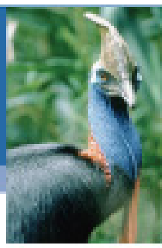
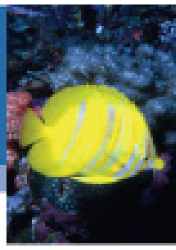
Marine and Tropical Sciences Research Facility

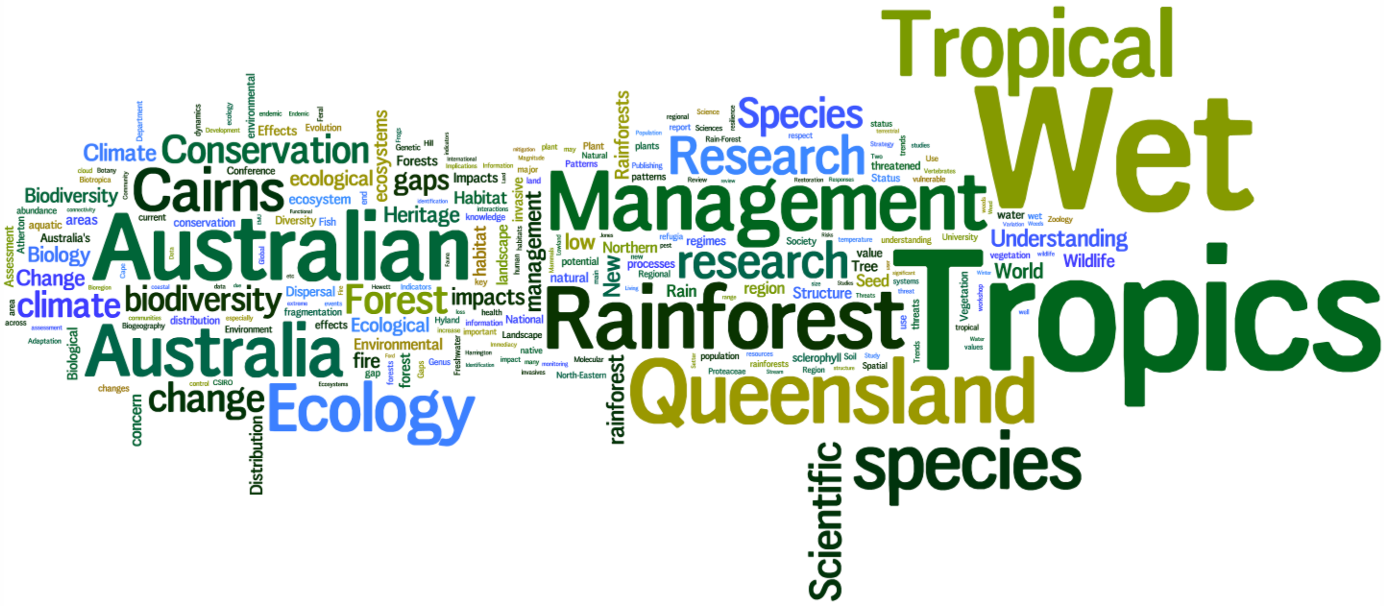




Australian Government

Department of the Environment, Water, Heritage and the Arts

Gap analysis of environmental research needs in the Australian Wet Tropics



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CENTRE FOR Tropical Biodiversity & Climate Change

WET TROPICS MANAGEMENT AUTHORITY

Reef & Rainforest RESEARCH CENTRE

Figure 1. (cover page) – Tag cloud displaying the key words mentioned in this document (tag cloud generated in http://www.wordle.net/create).

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1 EXECUTIVE SUMMARY

Environmental research involves "understanding how environmental systems function and interact, and the impact that humans are having on the environment". Strengthened linkages between terrestrial biodiversity researchers and end-users are desirable to reduce duplicative effort and achieve maximum return on public investment in applied research. To assist this process, our analysis provides a significant review and consultation process with the aim of identifying end-user needs, research gaps and possible synergies, delivering a valuable resource for terrestrially focussed research providers and end-user groups.

This report provides a resource for research providers by helping to locate relevant research information more efficiently, and by ensuring that proposed research is strategic and targeted at the needs of the end-users. It provides a resource for end-users by delivering a repository of biodiversity research that is digested and easily accessible, and by identifying the areas of research where stakeholder interests overlap. Finally, the report can also be used by funding bodies to help guide the prioritisation of resources into future biodiversity research in the Wet Tropics bioregion.

The tangible outputs are:

1) **Broad systematic review of biodiversity research in the Wet Tropics**. This report makes accessible 824 references from the peer-reviewed and grey literature. It categorises the literature according to three main categories of biodiversity research ('status and trends', 'risks and threats', 'mitigation and adaptation') and a range of logical sub-categories. In doing so it provides a relative indication of the effort allocated to the various areas of biodiversity research in the Wet Tropics.

2) **List of research gaps** – The report provides a list of 195 research gaps as identified during a workshop by 15 expert end-users and research providers in the region, and categorised according to the same categories as the broad systematic review.

3) **Identification of possible synergies** - Each research gap has also been rated by representatives from 13 end user and research provider organisations, enabling the identification of shared stakeholder interest.

4) **Major reference database** – The report incorporates a major electronic reference list (N > 2500 references) of the peer-reviewed and the grey literature on biodiversity research in the Wet Tropics.

We envision that these outputs are updated on a 5-year cycle, so that our approach can continue to provide a valuable resource for terrestrially focussed end-user groups .

List of the 20 highest-value biodiversity research gaps, identified by research experts and rated by organisations with a stake in biodiversity research in the Wet Tropics. During our workshop a total of 195 research gaps (Appendix 8.1.) was identified by 15 people with expert knowledge in biodiversity research in the Wet Tropics. Subsequently, representatives from 13 regional stakeholders were asked by email to rank each gap in terms of its 'relative value' to the stakeholder's organisation (1 = 'low value; 5 = 'high value') (for methodological details, see sections 4.4.2 & 4.4.3).

●	Key research gaps	Average value
1	Long-term monitoring data, essential for decision making	4.28
2	Understanding how to create a resilient landscape in the face of climate change - What criteria? Where? Why?	4.19
3	Maps of habitats of all endangered and vulnerable species	4.18
4	Establishing monitoring and conservation strategies for key species vulnerable to climate change	4.11
5	Information on the distribution and abundance of weeds and invasives	4.08
6	Understanding which ecosystems and species are most vulnerable to climate change (including shifts in averages and extreme events)	4.02
7	Understanding of the key indicators of ecosystem health that can be regularly measured at a landscape scale, with a focus on rare regional ecosystems that are threatened by antropogenic (climate) change	4.02
8	Research into thresholds or tipping points that lead to catastrophic irreversible ecological changes	4.00
9	Quantification of the value of restoration and regrowth in maintaining and improving ecosystem function	3.97
10	Identification of species-specific mitigation strategies for keystone / flagship species	3.97
11	Understanding the threat of climate change to ecosystem processes, e.g. primary production, dispersal, water relations, etc.	3.96
12	Understanding how to increase regional resilience - identification of options to extend conserved areas and the connectivity between them?	3.95
13	Greater emphasis on adaptive management between researchers and management	3.95
14	A baseline health status assessment of key threatened and endemic species	3.93
15	Understanding the interactions of climate change with other threats, e.g. invasive species	3.93
16	The assessment of the abundance and population structure of threatened and endemic species	3.92
17	Understanding the role of refugia under climate change; at what scales do they exists, where they, and what is their value?	3.92
18	A characterisation and mapping of the key climate refugia as a basis for management intervention	3.92
19	Knowing the risk of loss of tall open forest in the Wet Tropics	3.90
20	Biodiversity Planning Assessment for the Wet Tropics	3.89

2 ACKNOWLEDGEMENTS

The authors wish to thank Andrew Maclean, Ellen Weber (WTMA); Andrew Krockenberger, Luke Shoo, Miriam Goosem (JCU); David Hilbert, David Westcott, Petina Pert, Rosemary Hill (CSIRO); Wolf Sievers, Andrew Millerd, Bruce Wannan, Mark Connell (DERM-QPWS); Rowena Grace (TERRAIN); Kylie Wells (SEWPaC); John Kanowski (Australian Wildlife Conservancy); Suzanne Jenkins (Australian Conservation Foundation); Malcolm Pearce (Fisheries Queensland); Nigel Tucker (Biotropica Australia P/L); John Winter (Independent researcher); Bruce White (Bana Yarralji Bubu Inc & Balkanu Cape York Development Corporation); Travis Sydes (Far North Queensland Regional Organisation of Councils); and Mellissa Jess (RRRC).

3 LIST OF ABBREVIATIONS

BVG	**Broad Vegetation Groups**
CERF	**Commonwealth Environment Research Facility**
CSIRO	**Commonwealth Scientific and Industrial Research Organisation**
DERM	**Queensland Department of Environment and Resource Management**
DEWHA	**Department of the Environment and Water, Heritage and the Arts (Commonwealth)**
DPI	**Department of Primary Industries and Fisheries**
ESU	**Evolutionarily Significant Unit**
GIS	**Geographic Information System**
JCU	**James Cook University**
MTSRF	**Marine and Tropical Science Research Facility**
NERP	**National Environmental Research Program**
QLD EPA	**Queensland Environmental Protection Agency**
QPWS	**Queensland Parks and Wildlife Service**
Rainforest CRC	**Cooperative Research Centre for Tropical Rainforest Ecology and Management**
RRRC	**Reef and Rainforest Research Centre Limited**
UNESCO	**United Nations Educational, Scientific and Cultural Organisation**
WoS	**Web of Science**
WTMA	**Wet Tropics Management Authority**

4 INTRODUCTION

4.1 The Wet Tropics - a biodiversity hotspot of global significance

Australia's Wet Tropics bioregion (1) (Figure 2) encompasses 1.85 million hectares of mixed tropical forest environments between the latitudes of 19°25'and 15°30' in north-eastern Queensland. It ranges from coastal lowlands to highlands at 800 meters, with isolated peaks up to 1,622 meters in the case of Mt. Bartle Frere, the highest mountain in Northern Australia .

It is a biodiversity hotspot of global significance, with a unique regional biota. It is probably the world's best understood tropical system (2). It comprises less than 0.1% of the Australian landmass, yet the Wet Tropics support the highest biodiversity value of Australia's bioregions, including 65% of its fern species, 36% of its mammals, 60% of its butterflies and 41% of its freshwater fishes (3; 4).

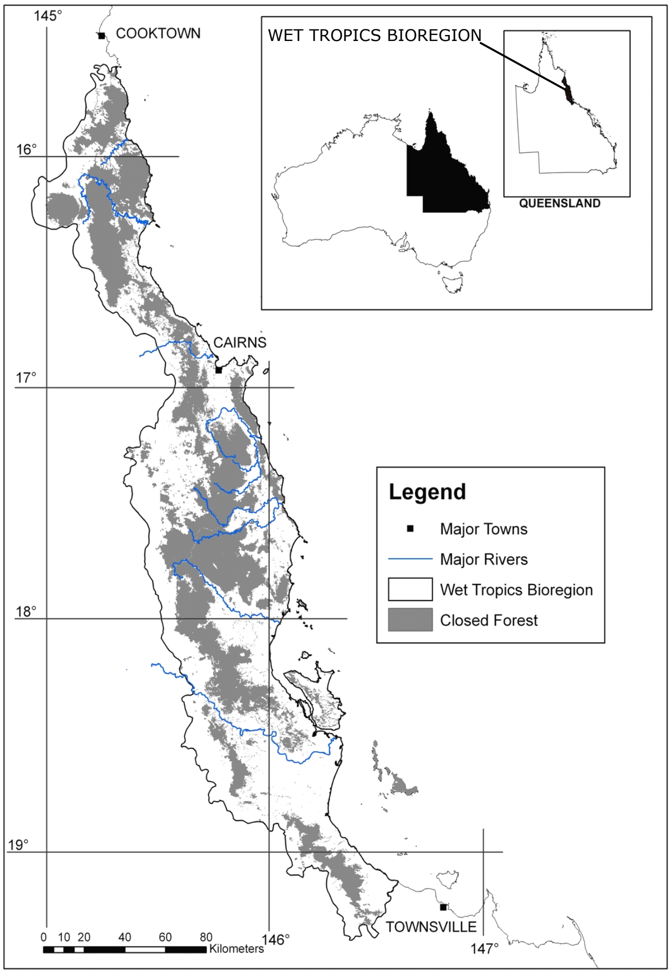


Figure 2. Map of Australia's Wet Tropics Bioregion

4.1.1 WORLD HERITAGE

Since 1988, nearly 40 percent of the Wet Tropics (894,420 ha) is protected within the Wet Tropics of Queensland World Heritage Area (for a review of the social and political processes that led the formal protection see 5). This area includes most of the rainforest in the region (circa 95%). The area meets all four natural criteria for World Heritage (6-8):

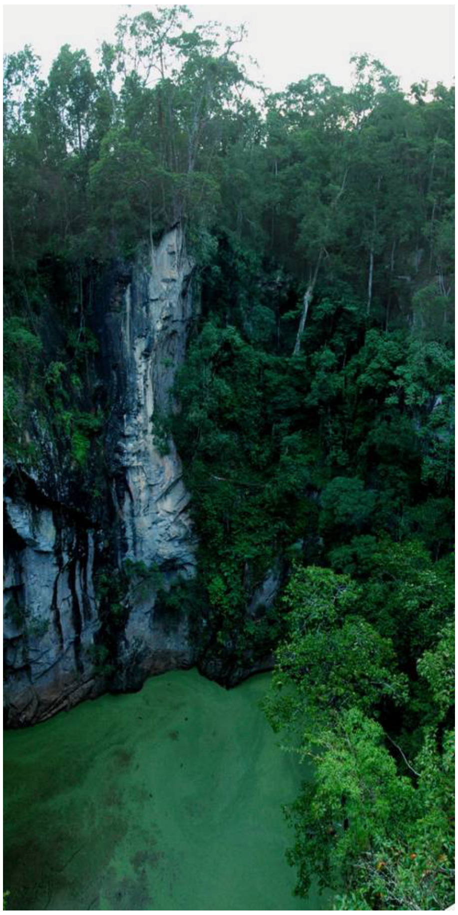
1. *to be outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features*: The area represents one of the most complete and diverse living records of the major stages in the

evolution of land plants, as well as one of the most important living records of the history of marsupials and songbirds.

2. *to be outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals*: The rapid and ongoing ecological, biological and geological processes have resulted in exceptionally high levels of biodiversity and endemism in the area.
3. *to contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance*: The area represents one of the most significant regional ecosystems in the world, with outstanding features of natural beauty and magnificent sweeping landscapes.
4. *to contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation*: The area conserves an extraordinary degree of biological diversity as well as providing the major habitat for in situ conservation for numerous threatened species of outstanding universal significance.

Although the area is not Heritage-listed for its cultural values, the Wet Tropics contain the only recognised existing Australian Aboriginal rainforest culture. The oral pre-history of the surviving Aboriginal rainforest culture is the oldest known for any indigenous people without a written language (9). Archaeological research has revealed a human antiquity of at least 8000 years BP within the rainforest and at least 30,000 years on the western edge (10). The northern tribes (Barrineans) are considered to represent the first wave of the Aboriginal occupation of Australia, making theirs the oldest rainforest culture in the world (7). Rainforest culture differed markedly from that of most other Australian Aboriginal tribes, with its heavy dependence on arboreal skills, everyday use of toxic plants and unique weapons (11). The area continues to hold great significance for the local Aboriginal communities (e.g. 12), who see themselves as rainforest people with deep cultural and spiritual links to the lands and waters of the region (13). The Wet Tropics Natural Resource Management Board and Traditional Owners have indicated support for a renomination of the Word Heritage Area based on cultural values. A detailed summary of the history of Aboriginal occupation is given in RCSQ (14).

4.2 Terrestrial biodiversity research in the Wet Tropics



Until recently, much of the research in the Wet Tropics was conducted from a local and regional perspective; however, the Wet Tropics have the natural assets, research infrastructure and credentials to aspire realistically to be an internationally recognised research centre for tropical terrestrial biodiversity and conservation biology. Many of the elements are currently in place to achieve this vision – extensive, accessible, protected, diverse forested landscapes, some of the best and most respected natural area research scientists, a burgeoning nature-based tourism industry, a high level of political and community support and a sense of identity centred on the region's rainforests and reef.

4.2.1 Brief history of research

Pre-1988 – Before the Wet Tropics of North Queensland were inscribed on the World Heritage List in 1988, only a handful of book sections, journal articles and reports had appeared, and therefore relatively little was known about the biological diversity of the region. There was no centralised approach to the research in the region and the research was mainly from individual researchers and by government agencies such as CSIRO and the then Australian National Parks and Wildlife Service.

1988-1993 - With the Heritage Listing of large parts of the Wet Tropics, the Wet Tropics Management Authority (WTMA) was charged with the responsibility of developing policies that would lead to the protection of the Wet Tropics World Heritage Area, and this required a strong scientific basis. During this period, new relevant research began to appear, administered and funded through WTMA.

1993-2006 - The Co-operative Research Centre for Tropical Rainforest Ecology and Management ('Rainforest CRC') began operations in August 1993. Participants were WTMA, CSIRO, and James Cook, Queensland and Griffith Universities, and involved over 84 scientists. Having achieved national and international recognition during its first phase, the Centre was successfully refunded in 1999, under a new and expanded partnership of twelve organisations. By that time it had developed a strong biodiversity knowledge base that supported the development of planning and conservation policy by agencies such as the Wet Tropics Management Authority. A range of research projects was conducted under the Rainforest CRC, structured under six programs: biodiversity, resource dynamics, socio-economic studies, integrated data exchange, education and technology transfer.

2006-2010 - With the wind-up of the Rainforest CRC in 2006, the Australian Government supported a new initiative, the 'Marine and Tropical Science Research Facility' (MTSRF). This facility was established to build upon the work of the Rainforest CRC as well as the CRC Reef Research Centre. The facility was a consortium of over 38 end-user organisations working with some 300 scientists from 15 research providers, and was administered by the Reef and Rainforest Research Centre Limited (RRRC), which acted as the 'knowledge broker' both within and outside the consortium to achieve maximum return on investment in applied research. Under the MTSRF program 80 research projects were conducted, structured under five 'themes'. (i.e. Status of the ecosystems; Risks and threats to the ecosystems; Halting and reversing decline of water quality; Sustainable use and management of natural resources; Enhancing delivery). It has resulted in about 150 peer-reviewed scholarly articles, as well as a wealth of other technical publications.

Present - The four-year term of the MTSRF officially concluded at the end of June 2010. The Commonwealth Environmental Research Facilities (CERF) established a Transition Program for the MTSRF aimed at delivering additional synthesis products based on the contemporary information needs and synthesis and analysis of pre-existing MTSRF outputs, as well as extending the research relevant to the future CERF key investment areas (i.e. Great Barrier Reef and Torres Strait, northern Australia and terrestrial biodiversity).

The objectives of the CERF Transition Program were to:

- Build on the outputs of the MTSRF to enable the delivery of synthesis products that reflect the contemporary information needs of major end-users;
- Foster the adoption of science-based knowledge into the policies and operational frameworks of major end-users; and
- Sustain the capacity to conduct environmental research on components of the CERF key investment areas of the Great Barrier Reef and Torres Strait, northern Australia and terrestrial biodiversity.

4.2.2 AUSTRALIA'S BIODIVERSITY CONSERVATION STRATEGY

Australia's Biodiversity Conservation Strategy (15) is a new approach to addressing biodiversity conservation in a rapidly changing world. It sets a national direction for biodiversity conservation over the next decade. The strategy reflects the intention of all Australian governments to ensure our biodiversity is healthy, resilient to climate change and valued for its essential contribution to our existence. Despite efforts to manage threats, biodiversity in Australia is still in decline. The strategy outlines the activities that must begin straight away and those that are needed to bring about longer-term change with a minimum 10-year outlook. All actions sit within a list of six 'priorities for change'. These priorities (building ecosystem resilience, mainstreaming biodiversity, knowledge for all, getting results, involving Indigenous peoples and measuring success) reflect the essential changes that need to be made urgently to achieve the strategy's vision.

Australia's Biodiversity Conservation Strategy identifies the following main threats to our national biodiversity:

1. climate change
2. invasive species
3. loss, fragmentation and degradation of habitat
4. unsustainable use of natural resources
5. changes to the aquatic environment and water flows
6. inappropriate fire regimes

In this report, we examine environmental research needs in the Wet Tropics explicitly in the light of these main threats. It is strategic to align future research with this framework because *Australia's Biodiversity Conservation Strategy* will likely guide how future research in the region will be funded.

4.3 Objectives

This report aims to i) provide a broad systematic review of the terrestrial biodiversity research that has been undertaken in the Australian Wet Tropics, ii) identify the gaps in this knowledge, and iii) highlight possible synergies for future research in the region. As such, it provides a valuable resource for researcher providers, end-users, and funding bodies:

- Research providers - it helps locate relevant research information more efficiently, and ensures that proposed research is strategic and targeted at the needs of the end-users.

- End-users - it delivers an accessible and useful repository of terrestrial biodiversity research and knowledge for terrestrially focussed end-user groups, and it identifies the areas of biodiversity research where stakeholder interests overlap.
- Funding bodies - it will help guide the prioritisation of resources into future research in the region.

We envision that these outputs are updated on a 5-year cycle. Updates would require relatively straightforward expansions of the review and reference list, and updates of the research gaps and their valuations.

This report has taken a 'biophysical' sciences approach; however, we acknowledge that the social sciences approach is clearly important for shaping conservation thought, policy and management practices in the Wet Tropics (e.g. 16-29). Unfortunately, despite several notable exceptions, comparatively little social sciences research has been conducted in the context of the Wet Tropics bioregion, and much of the existing work is buried deep in internal policy documents. This only highlights the need for identification and prioritisation of the management and social science gaps in the Wet Tropics bioregion, and we strongly encourage such an analysis, in parallel with this report.

4.4 Methodology

4.4.1 Broad Systematic Literature Review

A systematic review is a tool used to summarise, appraise and communicate the results and implications of a large quantity of research information.

For the purpose of reviewing the information on terrestrial biodiversity research in the region, we sorted the literature according to three main biodiversity research categories ('status and trends', 'risks and threats', 'mitigation and adaptation'). This approach is equivalent to the conventional pressure-state-response model used in analysing the interactions between environmental

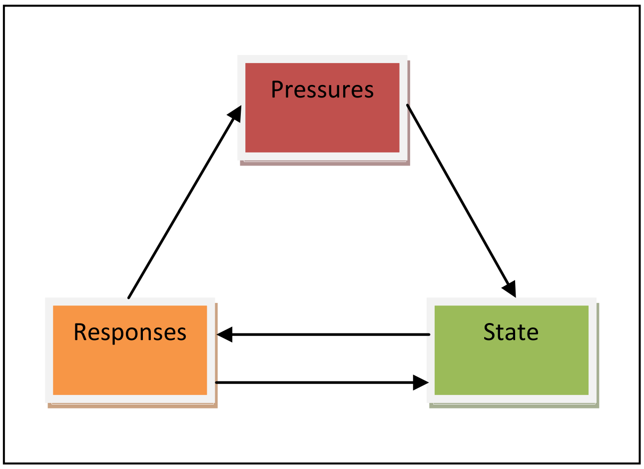


Figure 3. The Pressure-State-Response model of environmental change. Pressures on the environment affect the state of the environment. Responses to the state of the environment affect both pressures on and the state of the environment.

pressures, the state of the environment, and environmental responses (30) (Figure 2). The main category 'Status and Trends' is further divided in several subcategories from 'landscapes' down to the level of 'individuals'. This was done to cover the status and trends of an as wide a range as possible of Wet Tropics life forms. The main categories 'Risks & Threats' and 'Mitigation & Restoration' have been further subdivided according to main threats to our national biodiversity as defined by Australia's Biodiversity Conservation Strategy (for explanation see section 4.2.2).

Next we conducted an exhaustive search of the peer reviewed and grey literature, and incorporated a sample of the references that we found (30% of N>2500) in the various subcategories mentioned above. The peer-reviewed literature for this review was primarily sourced from Web of Science (isiknowledge.com), and cross-referenced with databases from WTMA, the Rainforest CRC and MTSRF. Grey literature was sourced from the major stakeholders, including WTMA, DERM and CSIRO, and cross-referenced with databases from Rainforest CRC and MTSRF (figure 2). For the purpose of this review, 'grey literature' was defined as any terrestrial biodiversity information produced by government or other agencies, not published as a peer-reviewed scholarly article.

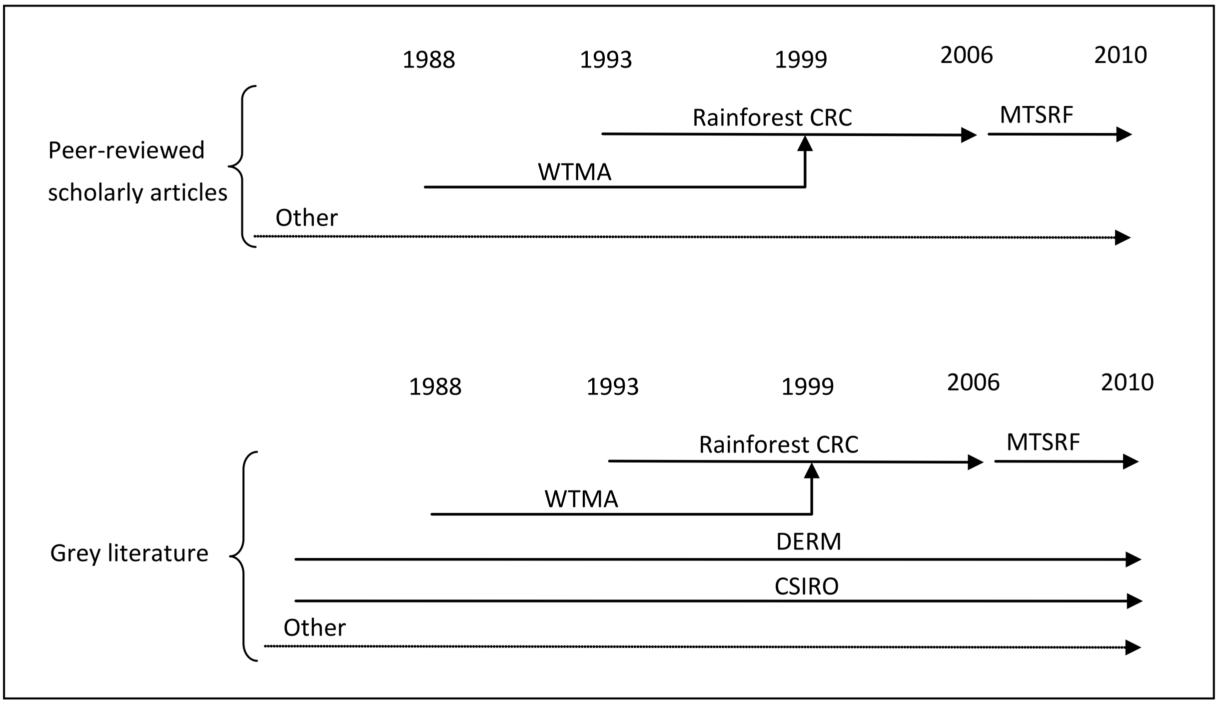


Figure 4. Time lines of sources of literature on biodiversity research in the Wet Tropics

The Web of Science (WoS) is currently one of the foremost online academic citation indices, encompassing more than 11,000 journals and with an indexing coverage from the year 1900 to the present. It is the primary citation index for the natural sciences. In searching for references in WoS the following 'topic' terms were used: "Wet Tropics" and "Australia"; "Humid Tropics" and "Australia"; "tropical" and "Queensland"; "tropics" and "Queensland". Various other combinations and strings were used until no new papers were found. All scholarly articles found this way (N > 2500) were included in the supplementary references list, which will be made freely available through the RRRC and the WTMA websites, and can be requested from the authors.

The combination of "Wet Tropics" and "Australia" yielded a list of 257 references of which more than 95% was relevant. Since the early 1990s, the number of scientific publications pertaining to the term "Wet Tropics" has been increasing steadily to about 30/year (Figure 4). The impact of these publications has been increasing exponentially, with Wet Tropics research currently being cited about 650 times per year (figure 5). However, the increase is partly due to the use of the term "Wet tropics" only becoming commonplace in the literature when the area was inscribed on the World Heritage List in 1988. Before then the area was variously referred to as "humid tropics" or "tropical Queensland" or simply as "tropics".

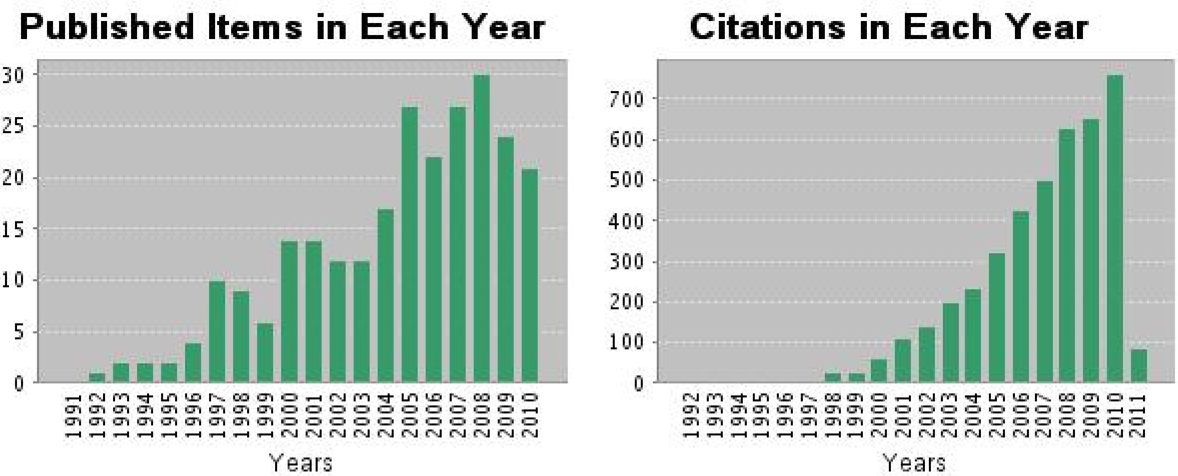


Figure 5. Web of Science citation reports for published items that include the terms "Wet Tropics" AND "Australia" (N=257 papers). a. Number of published items in each year; b: number of citations of published items in each year. Total citations = 4,192; average number of citations per Item = 16.31, h-index = 34.

The systematic review incorporates several existing reviews of Wet Tropics research. In particular, the wonderful book 'Living in a tropical landscape' (2) brings together a wealth of scientific findings and ecological knowledge about the "Wet Tropics" rainforests. It represents the most thorough compendium of a tropical forest landscape to date, and is the first interdisciplinary text to provide a truly holistic assessment of any tropical forest environment, including the social and economic dimensions. In a large part it reflects the research achieved under the Cooperative Research Centre for Tropical Rainforest Ecology and Management (the Rainforest CRC) from 1993-2006.

4.4.2 Identification of research gaps

195 Gaps in biodiversity research in the Wet Tropics bioregion were identified during a workshop held in Cairns on 8 October 2010 (see Appendix section 8.2). The workshop aimed to ensure that those with a vested interest in biodiversity research had an opportunity to participate in identifying the research gaps and end-user needs in the region.

People who attended were: Steve Goosem, Andrew Maclean, Ellen Weber (WTMA); Andrew Krockenberger, Steve Williams, Justin Welbergen, Alma, Ridep-Morris, Miriam Goosem (JCU); David Hilbert, Petina Pert, David Westcott (CSIRO); Bruce Wannan, Andrew Millerd, Mark Connell (DERM-QPWS); and Mellissa Jess (RRRC).

At the start of the workshop Steve Williams gave a short presentation delineating the area of interest of the analysis (i.e. 'biodiversity' or 'biophysical' research) and outlining how the gap analysis would likely fit with the future regional funding environment. Next, Steve Goosem gave a presentation on the importance of identifying biophysical research gaps for end-user organisations, and on how biophysical research is used by WTMA. Justin Welbergen then gave a short presentation presenting the outline of this report and an overview of its main deliverables, followed by an explanation of the workshop procedures and agenda.

Participants were then randomly assigned to groups (three or four people per table) and were asked to identify as a group, but to the best of their personal expertise, the research gaps within the same three main categories as found in this report, i.e. 'Status & Trends' (what is there and what is changing?), 'Risks & Threats' (what is causing the change?), and 'Mitigation & Adaptation' (what can be done about the change?). Next, the participants were asked to rate each gap according to its perceived 1) immediacy of concern (low, medium, high, very high), i.e. '*the need to fill the gap now*'; and 2) magnitude of concern (low, medium, high, very high), i.e. '*the magnitude or seriousness of the issue that has the gap*'. Several examples were given to make the process as straightforward as possible.

The research gaps are presented in a common format throughout this report:

	Research gaps	Immediacy of concern	Magnitude of concern
ST.1	Higher-resolution climate data reflecting the spatial and topographic vulnerability of the region	medium	high
ST.2-3	Effective remote sensing approaches for rapid identification of landscape change	medium	medium-high

The column on the left contains a gap identifier (e.g. ST.1 = Status & Trends, gap 1) that corresponds to the gaps as literally formulated by the workshop participants, and listed in full in Appendix 1. The next column contains the actual research gap. It reads like it follows on from the sentence 'the workshop participants expressed a need for' [...]. Usually this gap corresponds directly to the gap as formulated by the workshop participants (e.g. gap ST.1), but in some cases when there was repetition, gaps were amalgamated into a single gap (e.g. ST.2-3 corresponds to gaps ST.2 and ST.3 in Appendix 1). Finally, on the right are the ratings in terms of immediacy and magnitude of concern, or in other words 'the need to fill the gap now' and 'the magnitude or seriousness of the issue that has the gap'.

4.4.3 HIGHLIGHTING POSSIBLE SYNERGIES FOR FUTURE RESEARCH

At the workshop, we asked the participants to identify gaps to the best of their personal expert knowledge so that we could maximise the coverage of potential research gaps. However, as we were also interested in identifying common institutional interest in specific areas of environmental research, we subsequently sought feedback from the main organisations with a vested interest in research in the region. We specifically asked them to rank each of the 195 gaps according to the relative value that it would represent to their organisation if the gap was filled. This way we were able to determine those research *needs* that, if met, would have the greatest value for end user organisations (see section 6). In addition, it enabled us to identify where interests of end user organisations overlap (see Appendix, section 8.1).

We kindly received feedback from representatives from the following 12 organisations: WTMA, TERRAIN, SEWPaC, Bana Yarralji Bubu Inc & Balkanu Cape York Development Corporation, Far North Queensland Regional Organisation of Councils, Australian Wildlife Conservancy, CSIRO, Australian Conservation Foundation, Fisheries Queensland, Biotropica

Australia P/L. In addition, JCU and DERM-QPWS provided feedback by three people each so their ratings were averaged to obtain single institutional values. John Winter also contributed as an independent researcher.

4.5 Navigating this report

The report is highly structured and hyperlinked throughout, which should help the reader quickly navigate the document. Cross-references to figures tables and other sections of the report will help in navigating within the document, and web links will take you outside the report to relevant internet material. The table of contents is hyperlinked as well, in case one gets lost or if one decides to quickly skip a section.

Citations (e.g., 2), when clicked, will take you directly to the relevant location in the reference list. The references are available in full (including abstracts and PDF links where available) in the extensive reference databases supplied with this report.

5 Broad Review of Current State of Knowledge

5.1 Status and trends

Different patterns emerge at different scales of investigation of virtually any aspect of any ecological system (31). To accommodate this issue and to cover the status and trends of as wide a range of life forms as possible, we have divided this section in four parts representing four main scales of analysis: landscapes, ecosystems, species, and individuals. We will now review these in turn as they relate to the status and trends in the Wet Tropics.

A wealth of additional recent information on Status and Trends can be found under MTSRF Program 2 - Status and Trends of Species and Ecosystems in the Wet Tropics Rainforests, which includes the general condition and trends of key ecosystem processes and biodiversity in the Wet Tropics rainforests; and under MTSRF Program 4 - Species and Communities of Conservation Concern, which includes the rainforest species and communities that are issues for conservation.

5.1.1 Landscapes (climate, geophysical processes, land usage)

The area is volcanic in origin with volcanism commencing at 7.1 Ma in the Atherton Basalt Province and continuing into the Early Holocene (32). The bioregion is dominated by rugged mountains, including the highest in Queensland (Mt Bartle Frere, 1,622 m). It also includes extensive tablelands along its western margin, as well as low-lying coastal plains. The most extensive lowlands are in the south, associated with the floodplains of the Tully and Herbert Rivers (33).

Empirical modelling confirms the highly dynamic nature of the Wet Tropics landscape and presents a detailed picture of landscape change since the late Pleistocene (34; 35). The range of rainforests within the Wet Tropics has oscillated with climatic fluctuations during the Quaternary, due to their specific temperature and rainfall requirements (36). Glaciation at higher latitudes was associated with a global reduction in rainfall, and during the last glacial maximum in the Pleistocene (13,000–8,000 years ago), most Australian tropical rainforest was displaced by drier sclerophyll forests, although some isolated moist refugia remained (37). Since then, rainfall has increased and rainforest has expanded to its current extent (38). Diatom records from Lake Euramoo on the Atherton Tableland suggest accentuated Late Holocene climate variability, which may help explain intensified land use in indigenous populations and suggests that Europeans may have arrived in the landscape at the time it was most vulnerable to perturbation (39; 40). The lake's pollen and charcoal record shows a rapid loss of forest diversity (particularly the long-lived taxa *Agathis* and *Podocarpus*) and increased burning coinciding with the arrival of European settlers (39; 41).

Many of the distinctive features of the region relate to the high rainfall and terrain diversity (33). The mean rainfall ranges between 1,200 mm to 8,000 mm per year, with up to 12,461 mm at Mt Bellenden Ker (42). The wetter parts of the region represent some of the wettest areas in the world (33). The bioregion plays a major role in the generation of runoff that drains to the world renowned Great Barrier Reef lagoon (e.g. 43).

Rainforests dominate the region, covering an area of slightly less than a million ha and distributed primarily along a series of disjunct mountain ranges (2). The rainforests have been subjected to a series of climate fluctuations over the Quaternary (e.g. 44; 45), often resulting in the rainforests contractions to small, fragmented refugia (46; 47) and expansions of Eucalypt woodland (48). The rainforests possess elements representative of tropical, subtropical, temperate, and monsoonal forest types, and occur across a diverse range of geologies, topographies, and evolutionary histories resulting in a spectrum of plant communities which are floristically and structurally the most diverse in Australia (49; 50).

The rainforests have been classified into 16 major structural types and 30 broad community types (51; 52; see also 53-55), which are fringed and dissected by a range of eucalypt forests and woodlands, mangroves, and *Melaleuca* swamp communities. The Department of Environment and Resource Management and the Queensland Herbarium provide high-resolution data on the historical and contemporary distributions of 'Broad Vegetation Groups' (BVGs) in the region; these BVGs amalgamate vegetation communities and regional ecosystems on an ecological basis (56).

Goosem et al. (4) identified 105 distinct ecosystems in the region, of which 24 (23 percent) were considered endangered at the time and a further 17 were of concern. Eighteen of the endangered ecosystems occur on the coastal plain as fragmented remnants, with another five confined to the gentle terrain associated with upland basalt tableland landscapes.

Analysis by Pert et al (57) suggests that some progress has been made towards halting biodiversity loss in the region; however, the overall status of most vegetation condition is still of concern. A collection of detailed annual reports on the state of the Wet Tropics World Heritage Area (e.g. 58) can be downloaded from the website of the Wet Tropics Management Authority. The most current account of the status and trends of native vegetation condition in the Wet Tropics can be found on this website. A more general but less recent report on the status and trends of the Wet Tropics Bioregion was prepared under the National Land and Water Resources Audit (59) and can be downloaded at the ANRA website. The Department of Environment and Resource Management provides detailed attributes for each regional ecosystem including its description, biodiversity status, ecological values, distribution and classification (60). Their database and maps can be downloaded from this website.


J. A. Welbergen

Table 1. Gaps in biodiversity research pertaining to 'Status and Trends – Landscapes'

	Research gaps	Immediacy of concern	Magnitude of concern
ST.1	Higher-resolution climate data reflecting the spatial and topographic vulnerability of the region	medium	high
ST.2-3	Effective remote sensing approaches for rapid identification of landscape change	medium	medium-high
ST.4	Answers to how best to monitor status and trends, and how to fund it	high	high
ST.5	A comprehensive and detailed assessment of land capability and land use risk	high	medium
ST.6	Maps of soil and nutrient distributions in the bioregion	medium	medium
ST.7	Higher-resolution vegetation mapping	medium	medium
ST.8	Understanding the connectivity processes and interactions, with reference to habitat quality issues	medium	high
ST.9	Understanding the main impacts of the interface between non-rainforest and rainforest habitat (considering edge effects in both directions)	medium	medium
ST.10-11	Information on regional hydrology (rain, ground, cloud, etc.) from summits to ocean, particularly with respect to identifying hydrorefugia as key conservation areas	medium-very high	medium-very high

5.1.2 Ecosystems (community structure, habitat diversity, functioning)

The diverse ecosystems of the bioregion have been described in some detail, but with a focus on community structure of rainforests (38; 61-72) and rainforest remnants (73; 74), reflecting the rain forests' predominance in the region. The next best described ecosystem is wet sclerophyll forest (75), but here studies generally focus on the ecological dynamics at the wet sclerophyll-rainforest boundary. These boundaries are highly dynamic, with the rainforests currently expanding most likely due to favourable fire regimes (76; 77; 78-80; see also 5.2.6).

Further studies focus particularly on the assemblage structure of various taxonomic groups, including mammals (81-83), frogs (84), fish (85-92, invertebrates (93-96) and plants (66).

There have been many studies looking at ecosystem functioning, particularly growth and photosynthetic responses to light, water and nutrients (97-108), but also plant metabolism (109). Another area of interest has been nutrient cycling, particularly in relation to physiognomic structure (110-112), succession (113; 114), species–soil and species–disturbance interactions (e.g. 115-118).

Table 2. Gaps in biodiversity research pertaining to 'Status and Trends – Ecosystems

	Research gaps	Immediacy of concern	Magnitude of concern
ST.12-15	Understanding of the key indicators of ecosystem health that can be regularly measured at a landscape scale, with a focus on rare regional ecosystems that are threatened by anthropogenic (climate) change	medium-high	high-very high
ST.16	Quantitative measures of forest health/degradation, such as growth or recovery rates across environmental gradients (e.g. elevation)	medium	medium
ST.17	Research into thresholds or tipping points that lead to catastrophic irreversible ecological changes	medium	very high
ST.18	Understanding the ecological function and other values of regrowth and non-remnant vegetation	very high	very high
ST.19	Quantification of the value of restoration and regrowth in maintaining and improving ecosystem function	high	high
ST.20	Understanding short-term vs. longer-term dynamics in the spatial and temporal distribution of ecosystems and component species	medium	medium
ST.21	Assessment of the functionality of current connectivity of ecosystems with respect to traits of a variety of species	high	very high
ST.22	Rationally based assessment of threatened Wet Tropics ecosystems	high	high
ST.23	Multi-layered systems for assessment of ecosystem health relevant to key values	medium	medium

	Research gaps	Immediacy of concern	Magnitude of concern
ST.24	Understanding the impacts of drought in dry sclerophyll forests	medium	high
ST.25	A better definition and separation of rainforest 'types' with respect to Queensland's statutory Regional Ecosystem framework which is more designed for open forest communities	low	low
ST.26	Higher-resolution mapping of the vegetation types of critically important areas (mapping units and map scale)	high	high
ST.27	Information on trends in cloud forests	high	very high
ST.28	Distribution and abundance of wet sclerophyll species	medium	medium
ST.29	Understanding the open forest/rainforest dynamics, with respect to edges and ecotones and transitional communities	high	very high

5.1.3 Species (distribution & abundance, taxonomy & phylogeography)

The essential characteristics of the Wet Tropics biota are exceptionally high species diversity and endemism (e.g. 119; 120); very restricted ranges and habitat requirements for many species; many highly specialised species; a small number of highly endangered species; a large number of potentially vulnerable species; and a high degree of fragmentation of particular communities (e.g. 121; 122).

Since the 1970s many new species have been discovered in the region, including: vertebrates such as bats (123), legless lizards (124), geckos (125-127), skinks (128), frogs (129-132) fish (133), insects (134-139), arachnids (140-149), chilopoda (150), snails (151), nematodes (152), lichens (153), liverworts (154); and many seed plants (see below).

There are numerous new records and descriptions of plants such as bushwillows (155); melaleucas (156); palms (157); Eucryphia (158); orchids (159-169); the families Rubiaceae (170; 171); Rutaceae (172); Myrtaceae (173-177); Araucariaceae (178); Lauraceae (179); Cycadaceae (180); Euphorbiaceae (181); Cunoniaceae (158; 182); Ptychomniaceae (183); and considerable effort has been devoted to representatives of the Proteaceae family in the region (e.g. 184-204). For new names of plants, algae and lichens in Queensland see this

website from DERM. For further research and information on the Queensland flora see the Queensland Herbarium website.

Distribution and abundance

Considerable knowledge has become available on distribution of rainforest biota (84 37; 205-211), patterns of phylogeography (133; 212-225) and historical paleodistribution of vegetation and climate (37; 47; 223; 224; 226-230).

Historical habitat fluctuations, coupled with subsequent localized extinctions, have likely been extremely important processes in determining current patterns of endemism in Australia's wet tropical rainforests (231). This is supported by a whole range of distributional (e.g. 119; 232; 233) and molecular data (e.g. 213; 217). The regionally endemic upland species are considered to be relicts of either an older connection with the upland fauna of New Guinea or from an older, cool temperate Australian fauna (234). In contrast, the lowland rainforest of the Wet Tropics has a higher affinity with the rainforests of Cape York and New Guinea, with dispersal from the north over the paleohistory of the region being an important process (234). Phylographic and biogeographic analyses of northern bettongs (235), endemic lizard species (212; 236-239), crayfish (240-242), dung beetles (216), flightless insects (233) support this scenario.

Historical contraction of rainforest to small refugia, followed by non-random species extinctions, may explain the relatively low endemism in the lowlands (231; 243), and the relatively high proportion in montane regions of narrow-range specialised taxa which are thought to be resilient relicts of past climate change (e.g. montane rainforest lizards, *Lampropholis* spp.; 244). The range-restricted specialists form a major component of the biodiversity in the Wet Tropics, and tend to have high uniform local abundance that offsets their geographic rarity, meaning that they have the potential to persist for long periods (245; 246).

The complex biogeographic history explains why elevation is the primary ecological gradient along which species richness and composition are organised in the region (231). Regionally endemic birds are known to exhibit complex variability in abundance within current elevation ranges (247) and the same has also been demonstrated for other vertebrate taxa in the region (and the world: 248), including arboreal mammals (249-251) and microhylid frogs (252).

Vertebrates - We now know that approximately 350 species of vertebrates occur in the rainforests of Wet Tropics, however, only about 153 species have their core distributions in the rainforest. Of the thirteen mammal species endemic to the region, all except the

Mahogany Glider and Tropical Bettong are rainforest dependent (209; 253; 254). Broad distributions, habitat preferences and abundance data of a range of vertebrates of the Wet Tropics have been well documented since the 1970s (e.g. 3; 208; 229; 234; 253-280). With the recent availability of systematic standardised surveys of vertebrates across the region, detailed geographic patterns of species richness are now available for 202 vertebrate species (253; 254).

Invertebrates - In tropical forests such as in the Wet Tropics, invertebrates show especially high species richness relative to vertebrates, and one possible cause is that they respond to historical habitat fluctuations on a smaller spatial scale (216; 281). Considerable knowledge has become available on broad distributions, habitat preferences and abundance of invertebrate species (135; 148; 151; 218; 225; 282-292), but we know less about the invertebrates than the vertebrates in the Wet Tropics.

Plants - The Wet Tropics are one of the main centres of endemism for Australian vascular plants (232; 293). It contains the highest number of 'primitive' plant families in the world, many endemic to the area and considered to be relicts of a once widespread Gondwanan flora (e.g., 294-297). Details on the identification, distributions, habitat preferences and abundance of a range of plants are available (52; 63; 66; 67; 298-304)

Taxonomy & phylogeography

Genetic variation can reveal species that are otherwise cryptic, and therefore it is recognized as a fundamental component of biodiversity (e.g. 305). As a result of its dynamic geological and climatic history (see 5.1.1), the Wet Tropics bioregion has a complex phylogeography and great diversity at a range of taxonomic levels. New genetic tools and DNA markers (e.g., 239; 306-309) allow us to study geographically structured genetic signals, both within and among species, and this can provides new insights into the process of speciation (e.g. 310) and parasite-host coevolution (e.g. 311). For example, several studies have documented the genetic effects of habitat contraction (e.g., 235; 281; 312; 313) and other potential evidence of bottlenecks (314). In addition, a range of phylogeographic studies (235; 313; 315-323) has revealed historical

biogeographic barriers to gene-flow, such as the Black Mountain corridor/barrier and the Burdekin Gap, which suggests pre-Pleistocene isolation (212). Similarly, some areas, especially mountains, have provided long-term protection to climate-induced fluctuations in distribution of rainforest habitat, and this too has led to local endemism and cryptic but highly divergent lineages with restricted geographical distributions (34; 46; 232; 237; 324-329), also called 'Evolutionarily Significant Units' (ESUs).

Table 3. Gaps in biodiversity research pertaining to 'Status and Trends - Species (distribution & abundance, taxonomy & phylogeography)'

●	Research gaps	Immediacy of concern	Magnitude of concern
ST.30	Improved knowledge of phylogeography of Wet Tropics plants	low	medium
ST.31	The assessment of the abundance and population structure of threatened and endemic species	high	medium
ST.32	An improvement of the very poor understanding of plant species distributions	low	low
ST.33	Improved identification of the major and minor natural disjunctures and genetic barriers in the landscape	medium	medium
ST.34	Information on the status and trends of wildlife dispersers of rainforest plants	high	high
ST.35	Basic bat distribution data	low	medium
ST.36	Maps of habitats of all endangered and vulnerable species	very high	very high
ST.37	Understanding the underlying mechanisms of species distribution and abundance	low	high
ST.38	Improved understanding of rainforest plant associations	low	low
ST.39	A baseline health status assessment of key threatened and endemic species	medium	medium
ST.40	An improved understanding of the biology of non-threatened species	medium	medium
ST.41	An improved understanding of the biology of mosses / cryptogams, threatened and endemic species, and climate change indicators	medium	high
ST.42	A solution for how to monitor cryptic rainforest species	medium	medium
ST.43	Understanding the role of vector-borne diseases in affecting abundance and distribution of wildlife, plants and humans	high	very high
ST.44	Data on the temperature tolerances of tree species, in particular on reproduction, growth, recruitment, and mortality	medium	high

5.1.4 Individuals (ecology, life-history, behaviour)

A variety of species have been studied individually with respect to their ecology, life-history, and behaviour. As is the case elsewhere, vertebrates, particularly mammals and birds, have been studied more intensely than their taxonomic representation would suggest.

Vertebrates - Studies on mammals include general descriptions of species morphology and ecology (330-334334-337), and more specific examinations of breeding ecology (338; 339), habitat preferences and habitat use (340-342), feeding ecology and dietary preferences (279; 330; 343-348), activity patterns (349; 350), and life-history and demography (351). In addition, there are several studies looking at the impact of mammals on the dispersal of seeds (e.g. 352; 353), fungal spores (354; 355), and even bryophytes (356).

Studies on birds include general descriptions of species morphology and ecology (357; 358), and more specific investigations of population ecology (359), breeding ecology (338; 339; 360-364), social organisation (360; 365-367), habitat preferences and habitat use (266; 368; 369), foraging ecology and dietary preferences (370-373), predation (432; 433374), song (366; 375-381), and nests, bowers and courts (358; 382-388).

Other vertebrates – There is little apparent work in this area. There are two general studies on the natural history of the slaty grey snake (*Stegonotus cucullatus*) and the brown tree snake (*Boiga irregularis*) (389; 390); two studies on social organisation and dispersal in the prickly forest skink *Gnypetoscincus queenslandiae* (391; 392); and one study of the effects of season and weather on calling in the frogs *Austrochaperina robusta* and *Cophixalus ornatus* (393). The remainder of the research concerns the ecology and behaviour of rainbowfish (*Melanotaenia* spp.) including reproductive biology (394), habitat-predator association and avoidance (395), microhabitat habitat use (396), and dispersal (397).

Invertebrates - There is very little apparent research in invertebrates at this scale of investigation (but see 398).

Plants - There is a broad body of work on plant-animal interactions, especially concerning herbivory (399-406)), pollination (180; 407-411), frugivory and seed dispersal (353; 371; 412-437), but also on the impacts of birds on seedling germination (438). Several additional studies deal with plant-fungi interactions, with a focus on mycorrhizas (354; 439-454) and disease (e.g. 455).

There are various studies on plant morphology (97; 190; 400; 456), including the chemical and spectral properties of canopy species (457). There have been several general studies on the mortality, recruitment and turnover rates of trees (458; 459), and various studies examine the role of seed bank composition in forest regeneration (70; 460-464). In addition, there are several studies on population ecology and genetics (192; 465; 466), and many consider specifically the mechanisms and ecological attributes affecting seedling survival (399; 467; 468 469), germination (470), growth (471-473), and recruitment (468; 471; 474). Other research includes general conservation biology (475-477) and causes of endemic and genetic rarity (478; 479).

Flowering and fruiting phenology has been well-studied and highlights the importance of competitive interactions and of physical and evolutionary factors as determinants of flowering time, intensity and co-occurrence in tropical forests (436; 480; 481). In addition, there have been various other studies on community phenological patterns (e.g. 482) looking at the temporal distribution and composition of pollen (483), seed rain (484) and litterfall (485; 486).

Table 4. Gaps in biodiversity research pertaining to 'Status and Trends - Individuals (ecology, life-history, behaviour)'

●	Research gaps	Immediacy of concern	Magnitude of concern
ST.45	Adaptation research, especially with respect to climate change (behavioural ecology, genetic and variations in life histories across gradients)	high	very high
ST.46	Data on population abundance of threatened species (as opposed to their distribution)	high	high
ST.47	Information on inbreeding in threatened species	medium	high
ST.48	Baseline research into disease and parasite loads of native animals and plants	low	high

●	Research gaps	Immediacy of concern	Magnitude of concern
ST.49-50	Understanding the patterns and controlling factors (both temporal and spatial) of phenology, particularly of flowering and fruiting patterns of rainforest trees	medium	Medium
ST.51	Cassowary behavioural response research (sound, sight, smell) especially with respect to threats such as roads and urbanisation	high	High

5.2 Risks and threats

Australia's Biodiversity Conservation Strategy (15; see 3.3) identifies the following main threats to our national biodiversity: 1) climate change; 2) invasive species; 3) loss, fragmentation and degradation of habitat; 4) unsustainable use of natural resources; 5) changes to the aquatic environment and water flows; 6) inappropriate fire regimes. We will now review these in turn as they relate to the Wet Tropics Bioregion.

5.2.1 Climate change

Climate shifts

It is now widely accepted that climate change is probably the most significant threat to global biodiversity and human well-being (487-490). The 2007 IPCC Fourth Assessment Report (491) predicts that the average global temperature will rise by 1.4 to 5.8°C by 2100, and the Australian Bureau of Meteorology has just announced that the decade ending 2010 was the hottest decade on record for Australia, with an anomaly of +0.52 °C (492). In the Wet Tropics Bioregion, annual temperature is projected to increase between 0.5 and 1.4°C by 2030 and between 1.0 and 4.2 °C by 2070 (493). Changes in rainfall patterns are predicted with rainfall becoming more variable, longer dry spells and increased frequency or intensity of disturbance events such as flooding rains and cyclones (494-496). Additionally, a rise in the average altitude of the orographic cloud layer is expected (497), which will likely exacerbate the effects of longer and more variable dry seasons due to a reduction in cloud capture by the canopy in mountain rainforests (498). As a consequence, environments will change; some species will be lost and others will not persist in their current locations (see: 499). Indeed, changes in Australian species and some ecosystems have already been detected that are consistent with recent changes in temperature, rainfall and sea level (499), and significant impacts are projected to occur in the Wet Tropics bioregion by 2020 (491).

Many studies have demonstrated, or predicted, that climate change will result in shifts in the latitudinal and altitudinal range of affected species, with concomitant complex changes in assemblage structure and ecosystem function (488; 489). There is a common, though incorrect, perception that the impacts of climate change will be worse in temperate regions than in the tropics although it is generally accepted that all mountain biota are extremely vulnerable. Mountain systems such as those found in the Wet Tropics Bioregion represent hotspots of biodiversity and endemism due to the compression of climatic zones over the elevational gradient (500). The rainforests of the Wet Tropics are isolated habitats with no potential for rainforest endemics to shift their latitudinal and altitudinal ranges (501), providing the ingredients for an impending environmental catastrophe (502). This is in accordance with predictive modelling of impacts on species distributions and abundance, which provides clear warnings regarding the potential for extinctions across a range of taxa in the Wet Tropics (227; 247; 502-506).

Vertebrates **-** Wet Tropics vertebrate species seem particularly vulnerable to climate change (502; 507; 508), and many are now considered severely threatened (502). Bioclimatic models of the spatial distribution for endemic rainforests vertebrates predict that many species will lose the majority of their core habitat under relatively small increases in temperature, resulting in an amplification of extinction rates and a significant reduction in overall biodiversity in the region (502; 508; 509). Isaac et al. (510) quantified the relative extinction risk in a diverse assemblage of Australian tropical rainforest vertebrates (24 frogs, 33 reptiles, 19 mammals and 87 birds), and found that frogs were the most vulnerable taxonomic group overall. It has also been predicted that for regionally endemic birds and frogs, as temperature increases, population size is likely to decline more rapidly than distribution area. This indicates that for these species, extinction risk associated with climate change will be more severe than expected from decline in distribution area alone (247; 503).

Shoo et al. (247) predict that 74% of rainforest bird species will become threatened as a result of projected mid-range warming in the next one hundred years. Upland birds are expected to be most affected and are likely to be immediately threatened by small increases in temperature. However, there is a capacity for the population size of lowland species to increase, at least in the short term (but see 511 for an example of an increase in the upland population instead). Many microhylid frog species are also predicted to suffer large declines in population size as climates that currently support high density populations of species on mountaintops are likely to disappear under moderate levels of climate warming (252).

Invertebrates **-** invertebrates also seem to be under threat, particularly high elevation assemblages (see 359). Studies on invertebrate fauna have found many species restricted to high altitudes with limited opportunity for dispersal, including a host of low vagility arthropods (219-222; 512; 513 but see 514; 515), schizophoran flies (359), ants (516) and snails (151). This suggests that the impacts on invertebrate assemblages will be similar to those predicted for regionally endemic vertebrates. Genetic diversity is likely to be low among the upper montane species, limiting their potential for climatic stress adaptation (e.g. 517).

Plants – Vegetation is also under threat. Bioclimatic modelling suggests that the tropical vegetation patterns of north Queensland are highly sensitive to climate change and substantial shifts in the distribution of these forests are likely to occur with minor variations in climate, and certainly within the range that is likely to occur in the next 50-100 years (e.g. 505; 518-523). Remotely sensed data combined with regional model analyses suggest that forest growth and biomass accumulation will be affected (524-527), which may contribute to global atmospheric greenhouse gases, including CO_2 and N_2O emissions, and CH_4 uptake (528-533). Assessments of water balance of rainforest canopies highlight the susceptibility to drought and the potential threat from climate change which could result in reduced cloud water interception and enhanced conditions for evaporation, especially in the upper montane cloud forests (43; 534-537).

For an overview of species and ecosystems under threat from climate change in Queensland, see (538); for a recent strategic assessment of the vulnerability of Australia's biodiversity to climate change, see (539).

Climatic extremes

In Australia the frequency of extremely warm days and nights has generally increased while that of extremely cool days and nights has decreased (540). Since 1950, the Wet Tropics' average maximum temperature has increased by 0.8°C (0.14°C per decade) and the average minimum by 0.91°C (0.16°C per decade) (493).

Many significant impacts of climate change may emerge through shifts in the intensity and the frequency of extreme weather events, including heatwaves, flooding rain and cyclones (541). Such extremes represent the way in which people, animals and plants will strongly experience climate change

(542). Extreme temperature events can cause mass mortality (543) and contribute significantly to determining which species occur in which ecosystems (544; 545). The frequency, duration and severity of extreme temperature events are rising faster than the means (494; 546-548), meaning that they will continue to gain significance as mechanistic drivers of ecological responses to climatic change (e.g.549; 550).

Although changes in the regimes of temperature extremes are expected to be most pronounced at high latitudes, tropical species may already be living closer to their maximum thermal tolerances and therefore even small changes could have disproportionally large impacts (551; 552). Little is known about the vulnerability of tropical rainforest biota to extreme temperature events. Cyclones are also important recurring extreme events affecting the structure and function of ecosystems in the region (see section 5.2.3). They are expected to increase in intensity and decrease in frequency under anthropogenic climate change, but little is known about and the ecological impacts of changes in cyclone regimes (553; 554).

Studies have only recently begun looking into the potential vulnerability of Wet Tropics' biota to extreme events. The few examples include studies on the potential of microhabitats to protect species against extreme heat stress under climate change (341; 555). Knowledge of species-specific differences in extreme temperature tolerances, and the probability that species will be exposed to temperature extremes, is critical for the successful development and targeting of proactive conservation strategies that minimise exposure (510).

Further information can be found under MTSRF Program 5ii - Climate Change: Rainforest and Catchments, on a new high-resolution software tool, OzClim, for the region that enable for uncertainty in future climate change projections to be represented (project 2.5ii.1); physiological and phenological responses to natural climate variability (project 2.5ii.2); responses at the ecosystem and species level to actual climate change (project 2.5ii.3); and on the potential of Wet Tropics species to adapt to climatic change through ecological and evolutionary mechanisms, and establish the potential for refuges to mitigate impacts on vulnerable species (project 2.5ii.4).

Additional relevant information can be found under MTSRF Project 1.2.1b - Biodiversity monitoring for climate change which aimed to provide the knowledge and methods needed for accurate and up-to-date state of the region reporting on the key biodiversity and ecosystem services and assets of the region.

Table 5. Gaps in biodiversity research pertaining to 'Risks and Threats – Climate change'

●	Research gaps	Immediacy of concern	Magnitude of concern
RT.1-2	Understanding which ecosystems and species are most vulnerable to climate change (including shifts in averages and extreme events)	very high	high-very high
RT.5	An evaluation of the mechanisms of impact of climate change; how does climate change affect species and ecosystems?	medium	Medium
RT.6	Understanding the threat of climate change to ecosystem processes, e.g. primary production, dispersal, water relations, etc.	medium	very high
RT.7	Understanding both cumulative and interactive effects; how do first order impacts translate into second and third order impacts?	medium	Medium
RT.8	Understanding what cascading effects will climate change-related increases in population size and distribution of some native species have on community dynamics	very high	very high
RT.9.11	Understanding the interactions of climate change with other threats, e.g. invasive species	medium-high	high-very high
RT.12-13	Understanding the threats of extreme climatic events to biodiversity, especially in relation to refugia and individual species	medium	very high
RT.14-15	Understanding the role of refugia under climate change; at what scales do they exists, where are they, and what is their value?	high	very high
RT.17	Knowledge of what mediated survival under historical climate change	low	High

5.2.2 INVASIVE SPECIES

'An invasive species is a species occurring, as a result of human activities, beyond its accepted normal distribution and which threatens valued environmental, agricultural or other social resources by the damage it causes' (556). The threats to the natural environment by invasive species are a global issue (557). Introduction of alien organisms frequently produces drastic impacts on the receiving biota and systems. They may reduce farm and forestry productivity, threaten native species and contribute to land degradation. Invasive species are widely accepted as one of the leading direct causes of biodiversity loss in the world, behind habitat loss and fragmentation (558). The Wet Tropics Bioregion is seen as particularly vulnerable to the threat of invasive pest species (559). Most pest invasions are closely related to human activity-related disturbances in the region, particularly clearings associated with service corridors such as powerline easements and roads which act as both habitats and conduits for pest dispersal (560; 561).

Vertebrates - Although the number of vertebrate pest species -28- has remained stable for several years, their population numbers, distribution and ecological impacts are generally very poorly understood (58). Harrison and Congdon (562) assessed the status of the 28 naturalised vertebrates within the region and found that the current major vertebrate pests are the pig, cat, cane toad, dog/dingo, and gambusia and tilapia (see also 563). These species rank as high impact due to their current levels of ecological damage and because of the current lack of feasible options to control them (563).

- Feral pigs (*Sus scrofa*) are believed to have a severe negative impact on the ecological values of the Wet Tropics because they modify the natural habitat, compete directly with native species for resources and carry and transmit disease and parasites (e.g. 564; 565). It has been estimated that there are currently about 27,000 feral pigs in the region (58). Most perceptions of the environmental impacts of feral pigs focus on their disturbance of the soil or surface material (566), which tend to predominantly occur in the early dry season and in moist soil (swamp and creek) microhabitats (e.g. 567; 568). Currently, most pig diggings were recorded in highland swamps (568), whereas a study in 1997 found that diggings were more prevalent in lowland areas and coastal swamp habitats (569).

- Cats (*Felis catus*) are well known for decimating ground dwelling bird and small mammal populations (570). Direct and indirect sightings of cats suggest they are widely, though not uniformly distributed throughout the closed and open forest communities of the Wet Tropics upland forests (571). The density of domestic cat populations possibly makes them a greater threat overall than feral cats due to numbers alone. Parasites such as ticks may be a limiting factor to cats in rainforest areas for Quolls inhabiting the same areas typically carry high tick loads (571).

- Cane toads (*Rhinella marina (Bufo marinus)*) are thought to be significant threats to quoll, monitor and native frog populations (570; 572). The pest potential of this species is well known but the long-term potential impacts on these threatened species have not been quantified (562).

- Dingoes (*Canis lupus dingo*) & domestic dogs (*Canis lupus familiaris*) – Dingoes/dogs in the Australian Wet Tropics are opportunistic predators of a wide variety of mammal species, with abundant terrestrial and forest edge-dwelling taxa the most susceptible to predation (573).

- Mosquitofish (*Gambusia Holbrooki*) – the current spread of gambusia is not well known, although its negative impacts on native fish and frog species and water quality are well documented (562; 563; 574-576)
- Tilapia – Two tilapia species have established in the Wet Tropics - the Mozambique mouthbrooder *(Oreochromis mossambicus)* and the black mangrove cichlid *(Tilapia mariae*)(e.g. 133; 577; 578). They dominate riverine communities by utilising all resources and modifying habitat to their advantage (579).

These species are considered important threats primarily due to their current levels of ecological impacts and because of the current lack of feasible control options (562). There are numerous other pest species with substantial current and/or future impact potential, notably the other invasive fish such as the guppy (*Poecilia reticulata*), swordtail (*Xiphorphorus hellerii*) and platy (*Xiphorphorus macularta*) (562; 563); as well as the rabbit (*Oryctolagus cuniculus*); European red fox *(Vulpes vulpes)* (e.g. 267; 343; 571; 580); Rusa (*Cervus timorensis*), Chital (*Axis axis*), and Fallow deer (*Dama dama*) (58; 561; 581); the goat (*Capra hircus*); and a host of 'sleeper' species (562; 563).

Invertebrates – Historically, research has been centred on those invertebrate pest species that have the potential to damage primary industries and, to a lesser extent, those that pose a threat to human health. Tramp ants, Yellow crazy ants (*Anoplolepis gracilipes*) and Fire ants (*Solenopsis invicta*), and Palm leaf beetle (*Brontispa longissima*) have been identified as potential major environmental pests in the Wet Tropics (560). Exotic earthworms (e.g. *Pontoscolex corethrurus*) are well-established and have the capacity to change ecosystem processes, soil nutrient availability and species composition within rainforests; however, virtually nothing is known about their ecological impacts (560). Honeybees are considered an undesirable introduction in tropical-rainforest systems in Australia (e.g. 582) because they may lower fruit set in some plant species by competing with native bee species that are more efficient pollinators. This may lead to colony decline and changes in reproductive performance of select native fauna and flora that are dependent upon bees for pollination or food (582; 583).

Diseases - Two soil-borne pathogens (*Phytophthora cinnamomi* and *Batrachochytrium dendrobatidis*) have caused significant mortality of woody plants and amphibians, respectively, during their invasion of the Wet Tropics:

- *Phytophthora* spp, including *P. cinnamomi*, have been isolated from dieback patches throughout the Wet Tropics by researchers from the Rainforest CRC (584), and is associated with roads and walking track access (585). The effects of *P. cinnamomi* on the region's rainforests vary from no visible impact to slight loss of canopy leaves in susceptible species to the death of all plants in virulent outbreaks. Although the onset of forest dieback may be dramatic, the impact over the longer-term is less certain (586). Nevertheless, Phytophthora forest dieback is the main cause of patch death in the WTWHA (58).

- Amphibian Chytrid Fungus (Chytridiomycosis) - Amphibian declines and extinctions are global and rapid: 32.5% of 5743 described species are threatened, with at least 9, and perhaps 122, becoming extinct since 1980 (587). Many species of amphibians in the wet tropics of Australia have experienced population declines or are missing (e.g. 588-594), and after many investigations into potential causal agents (e.g. 595) has now been linked with the emergence of a skin-invasive chytrid fungus (596-605).

These pathogens continue to be the focus of research and management (560). A checklist of plant pathogenic and other microfungi in the rainforests of the Wet Tropics is available (606)

Plants - Much work has been done on invasive weeds in the Wet Tropics (for general reviews, assessments and recommendations see: 33; 560; 561; 607-614). The Wet Tropics are considered intrinsically vulnerable to invasive weeds because of the relatively low number of native rainforest pioneer species in the region -20-, and relatively low numbers in certain distinct plant groups, such as shrubs and ground cover herbs (614; 615). Within the Wet Tropics bioregion, more than 500 exotic plant taxa have been identified as having become naturalised (33; 614), which amounts to more than 10% of the region's native flora and represents close to 40% of Queensland's naturalised alien plant species total (616).

The two species that ranked as the highest priority for control in (33) were *Annona glabra* (Pond Apple) and *Leucaena leucocephala* (Leucaena). The former is classified as a Weed of National Significance (611; 617-626), while the latter has demonstrated gross weedy tendencies overseas and is among the 32 land plants in the list of the world's 100 worst invasive species. WTMA (561; 614) modified Werren's priority ranking by incorporating management feasibility criteria with the emphasis on the prevention or eradication of newly emerging highly invasive species and containment of established species. Thus the priority 1 weed species identified are:

- Miconia (*Miconia calvescens*) or bush current is perhaps the greatest potential weed threat facing the Wet Tropics at present (561). It has very heavy seed set and can invade any spot in the understory that receives some sunlight. Its large leaves then shade out all the space below them, preventing any other plant from growing nearby. It is arguably the worst invasive plant in Hawaii and an important issue on Tahiti, and currently poses a major threat to native biodiversity in the Wet Tropics (611).
- Koster's curse (*Clidemia hirta*): Koster's curse can form dense thickets that smother native vegetation. It is a highly invasive, perennial shrub with potential to become a major weed in many parts of Queensland and elsewhere in Australia (e.g. 627)
- Siam weed (*Chromolaena odorata*) is also a significant threat due to its dense smothering habit (e.g. 628; 629). It is considered one of the world's most invasive weeds and has the potential to spread across northern Australia and down both the eastern and western coastlines (630)
- Hiptage (*Hiptage benghalensis*) is currently invading the Wet Tropics. It forms impenetrable thickets that smother native vegetation (e.g. 631).
- Mikania vine (*Mikania micrantha*) is a rapidly growing, scrambling perennial vine with many branches that smother other plants. It is a major environmental weed that has the potential to rapidly spread across the Wet Tropics and other humid regions of northern Australia with serious consequences (632).

The Wet Tropics Aboriginal Cultural & Natural Resource Management Plan launched in May 2005 identifies weeds as an issue, and highlights the different values that Aboriginal people may use to determine the significance of a particular weed species (e.g., 612).

Further relevant information can be found under MTSRFs Project 2.6.2 - Identification and impact of invasive pests in the Wet Tropics rainforests, including on the distribution and impacts of invasives.

Table 6. Gaps in biodiversity research pertaining to 'Risks and Threats – Invasive species'

●	Research gaps	Immediacy of concern	Magnitude of concern
RT.18-20	Strategic approaches and better understanding of the invasive process, including identification of where in the landscape invasives have the potential to become major drivers impacting on ecological health	high	high-very high
RT.23	Information on the distribution and abundance of weeds and invasives	high	high
RT.24	Information regarding the spatial extent of ecosystem impacts of priority invasives in the Wet Tropics	high	high
RT.25	Understanding the impacts of the stocking and translocation of fish	medium	high
RT.26	Information on the whereabouts and risks of cats	medium	medium
RT.27	A risk assessment of potential invasive species	high	high
RT.28	Knowing the weed species or diseases that cause, or are likely to cause, the greatest environmental harm	high	high
RT.29	Understanding disease spread through wildlife populations, and the relationship between wildlife, human and agricultural diseases	low	medium
RT.30	Understanding the biology and ecology of invasive species as a basis for risk management	high	high
RT.31	A methodology to predict properties of species leading to invasiveness in the Wet Tropics	medium	high
RT.32	Understanding invasion pathways	medium	high
RT.33	Understanding the properties of ecosystems that increase the potential for invasion	medium	medium
RT.34	Understanding the interaction of global change drivers, such as climate and land use change, on key biological invasions and invasibility	high	high
RT.35	Determination of the triggers for concern for invasive invertebrates (e.g. ants, bees)	high	high

5.2.3 Loss, fragmentation and degradation of habitat

Habitat destruction/degradation and fragmentation may render an area functionally unable to support the species present, and so reduce biodiversity. There are very few native natural habitats in Australia that have not been affected by human activities. Natural habitats have been destroyed, fragmented and modified, resulting in widespread changes to the distribution and abundance of native plants and animals.

Habitat loss and degradation

Habitat loss and degradation poses the greatest threat to the world's biodiversity and has been identified as the main threat to 85% of all species described in the IUCN's Red List (558). The Wet Tropics still suffers from habitat loss through clearing for residential settlement and agricultural expansion, although compared to other tropical forests, and in relation to other parts of Australia, human impact is relatively low, with a large proportion of the region's forest cover remaining from the time of first European settlement. (6; 58). The majority of the region's lowland and basalt tableland forest cover has been cleared for agricultural purposes (633). The combined human impacts have resulted in substantial reductions particularly in the area of Melaleuca, rainforest, and eucalyptus-dominated land-cover patterns (634). For a synoptic description of the change in the vegetation extent in the Wet Tropics between 1972-2006, see here.

Large-scale deforestation in the region has ceased with the World Heritage Area designation in 1988, but some forest clearing and selective logging still occurs on private lands (6; 635; 636– for specific impacts of Queensland's selective logging system see 637; 638). Logging has a variety of effects on the natural values of the Wet Tropics, including on birds and mammals (342; 387; 639; 640), other than the obvious broad-scale changes to the landscape.

Landscape-scale impacts of cyclones show that they are important disturbance agents affecting the structure and functioning of Wet Tropics' forest ecosystems (641), and the impacts are likely to become more important due to the expected increase in the intensity (but not frequency) of cyclones in the light of anthropogenic climate change (553; 554). Increased cyclone intensity may have important impacts at both the species- and community-level (642). For example, those species most susceptible to high levels of damage at lower wind speeds would likely become restricted to leeward-facing slopes and upland areas away from the coast, whereas more resilient species would increase in lowland coastal areas. Unwin (643) describes a typology for describing and 'mapping' the variable impacts that cyclones have on vegetation along their paths. Cyclone Larry had the greatest impact both at on the vegetation structure of monoculture plantations, with impacts being intermediate in mixed species plantations and rainforest, and the lowest in restoration plantings (644; but see 645). Cyclone damage also depended on the soil substrates, with more severe modification of leaves, branches, and stems on relatively nutrient-rich basalt soils, as compared to nutrient-poor schist soils (117). Studies so far suggest that the larger rainforest mammals, such as possums and flying-foxes, are surprisingly resilient to severe cyclone damage (646; 647).

Habitat fragmentation

Habitat fragmentation is the breaking up of a large intact area of a single vegetation type into multiple smaller intact units (648). Usually, the ecological effects are negative because small fragments of habitat can support only small populations that are more vulnerable to local extinction (e.g., 649).

The Wet Tropics are fragmented. The area is long and thin and divided into a number of segments by very narrow junctures. Apart from the fragmentation and isolation of rainforest patches resulting from broad-scale agricultural land uses, there is also the impact of internal fragmentation of the main rainforest blocks. A network of linear infrastructure, including over 222 km of powerline clearings and 1,217 km of maintained roads, extend through the rainforest and act as effective barriers to the movement of many rainforest species while providing a conduit for pest and fire intrusion into rainforest areas (58; 650-655).

Habitat fragmentation has important impacts on the mammals of the Wet Tropics (654; 656-662). Assemblages of large Wet Tropics mammals (possums, tree-kangaroos, pademelons) differ markedly between fragmented and more intact forest, with species richness and abundance declining over time in the fragmented patches (658). The genetic structure of some species, such as prickly forest skink (*Gnypetoscincus queenslandiae*) appears to be dominated by historical (natural) rather than current (anthropogenic) fragmentation (663; 664); however, fragmentation does affect the patterns of dispersal in the species, with males likely having to move further in fragmented habitats in order to find mates or suitable habitat logs (665). Surprisingly little information is available on the impacts of habitat fragmentation on the invertebrates of the Wet Tropics.

Habitat fragmentation also creates more habitat edges and this has important impacts on forest microclimate and structure (636), and may disrupt community structure (653), augment folivore population density (e.g. 666), and increase predation (374). Such edge effects can be exacerbated by cyclones and seasonal windstorms (636) that may promote recruitment of exotic (667-669) and disturbance-adapted plants (670), and lead to pulses of gregarious flowering (671).

Further relevant information can be found under MTSRF Project 4.9.5 - Restoring tropical forest landscapes, including the ecological processes involved in reforestation, and biodiversity outcomes of habitat restoration.

Table 7. Gaps in biodiversity research pertaining to 'Risks and Threats – Loss, fragmentation and degradation of habitat'

●	Research gaps	Immediacy of concern	Magnitude of concern
RT.36	Understanding the changes to ecological processes resulting from a fragmented landscape (both terrestrial and aquatic), including effects on dispersal patterns and metapopulation dynamics	low	medium
RT.37	Understanding the impacts of fragmentation on rare and threatened ecosystems	high	high
RT.38	Better knowledge of the effects of internal fragmentation resulting from human infrastructure (e.g. roads, powerlines, pipelines) dissecting rainforests and protected areas	medium	high
RT.39	Understanding the localised impacts of human habitation on ecological processes	medium	medium
RT.40	Understanding the processes affecting population viability in fragments	high	medium
RT.41-44	A better understanding of what constitutes critical patch size thresholds and corridor widths for maintaining biodiversity at landscape and ecosystem scales	high-very high	high-very high
RT.45	The size requirements for sustainable populations of species in refugia in the face of climate change	low	very high
RT.46	Characterisation and evaluation of remnant vegetation and description of its role in landscape function	medium	medium
RT.47	Information on the March-December 2009 drought in the Herberton-Wairuna province	low	high
RT.48	Methodologies for effective management of forest edges	medium	medium

5.2.4 UNSUSTAINABLE USE OF NATURAL RESOURCES

Continued urban expansion and increasingly intensive agricultural practices create serious issues for biodiversity conservation (15). However, compared to the issues of invasive species, habitat degradation and climate change, unsustainable use of natural resources seems a relatively minor issue facing the biodiversity of the Wet Tropics. Nevertheless, there is a correlation between urban expansion and areas of high conservation value (15), and the population of Far North Queensland is predicted to grow by between 75,000 to 150,000 residents over the next twenty years (672). This implies intensified management of ecosystems for resource extraction in the region, which has the potential to increase their vulnerability to future disturbances (673).

A growing Wet Tropics population is causing increased demands for powerlines, dams, roads and telecommunication facilities, with negative consequences for habitat as described above. The coastal lowland areas are threatened by the demand for urban and rural residential expansion, tourism facilities and pressures on marginal agricultural lands. It will likely also be associated with increased use of freshwater, vegetation clearing for agriculture, the introduction of pastoral and horticultural plant species, and increases in the number of weeds, feral animals and diseases (e.g. 674).

Visitors also impact on the Wet Tropics' biological and cultural values, both indirectly through their demands for increased infrastructure, and directly by disturbing fauna and damaging vegetation, increasing fire-risks, and introducing weeds and diseases (e.g., 675-683). The annual number of visitors to the region increased from 840,000 in 1985 to around 2 million in 1995, and was predicted to double by 2016 (616).

Further relevant information can be found under MTSRF Program 9 - sustainable Use, Planning and Management of Tropical Rainforest Landscapes, including on impacts of urban and rural development (project 4.9.3), nature based tourism (project 4.9.2), indigenous natural resource use (project 4.9.1) on Wet Tropics ecosystems.

Table 8. Gaps in biodiversity research pertaining to 'Risks and Threats – Unsustainable use of natural resources'

●	Research gaps	Immediacy of concern	Magnitude of concern
RT.49	Establishment of indicators of the limits of acceptable change for grazing in native ecosystems	medium	medium
RT.50	Understanding the impacts of grazing on wet sclerophyll, dry sclerophyll and rainforest gradients	medium	medium
RT.51	Suitable indicators for quantifying and monitoring grazing impacts in woodland, forests and grazing, (especially for the Herberton-Wairuna province)	medium	medium
RT.52	Understanding the impacts of water extraction and changes in drainage patterns	high	high
RT.53	Better information on the ecological effects of extraction of underground water resources both on the coastal lowlands and on the Tablelands	high	high
RT.54	Improved knowledge of sustainable agroforestry methodologies that will contribute to landscape health, agricultural enterprises, and other 'good things'	low	medium

●	Research gaps	Immediacy of concern	Magnitude of concern
RT.55	Assessment of the extent and ecological impact of open forest logging outside of protected areas (e.g. for sleepers, etc)	low	low
RT.56-57	A better understanding of how urbanisation and changing patterns of human population affect wildlife populations and ecosystem function	low-medium	low-medium
RT.58	Understanding the (dis)services that urban ecology provides to wildlife and natural ecological processes	low	low
RT.59-60	Information on the impacts of infrastructure on rainforests and wildlife, etc.	low-medium	medium
RT.61	Information on human-wildlife interactions and conflicts (especially involving cassowaries, crocodiles, flying foxes, dingoes, and wallabies)	medium	high
RT.62	Understanding the impacts of unsustainable mushroom collection	low	low

5.2.5 CHANGES TO THE AQUATIC ENVIRONMENT AND WATER FLOWS

Biodiversity in aquatic ecosystems in Australia is under threat from the combined effects of river regulation, over-allocation of water for irrigation, pollution, agriculture and habitat degradation (15). Natural patterns of wetting and drying have been altered and the frequency and magnitude of floods have changed. Significant numbers of floodplain wetlands across Australia have been lost as a result (15).

Demands on the water resources of the Wet Tropics Bioregion is increasing in line with the regional population growth (above) and changes in land-use practices (684). This increasing demand increases the threat to aquatic flora and fauna, but indeed also whole ecosystems that are dependent on the provisioning of adequate water flow (685). Dams, weirs and culverts are major landscape modifiers that result in the direct loss of both terrestrial and aquatic habitats through fragmentation of aquatic habitats and the altering of stream flow patterns. While aquatic ecosystems have been studied extensively (e.g. 85; 86; 91; 92; 133; 137; 255; 269; 394; 396; 686-694), comparatively little has been published on how they are affected by physical changes in the aquatic environment and water flows (but see 89; 688; 695-699).

Further relevant information can be found under MTSRFs Project 3.7.3 - Freshwater indicators and thresholds of concern, including biophysical models to identify (i) appropriate indicators of waterway health, and (ii) probable thresholds of concern, in terms of contaminant concentrations, ecological processes and biodiversity.

Table 9. Gaps in biodiversity research pertaining to 'Risks and Threats – Changes to the aquatic environment and water flows'

●	Research gaps	Immediacy of concern	Magnitude of concern
RT.63	Better knowledge of groundwater-surface interactions	high	medium
RT.64	Better information on stream flow rates and barriers, especially with respect to climate change and changing land use patterns and intensities	low	low
RT.65	Understanding the impacts of dams and other infrastructure on environmental flows	low-medium	low-medium
RT.66	Understanding the impacts of land use on aquatic environments	medium	high
RT.67	Information on water quality and resilience in the riparian zone	high	high
RT.68	Knowing the functional riparian widths necessary to maintain instream processes	high	high
RT.69	Understanding how climate change will influence aquatic systems and structure of aquatic communities (including El Niño and cyclonic events)	low	low
RT.70	Understanding the impacts of climate change on cloud interception and cloud base lift	low	very high
RT.71	Understanding the threats to highland aquatic biodiversity and fresh water flows in the dry season due to reduced cloud stripping	high	very high
RT.72	Established environmental flow regimes for Wet Tropics rivers and streams (including low flow tributaries)	high	medium
RT.73	Development of a classification and conservation status framework for aquatic ecosystems to compliment the statutory regional ecosystem (RE) framework in place for terrestrial ecosystems	medium	low

5.2.6 Inappropriate fire regimes

Fire is important in determining the distribution of rainforests in Australia (700). The boundary between the rainforest with the open forest and woodlands is largely determined by the interaction of topography, soil fertility and fire history (700). In the Wet Tropics this boundary is a dynamic ecotonal community forming distinct forest types termed wet sclerophyll forest in a discontinuous strip less than 4 km wide along the western margin of the Wet Tropics (75; 701; 702, see also 78).

Natural oscillations of this boundary have likely been occurring over long periods of time (48; 520; 703; see also 704), but recent widespread expansions of rainforest into wet sclerophyll forest have been reported to have occurred over the last 50 years (79; 705). Changes in fire regimes induced by the European introductions of extreme fire control as part of pastoral land management and a concomitant decrease in Aboriginal management have been suggested to be responsible for these expansions (38; 39; 76; 706-708). Considerable evidence exists of burning in rainforest areas in pre-European times (see 700 and references therein). It is likely that pre-European fires regimes were also affected by human influence, but identifying the magnitude of this influence is a complex issue, because separating the anthropogenic from the natural sources of ignition is difficult (10). Nevertheless, it has been suggested that burning activities by Aborigines in the coastal lowlands were sufficient to re-establish wet sclerophyll forests during the latter part of the Holocene from approximately 4,000 BP following a warmer and wetter period which would have been conducive to rainforest re-expansion (38; 41). Current loss of wet sclerophyll forests due to such “rainforestation” is a cause for concern, not only for the loss of its distinct forest types but also because of the unique ecotonal species assemblages that are dependent on it (e.g. 79; 83; 340; 370; 398; 709-711).

Some further relevant information on the impact of fire and fire history in the region can be found under MTSRF Project 1.4.3 - Rainforest threatened species and communities and ecosystem processes.

Table 10. Gaps in biodiversity research pertaining to ‘Risks and Threats – Inappropriate fire regimes’

●	Research gaps	Immediacy of concern	Magnitude of concern
RT.74	Understanding the boundary dynamics at wet sclerophyll, dry sclerophyll, rainforest transition zones, and coastal mosaics, and the interactions with climate change	high	high
RT.75	Knowing the risk of loss of tall open forest in the Wet Tropics	high	very high
RT.76	Understanding the rainforest-sclerophyll boundary in relation to fire	high	high
RT.77	Knowing the spatial and temporal dynamics (short and long-term) of wet sclerophyll forests	very high	high
RT.78	Research on the fire dynamics in wet sclerophyll forests	medium	medium
RT.79	Understanding the interactions and cumulative effects between inappropriate fire regimes and weed invasions/changing fuel characteristics	high	very high
RT.80	Knowing post-cyclone fire danger in rainforest	medium	high
RT.81	Indicators and criteria to support fire management decision making	medium	medium
RT.82	Application of Traditional Ecological Knowledge about fire in current management regimes	medium	medium

5.3 Mitigation & Adaptation

Having provided a broad overview of the risks and threats affecting the status and trends of the biodiversity in the Wet Tropics bioregion, we will now provide a brief overview of what is known about how these risks and threats are addressed. There are two main categories of human responses to risks and threats: mitigation and adaptation. Mitigation can be defined as the reduction or prevention of the effects of undesirable change. Adaptation can be defined as adjustments of a system to reduce vulnerability and to increase the resilience of system to change.

5.3.1 CLIMATE CHANGE

In the context of climate change, mitigation involves actions that are intended to reduce the magnitude of our contribution to climate change. It includes strategies to reduce greenhouse gas sources and emissions and enhance greenhouse gas sinks. Adaptation consists of actions undertaken to reduce the adverse consequences of climate change, as well as to harness any beneficial opportunities. Adaptation actions aim to reduce the impacts of climate stresses on human and natural systems.

There is no published information on specific adaptations actions undertaken in the Wet Tropics Bioregion; however, several important documents (e.g. 499; 538; 539, and particularly 712) make strong recommendations. Most of the recommendations revolve around decreasing existing stresses and building ecological *resilience*, which is defined as the capacity of an ecosystem to tolerate or recover from disturbance without collapsing. A major benefit of managing natural systems for overall resilience is that it provides the best general insurance against current and emerging threats (713; 714).

Factors contributing to ecological resilience include (from 712):

- **Biological diversity** - Ecological systems with high biological diversity will generally have greater inherent resilience, largely because they will have more diverse responses and capacities available to them, which can provide the basis for adaptation (e.g. 715).
- **Connectivity -** The capacity of natural systems to recover after a disturbance, or to reorganise in the face of new or intensified pressures, depends to a large extent on the ability of plant and animal populations and ecological processes to disperse or move across the landscape (e.g. 538; 716).

- **Refugia** –It is increasingly recognised that an important, and relatively cost-effective, adaptation strategy for increasing landscape resilience will be the identification and protection of natural refugia that buffer biodiversity from the worst impacts of climate change (e.g. 717; 718); however, as yet little is known about which refugia best promote ecosystem resilience in the Wet Tropics, nor how to identify them in the landscape.

Climate change will cause many organisms to migrate to track climatically-suitable habitat. In many cases, this will happen naturally, but in others, human intervention may be necessary in the form of translocation (or 'assisted colonisation' or 'assisted migration') of species (719). This measure of last resort entails many great known and even more unknown risks and is fraught with scientific uncertainties (491; 719).

Further relevant information can be found under MTSRF Program 5ii - Climate Change: Rainforest and Catchments, including strategic knowledge on the management options for how to mitigate against the negative impacts of climate change (projects 2.5ii.3 and 2.5ii.4).

Table 11. . Gaps in biodiversity research pertaining to 'Mitigation and Adaptation – Climate change'

●	Research gaps	Immediacy of concern	Magnitude of concern
MA.1	Understanding how to create a resilient landscape - What criteria? Where? Why?	very high	very high
MA.2	Understanding how to increase regional resilience - identification of options to extend conserved areas and the connectivity between them?	high	very high
MA.3	Understanding whether movement corridors will work for increasing resilience to climate change	high	very high
MA.4	Establishing monitoring and conservation strategies for key species vulnerable to climate change	high	high
MA.5	Understanding how to effectively manage refugia to maintain integrity	high	very high
MA.6	Management and maintenance of the resilience of refugia as well as microhabitats to help species adapt to climate change	high	very high
MA.7	Knowing whether we need to identify and isolate evolutionary refugia and prevent movement of common species competing with restricted endemic specialist species	high	very high
MA.8	Maintaining refugia to provide buffers against the effects of extreme events	medium	very high
MA.9	Trailing the creation of cool refugia across the landscape such as shade, water features, rock piles, nesting boxes, logs, hollows, etc)	high	very high
MA.10	Understanding genetic translocation and species translocations as a means for offsetting detrimental effects of climate change	medium	high

	Research gaps	Immediacy of concern	Magnitude of concern
MA.11	Translocations of critically endangered species from lower to higher mountaintops	low	medium
MA.12	Understanding how conservation policy should adapt to rapid climate change	high	very high
MA.13	Understanding responses to re-introduction and relocation	medium	low
MA.14	Genetic modification for higher temperature tolerance	low	medium
MA.15	Management as starting point for adapting to climate change	high	high

5.3.2 Invasive species

Invasive species pose major management problems in the Wet Tropics and elsewhere because their control is labour intensive, costly and requires a long-term management commitment. The Wet Tropics Conservation Strategy (561) sets out a strategic approach to control environmental pests, including weeds, pest animals, and diseases. The emphases are on prevention and eradication, and on awareness-raising, and ecological research:

- Prevent the introduction of new species
- Eradicate new and localised outbreaks of invasives before they become established
- Focus on invasives that threaten rare, threatened and endemic ecosystems and pristine areas
- Ensure eradication programs are achievable and incorporate long term monitoring and rehabilitation
- Provide educational materials about the identification, reporting and eradication invasives for land managers and the public
- Research the ecology and management of invasives.

A broad suite of methods and techniques are currently available for the control of invasive species in the region, including chemical controls such as baiting, fumigation and spraying, and physical controls such as trapping, shooting, fencing and poisoning. Integrated management uses a range of the above control measures in combination. However, successful long-term management of pest animals relies on the coordination of trans-boundary control activities.

Given that the type of control method chosen depends on the target species and specific environmental conditions, it is not surprising that by far the most information on control and management implementation is either not collated, is hidden in grey literature, or is for internal departmental access only (e.g. 560). Nevertheless, there are very useful and accessible publications in the grey literature (e.g. 561; 612; 720) and, importantly, on web sites maintained by DPI, DERM and WTMA (weeds & pest animals). However, a substantial but somewhat disjointed body of published research is available on the effectiveness and environmental side-effects of various control methods of weeds (e.g., 412; 611; 624; 625; 631; 721-725), pest animals (e.g., 726-735), and diseases (e.g., 736; 737).

Further relevant information can be found under MTSRF Project 2.6.2 - Identification and impact of invasive pests in the Wet Tropics rainforests, including research needs for management of invasives; development of frameworks and tools for predicting invasive species' spread through rainforest landscapes; and research into priorities species.

Table 12. Gaps in biodiversity research pertaining to 'Mitigation and Adaptation – Invasive species'

●	Research gaps	Immediacy of concern	Magnitude of concern
MA.16	Cost-effective control and eradication techniques	high	high
MA.17	R&D of monitoring for detection of invasions and spread of emerging and established invasives, including remote detection and delimiting methods	medium	high
MA.18	R&D of feasibility, options and cost benefits of remote sensing and novel technologies for detection, identification and mapping of invasives	medium	high
MA.19	Predicting and modelling problem species (including invertebrates), and assess their risks - what are the triggers for early control	high	very high
MA.20	Assessment of the effectiveness of current methods to detect new invasions, and develop new detection methods	very high	very high
MA.21	Understanding where investment in pest animal research and management should be directed	high	high
MA.22	R&D of frameworks for strategic, process-based approaches to invasive species management	very high	very high
MA.23	Understanding how, when, and whether to manage invasive species with respect to their traits and scale of invasion	high	high
MA.24	Methodologies to improve biodiversity in areas by preventing deflected and/or arrested succession caused by invasives	medium	medium
MA.25	The cessation of fish stocking	high	high

5.3.3 LOSS, FRAGMENTATION AND DEGRADATION OF HABITAT

When habitat is fragmented, degraded or lost it is a major challenge to restore its ecological function. Habitat restoration is accomplished through management, protection, and reestablishment of plants by returning abiotic factors (e.g., soil chemistry, water content, disturbance) and biotic factors (e.g., species composition, interactions among species) to historical levels (738). Rainforest rehabilitation and restoration is slow and costly process, but restorative projects can increase the effective size of a habitat by simply adding area or by connecting isolated fragments.

Reforestation ranges from intensive native ecosystem reinstatement to farm forestry with an expected timber product. In the Wet Tropics, the resiliency of tropical soils to recover from deforestation and cultivation induced degradation is generally considered poor (739), but nevertheless, habitats can be restored by habitat re-establishment plantings (e.g.,740-742), or by increasing connectivity between habitat fragments with over and underpasses (743-750). Timber plantations are another means by which cleared or degraded landscape can be reforested, but although even monoculture plantations can successfully restore some rainforest functions (751), plantations usually do little to recover biological diversity. However, some approaches might both yield valuable timber and restore some proportion of former biodiversity (e.g., 752; 753).

Further relevant information can be found under MTSRF Project 4.9.5 - Restoring tropical forest landscapes, including on managing forest restoration and degradation for biodiversity outcomes, and on the development of tools for monitoring and evaluation of forest disturbance, recovery and restoration.

Table 13. Gaps in biodiversity research pertaining to 'Mitigation and Adaptation – Loss, fragmentation and degradation of habitat'

●	Research gaps	Immediacy of concern	Magnitude of concern
MA.26	An assessment of landscape restoration practices especially with respect of tree planting	medium	medium
MA.27	Rehabilitation methods for degraded lands to provide various ecosystem functions	medium	medium
MA.28	Rationally-based criteria for acquisition and restoration of critical habitat	medium	medium
MA.29	Increased understanding of the impacts of fragmentation on biodiversity assets (with respect to spatial parameters such as size,	low	medium

●	Research gaps	Immediacy of concern	Magnitude of concern
	shape and connectedness of fragments)		
MA.30	Understanding how you design landscapes for maximum connectivity or ecosystem function	very high	high
MA.31	Information on economically feasible improvements in management to increase connectivity	medium	medium
MA.32	Better understanding of what is appropriate connectivity (patch size, corridor width, etc), which is expected to be context and case dependent	high	high
MA.33	An assessment of the efficacy of corridors: location, design, width, species selection, density, functional groups, processes	very high	very high
MA.34	The incorporation of ecological knowledge into cyclone preparation and rehabilitation	medium	medium
MA.35	Understanding better and developing new indices of forest health	low	medium
MA.36	Strategies for integrating environment and production goals on privately managed land	low	medium
MA.37	Assessing whether mitigation measures are effective on a genetic, population and community basis	medium	high

5.3.4 Unsustainable use of natural resources

In 1992, Australia's National Strategy for Ecologically Sustainable Development (754) defined ecologically sustainable development as: '*using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased*'. The current challenge is the same as it was then: to accommodate population growth without increasing our ecological footprint, particularly by ensuring that regional development is achieved in a sustainable way (e.g. 15; 672).

To achieve ecologically sustainable development in the Wet Tropics it is necessary that threats to natural and cultural values of the World Heritage Area are confined to ecologically sustainable levels (e.g. 755). In their Regional Plan for Natural Resource Management, Armour et al. (756) provide a compilation of the available research and natural resource management experience of the Wet Tropics and make recommendations for sound strategies and management to achieve that aim.

Further relevant information can be found under MTSRF Program 9 - sustainable Use, Planning and Management of Tropical Rainforest Landscapes, including a wealth of knowledge to promote sustainable economic activities (notably agriculture, agroforestry (projects 4.9.4 & 4.9.5), tourism (project 4.9.2) and Indigenous enterprises (project 4.9.1); to integrate complex social, economic and environmental considerations in maintaining essential ecosystem services across the Wet Tropics landscape (project 4.9.4) and in the face of urban development (project 4.9.3); and to implement approaches for improved natural resource management and conservation (project 4.9.6).

Table 14. Gaps in biodiversity research pertaining to 'Mitigation and Adaptation – Unsustainable use of natural resources'

●	Research gaps	Immediacy of concern	Magnitude of concern
MA.38	Designing and implementing policies for restricting and making more efficient water extraction in the Wet Tropics	medium	high
MA.39	Establishing optimal grazing systems	low	low
MA.40	Reducing current deer stock	low	low
MA.41	Fencing of high-value areas	low	low

5.3.5 Changes to the aquatic environment and water flows

Maintaining a healthy waterway and retaining remnant riparian vegetation will offer the possibility to obtain many economic, biodiversity and aesthetic benefits both within the catchment and downstream as far as the Great Barrier Reef (757), which is particularly important given the high biodiversity of the aquatic systems in the Wet Tropics compared with those in the rest of the continent (758).

Further relevant information can be found under the Rainforest and the Reef CRCs' 'Catchment to Reef' program, including on the development of cost-effective tools, protocols and expertise to identify, monitor and mitigate riparian and water quality problems and to assess the functional health of aquatic ecosystems in the Wet Tropics and Great Barrier Reef World Heritage Areas.

Additional relevant information can be found under MTSRF Program 7 - Halting and Reversing the Decline of Water Quality, including on the development of monitoring systems using physical, chemical and ecological indicators of freshwater ecosystem health (project 3.7.3) , the delivery of social and economic indicators of water quality (project 3.7.6), and the socio-economic risks and constraints associated with land use and management options for water quality improvement at the private and social level (project 3.7.5).

Table 15. Gaps in biodiversity research pertaining to 'Mitigation and Adaptation – Changes to the aquatic environment and water flows'

	Research gaps	Immediacy of concern	Magnitude of concern
MA.42	Strategies for maintaining appropriate environmental flows, despite dams and other infrastructure	medium	high
MA.43	Identification and prioritisation of removal of barriers and description of impacts and ecological consequences of removal	high	high
MA.44	Identification of indicators of progress towards restoring ecological processes and function (including control of invasive aquatic pest species)	medium	high
MA.45	Determining whether it is possible to restore hydrological and ecological processes and function to modified coastal wetlands and other aquatic systems	high	high
MA.46	Economically feasible means of restoring riparian habitats	high	high
MA.47	Means of removal of invasive fishes	medium	high
MA.48	Emission mitigation to halt lift of cloud base	very high	very high

5.3.6 INAPPROPRIATE FIRE REGIMES

Post-European alterations to fire regimes appear to be having an array of ecological impacts (see section 5.2.6); however, knowledge of what constitutes ecologically appropriate fire regimes in the Wet Tropics context is incomplete (58). Interpreting what regimes are appropriate for protecting Wet Tropics biodiversity values is proving problematic because (from 561) i) the general difficulties in determining pre-European fire regimes (e.g. 708; 759); ii) the little scientific information on the effects of fire intensity, frequency and timing (e.g. 708; 711); iii) the impact of introduced species altering fuel loads and burning characteristics (e.g. 760); and iv) the potential for climate to increase fire risk (708). Uninformed and inappropriate fire management is risky and can adversely affect plant communities that are not adapted to burning (e.g., 52; 761). Nevertheless, systematic fire planning and management of the open forests and woodlands within the region is progressing on an ever more rigorous and scientific basis (58; 762).

The Wet Tropics Conservation Strategy (561) sets out a strategic approach to address the issue of fire in the region:

- Maintain and promote a diversity of habitats and associated plant and animal species through appropriate fire regimes
- Focus fire management on rare and threatened habitats and species which rely on specific fire regimes
- Research optimal fire regimes for biodiversity conservation
- Implement the QPWS Fire Management System as the basis for fire management and research
- Involve Traditional Owners, landholders and neighbours in fire management programs (see also 763; 764).

Of greatest concern are the altered fire regimes in the wet sclerophyll communities and their role in rainforest expansion (see section 5.2.6). Records show that fires have long been a factor in rainforest dynamics in the region (46; 765), so understanding the fire regimes from the past will be critical for managing the boundary dynamics at the wet sclerophyll and rainforest ecotones.

Further relevant information can be found under MTSRF *Project 1.4.3 - Rainforest threatened species and communities and ecosystem processes*, including on the collation of fire history in the region to inform QPWS management policy.

Table 16. Gaps in biodiversity research pertaining to 'Mitigation and Adaptation – Inappropriate fire regimes'

●	Research gaps	Immediacy of concern	Magnitude of concern
MA.49	Understanding cause and effect relationships (including interactions with invasive species, nutrient cycling/dynamics, etc.), and modelling consequences of different fire management scenarios to develop science-based fire management options	very high	very high
MA.50	Perfected remote sensing methods for fire history mapping	medium	medium
MA.51	Implementation of long-term monitoring and assessment regime for fire, linked to information repository	high	high
MA.52	Prescribed burning and clearing regimes to allow regrowth	medium	medium
MA.53	Knowing how to adapt systems to shifting boundaries	low	low
MA.54	Knowing where in the landscape should open forest/rainforest ecotones be valued and preserved?	very high	very high
MA.55	Small-scale examinations of recruitment of wet sclerophyll versus rainforest species under several fire regimes	high	high
MA.56	Managing boundary dynamics at the wet sclerophyll, dry sclerophyll and rainforest gradient, using scientific, evidence-based fire management regimes	high	high
MA.57	Managing fire to affect boundary dynamics in coastal mosaics, using scientific, evidence-based fire-management regimes; and the interaction with drainage patterns	medium	medium

6 KEY GAPS FOR TERRESTRIAL BIODIVERSITY RESEARCH

After the workshop the research gaps were sent to various end-user and research provider organisations for evaluation in terms of their 'perceived value to the organisation if the gap was filled' (see section 4.4.3. There was significant agreement between organisation as to which of the gaps represented a greater value if filled (Kendall's W = 0.21, $p<0.001$) (see Appendix, section 8.1). Of the 195 research gaps identified, 145 were rated at an average of 3 (medium value) or higher, and 8 were rated at an average of 4 (high value) or higher.

Table 17 lists the top 10 research gaps in terms of their 'perceived value if filled'. However, it is important to note that 10 is an arbitrary number and there are several other important gaps that score nearly as high, for example gaps RT.6, MA.2, O.1, ST.39, RT.9.11, ST.31, RT.14-15, RT.16, RT.75, O.3, MA.5 all have high average values (in descending order, see Appendix section 8.1).

Table 17. Highest-value research gaps as rated by end users and research providers with an interest in the Wet Tropics (1 = 'low value; 5 = 'high value')

●	Key research gaps	Average value
O.2	Long-term monitoring data, essential for decision making	4.28
MA.1	Understanding how to create a resilient landscape in the face of climate change - What criteria? Where? Why?	4.19
ST.36	Maps of habitats of all endangered and vulnerable species	4.18
MA.4	Establishing monitoring and conservation strategies for key species vulnerable to climate change	4.11
RT.23	Information on the distribution and abundance of weeds and invasives	4.08
RT.1-2	Understanding which ecosystems and species are most vulnerable to climate change (including shifts in averages and extreme events)	4.02
ST.12-15	Understanding of the key indicators of ecosystem health that can be regularly measured at a landscape scale, with a focus on rare regional ecosystems that are threatened by anthropogenic (climate) change	4.02
ST.17	Research into thresholds or tipping points that lead to catastrophic irreversible ecological changes	4.00
ST.19	Quantification of the value of restoration and regrowth in maintaining and improving ecosystem function	3.97
O.4	Identification of species-specific mitigation strategies for keystone / flagship species	3.97

From Table 17 it is apparent that there is a need for long-term investment, particularly an enduring commitment to collect systematic monitoring data, to combine existing monitoring databases, and to make them available in an easily accessible format for research and management activities (gap **O.2 -**Table 17). Conservation and environmental management are long-term activities that ideally rely on evidence-based practices that incorporate information on effectiveness of management and policy interventions as well as data on threats (765). There have been several excellent initiatives (e.g. 766-769), but the current lack of detailed, long-term data on the condition of Wet Tropics ecosystems, particularly involving the habitats of endangered and vulnerable species (gap **ST.36 -** Table 17), appears to limit the ability to report on biodiversity condition and so undermines the protection of biodiversity values within the region (e.g. 57; 770; 771).

Improved understanding of the status and trends of the biodiversity in the Wet Tropics is essential for conservation and environmental management, but regularly assessing the condition of all natural assets is clearly impossible because of the limits to time and resources. Therefore, there is a need for key indicators of ecosystem health that can be regularly measured at a landscape scale (gaps **ST.12-15 -** Table 17). Various indicators of ecosystem health are available but their usefulness is often limited to particular taxonomic levels, communities or habitats (94; 516; 696; 767; 772-785). Currently, practical means of reporting on trends in overall 'health' or 'condition' in near real-time and on a regular, repeatable, affordable basis is lacking. However, remote sensing (reviewed in 786; 787) holds much promise for monitoring ecosystem health in the Wet Tropics (e.g. 788-790), including for determining distributions and abundances of weeds and invasives (gap **RT.23 -**Table 17). Indeed, due to recent increases in spectral resolution, fine-scale, species-specific land-cover classification has already become possible abroad (for 791 'hyperspectral remote sensing').

Managing habitat restoration and degradation in the Wet Tropics landscapes is crucial for restoring integrity to previously logged parts and to progressively enhance connectivity and ecological processes to other areas of disturbance (see section 5.3.3). An unfortunate, but common public perception is that only endangered or of concern vegetation is of any environmental importance – whereas all native vegetation, including regrowth has some ecological value (58). However, little is known about the actual value of restoration and regrowth in maintaining and improving ecosystem function, and thus this clearly needs to be quantified (gap **ST.19 -** Table 17).

Climate change is expected to become an increasingly serious issue for conservation and environmental management in the Wet Tropics (see section 5.2.1). The most important management interventions will be those that build ecological resilience (58). However, such interventions depend on knowledge of where in the landscape efforts should be focussed and what practices for increasing resilience are most appropriate (gap **MA.1 -** Table 17); and in turn, this depends critically on the understanding of which ecosystems and species are most vulnerable to climate change (gap **ST12-15 -** Table 17). In particular there is a need for establishing monitoring and conservation strategies for key species that are vulnerable to climate change (gap **MA 4 -** Table 17) because these are the canaries in the coalmine that will be the first in need of climate change adaptation action. Furthermore, responses of biological systems to climate change can be non-linear, and involve tipping points that result in potentially irreversible changes and new ecosystem states. As yet there is no research into tipping points in the Wet Tropics (gap **ST.17 -** Table 17), and so we are completely in the dark as to what catastrophic irreversible ecological changes the future holds in the region.

With many species of concern, the identification of selected keystone (792), flagship (793), or umbrella (794) species may make conservation decisions easier (793). Such surrogate species tend to be relatively large-bodied and wide-ranging species of higher vertebrates, but need to be used with great care if they are to be useful in conservation management (795). There are several species in the Wet Tropics that can be surrogate species, and they have accordingly been studied quite intensively (e.g. cassowaries 314; 371; 419; 429; 620; 796-805; tree kangaroos 312; 806-813; possums 277; 814-817; and flying foxes 335; 347; 351; 428; 647; 818-824), which makes them excellent targets for species-specific mitigation strategies (gap **O.4 -** Table 17).

Interestingly, two of the top 10 gaps (i.e. O.2 and O.4) were included under the ‘other’ category because they did not fit easily in any of our predetermined categories (see Appendix, section 8.1.4). Four out of the five such gaps (i.e. O.2, O.4, O.1, O.3) appeared in the top 20, and all pertained to management issues. This clearly shows, that the old adage “there can be no conservation without people” holds true, and this highlights the importance of a gap analysis with a focus on the social and management aspects of biodiversity conservation in the Wet Tropics, analogous to ours (see also section 4.3).

7 CONCLUSIONS

The Wet Tropics have been referred to as a 'learning landscape' (755) because the region provides outstanding opportunities for collaborative research across disciplines such as ecology, climatology, tourism, sociology and economics based on tropical ecosystems. Well-managed scientific research can benefit the conservation and management in various important ways. For example, it is needed to ensure that use and management are such that no natural values are lost or unacceptably degraded, and so it can improve the sustainability of management and use of Australia's environmental assets. In addition, it can support an integrated and adaptive management approach to solving management issues, and it can set an objective basis for making decisions and policy development. Finally, scientific information and knowledge form the basis for much of the presentation and interpretation of the Wet Tropics and so has a crucial role to play in peoples' perceptions.

This report has provided a broad and accessible repository of the available biodiversity research information, and has identified the knowledge and data gaps that people with a vested interest in the region would like to see addressed. In doing so, we hope that it facilitates relevant biodiversity research, and that it benefits the management and conservation of this most wonderful and fascinating place.

8 Appendices

8.1 Appendix 1 - Full list of research gaps & end user values

Table 18. All research gaps pertaining to 'status and trends' (see section 5.1) as formulated by the workshop attendants and rated by representatives of end user and research provider organisations (1 = 'low value; 5 = 'high value')

8.1.1 Status & Trends

	Research gaps as identified by workshop participants	Average value	JCU	CSRIO	WTMA	TERRAIN	DERM -QPWS	SEWPaC	Fisheries Qld	FNQ Regional Organisation of Councils	Biotropica Austr. P/L	ACF	AWC	Bana Yarralji Bubu Inc & Balkanu Cape York Dev. Corp.	Independent
ST.1	**Higher-resolution climate data reflecting the spatial and topographic vulnerability of the region**	**3.5**	4	5	3	3	4	2	3	4	3	4	3	5	
ST.2	**Methodologies for rapid update of land use derived from remotely sensed data**	**2.6**	3	5	2	1	3	3	3	2	4	1	2	2	
ST.3	**Remote sensing approaches to identify land cover change overcoming problems of terrain and climate**	**2.7**	3	5	5	2	4	2	2	2	2	1	3	2	
ST.4	**How to monitor status and trends (and how to fund it)**	**3.8**	4	5	5	4	4	3	4	5	3	1	3	5	
ST.5	**A comprehensive and detailed assessment of land capability and land use risk**	**2.6**	2	5	3	2	3	3	2	4	3	1	1	2	

8.1.1 Status & Trends

	Research gaps as identified by workshop participants	Average value	JCU	CSRIO	WTMA	TERRAIN	DERM -QPWS	SEWPaC	Fisheries Qld	FNQ Regional Organisation of Councils	Biotropica Austr. P/L	ACF	AWC	Bana Yarralji Bubu Inc & Balkanu Cape York Dev. Corp.	Independent
ST.6	Maps of soil and nutrient distributions in the bioregion	3.0	4	5	4	2	3	3	2	4	3	1	2	4	
ST.7	Higher-resolution vegetation mapping	3.1	3	5	3	2	4	4	3	4	2	1	3	4	
ST.8	Connectivity processes and interactions, with reference to habitat quality issues	3.6	3	5	5	3	3	5	4	3	4	2	2	4	
ST.9	What are the main impacts of the interface between non-rainforest and rainforest habitat (considering edge effects in both directions)	3.8	4	5	5	2	5	5	3	4	4	2	3	5	
ST.10	Hydrological processes from summits to ocean	3.0	3	4	3	2	3	4	4	3	2	1	2	5	
ST.11	Regional hydrology (rain, ground, cloud, etc.), particularly with respect to identifying hydrorefugia as key conservation areas	3.4	4	5	4	2	4	3	4	3	3	1	3	5	5
ST.12	What are the key indicators of health of threatened and regional ecosystems	4.3	4	5	5	3	4	5	4	5	3	4	4	5	
ST.13	How to assess and monitor ecosystem health in the face of climate change and other anthropogenic change	4.2	4	5	4	3	4	4	4	5	4	4	4	5	

8.1.1 Status & Trends

	Research gaps as identified by workshop participants	Average value	JCU	CSRIO	WTMA	TERRAIN	DERM -QPWS	SEWPaC	Fisheries Qld	FNQ Regional Organisation of Councils	Biotropica Austr. P/L	ACF	AWC	Bana Yarralji Bubu Inc & Balkanu Cape York Dev. Corp.	Independent
ST.14	**The key indicators of forest health that can be regularly measured at a landscape scale, with a focus on threatened and rare regional ecosystems**	**4.2**	4	5	5	4	5	4	3	5	3	4	4	5	
ST.15	**Regional remote sensing approaches for determining ecosystem health**	**3.5**	4	5	5	3	4	4	3	4	2	1	4	3	
ST.16	**Quantitative measures of forest health/degradation, such as growth or recovery rates across environmental gradients (e.g. elevation)**	**3.3**	3	5	4	3	3	3	3	4	3	1	4	3	
ST.17	**Research into thresholds or tipping points that lead to catastrophic irreversible ecological changes**	**4.0**	5	5	4	5	4	4	4	4	4	1	3	5	
ST.18	**The ecological function and other values of regrowth and non-remnant vegetation**	**3.6**	4	5	5	4	4	5	2	3	4	1	3	3	
ST.19	**Quantification of the value of restoration and regrowth in maintaining and improving ecosystem function**	**3.9**	4	5	5	5	3	5	4	5	4	1	3	3	5

8.1.1 Status & Trends

	Research gaps as identified by workshop participants	Average value	JCU	CSRIO	WTMA	TERRAIN	DERM -QPWS	SEWPaC	Fisheries Qld	FNQ Regional Organisation of Councils	Biotropica Austr. P/L	ACF	AWC	Bana Yarralji Bubu Inc & Balkanu Cape York Dev. Corp.	Independent
ST.20	**Better understanding of the short-term vs. longer-term dynamics and movement (spatial and temporal distribution) of ecosystems (and component species)**	**3.3**	3	5	3	3	3	3	3	4	4	1	3	4	
ST.21	**Assessment of the functionality of current connectivity of ecosystems with respect to traits of a variety of species**	**3.7**	3	5	5	4	4	5	3	4	4	1	3	4	
ST.22	**Rationally based assessment of threatened Wet Tropics ecosystems**	**3.7**	2	5	3	3	4	5	4	3	3	5	3	4	
ST.23	**Multi-layered systems for assessment of ecosystem health relevant to key values**	**3.5**	2	5	4	3	3	4	4	5	2	2	4	4	5
ST.24	**Impacts of drought in dry sclerophyll forests**	**2.8**	3	4	2	3	4	3	2	2	2	1	4	4	
ST.25	**A better definition and separation of rainforest 'types' with respect to Queensland's statutory Regional Ecosystem framework which is more designed for open forest communities**	**3.0**	2	4	4	2	4	3	2	4	2	1	3	4	
ST.26	**Higher-resolution mapping of the vegetation types of critically important areas (mapping units and map scale)**	**3.4**	3	5	4	2	4	5	3	3	3	1	4	4	
ST.27	**Trends in cloud forests**	**3.0**	4	4	4	3	3	3	2	3	3	1	2	4	

8.1.1 Status & Trends

	Research gaps as identified by workshop participants	Average value	JCU	CSRIO	WTMA	TERRAIN	DERM -QPWS	SEWPaC	Fisheries Qld	FNQ Regional Organisation of Councils	Biotropica Austr. P/L	ACF	AWC	Bana Yarralji Bubu Inc & Balkanu Cape York Dev. Corp.	Independent
ST.28	**Distribution and abundance of wet sclerophyll species**	**3.1**	4	5	3	2	4	3	1	4	3	1	3	4	5
ST.29	*Open* **forest/rainforest dynamics, with respect to edges and ecotones and transitional communities**	**3.6**	4	4	5	2	5	5	3	3	3	1	4	5	5
ST.30	**Improved knowledge of phylogeography of Wet Tropics plants**	**3.0**	4	4	4	2	4	3	3	3	4	1	2	2	
ST.31	**Assessment of the abundance and population structure of threatened and endemic species**	**3.8**	4	4	3	4	4	5	3	4	4	4	3	4	5
ST.32	**Improvement of the very poor understanding of plant species distributions**	**3.6**	4	4	4	2	4	3	3	5	4	3	2	5	
ST.33	**Improved identification of where in the landscape are major and minor natural disjunctures and genetic barriers**	**2.9**	4	4	4	2	3	3	3	3	2	1	2	4	
ST.34	**Status and trends of rainforest plant dispersers (wildlife)**	**3.5**	3	4	3	4	3	5	4	4	4	2	2	4	
ST.35	**Basic distribution data of bats**	**2.9**	4	4	2	2	4	4	2	4	4	1	2	3	
ST.36	**Maps of habitats of all endangered and vulnerable species**	**4.2**	4	5	4	5	5	5	4	3	3		3	5	
ST.37	**Underlying mechanisms of species distribution and abundance**	**3.5**	4	5	2	3	5	4	4	4	2	1	3	5	

8.1.1 Status & Trends

	Research gaps as identified by workshop participants	Average value	JCU	CSRIO	WTMA	TERRAIN	DERM -QPWS	SEWPaC	Fisheries Qld	FNQ Regional Organisation of Councils	Biotropica Austr. P/L	ACF	AWC	Bana Yarralji Bubu Inc & Balkanu Cape York Dev. Corp.	Independent
ST.38	**Improved understanding of rainforest plant associations**	**2.8**	3	4	4	2	3	3	2	3	2	1	2	4	
ST.39	**Baseline health status assessment of key threatened and endemic species**	**3.9**	4	4	4	4	5	5	3	4	3	4	3	5	
ST.40	**Improved understanding of the biology of non-threatened species**	**3.1**	4	4	3	2	3	3	3	3	4	1	3	5	
ST.41	**Improved understanding of the biology of mosses / cryptogams, threatened and endemic species, and climate change indicators**	**2.9**	3	4	3	3	3	5	1	3	3	1	1	5	
ST.42	**How to monitor cryptic rainforest species**	**3.0**	2	4	4	1	3	4	4	3	4	1	2	4	
ST.43	**Role of vector-borne diseases in affecting abundance and distribution of wildlife, plants and humans**	**3.0**	3	4	4	1	3	4	3	3	4	1	2	4	
ST.44	**Temperature tolerances of tree species (reproduction, growth, recruitment, mortality)**	**2.8**	4	4	3	3	3	3	2	4	2	1	2	3	5
ST.45	**Adaptation research especially with respect to climate change (behavioural ecology, genetic and variations in life histories across gradients)**	**3.3**	3	5	3	2	3	3	4	4	3	1	3	5	5

8.1.1 Status & Trends

	Research gaps as identified by workshop participants	Average value	JCU	CSRIO	WTMA	TERRAIN	DERM -QPWS	SEWPaC	Fisheries Qld	FNQ Regional Organisation of Councils	Biotropica Austr. P/L	ACF	AWC	Bana Yarralji Bubu Inc & Balkanu Cape York Dev. Corp.	Independent
ST.46	**Population abundance (as opposed to distribution) of threatened species**	**3.7**	4	4	4	3	5	5	4	5	3	1	3	4	
ST.47	**Inbreeding of threatened species**	**2.8**	3	4	3	3	3	4	2	3	2	1	2	3	5
ST.48	**Baseline research into disease and parasite loads of native species (animals & plants)**	**2.7**	3	4	5	1	3	4	3	2	2	1	2	3	
ST.49	***S*patial variability of phenology- flowering and fruiting patterns of rainforest trees**	**2.7**	3	4	4	1	3	3	2	3	2	1	1	5	
ST.50	***W*hat are the patterns and controlling factors (both temporal and spatial) of phenology**	**2.6**	3	5	3	1	3	2	3	2	2	1	1	5	
ST.51	**Cassowary behavioural response research (sound, sight, smell) especially with respect to threats such as roads and urbanisation**	**3.1**	3	5	5	3	4	5	1	4	4	1	1	2	

Table 19. All research gaps pertaining to 'risks and threats' (see section 5.2) as formulated by the workshop attendants and rated by representatives of end user and research provider organisations (1 = 'low value; 5 = 'high value')

8.1.2 Risks & Threats

	Research gaps as identified by workshop participants	Average value	JCU	CSRIO	WTMA	TERRAIN	DERM -QPWS	SEWPaC	Fisheries Qld	FNQ Regional Organisation of Councils	Biotropica Austr. P/L	ACF	AWC	Bana Yarralji Bubu Inc & Balkanu Cape York Dev. Corp.	Independent
RT.1	What ecosystems and species are most vulnerable to either temperature trends or to extreme events such as heat waves, droughts, cyclones)	4.0	5	5	5	3	4		4	5	3	3	3	4	
RT.2	The ecosystems and species that are likely to be susceptible to climate change (key indicators)	4.1	4	5	5	3	4	4	4	5	4	3	3	5	
RT.3	Which native species are likely to be climate change 'winners'	3.7	4	5	5	3	3	4	4	3	2	4	3	4	
RT.4	Impacts of climate change on high elevation endemics, including plants	3.7	4	5	5	3	3	4	2	4	3	4	3	4	
RT.5	Evaluation/determination of mechanisms of impact of climate change; how does climate change affect species and ecosystems	3.8	4	5	4	3	4	4	3	4	2	4	3	5	
RT.6	What is the climate change threat to ecosystem processes, e.g. primary production, dispersal, water relations, etc.	4.0	4	5	4	4	4	4	4	4	4	4	3	4	
RT.7	Cumulative and interactive effects; how do first order impacts translate into second and third order impacts	3.4	4	4	4	3	3	3	3	4	3	2	3	5	
RT.8	What cascading effects will climate change-related increases in population size and distribution of some native species have on community dynamics	3.7	4	5	4	3	4	3	4	3	3	4	3	5	
RT.9	Interactions of climate change with other threats	4.0	4	5	5	4	3	4	4	4	3	4	4	4	

8.1.2 Risks & Threats

	Research gaps as identified by workshop participants	Average value	JCU	CSRIO	WTMA	TERRAIN	DERM -QPWS	SEWPaC	Fisheries Qld	FNQ Regional Organisation of Councils	Biotropica Austr. P/L	ACF	AWC	Bana Yarralji Bubu Inc & Balkanu Cape York Dev. Corp.	Independent
RT.10	**Climate and the interaction with invasive species**	**4.1**	4	5	5	4	4	4	4	5	3	4	4	3	
RT.11	**How the potential for invasiveness changes under climate change**	**3.7**	4	5	4	3	4	3	4	5	3	4	3	3	
RT.12	**The impacts of extreme (climatic) events on species distributions**	**3.9**	4	5	5	4	4	3	4	4	3	5	3	3	
RT.13	**Threats to biodiversity of extreme climatic events, especially in relation to refugia and individual species**	**3.8**	5	5	5	4	4	4	2	4	2	4	3	4	
RT.14	**The role of refugia under climate change**	**3.9**	5	5	5	4	3	4	3	5	2	4	2	5	
RT.15	**Research into whether climate change refugias exists (at multiple scales), and if so, where they are and what is their value**	**3.8**	4	5	4	4	4	4	4	4	3	4	2	4	5
RT.16	**Characterisation and mapping of key climate refugia as a basis for management intervention**	**3.9**	4	5	5	4	4	4	4	4	3	4	2	4	
RT.17	**Knowledge of what mediated survival under historical climate change**	**3.1**	4	5	3	4	2	2	3	3	2	2	3	5	
RT.18	**Strategic approaches and better understanding of the invasive process including identification of which parts of the landscape are most vulnerable to invasion.**	**3.7**	4	5	5	4	5		3	5	3	2	3	3	
RT.19	**Identification of the high-susceptibility areas where weeds and pest animals have the potential to become major drivers impacting ecological health**	**3.9**	4	5	5	4	4	4	3	5	3	3	3	4	

8.1.2 Risks & Threats

	Research gaps as identified by workshop participants	Average value	JCU	CSRIO	WTMA	TERRAIN	DERM -QPWS	SEWPaC	Fisheries Qld	FNQ Regional Organisation of Councils	Biotropica Austr. P/L	ACF	AWC	Bana Yarralji Bubu Inc & Balkanu Cape York Dev. Corp.	Independent
RT.20	**The key areas of susceptibility to weeds and disease**	**3.9**	4	5	5	4	5	4	3	5	3	3	3	3	
RT.21	**Identification of ecosystems of particular risk to invasive species**	**3.9**	3	5	4	4	4	4	3	5	3	4	3	4	
RT.22	**The status and trends of weeds**	**3.5**	3	5	5	4	5	4	1	4	3	2	3	3	
RT.23	**The distribution and abundance of weeds and invasives**	**4.0**	4	5	5	3	4	4	4	5	3	4	3	4	5
RT.24	**Spatial extent of ecosystem impacts of priority invasives in the Wet Tropics**	**3.6**	3	5	4	4	4	4	5	4	3	2	3	3	
RT.25	**Impacts of the stocking and translocation of fish**	**3.3**	3	5	4	2	4	3	5	5	3	1	2	3	
RT.26	**Cats - where are they, and are they a risk?**	**3.0**	3	5	3	2	4	3	1	5	2	1	4	3	
RT.27	**Risk assessment of potential invasive species**	**3.6**	3	5	4	3	4	4	5	4	2	4	3	3	
RT.28	**The weed species or diseases that cause, or are likely to cause, the greatest environmental harm**	**3.5**	3	5	5	3	4	4	3	4	3	2	3	3	
RT.29	**Better understanding of disease spread through wildlife populations and the relationship between wildlife, human and agricultural diseases**	**3.2**	3	5	4	2	5	5	3	3	2	1	2	3	
RT.30	**Understanding of the biology and ecology of invasive species as a basis for risk management**	**3.6**	2	5	4	3	5	3	4	4	4	3	3	3	

8.1.2 Risks & Threats

	Research gaps as identified by workshop participants	Average value	JCU	CSRIO	WTMA	TERRAIN	DERM -QPWS	SEWPaC	Fisheries Qld	FNQ Regional Organisation of Councils	Biotropica Austr. P/L	ACF	AWC	Bana Yarralji Bubu Inc & Balkanu Cape York Dev. Corp.	Independent
RT.31	**A methodology to predict properties of species leading to invasiveness in the Wet Tropics**	**3.2**	3	5	4	3	5	3	3	4	2	1	2	3	
RT.32	**Understanding of invasion pathways**	**3.1**	3	5	3	3	4	3	2	5	2	1	2	4	
RT.33	**Properties of ecosystems that increase the potential for invasion**	**3.4**	3	4	4	4	4	3	3	5	2	3	3	3	
RT.34	**Better understanding of the interaction of global change drivers such as climate change and land use change on key biological invasions and invisibility**	**3.4**	3	4	4	2	4	3	4	4	2	4	3	3	
RT.35	**Determination of the triggers for concern for invasive invertebrates (e.g. ants, bees)**	**3.2**	3	4	5	2	4	4	3	4	3	1	3	3	
RT.36	**The changes to ecological processes resulting from a fragmented landscape (both terrestrial and aquatic), including effects on dispersal patterns and metapopulation dynamics**	**3.4**	3	5	3	4	3	5	4	3	4	2	2	3	
RT.37	**The impacts of fragmentation on rare and threatened ecosystems**	**3.5**	3	5	4	4	3	5	3	4	3	2	2	3	
RT.38	**Better knowledge of the effects of internal fragmentation resulting from human infrastructure (e.g. roads, powerlines, pipelines) dissecting rainforests and protected areas**	**3.3**	2	5	5	2	2	5	5	3	3		1	3	
RT.39	**Localised impacts of human habitation on ecological processes**	**3.2**	2	5	2	4	3	4	3	4	2		2	4	
RT.40	**Processes affecting population viability in fragments**	**3.2**	3	5	3	4	3	5	3	3	3	1	2	3	5

8.1.2 Risks & Threats

	Research gaps as identified by workshop participants	Average value	JCU	CSRIO	WTMA	TERRAIN	DERM -QPWS	SEWPaC	Fisheries Qld	FNQ Regional Organisation of Councils	Biotropica Austr. P/L	ACF	AWC	Bana Yarralji Bubu Inc & Balkanu Cape York Dev. Corp.	Independent
RT.41	**What degree of connectivity is appropriate - methods to determine optimal spatial properties of corridors and patch size**	3.7	3	5	5	4	4	5	4	5	4	1	1	3	5
RT.42	**What constitutes critical patch size thresholds and corridor widths for wildlife associated with different landscape types**	3.6	4	5	5	4	4	5	4	4	4	1	1	3	5
RT.43	**The minimal viable patch size for target wildlife taxa (taking into account shape, isolation and past history also)**	3.3	3	5	4	4	3	5	3	4	3	1	1	3	
RT.44	**The fragmentation, patch size and connectivity thresholds for each Broad Vegetation Group that will maintain biodiversity and ecosystem processes**	3.3	3	5	4	4	3	5	3	4	4	1	1	3	
RT.45	**Size requirements for sustainable populations of species in refugia in the face of climate change**	3.6	5	5	4	4	3	4	3	4	4	1	2	4	
RT.46	**Characterisation/evaluation of remnant vegetation and description of its role in landscape function**	3.0	2	5	3	4	3	3	2	5	4	1	1	3	5
RT.47	**The impact of the March-December 2009 drought in the Herberton-Wairuna province**	2.4	3	5	1	2	4	2	2	3	3	1	1	2	
RT.48	**Methodologies for effective management of forest edges**	3.5	3	5	5	4	3	5	2	5	3	2	1	4	
RT.49	**Establishment of indicators of the limits of acceptable change for grazing in native ecosystems**	2.8	3	5	2	3	3		3	3	2	1	3	3	
RT.50	**Impacts of grazing on wet sclerophyll, dry sclerophyll and rainforest gradients**	3.0	3	5	2	4	3	2	2	3	3	1	4	4	5

8.1.2 Risks & Threats

	Research gaps as identified by workshop participants	Average value	JCU	CSRIO	WTMA	TERRAIN	DERM -QPWS	SEWPaC	Fisheries Qld	FNQ Regional Organisation of Councils	Biotropica Austr. P/L	ACF	AWC	Bana Yarralji Bubu Inc & Balkanu Cape York Dev. Corp.	Independent
RT.51	**Suitable indicators for quantifying and monitoring grazing impacts in woodland, forests and grazing (especially for the Herberton-Wairuna province)**	**2.7**	2	5	2	3	3	2	2	4	3	1	3	2	5
RT.52	**Impacts of water extraction and changes in drainage patterns**	**3.5**	3	5	3	3	5	4	5	4	4	3	1	2	
RT.53	**Better information on the ecological effects of extraction of underground water resources both on the coastal lowlands and on the Tablelands**	**3.1**	2	5	4	3	5	4	5	3	2	1	1	2	
RT.54	**Improved knowledge of sustainable agroforestry methodologies that will contribute to landscape health, agricultural enterprises, and other 'good things'**	**2.6**	2	5	2	2	4	2	3	2		1	1	5	
RT.55	**Assessment of the extent and ecological impact of open forest logging outside of protected areas (e.g. for sleepers etc)**	**2.4**	2	5	1	2	3	1	2	3	2	3	3	2	5
RT.56	**Urbanisation and changing patterns of human population effects on wildlife populations and ecosystem function**	**3.3**	3	5	3	3	4	5	4	4	3	1	1	3	
RT.57	**Urbanisation impacts - how do we understand the impacts of urbanisation on adjacent ecosystems**	**3.1**	2	5	3	3	4	5	4	4	2	1	1	3	
RT.58	**Urban ecology/biology and array of services and dis-services provided to different species of wildlife and natural ecological processes**	**3.0**	3	5	3	3	3	4	4	4	2	1	1	3	
RT.59	**Impacts of infrastructure on rainforests etc.**	**3.1**	2	5	5	2	4	5	3	3	3	1	2	3	

8.1.2 Risks & Threats

	Research gaps as identified by workshop participants	Average value	JCU	CSRIO	WTMA	TERRAIN	DERM -QPWS	SEWPaC	Fisheries Qld	FNQ Regional Organisation of Councils	Biotropica Austr. P/L	ACF	AWC	Bana Yarralji Bubu Inc & Balkanu Cape York Dev. Corp.	Independent
RT.60	**Impacts of roads and traffic on threatened wildlife**	3.7	2	5	5	4	4	5	5	4	4	1	2	3	
RT.61	**Human-wildlife interactions and conflicts (especially involving cassowaries, crocs, flying foxes, dingoes, and wallabies)**	3.7	2	5	5	3	4	5	4	4	4	1	2	5	
RT.62	**Impacts of unsustainable mushroom collection**	1.8	1	5	1	1	2	2	1	2	2	1	1	2	
RT.63	**Better knowledge of groundwater-surface interactions**	3.2	2	5	4	3	3	4	4	4	2	1	1	5	
RT.64	**Better information on stream flow rates and barriers, especially with respect to climate change and changing land use patterns and intensities**	3.3	3	5	4	4	3	4	5	4	2	1	1	3	
RT.65	**The impacts of dams and other infrastructure on environmental flows**	3.5	3	5	4	3	4	5	5	4	3	3	1	2	
RT.66	**Impacts of land use on aquatic environments**	3.5	3	5	3	3	3	5	5	5	3	3	1	3	
RT.67	**Water quality and resilience in the riparian zone**	3.6	2	5	3	4	3	5	4	5	3	3	1	5	
RT.68	**The functional riparian widths necessary to maintain instream processes**	3.8	2	5	4	4	3	5	5	5	4	3	1	4	
RT.69	**How climate change will influence aquatic systems and structure of aquatic communities (including El Niño and cyclonic events)**	3.5	4	5	3	3	3	3	5	4	3	3	1	5	

8.1.2 Risks & Threats

	Research gaps as identified by workshop participants	Average value	JCU	CSRIO	WTMA	TERRAIN	DERM -QPWS	SEWPaC	Fisheries Qld	FNQ Regional Organisation of Councils	Biotropica Austr. P/L	ACF	AWC	Bana Yarralji Bubu Inc & Balkanu Cape York Dev. Corp.	Independent
RT.70	**The impacts of climate change on cloud interception and cloud base lift**	**3.2**	5	5	3	1	3	3	3	3	3	3	2	4	
RT.71	**Threats to highland aquatic biodiversity and fresh water flows in the dry season due to reduced cloud stripping**	**3.3**	5	5	3	1	3	3	4	3	3	3	2	5	
RT.72	**Establish environmental flow regimes for Wet Tropics rivers and streams (including low flow tributaries)**	**3.2**	3	5	4	4	4	4	5	3	2	1	1	3	
RT.73	**Development of a classification and conservation status framework for aquatic ecosystems to compliment the statutory regional ecosystem (RE) framework in place for terrestrial ecosystems**	**3.4**	2	5	5	3	3	4	4	3	4	1	2	5	
RT.74	**Boundary dynamics at wet sclerophyll, dry sclerophyll, rainforest transition zones, and coastal mosaics, and the interactions with climate change**	**3.7**	4	5	4	3	3	3	2	4	3	4	4	5	5
RT.75	**Risk of loss of tall open forest in the Wet Tropics**	**3.9**	4	5	5	3	5	4	2	4	3	4	4	4	
RT.76	**The rainforest-sclerophyll boundary in relation to fire**	**3.8**	5	5	5	4	4	3	2	4	3	1	4	5	5
RT.77	**The spatial and temporal dynamics (short and long-term) of wet sclerophyll forests**	**3.6**	4	5	4	3	4	3	3	5	3	1	4	4	5
RT.78	**Research on the fire dynamics in wet sclerophyll forests**	**3.7**	4	5	5	3	5	3	1	4	3	1	5	5	
RT.79	**Interactions and cumulative effects between inappropriate fire regimes and weed invasions/changing fuel characteristics**	**3.4**	3	5	3	3	5	4	2	4	3	2	4	4	

8.1.2 Risks & Threats

	Research gaps as identified by workshop participants	Average value	JCU	CSRIO	WTMA	TERRAIN	DERM -QPWS	SEWPaC	Fisheries Qld	FNQ Regional Organisation of Councils	Biotropica Austr. P/L	ACF	AWC	Bana Yarralji Bubu Inc & Balkanu Cape York Dev. Corp.	Independent
RT.80	**Post-cyclone fire danger in rainforest**	**3.4**	3	5	3	3	5	5	2	3	3	1	3	5	
RT.81	**Indicators and criteria to support fire management decision making**	**3.7**	3	5	5	3	5	3	1	4	4	3	3	5	
RT.82	**Application of Traditional Ecological Knowledge about fire in current management regimes**	**3.7**	3	5	4	3	4	4	3	4	3	4	3	5	

Table 20. All research gaps pertaining to 'mitigation and adaptation' (see section 5.3) as formulated by the workshop attendants and rated by representatives of end user and research provider organisations (1 = 'low value; 5 = 'high value')

8.1.3 Mitigation & Adaptation

	Research gaps as identified by workshop participants	Average value	JCU	CSRIO	WTMA	TERRAIN	DERM -QPWS	SEWPaC	Fisheries Qld	FNQ Regional Organisation of Councils	Biotropica Austr. P/L	ACF	AWC	Bana Yarralji Bubu Inc & Balkanu Cape York Dev. Corp.	Independent
MA.1	How to create a resilient landscape - What criteria? Where? Why?	4.1	5	5	5	5	4	5	3	4	4	3	2	5	5
MA.2	How to increase regional resilience - identification of options to extend conserved areas and the connectivity between them?	3.9	4	5	5	5	3	5	3	5	4	3	1	4	5
MA.3	Movement corridors will work for increasing resilience to climate change	3.8	4	5	5	4	3	4	4	3	4	4	1	4	
MA.4	Establish monitoring and conservation strategies for key vulnerable species	4.1	4	5	4	5	4	5	4	4	4	2	4	4	
MA.5	How we effectively manage refugia to maintain integrity	3.8	5	5	4	4	3	5	3	4	3	2	3	5	5
MA.6	Management and maintenance of the resilience of refugia as well as microhabitats to help species adapt to climate change	3.6	5	5	5	4	3	4	2	3	3	2	2	5	
MA.7	We need to identify and isolate evolutionary refugia and prevent movement of common species competing with restricted endemic specialist species	3.3	5	5	5	3	3	4	2	3	3	2	1	4	

8.1.3 MITIGATION & ADAPTATION

	Research gaps as identified by workshop participants	Average value	JCU	CSRIO	WTMA	TERRAIN	DERM -QPWS	SEWPaC	Fisheries Qld	FNQ Regional Organisation of Councils	Biotropica Austr. P/L	ACF	AWC	Bana Yarralji Bubu Inc & Balkanu Cape York Dev. Corp.	Independent
MA.8	**Maintaining refugia to provide buffers against the effects of extreme events**	**3.5**	5	5	4	4	4	4	3	3	3	2	2	4	
MA.9	**Trial of the creation of cool refugia across the landscape such as shade, water features, rock piles, nesting boxes, logs, hollows etc)**	**3.4**	4	5	5	4	4	4	2	1	4	2	1	5	
MA.10	**Genetic translocation and species translocations to offset detrimental effects of climate change**	**3.0**	3	5	2	2	4	2	3	2	2	2	4	5	3
MA.11	**Translocations of critically endangered species from lower to higher mountaintops**	**2.8**	4	5	2	2	4	2	2	3	2	2	2	4	1
MA.12	**How conservation policy should adapt to rapid climate change**	**3.7**	3	5	3	4	4	3	2	5	3	4	3	5	
MA.13	**Responses to re-introduction and relocation**	**3.2**	4	5	3	2	4	3	4	3	3	1	3	4	
MA.14	**Genetic modification for higher temperature tolerance**	**2.0**	3	5	2	1	3	1	1	1	1	1	2	3	1
MA.15	**Management as starting point for adapting to climate change**	**3.6**	3	5	3	4	4	3	2	5	3	4	3	5	
MA.16	**Cost-effective control and eradication techniques**	**3.4**	3	5	4	4	3	2	5	3	3		3	3	

8.1.3 Mitigation & Adaptation

	Research gaps as identified by workshop participants	Average value	JCU	CSRIO	WTMA	TERRAIN	DERM -QPWS	SEWPaC	Fisheries Qld	FNQ Regional Organisation of Councils	Biotropica Austr. P/L	ACF	AWC	Bana Yarralji Bubu Inc & Balkanu Cape York Dev. Corp.	Independent
MA.17	**R&D of monitoring for detection of invasions and spread of emerging and established invasives, including remote detection and delimiting methods**	3.5	3	5	5	3	5	3	5	3	3	1	3	3	
MA.18	**R&D of feasibility, options and cost benefits of remote sensing and novel technologies for detection, identification and mapping of invasives**	3.6	3	5	5	3	5	3	5	4	3	1	3	3	
MA.19	**Predict and model problem species (including invertebrates), and assess their risks - what are the triggers for early control**	3.4	3	5	4	3	5	3	4	4	2	1	2	4	
MA.20	**Assessment of the effectiveness of current methods to detect new invasions, and develop new detection methods**	3.1	3	5	4	3	4	3	4	5	2	1	1	3	
MA.21	**Where investment in pest animal research and management should be directed**	3.2	3	5	4	4	5	2	4	3	2	1	2	4	
MA.22	**R&D of frameworks for strategic, process-based approaches to invasive species management**	3.2	2	5	3	4	5	2	4	4	3	1	2	4	
MA.23	**How, when , and whether to manage invasive species with respect to their traits and scale of invasion**	3.4	3	5	3	3	4	2	5	5	4	1	2	4	
MA.24	**Methodologies to improve biodiversity in areas by preventing deflected / arrested succession caused by invasives**	3.2	3	5	4	4	5	3	4	3	2	1	2	3	

8.1.3 Mitigation & Adaptation

	Research gaps as identified by workshop participants	Average value	JCU	CSRIO	WTMA	TERRAIN	DERM -QPWS	SEWPaC	Fisheries Qld	FNQ Regional Organisation of Councils	Biotropica Austr. P/L	ACF	AWC	Bana Yarralji Bubu Inc & Balkanu Cape York Dev. Corp.	Independent
MA.25	**Stop fish stocking**	**2.6**	3	4	3	2	3	2	5	2	2	1	1	3	
MA.26	**Assessment of landscape restoration practices especially with respect of tree planting**	**3.2**	3	4	5	4	3	4	2	3	4	1	1	4	
MA.27	**Rehabilitation methods for degraded lands to provide various ecosystem functions**	**3.5**	3	4	5	4	3	4	4	4	2		3	3	
MA.28	**Rationally-based criteria for acquisition and restoration of critical habitat**	**3.6**	2	5	3	4	3	5	4	5	4	3	3	2	
MA.29	**Increased understanding of the impacts of fragmentation on biodiversity assets (with respect to spatial parameters such as size, shape and connectedness of fragments)**	**3.3**	3	5	4	4	3	5	2	4	4	2	1	3	5
MA.30	**How you design landscapes for maximum connectivity or ecosystem function**	**3.7**	4	5	5	4	3	5	4	5	2	2	1	4	5
MA.31	**economically feasible improvements in management to increase connectivity**	**3.3**	4	5	4	4	3	5	3	4	2	1	1	4	
MA.32	**Better understanding of what is appropriate connectivity (patch size, corridor width, etc.), which is expected to be context and case dependent**	**3.4**	4	5	5	4	3	5	3	4	3	1	1	3	5

8.1.3 Mitigation & Adaptation

	Research gaps as identified by workshop participants	Average value	JCU	CSRIO	WTMA	TERRAIN	DERM -QPWS	SEWPaC	Fisheries Qld	FNQ Regional Organisation of Councils	Biotropica Austr. P/L	ACF	AWC	Bana Yarralji Bubu Inc & Balkanu Cape York Dev. Corp.	Independent
MA.33	**Assessment of the efficacy of corridors: location, design, width, species selection, density, functional groups, processes**	**3.4**	4	5	5	4	3	5	3	3	4	1	1	3	
MA.34	**Incorporation of ecological knowledge into cyclone preparation and rehabilitation**	**3.8**	3	5	5	4	5	4	3	5	3	1	2	5	5
MA.35	**To understand better and develop new indices of forest health**	**3.2**	3	5	5	3	5	4	1	3	2	1	2	5	
MA.36	**Strategies for integrating environment and production goals on privately managed land**	**3.4**	3	5	2	4	3	5	1	4	4	1	3	5	
MA.37	**Assessments of whether] mitigation measures are effective on a genetic, population and community basis**	**3.3**	4	5	4	4	3	4	3	3	3	1	2	4	
MA.38	**Designing and implementing policies for restricting and making more efficient water extraction in the Wet Tropics**	**3.1**	3	5	3		5	4	4	3	3	1	1	2	
MA.39	**Establishing optimal grazing systems**	**2.6**	2	5	2	3	3	3	1	4	2	1	3	2	5
MA.40	**Reducing current deer stock**	**2.3**	2	3	3	2	3	2	1	4	2	1	2	2	5
MA.41	**Fencing of high-value areas**	**2.9**	2	5	4	2	4	4	1	3	2	1	4	3	

8.1.3 Mitigation & Adaptation

	Research gaps as identified by workshop participants	Average value	JCU	CSRIO	WTMA	TERRAIN	DERM -QPWS	SEWPaC	Fisheries Qld	FNQ Regional Organisation of Councils	Biotropica Austr. P/L	ACF	AWC	Bana Yarralji Bubu Inc & Balkanu Cape York Dev. Corp.	Independent
MA.42	**Strategies for maintaining appropriate environmental flows, despite dams and other infrastructure**	**3.2**	3	5	4	3	4	4	5	3	3	1	2	2	
MA.43	**Identification and prioritisation of removal of barriers and description of impacts and ecological consequences of removal**	**3.5**	3	5	4	3	4	4	5	5	3	1	2	3	
MA.44	**Identification of indicators of progress towards restoring ecological processes and function (including control of invasive aquatic pest species)**	**3.3**	3	5	3	3	4	3	4	4	3	2	2	3	
MA.45	**Is it possible to restore hydrological and ecological processes and function of modified coastal wetlands and other aquatic systems**	**3.4**	3	5	3	4	4	4	5	4	2	3	1	3	
MA.46	**Economically feasible means of restoring riparian habitats**	**3.8**	3	5	4	4	4	4	4	5	2	4	3	3	
MA.47	**Means of removal of invasive fishes**	**3.6**	3	5	5	4	4	2	5	4	3	2	3	3	
MA.48	**Emission mitigation to halt lift of cloud base**	**2.3**	3	3	1		3	2	3	3	3	1	1	3	
MA.49	**Cause/effect relationships (including interactions with invasive species, nutrient cycling/dynamics, etc.) and modelling consequences of different fire management scenarios to develop science-based fire management options**	**3.2**	4	5	3	4	4	2	2	3	3	1	3	5	5

8.1.3 Mitigation & Adaptation

	Research gaps as identified by workshop participants	Average value	JCU	CSRIO	WTMA	TERRAIN	DERM -QPWS	SEWPaC	Fisheries Qld	FNQ Regional Organisation of Councils	Biotropica Austr. P/L	ACF	AWC	Balkanu Cape York Dev. Corp. Bana Yarralji Bubu Inc &	Independent
MA.50	**Perfected remote sensing methods for fire history mapping**	**3.1**	4	5	3	2	4	2	1	3	2	2	5	4	
MA.51	**Implementation of long-term monitoring and assessment regime for fire - link to information repository**	**3.0**	4	5	4	2	5	2	2	3	2	1	3	4	
MA.52	**Prescribed burning/clearing to allow regrowth**	**2.7**	3	5	3	3	3	2	1	3	2	1	3	4	
MA.53	**how to adapt systems to shifting boundaries**	**3.1**	3	5	4	3	3	5	1	3	2	2	2	4	
MA.54	**Where in the landscape should open forest/rainforest ecotones be valued and preserved?**	**3.5**	4	5	5	4	4		1	4	3	2	3	4	
MA.55	**Small-scale examinations of recruitment of wet sclerophyll versus rainforest species under several fire regimes**	**3.5**	4	5	5	4	4	2	1	4	2	1	5	5	
MA.56	**Managing boundary dynamics at the wet sclerophyll, dry sclerophyll and rainforest gradient, using scientific, evidence-based fire management regimes**	**3.4**	4	5	5	4	4	2	1	4	2	2	5	3	
MA.57	**Manage fire to affect boundary dynamics in coastal mosaics, using scientific, evidence-based fire-management regimes; and the interaction with drainage patterns**	**3.4**	3	5	4	4	4	2	1	5	4	4	1	3	

Table 21. All remaining research gaps that could not easily be categorised under 'status and trends', risk and threats, and 'mitigation and adaptation'. Gaps are as formulated by the workshop attendants and rated by representatives of end user and research provider organisations (1 = 'low value; 5 = 'high value').

8.1.4 OTHER RESEARCH GAPS

	Research gaps as identified by workshop participants	Average value	JCU	CSRIO	WTMA	TERRAIN	DERM -QPWS	SEWPaC	Fisheries Qld	FNQ Regional Organisation of Councils	Biotropica Austr. P/L	ACF	AWC	Bana Yarralji Bubu Inc & Balkanu Cape York Dev. Corp.	Independent
O.1	**Greater emphasis on adaptive management between researchers and management**	**3.9**	4	5	5	3	5	4	3	4	3	2	3	5	5
O.2	**Long-term monitoring data, essential for decision making**	**4.2**	4	5	4	4	5	5	5	4	5	2	3	5	5
O.3	**Biodiversity Planning Assessment for the Wet Tropics**	**3.9**	4	5	5	3	5	4	4	4	4	3	1	5	
O.4	**Identification of species-specific mitigation strategies for keystone / flagship species**	**4.0**	3	5	4	4	4	5	3	5	4	3	3	5	
O.5	**Reassessments past development approvals/EIAs etc to see if predictions and mitigation strategies were successful in the longer term**	**3.1**	2	5	5	2	3	3	4	4	3	1	1	4	

8.2 Appendix 2 – Workshop documents

Marine and Tropical Sciences Research Facility

Australian Government
Department of the Environment, Water, Heritage and the Arts

Workshop

Gap analysis of environmental research needs in the Australian Wet Tropics

Date: 8 October 2010

Time: 9:00 am to 3:00 pm

Location: Rydges Plaza Hotel, Cairns (Cnr Spence & Grafton Streets, QLD 4870)

Workshop organisers:
Prof. Stephen Williams (*Centre for Tropical Biodiversity & Climate Change, James Cook University*)

Dr Justin Welbergen (*Centre for Tropical Biodiversity & Climate Change, James Cook University*)

Dr Steve Goosem (*Wet Tropics Management Authority, Cairns, Qld*)

Reef & Rainforest Research Centre

James Cook University Australia

Wet Tropics Management Authority

Marine and Tropical Sciences Research Facility

Australian Government
Department of the Environment, Water, Heritage and the Arts

Rationale

Strengthened linkages between terrestrial biodiversity researchers and end users across northern Australia are desirable to reduce duplicative effort and achieve maximum return on public investment in applied research. To assist this process, our report facilitates a significant review, synthesis and consultation process with the aim of identifying end-user needs, research gaps and possible synergies, delivering an accessible and useful resource for terrestrially focussed end-user groups.

Our final report will provide a valuable resource for researcher providers as a review of previous research in the region and to ensure their proposed research is strategic and targeted at the needs of the end-users, whilst at the same time deliver a repository of information that end-users can easily access. The report will also be used by DEWHA and other funding bodies to help guide the prioritisation of resources into future biodiversity research in the Wet Tropics bioregion.

This workshop aims to ensure that multiple end-users with a vested interest in biodiversity research will have an opportunity to actively collaborate in identifying the research gaps and end-user needs in the region.

Objectives

The objective of the workshop is to identify the gaps in biodiversity research in the Wet Tropics bioregion through end-user consultation.

Outputs

A list of research gaps covering

- the *status and trends* of the biophysical reality within the Wet Tropics bioregion,
- the *risks and threats* to its biological integrity, and
- the *mitigation and adaptation* strategies that address the risks and threats.

All gaps identified by the participants will be included in the final report.

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James Cook University Australia

Wet Tropics Management Authority

Marine and Tropical Sciences Research Facility

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Methodology

We aim to get an as wide as possible coverage of the existing knowledge gaps, including in areas that fall outside the boundaries of institutional interest. Therefore, participants will be asked to 'remove their institutional hats' and help identify the gaps to the best of their personal knowledge. We are nevertheless also interested in the institutional interest, but these will be addressed during the follow-up phase (see below) through written consultations with the end-user organisation.

Participants will be randomly assigned to a table, and each table is asked to identify research gaps within three main areas of concern (i.e. 'Status and Trends', 'Risks and Threats', 'Mitigation and Adaptation'). There are three questionnaires corresponding to the three areas of concern, with several categories within each area. For clarification, we have included examples of the three questionnaires on the following pages.

Agenda

Introduction	09:00 – 10:00
Status and Trends	10:00 – 11:00
Break	11:00 – 11:30
Risks and Threats	11:30 – 13:00
Break	13:00 – 13:30
Mitigation and Adaptation	13:30 – 15:00

Follow-up

The main output of the workshop will be a list of research *gaps* as identified by the participants. This list will then be sent to the end-user organisations, and we will ask the organisations to rank each gap according to the relative value that it represents to the end-user organisation. This way we will be able to determine those research *needs* that, if met, would have the greatest value for end-user organisations, and in addition, it will enable us to identify where the research interests of end-user organisations overlap.

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Example workshop questionnaire 1 (with some mock answers)

Status and trends
(what is there and what is changing)

STEP 2: rate each gap in terms of:			
Please identify between 0 and 3 research gaps within each category below	**Immediacy of need**	**Immediacy of concern**	**Magnitude of concern**
Landscapes (climate, geophysical processes, land usage)			
• *e.g. 'high-resolution forecasting of the Wet Tropics' rainfall patterns in the next 50 years'*	*high*	*very high*	*medium*
• *e.g. 'hydrology of open forests'*	*medium*	*medium*	*low*
• *etc..*	--	--	--
Ecosystems (functioning, community structure, species assemblages)			
• *e.g. 'the key indicators of rainforest health that can be regularly measured over large spatial scales'*	*high*	*very high*	*medium*
• *e.g. 'patterns of mammal assemblage structure in fragmented open forest'*	*medium*	*medium*	*low*
•			
Species (distribution, abundance, phylogeography)			
• *e.g. 'more detailed information on distributions of bats'*	*medium*	*medium*	*medium*
• *etc..*			
•			
Individuals (ecology, behaviour & genetics)			
• *e.g. 'the social organisation of cassowaries'*			
• *e.g.*			
•			
Others?			
•			
•			

Example workshop questionnaire 2 (with some mock answers)

Risks and threats
(what is causing change)

Please identify between 0 and 3 research gaps within each category below	STEP 2: rate each gap in terms of: Immediacy of need	Immediacy of concern	Magnitude of concern
Climate change			
• *e.g. 'the Wet Tropics ecosystems that are most at risk from climate change'*	*high*	*very high*	*medium*
• *e.g. 'the future impacts of extreme temperatures on the lemuroid possum'*	*medium*	*medium*	*low*
•	--	--	--
Invasive species			
• *e.g. 'the weed species that cause, or are likely to cause, the greatest environmental harm'*	*high*	*very high*	*medium*
• *e.g. 'the current impact of Chytrid Fungus on the Australian waterfall frog'*	*medium*	*medium*	*low*
• *e.g. ___*			
Loss, fragmentation and degradation of habitat			
• *e.g. 'the most important causes of degradation of rainforest habitat'*	*high*	*very high*	*medium*
• *e.g. 'the impacts of roads on Bennett's tree-kangaroo'*	*medium*	*medium*	*low*
•			
Unsustainable use of natural resources			
• *e.g. 'the impacts of recreational use of lake Eacham on endemic aquatic fauna'*	*medium*	*medium*	*low*
• *e.g. ___*			
• *e.g. ___*			
Changes to the aquatic environment and water flows			
• *e.g. ___*			
• *e.g. ___*			
• *e.g. ___*			
Inappropriate fire regimes			
• *e.g. ___*			
• *e.g. ___*			
• *e.g. ___*			
Others?			
• *e.g. ___*			
•			
•			

Example workshop questionaire 3 (with some mock answers)

Mitigation and adaptation
(what can be done about the change)

	STEP 2: rate each gap in terms of:		
Please identify between 0 and 3 research gaps within each category below	IMMEDIACY OF NEED	IMMEDIACY OF CONCERN	MAGNITUDE OF CONCERN
Climate change			
• *e.g. 'the most effective ways to increase resilience of Wet Tropics biota to climate change'*	*high*	*medium*	*very high*
• *e.g. 'how to mitigate the impacts of heatwaves on Lemuroid possums'*	*high*	*high*	*medium*
• *e.g. .....*			
Invasive species			
• *e.g. 'the best ways to eradicate bush currant'*	*medium*	*medium*	*medium*
• *e.g. .....*			
• *e.g. .....*			
Loss, fragmentation and degradation of habitat			
• *e.g. 'the effectiveness of mitigation strategies that aim to maintain ecological function within the community infrastructure matrix (e.g. roads, etc.)'*	*high*	*very high*	*medium*
• *e.g. .....*			
• *e.g. .....*			
Unsustainable use of natural resources			
• *e.g. .....*			
• *e.g. .....*			
• *e.g. .....*			
Changes to the aquatic environment and water flows			
• *e.g. .....*			
• *e.g. .....*			
• *e.g. .....*			
Inappropriate fire regimes			
• *e.g. .....*			
• *e.g. .....*			
• *e.g. .....*			
Others?			
• *e.g. .....*			
•			
•			

Example follow-up questionnaire (with some mock answers):

End user organisation name:	
Research gaps (as identified by workshop participants):	**Please indicate below the value to your organisation if the research gap was filled (1 = low; 5 = high relative value)**

Landscapes (climate, geophysical processes, land usage)	
• *'high-resolution forecasting of Wet Tropics' rainfall patterns in the next 50 years'*	*3*
• *'hydrology of open forests'*	*2*
• *etc*	..
• *etc*	
..	
..	

Ecosystems (functioning, community structure, species assemblages)	
• *e.g. 'the key indicators of rainforest health that can be regularly measured over large spatial scales'*	*4*
• *e.g. 'patterns of mammal assemblage structure in fragmented open forest'*	*1*
• *etc.*	..
• *etc..*	
..	

Etcetera, for each category under all three areas of concern.

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