droughts, their replacement by new genotypes should be a consideration.

Because climate change is proving more pronounced at high latitudes, trees are likely to die in Europe and North America before they do so in Queensland, and that is not yet occurring, and may not occur for many years. Northern hemisphere trends should be monitored, to see if the mass deaths of butterflies and montane rodents recorded in recent years (Parmesan 2006) are followed by deaths of plants.

Conserve 'Cool' Sites

South-facing slopes, rock outcrops and deep gullies offer relief to some animals and plants from excessive temperatures. When decisions are made about development applications and bushland acquisitions, special priority should be given to landscape features that suggest a mild microclimate. A city-wide map could be produced as an aid to planning, showing steep, south and southeast-facing slopes.

Enhance Habitats

Habitats can be enhanced to improve the prospects of species surviving. Shady riparian vegetation can be restored, and large logs installed to replace those lost to fires in the past. Trees can be replanted in clearings. Brisbane waterways offer many opportunities for habitat enhancement and these are considered in the next section.

If the future becomes more desperate, artificial manipulation of habitats could be considered. Hannah and Salm (2005), writing about montane forest in Costa Rica, suggest that drip irrigation be introduced to assist declining frogs. In Brisbane, dams could be excavated in reserves and rock piles provided. Warburton (2007) has suggested the use of solar-powered pumps in Brisbane streams to increase oxygenation. Interventions like these would need to be properly monitored, and reversed if found to be counterproductive. One risk would be that introduced pests (eg. cane toads) might benefit more from such interventions than native species.

Restore Waterways

Brisbane's urban waterways are highly degraded in ways that will exacerbate the negative impacts of global warming. The loss of shady riparian vegetation, silting up of deep pools, and water extraction lowering water levels in rural areas, lead to high temperatures in streams that fish cannot always tolerate. Pusey et al. (2004) found that many fish species in south east Queensland do not occur where water temperatures exceed 31-34 °C. Exotic mosquitofish (*Gambusia holbrooki*) and swordtails (*Xiphophorus helleri*) dominate warm surface waters in Brisbane streams.
Warburton (2007) has proposed strategies for improving habitat quality in Brisbane streams, that include the creation of permanent deep pools and restoration of riparian cover. The BCC is trialing habitat improvements through its Waterway Enhancement Prioritization Project (Amanda Brigden pers. comm.). Although not designed to ameliorate climate change impacts, these measures will assist to that end.

Conserve Aquatic Drought Refugia

The Natural Environment and Sustainability Branch of the Brisbane City Council, in conjunction with Kev Warburton at the University of Queensland, has initiated the Cool Pools project, to identify the pools in streams that serve as drought refuges for fish and other aquatic species. Although still in its early stages, this project could result in recommendations for the enhancement of these pools, for example by extending them downstream by excavation, planting riparian trees to increase shade, adding submerged logs to increase habitat diversity, and involving local community groups in monitoring and protection (Kev Warburton pers. comm.).

Reduce the Weed Threat

South east Queensland harbours more than a thousand weed species (Batianoff and Butler 2002), a number that keeps growing. Most of them are escapes from cultivation (Batianoff and Butler 2003), especially garden plants. Under climate change, the potential for weed invasion of bushland reserves will rise dramatically. As trees and other plants die from heat stress, drought, fires, cyclones and floods, their places will often be taken by weeds spreading

from nearby gardens or from existing feral populations. The role of disturbance events in promoting weed invasion is well recognised (Hobbs 1991, Hobbs and Huenneke 1992), and climate change portends a much weedier world (Cox 2004, Lovejoy and Hannah 2005).

The BCC should invest substantially more in weed control and education, as one of the most important actions to mitigate against climate change. One priority should be to remove weed species that are rare in Brisbane but appear to pose a high weed risk. Hiptage is one example (see box), and there are many others. Eradication of such weeds would provide a very high return on investment.

Another priority should be stronger engagement with the nursery industry to remove high risk species from sale. More public education is also needed. Many residents will want to help mitigate against climate change, and they could be told that removing their backyard Chinese elms and ochna plants will help. This could be done through the Brisbane City Council's CitySmart program and Green Choice Gardening program.

The Taskforce report advocates more cultivation of food in gardens, but there is a slight weed risk inherent in this. Alligator weed is a major aquatic weed that established in Brisbane streams after escaping from cultivation as a food plant. Ivy gourd (*Coccinia grandis*) gherkin (*Cucumis anguria*), air potato (*Dioscorea bulbifera*) and taro (*Colocasia esculenta*) are other examples of weedy food plants. Public education about the weed threat posed by certain plants would be justified.

Another likely impact would be increased nutrient flows into streams as garden fertilisers wash into catchments after heavy falls of rain. Public education to reduce this risk would also be desirable.

HIPTAGE (*Hiptage benghalensis*) is a garden vine from South East Asia listed by the World Conservation Union as one of the world's 100 worst invaders. In Brisbane it is only weedy at a few sites, notably a gully in Fig Tree Pocket, although it is also cultivated in gardens, but only sparingly. It is highly invasive along the Mossman River in north Queensland (see http://www.wsq.org.au/hiptage.html), and highly invasive at the one site in Fig Tree Pocket, where it climbs up into the canopy of trees.

If a cyclone struck Brisbane at a time when hiptage was in seed, its winged seeds could be dispersed widely, leading to germination in many cyclone-damaged gullies. Vines benefit more from cyclones than other growth forms, and vines also benefit greatly from rising carbon dioxide levels.

Educate Fish Owners

Climate change will increase stress on some native fish species, and increase the risk of introduced fish replacing them. Most of the introduced fish appearing in Brisbane streams (see Warburton and Chapman 2005) in recent years are released aquarium fish, most of which favour warm waters. Pet owners should be warned about the hazards of releasing fish (and water plants and snails) into streams. Warnings posted in pet shops are probably the most effective way to sell this message.

Reduce Other Stresses

Animals and plants are more likely to survive climate change if they are not also under stress from other impacts. As Hannah and Salm (2005) note: 'One of the best safeguards against climate change impacts is to reduce stress on biodiversity from nonclimate sources.' Climate change adds urgency to the need to control excessive burning (including arson), hydrological changes, and nutrient enrichment (from dog faeces and storm water runoff) and other forms of pollution. These stresses also contribute to the likelihood of weeds replacing native plants in bushland reserves. In Brisbane's urban streams, which are highly modified, climate change justifies more investment in waterway restoration, as advocated by Warburton (2007).

Conserve Long-Range Pollinators

Some of the most ecologically significant trees in Brisbane (*Eucalyptus tereticornis, Corymbia citriodora, Melaleuca quinquenervia*) have highly mobile pollinators, and the transfer of pollen southwards will help them produce offspring well-adapted for the future. Eucalypt pollen can remain viable for up to a week, during which time it can be carried hundreds of kilometres by bats or birds. Little red flying foxes track flowering eucalypts and paperbarks over large areas of Queensland and they are possibly the most important pollinators for Brisbane trees under climate change. Yellow-faced honeyeaters also migrate large distances across eastern Australia. Other flying foxes and honeyeaters, and lorikeets, travel shorter but still substantial distances. The protection of long-range pollinators – flying foxes, honeyeaters, lorikeets - should be a high priority for the BCC. Flying foxes face many threats, and scaly-breasted lorikeets have declined in Brisbane. The BCC has draft guidelines for flying fox conservation (Booth and Low 2005), which include the recommendation that trees be planted that flower in winter and spring, which are times of nectar shortage. Paperbarks flower during these seasons, but they could be lost to rising sea levels.

The conservation of long-range seed dispersal agents (fruit-eating birds and bats) would also be a priority (Hannah, et al. 2002) except that in Brisbane

they are very often implicated in the spread of weeds. Most of the exotic trees and shrubs invading local bushland have seeds dispersed by birds (figbirds, currawongs, silvereyes) or flying foxes, and in reserves dominated by eucalypts or paperbarks, these dispersal agents are more detrimental than beneficial.

Identify Significant Species at Risk

As a first step towards identifying wildlife at risk, the BCC should compile a list of 1) all species confined to high altitudes within Brisbane; 2) species that reach their northern limit in the region south of Gladstone; 3) species segregated into small, genetically isolated populations. The lists could then be analysed to identify: 1) species at risk of complete extinction from Australia, and; 2) species whose loss from Brisbane would compromise ecological function. The BCC could then determine what actions could be undertaken to facilitate their survival.

Monitor

Because climate change entails so many uncertainties, monitoring of impacts on wildlife will become essential (Hannah and Salm 2005). The most northerly populations of species are likely to be especially vulnerable. If the BCC could facilitate the monitoring of the northernmost stands of scribbly gums, tallowwoods, and other significant species at risk of loss, this information could help guide management decisions in Brisbane. Monitoring would become a priority when tree deaths attributed to climate change are recorded elsewhere in the world. The BCC should also encourage local naturalists to record any local die-offs and disappearances. Tree saplings should be monitored to ensure that the dominant eucalypts are reproducing successfully.

At present there is little evidence of widespread deaths in Australia from climate change (except on coral reefs), and monitoring is not yet an urgent priority. Even in high latitudes of the northern hemisphere where temperature rises are higher than in Australia, and where many responses to climate change have been noted, die-offs have been recorded in relatively few studies (affecting butterflies, rodents and polar bears [Parmesan 2006]). But

some eucalypts in Brisbane reserves have died during the recent drought, and the identity of these trees should be recorded to see if species with a temperate distribution are disproportionately represented.

Promote Research

Many university students will be seeking careers in climate change biology. The BCC could facilitate postgraduate research on the thermal tolerances of threatened species, and on potential mitigation measures.

Translocate

Translocations entail risks. As the Intergovernmental Panel on Climate Change (Gitay, et al. 2002) warns: 'Moving species to adapt to the changing climate zones is fraught with scientific uncertainties… The consequences of invasive organisms cannot be predicted; many surprises would be expected.' Diseases could be introduced to populations with no resistance. Official translocations might well inspire irresponsible copycat behaviour. People holidaying in north Queensland would bring back frogs and seeds to 'help nature adapt'. Because of the inherent risks, translocation is identified here as a policy of last resort, as something to address in future but not consider today.

As examples to consider in future, translocation of elf skinks from the lowlands to Mt Nebo would introduce more genetic diversity to the montane population, hopefully increasing their chances of surviving. The planting of tallowwood and scribbly gum seedlings sourced from Maryborough might help these species survive locally.

Breed in Captivity & Cultivate

Captive breeding populations could be established for species at high risk of extinction such as elf skinks and Mount Glorious spiny crayfish. Rare plants could be cultivated in gardens where extra water and shade could be provided. The Brisbane Botanic Gardens could play a key role in conserving at-risk species, and in educating the public about climate change mitigation. Ultimately, Brisbane plants could be cultivated in northern New South Wales

as insurance against their loss from the wild. They should cultivated away from bushland if there are concerns about their spread into the wild, although this might be considered a desirable outcome.

Conserve Genetic Resources

Seeds for Life is a joint venture between the Millennium Seed Bank, based at Kew Gardens, and various Queensland organisations, to conserve the seeds of 1,000 Queensland plant species at Kew. The BCC, though the Brisbane Botanic Gardens, is a partner in this, responsible for collecting and preparing seed. Some of the collection sites have been in or near Brisbane, including Toohey Forest and the Boondall Wetlands, and the species collected include Plunkett mallee and smudgee (*Angophora woodsiana*). Collections are on-going, but with no particular focus on collecting around Brisbane.

The Australian Plant DNA Bank at Southern Cross University in Lismore hopes to preserve representative genetic information from the entire Australian flora. As climate change impacts worsen, there will be more interest in conserving plant seeds and animal DNA.

Engage the Community

The tasks are so immense that massive community support will be required. As wildlife suffers, a groundswell of community support can be hoped for. Partnerships between government, business and the community will offer the best way forward, with governments providing expertise, equipment, funding and some labour; businesses providing funding and some expertise, equipment and labour; and the community providing labour and some expertise and funding. The BCC already has a good relationship with bushcare groups and some conservation groups to build upon. The Taskforce report calls for 'Partnering' between individuals, businesses and government agencies, and their recommendations can be extended to biodiversity conservation.

Community groups could assist with most of the actions listed here, including habitat enhancement, weed control, monitoring, seed collection and captive breeding and cultivation. The BCC could support the formation of groups

devoted to the conservation of particular threatened species, as already occurs with the Glossy Black Cockatoo Conservancy. The BCC could help ensure that obscure species such as the elf skink and rainforest snails are assisted, and not just charismatic mammals and birds. The Bush Neighbour Program is one existing tool that could be expanded to *

Educate the community

Climate change poses immense challenges, and understanding its impacts on biodiversity, and averting them, are two of the greatest. Brisbane residents need to understand the problems and possible solutions, since their contribution will become necessary. The Taskforce report recommends that the BCC establish a 'significant umbrella communication and branding program' as part of its response to climate change. As well as broad community engagement, the BCC will also need to establish specialist partnerships with nature-based community groups, which have the expertise and willingness to undertake monitoring, replanting and weed control.

2.2 More Fires

The Taskforce report predicts more bushfires for Brisbane. This accords with predictions under climate change of more fires for Australia generally (Bushfire CRC 2006, Intergovernmental Panel on Climate Change 2007b, Williams, et al. 2001), for south-eastern Australia (Hennessy, et al. 2005), and for South East Queensland (Gillen and Moss 2006). The conclusion of Gillen and Moss (2006) is that climate change impacts have the potential 'to dramatically increase the bushfire risk in south-eastern Queensland over the next 25 to 65 years'.

Brisbane can expect more fires, and more intense fires, for the following reasons:

- Hotter temperatures
- More droughts
- Less rainfall in winter/spring
- Longer periods of low humidity
- CO_2-induced increases in biomass

- Smaller windows of opportunity for prescribed burns

Williams and Ryan (2002) suggest that in South east Queensland, forest growth will increase by 12 - 18 per cent with a doubling of carbon dioxide, even though winter rainfall is predicted to decline slightly. The density of shrubs within eucalypt forest may increase significantly, resulting in more elevated fine fuel loads, increasing the risk of higher-intensity bushfires. More leaf litter and fallen twigs and bark can be expected as a consequence of increased productivity and these will contribue to the fire risk.

In North America, South America, Russia and southern Europe, fires have already become significantly more frequent and more intense (Dick Williams pers. comm.). In the United States, major wildfires are now four times more common, and the areas burnt six times larger, than in the period from 1970 to 1986 (Westerling, et al. 2006). Large fires now burn in the US for an average of 37.1 days compared to a previous average of 7.5 days. Australia may also experience a substantial increase in fire frequency, fire duration and fire extent.

An increased fire regime could, on its own, have serious consequences for biodiversity in Brisbane. Open forest ecosystems in Australia are adapted to fire, but too frequent fires reduce animal and plant diversity. Fires of increasing intensity may reduce the capacity of vegetation communities to recover afterwards. Rainforest plants are especially fire sensitive, and an increase in fire frequencies or intensities would result in a contraction of rainforest and riparian forest, both of which are key habitats in Brisbane and already greatly reduced in extent. Where soils are relatively deep and fertile, the trend may be from open forest towards grassy woodlands. These changes will exacerbate the impacts of climate change by producing habitats with less shade, and which store less carbon.

Many plants, especially grasses, benefit from frequent fires, which facilitate their dominance and spread (Bond and Keeley 2005, D'Antonio and Vitousek 1992, Low 2004). By killing seedling trees and shrubs, regular grass fires assist grasses to maintain a competitive advantage over woody plants. Many regions of the world, including the savanna woodland belt of Australia, are capable of supporting forest, but frequent fires maintain a high density of

grasses at the expense of woody vegetation (Bond, et al. 2005). If fires become more frequent, as predicted under climate change, the balance between grasses and woody plants is likely to shift in favour of grasses.

Within intact forests, rising levels of carbon dioxide could counter this trend by producing a thicker forest canopy that reduces light availability to grasses. Rising carbon dioxide levels also benefit trees and shrubs more than subtropical grasses because of their differing photosynthetic pathways (Poorter and Navas 2003).

A higher fire risk would justify more regular fuel reduction burning, as a management measure to reduce the risk of large and intense fires. But frequent reduction burning imposes ecological costs (Whelan, et al. 2006), some of which can exacerbate certain impacts of climate change.

In a study of hazard reduction burning conducted in northern New South Wales, York (1999) found that 'Top-soil moisture levels were, on average, 18% lower following 20 years of frequent burning, whereas the amount of light reaching ground level had increased (on average) by 125%...' York recorded substantial declines in terrestrial invertebrates after frequent fuel-reduction burning, and suggested that regional losses of invertebrate biodiversity could potentially reach as high as 50 per cent.

Changes in the abundance of leaf litter and ground invertebrates affect ground-feeding vertebrates including frogs, reptiles, mammals and birds. In a review of studies on eucalypt forest birds, Woinarski (1999) concluded that consistent and frequent fires disadvantage birds that either like a shrubby understorey or dense leaf litter.

Around Sydney, Morrison et al. (1996) found that regular fuel reduction burns conflicted with biodiversity goals by eliminating long-lived woody shrubs. These and similar studies show that while fire managers may focus on preventing large crown fires, a regime of regular understorey fires can also reduce biodiversity.

The challenge for the BCC will be to devise fuel reduction regimes that maximise biodiversity. Fires need to be lit often enough to reduce the risk of extreme fires, but not so often that biodiversity is greatly compromised.

Flammable weeds are a complicating factor in many bushland reserves in Brisbane. Introduced pasture grasses have often invaded, especially around the edges where trees are often sparse. These grasses benefit from a variety of disturbance events, including nutrient enrichment, but a particular concern is their capacity to benefit from frequent fires. These grasses were imported from Africa on behalf of graziers because they produce more leaf matter than native grasses, but what serves as food for a cow also serves well as fuel for a fire (Low 1999). Introduced grasses are serious invaders because they promote fire and in turn are promoted by fire. Their seeds germinate *en masse* after fires, and by growing taller or thicker than native grasses they can dominate the understorey over large areas, replacing native grasses and spreading fires over increasing areas. A grass-fire cycle of invasion by exotic grasses has been documented in many parts of the world including Australia (Brooks, et al. 2004, D'Antonio and Vitousek 1992, Rossiter, et al. 2003). Guinea grass (*Panicum maximum*) and molasses grass (*Melinus repens*), which are common invasive grasses in Brisbane, are both recognised internationally as contributing to this problem (Brooks, et al. 2004, D'Antonio and Vitousek 1992). Gillen and Moss (2006) warn that introduced grasses 'may dramatically increase fire frequency' in the Ipswich to Toowoomba region, a conclusion that is also relevant for Brisbane.

Other weeds can also contribute to the fire risk. Weedy shrubs and vines that reach or climb towards the canopy can act as 'wicks' or 'ladders' spreading flames from the understorey into higher strata (Brooks, et al. 2004, Panton 1993). Lantana (*Lantana camara*) is a species of particular concern in Brisbane because of its propensity to dominate gullies, where it often scrambles into the lower crowns of trees. Lantana may not benefit from an increase in the fire frequency, but as a fast-growing plant it will benefit from rising carbon dioxide levels.

The BCC should invest more in the control of flammable weeds as one strategy to reduce the fire risk. Frequent fuel reduction burning can be

controversial, whereas weed control has strong community support and brings obvious biodiversity benefits.

Pasture grasses, and lantana in particular, are utilised by some native animals for shelter and food, a point to consider in reserve management. The habitat value provided by these weeds may in some situations matter more than the fire risk they pose, although their replacement by less flammable native grasses and shrubs will usually be a better outcome.

2.2.1 Mitigation

Model the Fire Risk

The fire risk to Brisbane under climate change should be modeled to provide a better estimate of future threat. Hennessy et al. (2005) did not consider any sites north of Coffs Harbour. If the modeling indicated a very high risk, this would justify a substantial increase in investment in mitigation, since biodiversity and property would both be at threat.

Control Flammable Weeds

Introduced grasses and lantana are two categories of weed that justify special control to reduce the fire risk.

Introduced flammable grasses are already considered a serious threat by Brisbane bushland managers – even without taking climate change into account (Dorean Erhart, Rachel Cruttenden, Rob Mollison, Melissa Cooper pers. comm.).

Guinea grass or green panic (*Panicum maximum*) is the species causing most concern, because it grows so much taller than local native grasses, and because it forms large dense stands on disturbed sites. In an assessment of 200 weed species in south-east Queensland, Batianoff and Butler (2002) rated green panic the 20^{th} worst weed, then one year later elevated its rating to 14th place (Batianoff and Butler 2003).

Molasses grass (*Melinus repens*) also grows taller than native grasses and also grows in much thicker stands which, like guinea grass, produce much hotter fires than native grasses. It was the other grass nominated as a very serious fire risk. It is recognised as a serious fire weed in Queensland, Latin America and Hawaii (D'Antonio and Vitousek 1992, D'Antonio, et al. 2000). Molasses grass can be controlled by very frequent fires (Williams and Bulley 2003), but spreads at the expense of native grasses if the fires intervals are three years or longer (P. Williams pers. Comm.).

Signal grass (*Brachiaria decumbens*) was identified by Rachel Cruttenden (pers. comm.) as another species posing a severe risk in reserves on the south side due to its capacity to form thick dense clumps. Dorean Erhart also nominated whisky grass (*Andropogon virginicus*) as a fire-promoting grass, although it appears to pose less of a threat than the other species. In Hawaii it was found to be a far less damaging fire grass than molasses grass (D'Antonio, et al. 2000). Setaria (*Setaria sphacelata*) is another weedy grass in Brisbane that probably contributes to the fire risk.

Whisky grass (*Andropogon virginicus*) is one of several introduced grasses in Brisbane that can increase flame height and fire spread by growing taller and more densely than native grasses.

Pasture grasses mainly invade from the disturbed edges of reserves. They can prevent shrub and tree recruitment both by shading out seedlings and by carrying hot fires that destroy them.

Lantana in the forest understorey increases the vertical fuel profile, and it too is a weed that can promote fire spread by growing in extensive contiguous stands. It should be replaced in gullies by native shrubs and trees posing a lower fire risk.

Consider Fire in Development Applications

Gillen and Moss (2006), in a recent review of bushfire risk in South East Queensland, in which climate change was considered, were highly critical of the inadequate focus on bushfire risk when houses are developed:

‘The continued subdivision of bushfire prone environments could be considered a poor institutional response, but the reality is that many fringe areas of the metropolitan area are bushfire prone…

‘Issues which need to be considered at the earliest stage include siting, away from ridgetops, setbacks and the creation of asset protection zones, dual-access arrangements for fire fighting crews, water supply requirements, building design and construction materials…’

The various concerns of Gillen and Moss should be addressed. When development applications are considered, the increased risk of fire to rural properties should be considered, especially in high-risk areas identified by the BCC and by the Queensland Fire & Rescue Service in their *I-Zone* classification. It should be a consideration when the State Planning Policy relating to bushfire is next revised.

Revegetate Clearings

Guinea grass favours high light levels and proves most invasive on the edges of reserves where the canopy has often been lost. Restoring the canopy by replanting trees and shrubs will reduce the fire risk by shading out pasture

grasses. Replanting woody vegetation also reduces atmospheric carbon dioxide.

Plant Less Flammable Vegetation

Many rainforest plants have a higher threshold to burning under low to moderate fire conditions, although their capacity to retard fire is reduced when fires are intense. Many of the gully lines in Brisbane that once supported rainforest are now choked with guinea grass and lantana, which promote fire when dry. These gully lines could play a limited role as fire breaks if they carried a cover of rainforest plants. Many of the 'dry' rainforest plants indigenous to Brisbane are very drought-hardy, often surviving droughts better than eucalypts. Rising carbon dioxide levels will increase their drought resistance. They would need to be established along gullies during La Niňa periods, when suitable rainfall for establishment would be available. Although their capacity to retard fire might prove limited, their planting would also achieve biodiversity goals.

Protect Climate Refuges

Under climate change, habitat structures that provide relief from high temperatures will play a critical role in conserving biodiversity. During heat waves, many reptiles, frogs and mammals will seek shelter inside large hollow trees, inside or under large logs, under rocks, and within patches of rainforest and riparian vegetation. Except for rocks, all of these features are vulnerable to destruction by repeated fires. If fire becomes an increasing problem, reserve managers may need to map out and protect those habitat features that provide mild microclimates. For example, fuel loads could be removed from around large stags and large fallen trees.

2.3 Cyclones & Floods

If Brisbane is struck by a cyclone the ecological implications will be serious. Within reserves, many native trees and shrubs will suffer damage. The destruction to existing vegetation, and soil disturbance where trees are

uprooted or soil eroded by water, will facilitate weed invasion, especially in riparian zones. In the United States, cyclones ('hurricanes') are recognised for the role they play in exotic invasions (Goodnough 2004, Horvitz, et al. 1998, Yager 2006). Floods also promote weed invasion in Australia and elsewhere (Griffin, et al. 1989, Hobbs 1991, Holloway 2004). Brisbane has small infestations of declared aquatic weeds such as alligator weed (*Alternanthera philoxeroides*), cabomba (*Cabomba carolineana*) and senegal tea (*Gymnocoronis spilanthoides*) that would be spread about by a floods and cyclones, greatly reducing the chances of eradication. Many other weeds would benefit as well.

In urban areas many houses and cars and even people would be harmed by wind-thrown branches and trees. Attitudes towards trees would change, perhaps very significantly. Many people would want all substantial trees removed from near houses and other infrastructure. In gardens they might seek to replace large trees with shrubs and very small trees (eg. *Eucalyptus curtisii*) which buffer houses from cyclone damage rather than exacerbating the risk. The end result could be fewer nectar-and fruit bearing trees for birds and flying foxes, and fewer tree hollows for birds and mammals such as white-striped freetail bats. However, a desire for shade to protect against rising temperatures could help counter this trend.

In rural areas, this issue could be very significant, because residents will face the prospect of more dangerous fires as well as the cyclone risk. The concept of living close to forest will lose some appeal, as residents seek to create large buffers of cleared land around houses.

In Florida, hurricanes have facilitated the escape of large numbers of exotic animals from reptile dealers, research institutes, and the Miami Zoo (Cleary 2005, Goodnough 2004). Brisbane does not have large captive populations of exotic animals, but this could change in future.

2.3.1 Mitigation

The threat of cyclones and storms adds to the need to control weeds, especially those that are spread by wind and water, and those that colonise damaged riparian zones.

When housing applications are considered for bushland areas, the risk of cyclone damage from nearby trees should be considered when housing sites are chosen.

If zoos or other facilities for maintaining large numbers of exotic animals are established, they should be constructed and managed to minimise the risk of animals escaping during cyclones.

2.4 Rising Sea Levels

The global average sea level rose at an averaged rate of 1.8 mm per year from 1961 to 2003 (Intergovernmental Panel on Climate Change 2007a). From 1993 to 2003 the rate of increase was 3.1 mm per year. At these rates of increase there is no looming threat to biodiversity in Brisbane, but the rate of increase may rise dramatically in coming decades. It is a matter of concern that during the last interglacial, about 120,000 years ago, when temperatures were 1°C higher than today, the sea rose an average of 4-6 metres (Kerr 2007). The IPCC predictions of sea level rise have been criticised as too conservative, and there are recent predictions of a sea level rise of several metres by the end of the century (Kerr 2007). The melting of icesheets on Greenland and the Antarctic Peninsula could trigger dramatic rises in coming decades. Rising sea levels will not affect all coastlines equally – in some regions the land is rising from tectonic movements and human impacts, and in some it is subsiding.

A slowly rising sea level might not threaten biodiversity immediately because mangroves and saltmarshes would migrate landward (Voice, et al. 2006). But a rise of several metres would eventually produce ‘coastal squeeze’ (Wormworth and Mallon 2007), resulting in the virtual elimination of several major Brisbane reserves – the Boondall Wetlands, Tinchi Tamba and Bayside Parklands - as the sea rose to meet developed land. Most of Brisbane’s paperbarks grow on marine alluvium that was exposed by a previous sea level drop, and if the sea reaches former levels, no substrate for extensive paperbarks will remain. Rapid sea level rise, especially in conjunction with more extreme events – cyclones and violent storms – would produce a narrower mangrove fringe and saltmarsh zone (Simas, et al. 2001) and reduced areas of less stable mudflats. The consequences for biodiversity would be dramatic. Brisbane would lose most of its habitat for migratory

waders and the flowering paperbark forests that sustain flying foxes and birds. Brisbane would also lose its population of the tree skink (*Egernia striolata*), among other species.

Mangroves would maintain a presence in alluvium along the banks of the Brisbane River, but these riparian strips are not utilised by most mangrove animals including varied honeyeaters and collared kingfishers. Paperbarks grow along some Brisbane streams, well above sea level, as far west as a tributary of Pullen Pullen Creek in Moggill, and these small riparian populations have good prospects of surviving, especially with sympathetic management.

2.4.1 Mitigation

Sea level rise offers few opportunities for mitigation. Mass plantings of paperbarks in parks and on private lands would replace nectar sources lost to inundation while also providing carbon storage. Paperbarks grow well in suburban parks.

2.5 Rising Carbon Dioxide

Increasing CO_2 has many impacts on plants, apart from those due to a changing climate. Experiments show that increasing CO_2:

- promotes plant growth by increasing photosynthetic efficiency (Dukes 2000, Poorter and Navas 2003, Ziska and Runion 2007);
- increases water thrift in plants (Ghannoum, et al. 2007, Ziska and Runion 2007);
- reduces the palatability of plants to herbivores (Bezemer and Jones 1998, Coviella and Trumble 1999, Johns and Hughes 2002);
- alters the pathogen-host relationship of plants in various ways (Chakraborty, et al. 1998, Johns, et al. 2003, Ziska and Runion 2007);
- reduces the effectiveness of glyphosate at killing weeds (Ziska, et al. 2004, Ziska and Goins 2006, Ziska and Runion 2007);
- assists fast-growing plants (which are often weeds) more than slow-growing plants (Poorter and Navas 2003).

Many of the impacts are poorly understood because laboratory studies are not easily extrapolated to whole ecosystems. Laboratory studies consistently show that plants exposed to elevated CO_2 produce thicker leaves with a lower carbon-nitrogen ratio, and often containing more unpalatable carbon-based compounds such as phenolics. Nitrogen is usually the limiting nutrient for plant herbivores. Lawler et al. (1997) maintained forest red gum seedlings (*Eucalyptus tereticornis*) under elevated CO_2, and found that leaf-eating beetles fared poorly on them. They concluded:

'The foliage of *Eucalyptus* species in many forests is considered to be of marginal quality for herbivores, particularly with respect to nitrogen concentrations… If increased atmospheric CO_2 reduces the nitrogen concentration below the threshold of approximately 1%, the consequences for insect herbivores may be great.'

Koalas and greater gliders could also suffer. The Lawler study found that the carbon-enriched leaves not only contained less nitrogen, but also more tannins and phenolics, which reduce digestibility. Kanowski (2001) grew rainforest tree seedlings under elevated carbon dioxide and, finding similar shifts, concluded that rainforest possums could suffer. But the Lawler and Kanowski studies were conducted on seedlings grown in pots, and studies of this kind may overstate the impacts of CO_2 enrichment on forest trees (Körner 2006). But nearly all studies of CO_2 enrichment on plants record declines in nutrient levels in leaves, and even very slight declines could significantly on koalas and greater gliders because their diets are considered nutritionally marginal. The most productive eucalypt forests were cleared for agriculture long ago, and gliders and koalas are mainly confined today to forest reserves located on infertile soils.

For most plants, rising CO_2 provides a benefit (Dukes 2000, Poorter and Navas 2003, Ziska and Runion 2007). The efficiency of photosynthesis is usually limited by carbon dioxide levels in the air, so that more CO_2 promotes plant growth. Plants need to transpire less, so they lose less water (Ghannoum, et al. 2007, Ziska and Runion 2007). Rising carbon dioxide can thus compensate plants to some extent for dry periods. At revegetation sites, trees will grow faster, and except when temperatures are higher, they will

need less water. Forest canopies may become thicker, provided that trees are not heat-stressed. Some experts believe that the forest thickening observed in inland Queensland in recent decades is a response to rising CO_2 levels (Berry and Roderick 2006). Higher plant productivity should result in more leaf litter, increasing the fuel load for fires.

Rising carbon dioxide will also benefit fast-growing weeds (Ziska and Runion 2007). Weedy trees, shrubs and especially vines will grow faster. In addition, glyphosate, the main herbicide used to control bushland weeds, will become less effective (Ziska, et al. 2004, Ziska and Goins 2006, Ziska and Runion 2007).

2.5.1 Mitigation

When eucalypts are planted for koalas and other wildlife, the selection of species and lines with a high nitrogen content and low phenol content will prove most beneficial. When land is acquired to conserve koalas or greater gliders, sites with the most fertile soils are more likely to retain their mammal fauna.

3. Adequacy of Taskforce Recommendations

The Taskforce report says very little about the need to conserve biodiversity under climate change. Biodiversity is only sparingly mentioned in the report and is not discussed in any detail. None of the vulnerabilities identified in this report are adequately considered by the Taskforce report. Biodiversity is mentioned on the following pages:

Page 18 makes the point that because of habitat loss, Brisbane's flora and fauna have a 'limited capacity to adapt by changing habitat'.

Page 32 mentions that there will be 'changes to habitat and habitat ranges for species' but provides no details.

In the section on Recommendations, biodiversity issues are mentioned three times, but only cursorily.

Recommendation 10 proposes a communication program focusing on many topics, including 'Effect of changing temperature range and rainfall patterns on gardens and bushland, including weeds.'

Recommendation 13 includes:

'Establish a policy of no net loss of vegetation through development and require satisfactory compensatory planting for any clearing, including a net gain in vegetation cover.'

The more substantive recommendations about biodiversity fall under section 6.7, titled Diversification and conservation of natural resources. This section focuses mainly on energy use and insulation, but includes three relevant recommendations towards the end:

'b) Increase bushland reserves and connectivity between them as a vital component of the Regional Carbon Sink and to provide additional protection of natural areas from changing micro-climatic conditions.

‘c) Investigate the vulnerability of significant local natural areas (e.g. wetlands) to climate changes.

‘d) Review and enhance the biodiversity strategy to account for current understandings about climate change risks to remaining natural areas in Brisbane.’

Revising the biodioversity strategy, as in recommendation (d) is of vital importance under a climate change scenario, but the Taskforce report does not advise how to do this.

The summary of the report contains a long list of recommendations (pages v-vii), but only one explicitly addresses biodiversity: 13g ‘No net loss of vegetation’.

The Taskforce Report thus provides little guidance for the protection of biodiversity, except by reducing greenhouse emissions.

Two of the Taskforce recommendations will have unanticipated implications for biodiversity. The proposal to encourage urban agriculture will result in many conflicts with wildlife as gardens are attacked by possums and birds. Brushtail possums and brush turkeys already annoy many Brisbane gardeners. If urban agriculture becomes a major enterprise there will be many conflicts with cockatoos, crows, currawongs, brush turkeys, and in rural areas, with red-necked wallabies, rabbits, hares and feral deer. The BCC will need to advise residents on how to cage gardens or otherwise deflect wildlife. An urban agriculture strategy would justify greater investment in the control of feral deer, a growing and potentially very serious problem.

Another problem will be increased nutrient enrichment in streams. Widespread use of fertilisers and compost will inevitably result in some increase in nutrient flows into catchments. This will reduce habitat quality, which in urban streams is already very compromised by a wide range of human impacts. Increased nutrefaction of urban streams may not result in much biodiversity loss because little of the original native biodiversity

remains, but in rural areas (e.g. Brookfield, Pullenvale) the consequences could be significant.

And as already noted, urban agriculture would entail a weed risk if unusual food plants escape from gardens.

4. Key Actions

The many recommendations made in section 3 are summarised here.

4.1 Reserve Management

Conserve Corridors

Under climate change, Brisbane Forest Park and surrounding forest offers the best prospects for conserving high diversity, due to the large contiguous area of intact forest extending over a large altitudinal range. Its protection should be the highest priority.

The BCC should work with other councils and the state government to maximise connectivity and protection within the D'Aguilar Range, which extends well beyond Brisbane Forest Park.

Other corridors in Brisbane do not extend over a significant altitudinal range, but their conservation will maximise local gene pools and thus improve the chances of local adaptation.

Plant Trees

Trees should be planted to rehabilitate reserves, improve corridor connections, and trap carbon dioxide. When koala food trees are planted, genotypes with a high leaf nitrogen content and low tannin and phenol content will offer a better diet under rising levels of carbon dioxide.

Paperbarks (*Melaleuca quinquenervia*) should be planted in parks to compensate for those that could be lost to marine encroachment. They are a key resource for long-range pollinators.

Conserve 'Cool' Sites

South-facing slopes, rock outcrops and deep gullies offer relief to some animals from excessive temperatures. When decisions are made about

development applications and bushland acquisitions, special priority should be given to landscape features that indicate a mild microclimate. A city-wide map could be produced as an aid to planning, showing steep, south-facing and south-western slopes.

Enhance Habitats

Habitats can be enhanced to increase cool microclimates. Shady riparian vegetation can be restored, and large logs installed to replace those lost to fires in the past. In drought refuge pools, gravel can be extracted to extend them, and logs installed to increase habitat diversity. If the future becomes more desperate, artificial manipulation of habitats would become an option of last resort.

Improve Weed Control

Weeds will pose a much greater threat to Brisbane biodiversity in years to come. Under climate change native plants may die en masse, only to be replaced by weeds. Weeds will benefit from many circumstances: carbon dioxide fertilisation, extreme climatic events, changing nursery trends, and reduced efficiency of glyphosate. The BCC should invest much more in weed control and education, as a key plank of climate change mitigation. One priority should be to remove weed species that are rare in Brisbane but appear to pose a high weed risk. The other priority should be to control flammable weeds, especially guinea grass (*Panicum maximum*), molasses grass (*Melinus repens*) and lantana (*Lantana camara*). Nurseries should be prevented from selling weedy species and residents from growing them.

Educate Fish Owners

Climate change will increase the risk of introduced fish species replacing native species. Pet owners should be warned about the hazards of releasing fish (and water plants and snails) into streams. Warnings posted in pet shops are probably the most effective way to sell this message.

Improve Fire Management

The BCC should invest more in fire management to reflect the increasing fire risk. The BCC should model the fire risk under climate change, and control invasive grasses and lantana, replacing them where appropriate with less flammable native vegetation. Habitat structures that provide fauna with relief from high temperatures should be protected.

Reduce Other Stresses

Climate change adds urgency to the need to control other stresses on ecosystems such as excessive burning, nutrient enrichment and other forms of pollution, hydrological changes, pest animals, logging and grazing and other pressures associated with an increasing human population.

4.2 Species Conservation

Identify Significant Species at Risk

The BCC should compile a list of 1) all species confined to high altitudes within Brisbane; 2) species that reach their northern limit between Brisbane and Gladstone; 3) species segregated into small, genetically isolated populations. The lists could then be analysed to identify: 1) species at risk of complete extinction from Australia, and; 2) species whose loss from Brisbane would compromise ecological function. The BCC could then determine what actions could be undertaken to facilitate their survival.

Conserve Long-Range Pollinators

Some of the most ecologically significant trees in Brisbane (*Eucalyptus tereticornis, Corymbia citriodora, Melaleuca quinquenervia*) have highly mobile pollinators - flying foxes, honeyeaters, and lorikeets - which should be conserved to promote genetic adaptation. The BCC has draft policy guidelines for flying fox conservation (Booth and Low 2005). In many urban centres in Queensland, residents have called upon local councils to evict flying fox colonies. Any such calls in Brisbane should be resisted.

Monitor

Monitoring will be necessary to detect tree deaths and other population declines. Monitoring should focus on species at special risk, but be flexible enough to detect any declines. Monitoring should be undertaken in Brisbane, but also north of Brisbane where many species reach their northern limits.

Monitoring should be by a partnership process involving community groups. Earthwatch Australia is a non-government organisation with funding to establish monitoring programs in different locations, mainly to detect phenological shifts. It is one example of an organisation the BCC could work with.

Translocate

Translocation of species will become a management option when conditions become more desperate. Translocations entail risk.

Captivity, Cultivation, Storage

Captive breeding populations could be established for species at high risk of extinction. Rare plants can be cultivated in Brisbane and further south. The Brisbane Botanic Gardens could play a key role in conserving at-risk species, and in educating the public about climate change mitigation. Seeds and DNA can be preserved.

Educate Fish Owners

Climate change will increase stress on some native fish species, and increase the risk of introduced fish replacing them. Most of the introduced fish appearing in Brisbane streams (see Warburton and Chapman 2005) in recent years are released aquarium fish, most of which favour warm waters. Pet owners should be warned about the hazards of releasing fish (and water plants and snails) into streams. Warnings posted in pet shops are probably the most effective way to sell this message.

4.3 Community Engagement

Engage the Community

The conservation tasks are so immense that massive community involvement will become necessary. Community support will hopefully increase as the situation worsens, with people growing more aware that they should help mitigate against climate change. Partnerships between government, business and the community will offer the best way forward, with governments providing expertise, equipment, funding and some labour; businesses providing funding and some expertise, equipment and labour; and the community providing labour and some expertise and funding.

Community groups could assist with most of the actions listed here, including habitat enhancement, weed control, monitoring, seed collection and captive breeding and cultivation. The BCC could support the formation of groups devoted to the conservation of particular threatened species, such as elf skinks, rainforest snails and Mt Glorious crayfish, ensuring that the less-charismatic species received adequate attention. Land-holders with voluntary conservation agreements with the Brisbane City Council could play a special role in species conservation.

Educate the community

The BCC should play a lead role in educating the community about climate change impacts and actions. A climate change forum, focused on biodiversity, would be a good first step. The Taskforce report calls upon the BCC to initiate major education.

Promote Research

The BCC should facilitate postgraduate research on the thermal tolerances of threatened species, and on possible mitigation measures.

Consider Risks in Development Applications

When development applications are considered, the increased risk of fire and cyclones should be considered.

4.4 Conclusions

The key recommendations are:

Under climate change, Brisbane Forest Park and contiguous forest offers the best prospects for conserving high biodiversity, due to the large area and large altitudinal range. Its protection should be a very high priority.

Under climate change, Brisbane can expect an explosion of weeds. The BCC can best mitigate against this be eradicating scarce weeds of high invasion potential, by targeting flammable grasses and lantana, and by enlisting community support for weed control as a core element of climate change adaptation.

Under climate change, the fire risk to Brisbane Bushland will rise substantially. The BCC needs to invest more in fire management. Flammable pasture grasses and lantana need controlling as a high priority.

Under climate change, the threats to biodiversity will become so great that community engagement will become essential to mitigation. The BCC will need to engage community groups, individuals and businesses in partnerships to monitor declining species, replant trees, remove weeds, and conserve threatened species.

The BCC will need a high level of ecological expertise to manage the changes.

5. Critical Information Gaps

The need for a better understanding of climate change impacts on biodiversity is well recognised. In June 2005 a workshop was run by the Biological Diversity Advisory Committee in Canberra to identify research and information gaps (Hilbert, et al. 2007). Research is now underway to answer some of the questions. Brisbane City Council planners will benefit from research conducted in Australia and overseas.

This report did not identify many information gaps that the BCC should address itself. The three that emerged were:

Identify Significant Species at Risk

This recommendation is considered in section 4.2. If this list was identified, the BCC could encourage university research on the climatic tolerances and management options for these species.

Model the Fire Risk

The fire risk to Brisbane under climate change could be modeled to provide a better estimate of future threat. The key paper by Hennessy et al. (2005) did not consider any sites north of Coffs Harbour. If the modeling indicated a very high risk, this would justify a substantial investment in mitigation, since biodiversity and property would both be at risk.

Identify Weeds for Eradication

Climate change scenarios indicate a much greater threat from weeds, implying that the BCC should invest more in their control. The best return on investment can be made where a weed can be completely eradicated from Brisbane. Dr. Sheldon Navie (pers. Comm.), the Education Research Officer for the CRC for Australian Weed Management, has compiled a large list of naturalising plants in Brisbane, and they include a number of species that are rare in cultivation and rare in the wild, representing cost-effective targets for eradication, for example satinleaf (*Chrysophyllum oliviforme*).

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