

Threats to ecosystems in the Wet Tropics due to climate change and implications for management

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SUMMARY

This report summarises recent research that suggests several likely changes and threats to biodiversity and ecosystem processes in the Wet Tropics Bioregion and briefly discusses the implication of these changes for management.

We used the artificial neural network classifier (Hilbert and van den Muyzenberg 1999) that was previously used to investigate the large expansions, contractions and spatial shifts of the environments of structural forest types in the Wet Tropics bioregion over the last 18 to 20 thousand years as well as changes due to one degree of future warming. In this project, four scenarios were considered. In the worst-case scenario (IPPC A1FI), rapid warming (5 °C) accompanied with reduced rainfall (-23%) by 2080, there are substantial decreases in the areas of environments that are characteristic of many important rainforest classes, although some increase. This analysis indicates, given the currently expected warming in this century, that the region's forests will be in a substantial disequilibrium with their environment. The large changes in the ecological environments of the bioregion will stress existing forest communities and ecosystems. Unfortunately, it is not possible to say where and when actual changes in forest structure and plant species composition will occur with confidence.

As the regional climate changes, the potential forest environments change spatially but, primarily because of soil and landform features, some areas may remain suitable for a certain vegetation type despite rather large changes in regional climate. These parts of the landscape, refugia, may be less impacted by climate change. Based on our methodology, refugia are not likely to be important at regional scales in the A1FI scenario except for some areas of Mesophyll Vine Forest environments in the central Wet Tropics.

Several clear ecological patterns are evident that correspond to changes in mean annual temperature across the project's plots. As mean annual temperature increases (decreasing elevation); forest basal area decreases and tree species endemism decreases although tree species richness and tree density do not change along the temperature/altitudinal gradient. These observations suggest a number of likely responses to global warming in the Wet Tropics' forests, including reduced basal area (C stock) and possible expansion of generalist lowland species with concomitant decreases in more cool-climate adapted upland endemics.

Based on a preliminary analysis of data from projects twelve plots, it appears that few tree species (approximately 10%) are altitudinal generalists while many species may be restricted to narrow altitudinal ranges (200m which is equivalent to a 1 °C range of mean annual temperature). This observation is quite significant, if supported by analyses of larger data sets, because it suggest that many tree species will rapidly be exposed to mean annual temperatures that are beyond their normal tolerances.

Mosquitoes, important vectors of wildlife and human diseases, were captured across the project's altitudinal transect at three heights relative to the forest canopy and in three seasons over three years. Both the abundance and diversity of mosquitoes increase with estimated mean annual temperature of the plots. We recently identified *Plasmodium* (malaria) using PCR techniques in the most common lowland mosquito that was captured, *Coquillettidia crassipes*. This genus was recently reported to be a vector of avian malaria in Africa but has not previously been implicated as a vector in Australia.

DNA was successfully extracted from blood samples of 614 birds captured across the project's altitudinal transect and amplified by PCR analysis to identify DNA from

haemosporidians. Infection by *Haemoproteus* is much more common than by *Plasmodium* and peaks at intermediate temperatures (and elevation) while infection rates of avian malaria (*Plasmodium relictum*) are highest in the warmer sites and decline to an average of approximately three percent at mean annual temperatures below about 22.5 °C.

1. INTRODUCTION

This report is a summary and synthesis of research findings from the Marine and Tropical Sciences Research Facility project “Understanding the Climate Change Threat to Ecosystems and Ecosystem Processes, and Developing Options for Mitigation”. It is intended to provide a timely overview of the project’s research before its publication. Consequently, the results discussed here have not been thoroughly reviewed. Research methodology is not discussed in detail as this is available in previous project reports and publications. A complete review of climate change research in the Wet Tropics is beyond the scope of this report.

Extensive, global research has demonstrated that Earth’s biodiversity has been affected by climate change in the previous decades (Parry et al. 2007) and climate change is one of the most significant threats to global biodiversity and human well-being. Various impacts of climate change on biodiversity in Australia have already been documented for C4 grasses (Johnson et al., 1999), CO₂ effects on vegetation (Berry and Roderick 2002), overall impacts (Hughes 2003), birds (Chambers et al., 2005), predator-prey interactions (Madsen et al., 2006), birds (Gibbs 2007) plant physiological changes (Cullen et al., 2008), and vulnerability (Steffen et al., 2009).

Much of Earth’s terrestrial biodiversity is concentrated in the tropics, with high levels of endemism, and the possible impacts of climate change here are relatively unknown compared to Northern Hemisphere temperate regions. Consequently, this project focused on understanding how climate change will affect biodiversity, communities and ecosystems in the tropical forest landscapes of the Wet Tropics Bioregion.

A number of publications, starting with Hilbert et al. (2001), used models of various kinds to project possible impacts of global climate change on the biodiversity of the Wet Tropics Bioregion with the general conclusion that this region’s biodiversity could be devastated by global warming. However, there is a general lack of long-term monitoring in the region with the exception of CSIRO’s long-term permanent plots. So, actual responses to climate change in the past decades are unidentified and largely unknowable. Consequently, the key land-managers, notably the Wet Tropics World Heritage Authority, identified monitoring as a high priority.

In response to this need for monitoring the project established twelve monitoring plots along an altitudinal gradient in the central wet Tropics. Consequently, many of the results summarised here provide an important base-line for the monitoring of future changes in the biodiversity of the region’s forest ecosystems. Since the monitoring plots were established along an altitudinal gradient with regularly changing climate, they also provide an immediate opportunity to assess how climate affects biodiversity patterns. The project also extended the modelling of forest environments to the entire bioregion and considered a broad range of climate change scenarios.

This report begins with the key results from new modelling of forest environments as they provide an indication of how ecological environments may change in the coming decades. Then results from the monitoring plots are summarised along with some complementary

analyses using an extensive literature survey. The monitoring plots were used to measure biodiversity patterns in relation to mean annual temperature (altitude) in two respects; 1) forest structure and plant biodiversity; and 2) mosquitoes and avian disease. These are discussed in turn and, finally, some implications of the results for management are discussed.

A particular concern is that the effects of climate change will continue for the next century even if near-term emission reduction efforts are successful (Fischlin et al., 2007) so there is an urgent need to develop on-ground climate adaptation policies for biodiversity (Westoby and Burgman 2006).

2. Forest environments will change greatly

At large scales, vegetation is thought to be in dynamic equilibrium with climate (Prentice 1986, Webb 1986) and the distribution of biomes is controlled by ecophysiological constraints related mainly to temperature and water availability (Schultze 1982, Woodward 1987). So our approach uses maps of vegetation classes along with detailed, spatial estimates of climate, topographic and edaphic variables to objectively classify environments that are characteristic of these vegetation classes. The goal is to transform a high dimensional, physical environment space (many climate variables and a number of terrain and soil variables) into a lower dimension, ecologically meaningful, biotically-scaled space. This is accomplished through supervised classification using artificial neural networks (Rumelhart & McClelland 1986). Then, given any spatial scenario of change in climate we can map these *ecological* environments in geographic space. In this way, we can predict how the extent and distribution of ecologically meaningful environmental classes may change in the future and infer how climate change may affect vegetation classes and, consequently, biodiversity and ecosystem function.

We used the artificial neural network classifier (Hilbert and van den Muyzenberg 1999) that was used to investigate the large expansions, contractions and spatial shifts of structural forest types in this bioregion over the last 18 to 20 thousand years (Hilbert et al. 2007) due to climate change. Using this model, the sensitivity of the Wet Tropics forests to climate change in the future was identified for the first time (Hilbert et al. 2001). This publication demonstrated that the propensity for ecological change in the region is high and, in the long term, significant shifts in the extent and spatial distribution of forests are likely. But this research took a conservative view about future warming and did not consider warming beyond 1°C. Here, we summarise the key results from a greater range of warming scenarios and changes in rainfall. The vegetation classification follows Tracey (1982).

Current projections for global warming by 2100 are between 1.4 and 5.8°C, relative to 1990. While individual climate models differ, this broad range of projections mostly reflects the large differences in anthropogenic carbon emissions in the various scenarios applied by the climate model simulations, from early and large mitigation to unconstrained and intensifying emissions. The rate of increase in anthropogenic emissions is now tracking or above the worst-case scenario used by the models (Le Quéré et al. 2009) so the upper limits of warming in the projections appear most likely.

Warming will be less severe in the tropics than at high latitudes but recent estimates for coastal north east Queensland indicate warming roughly equal to the global average.

Table 1. Climatic changes used in the scenarios, figures in bold show the values for the high-dry scenario (A1FI).

date	Warming (°C)		Rainfall (%)	
	low	high	dry	wet
2020	0.3	0.9	-4	3
2030	0.5	1.4	-6	5
2040	0.6	1.9	-9	6
2050	0.7	2.5	-11	8
2060	0.9	3.3	-15	11
2070	1.0	4.2	-19	14
2080	1.1	5.0	-23	17

Large and rapid changes in the extent and spatial distribution of forest environments in the Wet Tropics will occur due to global climate change (Table 1). In the worst-case scenario (hereafter, high-dry), rapid warming (5 °C) accompanied with reduced rainfall (-23%) by 2080, there are substantial decreases in the areas of environments that are characteristic of many important rainforest classes, although some increase. Note that the rate of warming accelerates with time. While projections of rainfall are uncertain, this scenario may be the most likely so it is the focus of this report. Future climate modelling may suggest other scenarios are more probable.

2.1. Changes in area of forest environments with climate change

By 2080, Complex Notophyll Vine Forest environments (including that of threatened Mabi forests) decline to less than 500 ha (Figure 1). Environments of Simple Notophyll & Simple Microphyll Forests and Thickets decline to c. 50 ha, compared to 240,000 ha today (Figure 2). Coastal Complex environments that contain both rainforest and Melaleuca swamp components decline to less than 1,000 ha (Figure 3) becoming more suitable to Mesophyll Vine forests only. The decreasing extent of these environments is similar in the high-dry and high-wet scenarios. Thus, the projections of large declines in these environments are insensitive to the uncertainty in climate models about changes in rainfall.

On the other hand, “lowland” Mesophyll Vine Forest environments increase from c. 375,000 ha today to c. 540,000 ha in the high-dry scenario and more than double in area in the high-wet scenario (Figure 4). Araucarian Vine Forest environments that are rare today and mostly restricted to the Paluma Range in the south expand greatly to c. 460,000 ha (Figure 5) and are found from the northern to the southern limits of the Wet Tropics in the future, irrespective of changes in rainfall. Similarly, Notophyll Semi-evergreen Vine Forests environments, rare today, increase substantially with warming but more so in the high-wet scenario.

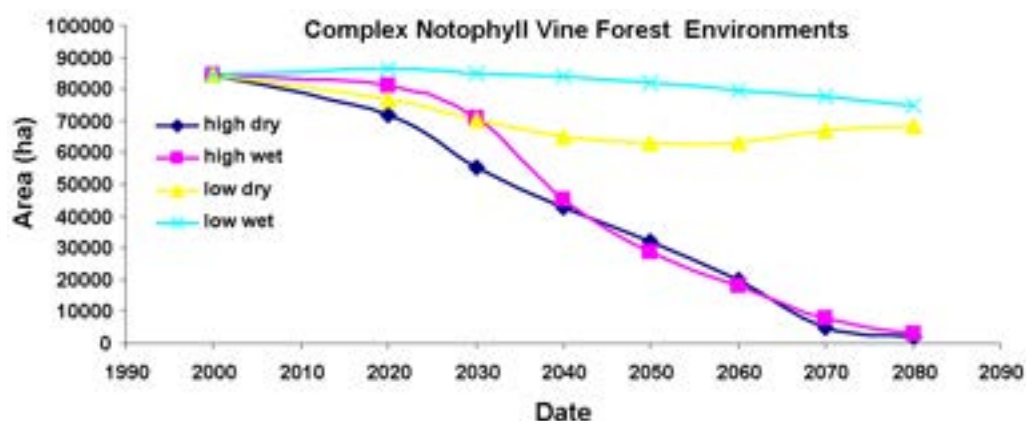


Figure 1. Area of environments suitable to Complex Notophyll Vine Forests from 2000 to 2080 in four scenarios.

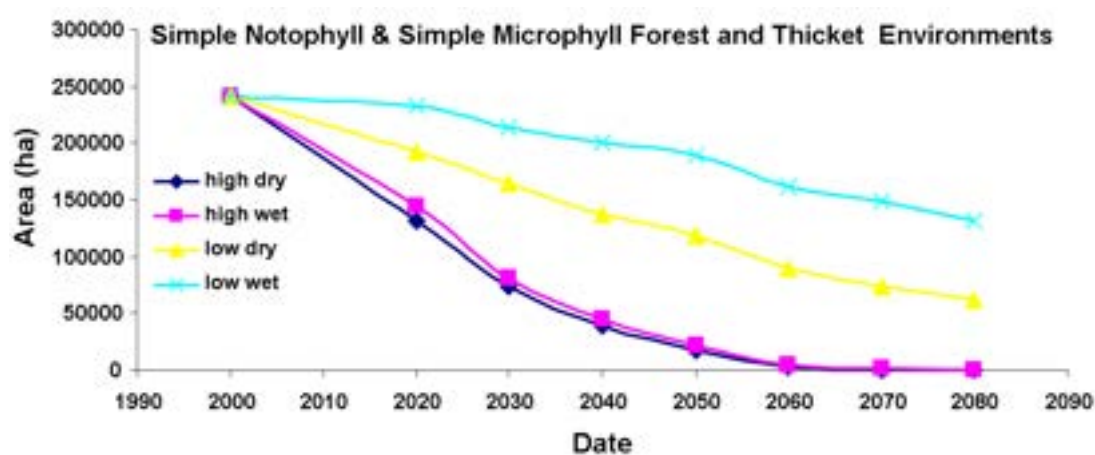


Figure 2. Area of environments suitable to highland rainforests from 2000 to 2080 in the four scenarios.

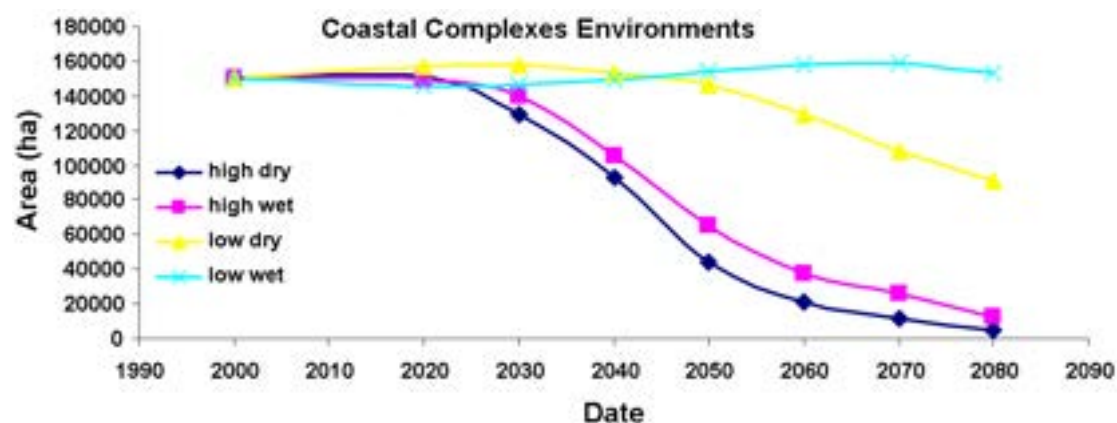


Figure 3. Area of environments suitable to Coastal Complexes from 2000 to 2080 in the four scenarios.

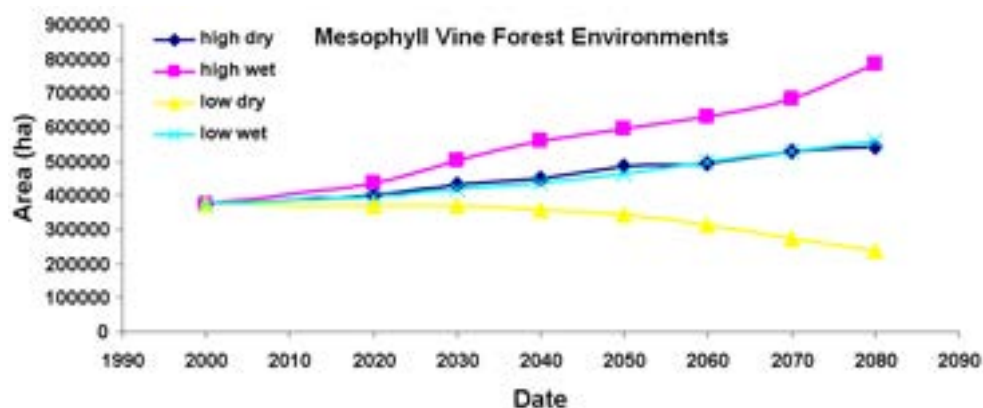


Figure 4. Area of environments suitable to Mesophyll Vine Forests from 2000 to 2080 in the four scenarios.

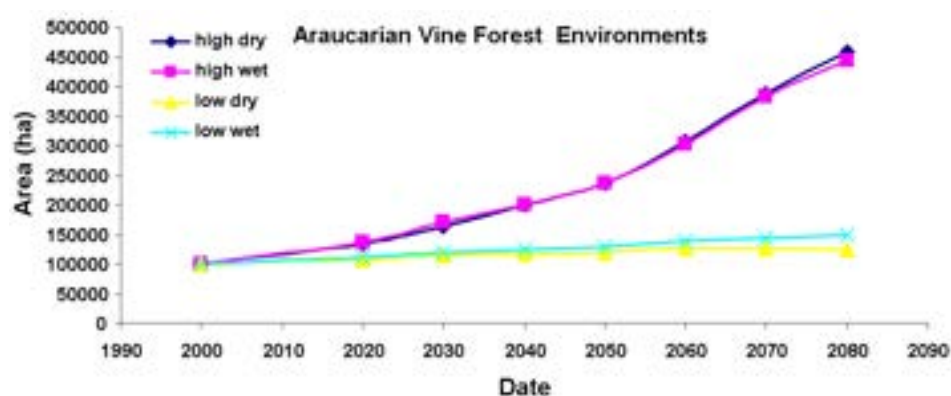


Figure 5. Area of environments suitable Araucarian Vine Forests from 2000 to 2080 in the four scenarios.

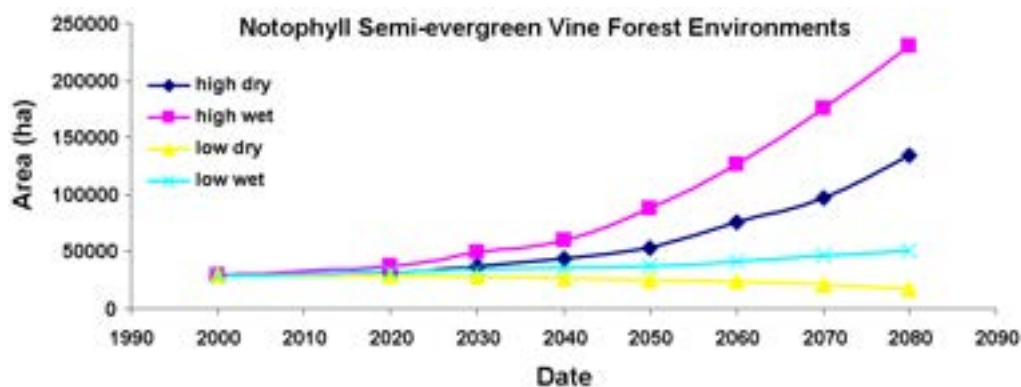


Figure 6. Area of environments suitable to Notophyll Semi-evergreen Vine Forests from 2000 to 2080 in the four scenarios.

This analysis indicates, given the currently expected warming in this century, that the region's forests will be in a substantial disequilibrium with their environment. All these figures are for areas of environments not forests *per se* and include areas within the bioregion that are now cleared.

Spatial changes in all the modelled forest environments in the central Wet Tropics are illustrated in Figure 7 using the high-dry climate scenario from the 2020 until 2080, excluding areas that are now cleared of native vegetation. The results using the observed bioclimatic variables over the past decades are presented as the year 2000.

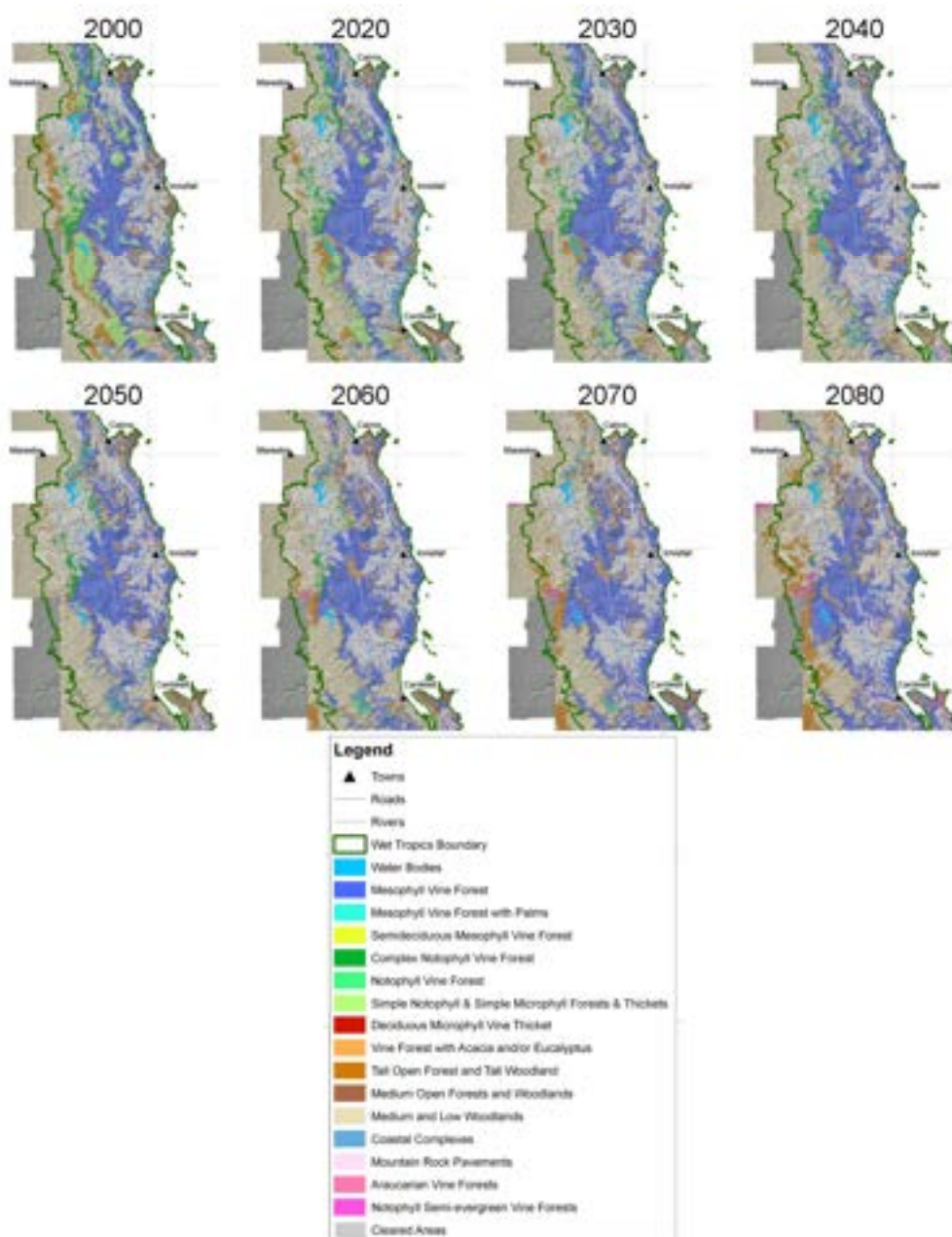


Figure 7. Area of environments suitable to all classes from 2000 to 2080 in the high-dry scenario.

This figure illustrates the complex spatial changes in forest environments that will occur under rapid climate change. Simple Notophyll and Simple Microphyll Forest and Thicket environments contract everywhere, initially replaced by Mesophyll Vine Forest or Tall open Forest environments. Coastal Complex environments are entirely replaced by Mesophyll Vine Forests by the middle of the century. Similarly, Tall Open Forest environments largely disappear by 2050 but then begin to increase along parts of the western margin of the

bioregion with Araucarian Vine Forest environments appearing for the first time in the central Wet Tropics. Complex Notophyll Vine Forest environments in the southern Atherton Tableland appear to be quite stable until mid-century after which they decline rapidly, replaced largely by Tall Open Forest environments.

Clearly these are large changes in the ecological environments of the bioregion that will stress existing forest communities and ecosystems. Unfortunately, it is not possible to say where and when actual changes in forest structure and plant species composition will occur with confidence.

2.2. Forest environmental refugia

The extent and spatial distribution of environments for the various forest types depend on the interaction among the regional climate, terrain features that determine the local climate and redistribution of water, the underlying soil parent material, and the ecological constraints particular to each vegetation class. As the regional climate changes, the potential forest environments change spatially but, primarily because of soil and landform features, some areas may remain suitable for a certain vegetation type despite rather large changes in regional climate. Climate change may have less impact on these parts of the landscape. For each decade of the high-dry climate change scenario, we calculated whether the environmental class at a location has remained unchanged since today's climate. If so, these areas can be considered to be refugia up to that decade. Or alternatively, up to the degree of climate change represented by the scenario at that time. These areas decline as climate change progresses. The following maps display this time series of refugia where browns indicate changes to another environmental class early in the century while greens indicate areas that are stable even under the much more severe climate change expected later. The results should be interpreted broadly without undue emphasis on the precise dates.

While Mesophyll Vine Forest environments expand in the high-dry climate scenario, the most important long-term refugia are mostly restricted to mid elevations in the central Wet Tropics (Figure 8). This rainforest environment has by far the largest refugial area compared to other rainforest environments. Refugia for Complex Notophyll Vine Forest environments are also concentrated in the central Wet Tropics in the southern Atherton Tablelands (Figure 9). However, the area of these refugia is very small. Not surprisingly, environments of Simple Notophyll and Simple Microphyll Forests and Thickets (Figure 10) are rapidly lost in the high-dry scenario and the only possible refugia are the summits of the two highest mountains, Bellenden Ker (1593 m) and Bartle Frere (1622 m). Two other important environments, Tall Open Forests and Coastal Complexes (Figures 11 and 12), with unique biodiversity values in the region, do not have refugia beyond mid-century in the high dry climate change scenario. Using this method, regional refugia are not likely to be important overall except for some areas of Mesophyll Vine Forest environments with large climate change as in the high-dry scenario. Local, fine-scale refugia may exist, however, that can not be identified with this method.

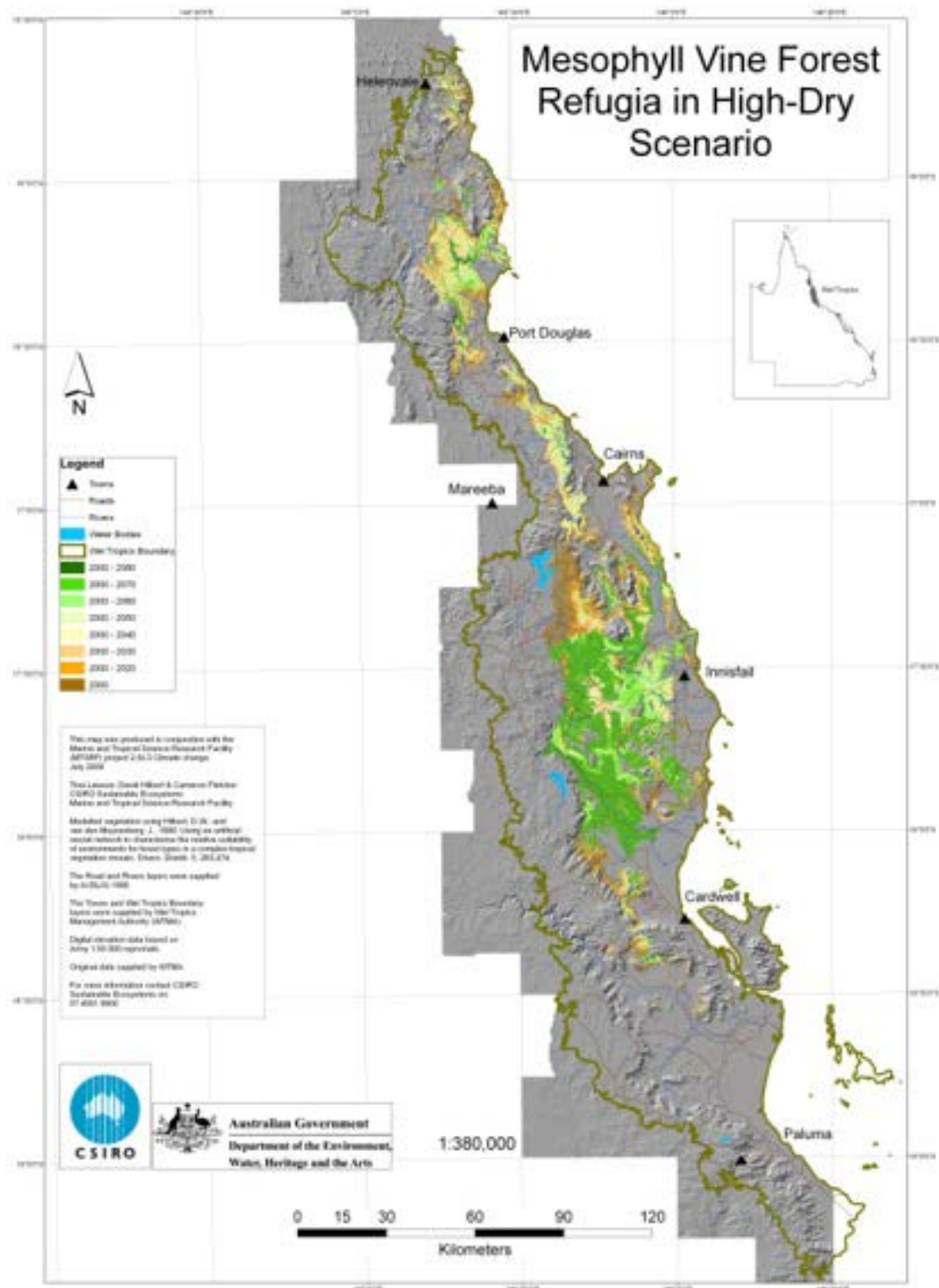


Figure 8. Mesophyll Vine Forest environmental refugia in the high-dry climate change scenario.

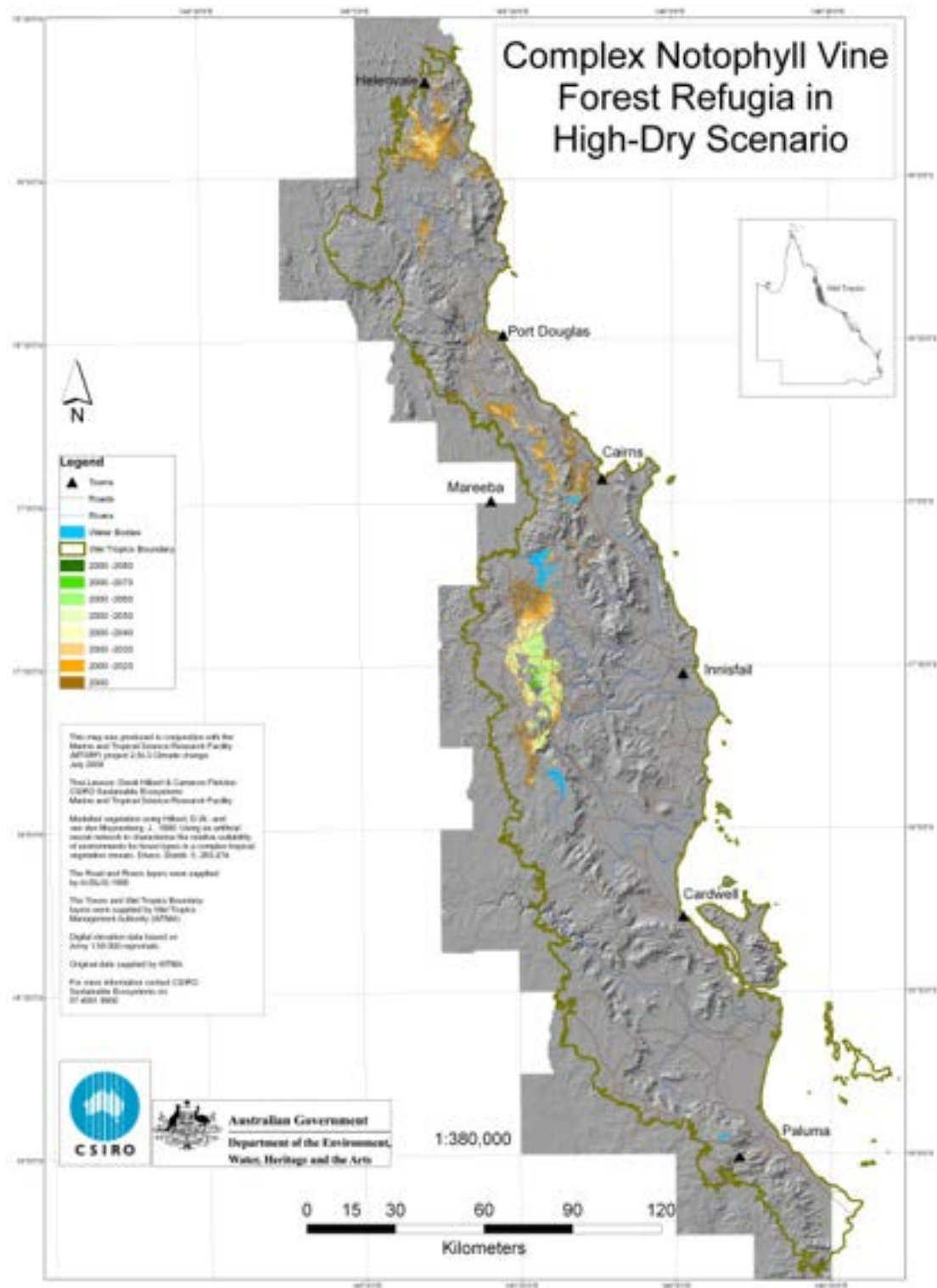


Figure 9. Complex Notophyll Vine Forest environmental refugia in the high-dry climate change scenario.

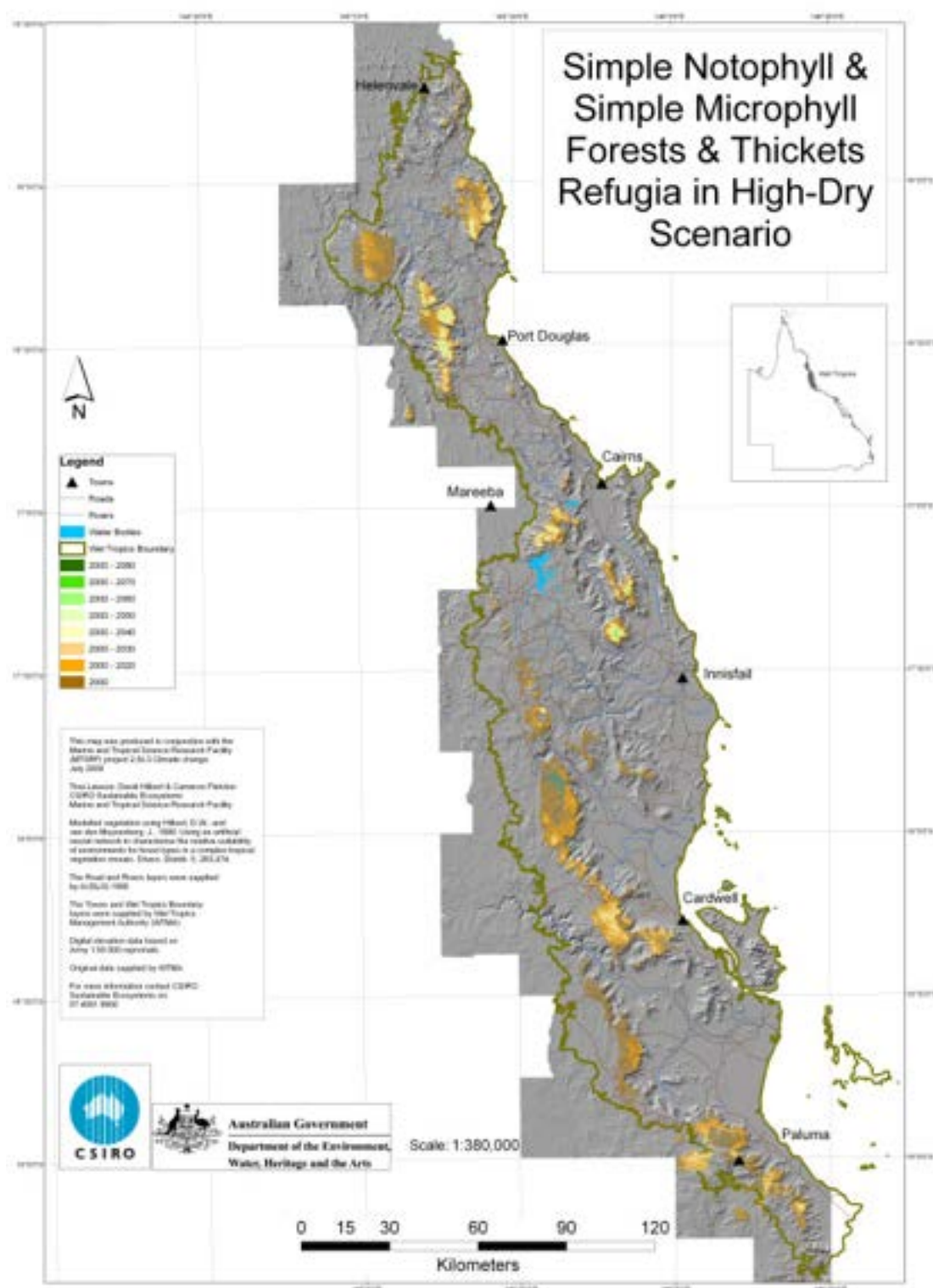


Figure 10. Simple Notophyll and Simple Microphyll Forest and Thicket refugia in the high-dry climate change scenario.

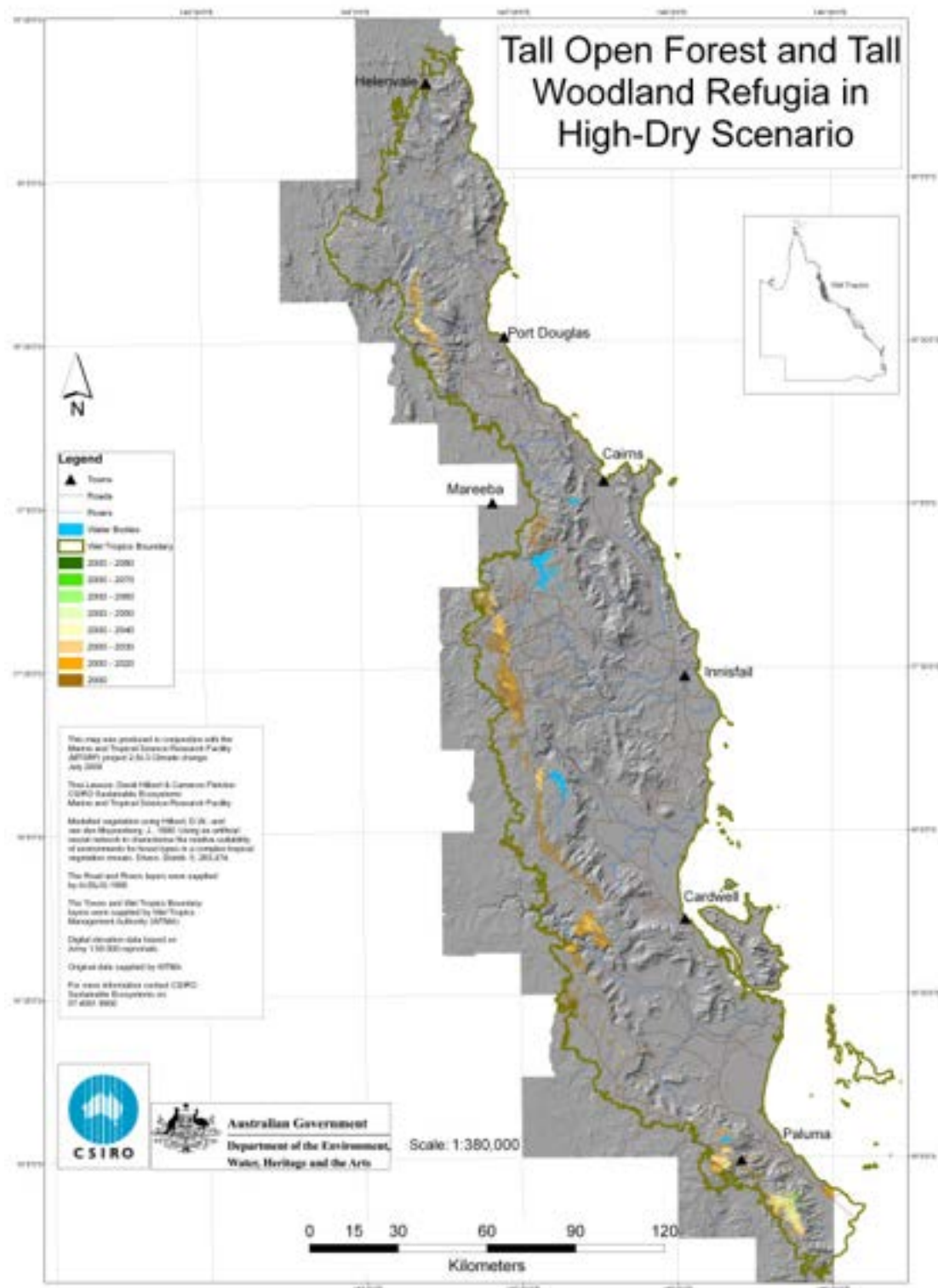


Figure 11. Tall Open Forest and Tall Woodland Refugia in the high-dry climate change scenario.

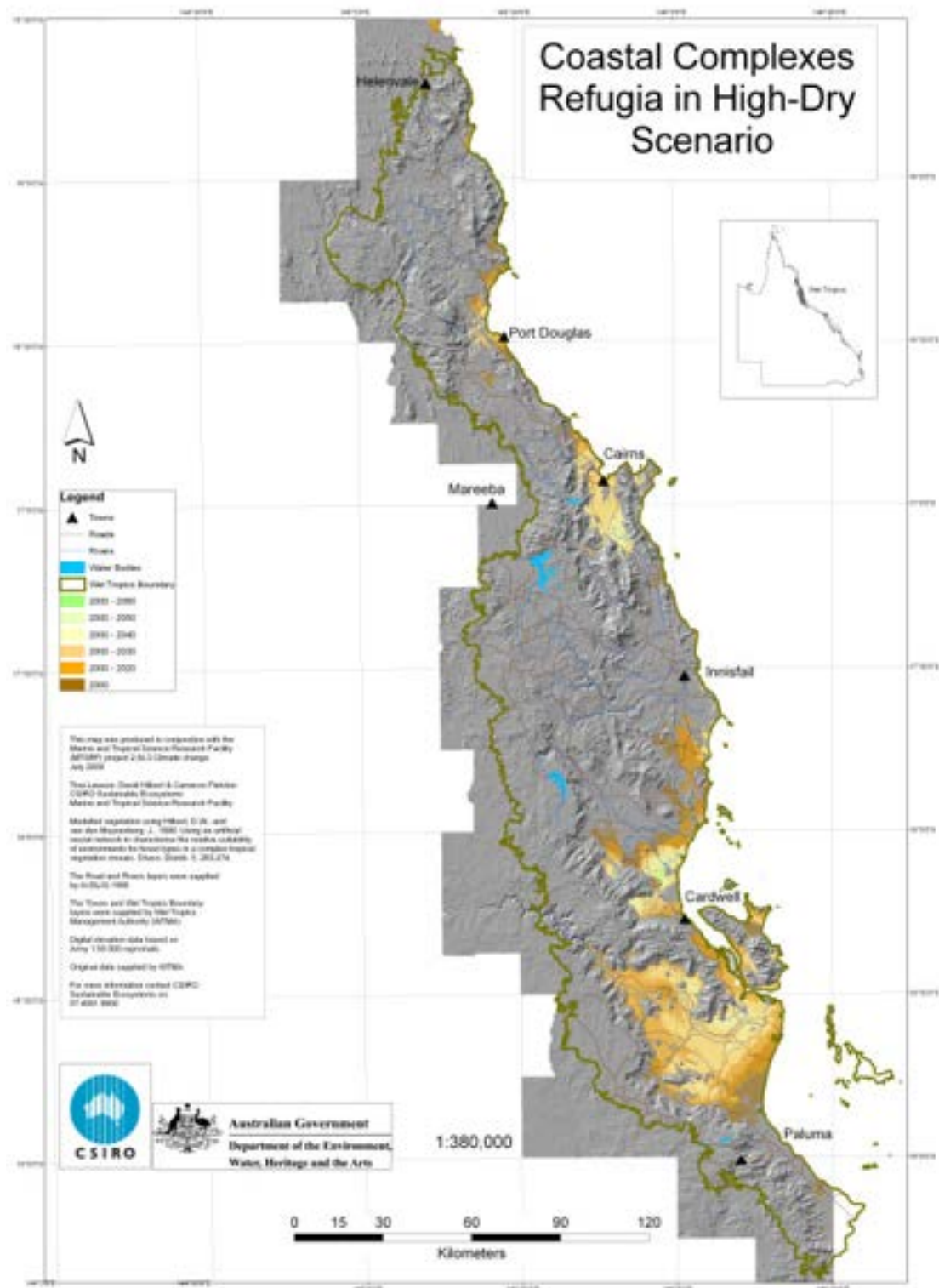


Figure 12. Coastal Complex Refugia in the high-dry climate change scenario.

These results show that the bioregion will experience severe changes in the distributions of its ecological environments such that very few forests in the Wet Tropics will experience conditions in the future that are characteristic of them today. Since the structure and physiognomy of the forest classes are largely controlled by these environments, this implies considerable environmental stress to the extant forests and that the abundance and survival of their biota will be strongly affected. In other words, the severe and rapid climate change that appears increasingly likely will create a large disequilibrium between the region's environments and the vegetation that has developed within them over thousands of years of comparatively stable climate. One can only speculate how this disequilibrium will change forest distributions in the Wet Tropics within this century because we know so little about the rates at which major changes in forest structure and composition can occur. However it is reasonable to infer that the health of these ecosystems will decline. For long-lived tree species, this stress may be difficult to detect because mature individuals can often survive in climatic conditions outside of those that are required for reproduction and tree communities display a large amount of inertia with slow rates of change.

3. Biodiversity and ecosystem processes are strongly correlated with mean annual temperature

Measurements carried out in the climate change monitoring plots established by this project inform projections of how warming may influence biodiversity patterns and ecosystem processes.

The project established an altitudinal transect of 12 permanent, climate-change monitoring plots to assess changes in forest structure and dynamics with climate, as influenced by elevation (Map 1). Each plot is approximately 100m in elevation from the next plot. Within each plot, which was surveyed and permanently marked, all trees >10cm diameter were recorded, given a unique identification tag and spot painted so that the diameters can be re-measured in the future. Surveys of all vascular plants were also carried out.

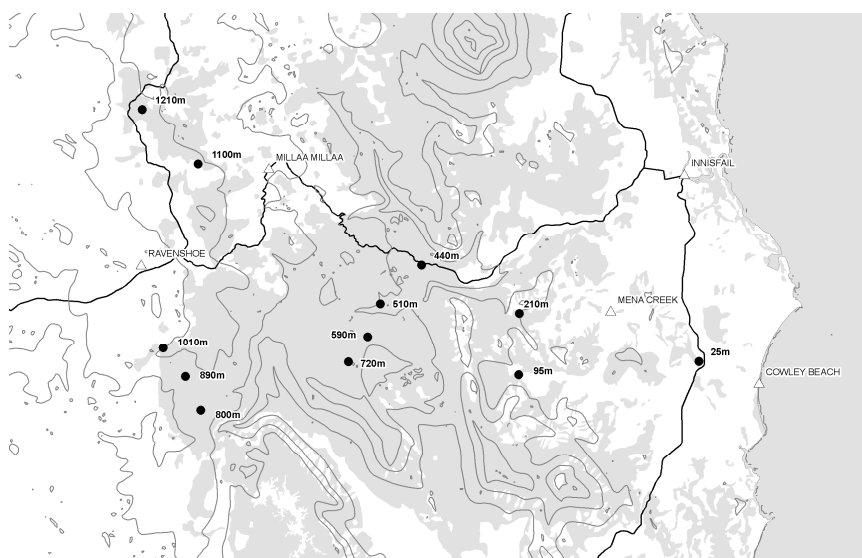


Figure 13. Locations and altitudes of the twelve, climate change forest monitoring plots. The grey area indicates rainforest.

3.1. Forest structure

This section provides a summary of the results of measuring twelve forest plots along an altitudinal gradient from near the coast to 1200 m in elevation. These plots were established as long-term climate monitoring plots in response to end-user requests for this kind of monitoring. All trees greater than 10 cm in diameter were measured and tagged for future measurement.

The statistically significant decline in forest basal area ($\text{m}^2 \text{ha}^{-1}$) in the project's twelve monitoring plots is presented in Figure 14. These local results are consistent with the project's extensive literature survey of basal area in relation to mean annual temperature throughout the tropics (Figure 15). These results strongly suggest that global warming will reduce the capacity of rainforest to stock carbon in the future.

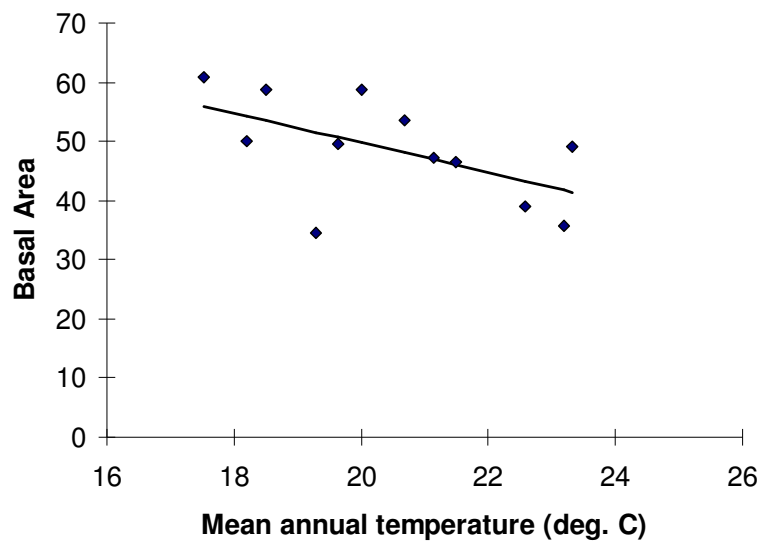


Figure 14. Basal area in relation to mean annual temperature ($^{\circ}\text{C}$) in the twelve plots.

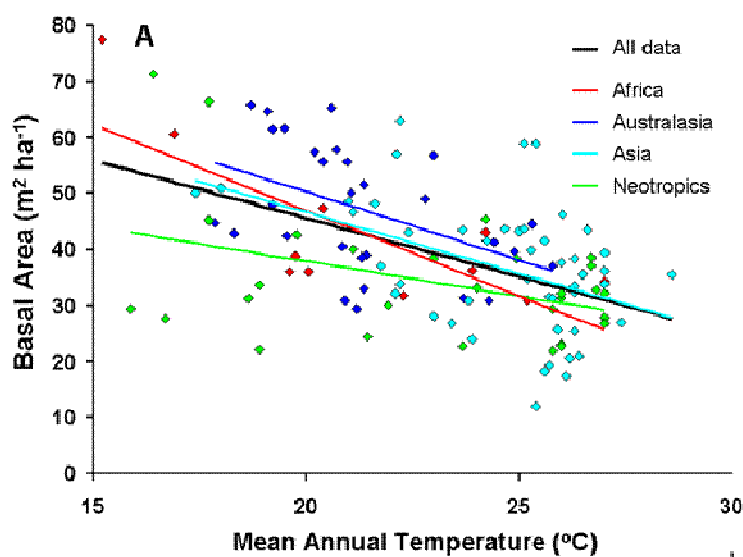


Figure 15. Pantropical pattern of declining basal area with increasing mean annual temperature.

3.2. Vascular plant diversity

In this transect, total vascular plant richness increases significantly with mean annual temperature (see Figure 16), although there is some variability. On the other hand, the number of tree species in a 0.10 ha plot is constant, approximately 40 species, across altitudes and mean annual temperatures (Figure 16). Considering either Australian or Wet Tropics endemic species, there is a clear pattern of increasing endemism with decreasing temperature that plateaus at around 20 °C or at approximately 600 to 700 m elevation in today's climate (Figure 17).

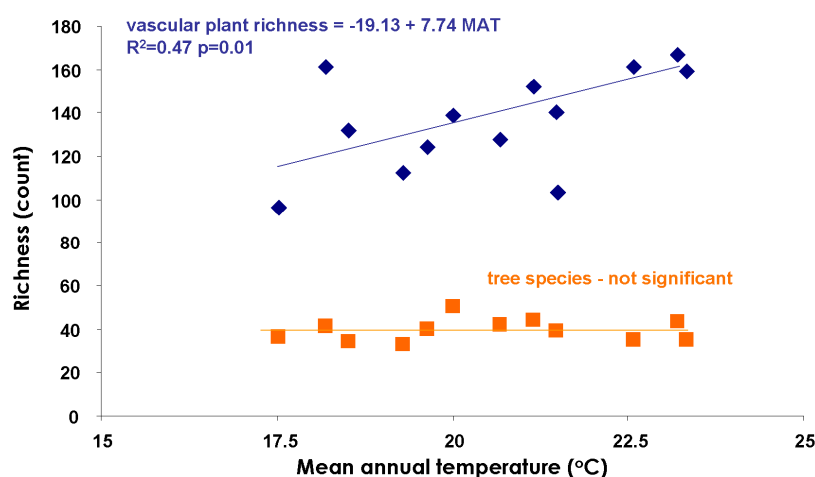


Figure 16. Counts of species (richness) in the twelve plots, related to the plots' estimated mean annual temperature.

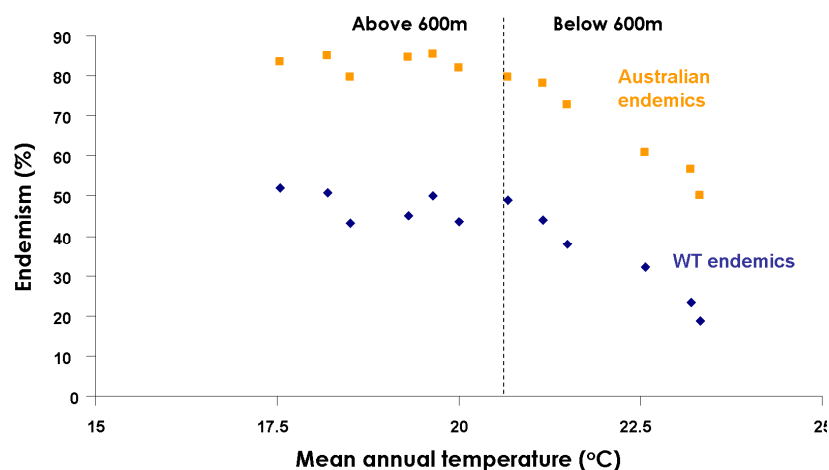


Figure 17. The percentage of species that are either Australian or Wet Tropics endemics in the twelve plots, related to the plots' estimated mean annual temperature.

These data suggest that while overall plant richness is positively correlated with mean annual temperature, global warming is a threat to upland and highland endemic species, now occurring above 600m.

3.3. Tree distributions by altitude

Using data from the twelve plots (Figure 18) it appears that few tree species (approximately 10%) are altitudinal generalists while many species may be restricted to narrow altitudinal ranges (200m which is equivalent to a 1 °C range of mean annual temperature). This pattern,

based on a small sample, needs to be further explored using the larger data sets that have been collected over many years by the Rainforest CRC and in other projects funded by MTSRF. This observation is significant, if supported by analyses of the larger data sets, because it suggests that many tree species will rapidly be exposed to mean annual temperatures that are beyond their normal tolerances. For example, a lowland tree species that is adapted to the range of mean annual temperatures of 23.0 to 24.0 (200m elevation range) may already be stressed by recent warming and would need to move upwards 1000 m by 2080 to exist in a similar temperature regime (see Table 1). For long lived trees in closed-forests, this rate of dispersal and establishment, if only over small geographic distances, seems unlikely to occur. In the case of lowland, warm-climate species we can not know their tolerances for higher temperatures since these do not occur in the region at present. So they may survive and flourish in the future at low altitudes even if they can not rapidly move upwards to follow rapid climate change. But the majority of tree species, especially the regional endemics, are adapted to cooler temperatures and are found only at mid to high elevations. For these species we have more confidence about their high temperature, lower elevation, limits. Like the lowland species, rapid climate change suggests the need to move upwards 1000 m by 2080 to remain in their observed climatic tolerances but with less uncertainty about their capacity to survive and reproduce at the warm extreme of their habitat.

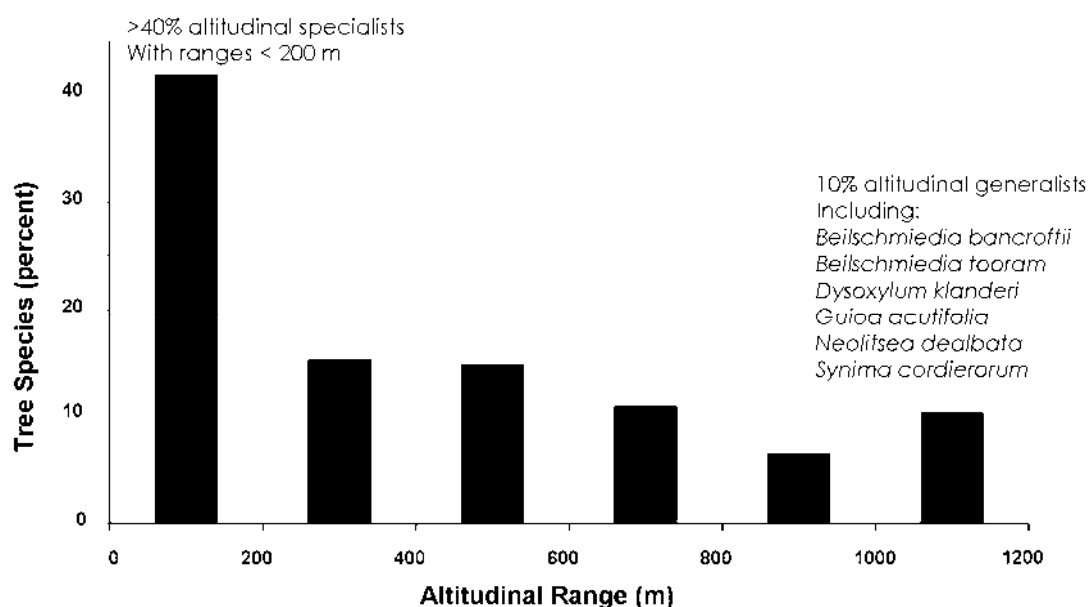


Figure 18. The percentage of tree species recorded in the twelve plots in relation to the altitudinal range at which they were observed. This can be converted to a climatic range from the lapse rate which is 0.5 °C per 100 m altitude.

3.4. Avian disease and its vectors

The majority of regional endemic vertebrates in the Wet Tropics (c. 70 species) are restricted to the cooler uplands and highlands and, based on bioclimatic analyses, all are threatened with rapid extinction if the region warms more than about 3.5 °C (Williams and Hilbert 2006). The golden bowerbird, is restricted to higher elevations and would likely become extinct if climate warmed by >3.0 °C (Hilbert et al. 2004). So, the current state of knowledge is that climate constrains many tropical species to high altitudes and global warming will rapidly lead to many extinctions. However, there are many uncertainties. For example, there is no known physiological or ecological reason for bird species' absence in the warmer, tropical lowlands. In the Wet Tropics, some bird species are altitudinal generalists (e.g., catbirds and

cassowaries) and are distributed from sea level to quite high altitudes. Consequently, the modelling results are controversial and partly mistrusted. Is it possible that climate per se is not the primary constraint on vertebrate distributions in the Wet Tropics and other mountainous, tropical regions? The conservation implications of this question are large – will many species be lost in a human generation? Other than climate change mitigation, is there anything we could do to save them? A preliminary hypothesis is that climate alone is not solely responsible for these patterns, implying that actions could be taken to reduce this threatened loss of biodiversity. These ideas motivated the project's preliminary studies of the arbovectors of and prevalence of avian haemoprotozoan diseases.

3.4.1. Mosquitoes

Mosquitoes, important vectors of wildlife and human diseases, were captured across the project's altitudinal transect at three heights relative to the forest canopy and in three seasons over three years. Both the abundance and diversity of mosquitoes increase with estimated mean annual temperature of the plots (Figures 19 and 20). These data represent the most extensive survey of rainforest mosquitoes in the Wet Tropics. Further research would be required to confirm that these patterns are primarily due to mean annual temperature. If they are temperature driven then global warming will clearly increase the diversity and abundance of disease vectors at all elevations.

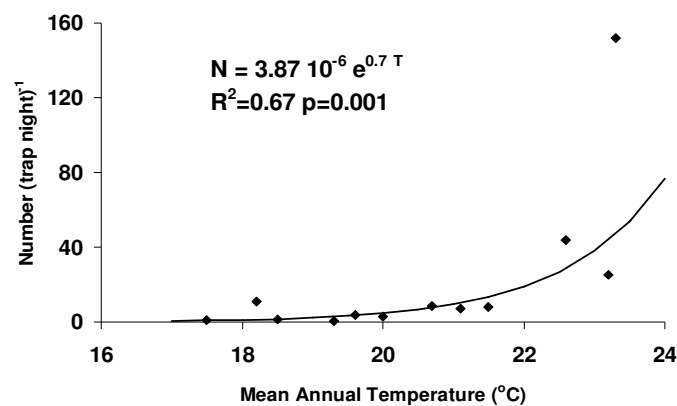


Figure 19. Regression of total mosquitoes captured per trap night (N) versus mean annual temperature (T)

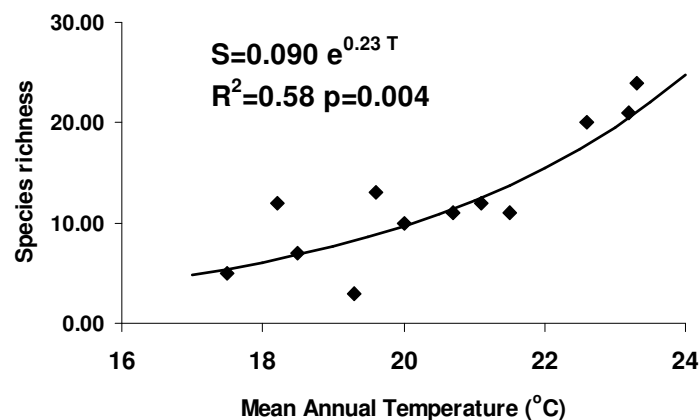


Figure 20. Regression of numbers of mosquitoes species captured (S) versus mean annual temperature (T)

3.4.2. Haemoproteus disease in birds

DNA was successfully extracted from blood samples of 614 birds captured across the project's altitudinal transect and amplified for PCR analysis to identify DNA from haemosporidia (*Plasmodium*, *Haemoproteus* and *Leucocytozoon*). *Plasmodium* spp. are transmitted by mosquitoes (Culicidae) while hippoboscids and ceratopogonid flies transmit *Haemoproteus* spp. and *Leucocytozoon* spp. are transmitted by simuliid flies. Infection by *Leucocytozoon* was rare in our samples.

Infection by *Haemoproteus* is much more common than by *Plasmodium* and peaks at intermediate temperatures (and elevation) while infection rates of avian malaria (*Plasmodium relictum*) are highest in the warmer sites and decline to an average of approximately three percent at mean annual temperatures below about 22.5 °C (Figure 21). For both of these blood parasites there appears to be a threshold at intermediate mean annual temperatures below which infection is less common. For *Plasmodium*, this may be due to the low abundance and diversity of mosquitoes in cooler climates (Figures 19 and 21). We recently identified *Plasmodium* using PCR techniques in the most common lowland mosquito that was captured, *Coquillettidia crassipes*. This genus was recently reported to be a vector of avian malaria in Africa (Njabo et al. 2009) but has not previously been implicated as a vector, to our knowledge, in Australia.

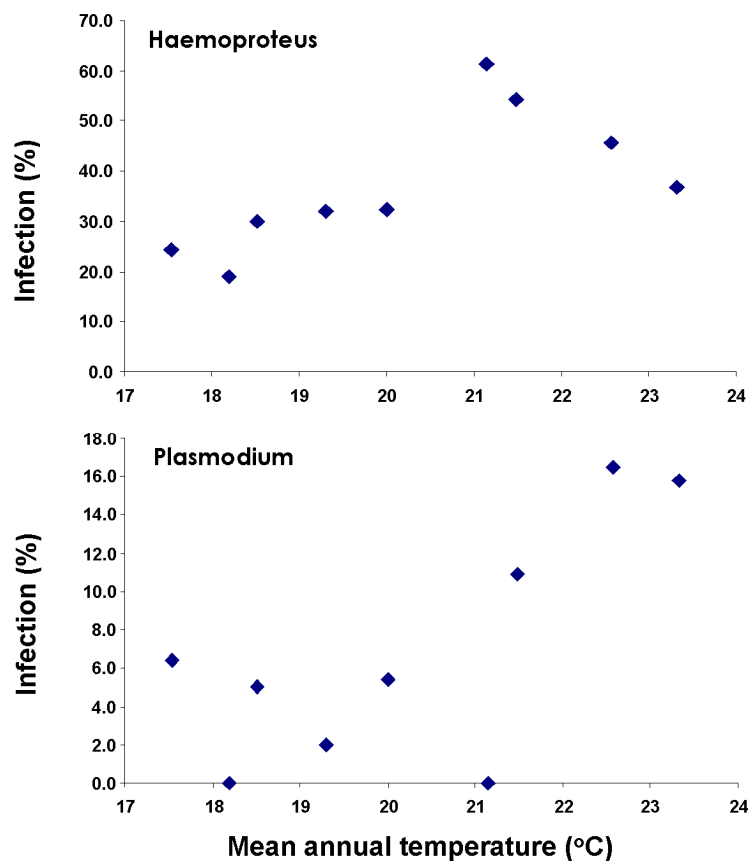


Figure 21. The percentage of birds captured in each plot that were infected by either *Haemoproteus* or *Plasmodium* based on PCR analyses of blood samples.

4. Discussion

Unfortunately, climate change is a significant threat to the long-term preservation of the biota in the Wet Tropics bioregion. Partly due to extensive clearing in the lowlands, most rainforest is now above 300m and almost all of the regionally endemic species are cool-adapted upland species above approximately 600m. Most of the regionally endemic rainforest vertebrates are distributed over areas with a very narrow range in annual mean temperatures and this research indicates that the same is true for plants. Consequently, the biodiversity and regionally endemic species that are key elements in the heritage values of the Wet Tropics World Heritage Area will be under severe threat over the next decades.

The analyses presented here demonstrate, once again, the great sensitivity of rainforests and their biota to climate change and suggest that it is imperative that we understand ecological patterns and processes over large spatial and temporal scales in the region and further develop predictive tools to enable realistic conservation planning for the continued preservation of the unique biota and ecosystems of the Wet Tropics and other rainforests in Queensland. Detecting stress and change in forests is challenging because of the long life spans of tree species, their ability to survive in environments where they can not reproduce and the slow rates of community change in the absence of severe disturbance. Consequently, managers could easily be deceived by superficially unchanging forests into assuming that climate change is having little or no impact. Monitoring strategies need be developed and employed that overcome this difficulty.

The unprecedented degree and rapidity of ecological change that are implied by the data and analyses and data in this report, assuming largely unmitigated climate change, suggests that conservation policies and management approaches will need to rapidly change and adapt to climate change. It looks increasingly likely that conservation policies and management that have long focused on preservation of a presumed static biodiversity-landscape will not be sufficient in the coming decades because of the unprecedented extent and rate of ecological change driven by changing climate. Of course the current policies and management that are aimed at reducing threats due to invasive species, linear corridors and land clearing, for example, need to be supported and intensified in the face of climate change. But it may be necessary, to conserve as much as possible of the region's biodiversity values, to go beyond the current more or less static paradigm and to consider management of rapid, unavoidable change in the near future. This may involve long-distance translocation of species, proactive fire management policies and other actions that would not be considered if it were not for the rapid ecological changes that this report and others suggest are likely.

The research summarised here is not sufficient to define an active management program that will preserve the biodiversity or heritage values of the Wet Tropics. But it does, along with other climate-change impacts research in the region, suggest that ecological change will be very rapid and, consequently, that conservation policies and management will need to become much more proactive. This will require a large change in perceptions and expectations by management agencies and the many stakeholders.

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