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LOWLAND RAINFOREST STRUCTURAL VEGETATION COMMUNITIES OF NORTHEASTERN AUSTRALIA: SPATIAL RESPONSE TO PREDICTED CLIMATE CHANGE

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Abstract: The Wet Tropics Bioregion (WETB) is situated along the tropical northeastern coast of Queensland, Australia. Of the two million hectare bioregion, 45% is listed as World Heritage Area. The bioregion is mainly comprised of rugged mountains, with an extensive plateau area along the western margin and low-lying coastal plains on the east. Vegetation within the WETB is mostly rainforest, but includes mangrove forests, wet sclerophyll forests and tall open forests. The WETB comprises nine subregions (Sattler and Williams, 1999), including the Innisfail Lowlands subregion which comprises 10% (202,000 hectares) of the WETB area (Fig. 1). The subregion extends in a narrow band between 145^{o}50' and 146^{o}10'E (2-38 km wide) and 16^{o}45' and 18^{o}00'S (about 145 km long) along the Wet Tropics coast from the Tully River in the south to Palm Cove, 25 km north of Cairns. The lowlands are mainly of low relief (0 – 300 m) and, consequently, exhibit little spatial variation in mean annual temperature (23.5º C – 24.75º C). Mean annual rainfall of 2000 – 4500 mm is highest at the foot of the Bellenden Ker Range and decreases rapidly to the northwest of the ranges and more gradually to the south. As the subregion has rich soils and high rainfall, it has been progressively developed for agriculture, mainly sugar production, since the 1880s. The majority of the clearing for sugar cane cultivation had been completed prior to 1940, with 43.4% of the subregion's natural vegetation remaining in 2005 (Accad et al., 2008a).

Although climate change affects individual species within vegetation communities in different ways and may lead to changing species composition in those communities, structural characteristics of vegetation communities vary systematically in response to climate. Furthermore, different structural vegetation communities will provide varied moderation of the effect of climate change on the same species. In this paper we investigate the potential changes in distribution of the structural rainforest communities of the Innisfail Lowlands subregion of northeastern Australia in response to climate changes predicted for the region. Predictions of increasing temperatures have a relatively high certainty, while changes in rainfall are less certain due to the complexity of the El Nino-Southern Oscillation. Exploratory data analysis (EDA) techniques and model-building procedures are applied using Generalised Linear Modelling (GLM) and Generalised Additive Modelling (GAM) methods. The effects of climate change on the distribution of suitable habitat for each rainforest structural type are modelled. Our results show that even small climatic changes are likely to have substantial and markedly different effects on the various vegetation communities of the Innisfail Lowlands subregion. These results can assist in biodiversity management and planning by identifying areas of each vegetation community that are least affected by climate change and thus are potential refugia. The modelling can also identify previously cleared areas which have the potential to support rainforest communities threatened elsewhere by changes in climate. Strategic regeneration and subsequent management should be considered for those areas.

Keywords: *Vegetation community mapping; Modelling; Generalised Linear Modelling (GLM); Generalised Additive Modelling (GAM); Climate change; Composite prediction map.*

1.INTRODUCTION

Climate change is projected to have wide ranging effects on biodiversity, including large scale impacts on the distributions of species (Parmesan, 2006). The Earth's mean surface temperature is projected to warm 1.4 to 5.8^{o}C by the end of the 21st century. In general, precipitation is predicted to increase in high-latitude and equatorial areas and decrease in the subtropics, with an increase in high intensity precipitation events (IPCC, 2007). A probable effect of projected climate change is that, where possible, the habitats of many species will shift to higher latitudes and elevations than their current locations. Vegetation classification is primarily based on structure, physiognomic and floristic composition (Adam, 1994). Rainforest communities in tropical forests often have more than 100 species per hectare and individual species co-occur in different rainforest communities. The species composition of vegetation communities is expected to alter under climate change (IPCC, 2007) whereas the structural characteristics of vegetation communities are likely to vary systematically in response to changing climate. For example, in the Wet Tropics region of northern Australia the structural groupings defined by Tracey and Webb (1975) have been shown to reflect environmental constraints (Hilbert et al., 2001) and thus remain meaningful in relation to past and future climates. Statistical models have been used to investigate vegetation communities' responses to variation in climate by, for example, Mackey (1993), Hilbert et al. (2001) and Accad et al. (2008b) in Australia and Franklin (1995, 1998) in California. Similarly, models were applied to determine climate change effects on past and future vegetation community distributions in the Wet Tropics (Hilbert et al., 2001; 2007). Preston et al. (2008) emphasised the importance of biotic interactions in modelling habitat for future climates and, therefore, constrained their models using structural vegetation communities. In this paper we investigate the potential changes in distribution of the structural rainforest vegetation communities of the Innisfail Lowlands subregion of the Wet Tropics bioregion of northeastern Australia, in response to climate changes predicted for the region. Climate is one of the primary determinants of biotic and abiotic environmental responses in the Wet Tropics region (Mackey, 1993; Turton et al., 1999). Turton et al. (1999) developed fine-scale rainfall surfaces to help understand and forecast the rainfall regimes determining the vegetation distribution patterns. These climate forecasts, coupled with vegetation modelling, allow vegetation predictive mapping to be applied to both remnant and cleared areas to infer past and future vegetation distributions (Hilbert et al., 2001; Accad & Neil, 2006). The CSIRO Marine and Tropical Sciences Research facility (Suppiah et al., 2008) regional climate model provides more detailed information and better represents the influence of mountains. For a medium emission scenario, the best estimate (50th percentile) regional average temperature increase is 0.8°C (with a range of uncertainty from 0.6 to 1.1°C) by 2030, an increase of 1.3°C (0.7 to 2.2 °C) by 2050, and an increase of 1.9°C (0.9 to 3.5°C) by 2070. Regional projections of precipitation change are for -1% (-8 to +6%) by 2030, -2% (-16 to +11%) by 2050 and -3% (-26 to +18%) by 2070 (Suppiah et al., 2008). We demonstrate the responsiveness of several of the lowland rainforest structural communities' habitat suitability to even small climate changes. The results identify areas for which there is greater than 50% probability that they can support each of the rainforest communities modelled under each of the climate change scenarios. Outlier upland rainforest communities such as type 6 Notophyll forest and non-rainforest communities are excluded from the analysis. It is assumed that, in the absence of disturbance factors (e.g. fire), rainforest communities will occupy the areas modelled to be capable of supporting them. The analysis investigates the effect of two climate change scenarios on the spatial distribution of each rainforest vegetation community's habitat (Accad et al. 2008b). Using these habitat distribution patterns, a composite rainforest vegetation community predicted distribution map is compiled. The composite rainforest maps indicate the likely distribution of the various structural rainforest communities as they collectively respond to climate change. Importantly, potential rainforest distributions under current climate and changed climate scenarios are modelled for both remnant and cleared areas. This discrimination of remnant and cleared areas in the modelling allows the identification of sites within cleared areas which may be important to otherwise

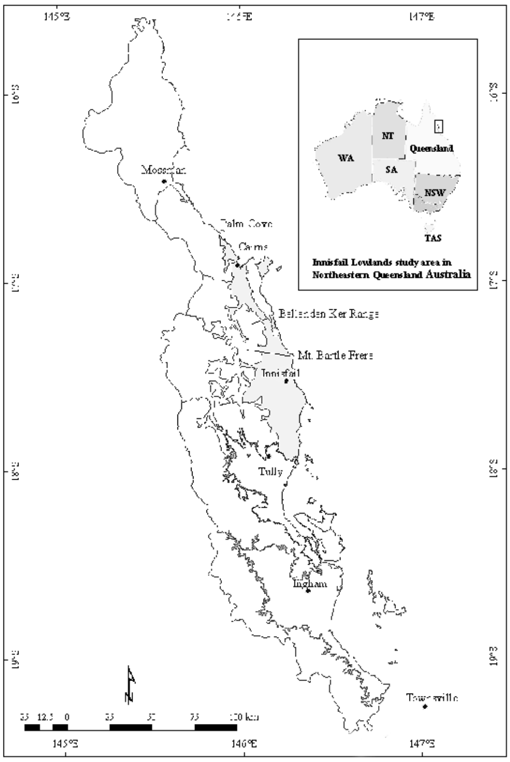

Figure 1: Wet Tropics Bioregion and Innisfail Lowlands Subregion

endangered remnant communities and provides a basis for conservation management across the region, irrespective of current land use. Hereinafter, vegetation communities refers to the structural vegetation communities as defined for the region by Tracey and Webb (1975).

2. METHODS

The modelling used herein (Fig. 2) is based on the integration of an ecological model, a data model and a statistical model (Austin 2002; Accad & Neil, 2006), each of which is outlined below.

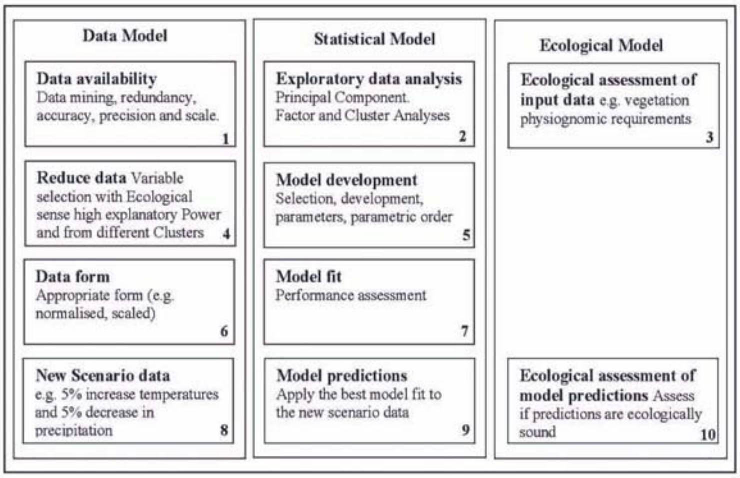

Figure 2: Integration of the data, statistical and ecological models.

2.1. Ecological model

Predictions of the distributions of plant species and communities, using associated environmental gradients and predictive models, can be developed using correlative multivariate statistical techniques. To be useful, these models need to be based on well-established ecological relationships, and be consistent with the statistical assumptions of the analysis. An ecological model (Fig. 3) of the Innisfail Lowlands subregion was developed from Goosem et al. (1996) modification of Tracey (1982). It describes the abiotic relationships between the structural rainforest communities occurring in the subregion (Accad & Neil, 2006). The Tracey (1982) structural classes reflect environmental constraints and, therefore, those classes remain meaningful when applied to past and future climates. Rainforest communities in tropical forests often have more than 100 species per hectare and individual species co-occur in different rainforest communities. Therefore, as an alternative to floristic (species-based) modelling, this analysis uses a structural community distribution modelling approach.

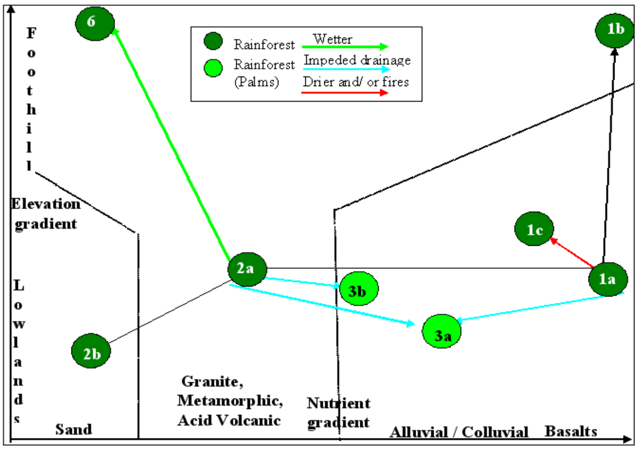

Figure 3: Ecological model for the Innisfail Lowlands rainforest structural communities.

2.2. The statistical model

In this study, the statistical model consists of four main components: sampling strategy; variable selection and reduction; predictive modelling of relationships between independent variables and vegetation community distribution; and model validation and performance and error assessment. Stratified random samples of the mapped remnant areas of each community were selected for that community, representing 'presence' sites. In addition, for each community a random sample from the other remnant communities was selected, representing 'absence' sites (Accad & Neil, 2006). A preliminary assessment of the input variables and their interaction was applied for each individual vegetation community using univariate, bivariate and multivariate statistics. Histograms were used to assess the form for each variable (e.g. normalised, log/log) was followed by principal components, power (Cairns, 2001) and cluster (Gordon, 1981) analyses which determined which variables have the highest predictive power (PCA and power analyses) and which are redundant (variable cluster analysis). These variables were presented for further data reduction using stepGAM (Venables & Ripley, 1999). The remaining variables were introduced to the statistical model (GLM) and used to generate the model fit. In previous research, various statistical models have been applied to the problem of vegetation mapping and Generalised Linear Models (GLM) and Generalised Additive Models (GAM) have been shown to be effective (Franklin, 1995; Guisan and Zimmermann, 2000; Elith et al., 2006; Austin, 2007). These methods (GLM and GAM) were applied to model the effect of climate change on the rainforest vegetation communities of the Innisfail Lowlands. The model fit uses the GLM statistical method with the logit link. The models were developed and evaluated using Receiver Operator Curve (ROC) diagnostics, Cross Validation Prediction (COR) coefficients (Lehmann et al., 2004) and Akaike

Information Criterion (Akaike, 1973). Model Robustness was assessed against CART model outputs (Accad & Neil, 2006) and evaluated within remnant areas to determine uncertainties.

2.3. The data model and application of climate change scenarios

The independent variables assessed in the data model are derived from the climatic (35 variables), soil (16 variables) and topographic (7 variables) characteristics of the study area The modelling integrates variables at their natural scales of variability, i.e. at a broad scale for climate variables and at a fine scale for soil nutrient and topographic variables (Accad & Neil, 2006). To assess the effect of climate change on the rainforest vegetation communities, modelled current climate (CC) distributions were compared with modelled distributions under two climate change scenarios within the bounds of the predictions of Suppiah et al., 2008. These are: Scenario A - an increase of 5% relative to CC temperature and decrease by 5% relative to CC precipitation (with mean annual temperature in the study area in the range 23.5-24.75^{o}C this represents a temperature increase around 1.2^{o}C and with mean annual rainfall in the range 2000-4500 mm, a precipitation decrease ranging from 100 to 225 mm); and Scenario B - an increase of 10% relative to CC temperature (a temperature increase of about 2.4^{o}C) and decrease by 10% relative to CC precipitation (a precipitation decrease ranging from 200 to 450 mm). The evaluation of the effect of climate change on each rainforest vegetation community of the Innisfail Lowlands is applied as maps of probability of occurrence for each community type. Composite rainforest vegetation community maps were generated using a similar process to the composite map generation of Accad & Neil (2006) where a vegetation community is assigned to an area if it has the highest probability (suitability) for that area. A cellular automata model (Ostendorf et al., 2001) that imposes spatial constraints on the transition to the best-suited vegetation community type is applied. In this study the application of the constraint was only relevant in areas where low soil nutrient levels previously excluded Complex Mesophyll Vine forest (CMVF, type 1a). In these areas, the next most suitable vegetation community type was assigned.

3. RESULTS

This section outlines the statistical results and the composite rainforest vegetation community distribution. To model CMVF (type 1a) the 58 variables were reduced to the 11 variables required, including four precipitation variables (annual precipitation, precipitation of wettest period and precipitation of wettest and driest quarter), two temperature variables (max temperature of warmest period and temperature annual range), three soil variables (clay in B horizon, soil nutrients, water capacity) and one topographic variable (Distance from the coast). The CMVF (type 1a) model was complex and introduced five variables at 3rd, five at 2nd, and one at 1st parametric order levels. The model for MVF (type 2a) was simpler with only eight variables (five precipitation, one temperature and two soils) presented to the model, three variables at 3rd and five at 2nd order parametric level. The MVF (type 2a) model introduced similar precipitation variables substituting precipitation seasonality and precipitation of warmest quarter for precipitation of driest quarter in CMVF type 1a. The MVF (type 2a) model substitutes BC6 and required only soil nutrients and water capacity variables for soil input and no topographic variable was required. All models were robust (very high ROC coefficients (> 0.97)) and stable COR coefficients (> 0.84)). Current climate GLM models are highly correlated with CART models, reflecting the low standard errors and high percentage of remnant area predicted (Accad & Neil, 2006). The distribution of Innisfail Lowlands rainforest communities under the two climate change scenarios were compared with the distribution under current climate conditions using composite rainforest distribution map. These maps illustrate the distribution of the rainforest community with the highest probability of occurrence at a given location under current climate and under climate change Scenarios A and B. Under Scenario A, CMVF type 1a habitat is predicted to increase by 72% within existing remnant areas (Figs. 4 and 5), with a slight decrease in the potential distribution in cleared areas. Under

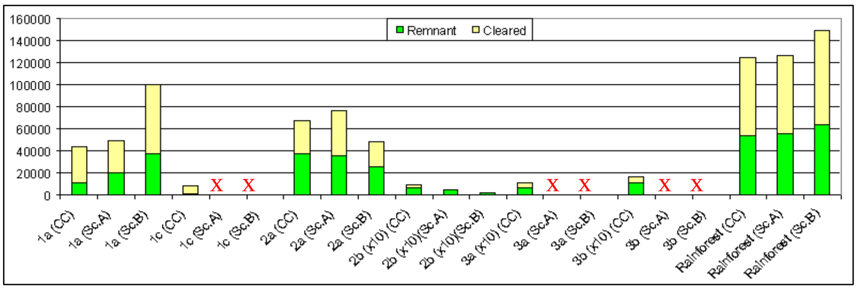

Figure 4: Predicted composite rainforest vegetation communities of the Innisfail Lowlands subregion. Assessment of potential rainforest vegetation distribution area under current climate conditions using GLM statistical modelling methods, and the effect on distribution of two likely climate change scenarios; CC = current climate; Sc. A = Scenario A; Sc. B = Scenario B; x – indicates prediction of local extinction in the Innisfail Lowlands subregion.

Scenario A, CMVF type 1a habitat is predicted to increase by 72% within existing remnant areas (Figs. 4 and 5), with a slight decrease in the potential distribution in cleared areas. Under Scenario B, type 1a is predicted to increase by 229% and 92% in remnant and cleared areas, respectively. Thus, under all three conditions (current climate, Scenario A, Scenario B) a greater proportion of the potential type 1a distribution lies within cleared areas than in existing remnants. Current climate remnant area of CMVF type 1c is 11.3% of the total pre-clearing area, however, under climate change Scenarios A and B, local extinction of this community is predicted irrespective of clearing (Figs. 4 and 5). Under Scenario A, MVF type 2a habitat decreases relative to current climate distributions by 3,000 ha (-8%) over remnant areas and increases by 12,300 ha (42%) over cleared areas (Figs. 4 and 5). By contrast, under Scenario B, type 2a shows a substantial decrease in area over both remnant (-33%) and cleared (-22%) areas, relative to current climate distributions. Under Scenario B the area of type 2b is only a third of what it could have been in the absence of clearing. The modelling results suggest that type 2b is largely replaced by the CMVF forest type 1a. MVF type 2b decreases by 1,000ha (-16.5%) and 3,700ha (-60%) over remnant areas under Scenarios A and B, respectively. Over cleared areas, less than 2% and 0.5% of current climate suitable habitat is predicted to remain under Scenarios A and B, respectively (Figs. 4 and 5). The modelling indicates that the remnant area of both MVF with dominant palms types 3a and 3b under current climate conditions is approximately 60% of the pre-clearing area. Projected climate change Scenarios A and B both result in local extinctions to both of these communities, irrespective of the potential contribution of cleared areas. The total modelled rainforest area within the Innisfail Lowlands under current climate conditions is about 124,000 ha, of which only about 43% lies within existing remnant areas. The remainder has been lost due to clearing. Although some of the rainforest vegetation communities are predicted to decrease relative to their current climate distribution, others are predicted to increase such that the total area that can support lowland rainforest is predicted to increase. All areas capable of supporting rainforest communities under current climate conditions are also predicted to be capable of supporting rainforest (of the same or other types) under both climate change scenarios. The rainforest area in existing remnant vegetation areas is predicted to increase by 4% and 19.5% under climate change Scenarios A and B, respectively (Fig. 5). Similar increases in the potential habitat area of rainforest are modelled for the presently cleared areas.

4. DISCUSSION

Our results show that climate change is expected to affect the various rainforest communities in different ways. Even structurally similar communities may be differently affected. For example, the area that can support CMVF (type 1a) vegetation community will increase in size while the area that can support CMVF (type 1c) vegetation community will decrease relative to current climate distributions. Similarly, the areas that support MVF (type 2a) will increase while the areas that support MVF (type 2b) will decrease relative to current climate distribution areas. The decrease in the area that can support the MVF dominated by palms (types 3a and 3b) will reduce these vegetation communities to local extinction. A large proportion of MVF with dominant palms (types 3a and 3b) in the Wet Tropics Bioregion is in the Innisfail Lowlands (65% and 45%, respectively), and 13% of the WETBs CMVF type 1c lies in the Innisfail Lowlands (Accad et al., 2008a). These three communities (3a, 3b and 1c) are typically coastal lowland communities and the local extinction of these communities in response to climate change, as predicted in this study for the Innisfail Lowlands subregion, may be indicative of the effect of climate change on these communities in the other coastal subregions of the Wet Tropics Bioregion. This outcome is of considerable significance in the context of biodiversity conservation in the region. Under Scenario A, the model predicts that CMVF (type 1a) and MVF (type 2a) will expand and replace the wetter habitat communities. Thus, those communities with the greatest extent under current climate conditions are predicted to expand. Importantly, those communities with the smallest spatial extent are likely to decrease in area (type 2b) or become extinct at the subregional scale (types 1c, 3a, 3b). It is also important to note that, in the mosaic of rainforest communities, Scenario A community distributions may not simply be a waypoint on a trajectory to Scenario B distributions. On the contrary, communities apparently advantaged by Scenario A climate may suffer a reduction in area if the climate changes further towards Scenario B, for example MVF type 2a (Fig. 4). Under Scenario B, individual community models predict very similar areas (just over 130,000 ha) for CMVF type 1a and MVF type 2a. However, the composite model results in large areas of type 2a on low nutrient soils being overridden by type 1a which is modelled as marginally more suitable than type 2a in these areas, despite the fact that type 1a does not presently occur on low fertility soils (Tracey 1982; Stanton and Stanton 2005). Application of the cellular automata spatial constraint replaces the CMVF type 1a on these less fertile soils with MVF type 2a which has a high probability of occurrence in these areas (similar to 1a) and is known to occur on the less fertile soils. This analysis has simplified the possible effects of climate change, accounting only for changes in temperature and precipitation. The Innisfail Lowlands, as other low lying coastal areas, are likely be influenced by other climate change factors, such as sea level rise, which will also affect vegetation

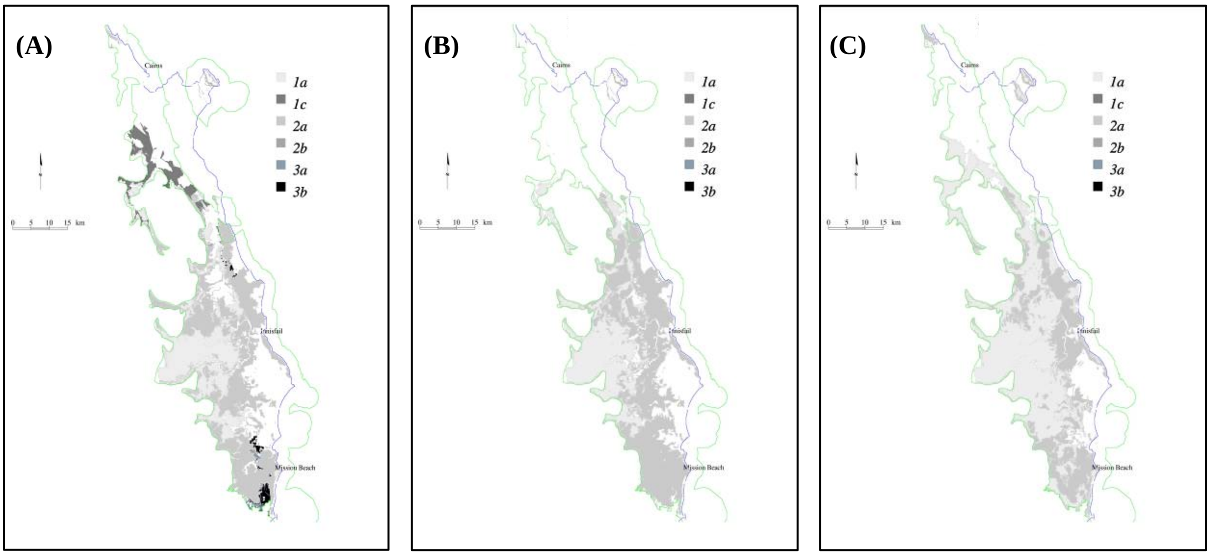

Figure 5: Modelled distribution of rainforest vegetation communities in the Innisfail Lowlands: A - Modelled current climate distribution; B - Scenario A distribution; C - Scenario B distribution.

distributions (IPCC, 2007). The effect of coastal inundation on rainforest distribution is not included in this analysis, but is likely to displace rainforest areas in favour of mangrove and associated coastal vegetation communities. Sea level rise should be included in future modelling of the effects of climate change on vegetation community distributions, as should the future probability of extreme events such as cyclones which may cause species and habitat loss. Climate envelope models have been widely used for prediction of the effects of climate change on species' distributions (Franklin, 1995). However, Preston et al. (2008) also highlight the importance of understanding biotic relationships in modelling climate change effects. In this study this has been achieved by utilising the ecological model as an intrinsic part of the analysis. Future studies should also incorporate the lag time between climatic conditions changing and vegetation response given that the focus here is tropical forest tree species that can live for many hundreds of years. The predicted drier climate is also likely to result in more frequent and/or intense fires in the Wet Tropics region which will adversely affect the distribution of rainforest communities in the Innisfail Lowlands subregion.

5. CONCLUSIONS

The potential effect of predicted climate change on current climate rainforest community distributions was assessed using vegetation modelling. The results indicate that likely climate change scenarios will alter current climate rainforest community distributions, with a potential expansion in the total area of rainforest, although some communities are likely to decrease in area or, in some cases, become locally extinct. Although the community modelling is not able to identify individual species at risk of extinction, the marked reduction in the remaining areas of four of the six rainforest community types modelled (1c, 2b, 3a and 3b) implies the risk of local extinction for species associated with these community types. The results indicate that, had they remained intact, cleared areas would not have provided a refuge for any of the three community types modeled to become locally extinct (1c, 3a, 3b) under both scenarios. Similarly, cleared areas do not provide a refuge for the near extinct type 2b. However, for type 2a, whose area is predicted to decrease in scenario B, past clearing may contribute to local extinctions of individual species associated with this community. The use of vegetation modelling to predict rainforest community response to climate change is shown to be an important management tool to, first, identify those communities which are at risk due to climate change and, second, provide a basis for development of appropriate planning and management processes to protect and maintain the biodiversity of the Wet Tropics region in both remnant and previously cleared areas.

REFERENCES

Accad, A. and Neil D.T. (2006) Modelling pre-clearing vegetation distribution using GIS–Integrated Statistical, Ecological and Data Models: A case study from the Wet Tropics Of Northeastern Australia. Ecol. Modelling 198 85-100.

Accad, A; Neldner, V.J; Wilson, B. A; and Niehus, R.E. (2008a). *Remnant Vegetation in Queensland. Analysis of remnant vegetation 1997-1999-2000-2001-2003-2005, including regional ecosystem information*. Brisbane: Queensland Herbarium, Environmental Protection Agency.

Accad, A., van Strien M. J, and Heitkönig I. M.A. (2008b) Are The Vegetation Communities Of Southeast Queensland Adequately Protected? Spatial Sciences Institute Queensland 2008 Meeting "Global Warning" 17-19 July 2008, Surfers Paradise Queensland Australia.

Adams, P. (1994). *Australian Rainforest.* School of Biological Science, University of New South Wales, Australia Oxford University Press.

Akaike, H., (1973). Information theory as an extension of the maximum likelihood. In: Petrov, B.N., Csaki, F. (Eds.), Second International Symposium on Information Theory. Akademiai Kiado, Budapest, Hungary, pp. 267-281.

Austin, M.P. (2002). Spatial prediction of species distribution: an interface between ecological theory and statistical modelling. Ecological Modelling 157: 101-118.

Austin, M.P. (2007). Species distribution models and ecological theory: A critical assessment and some possible new approaches. Ecological Modelling 200: 1-19.

Cairns, D.M. (2001). A comparison of methods for predicting vegetation type. Plant Ecology 156: 3-18.

Elith, J., et al., 2006. Novel methods improve prediction of species distribution from occurrence data. Ecography 29, 129-151.

Franklin, J. (1995). Predictive vegetation mapping: Geographic modelling of biospatial patterns in relation to environmental gradients. Progress in Physical Geography, 19(4): 474-499.

Franklin, J. (1998). Predicting the distribution of shrub species in southern California from climate and terrain-derived variables. Journal Vegetation Science, 9(5): 733-748.

Goosem, S., Saxon, E., Accad, A., Wickers, J. and Ford, K. (1996). Tracey and Webb vegetation classification model. Poster presented at the World Heritage Tropical Forests Conference: Science for Better Management and Understanding. 2-6 September 1996. Cairns, Far North Queensland, Australia.

Gordon, A. D. (1981). Classification: Methods for the Exploratory Analysis of Multivariate Data. London: Chapman and Hall.

Guisan, A., Zimmermann, N.E. (2000). Predictive habitat distribution models in ecology. Ecological Modelling 135: 147-186.

Hilbert, D.W., Ostendorf, B. and Hopkins, M. (2001). Sensitivity of tropical forests to climate change in the humid tropics of North Queensland. Austral Ecology 26: 590-603.

Hilbert, D.W., Graham, A. and Hopkins, M. (2007). Glacialand interglacial refugia within a long-term rainforest refugium: The Wet Tropics Bioregion of NE Queensland, Australia. PALAEO 251: 104-118.

IPCC (Intergovernmental Panel on Climate Change) (2007) Climate Change 2007: The Physical Science Basis, Summary for Policymakers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC Secretariat, Geneva, Switzerland.

Lehmann, A., Leathwick, J.R. and Overton, J.McC. (2004). GRASP v.3.0 User's Manual. Swiss Centre for Faunal Cartography, Switzerland.

Mackey, B.G. (1993). Predicting the potential distribution of rain-forest structural characteristics. Journal Vegetation Science. 4: 43-54.

McCullagh, P. and Nelder, J.A. (1989). 'Generalized Linear Models'. 2ed. Chapman and Hall, London.

Ostendorf, B. Hilbert, D. W. and Hopkins, S. 2001. The effect of climate change on tropical rainforest vegetation pattern Ecological Modelling, Volume 145, Issues 2-3: 211-224.

Parmesan C (2006) Ecological and evolutionary responses to recent climate change. Annual Review of Ecology, Evolution, and Systematics, 37, 637–669.

Preston, K. L., Rotenberry, J. T., Redak, R. A. and Allen, M. F. (2008) Habitat shifts of endangered species under altered climate conditions: importance of biotic interactions, Global Change Biology 14: 2501-2515.

Sattler, P.S. and Williams, R.D. (eds) (1999). The Conservation Status of Queensland Bioregional Ecosystems. Brisbane: Environmental Protection Agency.

Stanton J.P. and Stanton, D. (2005). Vegetation of the Wet Tropics of Queensland bioregion. Wet Tropic Management Authority Cairns.

Suppiah R., Macadam I., Watterson I. G., Page C.M., Bathols J. and Whetton P. H. (2008) Probabilistic Climate Change Projections for the MTSRF Region. A report prepared for the Marine and Tropical Sciences Research Facility July 18th, 2008

Tracey, J.G. (1982). The Vegetation of the Humid Tropical Region of North Queensland, CSIRO, Melbourne, 124 pp.

Tracey, J.G. and Webb, L.J. (1975). Vegetation of the Humid Tropical Region of North Queensland. (15 maps at 1: 100,000 scale + key.) CSIRO Aust. Long Pocket Labs: Indooroopilly, Qld.

Turton, S.M., Hutchinson, M.F, Accad, A., Hancock, P.E. and Webb, T. (1999). Producing fine-scale rainfall climatology surfaces for Queensland's wet tropics region. In: Geodiversity: Readings in Australian Geography at the close of the 20th Century. (Eds. J.A. Kesby, J.M. Stanley, R.F. McLean and L.J. Olive),. Special Publication Series No. 6, Canberra, ACT, School of Geography and Oceanography, University College, ADFA, p. 630, 415-428.

Venables, W.M. and Ripley, B.D. (1999). Modern applied statistics with S-Plus. Springer-Velag New York,