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Glacial and interglacial refugia within a long-term rainforest refugium: The Wet Tropics Bioregion of NE Queensland, Australia

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Abstract

An artificial neural network is used to classify environments, including climate, terrain and soil variables, according to their suitability for fifteen structural/environmental forest classes in the Wet Tropics Bioregion of north-east Queensland. We map the environments characteristic of these forest classes in four climate regimes (the present and three past climate scenarios), quantify the changes in area of these environments in response to past regional changes in climate and identify areas that would have been environmentally suitable for rainforests at last glacial maximum (glacial refugia). We also identify areas that would have been suitable for upland and highland rainforest classes during the warmest parts of the interglacial (interglacial refugia) and map locations that consistently remain favourable to specific forest classes despite large changes in climate.

In the climate of the last glacial maximum (LGM), rainforest environments are predicted in three relatively distinct refugia in the northern, central and southern Wet Tropics. Only three percent of the total area contains lowland, Mesophyll Vine Forest and the majority of the area of the rainforest refugia supports upland rainforest classes. In the cool, wet climate of the Pleistocene/Holocene transition (PHT), rainforest environments expand to form a more or less continuous block from the northern limits of the region to the Walter Hill Range, except for discontinuous patches extending through the Seaview and Paluma Ranges in the south. During the Holocene climatic optimum (HCO), rainforest environments become more fragmented, especially in the south. Lowland rainforest environments are very extensive in this climate while upland rainforest classes are restricted to what we term "interglacial refugia".

Estimated distributions and stable locations (consistently predicted in all four climate scenarios) for the various rainforest environment classes are our main, novel contribution. Each forest environment responds individualistically to climate change. Our results confirm the highly dynamic nature of the Wet Tropics landscape and present a much more detailed picture of landscape change since the late Pleistocene than previously has been available. This mapping exercise should be useful in the future for analyses of present-day biogeographic patterns. We argue that empirical modelling approaches have an important role in palaeoecology and global change research that is complementary to the developing mechanistic methods.
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Keywords: Palaeoenvironmental modelling; Rainforest distributions; Climate change; Pleistocene; Late Quaternary

1. Introduction

In this paper we describe how the environments of the structural/environmental forest classes within the Wet Tropics Bioregion region have changed in response to

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climate changes since the last glacial maximum (LGM). We show that, while rainforest environments as a whole contracted to several regional refugia at the LGM, the cooler upland and highland rainforest environments are restricted to regional refugia during interglacial times, especially the Holocene climatic optimum (HCO). Our quantitative modelling approach provides much greater resolution of palaeo-biogeographic dynamics, as well as regions of relative stability, than previous bioclimatic analyses and should be of considerable use in the future in explaining current biogeographic patterns of the region's unique flora and fauna.

1.1. The Wet Tropics Bioregion

There are several long-term rainforest refugia in Australia (Adam, 1992), primarily along the east coast. These are thought to be remnants of rainforests that were widely distributed in Australia in the Miocene/Early Tertiary (Truswell, 1993). The Wet Tropics Bioregion (see Fig. 1; Williams et al., 1996), located between 15° and 19°S, long. 145°–146°30′E, is the largest of the tropical to warm-temperate rainforest refugia and is considered to be one of the most significant regional ecosystems in the world (Webb, 1984). It is rich in regionally endemic biodiversity, including 53 genera of vascular plants (Metcalfe and Ford, in press). Only New Caledonia has a greater concentration of endemic plant genera (Webb and Tracey, 1981). While retaining unique tropical rainforests in the lowlands, the richness of its endemic flora and fauna increases with altitude. The rainforest vertebrate fauna includes 66 species endemic to the region (Williams et al., 1996). Land snails are exceptionally diverse and mostly endemic, with 185 out of 222 known Australian species being endemic to the region (Stanisic et al., 1994).

The topography of the region is complex with elevations ranging from sea level to 1615 m and there are steep gradients of temperature and rainfall. Mean annual precipitation varies from greater than 8000 mm at higher altitudes to approximately 600 mm at drier, inland locations. Interannual variability of rainfall is high. Annual mean temperatures vary from above 25.0 °C at some coastal locations to less than 17.0 °C on the higher mountains. The combination of high topographic, edaphic, and climatic variability over the region results in a very complex mosaic of diverse forest types.

1.2. Quaternary climate change and rainforests

It is now widely recognized that climates changed appreciably in the tropics throughout the glacial cycles of the Pleistocene (Farrera et al., 1999). In the Neotropics, climate changes during the late Tertiary and Quaternary periods indicate low-latitude temperature fluctuations of up to 5 or 6 °C (Colinvaux et al., 1996; Burnham and Graham, 1999; Heine, 2000) and similar glacial cooling was widespread throughout the tropics (van der Kaars and Dam, 1997). In general, glacial cooling and aridity restricted the extent and altered the spatial distribution of tropical rainforests and depressed altitudinal zones while warmer and wetter conditions during the Holocene allowed marked expansion of rainforests (Walker and Chen, 1987; Flenley, 1998). African lowland rainforest, for example, may have contracted to 25% of its present area at last glacial maximum (LGM), ca. 20 to 18 kyr BP, and expanded to three times its present area during the Holocene climatic optimum (HCO), ca. 5 kyr BP (Hamilton, 1976). During glacial periods, these rainforests may have been replaced by tropical seasonal forest, seasonal or dry forests were replaced by savanna or steppe and mountain forests occurred at lower elevations than today (Elenga et al., 2000).

In Mesoamerica, during the late Pleistocene, lowland rainforest species may have been limited to riparian habitats and expanded with increased temperature and rainfall approximately 12 kyr BP (Aide and Rivera, 1998). In contrast, rainforest remained in the Amazonian lowlands throughout the Pleistocene and the main effect of climate changes may have been on the distribution of heat intolerant plants responding to Holocene warming (Haberle, 1999; Colinvaux et al., 2000; Colinvaux and De Oliveira, 2001). In the Sunda shelf of Southeast Asia, drier climates during the peak of the last ice age led to a reduction in the extent of rainforests (Taylor et al., 1999). Rainforests in central New Guinea contracted to 75% of their present area at LGM (Walker and Chen, 1987) and tree line in the central highlands was 1500 m lower than today (Walker and Flenley, 1979; Walker and Hope, 1982).

In Australia, during the last glacial cycle, the most important climatic feature has been variation in precipitation with the driest conditions occurring during the transition from the peak of the last glacial to the Holocene (Kershaw and Nanson, 1993). The major change in the vegetation of Australia, occurring within the last 140 kyr BP, involved the replacement of extensive moist rainforest by open eucalypt woodland, postulated to have been caused by the burning activities of Aboriginal people (Kershaw, 1994). In the central Wet Tropics, volcanic activity within and adjacent to the catchments of the Barron, Mulgrave and Tully Rivers (Whitehead et al., in press) would have initiated forest fires during this period. Over long-term and continental

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