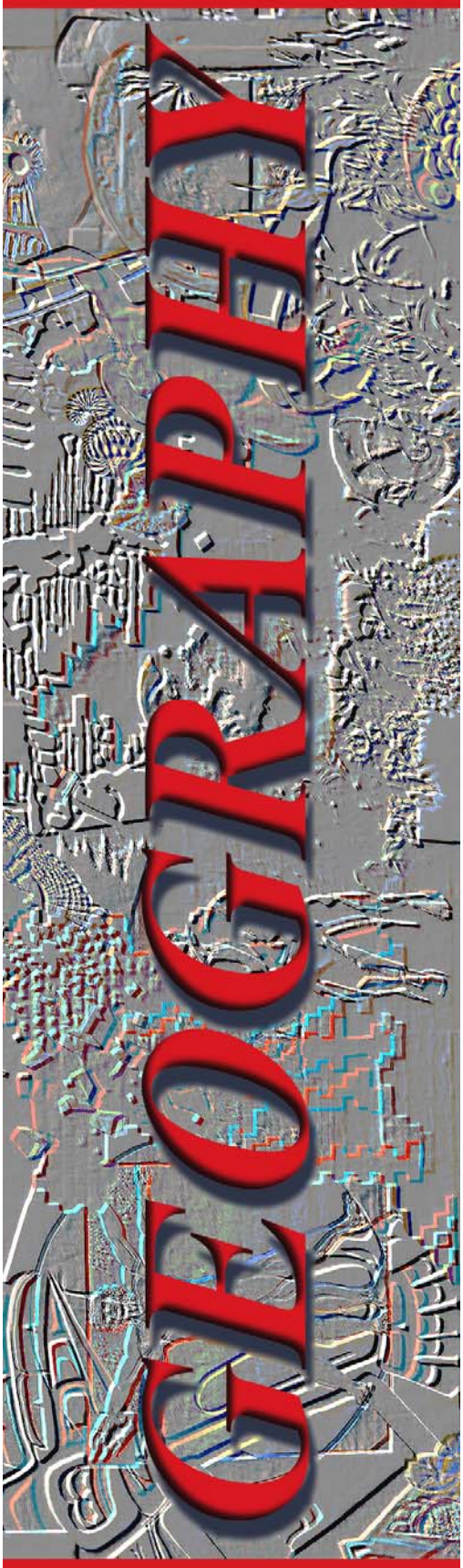

Araucaria angustifolia -

its Geography and Ecology

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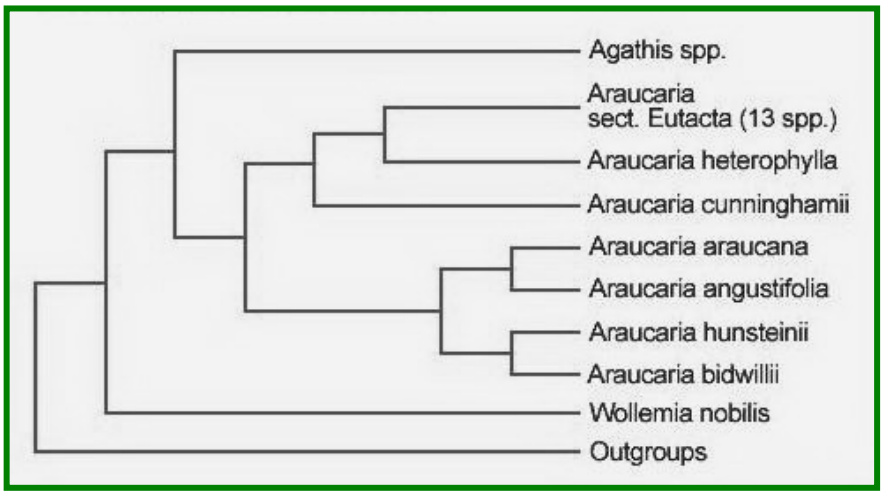
1. Introduction

Araucaria angustifolia (Parana pine) forest has virtually disappeared in the last 100 years from southern Brazil as a result of logging and clearance for agriculture. The species is now found in its pristine state in only a few locations, otherwise as fragments and isolated trees of former continuous forest. Where araucaria forest survives at least 40 percent of trees are *A. angustifolia*. Traditional systems of agri-silviculture - faxinal - still survive in some areas, particularly in Parana state. However, the future of this emblematic species remains under threat unless effective plans for restoration can be devised and implemented.

2.1 The Araucariaceae

Evergreen trees are confined to the southern hemisphere occurring in S. America, Australia, New Caledonia, the New Hebrides and Norfolk Island (Dallimore and Bruce Jackson, 1948). Although the members of the Araucariaceae are restricted to the southern hemisphere, fossil evidence shows that the family previously occurred in the northern hemisphere (Hill, 1995; Veblen et al., 1995). The Araucariaceae family contains three genera: Araucaria, Agathis and Wollemia. The two extant genera in the family, *Agathis* and *Araucaria*, occur as trees. The second genus is represented by a unique species, *Araucaria angustifolia*, which occurs in southeastern Brazil, northeastern Argentina and Paraguay (Veblen et al., 1995), along with *Podocarpus lambertii* Klotz (pinheiro-bravo) and *Podocarpus sellowii* (pinheiro-bravo-da-folha-larga).

Figure 1: Phylogenetic relationships within the Araucariaceae inferred from gene sequences (Kershaw, 2001)



2.2 Araucaria angustifolia

Antonio Bertoloni, a European naturalist, described the *Araucaria angustifolia* scientifically. It is a sub-tropical species of the family Araucariaceae, order Coniferales. This species of araucaria features a rectilinear, even, cylindrical trunk. It can reach 25 to 50 meters and the trunk may range between 1-2 meters diameter at breast height (Klein, 1960). The average age for an Araucaria tree to reach 75 cm diameter is 150 years (Voltolini, 2000) . The young tree is symmetrical, cone shaped, clothed with branches from base to summit. Its leaves are hard, sharp-pointed, perennial, and remain attached to the tree for many years. Old trees are clear of branches for the greater part of the tree's height (Dallimore and Bruce Jackson, 1948). As it grows older, the canopy becomes chalice shaped.

Araucaria is usually dioecious, rarely monoecious , and presents 2n = 26 chromosomes (Bandel, 1967). The male catkins are dense, cylindrical, solitary or in clusters, consisting of numerous spirally-arranged stamens. Cones are broader than they are long, globular or ovoid, with woody, closely overlapping scales, which fall when the seeds are mature (Dallimore and Bruce Jackson, 1948). Like other conifers, pollination is by the wind.

Pollination occurs from September to October (Sousa, 2000). Generally, only three years after pollination, the seed cones begin maturing. However, the complete cycle, from primordial carpel to seed, takes four years (Shimoya, 1962; Sousa, 2000). The seeds are bright brown (Dallimore and Bruce Jackson, 1948). Young trees generally begin to set seed between 12 and 15 years of age. The seeds are dispersed mainly from May to August (Carvalho, 1994). Foraging animals, such as jays, rodents, domestic pigs and peccaries, disperse the heavy seeds. The seeds have longevity of no longer than six weeks.
The seeds germinate as soon as they fall from the parent tree (Ntima, 1968).

Figure 2: Morphology of *Araucaria angustifolia* (J. Bittencourt, May 2003)

a) 'Isolated tree remaining after clearance of surrounding forest

b) *A. angustifolia* tree in forest environment

On the basis of photosynthetic and growth responses of araucaria trees under different light conditions (Einig, 1999; Inoue et al., 1979), *A. angustifolia* was found to be well-adapted to moderate shade. However, since there is little information on the species'

behavior under natural light conditions and an observed absence of seedlings in some shaded environments, there is a commonly-held belief that araucaria is a sun-loving, pioneer species that would not regenerate in a forest understorey.

2.3 The diversity of the species

Using non-adaptive markers, several authors have identified genetic variation across the species' natural range. For example, (REITZ, 1966) described nine botanical varieties of *A. angustifolia* based on ripening time and seed colour (Mattos, 1972). Genetic variation was detected within and among three natural populations (Kageyama and Jacob, 1980; Klein and Reitz, 1966). *A. angustifolia* collected from five Brazilian states showed statistically significant differences in wood production (Monteiro and Speltz, 1980). Studies of araucaria using biochemical and molecular markers have been undertaken to determine the species' genetic diversity across its natural range (Mazza, 1997; Schlogl, 2000; Shimizu et al., 2000). It was found that lower genetic similarities among araucaria populations were associated with larger geographical distances.

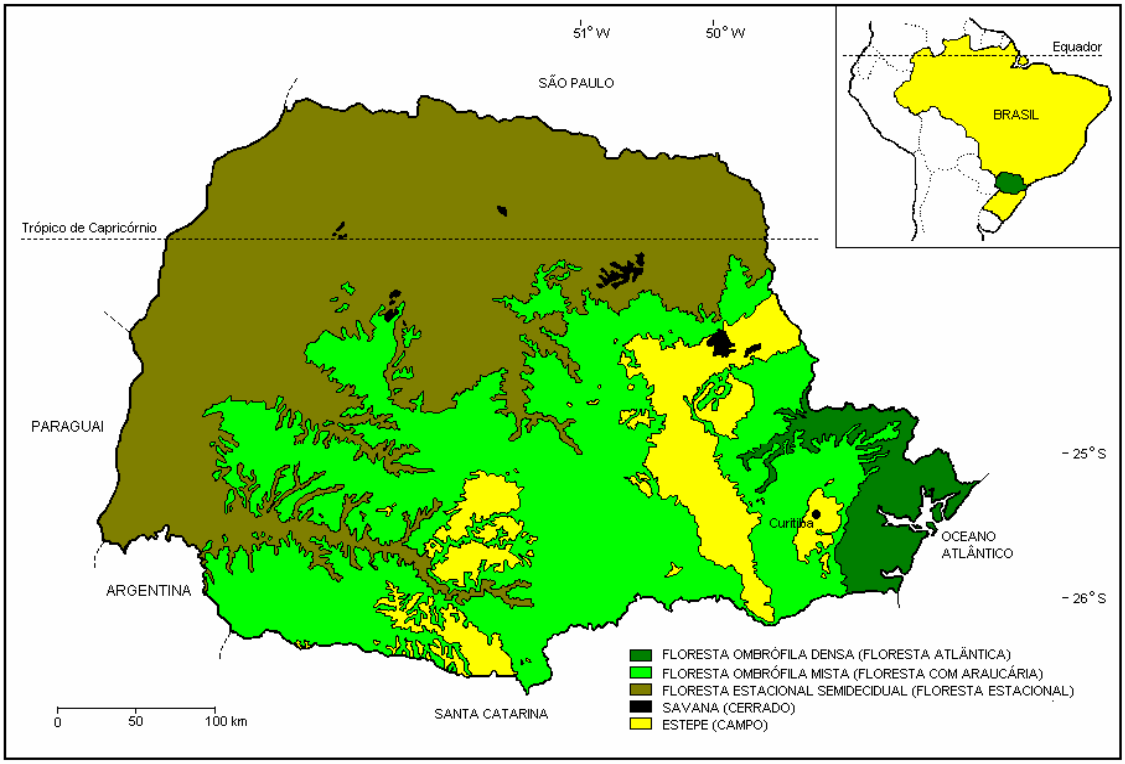
2.4 The distribution and characteristics of *A. angustifolia* forest in Brazil

Araucaria angustifolia is a dominant tree of subtropical to temperate rainforest at latitude 18° to 30 S in southeastern Brazil, where the largest forest formation is located **(Figure 3).** However, it is also found in northeastern Argentina and the eastern Paraguay, respectively in Missiones province and east in Alto Paraná. Their characteristic dark green color has earned it the nickname "black wood" and Araucaria forests are often referred to as "black woods" in contrast to "white woods" or forest without araucaria trees. Due to the characteristic shape of *A. angustifolia*, its comestible seeds and long history of exploitation the species is one of the most charismatic in the southern states of Brazil. Indeed, the tree is a symbol for the State of Paraná.

Until the 20th century, Araucaria forest dominated the southern Brazilian landscape, covering the better part of the Meridional Plateau. The species is a key in this forest type, which used to cover an area of approximately 200 000 square kilometers. This represented 40% of Paraná state, 30% of Santa Catarina state and 25% of Rio Grande do Sul.
Small areas of Araucaria forest was also found in northeast Brazil, 3% in São Paulo state and 1% in Rio de Janeiro and Minas Gerais.

The Araucaria forest is also called mixed tropical rainforest. The term "mixed" is used because it reflects occurrence of two-forest types: Austral-Brazilian Temperate, and Afro-Brazilian Tropical (Klein and Reitz, 1966; Leite, 1994). *Araucaria angustifolia* (Bert.) O. Ktze. represents more than 40% of the trees in this forest type (Longhi, 1980; Oliveira and Rotta., 1982). It has often been argued that many of the conifers of south America are not adequately regenerating and are being replaced by angiosperm trees (Maack, 1950) (Veblen et al., 1995).

Figure 3: Original araucaria forest biome (light green area) in Parana State, Brazil.
Source: (Roderjan, 2002)



Southern Brazil is a matrix of patches of subtropical rain forest interrupted by often extensive grasslands e.g. campos (Klein, 1960). The same author also describes the natural distribution as isolated individuals or groups. It commonly occurs as an emergent or as dominant canopy tree, but is often poorly represented in smaller size classes.

In the state of Paraná c. 1950, there were 66 000 km^2 of Araucaria representing c. 33% of the original 200 000 km^2. The forest was distributed mainly on the first and second plateaus of the state (Maack, 1950).

Primary Araucaria Forest is composed of a mixture of species, usually with three canopy layers. The uppermost layer consists of the crowns of old araucaria trees which allows for light penetration. The middle canopy layer is characterized by species of the Lauraceae family and the lowermost canopy by species of the Myrtaceae family and *Ilex paraguariensis*, the "erva-mate". Forest composition varies regionally (Leite, 1994).

A group of araucarias in grassland form an impressive landscape of thickets.
The Portuguese word *capão* (thicket) is of Indian origin and means "round wood". These thickets are located in small depressions in the landscape where humidity is high enough to support trees (Koch and Correa, 2002).

Little or almost nothing is known of the dynamics of natural stands of *Araucaria angustifolia* and the regeneration strategy of the species (Soares, 1980). Klein (1960) believes the species is a relict of the vegetation which dominated the region under a formerly drier climate, and then became a pioneer species, invading the campos. On the other hand, Soares (1980) argues that *A. angustifolia* is not a pioneer species but that its regeneration is dependent on regular disturbances, mainly fire.

3. Uses and importance of the species in Brazil

This species has been the most important commercially important native conifer in Brazil, possibly in all of South America over the last century (Guerra et al., 2002; Seitz and Kanninen, 1989) until the end of the 1970s (Guerra et al., 2002). Bigg - Wither (1974), an English engineer, described Araucaria forest in the 19th century. He had travelled through Paraná state from 1872 to 1875 with the objective of studying the region for railway construction. His description gives a good impression of the Araucaria forest during that time. According to him the trees had a circumference of 6 to 7 m and were 37 to 42 m in height. He called it "Mushroom forest".

A. angustifolia was a major resource for social and economic development, providing high quality timber for general construction, furniture and long-fibre cellulose (Carvalho 1994).

The araucaria buds are used in popular medicine (Marquesini, 1995). The araucaria seeds, known as *pinhão*, are also consumed as food. The forest thus provides a source of wood, medicinal leaves, food and different fruits.

Native Araucaria Forest was the most heavily exploited forest type in Brazil, according to the RADAMBRASIL project. In a study of the Contestado region (southwest of Paraná and north of Santa Catarina state) timber density in some forest relicts was found to be as high as 516 m^3 of wood per hectare of which 428 m^3 ha was from *Araucaria angustifolia* alone (Thome, 1995). According to the same writer it is unusual to find such productive forest even in comparison with the typical 215 m^3 ha found in Amazonian forest.
The other species of economic importance in Araucaria Forest is erva-mate (*Ilex paraguariensis*). The use of its leaves for tea is very important, even today (Wachowicz, 2001).

3.1 Logging Araucaria resources in southwest Paraná state

In the second half of the 19th century, the continental lands in the south began to be gradually colonised by European settlers (Koch and Correa, 2002). The native peoples (Indians) were excluded from their land and timber was logged for the construction of settlements.

The sovereignty of southwest Paraná remained contested between the Portuguese and Spanish during the colonization. Subsequently the region became part of Brazil which had a primary interest in the region for cattle ranching. Cattle rearing became the most important economic activity of that time. Thus exploitation opened new areas for "shifting" agriculture. The colonists did not use the tree, but burnt the forest to open the lands for agriculture.

The early settlers therefore, were essentially cattle farmers who preferentially selected natural grassland rather than forest for settlement. Penetration of the Araucaria Forest was not significant until 1918 when the colony of *Colonia Bom Retiro* was established (Voltolini, 2000).

The establishment of companies in southwest Paraná was another major factor that contributed to the destruction of the State's forest. Between 1918 and 1920 the state government encouraged the southwest colonization because of American interest in

building the Brasil Railway between São Paulo and Rio Grande do Sul. This contributed towards the onset of the Contestado civil war between the colonists and the Railroad company because the government appeared to benefit the lumber companies at the expense of the farmer settlers. (Wachowicz, 2001).

The forest was always a big problem for local people, because they saw it as an obstacle to cultivation (Voltolini, 2000). Until the 1930s this situation did not change; the forest continued to be an obstacle for farmers and explorers. As clearance began, settlements were established and houses, furniture and fences were produced using Araucaria.

After the start of the First World War in 1914, the araucaria wood industry grew and exports were stimulated as a result of the collapse of the global timber market and the strategic need for timber. By 1920 the lumber companies in Paraná state supplied markets in São Paulo, Rio de Janeiro and Buenos Aires. As transportation improved with the development of a railroad connection between São Paulo and Rio Grande do Sul, logging of Araucaria forest became the major economic activity in Paraná. This is referred to as the 'Paraná pines' economic cycle (Koch and Correa, 2002).

After 1945 post-war European colonization changed as Italian and Polish migrants settled in the southwest of Paraná. Rural villages became established, coinciding with rapid urban expansion (Voltolini, 2000). In thirty years, from 1945 to 1975, 3.3 million Araucaria trees were removed, i.e. 23 million cubic meters of wood. The wood companies sold to rest of the country and abroad.

The geographer R. Maack (1939) stated: "What the men in Paraná did by felling and burning the woods is indescribable. In no other country in the world, woods are as ruthlessly destroyed as here; and huge wooded areas that in 1926 impressed me so such for their primitive grandiosity, in 1930 were just thickets" (Koch and Correa, 2002). In 1926 a journalist and historian, Romário Martins, suggested that a law should be passed to protect the Araucaria forest in Paraná state with the creation of conservation areas. This proposal was visionary for the time (Koch and Correa, 2002).

Today, *A. angustifolia* is on the list of Brazilian flora threatened with extinction and listed in the IUCN Red Data Book as vulnerable. The State of Parana covers 19.5 million hectares, representing 2.3% of the country of Brazil. Eight-two percent of its population of 9.5

million people reside in urban areas. Paraná State's agricultural production is the highest in Brazil, representing 23% of agricultural production of the country.

Table 1: Evolution of forest cover in the state of Paraná

Year	Araucaria forest (ha)	Remaining of forest (%)	Forest cover in the state (%)
1890	7.378.000	100	36,9
1930	3.958.000	53,60	19,8
1937	3.455.000	46,8	17,3
1950	2.522.400	34,2	12,6
1955	2.203.200	29,9	11,0
1960	2.043.200	27,7	10,2
1963	1.567.700	21,2	7,8
1965	1.593.200	21,6	8,0
1973	433.500	5,9	2,2
1974	316.620	4,3	1,6
1977	151.620	2,1	0,8
1984	269.631	3,7	1,3

Adapted from (Castella and Britez, 2004)

Between 1960 to 1970 an estimated 240 000 hectares of forest were felled every year in Paraná, for the purpose of expanding the agriculture frontier in the west of state (Gubert Filho, 1990). A brief history of Araucaria logging in the state of Paraná is given in **Table 1**.

The data in table 1 were obtained from the results of different projects, carried out with different technologies, so it is difficult to compare the relative numbers directly. However, the data clearly reflect the massive logging of this forest ecosystem (Castella and Britez, 2004).

Since the start of commercial exploitation, the practices adopted to harvest Araucaria were not inspired by a philosophy of sustainable use. Surveys of secondary araucaria forests harvested more than 50 years ago (Bittencourt et al., 2005), showed that the numbers of juvenile and adult araucaria trees that were expected to have originated from natural regeneration were not found. Only when weeds were controlled and when the light needed for regeneration was manipulated by silvicultural treatments did new trees do well.
In 1993 the Brazilian government introduced new legislation (*Decreto-lei* no 750) that established rules for the sustainable management of Araucaria forests. According to the

rules adopted in Paraná State, only trees with more than 40 cm dbh (diameter at breast height) could be logged and at least ten mother-trees in this diameter class per hectare had to be left unlogged.

Araucaria harvesting was prohibited by law in 2001 when surveys showed that less than 3% of the original Araucaria forest cover remained as fragmented forest land (FUPEF, 2002); (Castella and Britez, 2004).

The transformation of most Araucaria native forests into pasture and arable land caused the extinction of many natural populations. Before the adoption of sustainable management regimes, the dysgenic selection that had occurred in exploited populations contributed to reducing their genetic variability to levels now low enough to compromise their use for conservation and breeding purposes (Bittencourt et al., 2005). As a result, restoration, conservation and breeding program are urgently needed and should be based on an understanding of the genetic structure of the remaining populations.

Awareness is growing in Brazil that *Araucaria angustifolia* is vulnerable. While not yet under threat of extinction, several geographic populations have already been lost. Many areas once occupied by araucaria are now used for cattle grazing or for plantations of fast-growing exotic trees. Reforestation programs have thus far been limited both in number and in success, and this may be related to the limited information on many important ecological and physiological features of the species (Bittencourt et al., 2005). No restoration plan has been implemented or developed.

The Brazilian government is now promoting several initiatives to protect araucaria genetic resources. For example, the law prohibits harvesting of naturally regenerated araucaria trees (PN-COMANA 278, July 18, 2001). More recently, the federal government selected five regions in Paraná State where genetic conservation of araucaria forests is a priority (PN MMA 507, December 20, 2002). Under this legislation, araucaria or other native species must be used in any expansion of forest plantation. However, financial constraints have limited the Brazilian government's ability to buy properties in order to establish conservation units like National Parks or Reserves.

The government of Paraná State has been involved in this effort through the establishment of 'biodiversity corridors' by state agencies. This is a multi-institutional initiative. It aims to

increase connectivity between the araucaria forest fragments which are of interest for genetic conservation. This project is supported by, the Critical Ecosystem Partnership Fund (CEPF); Conservation International (CI); the Global Environment Facility (GEF); the Government of Japan; the MacArthur Foundation and the World Bank. The project is part of a program designed to safeguard the world's threatened biodiversity hotspots in developing countries.

3.2 The future

The current, poor condition of natural Araucaria forest in Brazil is a consequence of the lack of an effective management plan for native forests that combines ecological, genetic, social and economic factors. At the moment arable crops, especially soya bean and corn, and forest plantations of exotic species are seen to be more profitable (Bittencourt et al., 2005).

Scientific knowledge obtained from studying the genetic diversity found in remaining araucaria populations(Bittencourt et al., 2005) is important for effective restoration plans:

1) Establishment of new araucaria plantations combined with collecting non-timber forest products (NTFP) by farmers and private forestry companies in remnant Araucaria forest. This option will require genetically improved seeds and efficient agro-silvicultural techniques to increase the profitability of the araucaria plantations.

2) Government or private initiatives to establish in situ and ex situ conservation programs for araucaria. These initiatives will require substantial financial resources in order to purchase, establish and maintain conservation areas. The creation of Private Nature Protected Reserves (RPPN) in araucaria forest areas, mainly by volunteer landowners, can lead to successful outcomes. However, local stakeholders would like to see the responsibility for this undertaking shared by local government with incentives and subsidies. Local landowners have expressed the opinion that the government should either buy the land to establish 'conservation areas' or it should provide subsidies to local stakeholders to maintain the current araucaria forest cover intact until scientifically-based, sustainable forest management practices are defined and adopted. This position has led to delays and so several araucaria forest fragments, extremely valuable for the conservation of the species genetic resources, have yet to be protected.

There is yet another management approach for Araucaria forests that could be considered (Bittencourt et al., 2005). It involves the cultural landscape-based system for natural resource management used by small farmers in the Paraná forest, called *faxinal* (Box 1). Historically, the Paraná countryside was organized into communities that kept agricultural land for individual use and forest land for common use.

The system is still practiced in some parts of Paraná State (Bittencourt and Higa, 2004). Nevertheless, while many of the existing araucaria forest fragments are found within these communal land management units, the system is not now sustainable for the species in the long run because the forest is being used for grazing and this adversely affects natural regeneration of araucaria trees. With modifications to the traditional faxinal system, the long term conservation and sustainable use of araucaria would stand a good chance of success.

Box 1. Faxinal: a traditional agroforestry system in the Brazilian *Araucaria angustifolia* forest region (Bittencourt et al., 2005)

Some rural communities in Paraná State (Brazil) still practice a traditional agroforestry system called faxinal. Immigrants introduced it in the 19th century. In this system, the community uses forestland for timber and non-timber forest products (NTFP), and for grazing for domesticated animals (mainly cattle, horses and pigs). The system is designed around collective use of land for animal production and is associated with low extraction of forest products, and a regular inflow of income to the communities is thus procured. Non-timber tree species like *Ilex paraguariensis*, whose leaves are used to make a tea called '*erva-mate*', play an important role in the system. *I. paraguariensis* occurs naturally in araucaria forests and its survival is dependent on their conservation.

Individual families in faxinal communities cultivate annual crops such as maize, black beans and cassava outside the native forest land, which is fenced in order to keep the animals inside and away from the cultivated areas. Some medicinal plants are grown in home gardens.

The faxinal system has contributed to the conservation of many of the remaining araucaria forests. Despite their ecological, social and cultural advantages, there are fewer and fewer faxinais today, mostly because traditional practices make it hard for them to compete with higher tech farming systems found in neighbouring areas. While the faxinal is a subsistence system with much lower agricultural and livestock production than modern farms, improvements in communal natural resource management could help the smallholder families remain on their traditional lands, improve their living conditions, and secure at the same time the conservation of the remnant natural araucaria forests.

The need for genetic conservation of araucaria forests has been recognized in Brazil since early in the last century. However, few government initiatives were undertaken to establish conservation areas (National Parks or Reserves) in the natural habitat of araucaria, though some plantation field trials occurred between the 1950s and the 1980s. Up until 1979, only about 90 000 ha of plantations had been established in Brazil (Shimizu, 1980). The reasons for this modest interest in araucaria plantations are thought to be: a) a lack of knowledge about the most suitable abiotic factors (soil and climate) conditions for wood production, b) difficulties in obtaining seeds from selected sites, c) the unavailability of genetically improved seeds, d) the absence of specific silvicultural techniques, and e) the slow growth rate of the species when compared to *Pinus* or *Eucalyptus* species (Shimizu, 1980).

Araucaria forest management procedures adopted in Brazil during the 19th and 20th centuries allowed for the removal of trees with 40 cm dbh or greater. It was believed that the remnant trees would retain the genes of the population gene pool and would produce the seeds needed for natural regeneration. However, evaluation of this management approach by IBAMA showed that it produced rates of natural regeneration lower than expected. As a result, legislation was changed in 1990 (O.S. IBAMA-PR 024/90) whereby at least 35% of trees above 40 cm dbh were required to be left uncut. Nevertheless fragments of araucaria forest continued to be harvested until 2001 when a new law (PN CONAMA 278) was passed that prohibited harvesting araucaria trees from any natural population in Brazil. This law brought significant changes to araucaria forest management, with NTFP becoming the main alternative cash-generating option for araucaria forests. Extraction of NTFP required a different approach to forest management, with the participation of local people being seen as a key to establishing viable and useful management strategies.

4. Conclusion

The combined threats of forest clearance for agriculture and the planting of exotic species, especially *Pinus spp.,* is leading to a continuing decline in the distribution and abundance of *A. angustifolia.* Whilst new laws are being drafted and implemented to protect the forest, a greater understanding of the genetic diversity and functional connectivity of the remaining fragments is required for the development of an effective conservation strategy.
This is being achieved with a detailed analysis of the effects of land-use change on the genetic diversity of species and gene dispersal across the current landscape.

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