NCCARF – Terrestrial Biodiversity 2009 Honours/ Masters Research Grant Report

Assessing uncertainty in climate change projections for cool temperate rainforest biota of southeastern Australia

Masters of Science (Zoology) thesis

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Study aims:

This research project had two main aims: to quantify uncertainty in climate change projections and their impact upon species distribution models and to assess the accuracy of these climate change projections. I quantified uncertainty as the variance in both future (2050 and 2080) and palaeo (mid-Holocene – 6k yr BP and the Last Glacial Maxima (LGM) – 21 k yr BP) projections in precipitation and temperature across multiple general circulation models (GCMs). This was done for four distinct sub-regions within the cool temperate rainforests (CTRF) of southeastern Australia. Uncertainty was also quantified in terms of the direction (e.g. contraction, expansion) and variance in predicted species distribution of representatives of CTRF taxa based on MAXENT models. To assess the accuracy of climate projections, I compared palaeo-climate projections (mid-Holocene and LGM) to two independent data sources (palaeo-climates derived from pollen-based vegetation reconstructions and estimates of Pleistocene refugia based on phylogeographic data).

Study system:

This research project used cool temperate rainforests (CTRFs) and four closely, associated endemic snails as a study system to address these aims. The CTRFs of southeastern Australia are found in four distinct sub-regions; the Central Highlands (west Gippsland) and Otway Ranges of Victoria, northeastern and western Tasmania. The dominant tree species of this ecosystem is the Antarctic Beech, *Nothofagus cunninghamii*. Each of the four distinct sub-regions has an endemic species of carnivorous snail from the genus *Victaphanta*; *V. atramentaria* (Central Highlands), *V. compacta* (Otway Ranges), *V. lampra* (northeastern Tasmania) and *V. milligani* (western Tasmania). The four *Victaphanta* species are adapted to each of the distinct sub-regions of CTRF and so offer a unique opportunity to compare the regionally specialised snails to the widely distributed *N. cunninghamii*.

Methods:

I modelled the current species distributions of *N. cunninghamii* and each of the four species of *Victaphanta* using the program MAXENT. To ensure that models could be extrapolated to future and past climates, they included only on two climate co-variates, temperature of the warmest quarter and precipitation of the coldest quarter. These species distribution models (SDMs) were then extrapolated onto future climate conditions (2050 and 2080) for six different general circulation models (GCMs) and into palaeo-climate conditions for the mid-Holocene (four GCMs) and the LGM (five GCMs). GCM projections for future climate conditions were downloaded from the Intergovernmental Panel for Climate Change (IPCC) Data Distribution Centre, and for palaeo-climate conditions from the Paleoclimate Modeling Intercomparison Project (PMIP Phase 2). These climate layers (for both future and palaeo-climates) were then statistically downscaled using ArcView 3.2. Variation in the area predicted to be climatically suitable for each GCM-derived climate layer was used to quantify uncertainty between the different projections. The accuracy of the GCMs to predict palaeo-climatic conditions was assessed using two qualitative methods: concordance with pollen-derived palaeo-climates and number of Pleistocene refugia with phylogeographic estimates.

Results:

Future climate projections of the six GCMs, in general, showed increases in temperature and a decrease in precipitation for the mainland and increases in temperature and increases in precipitation for Tasmania. The pattern of these projections was similar in 2050 and 2080, with 2080 showing more severe changes. Under future climate conditions, all species in all regions were predicted to experience major contractions, with the exception of *V. milligani* in western Tasmania. The Otway Ranges were most severely affected with *V. compacta* predicted to have no climatically suitable habitat remaining by 2080. Variability among GCMs was highest in Tasmania with precipitation projected to both increase and decrease in both sub-regions. All GCMs led to decreases in the predicted amount of suitable habitat for both species on the mainland. There were notable differences in predictions for *N. cunninghamii* and *Victaphanta* spp in the same sub-region unde projected future climates. This is particularly interesting as both occupy a similar climate space across the four regions of CTRF. The only difference in the modelling was that *N. cunninghamii* models were developed using presence data from all four sub-regions of CTRF, whereas each of the *Victaphanta* spp. were developed using presence data from the relevant sub-region only. The disparity between *N. cunninghamii* and *Victaphanta* spp. predictions indicates that the scale at which species distributions are modelled can be influential.

Palaeo-climate projections, in general, showed decreases in temperature and precipitation with these being more different to current conditions at the Last Glacial Maxima (LGM) compared to the mid-Holocene. Palaeo-climates showed similar patterns of variation, with very little variability between the four sub-regions. Comparisons to pollen-based palaeo-climate estimates indicated general consensus for temperature and precipitation at the LGM and for temperature during the mid-Holocene. Temperature estimates from GCMs were generally less extreme than projected by pollen reconstructions. Precipitation estimates for the mid-Holocene were not concordant between the GCM-derived and pollen-derived palaeoclimates with GCMs predicting decreases and pollen-derived estimates indicating increases.

Molecular studies of *V. atramentaria* (Central Highlands of Victoria) and *V. compacta* (Otway Ranges of Victoria) showed very little variation, with the exception of a divergent population existing in the western most parts of *V. compacta*'s distributions. In general, there is broad concordance between phylogeographic estimates of Pleistocene refugia and the inferred distribution of these species at the LGM.

Major findings and outcomes:

There were two main aims for this research project. These were; 1) quantifying uncertainty in general circulation model (GCM) projections of novel climate conditions and 2) assessing the accuracy of GCM projections by comparison with independent palaeo-climate data. My results showed that there was substantial variation among GCMs in their projections of both future and palaeo-climatic conditions, with this variation changing depending on the sub-region being investigated. Assessment of the accuracy of GCM projections indicated that; in general GCM projections were broadly consistent with estimates of palaeo-climatic conditions from pollen and genetic data with the exception of precipitation during the mid-Holocene. The MIROC GCM was identified as being the most able to accurately predict palaeo-climate conditions at both the mid-Holocene and the LGM for the region of southeastern Australia.

Significance to adapting and protecting Australia's terrestrial biodiversity:

This research project highlighted the fact that while GCMs generally predict the same direction of change when extrapolated to novel climate conditions (both in the future and in the past), there is significant variation in the predicted impact of these changes. This is particularly important for the application of future climate projections on a fine scale such as for management and conservation efforts. This highlights the danger of using only a single general circulation model (GCM) for fine-scale assessment of the impact of future climate change. It is important to be able to assess the potential impact of climate change before adaptation research is undertaken so that the requirements for persistence are known. The simple species distribution models (SDMs) used in this study (based on one temperature and one precipitation variable) are likely to be an overestimation of the potential impact of climate change. This is because predicted species distributions can be refined by a variety of variates other than climate, such as geographic orientation, fire history and the presence of other species. These variables were not considered in this study as they would have been difficult to project into both future and palaeo-climate conditions. Due to the drastic decreases in distribution indicated by this research, particularly on mainland Australia, these species and their ecosystem are under grave threat. More research is needed into this ecosystem to be able to more accurately predict the impact of climate change, for example, physiological research into the heat and fire tolerances of these species.

Further research suggestions

There are several areas in which this research project could be expanded. These include; increasing the scale of the project, increasing the complexity of the species distribution models (SDMs), increasing sampling for molecular analyses, using other species distribution modelling techniques and physiological studies to determine the adaptive ability of this ecosystem. This research project was done at a relatively fine spatial scale compared to the global scale of general circulation models (GCMs). This approach could be used to assess how GCMs vary on a larger scale (such as eastern Australia or Australia). This would allow greater insight into how GCMs vary spatially across a larger area. Increasing the complexity of the SDMs would allow more precise estimates of how this ecosystem may respond to climate change. Increasing the amount of molecular data and using molecular data from multiple cool temperate rainforest (CTRF) restricted species would provide a more complete picture of how this ecosystem has responded to past climate changes and would enable a more quantitative comparison between molecular data and GCM-derived climates projections. Using additional SDM techniques (e.g. General Linear Models (GLMs) would enable us to assess the relative contribution of species distribution modelling approaches and GCMs to variation and uncertainty in the predicted impacts of climate change on species distributions. Physiological studies, for example on thermal tolerances are essential to assess physiological limits of species would link into how these species and ecosystem may be able to adapt to future changes to our climate system.