National Environmental Research Program

TROPICAL ECOSYSTEMS hub

The Importance of Protecting and Conserving the Wet Tropics

Synthesis of NERP Tropical Ecosystems Hub Tropical Rainforest Research Outputs 2011-2014

Compiled by RRRC

Australian Government
Department of the Environment

Reef & Rainforest RESEARCH CENTRE

The Importance of Protecting and Conserving the Wet Tropics

A Synthesis of NERP Tropical Ecosystems Hub Tropical Rainforest Research Outputs 2011-2014

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The Tropical Ecosystems Hub is part of the Australian Government's National Environmental Research Program. The NERP TE Hub is administered in North Queensland by the Reef and Rainforest Research Centre Limited (RRRC). The NERP Tropical Ecosystem Hub addresses issues of concern for the management, conservation and sustainable use of the World Heritage listed Great Barrier Reef (GBR) and its catchments, tropical rainforests including the Wet Tropics World Heritage Area (WTWHA), and the terrestrial and marine assets underpinning resilient communities in the Torres Strait, through the generation and transfer of world-class research and shared knowledge.

Cover photograph: D. Westcott

This report is available for download from the NERP Tropical Ecosystems Hub website:
www.nerptropical.edu.au

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Acronyms & Abbreviations

ATH	Australian Tropical Herbarium
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DoE	Department of the Environment
DEHP	Department of Environment and Heritage Protection
DNPRSR	Department of National Parks, Recreation, Sport and Racing
EPBC	Environment Protection and Biodiversity Conservation Act 1999
FNQROC	Far North Queensland Regional Organisation of Councils
Ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
LGA	Local Government Area
LR&CVToEA	Littoral Rainforest & Coastal Vine Thickets of Eastern Australia
NCA	Nature Conservation Act 1992
NERP	National Environmental Research Program
NRM	Natural Resource Management
RAPA	Rainforest Aboriginal Peoples Alliance
RCP	Representative Concentration Pathways
RRRC	Reef and Rainforest Research Centre Limited
TE	Tropical Ecosystems
TTNQ	Tourism Tropical North Queensland
WT	Wet Tropics
WTMA	Wet Tropics Management Authority
WTWHA	Wet Tropics of Queensland World Heritage Area

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About this Report

This report provides an overview and synthesis of the key findings of research conducted under the Australian Government's National Environmental Research Program (NERP) Tropical Ecosystems (TE) Hub relevant to tropical rainforests including the Wet Tropics of Queensland World Heritage Area and Cape York. The NERP rainforest research theme comprised ten projects undertaken by researchers from James Cook University, Griffith University, the University of Queensland and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in collaboration with partner agencies.

The intent of the NERP funded rainforest research was to improve our understanding of the impacts of future climate change and extreme events on plant and animal biodiversity; gain new insights for beneficial indigenous co-management of protected areas; identify the importance of tourism and community values; determine the status of threatened key indicator species; examine options regarding natural resource management (NRM) governance under greenhouse gas abatement measures; determine the role of fire in the management of the Environment Protection and Biodiversity Conservation (EPBC) Act 1999 listed ecosystems and species; and invasive species management. The research aimed to inform and facilitate management action and remediation to reduce, restore and increase resilience of the Wet Tropics ecosystems. The research findings are also applicable elsewhere, particularly in tropical ecosystems more broadly, but many outcomes can be translated for general application in terrestrial ecosystem management.

The report provides an introduction to the Wet Tropics region, a synthesis of key ecological and socio-economic project highlights for the region (including status and trends), future pressures and threats, how research has informed policy and management, and future research priorities.

This report provides a synthesis of one key theme in the NERP Tropical Ecosystems Hub, and is one of several such reports in a series of information products that summarise NERP research findings relevant to policy and management in tropical North Queensland. Other NERP synthesis products include:

- Devlin, M., Fabricius, K., Negri, A., Brodie, J., Waterhouse, J., Uthicke, S., Collier, C., Pressey, B., Augé, A., Reid, B., Woodberry, O., Zhao, J-x., Clarke, T., Pandolfi, J., Bennett, J. (2015) Water Quality - Synthesis of NERP Tropical Ecosystems Hub Water Quality Research Outputs 2011-2014. Report to the National Environmental Research Program. Reef and Rainforest Research Centre Limited, Cairns (55pp.).
- Donnelly, R., Sweatman, H., Emslie, M., Russ, G., Williamson, D., Jones, G., Harrison, H. (2015) Effects of Management Zoning on Coral Trout Populations in the Great Barrier Reef Marine Park. Report to the National Environmental Research Program. Reef and Rainforest Research Centre Limited, Cairns (12pp.).
- Donnelly, R., Yates, P., Schlaff, A., Espinoza, M., Matley, J., Ledee, E., Currey, L., de Faria, F., Moore, S. (2015) Spatial Management and Sharks on the Great Barrier Reef. Report to the National Environmental Research Program. Reef and Rainforest Research Centre Limited, Cairns (10pp.).

- Johnson, J.E., Marsh, H., Hamann, M., Duke, N., Burrows, D., Bainbridge, S., Sweatman, H., Brodie, J., Bohensky, E., Butler, J. and Laurance, S. (2015) Tropical Research in Australia's Torres Strait region. Report to the National Environmental Research Program. Reef and Rainforest Research Centre Limited, Cairns (33pp.).

Many of the findings presented in this report were derived from large collaborative projects funded from several sources, including the NERP, and the research institutions have also contributed significant in-kind resources. Publications specifically generated through research funded by the NERP are identified at the end of this synthesis report.

Executive Summary

In 2013, the Wet Tropics of Queensland World Heritage Area (WTWHA) was identified as the sixth most irreplaceable area on Earth for conservation of amphibian, bird and mammal species. It also ranked globally as the second most irreplaceable natural World Heritage site. These rankings were based on data of 173,000 terrestrial protected areas and assessments of 21,500 species, highlighting the global importance of Australia's Wet Tropics. The IUCN World Heritage Outlook (2014) listed the Wet Tropics of Queensland as of Significant Concern assessing the current state and trend of values as of high concern on a deteriorating trend and overall threats as high. Overall protection and management is considered effective however the IUCN Committee indicated "the insidious and damaging threat posed by invasive plants, animals and diseases, exacerbated by predicted impacts of climate change present a real danger to the continuing integrity of the site's biodiversity and associated endemic species. Whilst significant efforts have been taken to address these threats on the ground, the level of investment does not appear to be commensurate with the urgency for significant preventative and remedial action, and likely consequences of an ineffective response" (IUCN World Heritage Outlook, 2014).

Climate change scenarios are suggesting a number of threats are imminent including increased temperatures, an increase in fire frequencies and extreme events, and the loss of endemic plant and animal species. The harsh reality is that the future vulnerability of the biodiversity of the region is high, particularly within the regionally-endemic species that are very significant to the Wet Tropics. Although there are challenges to restoration, the consideration of regrowth methods for priority conservation areas is important for mitigating climate change impacts if greenhouse gas emissions continue on a 'business as usual' trajectory.

The importance of protecting and conserving the Wet Tropics rainforests has been exemplified by the long-term monitoring of the status and trends of rainforest biodiversity together with an increased understanding of ecosystem function and cumulative pressures. The socio-economic value of the rainforest to communities, Indigenous traditional owners and the tourism industry coupled with the natural and anthropogenic pressures on this World Heritage Area and surrounds provides a compelling argument for management regimes to adjust and identified priority conservation areas be considered. Relying on a strategic and integrated governance system, transformational change will lead to restored ecosystem function across the landscape, significant threat abatement and declining water pollution.

All levels of government, NRM bodies and industry groups have been involved in a collaborative approach to managing the NERP TE Hub research outcomes and its application. However, there is more to be done. The inclusion of traditional ecological and cultural knowledge with western science in the management of the Wet Tropics landscape will be integral to the future mitigation and abatement of threats and pressures to the north Queensland rainforests. Attention to socio-economic trends of the region and continued awareness of satisfaction and importance of protecting and conserving the Wet Tropics bioregion will assist in informing management actions. Any degradation to the natural assets will have cumulative impacts for the economic and social fabric of the region.

1.0 Introduction to the Wet Tropics region

The Wet Tropics of Queensland were inscribed on the World Heritage list in December 1988 on the basis of its outstanding universal value. The Wet Tropics stretches along the northeast coast of Australia for 450 km from just south of Cooktown to just north of Townsville and to the western boundary of the Great Dividing Range.

Encompassing some 894,420 ha of mostly tropical rainforest, this stunningly beautiful area is extremely important for its rich and unique biodiversity. It presents an unparalleled record of the ecological and evolutionary processes that shaped the flora and fauna of Australia, containing the relicts of the great Gondwanan forest that covered Australia and part of Antarctica 50 to 100 million years ago. All of Australia's unique marsupials and most of its other animals originated in rainforest ecosystems, and their closest surviving relatives occur in the Wet Tropics. These living relicts of the Gondwanan era and their subsequent diversification provide unique insights to the process of evolution in general. They also provide important information for the interpretation of fossils of plants and animals found elsewhere in Australia, and about the evolution of Australia's sclerophyll flora and marsupial fauna in particular.

The property supports tropical rainforests at their latitudinal and climatic limits, and unlike most other seasonal tropical evergreen equatorial forests, are subject to a dry season and to frequent cyclonic events. Many of the distinct features of the Wet Tropics relate to its extremely high but seasonal rainfall, diverse terrain and steep environmental gradients. The WTWHA is recognised as an area possessing outstanding scenic features, natural beauty and magnificent sweeping landscapes, wild rivers, waterfalls, rugged gorges and coastal scenery. The Area holds an intact flora and fauna with hundreds of locally endemic species restricted within its boundaries and provides the only habitat for numerous rare or threatened species of plants and animals.

The Wet Tropics of Queensland contains one of the most complete and diverse living records of the major stages in the evolution of the very first land plants to the pteridophytes, gymnosperms and angiosperms. Most of the relicts that exist on Earth of the flora of the forests which were part of the super continent Gondwana are found in the Wet Tropics of Queensland contains. The rainforests, which constitute about 80% of the WTWHA, have more taxa with primitive characteristics than any other area on Earth. One of the outstanding features is that the Area contains a high diversity of ancient taxa representing long evolutionary lineages which preserve a greater degree of evolutionary heritage than places with a similar number of species but containing a succession of closely allied forms.

The Wet Tropics of Queensland provides an unparalleled living record of the ecological and evolutionary processes that shaped the flora and fauna of Australia over the past 415 million years when first it was part of the Pangaean landmass, then the ancient continent Gondwana, and for the past 50 million years an island continent. During the 415 million years of evolution, the processes of speciation, extinction and adaptation have been determined by history, particularly continental drift and cycles of climatic change. The WTWHA contains a unique record of a mixing of two continental floras and faunas. This mixing occurred following the collision of the Australian and Asian continental plates about 15 million years ago. This collision was a unique event in that it mixed two evolutionary streams of both flora and fauna, in some cases of common origin that had been largely separated for at least 80 million years. As a centre of endemism, the Wet Tropics of Queensland provides fundamental insights into evolutionary patterns both in isolation from, and in interaction with, other rainforests.

The ancestry of all of Australia's unique marsupials and most of its other animals originated in rainforest ecosystems of which the Wet Tropics of Queensland still contains many of the closest surviving members. It contains one of the most important living records of the history of marsupials and songbirds. The Riversleigh fossil deposits (Australian Fossil Mammal Sites (Riversleigh/Naracoorte) World Heritage Area) are rich in marsupial fossil taxa closely related to those still living in the rainforests representing the best surviving equivalent of the Oligo-Miocene rainforests of Riversleigh.

The Wet Tropics bioregion, although accounting for only 0.26 percent of the total area of the Australian continent, conserves a large proportion of Australia's biodiversity. The WTWHA occupies 0.12% of Australia and contains an amazingly large share of Australia's terrestrial biodiversity. This includes 65% of Australia's fern species, 30% of orchid species, 58% of Australia's bats, 40% of bird species, 42% of freshwater fish, 30% of the country's marsupials, 29% of frog species and 26% of vascular plant species. The diverse range of vegetation communities are habitat to numerous rare and threatened species. Many plant and animal species in the Wet Tropics are found nowhere else in the world.

The WTWHA was recognised in 2012 as of national significance for its Indigenous cultural values (Pert *et al.* 2015 in press). This listing recognises that the Wet Tropics is the only place in Australia where Aboriginal people permanently inhabited rainforest prior to European arrival. The technical achievements underpinning this occupation enabled them to utilise a suite of endemic toxic plants, and to manage vegetation patterns using fire, and are of outstanding heritage value to the nation (Australian Government, 2012). Rainforest Aboriginal people have a specialised and unique material culture including bicornual baskets made from lawyer vine, grooved grinding slabs, crushing stones, anvils pitted with small hollows, hammerstones and polished waisted stone axes called *ooyurkas*. The unique traditions established by creation beings, instructing Rainforest Aboriginal people about their foods and how to make them edible, are inscribed in the landscapes, imbuing them with deep spiritual and cultural significance (Pannell, 2008).

The Wet Tropics is a mega-diverse region and is represented on *The Global 200* list which is a collection of the Earth's 200 most outstanding, important and diverse terrestrial, freshwater and marine habitats that harbour exceptional biodiversity and are representative of its ecosystems. Effective conservation in these eco-regions will help conserve the most outstanding and representative habitats for biodiversity on this planet.

A Learning Landscape

The Wet Tropics provides an ideal location to undertake globally relevant applied tropical ecosystem research for the understanding, conserving and responsible management of tropical ecosystems. The natural and cultural landscapes of the WTWHA are substantially intact, which is why the Area is attractive to tourists, valued by scientists, conservationists, and Aboriginal peoples and presents amazing opportunities for eco-, nature-based and cultural tourism.

Government support of Wet Tropics rainforest research since the early 1990s has produced major advances in climate change science, infrastructure management, biodiversity monitoring, canopy research, restoration ecology and Rainforest Aboriginal cultural research. Research funded by the Cooperative Research Centre for Tropical Rainforest Ecology and Management (Rainforest CRC) from 1993-2006 provided breakthroughs in conservation genetics, vegetation modelling, agroforestry and revegetation techniques, community infrastructure impact management, biodiversity assessment, modelling of climate change impacts, and understanding of the Aboriginal cultural landscapes, and practices underpinning fire management and toxic seed processing (Stork & Turton, 2008).

The Rainforest CRC investment was followed by the Marine and Tropical Sciences Research Facility (MTSRF), a part of the Australian Government's Commonwealth Environmental Research Facilities Program (CERF). From 2006-2010, a highly collaborative model of research projects focused on the status and trends, risks and threats, and sustainable use of ecosystems. Some of these projects were continuations of previous Rainforest CRC supported research. The MTSRF produced knowledge across a range of disciplines including biological and physical sciences, economics and social science. Both the Rainforest CRC and the MTSRF frameworks involved numerous collaborations between researchers and research users, with much of the research driven by the needs of various industry sectors and government management agencies.

The NERP (2011–2014) has built on the legacy and lessons from these previous Australian Government investments. The NERP Tropical Ecosystems Hub has aimed to address issues of concern for the management, conservation and sustainable use of the Wet Tropics rainforests, through the generation and transfer of world-class research and shared knowledge.

These successive research programs have sought to improve regional environmental decision making and inform stakeholders through better understanding of:

- The status and future trends of key species and ecosystems in north Queensland;
- The social and economic interactions between north Queensland communities and their regional environmental assets; and
- Adaptation options and management approaches for enhancing ecological and social resilience in a changing environment.

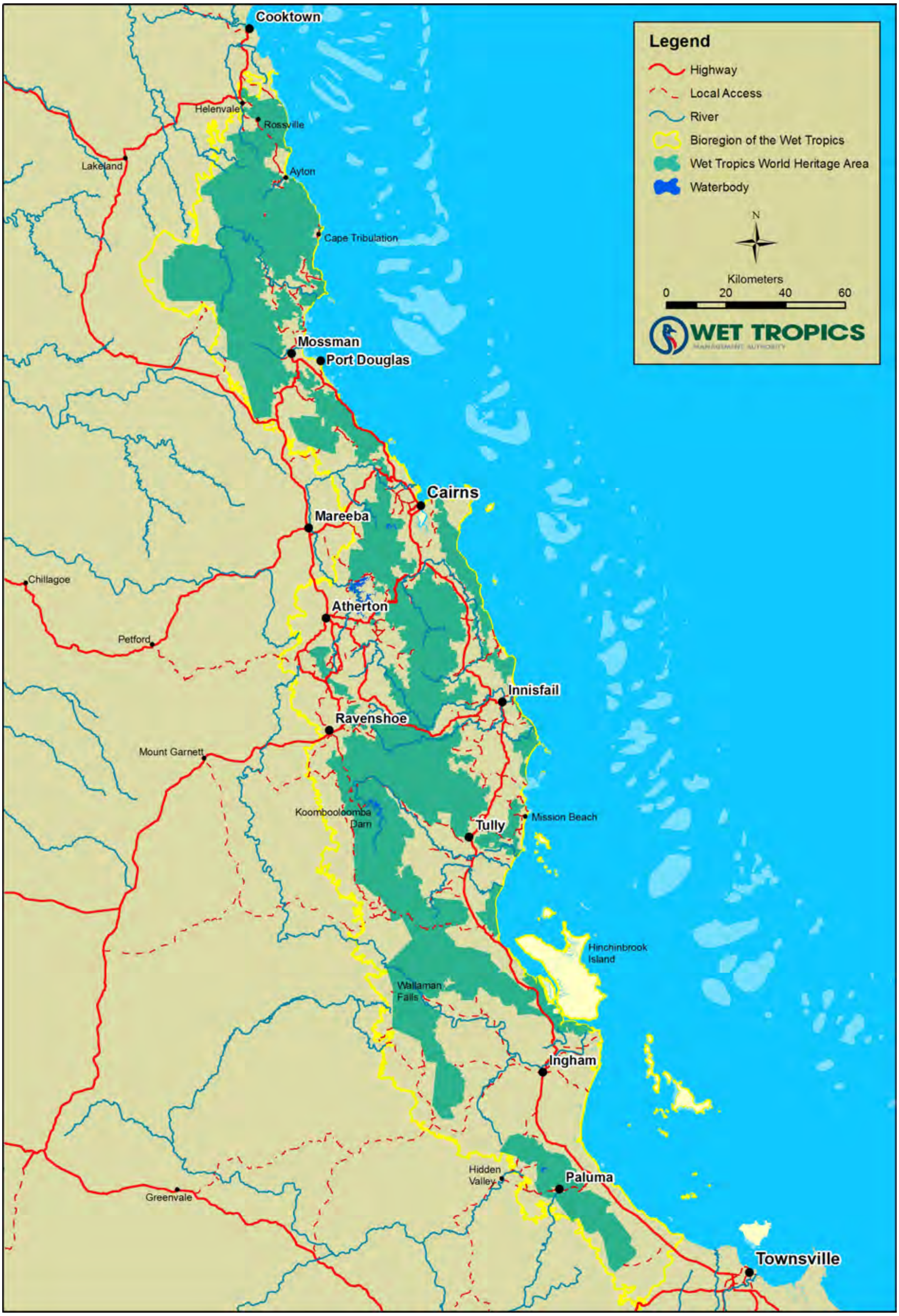

Figure 1. The Wet Tropics of Queensland World Heritage Area (Wet Tropics Management Authority)

The NERP Tropical Ecosystems Hub rainforest research projects have been structured under three key themes:

THEME 1: ASSESSING ECOSYSTEM CONDITION AND TREND: Understanding the condition, trend and interdependencies of unique environmental assets of the North Queensland region; building the capacity to predict how ecosystems and biodiversity will respond to change.

Program 3: Condition and trend of north Queensland rainforests

Project 3.1:	Rainforest Biodiversity (Professor Stephen Williams, James Cook University)
Project 3.2:	What is at risk? Identifying rainforest refugia and hotspots of plant genetic diversity in the Wet Tropics and Cape York Peninsula (Professor Darren Crayn, Australian Tropical Herbarium/James Cook University)
Project 3.3:	Targeted surveys for missing and critically endangered rainforest frogs in ecotonal areas, and assessment of whether populations are recovering from disease (Dr Conrad Hoskin, James Cook University)
Project 3.4:	Monitoring of key vertebrate species (Dr David Westcott, CSIRO)

THEME 2: UNDERSTANDING ECOSYSTEM FUNCTION AND CUMULATIVE PRESSURES: Understanding how ecosystems and biodiversity respond to cumulative pressures, and the social and economic implications for the North Queensland region.

Program 7: Threats to rainforest health

Project 7.1:	Fire and rainforests (Dr Dan Metcalfe, CSIRO)
Project 7.2:	Invasive species risks and responses in the Wet Tropics (Dr Helen Murphy, CSIRO)
Project 7.3:	Climate change and the impacts of extreme events on Australia's Wet Tropics biodiversity (Dr Justin Welbergen, James Cook University)

THEME 3: MANAGING FOR RESILIENT TROPICAL SYSTEMS: Partnering with key environmental decision-makers in government, industry and community to develop information, systems and tools to assist ecologically-sustainable management and strengthen environmental and social resilience.

Program 12: Managing for resilience in rainforests

Project 12.1:	Indigenous co-management and biodiversity protection (Dr Ro Hill, CSIRO)
Project 12.2:	Harnessing natural regeneration for cost-effective rainforest restoration (Professor Carla Catterall, Griffith University and Dr Luke Shoo, University of Queensland)
Project 12.3:	Relative social and economic values of residents and tourists in the WTWHA (Professor Natalie Stoeckl, James Cook University)
Project 12.4:	Governance, planning and the effective application of emerging ecosystem service markets: climate change adaptation and landscape resilience (Professor Allan Dale, James Cook University)

2.0 Research Highlights

Highlights from the rainforest research undertaken through the NERP TE Hub have focused on the ecological features of the region including the biodiversity, ecosystem function and cumulative pressures and managing for a more resilient tropical forest system.

2.1 Ecological features of the region

The assessment of conditions and trends of North Queensland rainforests has focused on the drivers of biodiversity the Wet Tropics rainforests. A particular emphasis has been on identifying rainforest refugia and hot spots of genetic diversity in the World Heritage Area, Eungella National Park and parts of the Cape York Peninsula region. The aim was to deliver species distribution models and composite biodiversity maps using long term data sets; describe patterns of environmental change; understand the genetic diversity of endemic vascular plant and fungi species; search for remnant populations of critically endangered frogs; and monitor the abundance of two key vertebrate species, the Southern Cassowary and the Spectacled Flying-fox. The results from this research will contribute to State of the Environment and World Heritage reporting for the Wet Tropics World Heritage Area, and provide information to assist development assessments and recovery plans under the *EPBC Act 1999*.

2.1.1 Vertebrates (Mammal and Avian Fauna)

The montane fauna of the Wet Tropics are very narrowly adapted to the high elevation climatic conditions and as a result the fauna within the higher altitude parts of the region are particularly susceptible to current and future climate change (Williams et al 2010). To understand the possible consequences of climate change to this region more thoroughly, the aim was to increase knowledge of present and future biodiversity patterns and drivers, environmental refugia and gain a greater understanding of the vulnerability and resilience of rainforest biodiversity in Australian tropical forests. Detailed mapping of present and future biodiversity patterns and drivers, environmental refugia and a comprehensive assessment of the region's vertebrates, predicting future trends and vulnerabilities of rainforest biodiversity in Australian tropical forests was considered necessary for identifying areas requiring priority conservation management attention.

The region's fauna was found to be already experiencing the effects of climate change. For the first time, long-term field based evidence shows that a significant number of bird and mammal species are already in decline and on the move, seeking refuge in higher, cooler mountain environs. Regional endemics appear to be most at risk. The research has confirmed the vulnerability of many rainforest species to climate change consistent with predictions, highlighting the need for urgent action to maximise regional resilience. Changes in the abundance and distribution of bird and mammal populations observed in a comprehensive long term monitoring program support the conclusions of regional climate change modelling predictions for the region, albeit the impacts occurring at a much faster rate than previously forecast.

Birds were found to have already shifted their distributional range over the past decade consistent with climate change modelling predictions. Significant changes in the distributions of 28 of 56 bird species for which data were sufficient were confirmed. Many of the upland bird species surveyed have declining populations which have been attributed to a combination of up-slope shift and declining habitat area driving the rapid decline in fourteen bird species, six of which are regionally endemic. Birds from the warmer lowlands are also being affected with fourteen species showing both increased population abundance and higher altitudinal distributional ranges than previously observed. For the bird species for which the survey data are sufficient, fifty percent are showing an upward elevational shift. A further 14 bird species show population increases, all of which are lowland species adapted to warmer climates. Figure 2 depicts the relative declines in bird populations over the last 10 years in the Wet Tropics bioregion.

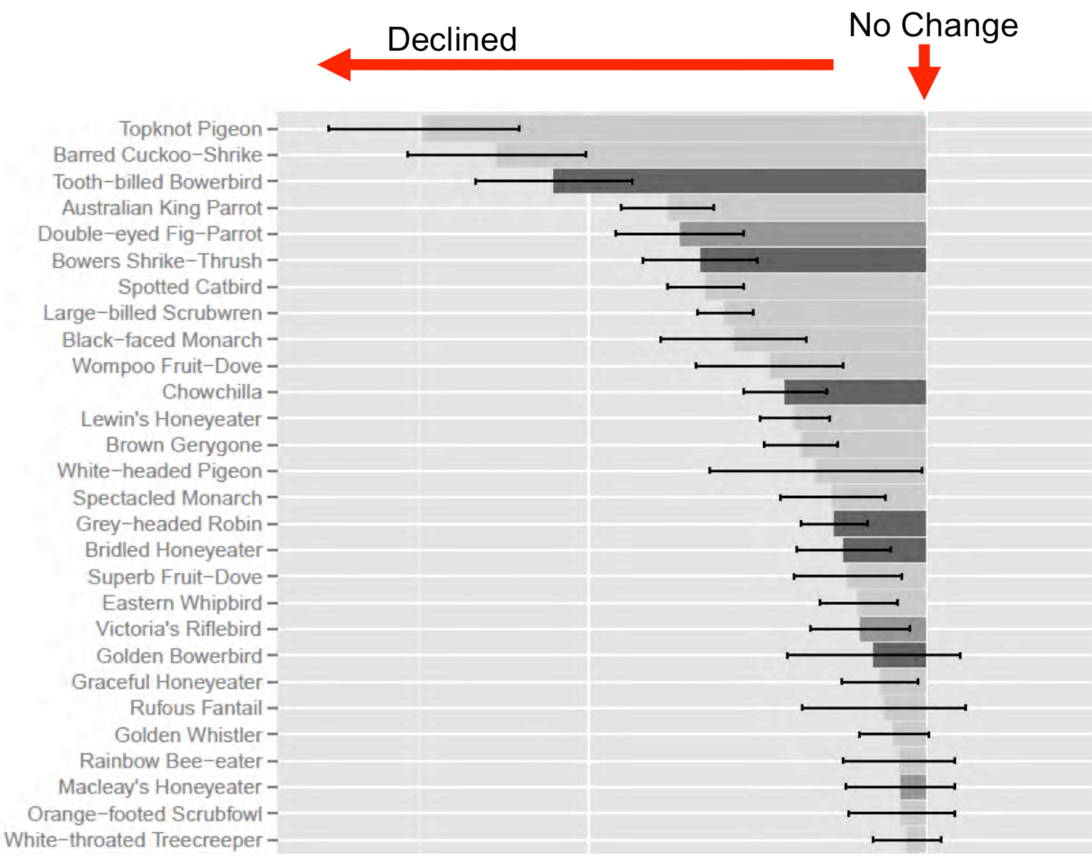

Figure 2. Bird Population Declines in the AWT. A representation of relative declines in bird populations over the last 10 years in the Australian Wet Tropical bioregion. For example, Bridled Honeyeater experienced a 30% decline in population size across the region (Williams, S., et al 2014)

This pattern is also evident with the mammal species for which there are long-term survey data. Mammal populations also show declines and upward distributional movements notably in a number of montane possum species. The rainforest endemic possums most at risk are the Herbert River ringtail possum (*Pseudocheirus herbertensis*), both the northern and southern WT populations of the Lemuroid ringtail possum (*Hemibelideus lemuroides*), the Green ringtail possum (*Pseudochirops archeri*) and the Daintree ringtail possum (*Pseudocheirus cinereus*). These endemic rainforest species are restricted to the upland areas and, as a consequence, occur as a number of isolated populations. For example, the southern population of the lemuroid ringtail possum occurs only above 550 metres on the Atherton Tableland. The smaller northern population of the lemuroid ringtail possum occurs only above 1,000 metres on the Mt

Carbine Tableland and is characterised by a greater proportion of white furred individuals. Some lowland mammal species have already expanded their distributional ranges into higher elevations and these trends and shifts are being detected with only an approximate 0.1 degree Celsius increase in average temperature.

As well as documenting changes that are already occurring in the Wet Tropics, the vulnerability and resilience of individual species and landscapes under different climate change scenarios were predicted. By considering the biological traits of the species and using sophisticated spatial analyses, the research has identified which species and areas require priority management focus, both now and into the future. Using IPCC temperature projections, the research forecasts significant changes in the conservation status of Wet Tropics vertebrates under a 'business as usual' scenario with considerable increases in the number of extinct, critically endangered, endangered and vulnerable species expected. The modelling suggests that this can be countered by a reasonable mitigation approach which would greatly strengthen the resilience of the threatened fauna.

2.1.2 Critically endangered frogs

Ten frog species disappeared from the upland rainforests of the Wet Tropics and Eungella during outbreaks of amphibian chytrid fungus (*Batrachochytrium dendrobatidis*) in the late 1980s and early 1990s, representing 25% of the frogs endemic to the Wet Tropics and all of the Eungella endemic frogs. Five of these species occurred only in the uplands and have been presumed extinct because no individuals have been found despite intensive and targeted searches. This represents a significant loss of endemic species diversity, particularly in the WTWHA. One of these 'presumed extinct' rainforest frog species, the Armoured Mistfrog (*Litoria lorica*) was recently rediscovered in high elevation dry sclerophyll forest close to rainforest sites it vanished from. This rediscovered population was found to be co-existing with chytrid fungus, suggesting that these species can persist with the pathogen under some environmental situations. This unexpected discovery was the impetus for undertaking further surveys to ascertain population status of these critically endangered and presumed extinct frog species. This rediscovery strongly suggested that other missing frogs may still be out there (including *Litoria nyakalensis, Taudactylus acutirostris, Taudactylus rheophilus* and even the Northern Gastric Brooding Frog *Rheobatrachus vitellinus*) but may have been overlooked because searches have focussed on rainforest and not the adjacent dry forest.

Until now, ecotonal dry forests bordering rainforest had rarely been surveyed for these frog species. These environmentally different sites are key to understanding how frogs can survive through disease outbreaks. These ecotonal and peripheral areas are also poorly surveyed for vertebrates in general and represent a gap in our biodiversity knowledge. A number of frogs declined dramatically during disease outbreaks but persisted in the lowlands (e.g. *Litoria nannotis, Litoria rheocola* and *Nyctimystes dayi*). Recent surveys suggest that some of these species are starting to reappear at historic upland rainforest sites. It is very important to know to what extent and where this is occurring and whether it represents population recovery. To gain such knowledge, rigorous, targeted surveys for the missing, critically endangered and endangered rainforest frog species of the Wet Tropics and Eungella have been undertaken. All vertebrates, in addition to frogs, were surveyed at all of the sites.

As a result of the extensive targeted surveys, it can be concluded that two Wet Tropics frogs (*Taudactylus acutirostris* and *Litoria nyakalensis*) and one frog of the Eungella rainforest (*Rheobatrachus vitellinus*) should be presumed to be extinct. This is also the likely conclusion for *Taudactylus rheophilus*, pending analysis of automatic call recording boxes currently deployed on Mt Bellenden Ker. No further populations of the rediscovered critically endangered species *L. lorica* were found. A second wild population was created by reintroducing frogs to another suitable site. The reintroduction of *L. lorica* was performed in two phases and monitoring indicates frogs are surviving at the new site. Continued monitoring is required over the next two years at least (2015, 2016) to determine whether sufficient frogs are surviving and breeding to establish a viable second wild population. The success or failure of this reintroduction attempt will be informative for the potential use of this management action for other critically endangered frogs.

The open forest ecotonal areas that form the western periphery of the Wet Tropics harbour significant populations of some endangered stream frogs (*L. nannotis, L. rheocola, L. lorica*). These populations are typically more abundant than those in adjacent upland rainforest areas where they were common pre-decline, and ecotonal populations occur in some areas where species did not persist in the rainforest (e.g., *Litoria nannotis* at Windsor Tableland; *L. lorica* at Carbine Tableland). These ecotonal populations persist despite high prevalence and infection loads of chytrid fungus. Few frogs show clinical symptoms of disease and the frogs are likely tolerating infection due to relatively high environmental temperatures at these sites. There is also some evidence for population recovery of two species (*L. nannotis, L. rheocola*) in parts of the central and northern Wet Tropics. This is particularly the case on the western Carbine Tableland where these species now occur at some upland rainforest sites they disappeared from during the initial disease declines. Continued monitoring of select sites is required to establish the extent of this recovery. The results of this project suggest changes in status/listing should be considered for a number of rainforest stream frogs. This includes upgrading the listing of some species and downgrading others. See Table 1 for details.

Table 1. Current and recommended listings for threatened rainforest stream frogs. Current listings are EPBC (national) and NCA (state). Categories are: Ex = extinct, CE = critically endangered, E = endangered, V = vulnerable, NT = near threatened, - = not listed. NCA (QLD listing) does not include the category 'critically endangered'. Bold in the final column marks recommended listing that requires a change in current listing. *Pending results for T. rheophilus from automatic call recording boxes currently deployed (Hoskin & Puschendorf, 2014).

Species	EPBC listing	NCA listing	Recommended
Taudactylus acutirostris	Ex	E	**Ex**
Taudactylus rheophilus	E	E	**CE/Ex***
Litoria nyakalensis	CE	E	**Ex**
Litoria lorica	CE	E	CE
Litoria nannotis	E	E	**V**
Litoria rheocola	E	E	**V**
Litoria dayi	E	E	E
Litoria myola	E	-	**CE**
Rheobatrachus vitellinus	Ex	E	**Ex**
Taudactylus eungellensis	E	E	E
Taudactylus liemi	-	NT	**V**

The surveying of peripheral areas gained many new vertebrate records, including important new sites for threatened species. Of particular note was the discovery of three new vertebrate species at Cape Melville: the Blotched Boulder-frog (*Cophixalus petrophilus*), the Cape Melville Rainbow Skink (*Carlia wundalthini*), and the Cape Melville Bar-lipped Skink (*Glaphyromorphus othelarrni*). The names were chosen in collaboration with the Traditional Owners

The persistence of endangered frogs in peripheral areas highlights the value of these areas for the short- and long-term resilience of the WTWHA. Environment and species interactions are different in these areas compared to core rainforest areas, potentially resulting in a greater ability of populations in these areas to persist through, and adapt to, change. Many of these peripheral areas fall outside the WTWHA, so management of these areas requires collaboration with parties neighbouring the protected areas of the WTWHA particularly Traditional Owners, private landowners and land management agencies. The research has shown the value of maintaining and improving links between a spectrum of habitats to enable recovery and recolonisation of species. Finally, the devastating impact an introduced fungus had (and continues to have) in driving declines and extinctions of populations and species is highlighted. Broadly, this brings attention to the importance of on-going biosecurity efforts in limiting the introduction of exotic species.

2.1.3 Southern Cassowary

The Southern Cassowary (*Casuarius casuarius johnsonii)* is listed as Endangered under Commonwealth legislation and has long been the focus of conservation concern in Australia. This large bodied (up to 74 kg) flightless bird, occurs at low densities, is dependent on closed tropical forests that are of limited extent in Australia, and is one of Australia's few specialist frugivorous species that play a critical role in tropical forests as seed dispersers (Westcott, 2014).

Prior to NERP, cassowary population estimates were based on data more than two decades old (Crome and Moore, 1990) and extrapolations and ad hoc modifications of this (Moore 2007). Decisions for cassowary protection and management have previously been made based on assumed numbers and continuing declines in abundance (e.g. WTMA 2002, 2007, 2009) in the absence of data. A systematic, objective and transparent monitoring program together with technology advancements, have enabled the implementation of a monitoring methodology based on the DNA fingerprinting of cassowary dung. This method significantly improves upon the approach that has underpinned cassowary management over the last decade by quantifying the relationship between cassowary sign and the density of birds in an area. The NERP research has provided updated data on species abundance and distribution.

Cassowary habitat was surveyed twice a year over a three year period, traversing approximately 2,000 kilometres of transects. All cassowary encounters, including sightings and signs of activity, collected feathers and dung were recorded. DNA was then extracted to identify individuals. Overall detection rates were low. The research by Westcott (2014) suggests that the cassowary population of the Wet Tropics Region is comprised of approximately 4,400 birds with a minimum of 5% of these being young of the year. While this is a larger population than is commonly reported in the media, it is by no means a large population for a species of this kind and there is no reason to be complacent about the species status.

The sub-regional approach indicates a final population estimate of 4,381 (4,059-4,707 95% CI range, precision 15%) cassowaries with the greatest numbers of birds being found in the largest forest blocks, i.e. the Tully, Russell, Koombooloomba and Palmerston sub-regions (Table 2). There was evidence (sign) of cassowaries in all sub-regions with the exception of Mt Windsor. Dung was collected from all but six regions; Cairns, Paluma, Ingham, Wallaman, Carbine and Mt Windsor. The failure to detect cassowary dung in the three southern sub-regions (Paluma, Ingham and Wallaman) is likely a reflection of actual low numbers resulting from the direct and indirect impacts of Cyclone Yasi (2011) and is consistent with reports from locals that cassowaries are less frequently encountered since that event. The failure to detect any sign of cassowaries at Mt Windsor probably reflects reality given the complete lack of records or reports of cassowaries in this sub-region, despite significant forestry, research and grazing activity over the last 70 years (Westcott & McKeown, 2014).

Table 2. Dung encounter rates, estimated densities and estimated populations for each of the sub-regions (Westcott & McKeown, 2014)

Sub-region	Mean dung encounter rate (dungs/km)	Cassowary density (birds/km^2)	Area (ha)	Estimated Population
North	0.13	0.22	35,147	79
Windsor	0.00	0.04	18,470	0
Daintree	0.25	0.39	27,691	109
Daintree River	0.02	0.07	78,750	59
Carbine	0.00	0.04	18,428	8
Black Mountain	0.06	0.12	29,962	37
Kuranda	0.09	0.17	11,939	21
Cairns	0.00	0.04	14,304	6
Mt Edith	0.07	0.14	25,454	36
Goldsbourough	0.06	0.13	33,033	43
Russell	1.07	1.55	39,535	614
Longlands	0.22	0.35	26,769	94
Bramston	0.55	0.81	19,878	162
Palmerston	0.34	0.52	63,526	333
Koombaloomba	0.75	1.11	47,404	527
Etty	0.30	0.47	8,247	39
Mission Beach	0.74	1.09	17,184	187
Tully	1.26	1.82	109,230	1,986
Ingham	0.00	0.04	39,530	17
Wallaman	0.00	0.04	21,072	9
Paluma	0.02	0.07	22,050	15
Total	-	-	707,603	4,381

The cassowary population in the Wet Tropics is distributed across a complex and highly fragmented landscape. While cassowaries are capable of crossing the habitat gaps, their ability to do so is being increasingly impacted upon by human activities and changes to the landscape, in particular roads. These two characteristics, small population size and fragmented range, are factors given high priority in increasing a species' threat status under classification systems such as the IUCN's Red List criteria (IUCN 2010). This should be sufficient cause for concern alone, however, under projections for the distribution of cassowary habitat under future climates (Mokany et al. 2014; Mokany et al, in press) it appears inevitable that essential cassowary habitat will decrease in area and increase in the degree to which it is fragmented. Add to this the predictions of more intense cyclones (Hilbert et al. 2014) and the outlook is not encouraging.

2.1.4 Spectacled flying-fox

In Australia, the spectacled flying-fox is restricted to tropical rainforest areas of north eastern Queensland with the largest population located in the Wet Tropics Bioregion and a much smaller population on Cape York in the Iron and McIlwraith Ranges. The species is listed as Vulnerable under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* and is the subject a national recovery plan to secure its long-term protection. Major threats to its population include loss of habitat and conflict with humans. The issue of conflict between flying-foxes and humans is not new in the Far North, or elsewhere in the Australian range of other flying-fox species. Historical references report damage to crops and from the early 1900s onwards cites efforts to remove flying-fox populations from urban centres in north Queensland. Despite a long history of persecution, there is no evidence to suggest that these efforts have had lasting success with crop damage still reported and flying-foxes still a significant management issue in urban areas.

The monitoring program that underpins this research is the only long-term, distribution-wide, flying-fox monitoring program in the world, and has been providing monthly data on population abundance and distribution across the species Wet Tropics range since 2004. The research has identified that spectacled flying-fox populations in the region are in a long-term decline. The long-term negative trend exhibited by the spectacled flying-fox is a significant cause for concern with the analysis suggesting that between 82,000 and 140,000 animals have disappeared from the population over a ten year period. The population counted in the first year of the monitoring was the highest recorded in the study with a maximum estimate in March of 2005 of 274,000 animals. In the following year this maximum estimate dropped to 214,750 and has fluctuated between 203,722 and 125,000 over the subsequent 9 years. Despite a concerted telemetry program to test the hypothesis that this decline reflected animals moving to unmonitored camps, few new camps have been found and these are all relatively small. This suggests that the decline is real.

Over the period of this research it has become clear that spectacled flying-foxes are urbanising, something that has been suggested but not shown, for other flying-fox species in eastern Australia. Given that this species has a long association with urban areas it is difficult to explain why this pattern would be emerging at this particular point in time. The research was able to test and reject a number of hypotheses for the species urbanisation, including: i) encroachment of urban areas on camps, ii) the gradual shift of camps towards urban areas, iii) loss of camps and camp habitat necessitating a move to urban areas. Alternative, and yet untested, explanations include, lower predation, better environments, and reduced human persecution in urban areas.

Despite the failure of past management efforts to dissuade flying-foxes from crops and urban areas, the management approaches employed have doggedly remained the same. In general terms these have been, manage the animals or manage the trees. A third option, managing the people, is rarely considered. With history showing that the expense and effort already invested in trying to move flying-foxes has provided little long-term relief, this research reinforces the need to better understand the drivers underpinning the urbanisation of this vulnerable species and the need to seek new approaches to living with these unique animals.

The data produced by this research on the dynamics of particular camps and the population as a whole continues to be called upon for decision making at all levels of government, it has underpinned the development of policy, and has informed the design and development of the Australian Government's National Flying-Fox Monitoring Program.

While this monitoring program has provided a good estimate of spectacled flying-fox population sizes thus far it has also identified a long term decline. This is a particular concern given the conflict surrounding the species. Monitoring needs to be continued to i) allow confirmation of the trend and ii) to allow monitoring of the impact of management, either to control the impacts of the species or to support its conservation, on the species population dynamics.

2.1.5 Mahogany Glider

Mahogany gliders (*Petaurus gracilis*) are listed as Endangered under both Commonwealth and State legislation. It is ranked as a critical priority under the Department of Environment and Heritage Protection (EHP) Back on Track species prioritisation framework. The species is restricted to the coastal southern Wet Tropics region of northern Queensland living in a narrow and highly fragmented strip of coastal lowland sclerophyll forest extending around 140 km from Toomulla, north of Townsville, to Tully and up to 40 km inland. Most recorded sightings have been at altitudes below 120 metres. The mahogany glider requires a relatively open forest structure for efficient gliding and tends to avoid dense vegetation such as rainforest (Department of Environment and Heritage Protection, 2015).

Unfortunately, approximately half of their habitat has been cleared with the gliders naturally occupying only some of what remains. Despite the establishment of legislation to protect the remaining habitat of the species, regional ecosystem mapping identified the true extent of habitat loss from clearing as well as the extent of habitat degradation due to the transition to rainforest and sclerophyll thickening. The total area of habitat available to mahogany gliders decreased by 49%, from 276 880 to 141 122 ha (from pre-clearing of 2007 to mapping in 2011), as a result of clearing of vegetation for agriculture and other human activities. The loss of habitat occurred mostly on freehold land where it has decreased from 129 435 ha to 26 852 ha. The impact of a large reduction in habitat area and decreasing habitat suitability has been compounded by habitat fragmentation (Jackson, 2011). Additionally, one third of the remaining mahogany glider habitat is expected to be lost due to impending vegetation thickening. Rainforest thickening occurs in the absence of fire in the landscape and is a major threat to the mahogany glider.

Fire can be seen as having a profound impact upon mahogany glider habitat, although the actual impact depends entirely upon: 1) the degree of invasion from rainforest species; 2) the time since the last fire once invasion had begun; and 3) the severity of the fire. In areas where rainforest invasion is low and fire frequency is high (2-4 years), habitat is usually maintained. However, once invasion is advanced and rainforest species are capable of resprouting the effectiveness of a fire is much reduced, so much so that grass and herbs can no longer persist in the new vegetation type as the canopy cover has shaded the sun-loving species out. Resprouting rainforest plants is not a new phenomenon, and the research recorded 41 species (or 81% of all resprouting species) of rainforest plants which survived a fire. Such data would suggest that once mahogany glider habitat has been heavily invaded it will never return to its original structure and floristics. A single fire, even a catastrophic one, will not promote grass to return and the majority of rainforest species will resprout and germinate quickly and recapture the site before a sclerophyll strata can return. Following a fire, species diversity at the majority of sites increased dramatically, due to germination and recruitment of opportunistic herbaceous species and species which remain dormant in the soil seed bank. It would appear that it is critical to retain existing good quality habitat with frequent low intensity fires. These fires will kill recently germinated seedlings of rainforest plants and promote sclerophyll maintenance. Thus, management of these habitats is crucial to ensure continued suppression of rainforest plants in sclerophyll forests and ensure mahogany glider habitat.

Monitoring vegetation response to management fires in rainforest-invaded woodlands formerly occupied by critically endangered Mahogany gliders suggests that an unexpectedly high proportion (81%) of rainforest species sucker or reshoot after a single fire, even if intense, and thus once such woodland habitat has been ‘captured’ by rainforest invasion, sporadic fires will not return it to a pre-invasion state. Consequently, prioritisation must be given to scheduled burning of high value Mahogany Glider habitat to prevent the absence of fire from further impacting this species.

2.1.6 Flora biodiversity

The rainforests in FNQ are internationally renowned for preserving one of the most complete and continuous records of Earth’s evolutionary history and harbours much of the remaining Gondwanan flora that was once widespread across the continent. Conserving genetic diversity ensures species will be more resilient to environmental change, will be less impacted and will recover faster from current and future unknown threats. Quantifying genetic diversity and its spatial distribution is essential for managing and prioritising biodiversity and for identifying and assessing stable evolutionary refugia and other priority conservation areas.

Mountain tops and high altitude plateaus across the Wet Tropics have been considered relatively stable through glacial cycles and these upland regions have provided refugia for rainforest throughout the major climatic fluctuations of the quaternary. The long term environmental stability of the region has allowed the persistence of endemic species, but it is now thought that these upland areas are especially vulnerable to climate change.

At the landscape scale, two main areas, the Mossman - Daintree and the Tully headwaters - Mission Beach areas, known to have ancient lineages of plants represented, have as expected shown up as particularly rich phylogenetically (Figure 3). However, the Daintree region has a lower than expected diversity, whereas Tully is higher than expected. As a consequence of differing evolutionary histories of these regions, the Tully area seems to have received an influx of northern hemisphere plant lineages that migrated into northern Australia in the last 15 million years, whereas the Daintree seems to have been the archetypal refugium for Gondwanan plants and fewer of the immigrant lineages were able to establish and persist there. Other notable areas are immediately south and west of Cooktown and the southern parts of the Paluma Range which showed relatively low overall diversity, but nonetheless much higher than expected. This suggests areas such as this have higher conservation significance than their species numbers alone would indicate.

Initial results from the finer scale research are more concerning. There are seven high altitude areas in the Wet Tropics that are of particular importance because they are the only known habitat for at least 33 plant species. Of the 19 Wet Tropics endemics modelled, 13 occur on Mt Lewis, and five of those are found only there and nowhere else (Table 3).

Table 3. Important upland habitats for endemic plants above 1,000 metres (Crayn & Costion, 2014)

Locality	Elevation (m)	Wet Tropics Endemics*	Local Endemics**
Mt. Lewis	1,383	13	5
Bartle Frere	1,622	8	2
Bellenden Ker	1,590	7	1
Thornton Peak	1,338	4	0
Mt. Finnigan	1,148	4	0
Lamb Ranges	1,308	2	0
Windsor Tableland	1,356	2	0

*Wet Tropics endemics are those species which are restricted to two or more mountains in the Wet Tropics.
**Local endemics are those species which are restricted to one mountain only.

Mapping the total area of suitable habitat predicted now and for 2040, 2060 and 2080 using best-case and worst-case IPCC4 emissions scenarios, preliminary results predict precipitous declines in the extent of suitable habitat for all 19 species, forecasting a minimum decline of 85% by 2060 and 96% by 2080. The Mount Carbine Tableland, the richest refugium for these plants, could lose its entire suite of endemic species by 2080, including the five species found nowhere else on Earth. There will be considerable loss in suitable habitat for all 19 species of mountain top endemics, and for eight species this may occur as soon as 2040, five of these are only known from the Bartle Frere-Bellenden Ker system (*Cinnamomum propinquum*, *Eucryphia wilkiei*, *Solanum eminens*, *Syzygium fratris*, *Tasmannia sp.* Mt Bellenden Ker). By 2080, all but four species are projected to be without suitable habitat. Three of these (*Cryptocarya bellendenkerana*, *Elaeocarpus linsmithii*, *Uromyrtus metrosideros*) are among the most widespread of the 19 species. The results for the mountain endemic species are only preliminary at this stage, but suggest that all assessed species may qualify for Critically Endangered status under the IUCN Red List conservation assessment process (Table 4).

Table 4. Projections of habitat disappearance under one emission scenario

Species	Current total suitable habitat (ha)	2040 % Decline	2060 % Decline	2080 % Decline
Austromuellera valida	1154	0-83%	0	75-96%
Cinnamomum propinquum	7138	99.6-100%	99.9-100%	100%
Cryptocarya bellendenkerana	12980	78-86%	93-96%	97-99%
Diospyros sp. Mt Spurgeon	8457	83-99%	99.5-99.9%	100%
Elaeocarpus linsmithii	8457	75-95%	93-98%	97-99.5%
Elaeocarpus sp. Mt Misery	12467	89-99.7%	99.8-99.9%	100%
Eucryphia wilkiei	716	98-100%	100%	100%
Micromyrtus delicata	9053	100%	100%	100%
Phaleria biflora	4380	99.2-100%	100%	100%
Planchonella sp. Mt Lewis	3954	95-100%	99.6-100%	100%
Polyosma sp. Mt Lewis	12498	90-99.1%	99.9-100%	100%
Solanum eminens	299	100%	96-100%	100%
Symplocos graniticola	12119	64-100%	85-99.8%	99.6-100%
Symplocos orbesia	11247	94%	99.2-99.9%	99.9-100%
Symplocos bullata	7340	99%	99.9-100%	100%
Syzygium fratris	790	95-100%	99.9-100%	100%
Tasmannia sp. Mt Bellenden Ker	5270	86-100%	95-100%	97-100%
Uromyrtus metrosideros	13055	63-71%	86-95%	97-98%
Zieria alata	8047	94-99.9%	100%	100%

* The results of this study should be regarded as preliminary and further research is needed to confirm.

These results are consistent with previous work by Williams, et al (2003) that found increased temperatures would result in significant declines in species richness of vertebrates endemic to the upland habitats of the Wet Tropics region.

2.2 Understanding ecosystem function and cumulative pressures

Regional Ecosystems are combinations of vegetation types which are consistently associated with particular combinations of geology, landform, soil and climate. They provide a basis for bioregional planning and for prioritising conservation efforts. The conservation status of the 105 Wet Tropics Regional Ecosystems includes: 24 endangered (less than 10 percent of the pre-European extent remains intact); 17 of concern (10-30 percent of pre-European extent remains intact); and 64 of no concern at present. Of the 105 Regional Ecosystems in the Wet Tropics bioregion, 94 are represented in the WHA, as are 18 of the 24 endangered ecosystems and all 17 that are 'of concern'. Endangered and 'of concern' ecosystems make up 141,000 ha (7%) of the bioregion. Most endangered ecosystems are on the coastal lowlands or the tablelands where clearing and drainage have drastically reduced their distribution. Mabi forest (RE 7.8.3) was the first Wet Tropics ecological community listed as endangered under the EPBC Act 1999 (Wet Tropics Management Authority, 2015).

Increasing the understanding of ecosystem function and the impact of synergistic and cumulative pressures is essential in developing effective management responses that promote ecosystem resilience. Critically Endangered threatened ecological communities within the Wet Tropics now require adaptive management actions to preserve their existence and connectivity including Mabi forest and the littoral rainforest and coastal vine thickets of eastern Australia (LR&CVToEA). Invasive weeds and feral pigs plus the areas projected to be impacted most by extreme weather events under climate change are priorities for management action and the future conservation and protection of these regional ecosystems of the Wet Tropics bioregion.

2.2.1 Coastal Littoral Rainforest

Littoral rainforest is found along the eastern coast of Australia from Cape York Peninsula to Victoria as well as on offshore islands. It occurs on a range of landforms which have been influenced by coastal processes including sand dunes and headlands. The defining feature of littoral rainforest is the influence of salt on the forest, which is delivered via the air, groundwater or occasional inundation. Littoral rainforest is listed as a Critically Endangered Threatened Ecological Community under Commonwealth legislation. Many remnant areas are fragmented and what remains is threatened by a range of factors including weed invasion, clearing and fire. Following the destruction to the Wet Tropics caused by Cyclone Yasi in 2011, the research in this area has focused on mapping the extent of littoral rainforest in the region. The extent of littoral rainforest in the Wet Tropics bioregion appears to be greater than the EPBC Listing Advice for Littoral Rainforest & Coastal Vine Thickets of Eastern Australia (LR&CVToEA) would suggest. This means that more of this critically endangered resource exists, but also means that those areas of it not yet formally identified are at risk of further loss.

Littoral rainforest and coastal vine thickets in the Wet Tropics bioregion are probably Australia's most species-diverse, extensive and tall littoral rainforests, the best connected to other rainforests, and the most cyclone-affected. Some patches are within the WTWHA and most are adjacent to the Great Barrier Reef World Heritage Area. They epitomise "where the rainforest meets the reef". They provide habitat for endangered and/or iconic fauna such as the southern cassowary and peppermint stick insect. Littoral rainforest and coastal vine thickets protect areas from erosion, filter sediments, nutrients and pollutants, mitigate the effects of flooding and wind during storm events, and provide supporting habitat for biodiversity. Littoral vegetation and natural dune structures also provide protection to coastal communities, beaches, infrastructure, and agriculture and aquaculture industries as vegetation attenuates waves and reduces the strength of storm surge. Other ecosystem services include the provision of shade, nesting sites and food resources for fauna, migration capacity for endemic and iconic species, and cultural and aesthetic services. Wet Tropics littoral rainforests represent a rare opportunity for proactive conservation of a relatively healthy ecological community that elsewhere is critically endangered (Metcalfe, et al, 2014).

A number of recommendations were made to improve existing mapping of LR&CVToEA, and a report has proposed alternative regionally-specific approaches that more comprehensively identify areas of littoral rainforest which should be recognised as compliant with the intentions of the listing advice. For more information see Metcalfe, D.J., O'Malley, T., Lawson, T.J. & Ford, A.J. (2014) *Mapping Littoral Rainforest & Coastal Vine Thickets of Eastern Australia in the Wet Tropics: Mission Beach Pilot Study.* Report to the National Environmental Research Program.

2.2.2 Mabi Forest

Mabi Forest has been listed as a Critically Endangered Threatened Ecological Community under Commonwealth legislation. It is also listed as an Endangered regional ecosystem (RE 7.8.3 and RE 7.3.37) under Queensland's *Vegetation Management Act 1999*. Mabi Forest is also known as Complex Notophyll Vine Forest 5b. Around 80% of Mabi forest has been cleared and what remains is highly fragmented, both internally, from roads and clearings, and externally. There is only 1,050 hectares of Mabi Forest left in a series of small isolated patches on the Atherton Tablelands, between the towns of Atherton, Kairi, Yungaburra and Malanda. There is also a small patch located at Shiptons Flat, south of Cooktown. Many of the remnant patches are being invaded by exotic vine and feral and domestic animals. Mabi Forest only occurs on highly fertile basalt soils located at the lower rainfall limit of rainforest distribution in the region and is characterised by a high proportion of deciduous and semi-deciduous canopy trees (which exhibit heavy leaf fall in times of moisture stress), along with a dense, well-developed understorey shrub layer. It is the dense shrub layer that is an important habitat for up to 114 bird species. Thirteen plant and 12 animal species that occur in Mabi Forest are listed as threatened nationally or in Queensland including the nationally threatened Spectacled Flying-fox and the Large-eared Horseshoe Bat. The Southern Cassowary and Musky Rat-kangaroo were once known to inhabit Mabi Forest as well but the area is now too small for these species (Department of Environment, 2004).

The research has shown fire in Mabi forest could be effective in weed control and in promoting tree recruitment (Metcalfe, *et al.* 2014). However, controlled burns are not permitted in Mabi Forest due to its small size and EPBC status. Preliminary analysis of experimental burning of Mabi forest litter under controlled environmental conditions suggests that the rainforest litter has a moisture content of fire extinction in the region of 13-15%, well below that of dry eucalypt which is around 20-25%. The fire tends to burn itself out and does not feed off additional leaf litter even with small winds pushing the fire. This finding underpins the observation that Mabi forest rarely burns whilst adjacent eucalypt woodland burns regularly. It also highlights that Mabi litter will propagate fire under extreme climatic conditions, and as such that charcoal, anecdotal evidence and traditional ecological knowledge does indicate that fire occurs in Mabi forest, albeit infrequently. The effects of these occasional fires, and the value of fire as a management tool for maintaining ecosystem health and weed control, need further study.

2.2.3 Invasive plant species

Land managers in the Wet Tropics region have increasingly recognised the necessity for a regional-scale, strategic approach to prioritising and managing invasive species that incorporates the complexity of ecological processes driving invasions and takes account of the spatial and temporal scale of invasion (see also Section XX Climate Change and Section 2.2.4). In this project we have used modelling approaches to assess the long-term costs and likely effectiveness of alternative strategies for managing invasions and in particular, where, when and why managers might shift their focus from eradication to containment. We derived rules to guide land managers in determining the circumstances under which a containment strategy is likely to be more effective or efficient than an eradication strategy, the effect of a breach of the management unit on each type of management strategy, and the situations in which containment would form a valid fall-back strategy if eradication is no longer feasible.

Eradication versus Containment Strategies

Containment is a frequently advocated strategic objective for countering plant invasions. The goal of containment is to prevent establishment and reproduction of a species beyond a predefined area, whereas eradication aims to remove all individuals of a species. Containment is often perceived as a valid fall-back option when eradication has failed or is deemed impossible with the available resources. However, many infestations are likely to be no more amenable to containment than eradication, because the ecological drivers that determine containment success are the same as those that limit successful eradication, e.g. seed-bank persistence, dispersal mechanisms and capacity, and detectability.

While containment has one major advantage over eradication, in that a smaller area can be managed, this must be balanced against its disadvantage; that it must continue indefinitely. The modelling has shown how different invasions will be more effectively managed by either eradication or containment based on the soil seed longevity, the discount rate, and most importantly, the size of the infestation relative to the width of the buffer zone which is defined by dispersal capacity. Thus, invasive species with long soil seed bank lifetimes in economic systems with high discount rates will tend to be better managed with containment than eradication. Crucially, there is a threshold invasion size below which it will be better to eradicate than contain, and above which the opposite is true. The two management strategies incur very different additional costs if they experience an unexpected breach.

It is vital that sensible decisions are made about whether a species can be contained with the resources available, and whether containment is the best option for a species given characteristics of dispersal, seed longevity, the size of the infestation and the logistics of containment such as detection, accessibility and other factors. Decisions about containment strategies for invasive plants should consider:

1. Containment strategies should employ containment units that are scaled to suit the species dispersal capacity in the specific environment where it is growing.
2. Containment should not be assumed to be easier than eradication, cheaper than eradication or an achievable fall-back option when eradication is judged no longer feasible.
3. Containment is not necessarily a valid fall-back option following a breach of an eradication strategy.
4. Managers should assess the likely long-term costs of both eradication and containment for each particular species and invasion context.

5. Weed management plans must apply a consistent definition of containment and provide sufficient implementation detail to assess its feasibility.
6. It is critical to have a good understanding of the key components underpinning a successful containment strategy and to have the capacity to adapt quickly as better knowledge is gained.

2.2.4 Feral Pig Management

The total number of feral pigs in Queensland is not accurately known but estimates range from 3-6 million, with the majority in North Queensland. Population densities in the Wet Tropics were estimated at 3.1 per square kilometre (DAFF, 2008). The feral pig population in the Wet Tropics has been notoriously difficult to control. They are mobile, widely distributed and breed quickly. Pigs are responsible for ecological damage and are a major vector of weeds, pathogens and parasites (Wet Tropics Management Authority, 2015).

A quantitative computer-based model of pig dynamics in the Wet Tropics landscape developed in 2014 reproduces the basic observed demographics of pig populations in the region, including birth rates, population densities and age structure, and simulates the distribution of the population and follows the life stages of individual pigs on a simplified representation across the actual landscape. Each individual pig is assigned a home range which it autonomously searches to optimise its consumption of food, water and shelter resources. When a pig consumes food resources it gains energy but when it moves it uses energy. If it runs out of energy it dies and if a sow gains enough energy she can reproduce. The distribution of food, water and shelter resources in the landscape is determined by the observed land use structure in the area. Six land use types are considered: forest, sugar, bananas, grazing, wetlands and cleared or urban land, each of which provides food, water and shelter resources that vary seasonally (Fletcher, ?).

The model also incorporates management actions, including baited trapping. Baited trapping is implemented in the model similar to its operation in the real world, using bait more attractive than the surrounding landscape to attract individual pigs within the model to a trap location. The effectiveness of trapping actions can be compared to the six years of trapping data collected by the on-ground stakeholders, Terrain NRM. Taking into account the spatial interaction between pest populations and management actions has led to improved management outcomes for feral pig invasion within the northern region.

In the field, an array of 20 fenced and 20 unfenced wild pig vegetation monitoring plots have been monitored bi-monthly since establishment in early 2013 and the third complete census of vascular plants was conducted in February 2014. A total of 72 weeks camera trapping was downloaded. Camera trapping and records of footprints, disturbance and scats indicate that wild pigs have been present at the study site throughout the study period (2013-2014). Preliminary data analysis indicates no difference in the trends of seedling diversity or recruitment between fenced and unfenced plots. Further refinement of the quantitative model and continued field monitoring will continue in collaboration with Terrain NRM to assist landowners and government agencies in better management actions and control of the feral pig population in North Queensland.

2.2.5 Extreme events

While gradual changes in climate means will have numerous effects on a range of environmental, social, and economic sectors, emerging evidence shows that many of the impacts of anthropogenic climate change will arise from shifts in the regimes of extreme weather and climatic events, including heat waves, fires, flooding rain, and cyclones (IPCC, 2013; IPCC, 2012). Such extreme events represent the way in which communities, animals and plants experience climate change (BoM-CSIRO, 2006). However, despite their clear importance for our understanding of climate change impacts (and hence adaptation action), very little is known about the effects of extreme events on natural systems (IPCC, 2012; Welbergen *et al.*, 2008).

Understanding the exposure and sensitivity of Wet Tropics biota to extreme climate and weather events and integrating this information enabled a quantitative assessment of the vulnerability of Wet Tropics biota to extreme temperature events (Figure 3). To date, this is the most comprehensive assessment of the vulnerability of biodiversity to extreme events. This is critical for informing proactive conservation strategies that minimise biotic vulnerability to such events in the face of climate change.

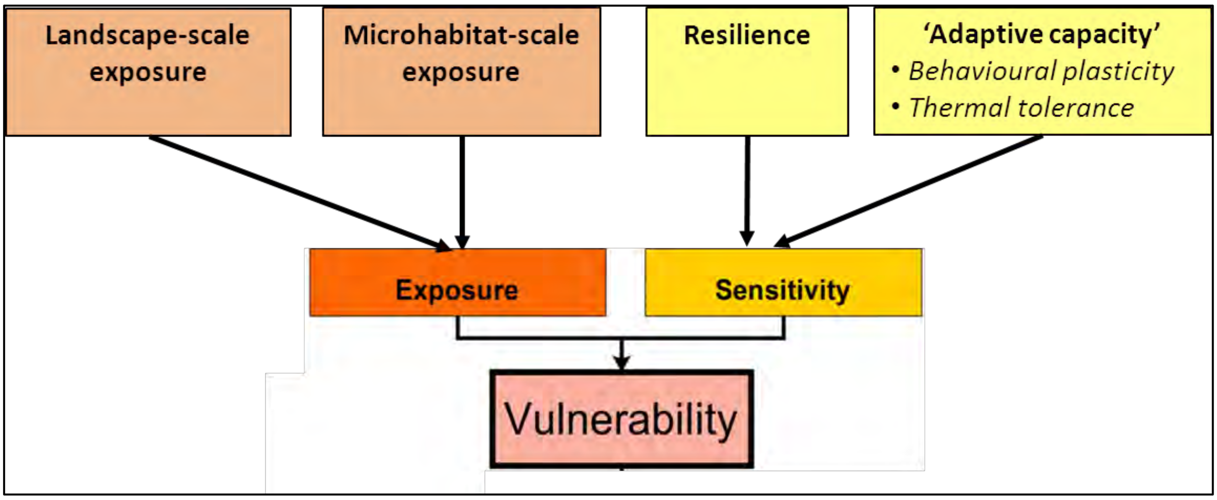

Figure 3. Assessing vulnerability of biodiversity to extreme events (based on Williams *et al.* 2008). Vulnerability is a function of the species' exposure and sensitivity to the impacts of changes in the extremes. Exposure to such impacts is a function of regional changes acting at the scale of populations across their distribution, and of local buffering effects acting at the scale of individuals in their microhabitats. Sensitivity is a function of the resilience of populations to recover from the impacts, and the 'adaptive capacity' (here 'behavioural plasticity' and 'thermotolerance') of individuals in the population to cope with the impacts.

The quantitative assessment revealed areas in the Wet Tropics landscape where species are most (thermal hotspots) and least (thermal refugia) vulnerable to (changes in the regimes of) extreme heat events.

The thermal hotspots showed a high (and encouraging) degree of spatial congruence, with disparate vertebrate groups expected to be vulnerable to extreme heat events in the same specific areas, both at present and in the future. For example, birds, mammals, reptiles and amphibians, are all most vulnerable in and around the Tully River Catchment, and this area also contains large numbers of the least resilient and Red listed species. Thus, by focussing on such areas, species conservation and habitat restoration management can efficiently improve the prospects of these groups simultaneously.

The thermal hotspots are important for habitat restoration and species' conservation because they represent:

- Areas where vulnerable species would benefit most from promotion of thermally sheltered microhabitats, such as understory and logs.
- Areas that may act as a source of relatively heat-tolerant individuals (i.e., 'locally adapted forms'), which are focal individuals for species translocations as a tool for biodiversity conservation under climate change (Hunter, 2007; IPCC, 2007).

The thermal refugia also showed a high spatial and temporal congruence, with representatives from all major taxonomic groups likely to find shelter from heat stress in the same areas both at present and in the future. For example, birds, mammals, reptiles and amphibians, are all expected to all find shelter particularly on Mt Windsor and the Carbine Tablelands, and these areas also contain the highest numbers of the least resilient and Red listed species. Thus, by focussing on such areas, species conservation and habitat management actions can efficiently improve the prospects of many vertebrates simultaneously.

The thermal refugia are valuable for species conservation and habitat preservation management because they represent:

- Areas where specific (assemblages of) (vulnerable) species would currently benefit most from habitat preservation.
- Areas that may act as the destinations of relatively heat-tolerant individuals translocated from thermal hotspots.

The thermal hotspots and refugia also have implications for the management of the intervening landscape matrix. By promoting the connectivity between the thermal hotspots and refugia, this will improve both the resilience and resistance of the Wet Tropics biodiversity to increasingly extreme temperatures under climate change. Connectivity will enable thermal hotspots to be replenished following local extinction from an extreme heat events with individuals from thermal refugia; and it will enable the most heat-tolerant individuals from thermal hotspots to contract to the thermal refugia a heat extremes become more frequent and intense.

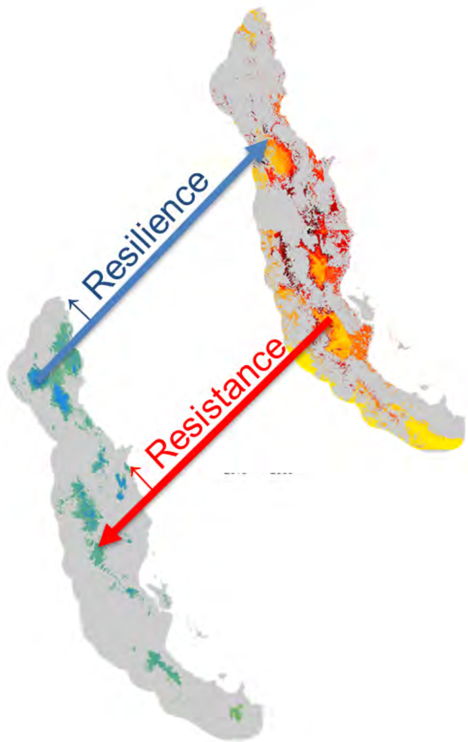

Figure 4. Promoting the connectivity between thermal hotspots and thermal refugia areas. The areas identified are key to enhancing resilience and resistance of the Wet Tropics landscape. Thermal hotspots (a) should be foci for habitat restoration and enhancement; Thermal refugia (b) should be foci for habitat protection. Combined with promoting the connectivity between thermal hotspots and refugia, this will improve the resilience and resistance of wildlife populations to increasingly extreme temperature events.

The research further identified several species of particular concern because they have a large part of their range exposed (Table 5), or have both a high exposure and high 'sensitivity'='vulnerability' (Table 6). A common feature of all these species is that they are mountain top species with small distributions in some of the most stable areas in the Wet Tropics, species already thought to be especially vulnerable to future regional shifts in climatic means (Shoo *et al.* 2005; Shoo & Williams, 2004; Williams *et al.* 2003).

For some such species the future prospects seem particular dire. For example, under the worst case emission scenario (RCP 8.5), 95% percent of the range of the Mountain Top Nursery-Frog *Cophixalus monticola* is expected to be exposed to extreme heat events that currently only affect five percent of the species range. This species also has a very low resilience and little opportunity to seek thermal shelter from heat events, contributing to a high sensitivity and thus high vulnerability of the species.

Table 5. The top 20 species *most* exposed to extreme temperature events by 2085 under the worst-case emission scenario RCP 8.5. An 'extreme temperature event' is defined as a temperature >95th percentile found within the locally coolest microhabitat of a species on a hot, 95th percentile day during the 1976-2005 baseline period. During the baseline period the median value of this exposure is approximately 0.05.

RANK	PROPORTION OF RANGE EXPOSED	FAMILY	SPECIES	COMMON NAME	IUCN STATUS
1	0.952	Microhylidae	*Cophixalus monticola*	Mountain Top Nursery-Frog	EN B1ab(v)+2ab(v)
2	0.797	Gekkonidae	*Phyllurus amnicola*	Mt. Elliot Leaf-tail gecko	NL
3	0.793	Microhylidae	*Cophixalus concinnus*	Beautiful Nursery-Frog	CR B1ab(v)+2ab(v)
4	0.734	Scincidae	*Carlia rhomboidalis*	Blue-throated Rainbow-skink	NL
5	0.725	Scincidae	*Lampropholis mirabilis*	Saxicoline Sunskink	NL
6	0.718	Scincidae	*Glaphyromorphus clandestinus*	Mt Elliot skink	NL
7	0.711	Gekkonidae	*Phyllurus gulbaru*	Gulbaru Gecko	NL
8	0.679	Elapidae	*Furina tristis*	Brown-headed Snake	NL
9	0.562	Microhylidae	*Cophixalus aenigma*	Tapping Nursery-Frog	VU D2
10	0.551	Elapidae	*Vermicella annulata*	Bandy Bandy	NL
11	0.544	Scincidae	*Saproscincus lewisi*	Lewis' shadeskink	NL
12	0.543	Microhylidae	*Cophixalus mcdonaldi*	Southern Nursery-Frog	EN B1ab(v)+2ab(v)
13	0.538	Microhylidae	*Cophixalus exiguus*	Bloomfield Nursery-Frog	NT
14	0.527	Elapidae	*Furina ornata*	Orange-naped Snake	NL
15	0.526	Elapidae	*Demansia psammophis*	Yellow-faced Whipsnake	NL
16	0.524	Scincidae	*Lampropholis robertsi*	Grey-bellied sunskink	NL
17	0.519	Colubridae	*Tropidonophis mairii*	Keelback	NL
18	0.501	Gekkonidae	*Nactus cheverti*	Chevert's gecko	NL
19	0.499	Myobatrachidae	*Limnodynastes peronii*	Striped Marshfrog	LC
20	0.497	Scincidae	*Cyclodomorphus gerrardii*	Pink-tongued Lizard	NL

Table 6. The top 20 species *most* vulnerable to extreme temperature events by 2085 under worst-case emission scenario RCP 8.5 [here 'vulnerability' is defined as the proportion of range exposed (Table 5 above) weighted by 'resilience' (Welbergen et al 2014].

RANK	FAMILY	SPECIES	COMMON NAME	IUCN STATUS
1	Scincidae	*Techmarscincus jigurru*	Bartle Frere cool-Skink	NL
2	Scincidae	*Eulamprus frerei*	Bartle Frere Barsided Skink	NL
3	Microhylidae	*Cophixalus neglectus*	Tangerine Nursery-Frog	EN B1ab(v)+2ab(v)
4	Microhylidae	*Cophixalus monticola*	Mountain Top Nursery-Frog	EN B1ab(v)+2ab(v)
5	Scincidae	*Lampropholis robertsi*	Grey bellied Sunskink	NL
6	Pseudocheiridae	*Hemibelideus lemuroides*	Lemuroid Ringtail Possum	LRNT
7	Myobatrachidae	*Taudactylus rheophilus*	Northern Tinkerfrog	CR A2ac; B2ab(v)
8	Phalangeridae	*Trichosurus vulpecula j.*	Coppery Brushtail Possum	LRLC
9	Dasyuridae	*Antechinus godmani*	Atherton Antechinus	LRNT
10	Microhylidae	*Cophixalus hosmeri*	Pipping Nursery-Frog	VU D2
11	Microhylidae	*Cophixalus concinnus*	Beautiful Nursery-Frog	CR B1ab(v)+2ab(v)
12	Scincidae	*Saproscincus czechurai*	Czechura's Litter Skink	NL
13	Scincidae	*Glaphyromorphus mjobergi*	Atherton Tableland Mulch-Skink	NL
14	Pseudocheiridae	*Pseudochirulus herbertensis*	Herbert River Ringtail Possum	LRNT
15	Gekkonidae	*Carphodactylus laevis*	Chameleon Gecko	NL
16	Scincidae	*Gnypetoscincus queenslandiae*	Prickly Forest Skink	NL
17	Muridae	*Uromys hadrourus*	Masked White-tailed Rat	LRNT
18	Acanthizidae	*Acanthiza katherina*	Mountain Thornbill	LC
19	Ptilonorhynchidae	*Prionodura newtoniana*	Golden Bowerbird	LC
20	Psittacidae	*Platycercus elegans*	Crimson Rosella	LC

However, from direct thermophysiological assessments, it became clear that some species that do not rank highly in terms of exposure, sensitivity and vulnerability, are nevertheless already regularly exposed to sub-extreme temperatures that cause heat stress (e.g., White-throated treecreeper *Cormobates leucophaeus minor*). Conversely, species such as the Golden Bowerbird *Prionodura newtoniana*, that have relatively high exposure, sensitivity and vulnerability, are not expected to be subjected to heat stress in large parts of its distribution even under the most pessimistic emission scenarios. This highlights the importance of incorporating physiological information into assessments of climate change vulnerability of individual species.

Extreme heat events are set to escalate this century as direct manifestations of anthropogenic climate change (IPCC, 2013; IPCC, 2012). Tropical fauna are thought to be living closer to their maximum thermal tolerances than in more temperate regions (Huey *et al.* 2009; Deutsch *et al.* 2008; Tewksbury *et al.* 2008). Therefore, the predicted impact of extreme heat events on the Wet Tropics vertebrates raises special concern, not only for the Wet Tropics biota but also for the sustainability of tropical ecosystems more widely.

2.3 Managing for resilient tropical systems

The Wet Tropics bioregion is a complex and often highly contested landscape with many competing interests from environmental managers, industry, Indigenous, and community groups. Attention was directed at determining the most effective approaches to collaborative governance, planning and co-management of biodiversity with Indigenous people through Indigenous Protected Areas and other mechanisms; the most appropriate ways to develop a carbon market within the Wet Tropics region; the best approaches to managing and accelerating revegetation including potential management interventions particularly in the rainforest uplands; and the social and economic value of environmental icons of the Wet Tropics rainforest and their contribution to northern Queensland (NERP TE Hub Multi-year Research Plan, 2011).

2.3.1 Indigenous co-management the future of rainforest protection

In 2012, the Australian Government announced the inclusion of the Indigenous Cultural Values of the Wet Tropics World Heritage Area on the National Heritage List (Australian Government 2012). This is the only place in Australia where Aboriginal Rainforest Peoples have lived continuously in the rainforest environment for at least 5,000 years and have a great wealth of ecological and management knowledge about its flora and fauna, landscapes and resources. The Wet Tropics region is home to 20,000 rainforest Aboriginal peoples, 120 clans within 8 language family groups, 80 legal entities including Registered Native Title Prescribed Body Corporates and registered Cultural Heritage Bodies, two Aboriginal Councils and 20 tribal groups defined across the northern, central and southern regions of the WT. These include Northern - Eastern Kuku Yalanji, Western Yalanji; Central - Djabugay, Gunggandji, Mamu, Mbabaram, Muluridji, NgadjonJii, Yidinji and Yirrganydj; and Southern - Bandjin, Djiru, Girramay, Gugu-Badhun, Gulnay, Jirrbal, Nwaigi, Warrgamay, Warungu and Wulugurukaba (RAPA 2013; Schmider 2014a; Hill et al. 2014).

A co-research team of scientists, land managers and Rainforest Aboriginal peoples considered the contributions of Indigenous Protected Areas (IPA), Indigenous Land Use Agreements (ILUA)and other collaborative planning models and mechanisms. The team focused on how these approaches enable recognition of Indigenous knowledge and values and improve joint management of the region (Maclean, K., et al, 2012). They looked broadly at what works well, and why, for Indigenous co-management and biodiversity protection specifically for Wet Tropics country.

The key finding of the co-research is that a focus *on collaborative governance* is critical for improving management of natural and cultural values. For many years, efforts to improve conservation of nature have focused on management on finding the best means of achieving management objectives. However, this co-research has shown that a focus on governance – who decides about what is to be done, and how those decisions are taken – is often more effective for improving conservation outcomes, and can deliver multiple benefits. It was found that collaborative governance is a flexible, solution-building process, involving extensive talking, negotiations and joint learning, so it gets better over time. Collaborative governance can enhance governance vitality (Figure 4), one of the three key dimensions recognised by the IUCN as central for governance of nature conservation (Borrini-Feyerabend and Hill 2015, in press).

Figure 5. The dimensions of governance for nature conservation (Borrini-Feyerabend and Hill 2015, in press)

IPAs are particularly effective at enhancing governance vitality because they are:

- led by Traditional Owners through their vision and plans (empowered)
- Bring partners around the table often for the first time (connected)
- Recognise Indigenous knowledge (wise)
- Flexible to respond to changing community contexts (adaptive)
- based on new multi-tenure arrangements in the wet tropics (innovative)

IPAs also support customary institutions for governance and novel communication techniques, for example combining Aboriginal art with vegetation maps to co-produce management zones (Davies *et al*. 2013). There are opportunities to value-add to the benefits from IPAs by expanding their coverage across the whole of the WTWHA, and focusing them on management of nationally and internationally significant values – both cultural and natural.

Protected Area Indigenous Land Use Agreements (ILUAs) under the Native Title Act 1993 (Cth), the other major initiative underpinning co-management of Wet Tropics country, show few of the features of governance vitality. Nevertheless, co-management of protected areas is in many cases the only substantive outcomes for many Indigenous groups in native title agreement-making. ILUAs concerning protected areas are often based on adversarial negotiations towards non-exclusive native title determinations. The negotiated outcomes typically focus on regulating native title rights, hunting, firearms, taking of species, camping, lighting fires and disposing of rubbish, with the rights of others prevailing over Indigenous rights. Little recognition is made of Indigenous knowledge, and few resources are provided for implementation. Protected Area ILUAs could be improved through adoption of Indigenous-led planning, placing the realisation of rights at the centre of agreements, recognition of Indigenous knowledge, and provisions to enter into collaborative management such as occurs in ILUAs in Cape York Peninsula.

The co-research found that there is currently inequitable progress on recognition of Indigenous knowledge and values in different parts of Wet Tropics country. Establishment of a knowledge-network could provide flexible and diverse ways for people working on similar issues to share experiences and help one-another, for example through dialogues, workshops, websites and social media. A knowledge network could support Aboriginal businesses, native title corporations, family groups, IPA and Ranger managers, research organisations, NRM and heritage managers to share knowledge about issues including Indigenous-driven planning; relationship-building; and practicing free prior and informed consent.

The co-research identified a wide range of multiple economic, social, political and cultural and environmental benefits (Figure 5) from effective collaborative governance of Wet Tropics country (Hill et al. 2011, Pert et al. 2015 in press). In addition, both bio-cultural diversity and governance are important for mapping Indigenous cultural ecosystem services were identified.

Figure 6. Multiple benefits of collaborative governance (Hill, et al, 2014)

2.3.2 Socio-economic values of the rainforest uncovered

From a recreational perspective, the WTWHA contains over 200 visitor sites and 150 managed walks showcasing outstanding biodiversity, iconic and endemic wildlife and spectacular scenic vistas. Socio-economically, the region is growing rapidly, with an average annual population rate of 1.6% over the last five years and visitation to the WTWHA by approximately five million local and international visitors annually (Queensland Government, 2009).

But what is it about the WTWHA that visitors think is important? And how about residents – how much do they 'value' living in the WTWHA? Significant knowledge gaps remain, with most prior studies having focused on a limited range of ecosystem services provided by the WTWHA. The research thus set out to improve understanding of the value which residents and tourists place upon the ecosystem services of the WTWHA, specifically looking at the relative importance of these services, the likely implications of changes in these services, and comparing the different techniques often employed to value them.

Figure 7. How important is a beautiful view?

It found that the single most important thing for residents and tourists alike, was knowing that family and friends were safe; after that, the region's ecosystems services featured prominently. For example, "having healthy native plants and animals", "having beautiful undeveloped scenery to look at", and "being able to go on forest walks, or relax and reflect in a natural setting" were considered, by residents, to be more important to the overall quality of life, than the jobs and incomes associated with different industries. Similarly, the environmental and recreational values of the WTWHA were considered to be more important 'draw-cards' for tourists than other market-related 'values' such as good quality accommodation, quality guided tours and attractions, and/or city entertainment.

The research also investigated relations between values, noting that many are inextricably linked (Figure 8). There was a notable link between aesthetic values (beauty, peacefulness, ability to relax and reflect), and intrinsic environmental values, such as having healthy native plants and animals, undeveloped regions without rubbish, and beautiful clear streams.

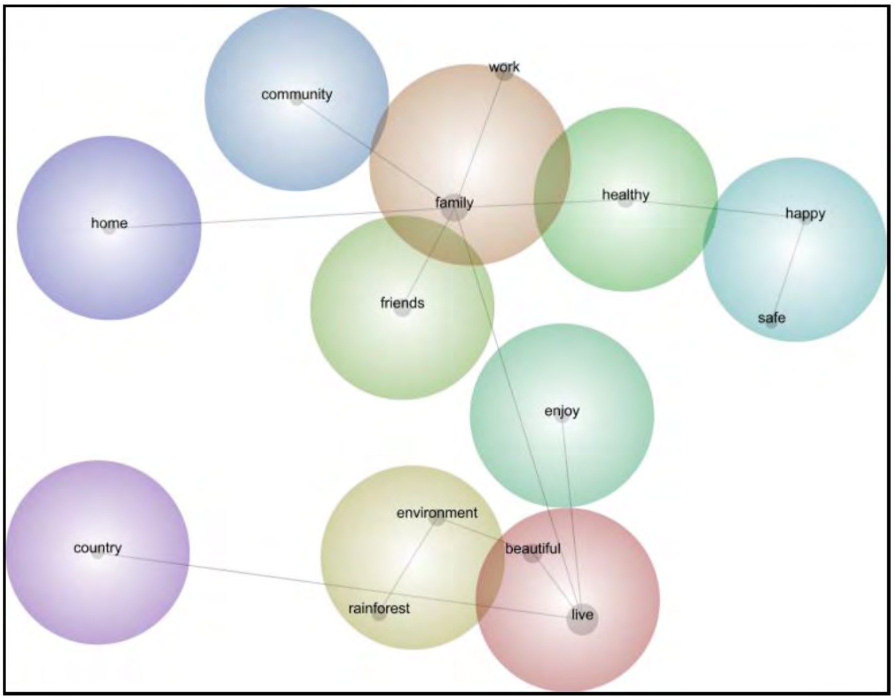

Figure 8. Concept map showing the relationship between values, as perceived by residents. *Family* (represented by the bigger size of the point) had a strong connection with *work, friends, community*, and *healthy*.

Significantly, this research revealed a 'gap, between the importance which tourists and residents attributed to different 'values', and their satisfaction with them, the latter being almost always less than the former. This was most apparent for intrinsic environmental values (considered very important, with relatively low levels of satisfaction), signalling a potential cause for concern. The 'gap' was relatively small for tourists, larger for non-Indigenous residents, but very large for Rainforest Aboriginal residents. There are potentially many reasons for these differences, one being varying reference points/baselines.

When presented with a series of (hypothetical) scenarios involving different types of environmental degradation, both residents and tourists reacted much more negatively to the prospect of environmental degradation (e.g. more pests and weeds, murkier rivers, more rubbish) than to the prospect of a 20% increase in prices. Residents noted they would be much less satisfied; tourists noted that such changes would mean they would not come to the region at all, or they would stay for a much shorter period of time.

That said, the research found clear evidence that different people value things differently. For example, residents who were dependent upon the mining and manufacturing or agricultural sectors for their household incomes, generally felt that environmental and cultural values were less important to their overall quality of life (and were willing to pay less to protect them) than residents dependent upon other industries (Figure 9). Those who identified as non-Indigenous were less interested by the prospect of having more information about Aboriginal culture than those who were Indigenous. Patterns were also evident in the tourist data: for example, visitors from Queensland considered safety of family and environmental factors to be relatively less important 'drawcards' than their non-Queensland counterparts.

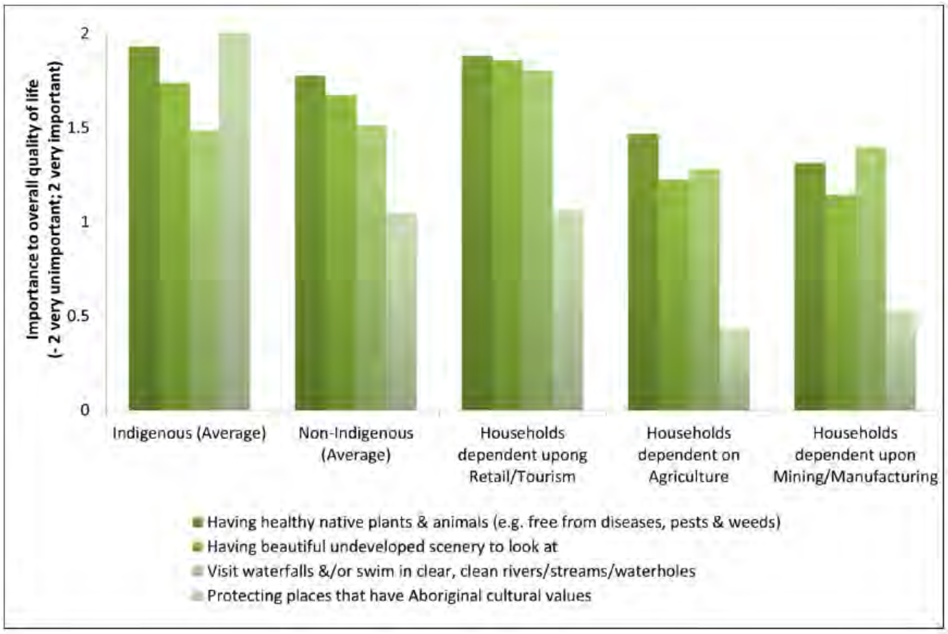

Figure 9. Predicted values for the importance of key ecosystem services to the overall quality of life of residents – differentiated by Indigeneity, and by Industry of association (controlling for other demographic differences such as income and gender).

This suggests that changes in the economic structure of the region or in the demographic composition of residents and tourists will lead to changes in 'values'. An increase in the mining/ports sector, for example, could be associated with a reduction in the community support for the protection of intrinsic, aesthetic or Aboriginal cultural values, relative to other values. Likewise, a change in the composition of tourists to the region, with more 'locals' (specifically, visitors from Queensland) compared to visitors from elsewhere in Australia, could mean a lesser appreciation of those same values.

In sum, the current evidence suggests that residents and tourists alike would respond much more negatively to environmental and/or cultural degradation than to increased prices, the implication being that the 'average' resident or tourist is likely to prefer developments that do not substantially degrade the ecosystem services provided by the WTWHA (Esparon, *et al*. 2014). But the WT region is particularly vulnerable to environmental change, since people in this region are so reliant upon it for livelihoods and wellbeing. Changes in social 'values' might thus occur in response to changes in the attitudes and priorities of people in the current population (affecting people's assessment of what is important), and/or to changes in the demographic composition of residents and tourists (since different people feel that different things are important). Moreover, changes are likely to occur if there are changes in the biophysical environment (which will affect people's perceptions and satisfaction). Evidently, it is important to monitor peoples' values along with more information about the biophysical environment (e.g. about the expected vulnerability and sensitivity to climate change projections as previously noted), given the significant interdependence of values and importance of protecting the region's natural assets.

2.3.3 Restoration and regeneration of the rainforest

Restoring forests on cleared lands is a global conservation priority, particularly in tropical regions where extensive deforestation persists. The world is losing an average of 13 million hectares of forest annually, an area nearly 15 times the size of the Wet Tropics World Heritage Area. This is despite deforestation rates having slowed in recent years. Half of the world's tropical forests have disappeared since World War II and tropical deforestation accounts for approximately twenty percent of global carbon emissions. With the Tropics being home to eighty percent of the world's terrestrial biodiversity, finding cost effective ways to successfully restore tropical forests on a large scale are imperative. Restoration can be achieved in a variety of ways, from planting trees to allowing forest to regrow naturally, with each method highlighting the need for strategic approaches to restoration to maximise ecological and financial returns. The potential for regrowth to "rescue" tropical forests from the otherwise inevitable cascade of biodiversity loss from land clearing coupled with future climate change has international attention. However, the potential for regeneration success lies in when and where low cost passive restoration may be preferred to high cost active restoration.

The research established a network of 29 regrowth sites which differed in age and landscape context and were located in comparable environmental conditions to a previously-surveyed network of 25 replanted sites on the Atherton Tablelands. The regrowth sites were identified with the aid of extensive historical aerial photography, dating back to the early 1940s, and obtained for repeated times during the period 1940-2011. The previously surveyed replanted sites are located in the south-central Atherton Tablelands, across an area of about 40 km by 22 km (from Yungaburra in the north to Millaa Millaa in the south), at 640–870 m altitude, and were aged 1-24 years at the time of survey.

These aerial photographs in Figure 6 show rainforest regrowth during 59 years following reduced livestock grazing in former pasture in the Tarzali region of the WT. In 1952 most of the area was heavily grazed, with a few remnant forest patches. In 1978 this regrowth would have comprised low vegetation, probably dominated by introduced species such as lantana, together with some native shrubs. By 2011, some of these areas had been re-cleared. Areas which escaped re-clearing had by 2011, progressed to dense forest regrowth (bottom photo) dominated by native rainforest trees (Catterall, Shoo and Freebody, 2014).

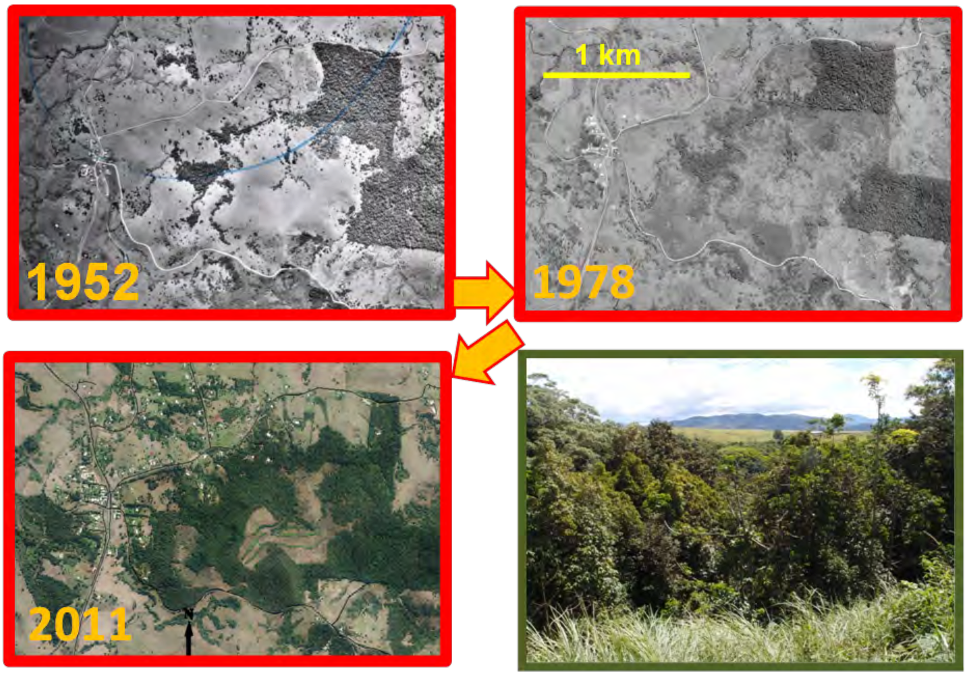

Figure 10. A case study of rainforest regrowth during 59 years following reduced livestock grazing in former pasture. (Catterall, Shoo & Freebody, 2014)

Forest restoration can occur either actively or passively. Passive regeneration occurs when forests regrow naturally, without human intervention. Active restoration involves people intervening to speed up the process, most often by planting trees. Both approaches have merit. For example, both types of restored forest can provide habitat for fauna, re-establish connectivity by linking remnant forest patches, help prevent erosion, improve soil and water quality and sequester carbon. However, there are also significant differences between the two approaches and one clear distinction is in cost. Active rainforest restoration is relatively expensive because it involves planting a high diversity of advanced seedlings at high densities. These types of plantings are therefore limited to small areas. On the other hand, they enable very rapid forest re-establishment, accelerating ecological recovery. Initial costs could be reduced by planting less advanced seedlings further apart, but this allows greater light penetration which promotes grass and weed growth, resulting in much higher and longer term maintenance costs.

It is a much cheaper option to simply enable rainforest to regenerate naturally (for example, by excluding livestock) but this regrowth takes much longer to re-establish. Also, natural regrowth can only occur by overcoming a range of ecological barriers. First, it relies on fruit-eating rainforest birds and bats to disperse new seeds into cleared areas. However, the most effective seed dispersers are bird species that rarely leave the refuge of intact forest to fly over clearings or to perch in open pasture. Second, even when rainforest seeds are successfully transported, they can fail to germinate or survive because of a range of physical limitations such as insufficient light, water and nutrients, as well as the risk of being consumed by seed-eating or leaf-feeding animals.

In some instances, natural regrowth can be assisted by the presence of woody weeds. This occurs when the seedlings of some weed species are able to successfully establish and compete with dense pasture grasses. As they grow, these woody weeds provide perches and food resources, attracting birds that bring in rainforest seeds which then germinate and grow in their shade. In the Wet Tropics, woody weeds such as lantana, wild tobacco and camphor laurel may act as catalysts for overcoming several of the barriers to rainforest regeneration. More investigations are needed to reveal in what situations they either aid the process of native tree regrowth, as described above, or suppress it, for example by forming a dense canopy that may shade-out native seedlings.

Figure 11 shows the differences in the percentage of canopy cover among replanted and regrowth sites that vary in age (each point represents a different site on the Atherton Tablelands). The blue line shows the average trajectory of development in replanted sites aged 1-25 years, and the orange line shows regrowth sites aged 1-67 years. The ranges of canopy cover values typically seen in pasture and mature rainforest are also shown. Regrowth sites had a more variable development rate: some had very high canopy cover within 20 years, while a few remained sparse and open even after 30-60 years. On average, their development was slower. Canopy cover in the best-developed sites, whether replanted or regrowth, exceeded that in rainforest - probably because they lack the natural "light gaps" which form in mature forest when large trees fall (Catterall, Shoo & Freebody, 2014).

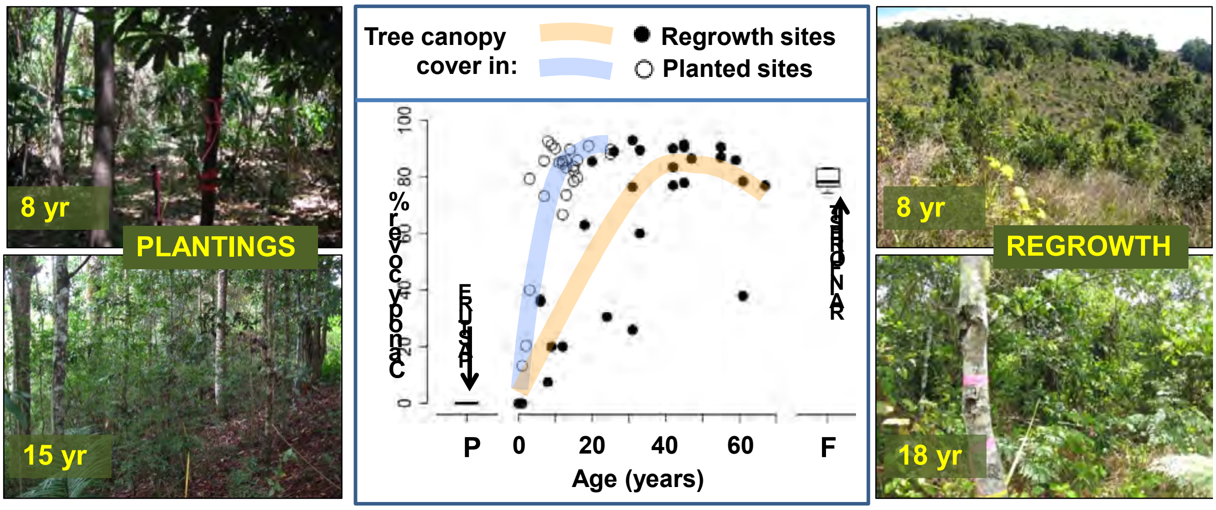

Figure 11. Differences in percentage of canopy cover among replanted and regrowth sites that vary in age (Catterall, Shoo & Freebody, 2014)

Given the costs and benefits of the different approaches, researchers and land managers are now looking at a more varied menu of restoration methods, such as assisting natural regrowth in some areas while planting trees in others. Combined approaches which involve interventions to remove barriers to regrowth are also being explored. In areas without much existing regeneration this may be achieved by increasing seed supply through methods such as direct seeding, installing artificial bird perches or by using herbicide to suppress pasture grasses. In areas where regeneration processes have already progressed to a stage where there are some established trees or a native seed or seedling bank, methods of 'assisted natural regeneration' (also known as 'bush regeneration') can accelerate the regrowth process. For example, in some areas where woody weeds have been established long enough to attract seed-dispersing birds and develop an understorey of native seedlings, herbicide treatment to kill these weeds may further accelerate the development of emerging native forest.

The research demonstrates the importance of weighing up the costs and benefits of different restoration approaches before making a strategic decision about which approach to employ in any given situation. It also highlights the need for further research to increase our knowledge about the effectiveness of the different methods. Lastly, it confirms the significant role that remnant forest plays in assisting natural regrowth, emphasising the importance of protecting the remaining areas of old-growth forest. For more information see Catterall, Shoo and Freebody (2014) Natural Regeneration and Rainforest Restoration - Outcomes, Pathways and Management of Regrowth.

2.3.4 The governance of natural resource management in Far North Queensland

The management of ecological and agricultural systems has long been argued in the literature as being important for securing landscape resilience in the face of climate change and other land use and natural resource pressures (Dale & Vella, 2012). The intent of this research was to focus on the health of the governance system for NRM in the region and in particulalr, the potential application of emerging ecosystem service markets for this purpose. Rapidly growing voluntary and regulated markets and standards in biodiversity, carbon and cultural service credits are creating new opportunities for the region.

The Wet Tropics region has internationally significant biodiversity, cultural and carbon values. The goal is to achieve an ecosystem services economy and transformational landscape change. Relying on a strategic and integrated governance system, transformational change will lead to restored ecosystem function across the landscape, significant threat abatement and declining water pollution. Four necessary governance foundations are key to transformational landscape change:

1. Bilateral policy frameworks for NRM integration, regulation and the establishment of markets and.
2. Regional scale and adaptive NRM planning and effort alignment.
3. Consistent and continuously improving property scale planning systems.
4. A fully integrated landscape scale research, development and education (RD&E) system.

Emerging market-based Greenhouse Gas Abatement (GGA) programs present a real opportunity to secure adaptation to climate change through enhanced landscape resilience. The Landscape-Based Greenhouse Gas Abatement Domain is hence a hybrid governance domain that straddles the historically separate worlds of GGA and NRM governance (Dale, Vella and McKee 2014). By partnering with Far North Queensland's key stakeholders, evaluations were made of the most effective governance foundations for the application of GGA opportunities for landscape-scale adaptation. In doing so, the research focused on several practical efforts including the design and implementation of the most appropriate regional governance systems needed to support regional scale adaptation to climate change; the design and and implementation of the most effective and integrated NRM planning arrangements for regional scale adaptation for biodiversity and other natural assets; and guiding and enhancing the carbon and other emerging ecosystem market investments towards priority biodiversity outcomes within the regional landscape.

3.0 Pressures and threats: current and future

The primary risks and threats to the environmental assets of North Queensland do not occur in isolation to each other and it is clear that a greater understanding of the cumulative and synergistic impact of these pressures is required for improved management. These pressures are not static therefore predicting and preparing for change is a significant challenge for environmental decision makers charged with stewardship of the Wet Tropics rainforest environment. Changing climates, extreme events, changes in natural resource use and population growth are some of the pressures facing these terrestrial ecosystems.

3.1 Climate change

Climate change scenarios are suggesting a number of threats are imminent including increased temperatures, an increase in fire frequencies, and the loss of endemic plant and animal species. As well, significant climatic shifts are predicted for Queensland's upland forests including an upward shift in cloud cover, a significant reduction in cloud interception and moisture inputs from mist, and outputs through stream flow. The harsh reality is that the future vulnerability of the biodiversity of the region is high, particularly within the regionally-endemic species that are very significant to the Wet Tropics. There are significant trends in population change across elevations consistent with climate change predictions.

The research has provided several lines of evidence to support the existing and ongoing impacts of a changing global climate on the biodiversity values of the Wet Tropical rainforests of Australia. Modelling of species abundances and in relating these trends to past climate change, there is clear evidence of future climate change impacts on rainforest fauna and flora. If past climate change can impact where species occur on today's landscape, it is logical to expect that present and future climate change will do the same. Unstable areas contain highly resilient species where stable areas contain species with a spectrum of resilience indicating that no filtering occurred in highly stable areas (Williams, et al. 2014).

It is now confirmed that current species populations have reduced on the 'hot' ends of their distributions and expanded on their 'cool' ends of their distribution. This was consistent for numerous mammal and bird species and shifts occurred within a very small timeframe suggesting that future warming as projected by IPCC warming scenarios will truly be catastrophic for rainforest fauna and flora (Williams, et al. 2014). Specifically, the identification and preservation of refugia areas will be essential in the long-term conservation of species in the region. Microhabitats within pristine rainforests will likely serve as the first line of defence against extreme weather events. These small habitats remain cool and wet during hot conditions and should provide conditions that species can survive within under short time frames. Large-scale refugia areas will, however, ultimately be required for successful long-term conservation of populations. These areas have been identified using spatially explicit modelling approaches that capitalize on long-term data of species distributions and climate modelling in the region.

The future predictions from modelling abundance changes into the future are consistent with the shifts that have been observed from the field. The most comprehensive analysis for this region to date, predicts that up to 92% of all Wet Tropics endemic vertebrates will be vulnerable or worse by 2085. However, a reduction of global emissions under a medium mitigation scenario could save the majority of the biodiversity in the Wet Tropics. A combination of mitigation and adaptation informed by prioritisation of species and places based on relative vulnerability is essential in order to conserve the unique biodiversity assets of the Wet Tropics World Heritage Area (Williams, et al, 2014). One example of a conservation prioritisation map is provided below (Figure 8). The most valuable areas for conservation are depicted in red. These results consider habitat suitability and home ranges for each species. Resilience for each species was calculated based on various levels of reproductive output, climatic niche marginality, and potential for dispersal (Williams, 2014).

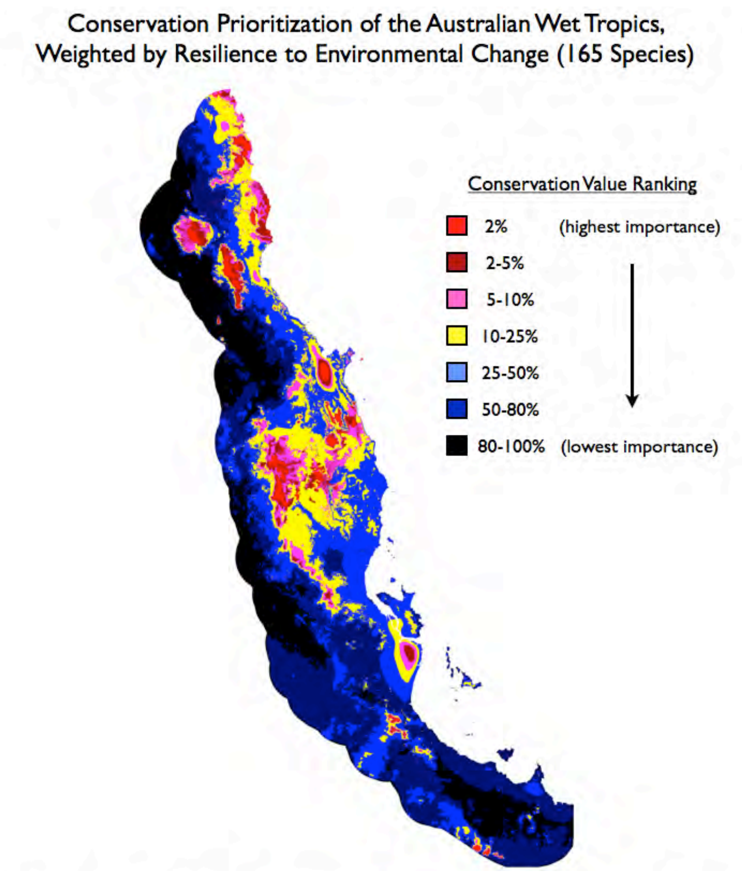

Figure 12. Areas of highest conservation concern for 165 species in the Australian Wet Tropics. Colours here denote priority rankings calculated in Zonation. A graduated colour scale shows the different zones with the most valuable areas for conservation shown in red and the least valuable shown in black. These results consider habitat suitability and home ranges for each species and were weighted by expected resilience to environmental change (calculated in Isaac 2008). Species with lower resilience scores were assigned higher weights (Williams *et al*. 2014).

Flora and climate change

The phylogenetic diversity analysis forecasts significant declines in suitable habitat and species richness for many of the endemic mountain top plant species, mirroring similar patterns of decline predicted for high altitude vertebrate species. Climate change is expected to seriously affect the hydrology of the region's montane ecosystems. As cloud cover shifts upwards, there will be a significant reduction in the amount of moisture input through 'cloud stripping'. This will affect not only montane areas but also downstream ecosystems through reduced stream flow. This is of particular concern in the Wet Tropics where a number of endemic plant species are found only at elevations higher than 1,000 metres. More than 90% of the endemics on mountaintops are forecast to be extinct by 2085 on a worst case climate change scenario.

The seven mountaintop plant species hotspots (Figure 13) identified below are congruent with areas that have been identified as of concern and requiring management attention for the preservation of endemic and iconic biodiversity.

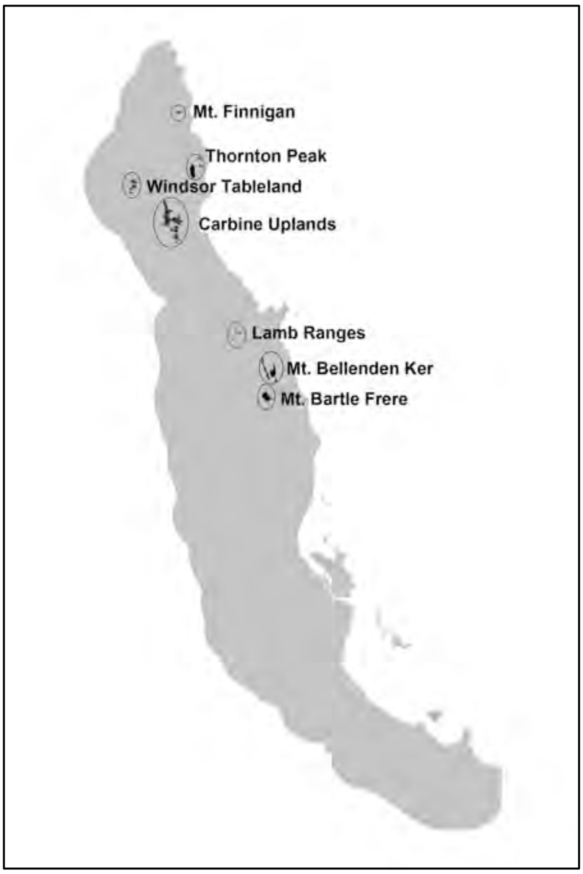

Figure 13. The seven mountaintop endemic plant species hotspots (from Costion, et al, 2014)

Studies into the genetic diversity among populations of these species and comprehensive field surveys need to be continued to more thoroughly assess the risks to this unique biota, and to inform decisions about appropriate conservation status and possible mitigation measures (Costion, et al. 2014). As with the fauna, a range of practical adaptation measures are needed to try and improve resilience amongst those species most at risk. Both in-situ and ex-situ approaches need further consideration and will likely be required (Welbergen, 2014).

If projected climate depart from recent and historical variability, biotic communities will undoubtedly pass through yet another extinction filter event. These results provide merit to our future predictions of population trends. If past climate change can strongly influence species distributions, as seen in the strong spatial signature of environmental stability and species patterns, then future climate change will undoubtedly have similar effects on species distributions (Williams, et al. 2014).

Contemporary modelling approaches assume that the current geographic ranges of species are largely determined by climate as a consequence of physiological tolerances and habitat requirements. Research usually has sought to quantify the risk of climate change to different species by mapping where those species occur today based on climate and then predicting where they may occur in the future. One key finding from much of the NERP rainforest research is that peripheral habitats are now challenging these assumptions.

Invasive Pest Management Planning

The direct and indirect effects of climate change and extreme climate events are very likely to exacerbate the spread and impact of invasive species as well as allow opportunities for new species to invade. In combination with climate change, invasive species are expected to contribute to interacting processes or ‘threat syndromes’ that could precipitate major environmental change and consequent impacts on biodiversity.

As a general rule, suitable habitat for most tropical invasive species will shift towards the south and contract towards the east coast. For example, for some weed species currently restricted to tropical north-east climates this may mean an expanded distribution into southern Queensland. However, while suitable climatic space shifts towards the south and contracts towards the east coast for many species, the Wet Tropics region generally remains suitable for tropical invasive weeds, functioning as a kind of weed refugia under climate change. In addition, in the face of an increasing intensity of cyclones, we are likely to see significant changes in structure and function of tropical forests in storm-prone areas as a result of weed invasion. These changes may include a decrease in diversity of native species, increasing degradation of forest fragments and ultimately a decrease in ecosystem function.

Understanding how tropical weed species will respond to climate change in terms of shifts in distribution and abundance is important for pro-active and strategic management planning. By considering how a current management plan interacts with future trends in suitable habitat and climate, a profile of future risk and a range of proactive management responses can be determined (Figure 14). Collaboration between end users and researchers has resulted in the development of a Pest Adaptation Response Strategy (PARS) for priority weed species in the Wet Tropics region. The PARS indicates in which parts of the landscape future investment is likely to need to increase in order to minimise future weed impacts, where it will need to remain stable, or where it may potentially decrease over time as the risk of spread or establishment is low. The PARS is tailored to assist each of the Local Government Areas (LGA) occupying the Wet Tropics WHA and have been developed to play an advisory, decision support role in the annual review of the Local Area Pest Management Plans. These are framed in terms of future risk and investment outlook for each LGA and for the region.

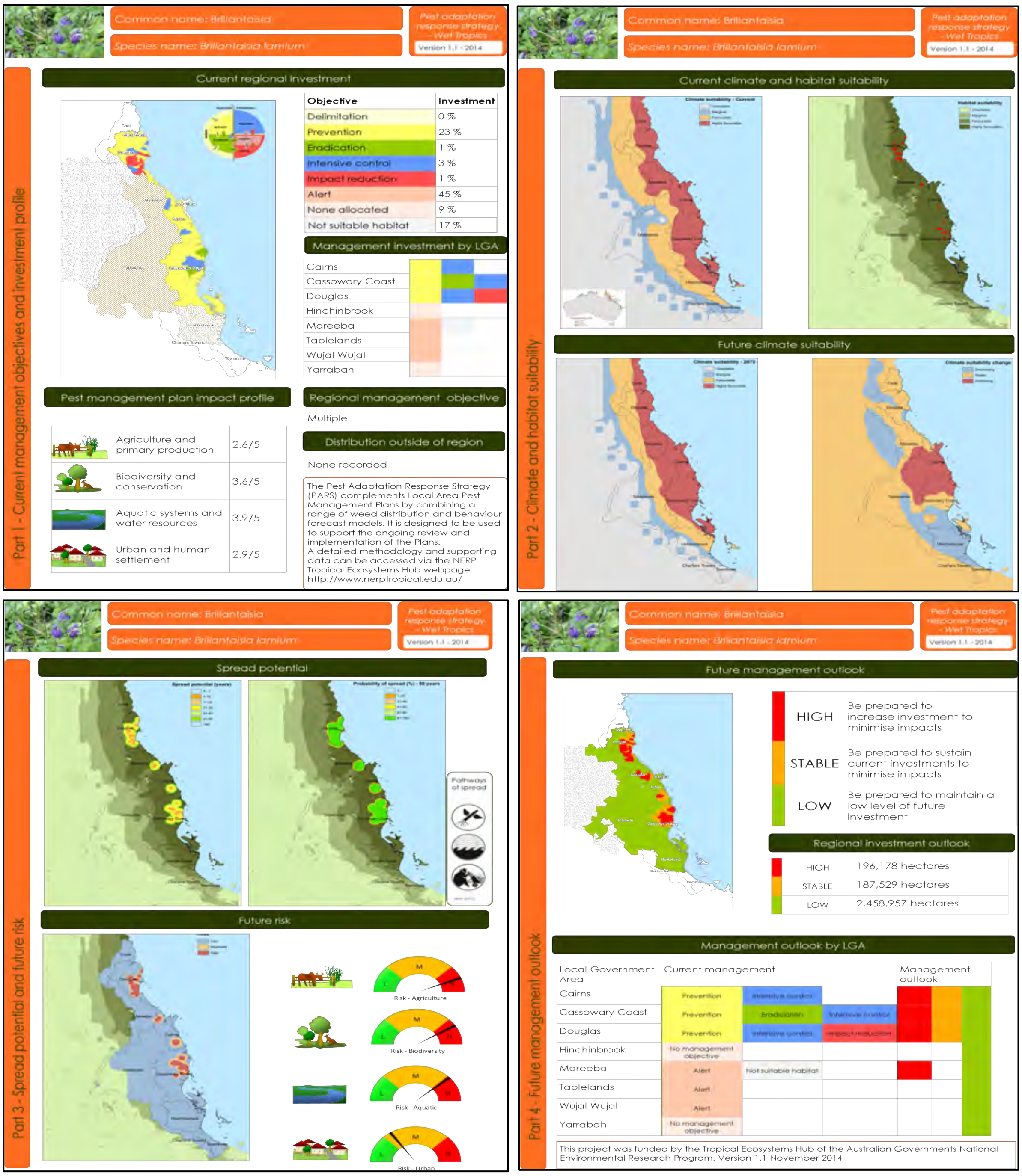

Figure 14. Pest Adaptation Response Plans (Murphy, et al, 2014)

3.2 Landscape resilience

Regional NRM planning has a strong focus on reaching collective agreement about the efforts required to preserve and restore landscapes, manage natural assets and undertake resource condition monitoring. This focus is also the key to building landscape and community resilience in the face of climate change. On ground actions that increase landscape resilience should be consistent with existing Regional NRM Plans, but the next generation of plans present an opportunity to more explicitly support resilience building (Preece, et al. 2013). Some of the greatest opportunities for large scale carbon sequestration lie with vegetation management and revegetation activities. Efforts to improve landscape resilience should reduce the vulnerability of NRM assets (e.g. by increasing the size of habitat patches, providing buffers above critical thresholds) and/or supporting adaptation responses through a focus on connectivity and diversity of habitats to allow species to move. Priority investments in vegetation for carbon benefits can focus on securing multiple benefits for terrestrial biodiversity and degraded landscapes. Potential terrestrial biodiversity co-benefits that can be further explored through enhanced spatial mapping, analysis and decision support include:

- restoring heavily cleared landscapes to and/or expand remnant patches;
- restoring heavily cleared regional ecosystems; and
- expanding habitat for threatened and other species.

With active restoration of the landscape quicker but more costly than passive restoration, decisions should be made now to quantify the costs and benefits of restoration. Although there are challenges to restoration, the consideration of regrowth methods for priority conservation areas is important for mitigating climate change impacts if greenhouse gas emissions continue on a 'business as usual' trajectory.

Spatially identifying potential areas for rainforest regeneration for habitat corridors near adjacent forest areas will contribute to a better success rate for regeneration. The research on rainforest restoration indicates many bird species will shelter in the adjacent forest and assist in seed dispersal. Collaborative efforts from community members, NRM bodies and government agencies could assist the return of forest to areas of previously-established pasture and raise community awareness of the benefits of doing so. Catterall, Shoo & Freebody (2014) have identified some barriers to rainforest regeneration including firstly suppressing pasture grasses until tree seedlings establish to sapling size and secondly, looking at the potential for mature trees to provide seed input to pasture areas adjacent to the edge of existing rainforest. Other factors to consider include the availability of rainforest trees and shrubs bearing fleshy fruits nearby which are designed for dispersal by fruit-eating animals and adding perches as bird-attracting structures during regrowth has the potential to increase the input of seed away from rainforest edges. However, simply restoring a dense cover of native trees and shrubs may not be enough to reinstate the diversity of the most specialised species (including endemics). The rainforest floor typically has coarse woody debris providing log habitat which takes a much longer time to develop, but is a critical resource for some animals. For example, the prickly skink (*Gnypetoscincus queenslandiae*) endemic to rainforest upland regions is typically rare in even well-developed replanted sites; and outside of remnant rainforest it has only been recorded in old plantations that contain abundant coarse woody debris. Such species may only be able to use revegetated sites if there are specific management interventions to provide the critical habitat features that they need (Catterall, 2013). It is this type of restoration research which can contribute to assisting in providing habitat refugia and habitat corridors for species movement.

3.3 Fire and Indigenous knowledge

Fire has been used in the Wet Tropics by Indigenous Traditional Owners for many thousands of years and their unique fire management practices are now recognised as of national heritage significance (Hill & Baird, 2003). The role of fire in rainforest management is often a point of heated debate amongst researchers and land managers. With the frequency and intensity of fires predicted to rise under climate change, increasing our knowledge about the role that fire plays is becoming increasingly important. The absence of fire allows rainforest to invade habitat – a key threatening process for mahogany gliders. Fire changes recruitment and survival patterns of rainforest and woodland species. The research has shown that rainforest invasions that are less than five years old can be reversed with relatively low intensity fires. However, invasions greater than ten years old require very high fire intensity burns which can negatively impact on other important habitat features and this has implications for the frequency and intensity of burning (Metcalfe, 2014). The mahogany glider recovery plan, which is currently being updated, aims to improve the conservation status of the species through, in part, protecting its remaining habitat. The research suggests that there needs to be major changes made to the way that fire is used to manage mahogany glider habitat. The integration of burning practices by Rainforest Aboriginal Peoples based on their ecological knowledge, traditions and history of adaptation to change may assist this transition (Hill, et al. 2000, Hill et al. 2001).

Initial results outline the benefits of using different fire regimes in management of different vegetation communities. This information can be used to better understand the use of fire as a tool to maintain overall ecosystem health in the Wet Tropics. It highlights the need for empirical data to underpin fire management and policy decisions. Experimental research of burning leaf litter from Mabi forest using different moisture levels in a controlled laboratory environment to see if the seasonally dry rainforest may support fires in exceptionally dry years found that it did burn under certain conditions. More research is required to determine if leaf litter fires in Mabi forest are an important management tool for controlling weeds and promoting tree recruitment.

The co-research with Rainforest Aboriginal Peoples presented in this synthesis has illustrated the benefits of land managers, scientists and Traditional Owners working together through Indigenous Protected Area models. However, support for Aboriginal burning practices is at an early stage of development in IPAS. Aboriginal Rangers are typically involved in on-ground works, but not in the design of fire policies and regimes. The collaboration between scientists and Mandingalbay Yidinji Rangers to re-introduce Aboriginal regimes into parts of their IPA is a notable exception. Nevertheless, traditional burning is specifically prohibited in many existing Indigenous Land Use Agreements. The recent recognition of Rainforest Aboriginal fire practices as of national heritage significance provides protection to the ongoing application of their fire regimes (Australian Government 2012). Better collaboration between Traditional Owners and government land managers will be required to develop effective fire regimes that protect both natural and Indigenous cultural values under conditions of environmental change.

Establishing a knowledge hub would provide flexible and diverse ways for people working on fire regimes and on-country burning to share experiences and help one-another for example through dialogues, workshops, and joint projects A knowledge hub could support government, non-government, Land and Sea Indigenous Rangers, managers, research organisations, NRM and heritage managers to share information regarding fire management and relationship-building, and the practice of free prior and informed consent (Hill, et al., 2014 conference presentation).

4.0 Research informing policy and management

The NERP Tropical Ecosystems Hub generated significant outcomes for informing the design and implementation of rainforest monitoring, evaluation and conservation programs. The findings of this research are directly relevant to government at all levels and managers of the Wet Tropics World Heritage Area and its catchments. Some examples of the management applications of the outcomes are provided below:

- ☑ The Queensland Government Environment Minister Andrew Powell has supported a state-wide analysis of biodiversity and resilience utilising both standard protected area priorities with future climatic resilience analyses to identify the highest priority areas for biodiversity conservation both now and in the future has resulted in the prioritisation of locations for acquisition into protected area estate in Queensland. Five new national parks have been acquired to date (2014) and a number of other purchases and tenure agreements are currently being negotiated
- ☑ Identified aggregations of climate resilient properties that support existing reserves. This included remnant vegetation, the potential to increase landscape connectivity, and the inclusion of rare habitats
- ☑ Identified priority conservation areas for now and in the future (2085)
- ☑ Produced high resolution maps of the exposure to temperature extremes as experienced by organisms in-situ
- ☑ Have produced detailed maps of the areas where vertebrate biodiversity is most and least vulnerable to temperature extremes, both in the present and in the future. The areas identified are key to enhancing resilience and resistance of the Wet Tropics landscape
- ☑ Have recognised the importance of fire as a management tool in the Wet Tropics landscape, both as a positive and negative influence
- ☑ Recommendations have been made for changing EPBC listings of some threatened frog species
- ☑ Informed the Draft EPBC Act Policy Statement - Guidelines for determining significant impacts on the Grey-headed and Spectacled flying-fox due to actions in or near their camps
- ☑ The Queensland Government has acknowledged the need to improve Traditional Owner engagement in management of the Wet Tropics and other World Heritage Areas "I [Minister Powell] envisage any new model for management would enable Traditional Owners to establish governance models for each property, developed with and by the Traditional Owners in a manner that suits their own cultural requirements. I also envisage the need for a Council of Traditional Owners, to ensure an open dialogue on broader issues of culture and conservation across World Heritage areas"
- ☑ At Commonwealth level, rainforest restoration outputs are relevant to government initiatives such as the 'Green Army' and '20 million trees' as well as to conservation and recovery planning for threatened species and ecosystems. A workshop on decision making about resource allocation to restoration has had input through direct knowledge transfer to people responsible for implementing government policy.
- ☑ The research significantly influenced the development and reform of the Carbon Farming Initiative nationally, and directly established the foundations for the scoping, funding and delivery and the nation's second generation of NRM plans.
- ☑ Outputs and data are included in the FNQROC local councils environmental planning.

- ☑ Pest Adaptation Response Plans have been produced for 20 weeds of significance for 9 regional councils of North Queensland.
- ☑ Recommendations have been made to the Commonwealth and State Government agencies for the mapping of coastal littoral rainforest and methods of protection following cyclone events.
- ☑ Spatial analyses of species vulnerability and landscape resilience has been used to identify priority restoration areas in the Wet Tropics. This work has informed the 'Making Connections' rainforest restoration project that was undertaken by the Wet Tropics Management Authority and the local community to create strategic wildlife corridors on the Atherton Tablelands.
- ☑ The communities of the Wet Tropics region are reliant upon the environment for livelihoods and wellbeing and the region is vulnerable to some types of change including environmental degradation of the natural assets.
- ☑ For the first time have quantitatively evaluated the pattern and rate of gain in biodiversity and ecological function resulting from both active and passive approaches to rainforest restoration
- ☑ The Wet Tropics Management Authority has extensively used research outputs in their Conservation Plans and Research Priorities documents.
- ☑ Terrain NRM Board references many of the publications in all regional natural resource policy and planning initiatives.

5.0 Conclusion and future research priorities

There are several lines of evidence to support the existing and ongoing impacts of a changing global climate on the biodiversity values of the Wet Tropics rainforests of Australia. While most models assume uniformity of climate responses below the species level, in reality local adaptation of different populations is common among many plants and animals, and intraspecific variation in climatic tolerances and local adaptation has been documented for many physiological and life-history traits. At the same time, there is evidence of attention being needed to manage the ecosystem services of the Wet Tropics with the resident community and tourism industry. Managing the conflict between humans and wildlife is necessary for the protection and conservation of the natural assets.

Monitoring can be effective with respect to the status and trends of components relevant to the Outstanding Universal Value of the WTWHA but it requires a consistent, long term approach. Similarly, genetic diversity contributes to resilience to environmental change, and knowing where it is concentrated in plant lineages will help make better conservation decisions. New understanding of climate change impacts has indicated climate change will create new opportunities for invasive species to recruit, spread and increase in abundance. In addition, we should expect to see significant structural and compositional changes to cyclone-prone forests as a result of weed invasion. Other measures that can enhance forest resilience include preventing and controlling biosecurity incursions, protecting important peripheral areas and establishing micro-habitat to provide thermal refugia for vulnerable species.

There is increasing recognition of the costs, benefits, and ecological processes involved in both active and passive rainforest restoration, but longer-term monitoring and experimentation with emerging novel methods is needed to enable more cost-effective planning and management. The continued development, testing and comparing of new and established techniques and approaches to the cost-effective restoration of rainforest habitat at large scales and in areas of high conservation priority will be critically important to the long-term persistence of Wet Tropics biodiversity.

Co-management of the WTWHA is vital for the future protection and conservation. Traditional owners, scientists, landowners and government need to collaborate and discuss methods for mitigation. The coordination of western science with traditional ecological and cultural knowledge is a way forward. NERP research outputs have recognised the benefits of value-adding to regulatory frameworks of IPAs and ILUAs by using a collaborative co-governance and co-management approach is desirable. Securing improved governance systems for land use and natural resource management are key to ensuring research influences outcomes.

Future research direction

The NERP TE Hub research outputs have also revealed knowledge gaps and new areas of research that should be progressed to inform continuous improvement of the Wet Tropics rainforests in North Queensland. The future research directions are summarised below for each system component that has been studied through the program.

- The mapping of current and future biodiversity hotspots under climate change projections with current tourism recreation sites may indicate some visitor sites which may need to be managed differently.
- The benefits of collaborative governance and co-management of the Wet Tropics WHA between Rainforest Aboriginal Peoples and government agencies also has the potential to increase economic opportunities for Traditional Owners.
- Peripheral areas are also considered vital for the long-term resilience of the Wet Tropics and efforts to manage these areas must include working with Traditional Owners and neighbours to the WTWHA (for example, Australian Wildlife Conservancy, cattle properties, private landholders).
- Monitoring rainforest frog populations to assess persistence and recovery, and the mechanisms underlying this will assist in assessing the potential role of reintroductions as a tool in frog conservation. This should begin with continued monitoring of the *Litoria lorica* populations and the success of the wild population reintroduction.
- Future research would be usefully applied to determining when and where the interaction between invasive species, climate change, and the frequency and intensity of cyclones might trigger threshold changes in the structure and function of tropical forest communities.
- The development of national policy options for NRM reform and ecosystems service market development and deliberative approaches to continuously improving the system of governance within the region.
- Progression of the World Heritage relisting of the Wet Tropics for its cultural values.
- Progression in methods for managing human-wildlife conflicts.
- The monitoring of Cape York cassowary populations is required to provide understanding of these populations, their status and trends.

Much of the NERP rainforest research has shown long-term data will be paramount for successful conservation in the region. Research has detected population level trends and species shifts from current climate change. The research on peripheral habitats highlights that a major challenge in predicting the impacts of climate change or disease on biodiversity is to move beyond species-level models and towards a greater consideration of intraspecific variation in tolerances due to local adaptation. To fully understand the consequences of long-term climate change and invasive species in order to respond accordingly to population decline and changes in socio-economic factors, more long-term monitoring of populations, communities and habitats including peripheral areas will be an important research investment pathway.

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7.0 Appendix A: Research Publications

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