THE POTENTIAL IMPACTS OF CLIMATE CHANGE ON THE DISTRIBUTION OF*NEPENTHES*AND DIPTEROCARPS OF THE TRUS MADI FOREST RESERVE

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ABSTRACT

We used past collection records and data collected during the Scientific Biodiversity Expedition to the Trus Madi Forest Reserve to generate EcologicalNiche Models (ENMs) for two *Nepenthes* species (*N. macrophylla* and *N. lowii*) and two dipterocarp species (*Hopea montana* and *Shorea monticola*). The ENMs were developed using soil and current climatic data. The ENMs were then projected over down scaled climate predictions from the **CCCMA'sGeneral Circulation Model** for the years 2050 and 2080 to model the potential impacts of climate change, under the A2a and B2a emission scenarios, on these species. The predicted impacts of climate change on these four species varied under the different emission scenarios and time frames. *Nepenthes macrophylla* is predicted to be the most severely affected species, with its preferred climate envelope predicted to disappear from Trus Madi by the year 2050. This loss of preferred climate envelope may increase the likelihood of this species becoming extinct.

INTRODUCTION

Climate change represents the greatest unknown when it comes to managing natural resources, protected areas or endangered species within the tropics. This is because we are unsure as to how much the climate is likely to change or how organism will respond to this change. Our understanding on the potential impacts of climate change is based on predictions from Global Circulation Models (GCMs), and the predictions obtained from these models vary between the different models and among the various emission scenarios (Figure 1).

Furthermore these GCM predictions are at a resolution of hundreds of kilometres which is too coarse for ecological application (Beaumont *et al.* 2008). For ecological or impact studies we need to know what is likely to happen within area of interest, so some form of downscaling of the prediction is required (Wilby *et al.* 2004). There a variety of methods available to downscale GCMs prediction, however, all methods have their limitations and can contribute to the uncertainty in the climate change predictions (Schmidli *et al.*2007). Further details on downscaling techniques and a discussion of their limitations can be found in Beaumont *et al.* (2008).

How a species responds to climate change is dependent on many factors, it can either shift its distribution to follow the changing environment, adapt *in situ* to the changing conditions, survive in refugia i.e. areas of unchanged environment or to become extinct (Wiens *et al.* 2009). With the limited ecological and physiological data available for most tropical species it is difficult to assess the likelihood of the later three; however, it is possible using ecological niche models (ENMs) to project how a species distribution may change under different climate change scenarios. Ecological niche modeling involves developing a model that explains the species distribution under current climatic and edaphic conditions, the model is then projected over the future climate change predictions to determine how the species distribution is likely to change. In this study we generate ENMs for two *Nepenthes* (*N. lowii* and *N. macrophylla*) and twoDipterocarp (*Hopea montana* and *Shorea monticola*) within the Trus Madi Forest Reserve, and project these ENMs on downscaled climate change prediction obtained from the Canadian Centre for Climate Modeling and Analysis (CCCMA) to examine the potential impacts of climate change on the distribution of these four species within the Trus Madi Forest Reserve.

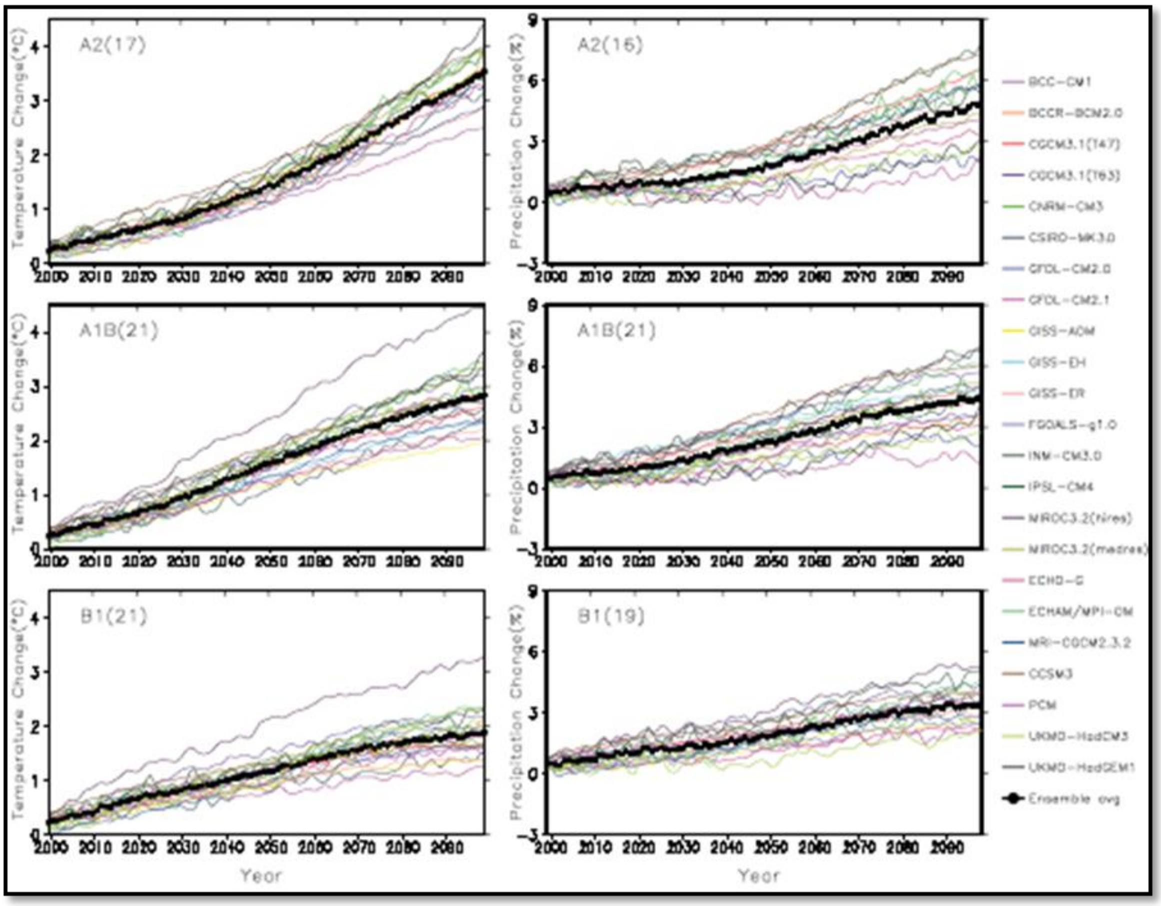

Figure 1: Globally averaged (left) surface air temperature change (°C) and (right) precipitation change (%) from the various global circulation models for the scenarios A2 (top), A1B (middle) and B1 (bottom) reproduced from Working Group I Report "The Physical Science Basis", Chapter 10 Global Climate Projections by Meehl *et al.* (2007)

METHODS

Species selection

We restricted this initial analysis to montane species as preliminary examination of the downscaled climate change predictions for Trus Madi, suggested that the montane areas are going to experience greater changes than low-lying areas (Appendix 1). To demonstrate how plant distributions might be affected by climate change, we selected two *Nepenthes* species (*Nepenthes lowii* and *N. macrophylla*) and two upland/montane dipterocarp species (*Hopea montana* and *Shorea monticola*).The two *Nepenthes* species are endemic to north Borneo, with *Nepenthes macrophylla* only known from the summit of Mt Trus Madi above 2500 m (Phillipps *et al.* 2008). *Nepenthes lowii* has a wider distribution and altitudinal range (1650 to 2600 m) being found in montane regions of central and northern Sarawak and throughout the montane regions of Sabah (Clark *et al.* 2000a, Phillipps *et al.* 2008). *Nepenthes lowii* and *Nepenthesmacrophylla* are currently listed as vulnerable and critically endangered, respectively, on the IUCN redlist (Clark *et al.* 2000a, 2000b).

The two dipterocarp species occupy alower altitudinal range with *Hopea montana* and *Shorea monticola* being found between 900 to 1200 m and 600 to 1500 m altitude, respectively. *Hopea montana* is found throughout the upland regions of Sumatra, Peninsular Malaysia and Borneo, and is listed as critically endangered (Ashton 1998). The conservation status of the Borneo endemic *Shorea monticola* has yet to be assessed.

Ecological Niche Modeling

An ecological niche models was generated for each species using Maxent 3.3.1. The ENMs were derived using locality data and a range of climatic and edaphic variables. Locality data for each species was obtained from the herbarium specimens at FRC, from the CAIMS database and research plots, as well as from recent survey conducted as part of the Heart of Borneo project and the Trus Madi expedition.All herbarium specimen locality records without geographical coordinates were georeferenced via consultation of 1:250000 soil maps and 1:50000 forest stratum maps. Samples that could not be confidently placed were excluded from the study to avoid the use of imprecise distributional information. Where multiple samples had been collected from one locality only one sample was included in the analysis to reduce sampling bias. GIS shapefiles of soil association, landform, soil suitability and soil parent material were obtained from the Sabah Forestry Department. These were converted from Timbalai Borneo RSO projection to WGS84 using ArcView Projection Utility and the shapefile converted to ESRI ASCII grid format at 6 arc-second resolution using ArcView Spatial Analyst. Altitudinal data at 3 arc-seconds resolution from the NASA Shuttle Radar Topographic Mission was obtained from the **CGIAR-CSI (**http://srtm.csi.cgiar.org**)and the data aggregated to 6 arc-seconds resolution using DIVA GIS.**Average monthly rainfall, and maximum and minimum temperature data for the period 1950-2000 was obtained from WorldClim (http://www.worldclim.org).

The data was in grid file format at 30 arc-seconds(~1 km^2) resolution, these monthly averages were converted to Bioclimatic variables and disaggregated to 6 arc-seconds resolution using DIVA GIS. Downscaled future climate predictions, for the years 2050 and 2080, from the Canadian centre for Climate Modeling and Analysis for the IPPC's A2a and B2a emission scenarios was obtained from WorldClim. The A2a and B2a emission scenarios correspond to an ~ 3° and ~ 2° rise in average global temperature by 2100, respectively. Further information on how this data was downscaled can be found at http://www.worldclim.org/downscaling.

We ran 100 replicated runs of Maxent on the full set of locality data with 10000 background point randomly selected per run. The importance of each of the environmental variables for each of the 100 replicated runs was measured using a jackknife approach (Philips & Dudik 2008). The models were the projected over the climate change prediction under the A2a and B2a emission scenarios for the years

2050 and 2080. From the ENMs, we determined a predicted area of occupancy within the TMFR under current and future climate conditions using the area function in DIVA GIS.

RESULTS

Three (*Shorea monticola, Nepenthes lowii* and *Nepenthes macrophylla*) of the four species examined showed a consistent reduction in area of occupancy (Figure 2). In these three species habitat loss was greatest under the A2a emission scenario. The amount of reduction varied among species, with the two *Nepenthes* species showing the greatest reduction in habitat. In the case of *Nepenthes macrophylla* allofthe suitable habitat is predicted to disappear by the year 2050. The fourth species (*Hopea montana*) showed a much more variable response, initially increasing its area of occupancy under the A2a emission scenario, before showing a decline in area of occupancy.

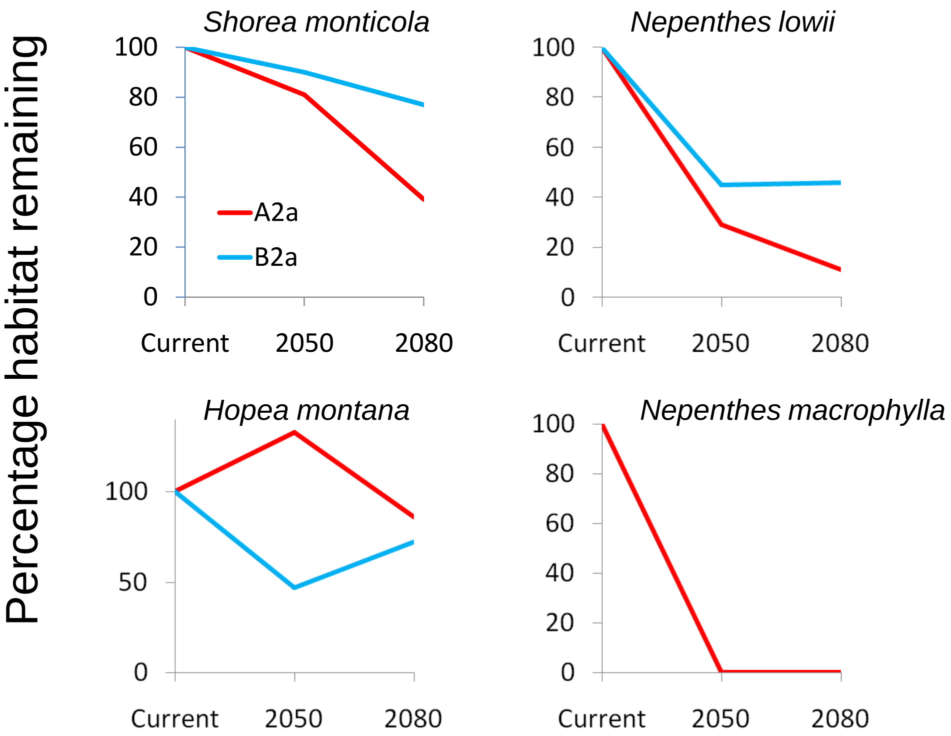

Figure 2: Predicted changes in area of occupancy within the TMFR for the years 2050 and 2080 under the A2a (red) and B2a (blue) emission scenarios. The data is expressed relative to current area of occupancy within the TMFR. The response of *Nepenthes macrophylla* was identical under the A2a and B2a emission scenarios so only one line is shown

DISCUSSION

This initial analysis of the potential impacts of climate change on four species within the TMFR suggests that different species will show different levels of susceptibility to climate change. The species listed in order of decreasing susceptibility to climate change were as follows;

Nepenthes macrophylla → *Nepenthes lowii* →*Shorea monticola* →*Hopea montana*

The two *Nepenthes* species showed a greater susceptibility to climate change than the two dipterocarp species. These differences may reflect the different habitat requirements of the species. The two *Nepenthes* species occupy higher altitudinal niches, than the two dipterocarp species, and these high altitudinal areas in Trus Madi are predicted to show a greater rise in average temperatures than the lower areas (Appendix 1). In the case of *Nepenthes macrophylla* the restriction of this species to the summit makes this species particularly susceptible to the impacts of climate change. Whether the rest of the summit shrub is as susceptible to the impacts of climate change remains to be determined, however, as this vegetation association is one of the key conservation targets of CAMP (2009) we recommend further investigation.

Using ecological niche models to make projection on a species future distributions is an educated guess (Weins *et al.* 2009), and a clear understanding on the underlying assumptions and limitations of these models is required. The ENMs at this stage cannot predict whether a species will be able to adapt to the changed environment nor are the models of high enough spatial resolution to predict whether or not refugia will remain. So while our prediction suggests that *Nepenthes macrophylla* faces an uncertain future, we can't conclude that it is certain to go extinct.

Another limitation of our study is that it was conducted using the prediction from a single GCM using only 2 of the 38 different IPPC emission scenarios. As can be seen in Figure 1, there is substantial variation among the different the GCMs and emission scenarios. At this stage we don't know which emission scenario will be realized or which GCMs gives the best predictions. So the recommended best practices for modeling how climate change will affect an organism's distribution involves using the predictions from multiple GCMs over a range of emission scenarios and then either averaging the results to arrive at a consensus (Weins *et al.* 2009), or to use the predictions from different models and emission scenarios to make probability distribution functions of the species response (Beaumont *et al.* 2008). A second limitation of our predictions is that the downscaled predictions used in this study where derived from the GCMs used in the IPCC Third Assessment Report (TAR). Comparisons of models used in the TAR and the more recent Fourth Assessment Report (AR4) show that the more recent models are better able to simulate seasonal patterns in precipitation and surface air temperatures than was possible at the time of the TAR (Randall *et al.*2007). Further refinement and improvement of the prediction of our ecological niche models is recommended.

While it is possible to improve our ENMs projection using the most recent predictions from multiple GCMs and emission scenarios, ecological modeling techniques are unable to take into account secondary impacts of climate change. In the case of the Trus Madi Forest Reserve, one of the potentially most important predicted changes in climate may be the increased seasonality of rainfall (Figure 3). The Trus Madi Forest Reserve is predicted to have dry seasons that are up to 20% drier than current, this coupled with increased temperature has the potential to increase the fire risk within the reserve. Without adequate fire management both within and outside Trus Madi Forest Reserve this increased fire risk has the potential to cause greater habitat loss than the direct effects of climate change.

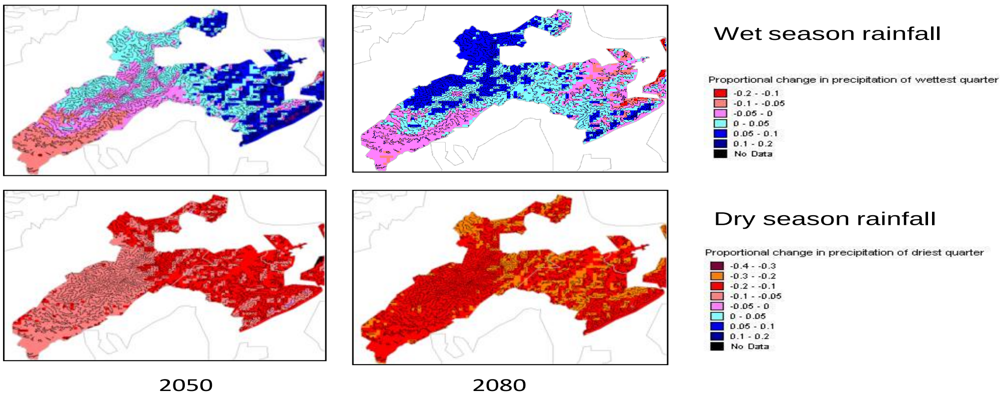

Figure 3: Change in precipitation, relative to current conditions, under the B2a scenario during the wettest and driest quarter in the Trus Madi Forest Reserve

CONCLUSION

Ecological niche modeling allows an educated guess on how species distribution might change under future climate change. It allows some assessment of which species are likely to face an uncertain future, however, this work is still in its infancy at FRC and further refinement and development of our system is required to yield the "best" predictions for management purposes.

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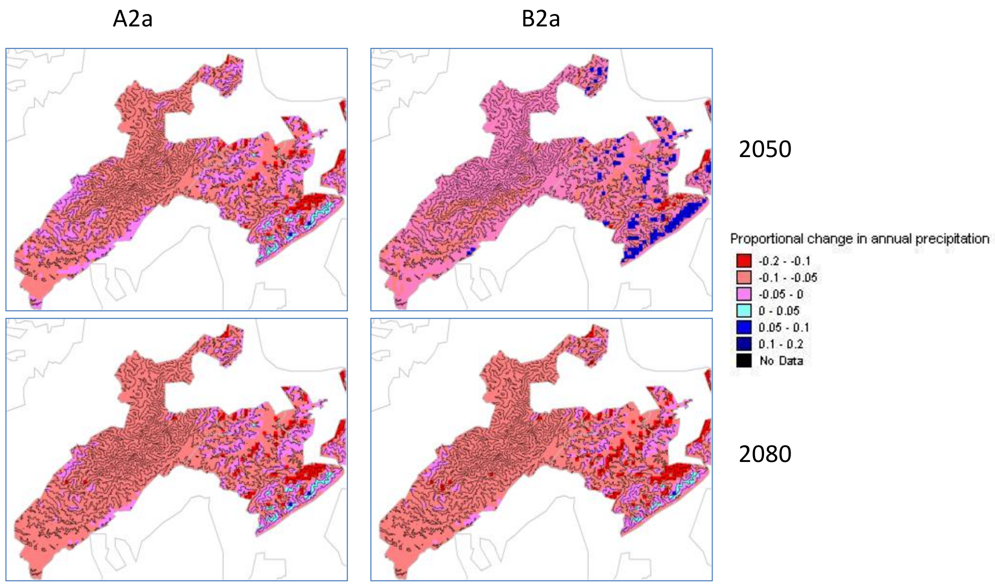
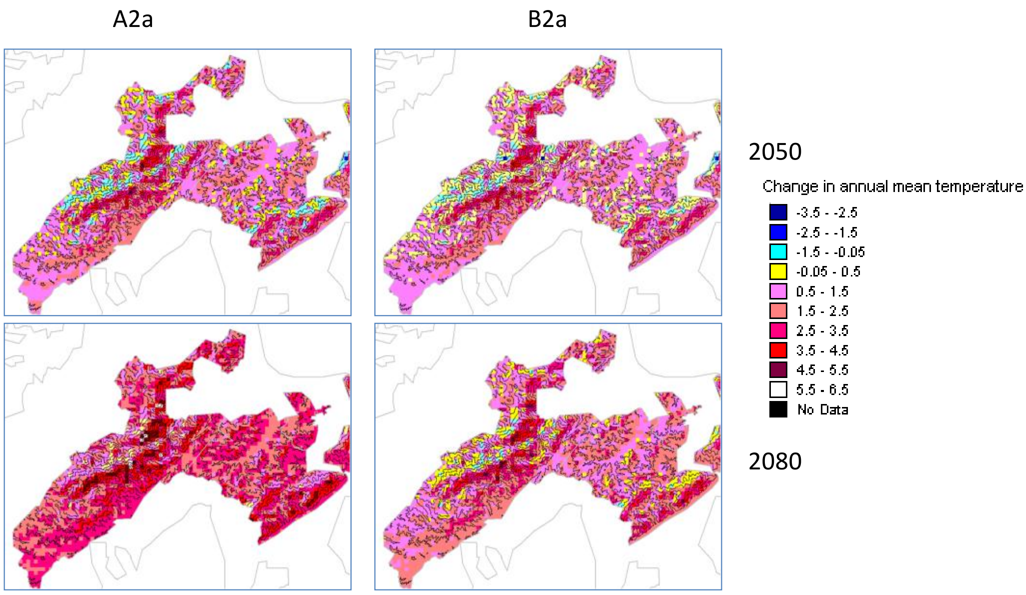
Appendix 1: Predicted changes in the climate of the Trus Madi Forest Reserve

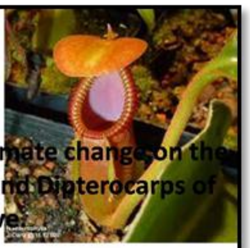
Change in annual precipitation, relative to current conditions, under the A2a and B2a scenarios in the Trus Madi Forest Reserve



Change in mean annual temperature (°C), relative to current conditions, under the A2a and B2a scenarios in the Trus Madi Forest Reserve



The potential impacts of climate change on the distribution of *Nepenthes* and Dipterocarps of the Trus Madi Forest Reserve.



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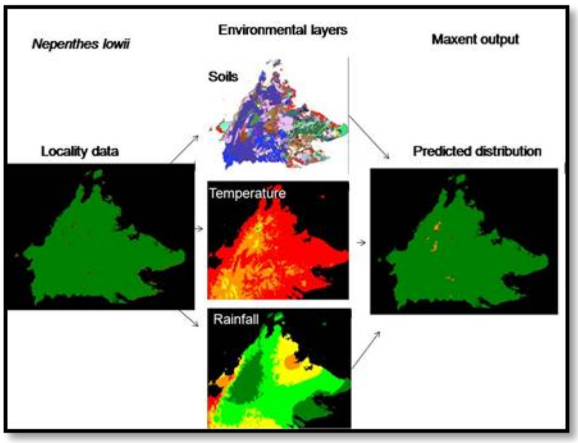
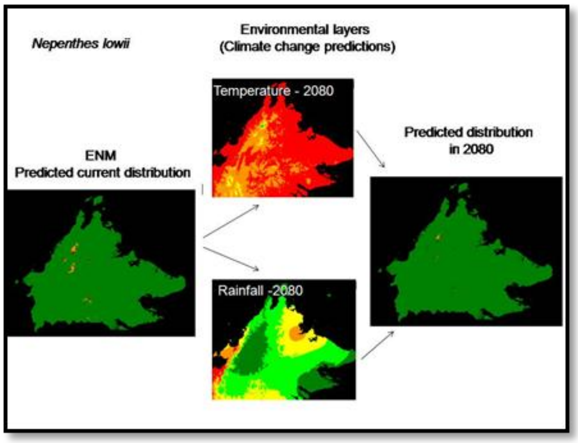
Ecological Niche Modeling

- Basic principle
  - Relates locality data to environmental data
  - Predicts where the species is likely to occur
- Many possible approaches to model the distribution plants in Sabah
- Maxent
  - Statistically powerful
  - Relatively easy to use
  - Free

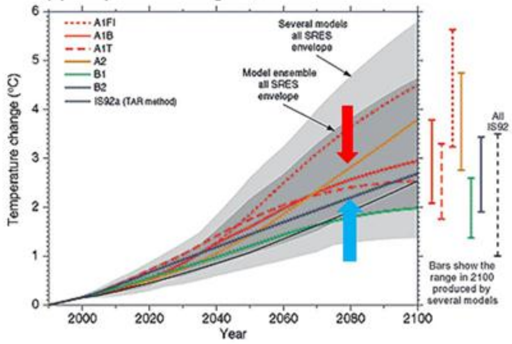


Application of ENM

- Conservation assessment of rare and endemic plants in Sabah
- Distribution of commercially important species in Sabah e.g. *Aqualaria* sp.
- Design restoration programs
- Potential impacts of CC
  - The ENM can be projected over different CC scenarios



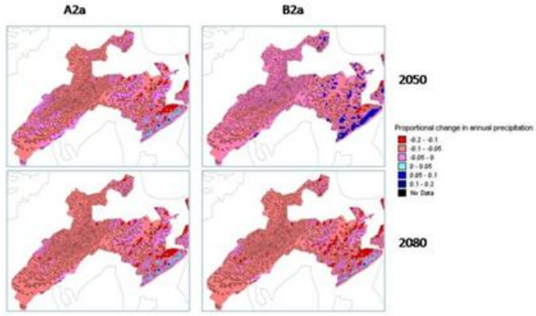
Climate change scenarios



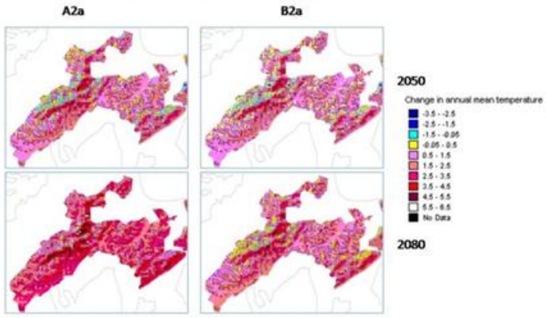
The need for downscaled climate change predictions

- GCM output at a resolution of ~ 3° = ~ 11 Mha
  - Not high enough resolution for management or conservation purposes
- Statistical (and dynamic) downscaling
  - Lots of techniques for statistical downscaling
  - Comparing the model output for the 20th century with long-term observations from a number of sites
  - Generates an empirical relationship between model output and observations
  - Applies this relationship to the future predictions

Change in annual precipitation, relative to current conditions, under the A2a and B2a scenario in the Trus Madi Forest Reserve.



Change in mean annual temperature (°C), relative to current conditions, under the A2a and B2a scenarios in the Trus Madi Forest Reserve.



Species selection and data

- *Nepenthes*
  - *N. lowii* & *N. macrophylla*
  - Both montane species and *N. macrophylla* is a Trusmadi endemic
- Dipterocarps
  - *Hopea montana* & *Shorea monticola*
  - Both upland/montane species
- Locality data
  - All of Sabah
    - BRAHMS database & CAIMS & research plot data
    - HOB & Conservation assessment surveys
    - **Trus Madi expedition**

ENM – Environmental data

- Soil data (Soils of Sabah)
  - Soil association, soil parent material & landform
- Altitude and Slope
  - SRTM 90m Digital Elevation Data
  - http://srtm.csi.cgiar.org/
- Climatic data (Rainfall, T_{max} & T_{min})
  - http://www.worldclim.org/
  - DIVA GIS to calculate 19 Bioclimatic variables

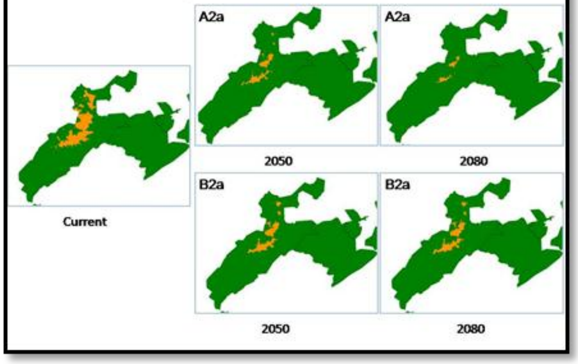
Current distribution of *Nepenthes lowii* in Trusmadi

Current

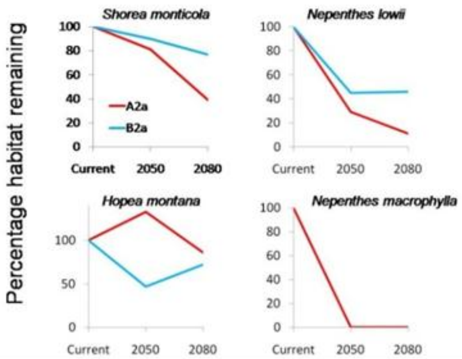
Future conditions

- Downscaled from GCM output, IPPC 3rd assessment by Worldclim
- Canadian Centre for Climate Modeling and Analysis GCM
  - to do HAD & CSIRO
- Rainfall, T_{max} & T_{min}
  - DIVA GIS to calculate 19 Bioclimatic variables
- A2a & B2a scenarios
- Years 2050 & 2080

Current distribution and predicted change in habitat of *Nepenthes lowii* in Trusmadi



Predicted change in habitat



Limitations with modeling

- Downscaled predictions can be dodgy
- IPPC 3rd assessment (2001)
- Need to develop high resolution downscaled prediction for Sabah
  - Ideally multiple GCM & CC scenarios using IPPC 4th assessment
- Limited to only direct affect of climatic changes can't deal with:
  - Resilience/adaptability of the species
  - Changes in biotic interactions
  - Indirect effects
    - Increased fire risk

Change in precipitation, relative to current conditions, under the B2a scenario during the wettest and driest quarter in the Trusmadi Forest Reserve.