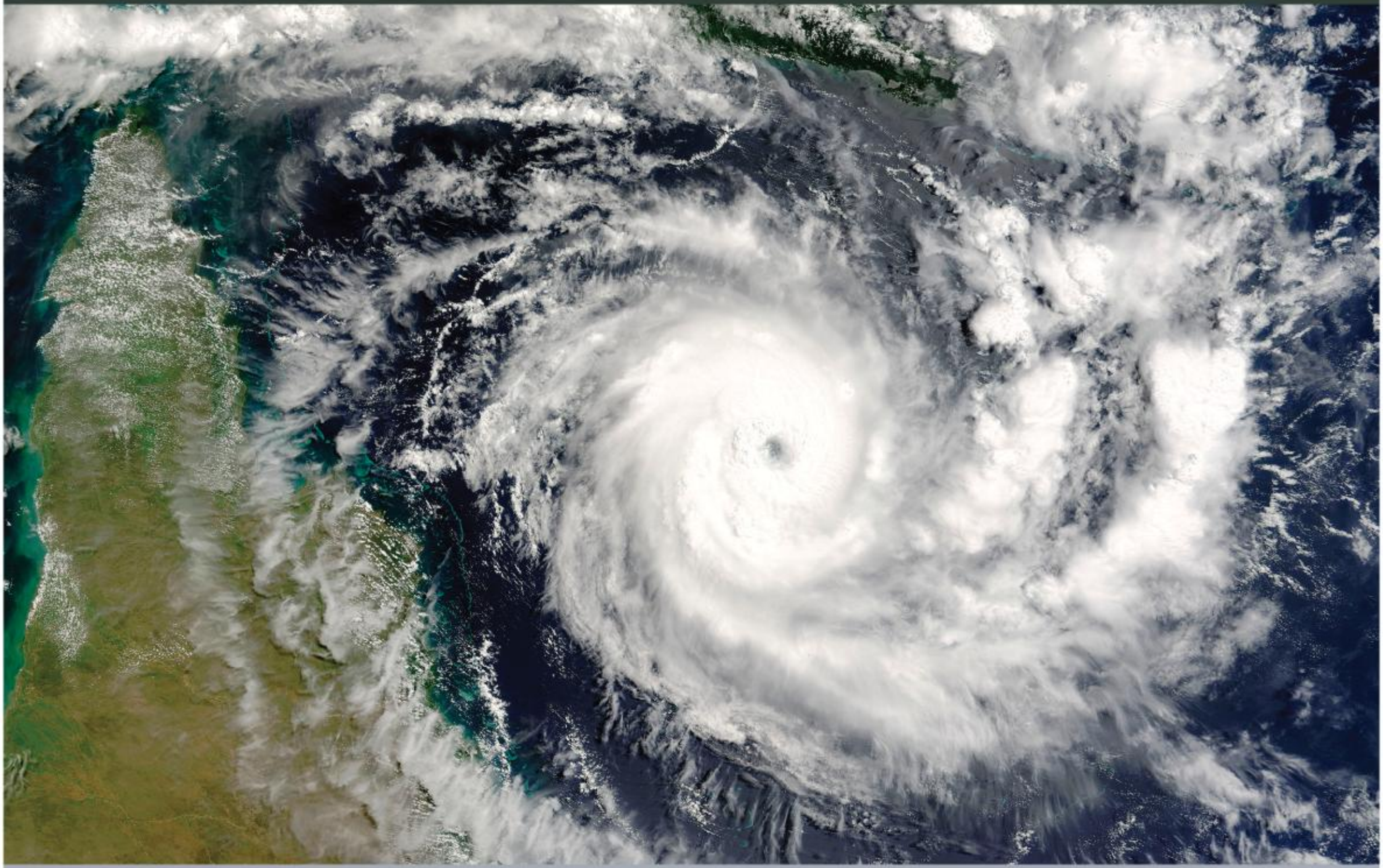
WET TROPICS
NRM CLUSTER

CLIMATE CHANGE IN AUSTRALIA
IMPACTS & ADAPTATION INFORMATION FOR AUSTRALIA'S NRM REGIONS



Adaptation Pathways and Opportunities for the Wet Tropics NRM Cluster region

Volume 1. Introduction, Biodiversity and Ecosystem services

Edited by Catherine Moran, Stephen M. Turton and Rosemary Hill

2. Biodiversity – Adaptation pathways and opportunities

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IN A NUTSHELL
• Impacts of climate change on biodiversity are already evident, and adaptation is required for the conservation of species and ecosystems. Managing to reduce current threats will improve the capacity of many species and ecosystems to adapt, but climate change introduces new and additional stressors that will require new conservation management approaches. • As well as protection, restoration (e.g., reforestation, coral reef rehabilitation) will be a critical part of climate change adaptation for biodiversity conservation. Ex situ actions may be important for highly threatened species. Adapting fire regimes will be an important challenge as well as management tool. • Successful adaptation management will require well-designed monitoring.

Precis

The possibilities, issues and barriers pertaining to the adaptation of biodiversity to climate change show similarities across the different ecosystem types, species and processes of the Wet Tropics Cluster (WTC) region. Many management actions for climate change are the same as those already known to be important to biodiversity management: reduce or eliminate other anthropogenic stressors in order to build integrity and resilience into natural systems and ideally assist them to withstand the future pressures associated with climate change. However, climate change will also involve different approaches in many respects including facilitating change, especially the movement of species and ecosystems as they track suitable climate and conditions. In addition, 'in situ' conservation – managing species in their habitat, or facilitating their dispersal within the landscape - will be less expensive than 'ex situ' conservation (managing species outside their current range). The key messages associated with each of the topics addressed in this chapter are:

TOPIC	KEY MESSAGES
Introduction	1. Successful biodiversity adaptation will be greatly constrained by the rate and ultimate degree of climate change. 2. Climate change is a different kind of threat to biodiversity so adaptation will require different approaches. 3. Effective adaptation strategies for biodiversity require awareness of the threat, reassessment of conservation objectives, and assessment of which conservation strategies will be most effective under climate change. 4. Adaptation and mitigation actions in the biodiversity sector will interact in complex ways with adaptation in other sectors.

TOPIC	KEY MESSAGES
From maintaining ecosystems to enabling adaptation	5. As ecological communities change, it may become more important to identify key processes, communities or functional types that contribute to the persistence of an ecosystem, and focus on protecting those.
Conceptual and practical management options for conservation	6. Conservation planning is concerned with where, when and how to act to achieve conservation objectives. Climate change will prove a challenge to current conservation planning, bringing novel conditions, including novel ecosystems, extreme events and unprecedented rates of change.
Identifying and protecting key refugia	7. Potentially the most cost-effective solution for biodiversity conservation under climate change is to identify and protect places in the landscape that will harbour many species from the worst impacts of climate change. 8. Refugia need to safeguard long-term population viability. 9. Refugia will need to be within the range of environmental parameters tolerable to species or ecological communities, or accessible if outside their current range. 10. Ideal refugia will provide protection against multiple threats. 11. Four different techniques used to identify refugia highlight the importance of the upland areas of the WTC Region as important refugia. 12. The current protected areas encompass the areas that are known to be important for many species currently in the Australian Wet Tropics (AWT); however they are likely to miss the areas important for species in other parts of Australia that are likely to move into the AWT as a result of climate change. 13. The southern upland rainforest of the AWT, particularly Hinchinbrook Island, Paluma Range and Mt Elliot, emerge as important refugia across all refugia analyses. 14. The east coast of Australia has a high proportion of the area that will be climate change refugia when compared to the rest of Australia. 15. The Australian Wet Tropics Bioregion is likely to be an important area for many species moving from the west and north. 16. Adaptation for freshwater ecosystems must include the identification, protection and management of current and future refugia, especially in areas predicted to remain climatically relatively stable. 17. The WTC region is expected to retain a large proportion of its freshwater biodiversity; therefore has conservation importance at a national level. 18. Identifying refuges specific to freshwater biodiversity will require the consideration of refuge value, including abiotic factors, biotic factors, anthropogenic factors, spatial factors and temporal factors. 19. Systematic conservation planning is an important tool for prioritising areas (e.g. refugia) for protection and restoration. 20. Restoration will need to be a major part of climate adaptation.

TOPIC	KEY MESSAGES
Translocation as a management tool	21. Any translocation of species is highly risky, with high failure rates, even to a historically occupied site. The factors that determine the success of translocations include: removing threats, number of individuals translocated and the genetic diversity of the founding population. The success of translocations is species and situation-specific and many factors need to be considered. 22. The facilitation of gene flow between populations through assisted interbreeding can be used to enhance the evolutionary potential of populations. 23. Isolated populations on the periphery of a species' distribution may be adapted to the climatic conditions that will develop in core areas of the species' distribution as climate change proceeds. 24. Facilitating gene flow between lineages and/or from peripheral isolates to core populations could bolster the evolutionary potential of populations in the WTC Region.
Triggers and thresholds	25. The uncertainty inherent in climate change predictions makes it almost impossible to determine set triggers or thresholds beyond which ecosystems are likely to change irrevocably. 26. Previous studies that have identified environmental thresholds have highlighted that these are often specific to a particular location or time. 27. Among the 10 Australian ecosystems considered most vulnerable to tipping points, eight occur in the WTC Region.
Fire management	28. Fire offers a number of opportunities for adaptation management, including prescribed burning of weedy flammable species and woody species encroaching on native grasslands. However, timing of burns will be critical to success in terms of biodiversity management. 29. Fire management strategies will need to be adapted for different habitats and woodland types, and take into account faunal species within communities and previous seasons for fire management.
Connectivity for movement and migration	30. Adaptation efforts will need to be geared towards maintaining connectivity for assemblages to expand into new areas; impact minimisation or mitigation will need to target not just existing communities, but areas to the south (for tropical marine communities) and west (coastal communities). 31. Increasing landscape connectivity is important for addressing conservation issues resulting from habitat fragmentation, and also for enabling shifts in species' distributions in response to climate change. 32. The amount of good quality habitat in a landscape is positively related to degree of connectivity. Linear features may also be important, especially at smaller spatial scales. 33. Many current projects are based on increasing connectivity at different spatial scales 34. Cleared and modified parts of the landscape may contribute to functional connectivity. 35. One of the risks of increasing connectivity is assisting dispersal of problem species or disease. 36. Connectivity can be improved by integrated farm management that includes protection of remnant habitat isolated trees and areas of regrowth, managing dams and modifying fence design. 37. Restoration, including biodiverse carbon plantings, may be able to increase connectivity in the landscape.
Invasive species	38. Existing invasive species threats should be controlled in order to increase the capacity of native biodiversity to adapt to climate change, and responses to climate change should not create new, or exacerbate existing, invasive species problems.

TOPIC	KEY MESSAGES
Reproduction in vegetation communities	39. Adaptation management actions will require a holistic approach, with the most cost-effective actions occurring for species in-situ. Ex-situ actions, for the most threatened species, may include seedbanking, genetic supplementation and/or assisted colonisation/dispersal and buyback of sites. 40. The risks and benefits of adaptations should be taken into account, particularly with actions such as assisted gene flow. Seed-based risk assessment could be an option for some species from the WTC Region. 41. Fire could be used as a management tool to promote seed germination in species adapted to a fire-prone landscape, with a 'sprouting' life-history strategy, but timing and frequency of burning should be considered on a case-by-case basis.
Adaptation for important species and communities	42. Adaptation options for marine turtles are mainly consistent with a reduction in other more immediate impacts. 43. Protecting nesting beaches is the most cost-effective strategy of increasing turtle populations. 44. A number of options exist to safeguard the most important nesting beaches from beach loss and inundation, effectively providing a buffer zone. Adaptation options will need to be tailored to individual beaches and the particular threats they face. 45. Maintaining connectivity to suitable nesting habitat near existing nesting beaches, especially inland, will make a considerable difference to the capacity for nesting turtles to adapt to sea level rise. 46. The identification and protection of turtle feeding grounds will also provide an important buffer to changing climate conditions. 47. Reductions in direct mortality of turtles from boat strike, fisheries by-catch, plastic debris and disease must be controlled, and stranded turtle rehabilitation need to continue. 48. Protecting dugong feeding habitat and reducing direct anthropogenic mortality should be the priorities of any adaptation program. 49. Dugong mortality can be minimised through fishing closures, gear modification and boating restrictions. 50. Creating protected areas achieves rehabilitation of coral reef systems. 51. The benefits of restoring coral reefs currently outweigh the costs, except at very localised scales. Opportunities for improving restoration options should be considered, as this may be increasingly necessary in the future. 52. Structural complexity is the most important restoration focus for coral reef communities. 53. Identifying future refugia for coral reef organisms, or even whole coral reef communities, will be a crucial factor in assisting coral reef adaptation to climate change. 54. Inshore reefs of the GBR are urgently in need of improved water quality management, both at the catchment scale and locally (e.g. around ports). 55. Many of the required strategies for adapting to climate change in the Torres Strait will ultimately protect both human populations and ecosystems. 56. For islands large enough to benefit from conservation actions, adaptation measures will be similar to those described for coastal assemblages turtles, dugongs, seagrass beds and coral reefs. 57. Due to their flying large distances, adaptation strategies for flying-foxes will need to be considered

TOPIC	KEY MESSAGES
	via a whole- landscape approach. 58. The increasing urbanisation of flying-fox camps will need to be managed through public education and when non-lethal dispersals occur the impacts will need to be closely monitored. 59. The greatest limiting factor for flying-fox persistence in the future is the quality and availability of food resources. Adaptation planning for these species should start with a good understanding of spatial and temporal resource distribution. 60. Species-specific adaptation actions for birds will need to take into account life history and ecology, but general management to increase the adaptive capacity of the entire WTC Region will benefit a suite of species. 61. The most important adaptation actions for birds will be managing current stressors, and in situ management including refugia identification and protection. Expensive ex situ options such as captive breeding and assisted migration should be considered a last option. 62. Landscape connectivity will greatly improve the cassowary's chances of survival.
Monitoring adaptation outcomes	63. Adaptation actions will require monitoring to ascertain whether they have produced desirable outcomes and to inform changes that may be required; ideally, monitoring should be embedded within an adaptive management framework. 64. Monitoring programs should be initiated with a specific objective, or set of objectives, in mind. 65. Monitoring should be embedded within a framework that involves scientists, management agencies, funding agencies and government. 66. The power to detect changes depends on the sampling design, methods, timing and frequency of the monitoring program. 67. Communication is the key link in all steps of embedding monitoring within an adaptive management framework.
Summary and conclusions	68. Ignorance and misinformation of the general public is a major obstacle at all levels, leading to disinterest and inertia, and supporting a continued lack of political will. Monetary cost is the most common perceived barrier to adaptation actions. 69. Conservation messages fail to capture the role of market mechanisms in persuading the public and governing bodies of the benefit and urgency of climate change adaptation.

Introduction

Successful biodiversity adaptation will be greatly constrained by the rate and ultimate degree of climate change.

The rate of climate change expected in this century is exceptional and climate modelling consistently demonstrates that global mean temperatures will become very high from the perspective of the past tens of millions of years if greenhouse gas emissions continue to increase as they are now (IPCC 2013). Biodiversity is vulnerable to climate change, with limited intrinsic capacity to adapt to extremely high rates of rapid change. Even for warming of 2°C, there will be unavoidable loss of biodiversity, and predictions state that 4°C warming is quite likely without mitigation, with greater increases possible in the next century, if not sooner (Dunlop *et al*. 2012). So the efficacy of adaptation management plans and actions, while useful and important, are limited without adequate and timely reductions in emissions.

Climate change is a different kind of threat to biodiversity so adaptation will require different approaches.

Climate change is a fundamentally different threat to biodiversity than other current threats such as habitat reduction and fragmentation, inappropriate and unsustainable land use, feral animals or invasive weeds. Consequently, in addition to the ongoing management of other threats, management of climate change impacts or adaptation will require different approaches.

Dunlop *et al*. (2010) lists ways in which climate change is unique, including:

- Climate change will lead to many different types of changes to species and ecosystems; some of those may result in loss, others will not.
- The impacts of climate change will be experienced across all biodiversity and cannot be excluded in the way legal protection can reduce habitat loss or pest exclusion can reduce the impacts of invasive species.
- The rate, scale and geographic extent of climate change and the responses of biodiversity make this a phenomenon of a much greater magnitude than other threats.
- All biodiversity will be affected and change will be on-going for many decades, if not centuries, requiring a major revision of the objectives of development and conservation.
- It is likely that systematic management responses are needed, as opposed to addition of climate adaptation bandaids to existing portfolios of conservation strategies.
- There is considerable uncertainty about future environmental change, how biodiversity will respond, where the losses will be and what actions might reduce those losses. And there will be limited opportunity to reduce those uncertainties by learning from locations that experience the impacts first or from early signals since changes will be occurring everywhere and many changes will be hard to detect against the noise of environmental and ecological variation.
- While much ecological and evolutionary theory is predictive when only one or two factors are varying, the circumstances of climate change make accurate prediction from available theories very difficult. For example, contrasting predictions about change and vulnerability can frequently be made from different strands of ecological theory.

Effective adaptation strategies for biodiversity require awareness of the threat, reassessment of conservation objectives, and assessment of which conservation strategies will be most effective under climate change.

Dunlop *et al*. (2010) adapted suggestions in Van Ittersum (1998) to propose three steps for developing effective responses to the impacts of climate change.

1. There needs to be awareness and agreement that climate change will affect biodiversity and action is required. In regions where biodiversity decline is on-going and significant due to other pressures (e.g. mammal decline in northern Australia), climate change adaptation may appear a lower priority. Likewise, it may appear in some regions that biodiversity will be resilient to climatic changes, or that little can be done about it. This step involves recognising that climate change will directly affect important biodiversity values and also affect the management of existing pressures.
2. Conservation objectives need to be reassessed in light of the likelihood of significant and continual future changes in species and ecosystems. Assessing the feasibility of different conservation goals involves understanding how the full spectrum of climate change impacts will affect a wide range of biodiversity values and how it may be possible to reduce future biodiversity losses by managing differently in response to climate change. In practice it is hard to move substantially beyond identifying additional monitoring and management actions that might help preserve currently threatened species or ecosystems at this stage of climate change. Future-oriented conservation strategies need to accommodate the likelihood of substantial changes in biodiversity at most locations. This step must include consideration of a wide range of types of change and values to be effective. The reassessment

of objectives should not to be bypassed in the haste to implement on ground action due to increasing sense of urgency.

3. Assess which conservation strategies will be most effective under climate change. This includes considering the revised conservation objectives, the availability of information, the effectiveness of different options, and the impact of uncertainty on outcomes and effectiveness. The types of strategies that are most suitable, and how species or locations are targeted, will depend on these factors.

To be effective and to promote adoption, adaptation strategies need to fit in with both local institutional and ecological contexts (Howden *et al*. 2007). The biodiversity chapter of the impacts report for the WTC Region (Hilbert *et al*. 2014) assists with step one by outlining the breadth and likely severity of the climate change threat. Step two will require a lengthy discussion among all stakeholders that is likely to be contentious and ongoing since it requires rethinking, perhaps radically, previous conservation paradigms. The third step, developing effective new conservation and adaptation strategies that address the new objectives will also be a lengthy process that might best be done through an adaptive management approach.

Adaptation and mitigation actions in the biodiversity sector will interact in complex ways with adaptation in other sectors.

The linkages between mitigation and adaptation are only beginning to be explored, but natural resource management is one of the areas with the greatest potential for synergies. Managing the trade-offs and promoting the synergies between adaptation and mitigation is likely to be important both in adaptation to climate change, and in limiting climate change to a level at which it is still possible to adapt (Campbell *et al*. 2009).

Ecosystem-based adaptation can be a cost-effective strategy to address the impacts of climate change, particularly in vulnerable areas where adaptive capacity is low (Campbell *et al*. 2009). For example, conserving coastal ecosystems can play a role in coastal protection and buffer the impacts of storms while maintaining fish breeding grounds; and help with climate change mitigation through large carbon storage potential. Conversely, engineering solutions such as sea walls might have detrimental effects on coastal ecosystems (see Connectivity for Movement and Migration section below).

From maintaining ecosystems to enabling adaptation

Historically, biodiversity conservation has emphasised the need to “protect” and “preserve” biodiversity, community structure, functional redundancy, ecosystem services and resilience; with the implication that the desire is to maintain current assemblages, communities and processes (Iwamura *et al*. 2010). However, given the predictions of species range shifts, and the fact that measured climatic changes have already surpassed predicted scenarios, this is unrealistic. Models of likely changes in suitable habitat for terrestrial, freshwater and marine species highlight areas that may serve as refugia in the future (See Refugia section below).

As ecological communities change, it may become more important to identify key processes, communities or functional types that contribute to the persistence of an ecosystem, and focus on protecting those.

Ecosystems are dynamic in nature, and change should be measured against an understanding of the background temporal and spatial dynamics in a system (Moritz and Agudo 2013a). Persistence of the whole ecosystem can rely on one or a few key species or processes that either build the habitat or maintain balance among the ecosystem components, often against a backdrop of periodic disturbances (Hedwall *et al*. 2013).

Hannah *et al*. (2002a) outlined five key elements for what they termed “climate change–integrated conservation strategies (CCS)”:

1. regional modelling of biodiversity response to climate change
2. systematic selection of protected areas with climate change as an integral selection factor

3. management of biodiversity across regional landscapes, including core protected areas and their surrounding matrix, with climate change as an explicit management parameter
4. mechanisms to support regional coordination of management, both across international borders and across the interface between park and non-park conservation areas
5. provision of resources, from countries with the greatest resources and greatest role in generating climate change to countries in which climate-change effects and biodiversity are highest.

Conceptual and practical management options for conservation

Conservation planning is concerned with where, when and how to act to achieve conservation objectives. Climate change will prove a challenge to current conservation planning, bringing novel conditions, including novel ecosystems, extreme events and unprecedented rates of change.

Under climate change, a static approach to ensuring the persistence and health of species and ecosystems within a conservation area will no longer be viable (e.g. Dawson *et al*. 2011). Management actions that safeguard species and ensure ecosystem persistence with changing conditions are considered no-regret or best practice strategies.

The evidence shows that species react idiosyncratically to climate change, and that species assemblages and ecological communities are likely to be different to the way they are now (Moritz and Agudo 2013b). Therefore, we use species as a conservation unit for much of the discussion in this chapter.

Garnett *et al*. (2013) identified adaptation strategies for multiple and single species and grouped them into three categories - immediate actions, ongoing actions and future action, for both inside a species' current range (in-situ) and outside a species' current range (ex-situ) (Table 2.1).

Table 2.1 Potential adaptation actions for ecosystems, communities and species

Adaptation action	*IN-SITU*	*EX-SITU*
Immediate Actions	• Modelling of climate change refugia • Species surveys • Baseline taxon management and research • Land management • Land purchase	• Assisted colonisation or dispersal • Assisted gene flow
Ongoing Actions	• Monitoring • Species management • Maintain and improve habitat quality • Control current stressors – introduced pests, clearance, etc. • Land management • Land purchase	• Captive breeding • Cryogenic seedbanking
Future Actions	• Establish new habitat • Feasibility study of potential management • Marine refugia modelling	• Genetic supplement ation • Assisted colonisation

Source: adapted from Garnett *et al*. (2013)

In-situ conservation is likely to be the most cost-effective way to increase adaptive capacity within a whole ecosystem, and suite of species including plants and fauna. However for the most endangered species, ex-situ actions, including captive breeding, re-introductions from botanic gardens or zoo populations, seedbanking, and assisted migration, could be a last, expensive, option to save the species in the wild

(Garnett *et al*. 2013, see sections on Genetic translocation in the Wet Tropics and Considerations for Translocating Species). We discuss a range of in-situ and ex-situ conservation strategies below.

Identifying and protecting key refugia

Potentially the most cost-effective solution for biodiversity conservation under climate change is to identify and protect places in the landscape that will harbour many species from the worst impacts of climate change.

The effect of climate change will not be experienced equally in all places because local weather systems and landscape features can act to amplify or dampen global patterns. By identifying parts of the landscape where species can retreat to and persist during the coming century (the timeline in which we can model); e.g. 'refugia', we are in an informed position to minimise biodiversity loss through management of these key areas (Reside *et al*. 2013). Currently "refugia" is used to refer to areas large enough to support populations of species under changing climatic conditions (evolutionary timescales), while "refuges" shelter individuals from short-term disturbances (ecological timescales) (Ashcroft 2010; Keppel *et al*. 2012).

Considerations for identifying terrestrial refugia

Refugia will be important for species persistence if they provide protection from climate change, safeguard long-term population viability and evolutionary processes and minimise the potential for deleterious species interactions. However, refugia can only provide these protections if they are available and accessible to species under threat.

Refugia need to safeguard long-term population viability.

For refugia to safeguard evolutionary processes, areas need to be large enough to sustain populations without erosion of genetic diversity (Ovaskainen 2002), and networks should capture a sufficient range of habitats and areas to maintain within-species genetic diversity (Reside *et al*. 2014). This would enable the maintenance of longer-term evolutionary processes, such as speciation and lineage sorting. A focus on identifying refugia for vertebrates is likely to capture areas that will act as refugia for invertebrates and many plants (subject to proximity constraints) (Moritz *et al*. 2001). Minimum refugium size will also depend on site-based factors such as latitude, productivity and environmental heterogeneity. However, overall larger refugia, and networks of refugia, have a higher likelihood of maintaining viable populations of many species (Ovaskainen 2002).

Refugia will need to be within the range of environmental parameters tolerable to species or ecological communities, or accessible if outside their current range.

Refugia within the area the species currently occurs are the most beneficial because fewer range shifts are required. The ability of a species to reach refugia outside its current range will depend on the distance from the current species' range, the dispersal ability of the species, the conditions in the intervening habitat (i.e., can individuals survive and reproduce), and whether or not there are any physical barriers to dispersal (e.g., rivers, mountain ranges). Factors such as competition from existing species may prevent arriving species from establishing.

Refugia availability is influenced by landscape position and structure. High topographic variability can reduce the distance a species is required to move to track its climatic envelope (Tzedakis *et al*. 2002). However, the reverse is true for species already confined to mountain tops; in which case the nearest refugia may be at higher latitudes with intervening lowlands creating a dispersal barrier (Anderson *et al*. 2012). There may be similar barriers for coastal or lowland species (see below). Connectivity of habitats throughout the landscape will be important for facilitating species movement.

Ideal refugia will provide protection against multiple threats.

Many locations can provide refugia from more than one climate change-related threat (Reside *et al*. 2014). In particular, the synergies between thermal, hydric and fire processes mean that refugia will often protect species from changes in these processes simultaneously (Figure 2.1). Areas of hydric refugia (e.g., streams, riparian zones) are often cooler (Dobrowski 2011) and less fire-prone than the surrounds as a result of riparian vegetation supported by the available water (Woinarski *et al*. 2000). Areas protected from direct sunlight have less evaporation and often less flammable material (Couper and Hoskin 2008). Mountains and rocky gorges provide thermal, mesic and fire refugia through physical barriers to radiation and fire; also water accumulation and subsequently less-flammable vegetation. Mountains also provide refugia from cyclones through protection from wind.

Four different techniques used to identify refugia highlight the importance of the upland areas of the WTC Region as important refugia.

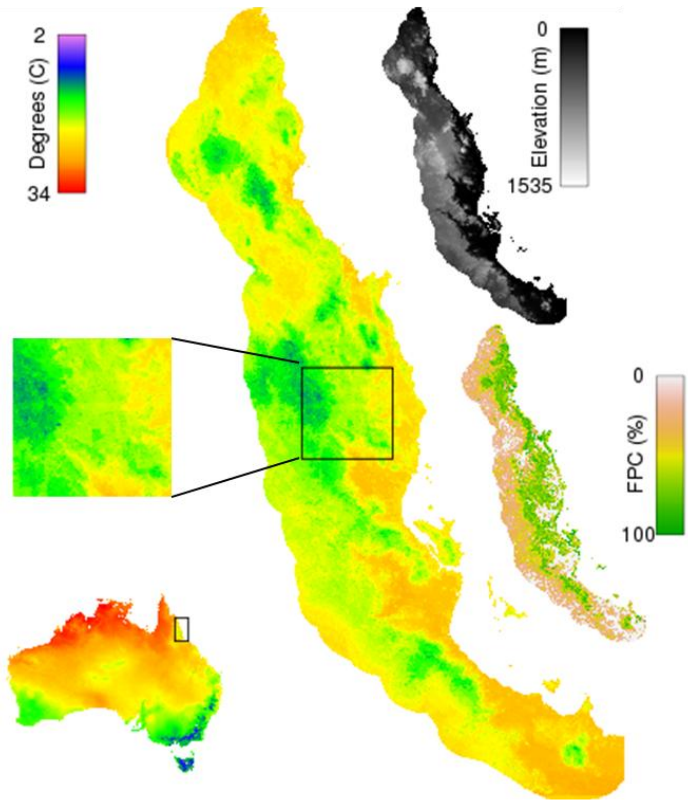

Figure 2.1 High-complexity areas can offer multiple refugial properties. The thermal gradient of a daily maximum temperature in a mountainous region: the Australian Wet Tropics (AWT). High temperatures indicated by warmer colours on the continental and regional maps. This rugged area provides thermal, hydric, and fire refugial properties at both local and continental scales. The upland areas are cooler than their surrounds, and generate substantial orographic rainfall; this in turn promotes the growth of rainforest communities and the suppression of fire. Additional refugial properties are generated by steep gullies (which may protect against cyclonic events and strengthen the hydric refugial properties of the region). Data shown is at a 250 m resolution, adapted from Storlie et al. (2013) and Reside et al. (2014). The large AWT is the temperature gradient, shown in detail in the middle left square insert. The top small AWT is the elevation gradient, and the bottom small AWT is foliage projective cover, with green the more vegetated areas.

An Australia-wide analysis was conducted via funding from the National Climate Change Adaptation Research Facility to identify the most likely areas for terrestrial (Reside *et al*. 2013) and freshwater (James *et al*. 2013) refugia. The terrestrial refugia analysis was composed of several different techniques:

1. Species distribution modelling, looking at areas of species richness current and projected into the future (Figure 2.2a)
2. Composition turnover modelling which uses topographically adjusted radiation, climate and moisture surfaces at 250m resolution across Australia to show areas where species would have to move the least in time and space to remain in suitable conditions (Figure 2.2b),.
3. The locations of current species- and lineage-level diversity for rainforest-endemic lizards that are likely to represent long term stability in conditions (Figure 2.2c)
4. Finally, a conservation-planning exercise incorporating measures of irreplaceability and complementarity, based on endemic rainforest vertebrates of the Australian Wet Tropics (AWT) bioregion (Figure 2.2d).

Analyses 1, 2 and 3 all extend beyond the AWT, however, the comparison for this region was made because each of these analyses did occur across this region (Reside *et al*. 2013).

The comparison shows that while there are some differences, there is good spatial congruence for the important refugia areas. In particular, the refugial value of the upland areas in the north (Carbine, Windsor, Thornton), central (Bellenden-Ker/Bartle-Frere, Lamb and Herberton ranges) and south (Spec and Elliot) are all represented by each of the four analyses. These upland areas are recognised as being of conservation importance, centres of evolution and containing endemic species (Williams 1996).

The current protected areas encompass the areas that

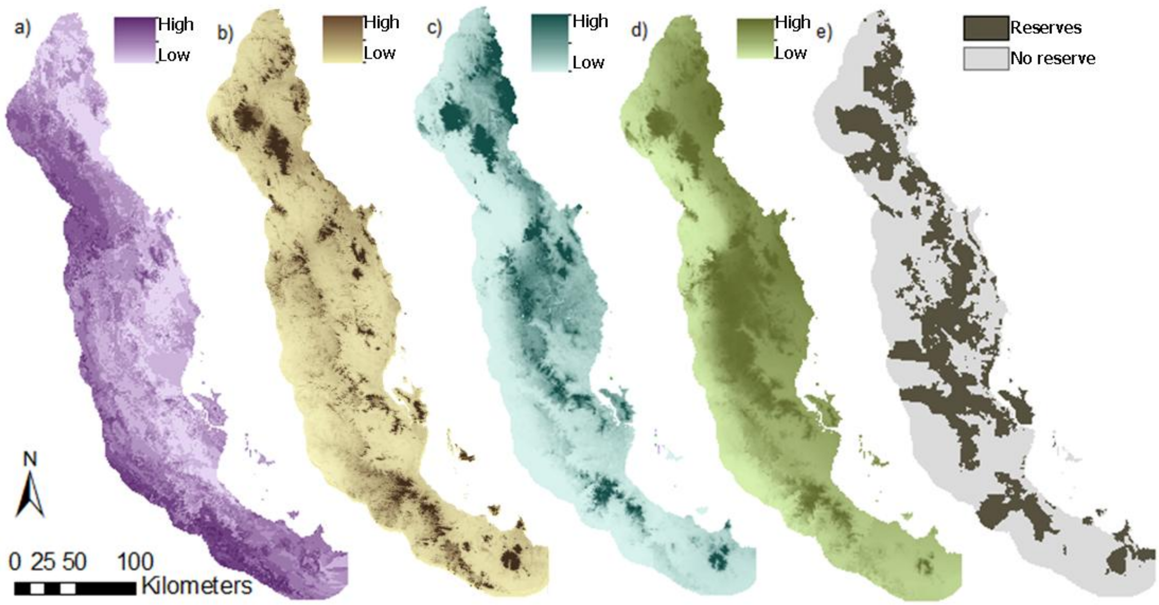

Figure 2.2 Comparison of four analyses techniques to identify important refugia that all overlap the Australian Wet Tropics bioregion. a) the species distribution modelling; b) the compositional turnover modelling, or Generalised Dissimilarity Modelling; c) the Evolutionary refugia: current species- and lineage-level diversity for rainforest-endemic lizards; d) the Zonation conservation planning analysis; and e) the current protected areas within this region.

Source: Adapted from Reside *et al*. (2013).

are known to be important for many species currently in the AWT; however they are likely to miss the areas important for species in other parts of Australia that are likely to move into the AWT as a result of climate change.

The current protected areas (Figure 2.2e) mostly overlap with the important refugial areas predicted by the analyses 2, 3 and 4; however, large areas of refugia predicted by analysis 1 fall outside the current protected areas. The differences resulting from analysis 1 in comparison to the others are almost certainly because this approach focuses on areas that will act as refuges for species that are moving from outside the AWT; namely, from the north and west, and moving uphill from the lowland areas of the western slopes. Additionally, these results do not account for endemism, or for specific habitats (e.g. rainforest endemics).

The southern Atherton Tablelands, which contains the largest tract of upland rainforest, some of the highest diversity and abundance of rainforest species, and high productivity, was well-represented by analysis 4, and by the evolutionary refugia (analysis 3), but under-represented by the two Australia-wide analyses (1 and 2). In contrast, the northern uplands of Windsor and Carbine Uplands gain particularly high refugia status across all techniques (Moritz *et al*. 2005). In the case of Windsor, it is currently moderately depauperate in comparison to other upland areas, with a fauna that is likely to have been recolonised after rainforest contractions in the past. It is also likely to be particularly vulnerable to changes in future rainfall, which is difficult to predict given the uncertainty around rainfall projections.

The southern upland rainforest of the AWT, particularly Hinchinbrook Island, Paluma Range and Mt Elliot, emerge as important refugia across all refugia analyses.

Southern and upland areas of the AWT hold high importance, even if current diversity is low, because the upland areas hold high potential for species currently at lower elevations or lower latitudes to move into. The evolutionary refugia are also concentrated at high elevations in most regions, indicating their importance as refugia from past climate change. Despite the differences, the congruence across techniques gives us confidence that the techniques used in this study are able to point to high value refugia.

The east coast of Australia had a high proportion of refugia when compared to the rest of Australia.

The Australian east coast is likely to be important by providing an opportunity for species to track their climatic niche south, where temperatures are lower, at the same time finding hydric refugia. While in combination Tasmania and the east coast of mainland Australia will be crucial for species persistence into the future, the refugia found away from the east coast will be crucial for maintaining the unique fauna in habitats other than what is found on the east coast.

The Australian Wet Tropics Bioregion is likely to be an important area for many species moving from the west and north of this region.

The distributions of 1681 species were modelled in an Australia-wide analysis, and their distributions were projected onto future climate change scenarios. More details on the methods can be found in the report by Reside *et al*. (2013). The species were grouped by class: birds, frogs, mammals and reptiles. Areas across Australia were scored for being the most important for both the number of species moving into an area, as well as the number of species that are likely to retain their current occupancy into the future (Figure 2.3). This analysis shows that the east coast is highly likely to be very important for many species in the future, particularly the western edge of the Wet Tropics region.

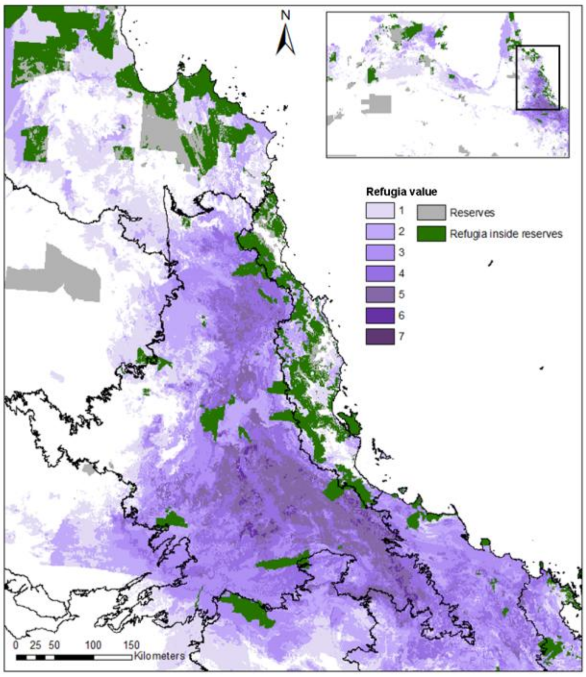

Figure 2.3 A detailed view of the protected areas in Australia's national reserve system, and how they relate to the projected refugia areas in 2085 for north-eastern Australia within the bioregion boundaries outlined in black. The detailed refugia are displayed, using the same scale as the refugia analysis, scaled from 1 (lowest priority) to 7 (highest priority), as the highest possible score '8' was not realised for any location.

Source: Adapted from Reside *et al*. (2013)

Considerations for identifying freshwater refugia

Adaptation for freshwater ecosystems must include the identification, protection and management of current and future refugia, especially in areas predicted to remain climatically relatively stable.

Species may shift in latitude and elevation (James *et al*. 2013), therefore it may be appropriate to consider higher-latitude habitats of the same nature, and all higher elevation habitats, as valuable in the future. Previous modelling work has identified areas in which biodiversity may remain stable or even increase (James *et al*. 2013). Natural adaptive range shifts are least likely to happen the higher the elevation of the habitat, as freshwater habitats become increasingly isolated from each other with increased elevation (Bush *et al*. 2012).

The WTC Region is expected to retain a large proportion of its freshwater biodiversity; therefore has conservation importance at a national level.

For freshwater fish and stream frog assemblages, the WTC Region is expected to remain relatively stable and retain a large proportion of its biodiversity (James *et al*. 2013); this region should therefore be considered especially valuable, at a national level, for freshwater conservation. Fortunately, there is already a strong overlap between the current areas of high value for frogs and the protected area network (James *et al*. 2013); strengthening compliance and education in these areas should be a priority. The WTC Region may also increase in refugial value for species expanding into the WTC Region from other areas (James *et al*. 2013). For crayfish, east coast habitat, which is already at higher elevations, is expected to contract or disappear entirely (James *et al*. 2013).

Identifying refuges specific to freshwater biodiversity will require the consideration of refuge value, including abiotic factors, biotic factors, anthropogenic factors, spatial factors and temporal factors.

James *et al*. (2013) modelled possible range expansions and contractions of Australian freshwater species (Figure 2.4), and discuss the merit of different adaptation options. Much of the scientific climate change adaptation literature has little to offer beyond recommending the protection of potential refuges (Table 2.2). James *et al*. (2013) further distinguish between refuges based on what kind of impact they might be protecting species from, such as warming and heatwaves (e.g. preservation or restoration of riparian vegetation cover, preserving and enhancing groundwater flows by minimising fine sediment input), flow regime changes, floods and droughts (provision of environmental flows and the maintenance of hydraulic habitat complexity), sea level rise and storm surges (maintaining, restoring or enhancing vegetation buffers to storm surges) and fire (protecting networked but unaffected reaches during the recovery phase, managed relocation of individuals from neighbouring catchments or anthropogenic refuges).

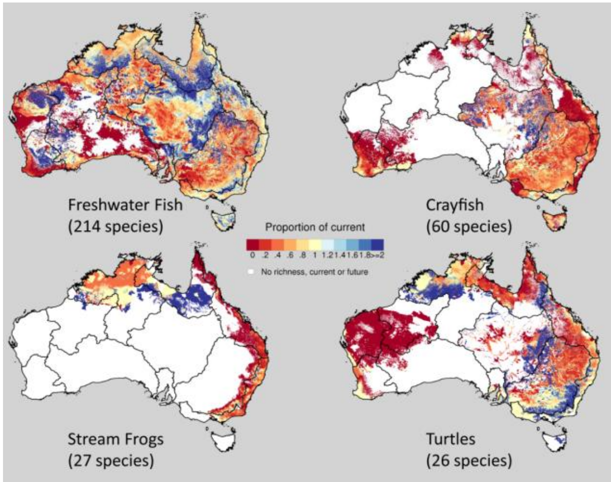

Figure 2.4 Proportionate change in environmental space suitable for freshwater biota between current and 2085 under RCP8.5. Figures represent the 50th percentiles across 18 GCMs. (Blue indicates gains in environments suitable for and red indicates losses in environments suitable)

Source: James *et al*. (2013)

Table 2.2 Specific adaptation options associated with the protection and/or enhancement of climate refuges for freshwater biodiversity.

ADAPTATION OPTION	REFERENCE	TYPE OF ACTION	TARGET BIODIVERSITY COMPONENT	RELEVANT SCALE(S)
Management of temperature inverted haloclines	Stith *et al*. 2011	Manipulation of abiotic factors	Florida manatees, temperature-sensitive species	Ecosystem
Water movement and use of waves to prevent build up of wave intolerant invasives in shallow habitats	Urban and Titus 2010	Manipulation of abiotic factors, Manipulation of biotic factors	Native aquatic plants	Habitat
Retain riparian trees in groups in forestry clearing practices	Chan-MacLeod and Moy 2007	Manipulation of anthropogenic factors, manipulation of spatial factors	Temperate pondbreeding frogs	Ecosystem, landscape
Provision of internal or peripheral islands in flood-prone habitats (e.g. reconstructed marsh) to provide 'lifeboats' for resident populations and 'landfalls' for flood-borne individuals swept downstream	Sexton *et al*. 2007	Manipulation of abiotic factors, manipulation of spatial factors	Semi-aquatic snakes	Landscape

ADAPTATION OPTION	REFERENCE	TYPE OF ACTION	TARGET BIODIVERSITY COMPONENT	RELEVANT SCALE(S)
Management of water levels (depths and duration) in 'holes'	Kobza *et al*. 2004	Manipulation of abiotic factors, manipulation of temporal factors	Native fish	Habitat
Creation of artificial refuges: creation of shallow channel for endangered fish where natural habitat destroyed	Winemiller and Anderson 1997	Manipulation of abiotic factors	Endangered fish	Ecosystem
Use of storage weirs to provide permanent water during droughts	Jacobsen and Kleynhans 1993	Manipulation of abiotic factors, Manipulation of anthropogenic factors	Aquatic biota	Ecosystem, landscape
Creation of stepping stone refuges or corridors for movement and dispersal	Robson *et al*. 2008	Manipulation of spatial factors	Aquatic biota	Landscape
Maintenance of water depth and duration in waterholes, pools etc.	Robson *et al*. 2008	Manipulation of abiotic factors, manipulation of temporal factors	Aquatic biota	Habitat
Maintenance of some flooding regimes for riparian vegetation, floodplain vegetation, floodplain wetlands, waterbird breeding, fish movement and food web dynamics	Robson *et al*. 2008	Manipulation of biotic factors, Manipulation of anthropogenic factors	Aquatic biota	Ecosystem, catchment, landscape
Prevention of physical disturbance of dry beds by limiting extraction, construction, off-road vehicle use	Robson *et al*. 2008	Manipulation of anthropogenic factors	Aquatic biota	Ecosystem
Protection of tributaries in good conditions	Robson *et al*. 2008	Manipulation of spatial factors	Aquatic biota	Catchment, landscape
Maintenance of physical structure and connectivity to provide refuges from flooding	Robson *et al*. 2008	Manipulation of abiotic factors	Aquatic biota	Ecosystem, landscape
Prevention of clearing of vegetation and woody debris	Robson *et al*. 2008	Manipulation of anthropogenic factors	Aquatic biota	Ecosystem, landscape
Prevention of draining of pasture wetlands and urbanisation	Robson *et al*. 2008	Manipulation of anthropogenic factors	Aquatic biota	Ecosystem, catchment, landscape
Topping up refuge pools	Robson *et al*. 2008	Manipulation of abiotic factors	Aquatic biota	Habitat, ecosystem
Piggy-backing flows on flood peaks	Robson *et al*. 2008	Manipulation of abiotic factors, Manipulation of anthropogenic factors	Aquatic biota	Catchment

ADAPTATION OPTION	REFERENCE	TYPE OF ACTION	TARGET BIODIVERSITY COMPONENT	RELEVANT SCALE(S)
Inundating lake and floodplain soils to replenish egg and seed banks	Robson *et al*. 2008	Manipulation of abiotic factors	Aquatic biota	Ecosystem
Dam removal	Robson *et al*. 2008	Manipulation of anthropogenic factors	Aquatic biota	Ecosystem,catchment
Removal of drainage systems	Robson *et al*. 2008	Manipulation of anthropogenic factors	Aquatic biota	Ecosystem, catchment, landscape
Revegetation	Robson *et al*. 2008	Manipulation of biotic factors, Manipulation of anthropogenic factors	Aquatic biota	Ecosystem, catchment, landscape
Replace woody debris	Robson *et al*. 2008	Manipulation of abiotic factors	Aquatic biota	Ecosystem
Managing and design anthropogenic habitat for use as refuges	Robson *et al*. 2008	Manipulation of anthropogenic factors	Aquatic biota	Ecosystem, catchment, landscape
Conserve forest remnants	Suga & Tanaka 2013	Manipulation of spatial factors	Macroinvertebrates	Catchment, landscape

Source: From James *et al*. (2013); see source for references

High-quality refuges tend to have relatively stable abiotic characteristics, including high climatic and habitat stability (but high habitat heterogeneity at larger spatial scales), and a level of uniqueness within their surroundings. These abiotic characteristics then ideally support key biotic components such as sufficient prey, the presence of symbionts and the absence of competitors or predators. Favourable refuges may be compromised by anthropogenic threats that alter landscapes and connectivity patterns; minimising these threats will be a crucial component in the adaptation of freshwater ecosystems to climate change (Figure 2.5).

Prioritising areas for either restoration or protection

Systematic conservation planning is an important tool for prioritising areas (e.g. refugia) for protection and restoration.

The current global network of protected areas alone is inadequate for conservation (Rodrigues *et al*. 2004); therefore, additional protected areas are required as well as managing unprotected areas to maximise biodiversity outcomes will be required to halt biodiversity decline. Prioritising areas for protection against threats (e.g. protected area) or for restoration accounting for species long-term persistence is best achieved through systematic conservation planning (from here on “conservation planning”) (Margules and Pressey 2000; Watson *et al*. 2011).

Biodiversity conservation, ecosystem service retention and carbon sequestration can all be achieved through prioritising areas for protection and restoration; and many studies are looking at ways to attain these simultaneous goals (Nelson *et al*. 2008; Thomas *et al*. 2012). The first priority is to establish and strengthen mechanisms for protection of existing vegetation of high value. Loss of existing habitat should always be avoided where possible, as re-creation of habitat rarely, if ever, compensates for the biodiversity lost when an area is cleared or intensively modified (Bekessy *et al*. 2010; Suding 2011), particularly for species requiring old-growth habitats (Lindenmayer *et al*. 2012b). Options for protecting existing habitats include national parks, World Heritage Areas, nature refuges, Ramsar wetland sites, incentives for protection on private land and local government zonings.

Considerations for conservation planning for climate change adaptation:

1. Identify species conservation requirements by predicting future distributions under climate change and identifying connectivity requirements for range adjustments.
2. Set specific objectives: qualitative and quantitative.
3. Identify and investigate trade-offs.
4. Incorporate uncertainty.
5. Locate the priority areas for protection and restoration using conservation planning software.

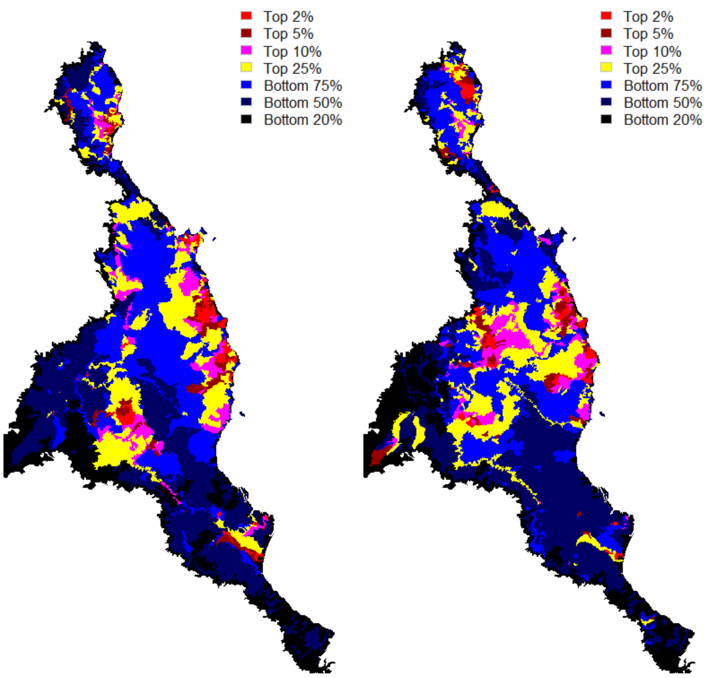

Figure 2.5 Conservation prioritisation of freshwater river catchments within the study area based on 57 fish species for (a) current-modelled species distributions (1990 climate); (b) future-projected species distributions (RCP8.5, 2085, based on the median model across all 18 GCMs). Prioritisation is hierarchical so that the top 2% of cells (red) are within the top 5% (burgundy) which are in turn within the top 10% (pink), 25% (yellow), 50% (blue), 80% (dark blue), the lowest priority 20% are black.

Source: James *et al*. (2013).

Trade-offs occur when one aspect of biodiversity is prioritised at the expense of another; but also when meeting other goals such as carbon sequestration. Trade-offs occur whether they are examined or not, therefore examination of trade-offs supports transparent decision making.

Various conservation planning software tools are available, and their strengths and weaknesses have been reviewed (Moilanen *et al*. 2012). A range of reserve selection algorithms can be used with these software, each weighting different priorities.

Restoration will need to be a major part of climate adaptation.

Restoration is a major part of many climate adaptation action plans, including restoring degraded systems or national parks and increasing connectivity (Gillson *et al*. 2013; Hannah *et al*. 2002b). Restoration has been shown to recover many ecosystem functions and many components of the original biodiversity (Chazdon 2008). Restoration will be required for areas identified as priority for future biodiversity that have become degraded (Shoo *et al*. 2011). Importantly, restoration can facilitate adaptation (restoring areas for species to move to) and mitigation (sequestering carbon) simultaneously, and be economically viable under particular carbon pricing schemes (Bekessy and Wintle 2008). Natural or passive regeneration is the cheapest and often the most effective alternative, but is not always an option (Lamb *et al*. 2005). Conservation planning, monitoring and adaptive management are key to successful restoration projects, regardless of the end goal.

Restoration best practice has evolved to incorporate considerations of climate change adaptation. In particular, focus has shifted away from prioritising local provenance seed and seedlings for planting. Instead, “composite provenancing” is recommended, which involves a mixture of seed from populations of increasing distance to mimic natural gene flow patterns, and increase the chance of bringing in climate change-resilient individuals (see Genetic translocation section) (Breed *et al*. 2013).

The benefits of restoration can often outweigh the costs (De Groot *et al*. 2013). De Groot *et al*. (2013)’s meta-analysis of restoration projects across multiple biomes showed a fairly linearly increasing cost of restoration with increasing distance from the shore: freshwater and inland wetlands had higher costs than terrestrial ecosystems, but lower than coastal wetlands, coastal systems and coral reefs. However, they found that restoration of coral reefs and coastal areas had among the highest natural-capital benefits. Restoring terrestrial systems can be advantageous for increasing both the ecosystem function of the land, and reducing the impact of aquatic systems through reduced runoff, buffering river water temperatures, adding terrestrial carbon for aquatic food webs and providing woody material for fish habitat (Davies 2010).

Translocation as a management tool

Species are likely to face the loss or geographic shift of suitable habitat with climate change (Reside *et al*. 2012; Reside *et al*. 2013). Where species are unable to disperse to new areas with suitable conditions due to lack of dispersal ability, geographic or biological barriers, or insufficient population capacity (Åizling *et al*. 2009; Boulangeat *et al*. 2012), assisted colonisation has been discussed as a potential adaptation option (Harris *et al*. 2013; Hewitt *et al*. 2011; Hoegh-Guldberg *et al*. 2008; Lunt *et al*. 2013). Assisted colonisation has recently been conducted in the Wet Tropics, in regards to the translocation of individuals of a critically endangered frog from the last remaining wild population to a nearby historical site. This frog declined due to disease, not for climate-change associated threats. However, some lessons may be taken from this case study; and further considerations for genetic translocation are discussed below.

General considerations for translocation

Translocation is here considered to be movement of individuals from a wild population directly to another wild site. The important distinction is whether the translocation involves movement of individuals within the known historic range (in which case it can be considered a ‘reintroduction’) or movement of individuals beyond the known range. The former of these has occurred many times in Australia and internationally, whereas the latter is highly controversial. Here we specifically discuss translocation within the known historic range as a potential management tool.

Any translocation of species is highly risky, with high failure rates, even to a historically occupied site. The factors that determine the success of translocations include: removing threats, number of individuals translocated and the genetic diversity of the founding population. The success of translocations is species and situation-specific and many factors need to be considered.

In September 2013, 40 individuals of the critically endangered Armoured Mist Frog (*Litoria lorica*) were translocated to a new site in an attempt to establish a second wild population. Extensive surveys had shown that there was only one population remaining of this species, on a stream on the western side of the Carbine Tableland (Conrad Hoskin & Robert Puschendorf, unpublished data). Like many Wet Tropics stream frogs, the species declined in the late 1980s and early 1990s due to chytrid fungus disease (Puschendorf *et al*. 2011). The translocation was conducted by Dr Conrad Hoskin (JCU) and the Threatened Species Unit of the Queensland Department of Environment and Heritage Protection. The translocation was to a site upstream, past a barrier of unsuitable habitat, to another extensive area of suitable stream habitat within the historic range. Both sites have been monitored for frogs for many years and are part of a study investigating environmental refuges from chytrid in the Wet Tropics (Puschendorf & Hoskin, unpub. data).

The decision to conduct a translocation in this species took many years and was based on the following criteria for conducting a translocation (Hoskin & Puschendorf, unpublished):

1. Only if the species is known (or very likely) to have been at the site in recent time.

This increases the likelihood that the environment at the new site is suitable for the species, and decreases the likelihood that the translocated species will detrimentally impact other species at that site (i.e., it will co-occur there with species it has co-occurred with in recent time).

2. Only if the species has been thoroughly surveyed for at this site and elsewhere across the historic range and adjacent areas.

Thorough surveys to determine the existence of overlooked populations are crucial. It needs to be certain that the translocation attempt is really necessary and that the species is definitely absent from the translocation site (to avoid mixing populations).

3. Only if threats are understood and there is a solid reason to believe the species will do well at the new site.

Is the threat absent at the new site? For how long? Or if it is present, can you be sure the species will handle it there?

4. Only if the source population can handle the removal of animals.

Translocations are inherently risky with no guarantee that the translocated animals will survive or establish a viable population; therefore, it is important to be sure that removing them will not be a significant threat to the source population. If the source population is persisting well (which requires extended population monitoring), it may be acceptable to take up to 10%. This is highly dependent on many factors, such as breeding strategy, breeding success, population trends, etc. Population modeling could be incorporated to quantify the risk.

5. If there are multiple populations, then the population genetics must be known to make an informed decision on which source population to use for translocation.

If there are multiple populations, then they are likely to be genetically different and this needs to be investigated. Highly localised species (e.g., single mountain-top endemics or those with a single population) tend to be genetically homogenous due to their small population size and connectivity. In these cases, the options to maximise genetic diversity in the translocated population include: (i) move as many individuals as is possible without impacting the viability of the source population, (ii) source individuals from different parts of the population, and (iii) maximise the number of individuals contributing to breeding (e.g., consider sex ratios and breeding systems).

These criteria were fulfilled in terms of the *Litoria lorica* translocation (Hoskin & Puschendorf, unpublished):

1. *L. lorica* was almost certainly present at the translocation site 25 years ago, pre chytrid disease outbreak in the Wet Tropics.
2. The northern Wet Tropics region was thoroughly surveyed over several years and *L. lorica* was found to be absent from all likely habitat elsewhere, and years of monitoring other frogs at the translocation site had shown with high certainty that the species was absent there.
3. Years of chytrid research in the region had shown that *L. lorica* and other stream frogs are persisting well despite chytrid infection at the source site (Puschendorf *et al*. 2011). With regards to this threat, the translocation site was deemed highly suitable due to environmental similarity to the source site and high abundance and persistence of the sister species *L. nannotis* there, despite chytrid infection
4. The main population of *L. lorica* is common throughout the area of suitable habitat and this site is considered 'at capacity'. The population size has been estimated, and monitoring shows no population decline over years. Less than 10% of adults were translocated.
5. Only a single population existed pre-translocation. To maximise genetic diversity, individuals were moved from the middle of the source population, equal number of males and females were moved, and almost all females were gravid when moved.

The translocated population of *L. lorica* is regularly monitored and it is too early to determine whether it has been successful. Measures of success will include: survival of the translocated adults, successful breeding and recruitment at the site over the next few years, and, longer-term, population growth at the site.

Meeting all the above criteria will maximise the likelihood of success for the population being translocated, and minimise the impact on the recipient environment. However, it is very rare that all these considerations will be met. The above criteria require thorough research and could only be realistically satisfied in some species. One of the biggest issues in the above list is understanding the threat posed to a species and determining with some certainty how the translocated population will handle that threat at the new site. In the case of the frog example here, the threat is disease and this threat has been studied in detail at all the sites involved. Disease is not a simple threat to study, but other threats, such as climate change, are considerably harder to resolve.

Another big issue in the above list is determining with a high degree of confidence what the impacts on the recipient environment will be. In the case of the reintroduction of a species to a site it was present at in recent history (as for *Litoria lorica*), such impacts can be assumed to be minimal. In the case of translocation of individuals beyond their known historic range, such impacts may be near impossible to determine and predict. Hence such translocations are highly contentious and have not been performed for native species in the Wet Tropics.

Another big issue in the above list is determining how many individuals can be removed from a source population without impacting its long-term viability. This is obviously very complex and will be species and situation-specific. What is the size of the source population? Is it continuous or structured? Is it stable or declining? How rapidly will removed individuals be replaced? From where should individuals be taken? And when? Allied to these questions is consideration of the genetic composition of the source and founding populations. All these are complex questions that can only be answered through detailed study of the specific system in question.

As stated at the outset, the above discussion is based on a case study of a single well-studied frog system. Considerations would be different for a different species of frog, let alone a threatened species of plant or invertebrate. And considerations would be very different when considering translocation as a management tool for climate change threats. In particular, climate change threats have raised discussion of moving species outside of their known historic range. Our discussion above does not deal with this. Support for this would need to be thoroughly scrutinised. In particular, there is the obvious potential for impacts on recipient environment. Shifting a species outside its range introduces a novel species into an environment, with potentially significant impacts on other species that would be very hard to accurately predict. Beyond this fundamental issue, moving a species outside its known range into a novel environment intuitively reduces the likelihood of establishment success. Translocation outside of the known range is, for good reason, very contentious and widely considered 'playing god'. It would require considerable debate that we do not enter into in detail here.

Ultimately, any translocation should be seen as a low success, last resort management option that requires detailed system-specific data.

Genetic translocation in the WTC Region

The facilitation of gene flow between populations through assisted interbreeding can be used to enhance the evolutionary potential of populations.

Species may adjust to a changing climate through evolutionary adaptation (Bradshaw and Holzapfel 2006). However, evolutionary responses are dependent on the presence of appropriate adaptive variation; if a population is to rapidly adapt to a different climate, it requires adaptive variation (genes) suited to that climate. Whilst there can be adaptive variation in climate sensitivity within populations, theoretical and empirical studies suggest the bulk of a species' adaptive variation is found across populations rather than within population (Hampe and Petit 2005). The facilitation of gene flow between populations through assisted interbreeding can, therefore, be used to enhance the evolutionary potential of populations of plants and animals. This emerging conservation tool is known as genetic translocation (Weeks *et al*. 2011).

Isolated populations on the periphery of a species' distribution may be adapted to the climatic conditions that will develop in core areas of the species' distribution as climate change proceeds.

Peripheral isolates — small, naturally isolated populations (as opposed to isolated through human-mediated habitat fragmentation) on the periphery of a species' distribution — are an important source of adaptive variation of climate-relevant traits. These populations are likely to be particularly diverse in terms of climate adaptation because: (1) their location at the periphery of the species' distribution means they are likely to be exposed to extreme climatic conditions (relative to the species' tolerance), and (2) their isolation decreases or prevents gene flow from neighbouring populations and allows for local adaptation to the conditions encountered in the isolate (Aitken *et al*. 2008). Peripheral isolates on the hot periphery of a species' distribution may, therefore, be adapted to hot conditions, i.e., they may be adapted to the climatic conditions that will develop in core areas of the species' distribution as climate change proceeds. Thus, hot-adapted peripheral isolates could hold the adaptive variation needed by core populations if core populations are to evolutionarily adapt to warmer conditions. As climate change proceeds, however, conditions will also become hotter in hot-adapted peripheral isolates at a much faster rate than in the past. Given the small size and isolation of these isolates, and given that they are already at the limit of the species' thermal tolerance, hot-adapted peripheral isolates are particularly vulnerable to climate change. Thus, as temperatures become even hotter, hot-adapted peripheral isolates may be some of the first populations to disappear. Thus, the application of genetic translocation in building resilience to climate change requires urgent attention.

Facilitating gene flow between lineages and/or from peripheral isolates to core populations could bolster the evolutionary potential of populations in the WTC Region.

Research in the WTC Region suggests genetic translocation could be used to improve climate change resilience of species from this region. The WTC Region consists of a complex network of rainforest patches, with large central patches of rainforest that experience relatively cool to mild climate, as well as smaller peripheral rainforest isolates that are exposed to more extreme conditions. Populations of rainforest specialists that have been able to persist in the small isolated patches of rainforest are likely to be adapted to the conditions encountered in the isolates; they may hold adaptive variation in thermal and desiccation tolerances that is not present in core populations. Furthermore, many WTC Region endemics display a complex phylogeography (geographic distribution of genetic groups), consisting of multiple lineages that are isolated from one another. In some cases, these lineages are known to be divergent in their climate sensitivity (Moritz *et al*. 2012). Thus, facilitating gene flow between lineages or from peripheral isolates to core populations could bolster the evolutionary potential of populations in this region. Genetic translocation is, however, a controversial and relatively costly conservation strategy (Shoo *et al*. 2013). Even so, it is a strategy that is increasingly being considered (Weeks *et al*. 2011), and appears particularly well-suited to the WTC Region given the structured phylogeography and local adaptation seen in species endemic to this region. Before genetic translocation can be safely and effectively used in this region, further research into its application is required. More specifically, genetic translocation protocols need to be developed to ensure that if/when this strategy is used it: (1) improves the resilience of recipient populations, and (2) threats associated with the transfer of organisms between habitat patches are minimised.

Triggers and thresholds

The uncertainty inherent in climate change predictions makes it almost impossible to determine set triggers or thresholds beyond which ecosystems are likely to change irrevocably.

Management of complex ecosystems depends on being able to measure the responses of organisms to the main drivers of change (Bino *et al*. 2014). The most useful information for managers to understand and act upon often take the form of indicators, thresholds and triggers (Eiswerth and Haney 2001; Werners *et al*. 2013). Threshold responses can be measured and quantified, identifying potential transitions between ecosystems states, with the inclusion of uncertainty in the form of the time range in which tipping points are likely to be reached (Werners *et al*. 2013). Understanding minimum thresholds transitioning from desired to undesired states can help manage the system for resilience (Groffman *et al*. 2006). However, thresholds can rarely be generalised across large spatial and temporal scales (de Boer 2007). Additionally, the uncertainty inherent in climate change predictions makes it almost impossible to determine set triggers or thresholds beyond which ecosystems are likely to change irrevocably. In the coral reef literature, for instance, there is much discussion of "phase shifts" from a desirable stable state (coral-dominated) to a less desirable stable state (e.g. algae-dominated), with very little prospect of a reversal (Graham *et al*. 2013). But even in this case, it has not been possible to define set thresholds in environmental parameters (e.g. temperature, nutrients, turbidity, herbivore biomass) that will trigger a phase shift, or even how long it takes a system, once the threshold has been crossed, to reach a new stable state (Graham *et al*. 2013). For instance, the bleaching threshold for Great Barrier Reef corals varies between species and across spatial scales, and is dependent on a complex set of variables including both the duration and magnitude of thermal stress (Spillman *et al*. 2013).

In the context of assessing the suitability of refugia for supporting future changes in species ranges and community structure, understanding thresholds is equally difficult. Managing the whole landscape, rather than refugia on their own, may provide a better safeguard where refugia do not perform as predicted under climate change. Understanding the resilience of refugia will depend on our ability to ascertain what the limits are of that resilience. For instance, there may be rainfall levels below which a refugium is no longer able to sustain species that migrate into it (Keppel and Wardell-Johnson 2012). Predicting the value of refugia based on thresholds is especially complicated in the case of species that are nomadic (Bino *et al*. 2014).

Previous studies that have identified environmental thresholds have highlighted that these are often specific to a particular location or time.

Bino *et al*. (2014) modelled fluctuations in 10 species of colonial waterbird species in the Macquarie Marshes of NSW over 24 years (1986-2010), and found that all species had different thresholds in water flows that triggered breeding events. Waterbird species included great egret (*Ardea alba*), intermediate egret (*A. intermedia*), little egret (*Egretta garzetta*), cattle egret (*Bubulcus rufous*), night heron (*Nycticorax caledonicus*), glossy ibis (*Plegadis falcinellus*), Australian white ibis (*Threskiornis mollucca*), straw-necked ibis (*T. spinicollis*), little pied cormorant (*Microcarbo melanoleucos*), and little black cormorant (*Phalacrocorax sulcirostris*). All these species also occur in some parts of the WTC Region, but may respond to different water flow thresholds in different parts of their range. Hilbert *et al*. (2014) used the known successful incubation temperature of turtles (25-34°C) to predict that nesting beaches in the northern Great Barrier Reef and Torres Strait region will produce a higher proportion of females by 2030 and will experience incubation temperature that constantly exceed the upper thermal incubating threshold by 2100.

Among the 10 Australian ecosystems considered most vulnerable to tipping points, seven occur in the WTC Region.

Among the 10 Australian ecosystems considered most vulnerable to tipping points, seven occur in the WTC Region (Table 2.3): elevationally restricted mountain ecosystems, tropical savannas, coastal floodplains and wetlands, coral reefs, drier rainforests, offshore islands, and salt marshes and mangroves (Laurance *et al*. 2011). Whilst specific tipping points are not identified or predicted, the authors recommend a number of actions to prevent tipping points. To determine whether a tipping point may be approaching, key ecological processes and ecosystem dynamics must be identified and examined. Disruptions to ecological processes and slowing of ecosystem dynamics may both point to impending shifts, as can increases in spatial variance and autocorrelation measured by remote sensing (Laurance *et al*. 2011). The authors also advocate for local management actions to reduce the risk of tipping points, such as increasing the protected area networks, limiting external disturbances such as habitat destruction for urban and road development, creating corridors and buffers, restoring habitat and managing fire regimes (Laurance *et al*. 2011).

Table 2.3 Intrinsic features and environmental threats that render the 10 most vulnerable Australian ecosystems prone to tipping points. For each ecosystem type, the most important feature is numbered 1 with those of lesser importance numbered subsequently.

	Mountains	Tropical savannas	Coastal wetlands	Coral reefs	Drier rainforests	Islands	Estuarine wetlands
Narrow environmental envelope	1		4	1	1	2	1
Near threshold	3			3			
Geographically restricted	2		1		2	1	2
History of fragmentation			2		3		4
Reliance on ecosystem engineers		3					
Reliance on framework species				2			6
Reliance on predators or keystone mutualists							
Positive feedback		1		4	4		
Proximity to humans			3	5	5		3
Social vulnerability		2					5
Increased temperatures	1			1	2	6	
Changes in water balance and hydrology	2		3		3		3
Extreme weather events	3	3	2	2		2	1
Ocean acidification				3			
Sea-level rise			1			3	2
Changed fire regimes	8	2	8		1		
Habitat reduction	5		5	5	5	4	4
Habitat fragmentation	6	4	6	6	6	5	
Invasives	4	1	4		4	1	
Pests and pathogens	7					7	
Salinisation				4			
Pollution			7				5
Overexploitation		5		7	7		

Source: Laurance *et al*. (2011)

Fire management

Fire offers a number of opportunities for adaptation management, including prescribed burning of weedy flammable species and woody species encroaching on native grasslands. However, timing of burns will be critical to success in terms of biodiversity management.

In general, fire offers more opportunities for adaptation management and intervention than other aspects of climate change (Low 2011). Prescribed burning at key times to manage fuel accumulation, particularly of invasive flammable grasses including gamba grass (*Andropogan gayanus*) and buffel grass (*Cenchrus ciliaris*), will become an important management strategy under climate change in order to decrease the potential for extensive wildfire and protect habitat for wildlife. However, climate change is expected to shift fire season length in the region, and shorten the time suitable for prescribed burns. There may also be complex effects on fuel loads - on the one hand, elevated CO_2 may enhance vegetation production and increase fuel loads, but on the other, drought may decrease long-term vegetation production (thereby decreasing fuel loads) and may decrease fuel moisture (thereby increasing potential rates of spread) (Williams *et al*. 2009).

Prescribed burns may also be critical in controlling the spread of woody plants into grasslands in the region (Witt *et al*. 2009). Woody thickening is a considerable problem in the region and has been observed most consistently in northern Australia. However, there is the potential for perverse outcomes associated with altered burning regimes which focus on reducing emissions, for example, in Far North Queensland, invasion of grasslands by paperbark is related to repeated early dry season burns and subsequent overgrazing (Witt *et al*. 2009). This highlights the current lack of integrated fire management regimes in the region.

For some terrestrial species, an increase in woody vegetation may provide more habitat, but other species rely on an open habitat and shade intolerant plants and native grasses could be threatened or outcompeted by encroaching shrubs and trees. Some species are directly threatened by woody thickening - the endangered golden shouldered parrot, endemic to Cape York Peninsula, is impacted through increased predation risk and impacts of thickening on seasonal food availability (Crowley *et al*. 2004). Prescribed burning is considered the best method to stall thickening, although the timing of the burn is vitally important - in the north, late dry season burns and storm-season burning favour the maintenance of grassland, while burns at other times favour the encroaching tree-line.

Fire management strategies will need to be adapted for different habitats and woodland types, and take into account faunal species within communities and previous seasons for fire management.

While there is great potential to use fire as an adaptation tool to manage some of the impacts of climate change on biodiversity, caution should be taken and the capability of different species and ecosystems to withstand fire must be considered in different regions. For example, while some plant species are well adapted to fire, others can be vulnerable to frequent fire events. Surveys following repeat fires suggest that most rainforest plants can survive high fire frequency and vegetatively resprout following fire (Williams *et al*. 2006b). However, some rainforest and sclerophyll plants are killed by high frequency fire, such as the rare, restricted shrub *Banksia plagiocarpa* (Williams *et al*. 2005b). Furthermore, burns too early in the season may not maintain an open structure, while very hot fires may kill seeds outright, especially of fire-sensitive species. For other species, fire could stimulate germination rates, though this can be detrimental when the interval between fires is too short and the regenerated plants are burnt before they fruit and restore the soil seed bank. Timing of burn has also been shown to influence native fauna, with wet season and dry season burns in the tropics favouring different assemblages in the time following the burn (Valentine *et al*. 2007).

In summary, the impacts of climate change on fire regimes in the WTC Region are complex and so developing adaptation management strategies to reduce risk to biodiversity and maintain ecological integrity will be challenging. Management decisions should reflect the fact that fire regimes will be influenced by other factors, such as exotic species and land-use change, which may affect fuel loads. Appropriate management actions for biodiversity will differ among regions, but may include regimes that aim specifically to manage fuel accumulation and flammable invasive grasses, such as prescribed burning, or planting fire retardant vegetation. The life history and other attributes of focal species should be taken into account, and diverse fire regimes should be applied to encourage habitat and species diversity.

Connectivity for movement and migration

Coastal and marine communities

Climate change is driving a southward migration of tropical marine communities (Beger *et al*. 2014) and, where undeveloped space is available, a landward migration of coastal communities such as mangroves and dunes (Saintilan *et al*. 2014). Some communities may replace others; for instance, mangroves have been replacing salt marshes, especially at their poleward limits (Saintilan *et al*. 2014). Traditionally, marine conservation planning has addressed climate change or connectivity, but not both (Magris *et al*. 2014).

Adaptation efforts will need to be geared towards maintaining connectivity for assemblages to expand into new areas; impact minimisation or mitigation will need to target not just existing communities, but areas to the south (for tropical marine communities) and west (coastal communities).

Mangroves, with their pioneer-species characteristics, have the ability to rapidly colonise new areas as these areas become suitable (Alongi 2008; Soares 2009); barriers to this movement will be the dense and rising coastal development taking place along the WTC Region coastline (Eslami-Andargoli *et al*. 2013). Similarly, coastal wetlands can adapt by maintaining their elevation relative to sea level, given the opportunity for the maintenance of sediment deposition rates and, where possible, active management of water flows (Rogers *et al*. 2014; Saintilan and Rogers 2013). Helping these coastal ecosystems to persist (and therefore migrate) will require the availability of space into which they can migrate (Gilman *et al*. 2008; Soares 2009) - recently termed “managed retreat” (Saintilan and Rogers 2013) - and adequate migration corridors (Williams *et al*. 2005a). This will require integration between climate change adaptation management and urban planning, and may result in “more compact urban forms that may lead to reductions in the cost of defence against sea level rise, reduce energy usage per person and provide more green space” (Burley *et al*. 2012).

Modelling can predict where, when and how severe coastal erosion and sea level rise might be (Nicholls and Tol 2006). Rehabilitation of coastal communities in areas that have become eroded due to sea level rise and increasingly intense tidal and storm surges is becoming more urgent, but can be expensive, and is not always a priority. Bell and Lovelock (2013) propose a scheme in which the coastal protection function provided by mangroves could be insured, and provide recommendations to policy-makers and the insurance industry. Given the similar function performed by most types of coastal vegetation, this concept could easily be extended to maintain or rehabilitate all coastal community types. Whilst “hard” adaptation options were most common in the past, “soft” options are increasingly considered (Hallegatte 2009) (Table 2.4).

Table 2.4 Hard and soft adaptation options highlighted by Burley et al. (2012), modified with information from Gilman et al. (2008)

	HARD	SOFT
Anticipatory	**Planning stage**	
	High resolution mapping of lands and the distribution of land use	Have risk-appropriate insurance policies
	Select locations for wetland migration inland to increase the probability of maintaining wetlands of sufficient size and diversity to achieve the objectives (maintenance of ecosystem services and biodiversity)	Have planning regulations to restrict the use of land in high-risk area for infrastructure, encouraging alternative uses (wetlands)
	Increase the density of the urban footprint (increase room for wetlands and decreasing costs associated with defence)	Have an institutionalised long-term planning horizon to anticipate responses & awareness of climate change effects on wetland distribution
		Planning regulations specifying optimal land use and greenhouse gas capture, that is, the amount of wetlands to be maintained, the amount of catchment sediment and nutrient loads
		Develop regional and town plans that take into account a changing climate
	Design and construction stage	
	Design landscapes to accommodate landward wetland migration	Financial incentives for the development of 'soft' engineering options for coastal protection
	Limit defence against sea level rise to high value infrastructure.	Financial incentives for retreat from high-risk property in order to increase size and connectivity of wetlands
	Redesign roads and other structures to accommodate wetland connectivity	Incentive payments for increased carbon sequestration
	Use 'soft' engineering approaches to sea level rise (beach or wetland nourishment)	
	Change land-use patterns in new developments to accommodate coastal wetlands at appropriate elevations relative to sea level (Andrey and Mills 2004)	
	Manage rate and location of groundwater extraction	
	Operating and maintenance stage	
	Weed and feral animal control	Financial incentives for better maintenance and operating practices
	Monitoring and management	Establish legal limits for tolerance of weeds, ferals, mosquito
	Improve access for the community (tracks, boardwalks, bird-hides, fishing)	Market-based incentives (increased housing prices with access to green space)

	HARD	SOFT
Reactive	**Maintenance and operating stage**	
	Nourish wetlands, mangroves and saltmarshes with sediment to allow wetland accretion to keep pace with sea level rise	Increase protection of vulnerable and endangered species (e.g. strengthen fisheries penalties, enforce protected area compliance). Eliminate non-climate stresses to augment overall ecosystem health
	Create artificial environments for the maintenance of species populations (e.g. production of juveniles, sturgeon)	Increase regulation of pollution (increase standards)
	Increase waste water treatment capacity	Emergency management plans, evacuation and climate advisories to reduce risk during storms
	Build walls, groynes, revetments, bulkheads for protection from storm surges and erosion	Incentives for mitigation projects
	Rehabilitation, reafforestation	Creation of information databases regarding climate impacts & effectiveness of adaptation strategies—learning by doing approach
	Production of flooding intensity maps for flooding relief	Monitoring programs and education of the public

Terrestrial biodiversity and landscape connectivity

Increasing landscape connectivity is important for addressing conservation issues resulting from habitat fragmentation, and also for enabling shifts in species' distributions in response to climate change.

Large areas of good quality habitat are the cornerstone of biological conservation and will be critical to the ability of species to adapt to consequences of climate change (Hodgson *et al*. 2011; Hodgson *et al*. 2009; Travis 2003). However, climate change will alter the distribution and extent of suitable climate space for Australian terrestrial animals (Reside *et al*. 2013) and plants (Hilbert and Fletcher 2012). Thus, connectivity between areas that lose and those that gain suitable climate space will be necessary to facilitate species' biogeographical range shifts. In the WTC Region for example, easterly shifts in suitable climate space into the Mackay-Whitsunday-Isaac and Wet Tropics areas are predicted for a large number of species from western parts of the region (Reside *et al*. 2013).

Connectivity is a landscape property that emerges from the interaction between attributes of the landscape and of plant and animal species. Connectivity relates to the amount, quality and spatial arrangement of habitat in a landscape and how this either enables or presents barriers to the movement of plants and animals. There has been a shift in emphasis from physical connectivity (i.e., structural features that are perceived by humans as being connected) to functional connectivity (i.e., whether or not a given species can actually move through a given landscape), where even habitats that appear to be physically unconnected may be functionally connected or conversely where habitats that appear to be physically connected may be functionally unconnected.

Habitat clearing and fragmentation have created barriers to movement for most taxa, and biodiversity conservation strategies typically include increased landscape connectivity as an important objective. Adaptation of terrestrial biodiversity to climate change will also require strategies that surmount barriers to movement, although the spatial scales involved are likely to be large and the time frame short.

Increasing connectivity has an important limitation as a strategy for adaptation to climate change in that suitable climate space is projected to disappear from the region for a range of species, such as endemic upland taxa in the Wet Tropics bioregion (Williams *et al*. 2003) and species dependent on coastal freshwater aquifers. Increasing landscape connectivity will contribute neither to the ability of these species to persist nor their adaptive capacity under climate change. While translocation to geographically distant areas with suitable climate space could potentially avoid species' extinction, it would likely only ever be an option for a small subset of species, would not preserve ecosystems, and may have negative impacts in recipient systems.

The amount of good quality habitat in a landscape is positively related to degree of connectivity. Linear features may also be important, especially at smaller spatial scales.

The degree of connectivity of a landscape is closely related to the amount and distribution of good quality habitat available (Hodgson *et al*. 2011; Hodgson *et al*. 2009). Simply increasing the amount of habitat in a landscape can increase connectivity for some species. For example, Doerr *et al*. (2013) modelled a range of plausible future landscapes for parts of northern New South Wales and determined that, in respect to connectivity, "Even random placement of new areas of native vegetation achieved similar outcomes for biodiversity on average as principles based on careful spatial planning". However, the importance of spatial arrangement of habitat increases dramatically as the level of landscape habitat cover decreases, so that where habitat cover falls below 30%, the spatial arrangement of any additional habitat has a strong effect on its contribution to connectivity. In a well-vegetated landscape, any addition of habitat is more likely to be near to (and functionally connected with) other habitat areas.

While strategies for improving connectivity now include generally increasing levels of good quality habitat cover in the landscape, continuous linear features may be important for increasing connectivity for some organisms, especially those that cannot traverse cleared and modified land. Continuous strips of vegetation are most typically located along watercourses, and these areas are commonly targeted for protection and restoration as movement corridors. Riparian areas are thought to be used for navigation through the landscape by mobile species such as flying foxes, are known to support high numbers of species and to provide critical habitat for a range of flora and fauna, especially in lower rainfall regions. Riparian areas also provide refuge during hot days, which are predicted to become more frequent throughout the Wet Tropics cluster. Furthermore, protection and restoration of riparian areas have potential co-benefits for the conservation of aquatic systems and water quality improvement. Importantly, fringing riparian vegetation can often be maintained or restored without the loss of substantial areas of productive land and so represents a relatively palatable option for land managers. However, because adjacent floodplain areas are highly productive, riparian vegetation is typically narrow, surrounded by cultivation or grazing. While riparian strips provide habitat for a large range of animals and plants, it has been suggested that corridors that are at least 300-500 m wide are needed to promote connectivity at regional scales (DECC NSW 2007). This would likely require legislative support given current patterns of land use. Importantly, riparian corridor networks will not improve connectivity for flora and fauna that are associated with non-riparian ecosystems, nor will they facilitate movement between riparian and non-riparian habitats. In order to understand the trade-offs of focussing conservation actions in riparian areas it would be useful to identify the species associated with riparian and non-riparian habitats, accounting for seasonal movements, together with their ability to move through cleared and modified landscapes.

The contribution of linear connectivity features to surmounting barriers to movement is easier to conceive at smaller spatial scales. For example, movement of rainforest arboreal mammals is deterred by breaks in forest canopies caused by transport, energy and water supply infrastructure (Goosem 2004). Rope bridges can transcend this barrier effect across small (ca. 15 m) gaps, although the effectiveness of these structures across larger gaps is uncertain (Goosem 2004). Road underpasses can improve connectivity, especially where they incorporate surrounding habitat restoration and elements of habitat structure (e.g., logs, rocks) (Goosem 2004). Other actions that improve connectivity across transport infrastructure include the use of roadside reflectors (e.g., successful in reducing roadkill in Proserpine rock wallaby *Petrogale persephone*; Johnson *et al*. 1993), elevated bridges that maintain canopy continuity, and swinging powerlines well above intact canopies. Although many of these measures can be expensive, improving functional connectivity across transport infrastructure is likely to strongly influence the adaptive potential of many species.

Many current projects are based on increasing connectivity at different spatial scales

Species' adaptation to climatic changes will in some cases require very large-scale distributional shifts along broad ecological gradients. This has prompted continental-scale connectivity initiatives such as the Great Eastern Ranges ('Alps to Atherton') project which aims to improve connectivity among habitats along the Great Dividing Range between southern Victoria and the Atherton Tablelands (Mackey *et al*. 2010). Challenges include identifying critical barriers to movement from present to predicted areas of suitable habitat, as well as facilitating such large geographical shifts over short time scales.

In the Terrain NRM region, the Wet Tropics Management Authority (WTMA) has implemented a "Making connections" project centred around high elevation rainforest areas of Atherton Tablelands, which are considered to be areas of potential refuge from climate change for cool upland endemic species, many of which have limited ability to move across cleared areas. The WTMA is in the process of updating their Connectivity Strategy, prioritising areas on the basis of protecting conservation values of the Wet Tropics World Heritage Area (WHA) specifically. Other areas of the landscape will be important for connectivity in current and future climates and across NRM regional boundaries.

Cleared and modified parts of the landscape may contribute to functional connectivity.

The functional connectivity or "permeability" of landscapes differs among species due to variation in dispersal and life history characteristics. A barrier to one organism may enhance connectivity for another (Manning *et al*. 2010).

It is understood that cleared and modified parts of the landscape (which would not necessarily be considered as habitat) may contribute to functional connectivity. For example, regrowth, including areas dominated by introduced weed species (e.g. *Cinnamomum camphora* camphor laurel) potentially contributes to functional connectivity for both animals and plants (i.e., regeneration opportunities) (Kanowski *et al*. 2003).

Urban and agricultural development can be major obstacles to landscape connectivity for many organisms. In the WTC region, urbanisation is concentrated in lowland coastal areas, especially in the Terrain and Reef Catchments NRM regions. Adaptation to climate change by certain plants and animals in coastal areas will be prevented by a lack of functional connectivity to westward areas (refer to previous section. This is likely to be especially significant for coastline species that will increasingly experience impacts of sea level rise and seawater inundation in the short term. Suggestions for improving connectivity in urbanised areas are typically based around parkland, open areas and street trees (e.g. Manning *et al*. 2010), although other strategies are being tested, such as 'green rooftops' (Braaker *et al*. in press).

One of the risks of increasing connectivity is assisting dispersal of problem species or disease.

One of the risks of increasing connectivity for target species is that it may inadvertently increase connectivity for problem taxa, fire and disease (see also Invasives section). For example, Doerr *et al*. (2013) report an increase in the spread of an introduced species (peppercorn *Schinus molle*) in model landscapes that included planting intended to improve connectivity. However, it is generally considered that the benefits of increasing connectivity outweigh the risks, especially in the context of climate change.

Connectivity can be improved by integrated farm management that includes protection of remnant habitat isolated trees and areas of regrowth, managing dams and modifying fence design.

There is a multitude of examples of integrated farm management actions that increase the connectivity of farmed landscapes for native plants and animals. Increasing habitat area is a primary strategy, achieved by protecting patches of remnant habitat, isolated trees, dams and areas of regrowth vegetation. Removing or reducing barriers to the movement of organisms across properties may also improve connectivity. This may include actions such as reducing the height of fences to allow passage by animals such as kangaroos, and replacing barbed wire with plain to avoid snagging bats and gliders.

Restoration, including biodiverse carbon plantings, may be able to increase connectivity in the landscape.

It is critical that restoration plantings do not replace existing habitat because plantings are likely to take many decades to attain habitat values similar to that of mature systems. Plantations *per se* will not necessarily increase habitat relative to pasture or agricultural land, especially if they comprise few species or low structural diversity. In contrast, biodiverse plantings have the potential to increase the amount of habitat available, even to species with fairly specialised habitat affiliations (Kanowski *et al*. 2005; Kanowski *et al*. 2003), and thus ahs the potential to increase overall landscape connectivity for these organisms (See restoration section).

Invasive species

The WTC Region is likely to remain suitable for many weeds and some, such as rubber vine, are predicted to increase under climate change (Hilbert *et al*. 2014). Climate change will also create new opportunities for invasive species to recruit, spread and increase in abundance, particularly following disturbance from extreme events such as cyclones and extreme rainfall (Hilbert *et al*. 2014). Invasive grasses, including gamba grass and mission grass in the monsoonal zone, and buffel grass (*Pennisetum ciliare*) in sub-humid areas are also likely to increase fuel load and foster larger, hotter fires (Fensham 2012; Hilbert *et al*. 2014).

Existing invasive species threats should be controlled in order to increase the capacity of native biodiversity to adapt to climate change, and adaptation responses to climate change should not create new, or exacerbate existing, invasive species problems.

Developing suitable adaptation actions to control invasive species under a changing climate will require planning at the species, local and regional levels. For example, weed control and habitat restoration should be ongoing actions in priority areas of the WTC Region, including areas identified as climate refugia for native biodiversity. This is because these areas are also likely to be exploited by invasive species (Low 2011), and could potentially allow pest species to persist then disperse when conditions improve. Efforts to create conservation corridors to help native species adapt to climate change may similarly promote the spread and dispersal of invasives unless they are effectively managed in these locations (Hellmann *et al*. 2008) (see also Refugia and Connectivity sections).

The Invasive Species Council (2011) advises that research and control efforts should be directed toward species predicted to exert the highest threats to biodiversity under climate change, such as *Phytophthora cinnamomi* and the flammable invasive pasture grasses. In general, invasive species management under predicted climate scenarios will require a more adaptive and strategic response, and will need to be supported by flexible investment strategies which enable timely responses at critical periods – for example following extreme events (Reardon-Smith *et al*. 2012). Tightening of quarantine and biosecurity measures, and education of landowners about introduced species and their impacts should also continue to be priority adaptation measures. Managers and land-owners should be urged to make use of weed risk-assessment tools freely available, such as http://weedfutures.net, which is a decision support tool enabling land managers to make informed decisions about the management of naturalised, but not yet invasive plants at a regional level (Hughes *et al*. 2013).

Reardon-Smith *et al*. (2012) outline a number of priorities to consider when considering climate change adaptation measures for invasive species, including:

- *Early Intervention* – under rapidly changing conditions, control efforts for invasive species are most likely to be successful when implemented at an early stage in the invasion process (Park 2004).
- *Utilise predictive modelling tools*, such as Bayesian Belief Systems – under uncertain outcomes, models can be used to 'test' the outcomes of alternative management approaches prior to their implementation (Liedloff and Smith 2010), thereby facilitating cost-effective on-ground invasive species management.
- *Seasonal climate forecasting* – climate forecasting models which can incorporate both invasion and climate change biology with seasonal ENSO forecasts could allow the prediction of outcomes of different management actions, and provide an analysis of the level of risk (or uncertainty) associated with these in different years/seasons. This could provide the capability to adapt invasive species management to changing environmental conditions (Hellmann *et al*. 2008).

Managing reproductive capacity in vegetation communities

Adaptation management actions will require a holistic approach, with the most cost-effective actions occurring for species in-situ. Ex-situ actions, for the most threatened species, may include seedbanking, genetic supplementation or assisted colonisation/dispersal.

The impacts of climate change on the reproductive success of most WTC Region plants is not well known, but growing season, flowering, germination and seeding success are likely to be affected (Low 2011). Obligate seeders, such as the restricted *Banksia plagiocarpa* from the Cardwell area will likely be particularly at risk (Williams *et al*. 2005).

Like other groups of species, adaptation management to maintain reproductive integrity in plant communities will require a holistic and fluid approach. The most cost effective actions will be in-situ, although ex-situ actions may be required for the most threatened species (Table 2.5).

Table 2.5 Potential adaptation management strategies for plant reproduction

	POTENTIAL ADAPTATION ACTIONS
Immediate Actions	• Control and eradication of introduced weed and grazing species • Halt to land disturbance and loss, maintaining canopy cover and favourable microclimates • Managing risks of adverse fire regimes • Land management and purchase • Water management • Baseline species and community studies of ecology and adaptive capacity • Risk-assessments of potentially at-risk species
Ongoing Actions	• Seedbanking • Assisted genetic flow in isolated populations • Assisted migration/dispersal • Species management
Future Actions	Assisted migration/dispersal

The risks and benefits of adaptations should be taken into account, particularly with actions such as assisted gene flow. Seed-based risk assessment could be an option for some species from the WTC Region.

Actions such as seedbanking, assisted migration and assisted genetic flow should, on the whole, be less expensive than comparable actions in faunal groups. Risks and benefits should be assessed, for example using the risk-assessment framework provided in Weeks *et al*. (2011). Aitken & Whitlock (2013) further stress that in order to weigh the risks of assisted genetic flow against those associated with maladaptation from climate change, it is imperative to know the species' extent of local adaptation to climate and other environmental factors, as well as pattern of gene flow. Thus baseline surveys and research into the ecology and genetics of key species will be priority ongoing actions. Cochrane *et al*. (2011) developed a seed-based risk assessment approach for Western Australian species under climate change, which could be adapted as a management tool to assess potentially at risk species in the region. They used a two-way temperature gradient plate to profile the germination of more than 45 species across fluctuating and constant temperatures ranging from 5°C to 40°C. Species which germinated within a narrow temperature niche were predicted to be susceptible to climate warming.

Fire could be used as a management tool to promote seed germination in species adapted to a fire-prone landscape and with a 'sprouting' life-history strategy, but timing and frequency of burning should be considered on a case-by-case basis.

Fire could potentially be used as a management tool to promote seed germination in some species and communities adapted to fire, which employ a 'sprouting' strategy following fire. However fire intervals are critical – in a study in the eucalypt forests between Townsville and Cardwell fire was found to promote seed germination and species richness, but intervals of more than eight years were required to allow for the maturation of shrubs (Williams *et al*. 2006b). However, there is the risk that longer fire intervals may lead to woody thickening in some areas – fire interval should be considered on a case-by-case basis.

Finally, when plant reproduction shifts in season, or failures occur, there are associated risks to nectivorous, frugivorous and granivorous fauna, and potentially a feedback effect on seed dispersal (Van der Putten *et al*. 2010). Management actions could include ensuring a diversity of species to ensure different flowering times and pollen supply, and landscape connectivity to ensure access to flowering or fruiting plants (Murphy *et al*. 2012). More specific targeted interventions to restore disrupted species interactions, including plant-pollinator or plant-herbivore relations, may also be required (Dawson *et al*. 2011).

Adaptation for important species and communities

Whilst broader climate change impacts need to be managed at national and global scales, it is widely recognised that assisting species and ecosystem in their adaptation to a changing climate needs to include strategies to enhance their persistence at local and regional scales. Therefore, management of local stressors is seen as equally valuable, especially because the results of such actions tend to be much more readily measurable, and tend to yield results over shorter timeframes (Ghedini *et al*. 2013). Priority species and communities for the WTC region include marine turtles, dugongs and coral reefs. This region also has the highest diversity of birds and flying foxes in Australia, so these are also covered in some detail.

Turtles

Adaptation options for marine turtles are mainly consistent with a reduction in other more immediate impacts.

Marine turtles are expected to be affected by different aspects of climate change depending on the stage in their life cycle. Nesting beaches are affected by rising sea levels and resulting erosion, and changes in temperature. Coastal feeding grounds such as seagrass beds and coral reefs are affected by rising SSTs and changing run-off and turbidity patterns from the land (larger and more frequent floods, storm events). Migration pathways may also be affected by changes in ocean temperature and circulation. While these changes are difficult to control, adaptation can be encouraged by reducing other, more immediate anthropogenic impacts: destruction of nesting habitat and predation of nests, disorientation of hatchlings by artificial lighting, degradation of nearshore marine habitats (especially seagrass beds and coral reefs), declining water quality, boat strike, incidental catch by commercial fisheries and traditional harvesting.

Protecting nesting beaches is the most cost-effective strategy of increasing turtle populations.

Protecting nesting beaches is the most cost-effective method of achieving increases in leatherback populations (Gjertsen *et al*. 2014); this is likely to be the case for other turtle species. Protection of turtles at the nesting stage can include banning beach access to vehicles, general beach closure, the enclosing or direct protection of nests (e.g. with mesh), controlling turtle egg predators (Whytlaw *et al*. 2013), or even surface treatment with habanero pepper powder to deter predators (Lamarre-DeJesus and Griffin 2013). Where beaches are being eroded by sea-level rise or changes in sand deposition patterns from coastal development, other adaptation options may be necessary, such as hard engineering structures or soft measures (see below; Fuentes *et al*. 2010b). Identifying nesting beaches that will either remain or become suitable for turtles in the future will determine where nesting site conservation efforts could be directed in the coming years. Such assessments and predictions could include temperature shifts (as hatchling production may decline for turtle nests in lower latitudes with rising temperatures (Pike 2014; Read *et al*. 2012)) and exposure to changing weather patterns and storm activity. The Relative Exposure Index, which characterises nesting beaches based on the degree of exposure to wind and waves, may be a useful tool in determining which beaches, beyond the ones already commonly used by nesting turtles, would provide suitable nesting sites. A recent analysis showed that turtles tend to nest on high exposure beaches along the mainland Queensland coast (Garcon *et al*. 2010). Some models predict that current turtle nesting beaches along the Queensland coast will be less affected by cyclones, possibly due to past natural selection pressure to nest on beaches less likely to suffer cyclonic conditions (Fuentes and Abbs 2010). Assessments of future range shifts in nesting beaches should take into account predictions of changes in cyclone activity (Fuentes *et al*. 2011); the restructuring of beaches during cyclones may be beneficial to hatching success on beaches with high nest density by removing accumulated nesting debris (Dewald and Pike 2014; Honarvar *et al*. 2011).

A number of options exist to safeguard the most important nesting beaches from beach loss and inundation, effectively providing a buffer zone. Adaptation options will need to be tailored to individual beaches and the particular threats they face.

A number of options exist to safeguard the most important nesting beaches from beach loss and inundation, including the construction of sea walls or groynes, beach nourishment, dune building, nest shading or setback regulations that prohibit construction within a set distance from the beach, effectively providing a buffer zone (Fish *et al*. 2008; Nicholls and Tol 2006; Wood *et al*. 2014). Moving nests, for instance away from light sources, high-use areas or areas of inundation and erosion, is also possible, and may be increasingly important in the future to safeguard endangered turtle populations (Pfaller *et al*. 2008). However, it is labour-intensive and requires relocation within two hours of oviposition to ensure maximum survival of moved egg clutches (Berry *et al*. 2013).

High sand temperatures can dramatically reduce hatchling success by increasing mortality of embryos (Wood *et al*. 2014). Furthermore, the sex ratio of embryonic marine turtles is determined by nest temperature (cooler nests tend to produce males, and warmer nests females), and climate change is likely to affect these ratios. Chronically biased sex ratios can eventually lead to population collapse (Pike 2014). Hatchling success is also affected by coastal development, especially in areas with bright lighting at night. Various solutions exist for this, including changes to the timing of lighting, the use of low-pressure sodium-vapour lights (which have proven less disruptive to at least loggerheads), reducing the number of lights, building light-barriers, and educating nearby residents (Berry *et al*. 2013).

Maintaining connectivity to suitable nesting habitat near existing nesting beaches, especially inland, will make a considerable difference to the capacity for nesting turtles to adapt to sea level rise.

Modelling studies exist that have explored different sea level rise scenarios in relation to known turtle nesting beaches (Daniels *et al*. 1993; Fish *et al*. 2005; Fuentes *et al*. 2010b; Katselidis *et al*. 2014). Katselidis *et al*. (2014) identified areas of beach currently used by turtles, the area anticipated to become inundated under each of three sea level rise scenarios, the area anticipated to become unsuitable for nesting under each scenario, the potential for habitat loss under each scenario, and the extent to which the beaches were likely to shift in relation to natural (i.e. cliffs) and artificial (i.e. beach front development) physical barriers. Similarly to other studies, they found considerable nesting habitat loss (31-48%) even under the most conservative scenario, but losses were much more pronounced when there were barriers. Maintaining connectivity to suitable nesting habitat near existing nesting beaches, especially inland, will make a considerable difference to the capacity for nesting turtles to adapt to sea level rise. In Australia, a similar study on islands of the far northern GBR concluded that up to 38% of green turtle rookeries could be inundated (Fuentes *et al*. 2010b).

The identification and protection of feeding grounds will also provide an important buffer to changing climate conditions.

Turtles in the coastal waters of the WTC Region feed primarily on seagrass beds and coral reefs. Both are under increasing pressure from a number of human impacts. Locating, protecting and enhancing turtle feeding habitats can ensure that adult turtles in coastal waters are able to persist. Seagrass and coral reef adaptation options are described in the following sections (Dugongs and Coral reefs).

Reductions in direct mortality from boat strike, fisheries by-catch, plastic debris and disease must be controlled, and stranded turtle rehabilitation need to continue.

Reductions in fisheries by-catch have already take place in Australian coastal fisheries, mainly through the implementation of turtle excluder devices (or TEDs)(Brewer *et al*. 2006). Identifying the intersections between foraging habitat and migration pathways and commercial fisheries can further help managers target these areas for conservation actions (Griffin *et al*. 2013). Ghost nets also continue to cause significant mortality in turtle populations in the Torres Strait and off Cape York; ongoing research seeks to understand and mitigate this impact (Wilcox *et al*. 2012). In areas where traditional sea turtle hunting continues, it is crucial that modern and traditional styles of management be interwoven to find a balance between resource management and conservation (Butler *et al*. 2012). Ongoing active rehabilitation of stranded and injured turtles should continue, especially the quest to discover the causes and sources of disease (Flint *et al*. 2010) and the reduction of plastic debris available for ingestion (Schuyler *et al*. 2013).

Dugongs

Protecting dugong feeding habitat and reducing direct anthropogenic mortality should be the priorities of any adaptation program.

The primary issues facing dugong populations are incidental catch, subsistence use, habitat destruction, and impacts of oceanic pollution (Gillespie 2005). On the GBR, the threats that most urgently require management are commercial netting and indigenous hunting, and vessel traffic, terrestrial runoff and commercial netting in more urbanised areas (Grech and Marsh 2008). Seagrass beds, the primary food source of dugongs, are being lost globally and in Australian coastal waters (Waycott *et al*. 2009).

As with marine turtles, protecting dugong habitat should be one of the priorities of any adaptation program with climate change in mind. The re-zoning of the Great Barrier Reef Marine Park in 2004 included the consideration of dugong habitat, but fell short of protecting 50% of high priority dugong habitat as recommended in the design guidelines (Dobbs *et al*. 2008). Consideration should be given to the fact that high priority dugong habitat identified then may have disappeared or moved; mapping current habitats and tracking their future movement will indicate where changes in protection might be required. Predictive modelling has been used to map known and likely seagrass habitats (Grech and Coles 2010), this could be expanded to indicate the likely future extent of seagrass beds. Seagrass is highly responsive to water quality (Grech *et al*. 2011), potentially exacerbating periodic seagrass dieback and adversely affecting reproduction and survival of dugongs (Marsh and Kwan 2008). Water quality must be improved if the inshore areas of the GBRMP are to provide suitable habitat for resilient ecological communities into the future (see also Coral reef section). Some water quality thresholds from the inshore GBR include:

- Mean daily irradiance > 5 mol m^{-2} d^{-1} was associated with gains in seagrass; 16–18% of days below 3 mol m^{-2} d^{-1} was associated with more than 50% seagrass loss (Collier *et al*. 2012).
- Four hours of light saturated irradiance was associated with increases in seagrass abundance, and less than 4 hours of light saturated irradiance with more than 50% loss (Collier *et al*. 2012).

Dugong mortality can be minimised through fishing closures, gear modification and boating restrictions.

Minimising direct mortality should also continue to be a priority, including fishing closures, gear modification (Hodgson *et al*. 2008), and boating restrictions. Commercial netting has been one of the most significant sources of dugong mortality on the GBR, but the rezoning of the GBRMP significantly reduced this threat (Grech *et al*. 2008). Gear modification of coastal fisheries with TEDs and by-catch reduction devices have further reduced direct mortality (Brewer *et al*. 2006). Minimising boat strike mortality must include speed or even access restriction of boats in critical dugong habitat, coupled with better knowledge of dugong movements (Whiting 2008). The management of traditional dugong hunting is a complex cultural, social, economic and environmental issue that continues to receive considerable attention (Kwan *et al*. 2006).

Coral reefs

Creating protected areas achieves rehabilitation of coral reef systems.

On coral reefs, local management actions are often focused on the reduction of immediate human pressures (Graham *et al*. 2013), such as by creating protected areas or reserves, with the hope that these will support the recovery of intact food webs, and therefore support the resilience of the community to the more global effects of climate change (Hughes *et al*. 2010; McClanahan *et al*. 2011; Pandolfi *et al*. 2011). This has proven to be successful in places where fisheries target a wide variety of prey including herbivores; once herbivores are protected, they reduce algal biomass and support the dominance of corals. On the GBR, herbivores are not targeted by fisheries; no-take areas generally result in the recovery of large piscivores such as coral trout and sharks. The most important factor in ensuring that marine reserves adequately protect the ecosystems within them is ensuring compliance (Pollnac *et al*. 2010). Building adaptive capacity to climate change into the design of marine reserve networks will require careful planning around size, shape, representation, connectivity and ecosystem-based management (Table 2.6) (McLeod *et al*. 2009).

In addition to recommendations following McLeod *et al*. (2009), a recent study outlines a framework to incorporate both climate change and connectivity into conservation planning (Magris *et al*. 2014). The following set of complementary approaches is described which relate to marine reserves:

1. stating preferences for spatial configuration of marine reserves and their placement relative to critical areas in the seascape
2. applying generic ‘rules of thumb’ for size and spacing of marine reserves
3. tailoring replication and representation objectives to the requirements of specific conservation features
4. using ecological insights to guide rules for spatial relationships among features in decision support tools
5. defining objectives for structural or functional surrogates
6. predicting and targeting functional surrogates based on analysis of dynamics (Magris *et al*. 2014).

Table 2.6 Recommendations for marine reserve design to maximise adaptation to climate change.

CATEGORY	RECOMMENDATIONS
Size	Bigger is better - MPAs should be a minimum of 10-20 km in diameter to be large enough to protect the full range of marine habitat types and the ecological processes on which they depend, and to accommodate self-seeding by short distance dispersers.
Shape	Simple shapes should be used, such as squares or rectangles, rather than elongated or convoluted ones, to minimise edge effects while maximising interior protected area.
Risk spreading (representation, replication and spread)	Representation: protect at least 20-30% of each habitat type. Replication: protect at least three examples of each marine habitat type. Spread: ensure that replicates are spread out to reduce the chances they will all be affected by the same disturbance event. Select MPAs in a variety of temperature regimes using historical sea-surface temperatures and climate projections to ameliorate the risk of reefs in certain areas succumbing to thermal stress caused by climate change.
Critical areas	Protect critical areas that are biologically or ecologically important, such as nursery grounds, spawning aggregations, and areas of high species diversity. Protect critical areas that are most likely to survive the threat of climate change (e.g. areas that are naturally more resilient to coral bleaching).These may include areas cooled by local up welling, areas shaded by high, steep-sided islands or suspended sediments and organic material in the water column, reef flats where corals are adapted to stress, and areas with large herbivore populations that graze back algae and maintain suitable substrates for coral larvae to settle on.
Connectivity	Take biological patterns of connectivity into account to ensure MPA networks are mutually replenishing, to facilitate recovery after disturbance. MPAs should be spaced a maximum distance of 15-20 km apart to allow for replenishment via larval dispersal. Accommodate adult movement of mobile species by including whole ecological units (e.g. offshore reef systems) and a buffer around the core area of interest. Where this is not possible (e.g. coastal fringing reefs), protect larger versus smaller areas. Take connectivity among habitat types into account by protecting adjacent areas of coral reefs, seagrass beds, and mangroves. Model future connectivity patterns to identify potential new coral reef substrates, so that measures can be taken to protect these areas now, and accommodate expansion of coral distribution to higher latitudes.
Maintain ecosystem function	Maintain healthy populations of key functional groups, particularly herbivorous fishes that feed on algae, facilitating coral recruitment and preventing coral-algal phase shifts following disturbances.
Ecosystem-based management	Embed MPAs in broader management frameworks that address other threats external to their boundaries (e.g. integrated coastal zone management or an ecosystem approach to fishing). Address sources of pollution (especially enrichment of water), which create conditions that favour algal growth and prevent coral larvae from settling. Monitor changes in precipitation caused by climate change that may increase runoff and smother reefs and seagrass beds with sediment

Source: McLeod *et al*. (2009).

The benefits of restoring coral reefs currently outweigh the costs, except at very localised scales, but opportunities for improving restoration options should be considered, as this may be increasingly necessary in the future.

While marine reserves continue to be the most common marine conservation tool, some scientists call for a wider range of approaches, including unconventional options (Table 2.7) (Rau *et al*. 2012). More direct local actions may involve active restoration through the transplantation of corals (especially more heat-tolerant species, populations or symbiont clades) to heavily degraded sites. In the context of climate change, active coral reef restoration remains hotly debated (Bellard *et al*. 2012; Briggs 2009). Generally, active restoration has been possible only at very small scales, and only with a limited range of coral species (Omori 2011). Only recently has coral "gardening" been advocated and trialled on a larger scale (Rinkevich 2008); in a recent study 10,000 planulae of the brooding coral *Stylophora pistillata* were reared to 5-month-old colonies - essentially genotypes of equal size to small branch fragments - requiring 676 person-hours (Linden and Rinkevich 2011). Critics argue that the cost outweighs the benefits due to the uncertainty of survival and establishment of transplanted populations at a new location, and the effects of relocated species on local populations may be detrimental. However, in some cases relocation (or "assisted colonisation") may be the only way for keystone species to overcome dispersal or migration barriers (Hoegh-Guldberg *et al*. 2008). The actual goal of restoration (enhancing coral cover or diversity, maintenance of heterogeneity, or recovery or endangered species) should drive the choice of species used (Muko and Iwasa 2011), and frameworks are being developed to manage the decision process and costings of relocation for climate change (Richardson *et al*. 2009).

Table 2.7 Examples of conventional and unconventional conservation methods, and their potential to address the global stressors of temperature, CO_2 acidity, and excess atmospheric CO_2. X denotes direct effect; (X) indicates possible indirect effect; ? indicates uncertain.

CONSERVATION METHOD	STRESSOR ADDRESSED			CONSERVATION METHOD	STRESSOR ADDRESSED		
Conventional:	Temp	Acid	CO_2	Unconventional:	Temp	Acid	CO_2
Marine reserves and coastal zone management	?	?	?	Physical — for example, sun shading, solar-radiation management; increased upwelling	X		(X)
Pollution and watershed management	?	?	?	Biological — for example, selective breeding, artificial selection, genetic engineering; creation of refuges; artificial preservation of genetic stock	X	X	(X)
Fisheries, shipping and recreation management	?	?	?	Chemical — for example, chemical, electrochemical or geochemical modification of seawater (alkalinity addition, pH elevation)	(X)	X	X
Carbon dioxide emissions reduction — increase energy efficiency and non-fossil fuel energy use; decarbonise fossil energy	X	X	X	Hybrid and other approaches — for example, conversion of waste carbon dioxide to ocean alkalinity; storage of land crop waste in ocean; ocean fertilisation	(X)	X	X

Source: Rau *et al*. (2012)

Rehabilitation may also consist of recreating underlying structural complexity where this has been destroyed (e.g. dredging, trawling, storms), giving settling coral larvae a chance to become established. Timing of restoration activities is likely to be crucial, and should coincide with relatively stable climatic periods (e.g. outside the cyclone / flood season) and periods of coral recruitment and episodic macroalgal die-off (Graham *et al*. 2013). Reef restoration has not been widely applied in Australia, but a risk assessment framework exists for minimising uncertainty (Hoegh-Guldberg *et al*. 2008). Translocation of corals to higher latitudes, which are the most likely refugia for tropical coral reefs in warming seas, has not yet been attempted (Beger *et al*. 2014). Difficulties arise based on the symbiosis between corals, their zooxanthellae and other microorganisms; within this complex relationship, the thermal tolerance of all components must be taken into account (Fine *et al*. 2013; Oritz *et al*. 2014; Weis 2010).

Structural complexity is the most important restoration focus for coral reef communities.

Any active restoration efforts should consider that coral reef communities depend on the coral for structural complexity more than anything else. Some fish eat live coral, and many others recruit into live coral (Graham *et al*. 2013; Pratchett and Berumen 2008), but much of the community depends on structural complexity over and above live coral cover. Once the coral dies, it can take years for the structure to erode to the point where the community shifts to an alternate stable state (Graham *et al*. 2013). This means that if the early stages of a shift are detected, the likelihood of a reversal is much higher (Graham *et al*. 2013). Steps that can be taken to halt or reverse a phase shift include timely management of fisheries to enhance large fishes, bolstering processes such as herbivory, and ensuring that habitat structure is not further eroded.

Identifying future refugia for coral reef organisms, or even whole coral reef communities, will be a crucial factor in assisting coral reef adaptation to climate change.

Coral reef organisms are likely to expand southward along the Queensland coast, as those closer to the equator reach the limits to their thermal tolerance, and southern waters warm to the point of providing favourable temperatures (Beger *et al*. 2014). Identifying future refugia for coral reef organisms, or even whole coral reef communities, will be a crucial factor in assisting coral reef adaptation to climate change. To this end, protection of subtropical reefs and future suitable reef habitat needs to be strengthened (Beger *et al*. 2014). Identifying source reefs and connectivity pathways (Beger *et al*. 2010), and enhancing connectivity between source reefs and future potential refugia will also become increasingly important; there will be a need to prioritise areas of lower environmental stress, relative climatic stability and high social and economic adaptability (Cinner *et al*. 2011). Modelling occurrences of high sea surface temperature anomalies on the GBR has already taken place (Ban *et al*. 2012), as well as the association between climate stress and coral reef diversity in the western Indian Ocean (McClanahan *et al*. 2011); extending this modelling to identify areas to the south likely to maintain temperatures that are relatively stable could be the next step.

Inshore reefs of the GBR are urgently in need of improved water quality management, both at the catchment scale and locally (e.g. around ports).

Currently, inshore reefs are in a state of decline because a naturally low density of large herbivores, high sedimentation rates and the artificial input of nutrients are enhancing the growth of macroalgae, and in recent years higher temperatures have prevented the seasonal macroalgal die-off. Additionally, it is thought that elevated nutrients enhance the survival of larvae of the corallivorous crown of thorns (COTs) sea star *Acanthaster planci*, which has been a major factor in coral cover decline on the Great Barrier Reef (De'ath *et al*. 2012; Sweatman *et al*. 2011), although not on inshore reefs. Most *A. planci* (corallivorous sea star, see coral reef section) larvae starve in conditions of chlorophyll < 0.5 $\mu g L^{-1}$. Above this level, there is a rapid increase of larval survival (Brodie *et al*. 2005). Coral restoration has been trialled in turbid inshore reefs in Singapore, with marginal success, but farmed corals that survived the initial 14 months had high growth rates and established persisting colonies (Bongiorni *et* *al*. 2011). High turbidity areas (e.g. the inshore GBR) may be suitable only to heterotrophic coral species with effective self-cleaning capacity (De'ath and Fabricius 2010). This has yet to be trialled on the GBR; ultimately, fundamental water quality problems need to be resolved before serious restoration activities can be considered (De'ath and Fabricius 2010; Grech *et al*. 2013). On the GBR coast, the Reef Water Quality Protection Plan (http://www.reefplan.qld.gov.au/) was put in place in 2003, and regularly releases “Report Cards” to measure its performance. By 2011 there had been some improvements (Reef Water Quality Protection Plan Secretariat 2013), but clearly better cooperation between local, state and federal governments and coastal developers will be crucial to secure lasting improvements. On the inshore GBR, various water quality measures (especially turbidity and chlorophyll concentration) were found to be good predictor of changes in biotic variables, but authors cautioned that thresholds may change spatially and temporally (Collier *et al*. 2012; de Boer 2007).

Inshore reefs bear the brunt of increased macroalgal growth as one of the responses to declining water quality (De'ath and Fabricius 2010). These reefs have naturally low herbivore biomass, and it may be useful to introduce invertebrate grazers like sea urchins or trochus (Villanueva *et al*. 2010)– which already occur in low densities – this would need to be properly trialled on fenced-off tracts of reef, to test for unfavourable interactions and outcomes. The captive breeding and introduction of marine species may be possible for some – where larval rearing techniques have been developed, and species are introduced into parts of their existing ranges where they may have become scarce – but introductions have had varying effects on the receiving environments, from boosting biodiversity and restoring ecological function (Bellard *et al*. 2012) to becoming dangerous pests (Albins and Hixon 2008; Gaither *et al*. 2013).

Small islands of the Torres Strait

Many of the required strategies for adapting to climate change in the Torres Strait will ultimately protect both human populations and ecosystems.

Small islands, such as those that predominate in the Torres Strait, are vulnerable to sea level rise, seawater intrusion into freshwater lenses, increased storm intensity and elevated temperatures (Hilbert *et al*. 2014). Their small size, relatively large coastal zones and isolation compound these impacts through restricting migration options and maximising exposure to coastal impacts. Changes in fire regimes and new pest and weed incursions could also have a disproportionally large impact on island vegetation and fauna communities. With changes to species ranges, the Torres Strait islands could also act as stepping-stones for diseases and exotic pests arriving from the north.

Adaptation planning for the Torres Strait is primarily concerned with human communities, but a growing body of research is establishing critical baseline data from many Torres Strait species and ecosystems which have been relatively understudied to date. Human and ecological systems in the region are strongly interlinked. Torres Strait ecosystems are mostly very healthy and adaptations options are limited, focusing primarily on reducing current anthropogenic stressors. Some of the required adaptation strategies will help to reduce climate change impacts on human populations and ecosystems, but there will also be trade-offs such as communities having to relocate to higher ground and into areas currently occupied by fauna and flora communities.

For islands large enough to benefit from conservation actions, adaptation measures will be similar to those described for coastal assemblages turtles, dugongs, seagrass beds and coral reefs.

Unlike mainland coasts, coastal communities migrating away from a shoreline affected by sea level rise on small islands will very rapidly run out of space, and simply disappear (Green *et al*. 2009). Coral cays may initially experience some growth as sea levels rise, but in the longer term this is likely to be overtaken as the rate of rise increases. Given a group of small islands such as the Torres Strait, identifying refugia and future habitat may therefore need to include identifying “sacrificial” islands for which nothing can be done. For those that can benefit from conservation actions, adaptation measures will be similar to those described for coastal assemblages turtles, dugongs, seagrass beds and coral reefs (see Turtles, Dugongs and Coral reefs sections above). Adaptation measures will need to be applied on an island by island basis (Figure 2.6) (Duce *et al*. 2010). In some cases, soft adaptation measures such as beach and mangrove revegetation, beach and berm nourishment will be preferable to most expensive options such as building hard erosion control structures (Duce *et al*. 2010). However, for many islander communities living in the coastal hazard zone on low-lying islands, seawalls are the only viable short to mid-term option to reduce the impacts of inundation and erosion.

As with the GBR coast, reducing local impacts to coral reefs and seagrass beds will enhance their resilience to climate change effects. Turtle egg harvesting is a culturally important activity that poses an additional threat to turtles nesting in the Torres Strait; moving egg harvesting activities to areas where the sand has exceeded the threshold for hatchling survival may be a further adaptation measure to protect nesting turtles (Fuentes *et al*. 2010a).

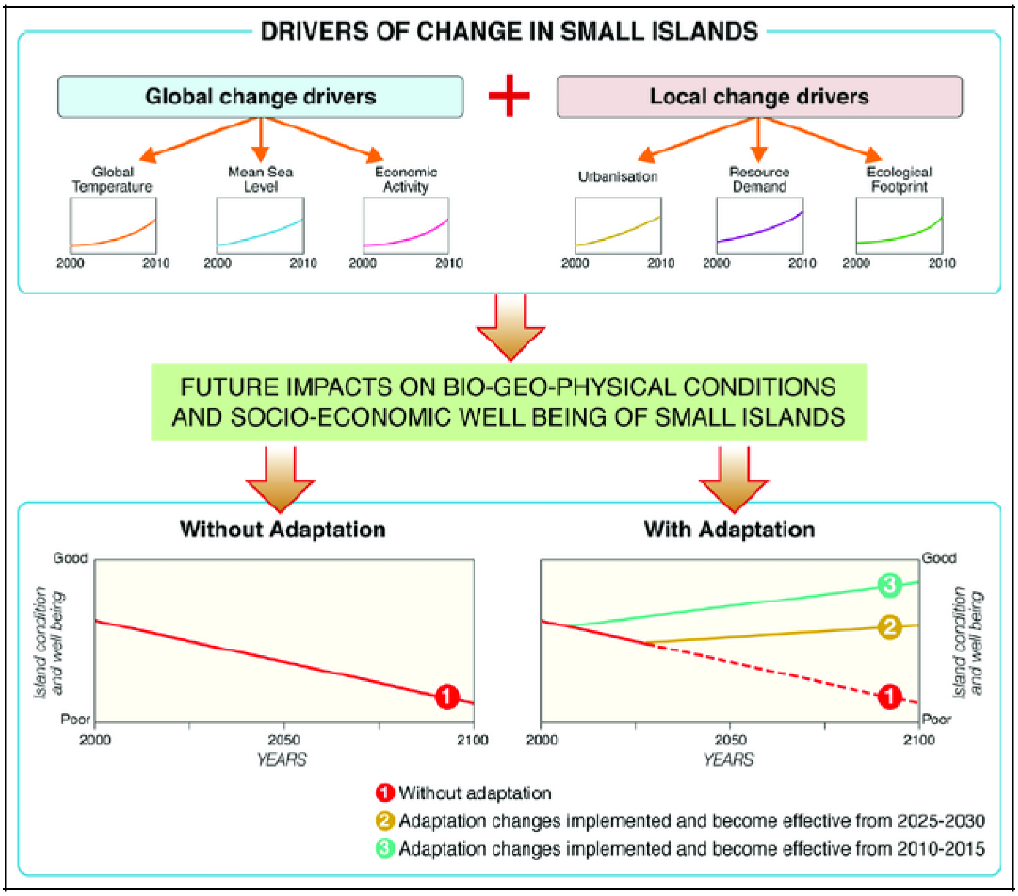

Figure 2.6 Drivers of change and potential consequences of different adaptation options specific to small islands

Source: Duce *et al*. (2010)

Flying foxes

Due to their flying large distances, adaptation strategies for flying foxes will need to be considered via a whole-landscape approach.

Australia's mainland flying-foxes (Chiroptera: Pteropodidae, *Pteropus* spp.) are large, highly mobile, flying mammals capable of travelling more than 20 km in one night (Markus and Hall 2004; Parsons *et al*. 2006) and hundreds of kilometres whilst migrating (Tidemann and Nelson 2004; Webb and Tidemann 1996). Therefore, adaptation strategies need to be considered via a whole-landscape approach. Flying-foxes are susceptible to extreme temperatures, and adaptation options during extreme heat waves include spraying camps with water to aid evaporative cooling (Welbergen *et al*. 2008). Range expansions and contractions have been shown and suggested in both the black flying-fox *Pteropus alecto* and the grey headed flying-fox *Pteropus poliocephalus* (Parsons *et al*. 2010; Roberts *et al*. 2012) but have not been shown as being attributable to climate change (Roberts *et al*. 2012).

The increasing urbanisation of flying-fox camps will need to be managed through public education and when non-lethal dispersals occur; the impacts will need to be closely monitored

Flying-fox camps have increasingly been found in urban areas, resulting from the growth of urban areas into existing camps and from flying–foxes establishing new camps in urban areas (for example, the Royal Botanic Gardens, Melbourne)(Parris and Hazell 2005; van der Ree *et al*. 2006; Williams *et al*. 2006a). It has been suggested that new camps being established in urban areas is a result of the urban heat island effect (Parris and Hazell 2005) and urban planting providing access to reliable, year round resources (Williams *et al*. 2006a). The increased presence of camps in urban environments has led to conflict in these communities. These conflicts result from public health concerns about virus transmission and complaints about noise, smell and tree defoliation (Roberts *et al*. 2011; Thiriet 2005, 2010). As a result, the non-lethal dispersal of camps has been attempted at a number of sites using noise, light, smoke, smell and roost modification (Roberts *et al*. 2011).

The long-term effect of dispersal attempts on flying-foxes is not known but regulations in regard to the timing of dispersals attempts to minimise the impact on populations. Spectacled flying-foxes *Pteropus conspicillatus* in the Wet Tropics region have recently had an increased number of dispersal attempts as a result of state government reforms. This is despite the species being listed as vulnerable (EPBC 1999). The impact that these dispersals have at the population level is unknown but dispersals can result in abandoned young, aborted foetuses and stresses on individuals (Thiriet 2005). Educating the community about human health risks and ways to live with flying-foxes could result in a reduction in dispersal attempts. In instances where dispersal is deemed necessary, the population will need to be closely monitored and dispersal ceased when mortality and/or injury occurs.

The greatest limiting factor for flying-fox persistence in the future is the quality and availability of food resources. Adaptation planning for these species should start with a good understanding of spatial and temporal resource distribution.

All four Australian mainland flying-foxes rely on a continuous temporal sequence of flowers and fruit (Eby and Law 2008; Parsons *et al*. 2006) and their success in Australia's patchy landscape has been attributed to their capacity to travel great distances to exploit resources and their adaptable diet (Birt *et al*. 1997). With predicted increases in temperature, CO_2 in the atmosphere and in particular precipitation seasonality (Pachauri and Reisinger 2007), the availability, nutritional quality, and distribution of plant resources is predicted to change (Hughes 2003; Lawler *et al*. 1997). The greatest limiting factor for flying-fox persistence in the future is the quality and availability of these food resources. Currently, food shortages are faced by many flying-fox species in the winter and many habitats where winter forage is available have been heavily cleared or are not protected (Eby and Law 2008). Adaptation planning for these species should start with a good understanding of spatial and temporal resource distribution. Suitable foraging habitat needs to be established through habitat restoration and protected areas, linked by migration corridors and is in proximity to suitable roosting habitat. Nectar mapping is available for Grey headed flying-foxes, *Pteropus poliocephalus* throughout their range in Victoria, New South Wales, ACT and Queensland (Eby and Law 2008).

Birds

Garnett *et al*. (2013) conducted a continent wide analysis of the effects of climate change on Australian birds, and identified species in the Wet Tropics bioregion and Cape York Peninsula as amongst the most likely to lose suitable climate space, as corroborated by earlier studies (Reside 2011; Reside *et al*. 2012).

Species-specific adaptation actions for birds will need to take into account ecology, but general management to increase the adaptive capacity of the entire WTC Region will benefit a suite of species.

A large number of at-risk endemic species overlap in location, such as in the Wet Tropics uplands rainforests, and thus general adaptation management actions such as identification of climate refugia, habitat restoration ad control of introduced pest species should benefit a suite of species. The relatively intact landscapes of Cape York Peninsula and the Wet Tropics uplands are the regions where most in situ adaptation (e.g. fire, weed and feral animal management) will need to occur, and where climate change refugia need to be identified (Garnett *et al*. 2013).

The most important adaptation actions for birds will be managing current stressors, and in situ management including refugia identification and protection. Expensive ex situ options such as captive breeding and assisted migration should be considered a last option.

The most cost effective method for conservation of avian species threatened by climate change will be in 'in situ', through identification and protection of climate refugia, and for the most threatened species, through specific management actions such as artificial nest site creation, and human-made microhabitat refugia such as nest boxes. For the most endangered birds, 'ex situ' actions including captive breeding will be necessary, though this should be considered a last option only if a species is unlikely to survive in the wild. Using the three categories for adaptation strategies for birds discussed in Garnett *et al*. (2013), and shown in Table 2.1, we develop case studies for adaptation pathways for two

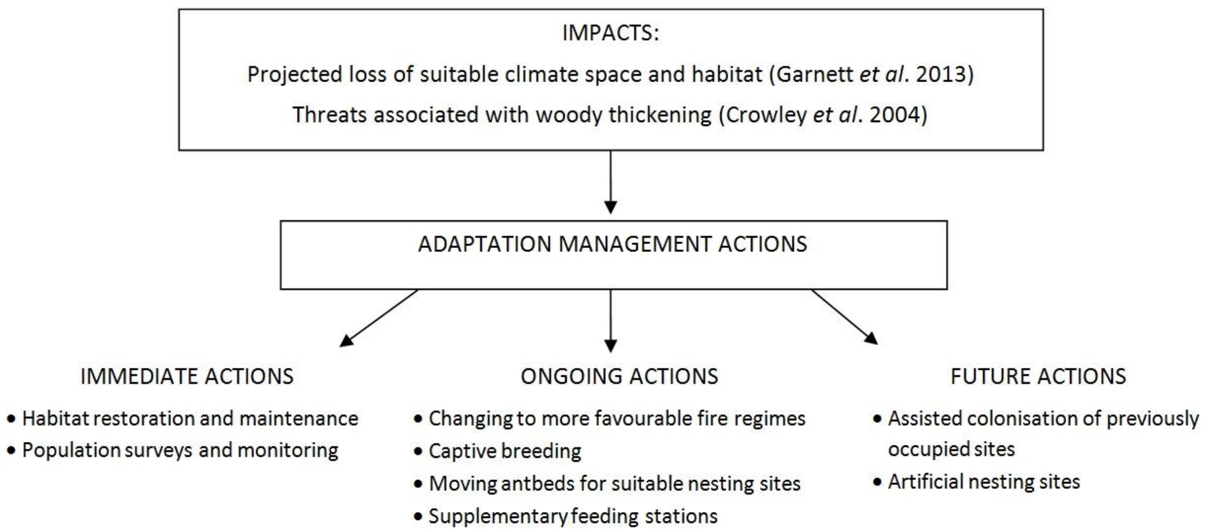

Figure 2.7 Adaptation Pathways – Case Study 1 – Golden shouldered parrot **Psephotus chrysopterygius.**

of the regions birds identified as being at high risk from climate change (Figure 2.7 and Figure 2.8).

The golden shouldered parrot is endemic to CYP and has been identified as being at high risk from climate change, having high sensitivity and high exposure (Garnett *et al*. 2013). It is also at risk from woody thickening, which has been associated with climatic change and CO_2 levels (Crowley *et al*. 2004). Immediate and ongoing actions listed above are already in place for this species, and management guidelines for its conservation are well established (i.e. Crowley *et al*. 2004). Future adaptation actions could include assisted colonisation and/or the possibility of developing artificial nesting sites.

The golden bowerbird is endemic to the high-altitude rainforest habitats of the Wet Tropics bioregion, and has long been identified as highly vulnerable to climate change due to its restricted geographical range and high ecological specificity (Garnett *et al*. 2013; Hilbert *et al*. 2014; Isaac *et al*. 2009; Shoo *et al*. 2005). Despite this, and in contrast to the Golden Shouldered Parrot, this species has no ongoing or planned conservation actions, and no management guidelines for its protection exist; it is currently listed as 'least concern' internationally and regionally (IUCN and DEHP Queensland). However, species surveys have been conducted for more than two decades (Williams *et al*. 2010), and modelling of climate change refugia in the WTC Region is ongoing. This species has been highlighted as one for whom assisted colonisation may be required in the future (Thomas 2011).

Cassowaries

Landscape connectivity will greatly improve the cassowary's chances of survival.

Improving landscape connectivity and building resilience will be key strategies to ensure that cassowaries have the capacity to adapt to shifting climatic zones (National Biodiversity Strategy Review Task Group 2009). The spatial adaptation strategies need to be focused on the 8 identified priority key areas in the WTC Region as identified in the recovery plan (Latch 2007). Suggested methods include:

- increasing the connectivity between ecosystem networks on a large spatial scale
- protection of sites in parts of the species' range where the climate is predicted to remain suitable over time
- isolated cassowary habitat that is within the new suitable climate zones will need to be linked to the nearest climate-proof and functional habitat network

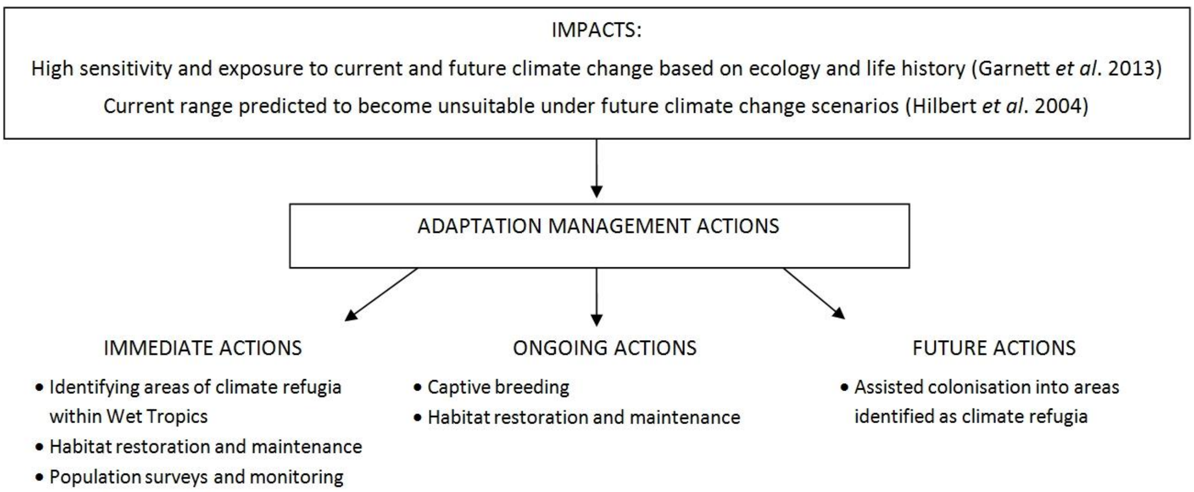

Figure 2.8 Adaptation Pathways – Case Study 2 – Golden Bowerbird **Priondurus newtoniana**

- optimise sustainable networks in climate refugia, the part of the cassowary's range where the climate remains stable
- increase colonising capacity in parts of the habitat network that remains suitable in future climate scenarios
- inclusion in (and updating) of the Recovery plan for the southern cassowary *Casuarius casuarius johnsonii* (Latch 2007) of treatment for the potential effects of climate change as well as inclusions as a threat specifically for the cassowary in the Back on track Actions for biodiversity plans (Department of Environment and Resource Management 2010)
- implement strategies to conserve cassowary habitat on private lands, nature refuges
- promote co-management of areas with Indigenous people (particularly coastal lowlands).

Additionally, monitoring the populations and abundance of cassowaries is crucial to their successful management.

Other suggested strategies at the property level are provided by the Queensland Government's Department of Environment and Heritage Protection - http://www.ehp.qld.gov.au/wildlife/threatened-species/endangered/endangered-animals/cassowary.html.

Summary of adaptation options for biodiversity

Table 2.8 Major impacts of climate change on biodiversity and potential adaptation options. Adaptation options that also potentially mitigate greenhouse gas emissions are marked **(M)**.

		EXAMPLE ADAPTATION OPTIONS		
Climate change	**Major impacts**	**Protect**	**Accommodate**	**Retreat**
Combined climate change effects	1. Areas within species' current geographic distribution will become unsuitable.		· Identify, conserve and restore refugia, especially those that protect from multiple impacts, and for species not currently occurring in the WTC region; · Promote functional connectivity at all spatial scales to aid species in accessing resources and refugia **(M)**; · Use 'composite provenancing' of seeds in restoration; · Adapt fire, weed and feral animal management to promote in situ; · Create artificial microhabitats.	· Assisted colonisation to new or historic locations; · Assisted interbreeding between populations; · Seedbanking
	2. Small islands are vulnerable to impacts and have limited migration opportunities.		· Manage trade-offs, e.g., relocation of human communities to areas that are currently in natural state.	· Identify 'sacrificial islands' for which conservation adaptation options are severely limited.
Increased average temperatures	1. Exceed thermal tolerances of terrestrial species, marine and coastal communities; leading to reduced survival, growth and reproduction in parts of current range.		· Conserve thermal refugia within species' current distributions; · Conserve or improve functional connectivity with thermal refugia **(M);** · Assisted gene flow with populations on	· Conserve thermal refugia outside species' current distributions; · Conserve or improve functional connectivity with thermal refugia **(M)**; · Assisted translocation;

			EXAMPLE ADAPTATION OPTIONS	
			‘hot periphery’ of current distribution.	· Ex-situ conservation.
	2. Exceed thermal tolerance of coral reef organisms		· Manage existing threats to inshore reef water quality, e.g., high sedimentation rates; · Identify and enhance connectivity to refugia; · Trial introduction of invertebrate herbivores to limit macroalgal growth.	· Translocation of corals to higher latitudes.
	3. Changed fire frequency, intensity, extent and timing	Active management to exclude fire from some systems **(M)**.	· Active fire management to promote desired vegetation communities **(M)**; · Conserve fire refugia within species’ current distributions; · Conserve or improve functional connectivity with fire refugia **(M)**.	· Conserve fire refugia outside species’ current distributions; · Conserve or improve functional connectivity with fire refugia **(M)**; · Ex-situ conservation.
	4. Increased survival, growth and reproduction of certain species, potentially including introduced species		· Management intervention to remove undesirable species and mediate negative impacts.	
	5. Impacts on freshwater ecosystems		· Preserve or restore riparian vegetation cover **(M)**; · Preserve and enhance ground water flows by minimising fine sediment input.	
	6. Immigration of plants and animals from other regions		· Conserve thermal refugia for species from other regions; · Conserve or improve functional	· Ex-situ conservation.

EXAMPLE ADAPTATION OPTIONS				
			connectivity with thermal refugia for species from other regions **(M)**.	
Sea level rise	1. Sea water inundation of fresh water bodies in coastal areas; Increased tidal reach in coastal watercourses	· Sea walls, dykes, storm surge barriers; · drainage channels, tidal gates	· Conserve freshwater refugia within species' current distributions; · Conserve or improve functional connectivity with freshwater refugia.	· Conserve freshwater refugia outside species' current distributions; · Conserve or improve functional connectivity with freshwater refugia; · Ex-situ conservation.
	2. Loss of turtle nesting beaches	· Construct sea walls, groynes, beach nourishment and dune building .	· Conserve landward buffer zones around current nesting beaches.	· Move nests from areas of inundation and erosion; · Ex situ conservation.
	3. Sea water inundation of coastal vegetation communities		· Conserve landward sea level rise refugia within ecosystems' current distribution; · Conserve or improve functional connectivity with sea level rise refugia **(M)**.	· Conserve landward sea level rise refugia outside ecosystems' current distribution; · Conserve or improve functional connectivity with sea level rise refugia **(M)**; · Ex-situ conservation.
	4. Impacts on freshwater ecosystems		· Conserve, restore or enhance vegetation buffers to storm surges	·
Extreme events (increased occurrence of high intensity cyclones, extreme rainfall events, heatwaves)	1. Physical damage to terrestrial, freshwater and marine systems due to high winds, wave action and storm surge.		· Management intervention to assist post-cyclone recovery.	
	2. Damage to coral reefs and other marine systems through freshwater pulses and pollutant runoff	Physical structures to mediate freshwater pulses.	· Improve water quality management of inshore reef areas via catchment management actions (e.g., around ports); · Improve restoration	

			EXAMPLE ADAPTATION OPTIONS	
			of coral reefs; · Reduce other immediate anthropogenic impacts.	
	3. Increased sedimentation of seagrasses, reducing feeding areas for dugongs		· Control sediment and nutrient runoff control; · Reduce anthropogenic mortality.	
	4. Thermal tolerances of animal species exceeded during heatwaves, leading to reduced survival		· Conserve heatwave refugia within species' current distributions; · Conserve or improve functional connectivity with heatwave refugia **(M)**; · Manage acute impacts, e.g., by spraying flying-fox camps with water.	· Conserve heatwave refugia outside species' current distributions; Conserve or improve functional connectivity with heatwave refugia **(M)**; · Ex-situ conservation.
	5. Coral bleaching during heatwaves events	· Sun-shading	· Restoration of coral reefs; · Conserve heatwave refugia within current coral reef system; · Transplant heat-tolerant coral species.	· Conserve heatwave refugia outside current coral reef system; · Conserve or improve functional connectivity with heatwave refugia.
	6. Increases in invasive species following disturbances		· Prioritise control of species expected to exert highest threat, including new invasive species.	
More variable rainfall	1. Changed patterns of plant and animal species' patterns of growth and reproduction		· Conserve hydric refugia within species' current distributions; · Conserve or improve functional	· Conserve hydric refugia outside species' current distributions; · Conserve or improve functional

EXAMPLE ADAPTATION OPTIONS				
			connectivity with hydric refugia **(M);** · Assisted gene flow with populations on drier or wetter peripheries of current distribution.	connectivity with hydric refugia **(M)**; · Assisted translocation; · Ex-situ conservation.
	2. Impacts on fire regime, together with impacts of increased CO_2 on fuel loads		· Implement integrated fire management regimes, with attention to timing, intensity, frequency and extent of burning.	
	3. Impacts on freshwater ecosystems		· Ensure provision of environmental flows; · Maintain hydraulic habitat complexity.	
Increased ocean acidification	1. Damage to coral reef systems and organisms		· Selective breeding of tolerant stock; · Modification of sea water (e.g., alkalinity).	

Monitoring adaptation outcomes

Adaptation actions will require monitoring to ascertain whether they have produced desirable outcomes and to inform changes that may be required; ideally, monitoring would be embedded within an adaptive management framework.

Based on recent reviews on the quality and outcomes of monitoring programs, Lindenmayer *et al*. (2012a) provided a set of guidelines for the implementation of monitoring programs in the future. Effective monitoring programs should:

1. deliver information on trends in key aspects of biodiversity (e.g. population changes)
2. provide early warning of problems that might otherwise be difficult or expensive to reverse
3. generate quantifiable evidence of conservation successes (e.g. species recovery following management) and conservation failures
4. highlight ways to make management more effective
5. provide information on return on conservation investment.

Below are a set of principles and considerations for successful monitoring programs.

Monitoring programs should be initiated with a specific objective, or set of objectives, in mind.

Optimal monitoring theory prescribes a decision-making framework in which management and monitoring are 1) decided and designed, 2) implemented, 3) monitored, 4) evaluated, and 5) adapted according to explicit objectives and budget constraints (Gerber *et al*. 2005). The objectives of monitoring will inform what should be measured (Lindenmayer *et al*. 2012a).

Monitoring should be embedded within an adaptive management framework that involves scientists, management agencies, funding agencies and government.

A successful monitoring program informs management

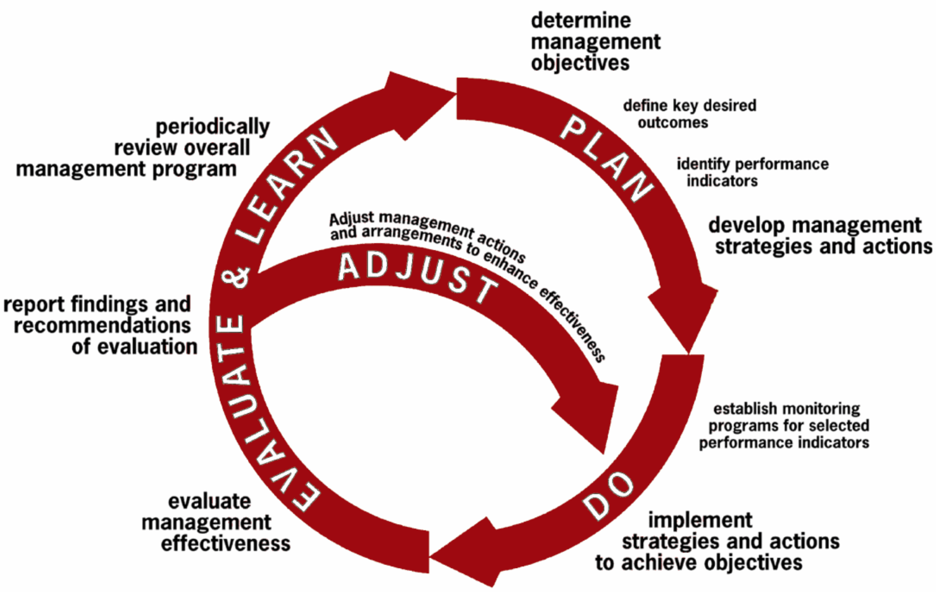

Figure 2.9 Example of an adaptive management cycle

Source: http://www.cmar.csiro.au/research/mse/.

about parameters relative to objectives; usually change in one or more indicators (Gerber *et al*. 2005). This then triggers changes in management actions by highlighting environmental or ecological conditions that may indicate the limitations of current management practices (Werners *et al*. 2013). While best outcomes can be achieved if such trigger values are defined before the start of a program, this requires sound predictions of ecosystem responses to either the management action or the threat the action is supposed to mitigate (Figure 2.9). Methods for allocating resources optimally in monitoring are also ideally embedded within the adaptive management framework (Field *et al*. 2007), especially when it comes to allocating funding between monitoring and other management actions (Regan *et al*. 2005). The cost of monitoring, monetary benefits for users, the cost of management and economic discounting of profit are all considered (Gerber *et al*. 2005).

The power to detect changes depends on the sampling design, methods, timing and frequency of the monitoring program.

Whilst the specific methods are variable between ecosystems, they generally seek to balance the need for the power to detect change (which usually means more time, samples, equipment, personnel) and budgetary constraints (which usually means less of the above). It is recognised that there is a need to invest in long-term monitoring, in adequate data storage and reporting mechanisms, in ongoing training for emerging ecologists to continue the monitoring effort in the long term and in continuously updating monitoring methods as new technology emerges (Lindenmayer *et al*. 2012a). Citizen science is emerging as a low-cost option for long-term monitoring that additionally has the benefit of educating and engaging the public (Tulloch *et al*. 2013).

Communication is the key link in all steps of embedding monitoring within an adaptive management framework.

Scientists have been notoriously reluctant to translate scientific findings into clear and simple messages for the public, managers and policy makers, and to give clear and constructive advice on what actions should be taken. However, it is increasingly recognised that this kind of communication in equally, if not more, important to publishing results in scientific journals. Monitoring programs and resulting conservation actions are in need of political and public support, in order to generate the political will to find and secure funding for long-term monitoring programs (Lindenmayer *et al*. 2012a).

Summary and conclusions

Barriers to climate change adaptation

Ignorance and misinformation of the general public is a major obstacle at all levels, leading to disinterest and inertia, and supporting a continued lack of political will. Monetary cost is the most common perceived barrier to adaptation actions.

A number of obstacles exist in the implementation of actions to assist the adaptation of WTC Region biodiversity to climate change, including competition for land, physical limits of organisms, knowledge gaps, cost of actions, existing markets, and social perceptions (Boulter 2012; Garnett *et al*. 2013). We need to alter political and public perceptions that ecosystem conservation and restoration incur a net cost. If ecosystem services were given a monetary value, in almost all cases restoration would, in fact, result in a net benefit (De Groot *et al*. 2013). Furthermore, resource allocation algorithms were recently developed for incorporating climate change into the prioritisation of areas for conservation (Iwamura *et al*. 2010). This highlights the need for much more intensive and targeted education of the public about ecosystem services that support our quality of life, the long-term consequences of ecosystem change, and the long-term value of ecosystem adaptation.

All conservation actions have costs associated with them, and adaptation to climate change will also incur costs. Projecting the ongoing costs of adaptation into the future is challenging, but the relative expenditure for different actions may be predictable based on current costs (Garnett *et al*. 2013). Generally, manipulative rehabilitation options (reforestation, building or engineering structures, relocation species) are more expensive than passive options (protected areas, management of particular human actions).

Conservation messages fail to capture the role of market mechanisms in persuading the public and governing bodies of the benefit and urgency of climate change adaptation.

Burley *et al*. (2012) take a significant step to include financial incentives as 'soft' adaptation options (Table 2.4). Ultimately, the use of these options would need to be tailored to specific locations, as human communities have slightly different drivers of environmental values and would therefore respond to different incentives. This is likely to be the case in the WTC Region, where communities range from urban centres (e.g. Cairns) to isolated and remote island communities (e.g. the Torres Strait).

- The Productivity Commission's report on barriers to adaptation further summarised the most important recommendations for effective adaptation (Productivity Commission 2012)
- Governments at all levels should:
  - embed consideration of climate change in their risk management practices
  - ensure there is sufficient flexibility in regulatory and policy settings to allow households, businesses and communities to manage the risks of climate change
- A range of policy reforms would help households, businesses and governments deal with current climate variability and extreme weather events. These reforms would also build adaptive capacity to respond to future climate impacts. Examples include:
  - reducing perverse incentives in tax, transfer and regulatory arrangements that impede the mobility of labour and capital
  - increasing the quality and availability of natural hazard mapping
  - clarifying the roles, responsibilities and legal liability of local governments, and improving their capacity to manage climate risks
  - reviewing emergency management arrangements in a public and consultative manner
  - retain all existing habitat
  - to better prepare for natural disasters and limit resultant losses
  - reducing tax and regulatory distortions in insurance markets
- Further actions are required to reduce barriers to adaptation to future climate trends and to strengthen the climate change adaptation policy framework. These include:
  - designing more flexible land-use planning regulation
  - aligning land-use planning with building regulation
  - developing a work program to consider climate change in the building code
  - conducting a public review, sponsored by the Council of Australian Governments, to develop appropriate adaptive responses for existing settlements that face significant climate change risks
- Some measures should not be implemented, as the costs would exceed the benefits:
  - Household insurance subsidies, or insurance regulations that impose net costs
  - Systematically reviewing all regulation to identify impediments to adaptation
  - Mandatory reporting of adaptation actions
- Some individuals and communities are likely to face greater challenges in adapting than others, implying a role for the tax and transfer system.

Concluding remarks

Some of the over-arching messages pertaining to the adaptation of biodiversity to climate change are fairly consistent across the different ecosystem types, species and processes. Consistent messages include:

- The threat of climate change is unlike many of the current threats to species and ecosystems; however,

- In many cases, management actions for climate change are similar to what is being conducted currently, or currently known to be important.
- Managing for climate change will need to involve facilitating change, in particular,
- Facilitating the movement of species and ecosystems as they track suitable climate and conditions. In addition:
- "In situ" conservation – managing species in their habitat, or facilitating their dispersal, will be less expensive than "ex situ" conservation, which will be far more resource-intensive.

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