Climate change and conservation of *Araucaria angustifolia* in Brazil

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Climate vulnerability mapping is used to predict areas where climate change will have drastic effects on given tree species or populations, so they can be prioritized for conservation

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The ombrophilous (high-rainfall tolerant) mixed forest of southern Brazil has a canopy dominated by Parana pine (*Araucaria angustifolia*) and is thus also referred to as *Araucaria* forest (Veloso, Rangel Filho and Lima, 1991), even though the composition of its vegetation may vary significantly according to latitude, altitude, soil and microclimate (Reitz and Klein, 1966). This forest type is found only in the Neotropics and is typical of the southern tableland.

Araucaria angustifolia forests are under considerable pressure today as they are usually located in densely populated areas. Recent and predicted climate change may present a further challenge to the future survival of these tree populations. This article describes the origin of the *Araucaria* forest and outlines how it has been influenced by climate change throughout the Cenozoic, the most recent (and ongoing) geologic era. It points out some of the limitations of current attempts to map climate vulnerability in the populations described, and considers the importance of maintaining their genetic variability to enable their adaptation to a changing climate and thus their conservation.

ABOUT *ARAUCARIA* FOREST AND *A. ANGUSTIFOLIA*

In Brazil, *Araucaria* forest occurs south of the Tropic of Capricorn between the altitudes of 50 and 1 800 m, most frequently between 500 and 1 200 m, and is surrounded by subtropical humid forest. Fragmented populations of *A. angustifolia* also occur in northeastern Argentina and southeastern Brazil (Hueck, 1953). The *Araucaria* forest covers 177 600 km^2 in Brazil (Leite and Klein, 1990) and 2 100 km^2 in Argentina (Giraudo *et al.*, 2003).

The presence of *A. angustifolia* in the Brazilian subtropical area has its origins in continental drift which resulted in the dispersion of *Araucaria* ancestors along with other vegetation. *Araucaria* fossils are distributed throughout the world, but surviving species today are found only in Australia (seven species) and South America (two species). The region of origin of *A. angustifolia* in southern Brazil is therefore uncertain. During the late Pleistocene (the era from 1.8 million to 10 000 years ago), elevation of the continental platform to altitudes that made the rainy climate suitable for *A. angustifolia* possible at this latitude allowed the formation of an ombrophilous nucleus or founder population. Subsequent geological phenomena caused this nucleus to expand and contract over time; at its largest the natural distribution reached northeastern Brazil (Veloso, Rangel Filho and Lima, 1991; Leite, 1994).

Araucaria angustifolia occurs naturally on a variety of soils, from shallow to deep and from wet to well drained. One of the main environmental features that determines its distribution, and consequently its susceptibility to climate change, is the presence of frost, which allows the species to outperform competing tree species at the higher altitudes where it thrives.

The species has been intensively exploited for timber, and the *Araucaria* forest area has also been reduced by expansion of agriculture. Even though

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***Araucaria angustifolia* dominates the forest canopy at Itaimbezinho Valley, Rio Grande do Sul State, Brazil**

today *A. angustifolia* is legally protected and its harvesting for timber is prohibited by law in Brazil, the remaining areas of the species in its natural distribution areas are fragmented and scattered, with few large populations remaining. The conservation status of this forest type is considered critical. In addition, the age distribution of the remaining populations is skewed towards older age classes.

A HISTORY LINKED WITH CLIMATE CHANGE

Palaeontological studies have attempted to relate past climate to the current vegetation in the southern tableland of Brazil. It is assumed that three to four periods of severe climate fluctuations in the Cenozoic have influenced current vegetation distribution and composition. Two dry periods have occurred, a drastic drought episode in the Pleistocene and a milder one during the subsequent Holocene (which began 10 000 years ago) (Klein, 1984).

In the dry and cold period before the last glacial maximum, 50 000 years ago, the vegetation was dominated by grasslands and shrubs, with forests restricted to deep valley refuges (Ledru *et al.*, 1996). From 45 000 to 33 000 years ago humidity increased, and evidence has been found of the presence of *A. angustifolia*, *Drimys brasiliensis* and *Cyathea* sp. Ombrophilous forest did not occur on the plateau, but only as small populations in refuge areas on the wetter coastal slopes and in river valleys (Ledru *et al.*, 1994). Possibly between 17 000 and 8 500 years ago, the region experienced a series of climate fluctuations dominated by cold dry conditions, interrupted by a brief period of higher humidity from 13 000 to 11 000 years ago. Around 8 500 years ago, temperatures continued to be low but humidity began to return, increasing the *Araucaria* presence associated with species of the genera *Symplocos*, *Drimys*, *Lithraea*, *Podocarpus*, *Myrsine* and *Alchornea* (Ledru, 1993).

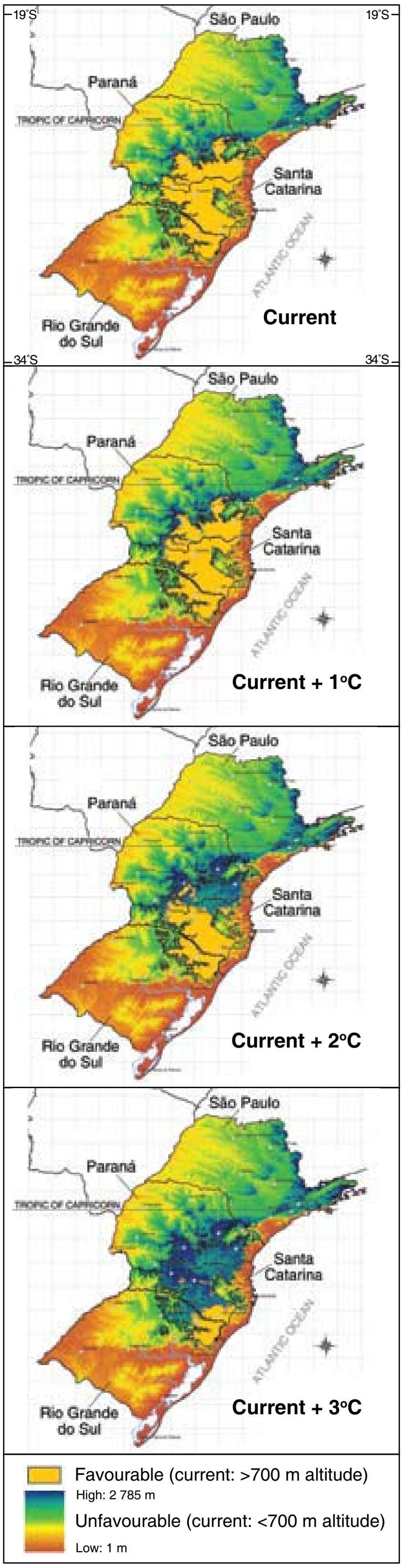
The current humid conditions returned from about 4 300 years ago (Behling, 2005). As the conditions became more steadily humid the *Araucaria* forest expanded to previous subtropical grasslands at higher altitudes. Ombrophilous forest has expanded significantly during the past 1 000 years in Paraná State and the past 1 500 years in Santa Catarina State.

CLIMATE VULNERABILITY MAPPING

In the present study, two models were used to predict the impact of different climate change scenarios on the distribution of *A. angustifolia*.

First, an envelope model was used to determine the range of favourable climatic conditions for *A. angustifolia* based on a 30-year climatic series from Brazil's southern region. Climate vulnerability mapping was used to predict the effect of 1º, 2º and 3ºC increases in temperature on the current natural distribution of *A. angustifolia*. The maps were developed based on linear regression with latitude, longitude and elevation to identify zones potentially suitable for the species under these scenarios. The maps predict a significant reduction of the area suitable for the species, indicating that with a temperature increase of 3ºC, only a small area at the highest part of the southern Brazilian tableland would be favourable (Figure 1).

Second, a regional circulation model developed by the Brazilian National Institute for Space Research (INPE) was used to generate scenarios for 2010, 2030 and 2050, based on changes in atmospheric circulation predicted by IPCC (2007). Temperature data were used to map areas suitable for *A. angustifolia*. The maps were developed using the geoprocessing program ArcGIS9. As in the first model, linear regression was used to relate temperature with latitude, longitude and elevation. This second simulation predicted less reduction in the species' distribution area (Figure 2).



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***Araucaria angustifolia** geographic distribution in southern Brazil according to various temperature scenarios*

GENETIC VARIATION AND ADAPTATION

Understanding of the factors affecting the past and present distribution of a species is important for conservation programmes. Responses of tree species to environmental change are complex. Their ultimate survival will depend on seed dispersal and on their ability to reproduce successfully. Vulnerability can be manifested in changes in flowering and seed germination, reduced regeneration success and diminished growth rates, and is often aggravated by increased disturbance by fire and insects and increased competition from competing or exotic (introduced) vegetation. The interaction of different stress factors is difficult to predict. For *A. angustifolia*, the main stress factors are water deficit and high temperatures.

Genetic variability in adaptive traits is required for a species or tree population to withstand adverse environmental conditions. Maintenance of genetic diversity is thus important for adaptation to new environments. Population variability studies using molecular genetic tools are now enhancing understanding of the genetic diversity status of key species and tree populations. In *A. angustifolia*, genetic variation is present both between populations (Kageyama and Jacob, 1980; Shimizu and Higa, 1980; de Sousa, 2000) and within populations (de Sousa, 2000; de Sousa *et al.*, 2005; Stefenon, Gailing and Finkeldey, 2008). Seed dispersal is limited, but pollen is dispersed over relatively long distances (Bittencourt and Sebbenn, 2007). Although natural regeneration in *Araucaria* species has been reported to be poor in most areas studied, levels of diversity in regenerating areas were still considered sufficient to ensure future survival of the species (de Sousa *et al.*, 2005; Stefenon, Gailing and Finkeldey, 2008).

As trees have long life cycles, the process of adaptation to changing conditions is probably slower than the predicted rate of global climate change (Hamrick, 2004). Most of the negative genetic effects caused by decline and fragmentation of populations of *A. angustifolia* are expected to become evident only after several tree generations (de Sousa, 2000).

CONCLUSIONS

Genetic variation is necessary for adaptation of tree species and populations to environmental changes and is a precondition for conservation. More efficient strategies for conservation, whether *in situ* or *ex situ*, can be established only based on knowledge about environmental requirements and variation patterns of targeted species and forest types, combined with future climate change scenarios.

Vulnerability mapping can be useful to predict areas where climate change will have drastic effects on given tree species or populations, so they can be prioritized for germplasm collection and *ex situ* genetic conservation activities. However, more climate variables and different climate models should be used to improve future maps.

Matching information on genetic variability of tree species and populations with climate maps may help support *Araucaria* conservation programmes. Special monitoring programmes and increased attention to basic physiological research are needed for better prediction of the species' response to climate change. ◆

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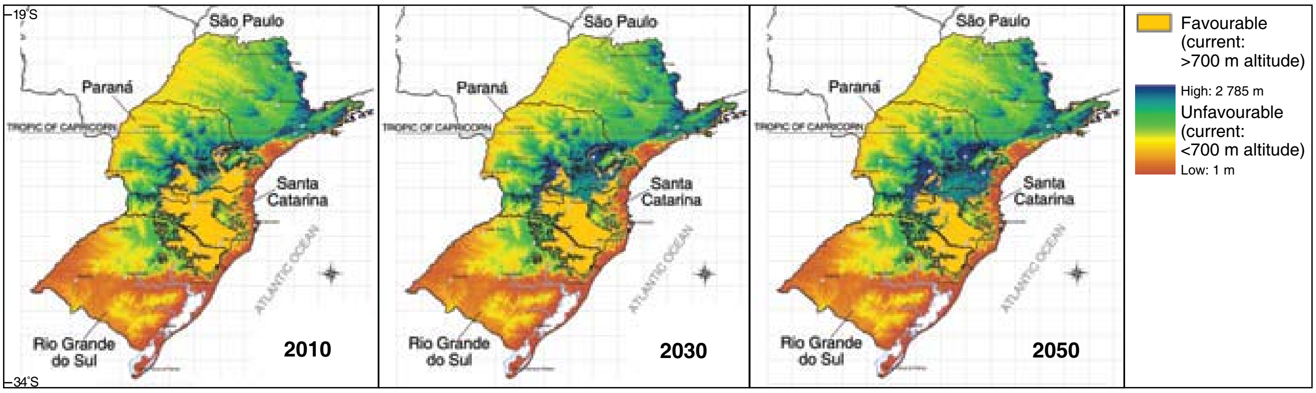

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