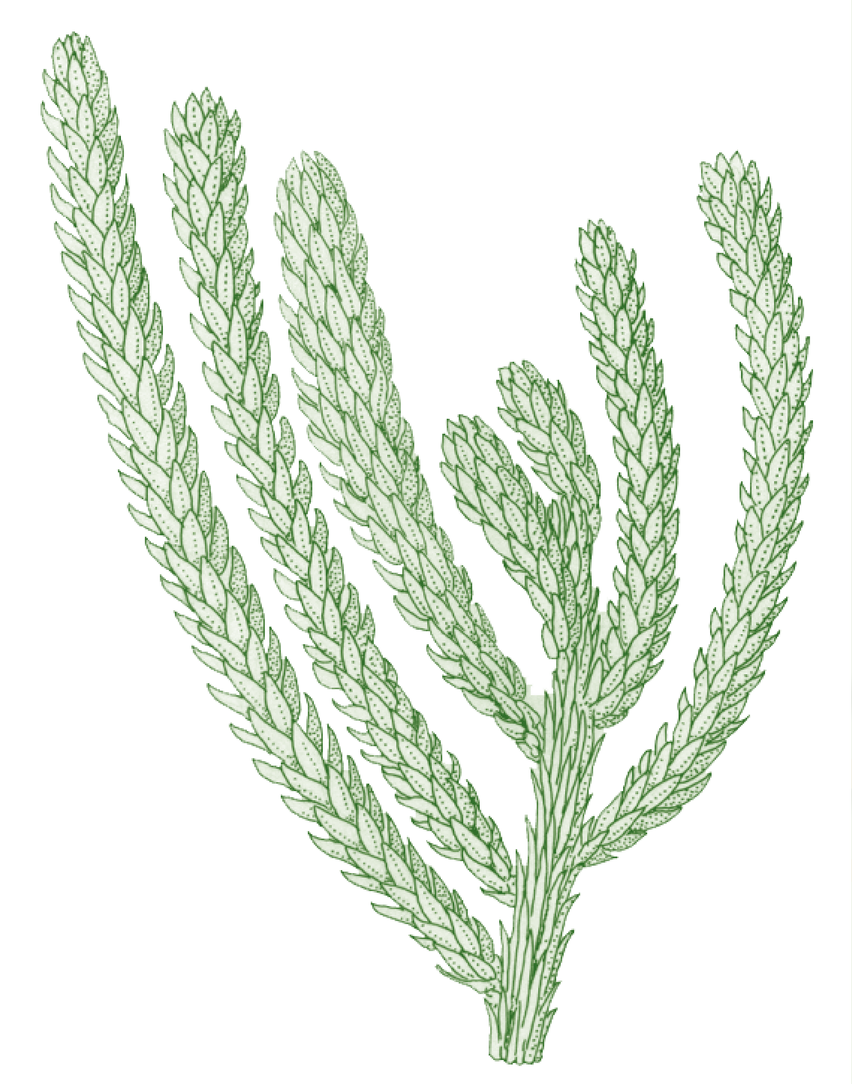
Forest Genetic Resources Training Guide

MODULE 3
Tree seed supply chains

Case study 3.1

Genetic bottlenecks in the restoration of *Araucaria nemorosa*

Chris Kettle and David Boshier



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Case Study 3.1

Genetic bottlenecks in the restoration of *Araucaria nemorosa*

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This paper presents information on *Araucaria nemorosa*, a critically endangered tree species endemic to a narrow area of the Pacific Island of New Caledonia. Use the information given here to map the seed/seedling supply chain and devise a strategy for collection and use of seed that will ensure the maintenance of genetic diversity in restoration efforts of this threatened species. The strategy should take into account both the levels of genetic variation found in the species and the forestry/socio-economic context of New Caledonia. **Make sure your supply chain and recommendations are specific and detailed**.

Step one - *A. nemorosa* seed/seedling supply chain – mapping

1. Draw a map (flow-chart) of the seed/seedling supply chain, from the source to end-use in restoration (from mother tree to a new seedling at the end use).
2. The map should identify:
   - Key actors (individuals, institutions) and processes in the *A. nemorosa* chain (what actors do).
   - Influences of the seed/seedling chain on the species genetic variation (bottlenecks, selection, genetic drift).
   - Social limits in the seed/seedling supply chain (e.g. policy/law, trade, institutional or capacity issues).

Step two - analysis

3. What are the genetic risks associated with the current seed/seedling system?
4. Make specific recommendations to improve the situation, addressing diversity issues in the seed/seedling system (e.g. practical ways to collect seed/seedlings that ensure genetic diversity in restoration).

In your group discussions you should, in particular, think about and respond to the following:

- How is human disturbance influencing genetic diversity in *A. nemorosa*?
- What are the mating system, seed and pollen dispersal mechanisms? What do these mean for conservation?
- What are the threats to *A. nemorosa* (short-term/long-term)? ***List problems*** by type: ***genetic*** (e.g. which populations are too small?); ***other types of problems*** (e.g. social, communication, resources - see Conservation status, Country profile section).

Introduction

New Caledonia is one of the world's 'biodiversity hotspots', with >3000 vascular plant species of which 77% are endemic. The rich flora and high endemism are thought to be due to its warm, wet climate, long isolation from other large landmasses, and unusual geology (half the island lies on ultramafic rocks, with soils very low in nutrients and high in toxic metals). Given the island's small size (19 000 km^2), its conifer biodiversity is particularly remarkable and important. All the island's 43 conifer species are endemic and represent almost 7% of the world's conifers, with 29 species classed as threatened (IUCN). New Caledonia has 13 of the world's 19 *Araucaria* species, 11 of which are classed as threatened.

Taxonomy and botanical features

Araucaria is a genus of evergreen coniferous trees in the family Araucariaceae. The 19 species in the genus have a highly disjunct distribution covering New Caledonia (with 13 endemic species), Norfolk Island, eastern Australia, New Guinea, Argentina, Chile, and southern Brazil.

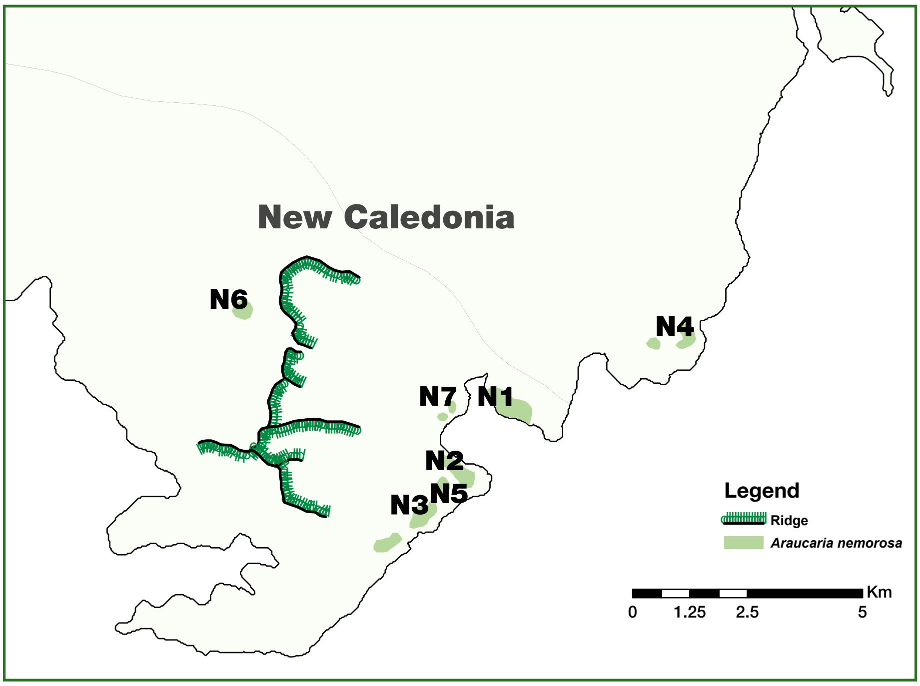
Araucaria nemorosa de Laubenfels: 3-20 m tall, 65-70 cm dbh (diameter at breast height), oval or conical crown. Branchlets 8-12 mm in diameter. Juvenile leaves needle-like, lanceolate, curved inwards, relatively thick. Adult leaves imbricate, lanceolate, narrow, scale-like, midrib prominent, 6-10 mm long by 1.5-3 mm wide. Male cone cylindrical, 8 cm x 14 mm, pollen triangular with six pollen sacs. Female cone ovoid, 11 cm by 5-9 cm, with reflexed bracts 12-20 mm long. Seeds up to 30 mm long, nut somewhat rectangular, wings broadly ovate.

Distribution

Araucaria nemorosa is the rarest of the New Caledonian Araucaria, extant in only eight known populations, with an area of occurrence of 9.8 km^2 and area of occupancy of 0.64 km^2 in the region around Port Boise (annual rainfall 2500-3000 mm). Almost all populations, except the tiny inland Forêt Nord population, are in coastal forest less than 2 km inland (altitudes <100 masl, usually < 20 masl). It is unclear whether the species' original distribution was wider. *A. nemorosa* dominates the arborescent stratum in maquis habitat at the extreme south of Grand Terre island (Fig. 1), while in some lowland forests it is a canopy emergent.

Most of the Araucariaceae species are distributed in the ultramafic soil (12 of the 13 *Araucaria* species including *A. nemorosa*, 4 of the 5 *Agathis* species) that dominates the south of the island. The soil supports a shrub-dominated habitat,

Figure 1. Distribution of *Araucaria nemorosa* in New Caledonia (from Kettle et al. 2008)



known as 'maquis' or 'maquis miniers' (mined maquis) as the rock is mined for nickel. The soil has very low concentrations of mineral nutrients and very high concentrations of metals (chromium, nickel, manganese) which are more or less toxic to plants. Worldwide, it is relatively unusual to find species that grow only on ultramafics, but this is not unusual in New Caledonia both for conifers and angiosperms. New Caledonia split from Gondwana between the Triassic and end of the Jurassic periods, prior to formation of the ultramafics. It is suggested that rapid adaptive evolutionary radiation in the conifers occurred in response to new edaphic conditions (ultramafic soils) after New Caledonia became an island, a fairly common situation in island biogeography – analogous to Darwin's finches on the Galapagos.

Uses and potential value

The species may have been used in the past for timber production, posts, poles, and roundwood, but such use is now prohibited owing to the species rarity. *A. columnaris* is of great symbolic importance to the indigenous Kanak people, but there is no published evidence as to whether this also applies to other *Araucaria* species in the area. As with many other *Araucaria* species, its greatest potential future value is as an ornamental, while CIRAD (Centre de coopération Internationale en Recherche Agronomique pour le Développement (see Table 3) aimed to explore its use for silviculture (timber) and post-mining re-vegetation.

Trial results

The remnant stands show variable density (mean basal area 5.29 m^2ha^{-1}, range 0.72-10.04 m^2ha^{-1}), with seedlings/saplings more common (dbh 0-5 cm) than any other size class. A paucity of trees in 5-20 cm dbh size classes indicates a lack of recruitment of seedlings/saplings into the mature population. The species may however rely on disturbance for effective recruitment, such that successful regeneration is episodic rather than continuous. Extrapolated growth rates from planted trees in less hostile soils, suggest the oldest trees are at least 90 years and probably many hundreds of years old.

Conservation status

A. nemorosa is classified under IUCN criteria as critically endangered (CR. B1+2c), i.e. the species faces an extremely high risk of extinction in the wild in the immediate future, as defined by these criteria:

B) Extent of occurrence estimated to be less than 100 km^2 or area of occupancy estimated to be less than 10 km^2, and estimates indicating both of the following:

1) Severely fragmented or known to exist at only a single location.
2) Continuing decline, observed, inferred or projected, in any of the following:
   c) area, extent and/or quality of habitat.

Over the last 150 years, increased fire frequency, introduction of mammals, logging and mineral mining have led to extensive habitat degradation, with less than 30% of the original vegetation remaining. Some 70% of the remaining stands of *A. nemorosa* (populations 1-6) are on the land of one family who are reported to be interested in the welfare of the populations and have a good working relationship with the Service de l'Environment. There is a need to develop restoration strategies for *A. nemorosa* that will augment current population numbers, re-establish populations on former sites and prevent escalation of associated genetic problems in wild seedling cohorts (reductions in genetic diversity and elevated inbreeding).

To achieve these restoration objectives, seedlings are currently reared in nurseries for planting on open ground that has been stripped of vegetation following mining activity or fire disturbance. Two contrasting methods have been used to obtain seed for *A. nemorosa* restoration: 1) direct collection of cones from mature trees and, 2) gathering freshly fallen seed from the forest floor. The genetic study below compared genetic attributes of two nursery stocks of *A. nemorosa*, one derived from a cone collection and the other from seed from the forest floor.

Phenology

A. nemorosa is a long-lived hermaphrodite tree, regenerating sexually by large female cones which bear several hundred seeds. Prompt collection of fallen seed is necessary as germination takes place within a number of days of release from the cone, while long-term storage is problematic as the seed is recalcitrant. Many seeds, though apparently normal, are not viable, restricting the potential of small remnant populations to regenerate. A survey in two 0.04 ha plots in each of six populations of *A. nemorosa*, covering most known sites (N1, N2, N3, N5, N6, N7; Fig. 1, Table 1) estimated:

i. density of adults of reproductive size
ii. proportion of reproductive size trees bearing cones
iii. variance in female cone production between reproductive size trees

Within each plot, all *A. nemorosa* trees with a stem diameter >2 cm were recorded, with dbh measured in trees >1.4 m tall. In the remaining smaller individuals, diameter was measured at a representative stem height. Each tree was scored for the presence and number of mature female cones.

Table 1. Distribution of mature cone production by *A. nemorosa* in two 0.04 ha plots in each of six natural populations

Population	Code	Area (ha)	N	Sample	Trees >15cm dbh	#trees with cones	#cones/ coning tree	Mean dbh of trees, cm	Minimum dbh of cone bearing tree, cm
Kaanua	N1	22.68	>1000	25	13	1	2	14.9	16
Vane	N2	15.72	>1000	15	8	1	7	25.6	48
New Forest	N3	15.2	>1000	63	45	4	1,2,3,3	18.2	18.5
Mini Nuri	N5	1.28	<500	36	22	4	2,2,7,5	18.4	22.5
Forêt Nord	N6	0.44	93	28	11	5	1,1,1,3,9	17.1	32.7
Natasha's	N7	1.48	<100	62	23	2	2,8	12.9	23.5

N is the estimated size of the population based on counts of mature trees from photographs taken at high elevation or direct counts; dbh is diameter at breast height.

Cone production in all six populations of *A. nemorosa* was very low with a high proportion of adult trees bearing no mature female cones (Table 1). The smallest tree with female cones was 16 cm dbh. Assuming all trees >15 cm dbh were sexually mature, the mean percentage of sexually mature trees bearing mature female cones was 13.9%, with 7.7% and 45.5% of mature trees bearing mature cones in Kaanua (N1) and Forêt Nord (N6), respectively. Within populations, there was high variation in female cone production among trees, with the variance in cone production twice and four times as great as the mean value in N5 (mean=3; r^2= 6) and N6 (mean=3; r^2=12), respectively.

In a preliminary assessment of the number and variability of viable seed set per cone, 13 mature cones were collected from populations N1 (1), N3 (4), N5 (6) and N7 (2). Mining activities meant cones could not be collected at Forêt Nord (N6). Cones were dissected and the number of seeds per cone recorded. The proportion of floating seeds was used as a minimum estimate of non-viable seeds, as seeds lacking embryos invariably float, while seeds which sank were assumed to be fertile. Seed set per cone, suggests that viable seed number can be very low in *A. nemorosa* with a high variance among cones. The number of seeds (filled+unfilled) produced per cone averaged 339 (range 279-422). However, the percentage of filled seeds per cone was very low and highly variable. Over 50% of the cones produced fewer than 10 filled seeds, while a single cone produced 125 filled seeds, so that >50% of the putatively viable seed from the 13 collected cones was from one cone.

Genetic variation in remnant populations, natural regeneration and nurseries

In 2001, two nurseries collected seed from two populations (Kaanua and Forêt Nord) for use in habitat restoration and to study the species' silvicultural potential. Kaanua (N1) is one of the largest populations of *A. nemorosa*, while Forêt Nord (N6) is the smallest, most isolated, and only inland population, located in a currently expanding nickel processing development by the Vale Inco mining company (Fig. 1, Table 1). One nursery, run by the Institut Agronomique Néo-Calédonien, collected cones from approximately 30 trees in Kaanua. The second nursery (Vale Inco) sampled newly fallen seed from an unknown area of the forest floor of Forêt Nord. After germination, seedlings were potted out and reared under shade in the nurseries. Germination rates were generally low (30–40%).

To study the genetic consequences of habitat degradation and the restoration efforts for *A. nemorosa* genetic markers (nuclear Simple Sequence Repeats - nSSR) were used to compare levels of genetic diversity and inbreeding among remnant wild populations (adults and established seedlings) and the two nursery populations derived from them. Forty seedlings were sampled from each of the nursery populations and from the same number of wild established seedlings (estimated age range 1-5 years) and adult trees in the same source populations (N1 and N6). Sampling extended over the full area of each population.

Genetic diversity in adult, wild seedling and nursery seedling populations

All seven nSSR loci assayed were polymorphic in wild seedling and adult cohorts from Kaanua and Forêt Nord, and in the Forêt Nord nursery sample. There was no significant difference ($P > 0.05$) in allelic richness or gene diversity among the Kaanua wild seedling and adult samples. However, nursery seedling stock from Kaanua was monomorphic at one locus and had significantly lower allelic richness (AE, $P < 0.05$) and gene diversity (He, $P < 0.05$) than the corresponding wild seedling and adult cohorts (Table 2). In contrast, there was no significant difference ($P > 0.05$) in allelic richness or gene diversity between nursery seedlings from Forêt Nord and either wild seedlings or adults from the same source population (Table 2). The percentage of rare alleles (frequency <0.1) was much lower ($\chi 2 = 21.9$, $P < 0.001$) in the Kaanua nursery seedling stock (N1N 38%) than in the wild seedling (N1W 74%) and adult cohorts (N1A 84%). In contrast, there was no evidence of a difference in the proportion of rare alleles among nursery seedlings, wild seedlings and adults at Forêt Nord ($\chi 2 = 0.132$, $P > 0.05$).

Table 2. Genetic diversity measures, percentage of rare alleles (frequency <0.1) and inbreeding coefficients for adult (A), wild seedling (W) samples derived from six natural populations and two nursery seedling (N) populations of *A. nemorosa* (n=40 for all samples).

Population	Code	Sample	$A_{E\ (S.E.)}$	$H_{e\ (S.E.)}$	% rare alleles	F_{IS}	N_e
Kaanua	N1	A	9.53 (2.46)	0.72 (0.09)	84	0.135*	
Kaanua	N1	W	8.83 (1.90)	0.71 (0.09)	74	0.194*	30
Kaanua	N1	N	2.81 (0.46)	0.46 (0.09)	38	-0.024n.s.	1
Forêt Nord	N6	A	6.12 (1.11)	0.65 (0.07)	68	0.009ns	
Forêt Nord	N6	W	5.59 (0.90)	0.62 (0.07)	65	0.168*	11
Forêt Nord	N6	N	6.40 (0.87)	0.69 (0.05)	65	0.282*	N/C
Vane	N2	A	7.9	0.64		0.135*	
Vane	N2	W	7.5	0.66		0.188*	
New Forest	N3	A	8.4	0.73		0.066	
New Forest	N3	W	7.3	0.69		0.219*	
Cap Reine	N4	A	7.4	0.70		0.160*	
Cap Reine	N4	W	7.0	0.68		0.241*	
Mini Nuri	N5	A	6.6	0.64		0.123*	
Mini Nuri	N5	W	6.8	0.64		0.142*	

A_E = allelic richness, H_e = gene diversity, F_{IS} = inbreeding coefficient within samples, S.E. = standard error, not available for populations N2-N5. Significance of differences from F_{IS} = 0 are shown; *P < 0.05, n.s. = non-significant. N_e = effective size of populations giving rise to wild seedlings and nursery seedlings. N/C = Not calculable (negative estimate obtained)

Inbreeding and genetic differentiation

In addition to the collections from N1 and N6, leaf needles were also sampled from 40 adults and seedlings in populations N2-N5 (Table 2; Fig. 1). Across the six populations the inbreeding coefficient (F_{IS}, heterozygosity deficit under Hardy-Weinberg expectations) was nearly twice as high in seedling populations as in the adults (mean F_{IS} = 0.192 and 0.108, respectively, P = 0.017). Although the difference was not significant at individual sites, all seedling populations had a higher inbreeding coefficient than the adults from the same site.

There was no evidence of inbreeding in the nursery seedling stock from Kaanua (F_{IS} -0.024), in contrast with the samples of wild seedlings and adults from the same site which showed significant inbreeding (F_{IS} values of 0.194 and 0.135, respectively, Table 2). At Forêt Nord the situation was different, with the inbreeding coefficient increasing from adult (F_{IS} = 0.009) to wild seedling (F_{IS} = 0.168) to nursery seedling stock (F_{IS} = 0.282).

There was no significant genetic differentiation (F_{ST}, values not shown) between adult and wild seedling cohorts across the six populations. Pairwise F_{ST} estimates, measuring genetic differentiation between wild (adult and seedlings) and nursery samples taken from the same site, indicated significant differences (P <0.05) between nursery seedling stock and both adult and wild seedling samples at Kaanua (F_{ST} = 0.160 and 0.167, respectively) showing sampling effects in the seed collection. Significant genetic differentiation was also found between nursery seedling stock and adult and wild seedling samples at Forêt Nord (P <0.05), but the degree of differentiation was only a quarter of that at Kaanua (F_{ST} = 0.042 and 0.047, respectively). Pairwise F_{ST} values showed genetic differences between the six populations which are likely due to their small population sizes.

The isolated inland population N6 was genetically the most distinct (pairwise F_{ST} values approximately twice those of other pairwise population comparisons).

Effective size of adult population

The effective size of the adult population contributing genes to wild and nursery seedling cohorts was calculated from changes in gene diversity between adult and seedling samples (Table 2). At Kaanua the estimated effective number of adult trees contributing to the wild seedling cohort was large (N_e = 30), while for the nursery stock the effective number was very small (N_e = 1). At Forêt Nord, the estimated effective adult population contributing to the wild seedling cohort was moderate (N_e = 11), while the slight increase in gene diversity in the nursery seedling stock compared with adults gives no evidence of a restricted number of adults contributing to the nursery seedlings at Forêt Nord, even though it was not possible to calculate the effective adult number.

Sampling of material for the nursery stocks and for genetic analysis and assessments of reproductive output were carried out in different years. Thus, the information on reproductive demography cannot be used to directly account for any diversity and inbreeding differences in nursery stock compared to wild source populations. Instead, the reproductive biology survey gives a general indication of seed set and viability in the species.

New Caledonia profile *(based on 2002 submission to FAO)*

Introduction

- Area: 238 539 km^2, most lies below 600 masl (metres above sea level); <10% above 300m; very few areas >1000masl.
- Population: 244 600 (January 2008).
- GDP per capita: US$25 485 (2004), relatively high compared to other overseas territories. Standard of living: similar to the EU. Economy and environment are vulnerable despite natural resources.
- World's fourth largest nickel producer (25% of global reserves). Mining regulated by three different provinces with imbalances that are detrimental to the Northern Province in particular.
- Per capita Gross National Product is US$11 800. Local consumption of saw timber in 1997 was 18 196 m^3, of which 18% (3 220 m^3) came from local production, compared to 30% in 1987. In 1997, 82% (14 976 m^3) of saw timber requirements were imported, compared to 70% in 1987, primarily conifer wood from Australia, Fiji, New Zealand and USA.

New Caledonia is a French overseas territory comprising several Melanesian islands in the southwest Pacific, some 1200 km east of Australia. It has its own administrative structures and institutions that are gradually acquiring more autonomy. New Caledonia was 'discovered' by Captain Cook in 1774 and named after old Caledonia (Scotland) as some parts of the island looked like Scottish moorland. Melanesians, known as Kanaks in New Caledonia, colonized New Caledonia 3500 years ago. In contrast with most tropical areas that face more acute threats from rapid population growth, extreme poverty, dysfunctional or non-existent government institutions, the territory's native flora is reasonably intact. New Caledonia's comparative wealth (per capita income similar to Australia and New Zealand), coupled with its current political and economic stability, preclude many of the devastating activities that lead to degradation and loss of millions of hectares of native vegetation in the tropics. New Caledonia nevertheless faces serious threats to its rich biodiversity through habitat destruction and species extinction. The situation is already critical for the tiny fragments of sclerophyll forest that remain, and could quickly become so for the island's other ecosystems, especially if the political environment deteriorates. New Caledonia is not resource-rich and its current prosperity is vulnerable. Appropriate action is required to protect an area of remarkable botanical diversity. Failure to do so, however, may condemn it to the same irreversible fate that so many other tropical floras have suffered.

Forest resources

New Caledonia is an ancient landmass that broke off Australia 85 million years ago, in the process saving ancient plants from that time period which have gone extinct elsewhere. The terrestrial vegetation of New Caledonia can be divided into three major native vegetation types: maquis scrub, rain forest, and tropical dry forest. Species endemism is highest in maquis vegetation (91%), a characteristic scrub-like heath on ultramafics, and in rain forests (87%), which occur both on and off these substrata. Endemism is lower in remnant stands of sclerophyll forest (59%), which are New Caledonia's most threatened habitat type, covering only 2% of its original, approximately 4500 km^2 area. An estimated 50 species face extinction or have already been lost from the New Caledonian flora. The threat to the flora and vegetation in the other principal habitats is currently much lower than in most tropical areas because of the island's comparative political and economic stability.

New Caledonia has a protected area network covering 22% of its land. However, the 24 reserves in IUCN categories I-IV cover only 2.6% of the land). Furthermore, 83% of New Caledonia's threatened plant species do not occur in any protected area. All higher altitude forests and 90% of the rain forests are protected by legislation, by relief or by their isolation. Several vegetation types are insufficiently represented in the protected areas network (Table 4), including: 1) sclerophyll forest, 2) mangrove vegetation, whose floristic composition differs between the east and west coasts, 3) moist evergreen forest primarily on non-ultramafic substrata in the north and centre of Grande Terre, 4) forests in the Loyalty Islands, and 5) maquis on various substrata, mostly in the north and northeast of the island. The primary threats are uncontrolled fires, land clearance, cattle ranching and deer. Strong winds and hurricanes cause some damage in open forests (plantations, arborescent savannah, etc.). In all logged forests (currently less than 40 ha/year), the Forest Service monitors application of regulations and of permits. With no large clear fellings, logging practices cause little deforestation, but damage to young trees and regrowth may be serious. Over-exploitative logging could be dangerous for some gregarious, dense and particular populations (e.g. *Agathis lanceolata*, *A. moorei*, *Araucaria columnaris*, *Arillastrum gummiferum*, *Intsia bijuga*).

The absence of a clearly articulated environmental policy, lack of effective management for protected areas and poor enforcement of protective legislation are major obstacles to effective long-term conservation. Only half of the existing parks have any restrictions on mining within their boundaries, and the others are open to mining activities. Nickel mining from 1950 to 1975 damaged and destroyed many landscapes and mountains in the south and west of the mainland. Great quantities of waste were produced and dumped into the nearest valleys, due to the absence of any control, with mangroves and lagoons polluted by sedimentation. Several species (e.g. *Agathis ovata*, *Araucaria montana*, *Arillastrum gummiferum*) are still cut and destroyed as present regulations are not sufficiently severe and the Provinces do not have legal jurisdiction over mining. The impact is however mostly localized. There is little conservation awareness among the population of New Caledonia, particularly with respect to terrestrial habitat. There is a need to control and inform landowners, and efforts toward this started in 1994 in Southern Province, and 1991 in Northern Province. Despite public education and efforts of fire-fighters, large areas are burnt each year (e.g. 3000 ha in 1996; 21 700 ha in 1997). Funding conservation work is difficult, as agencies like the World Bank and European Union will not designate money for work in New Caledonia, which is technically part of France. France recently made the conservation needs of the island a priority.

Forestry and phytogenetic resources

There are six New Caledonian institutions working in connection with forest resources (Table 3), with trained, experienced staff. There is some shortage of technicians, but the equipment is efficient and sufficient. The large area of New Caledonia, the scattered nature of the forests, the difficult choice of appropriate stands, land tenure, competition with agricultural or industrial projects, and costs, all complicate the roles and actions of the institutions.

Table 3. Institutions in New Caledonia active in the sphere of forest genetic resources

Name and principal location(s)	Specialities
Research Institutes	
Research Institute for Development (IRD) (formerly ORSTOM) Nouméa (Southern Province)	Botanical and ecological studies Specific censuses Trials on mining stands International cooperation New Caledonia herbarium New Caledonia publications
International Cooperation Centre on Agrarian Research for Development (Centre de coopération internationale en recherche agronomique pour le développement - CIRAD) Nouméa (Southern Province) Port Laguerre (Southern Province)	Forest researches and studies Forest census Genetic selection and improvement Collection and storage of seeds Monitoring of trials and seed orchards International and regional cooperation
Public Administration	
Rural Development Department of the Southern Province (Forest office) Nouméa (Southern Province)	Plantations, nurseries Control of logged forests Funds for industry and private projects
Department of Natural Resources of the Southern Province - Environment Service Nouméa (Southern Province)	Environmental regulations, controls, monitoring, relationships and surveys Local cooperation
Department of Natural Resources the Southern Province - Park and Conservation Areas Service Nouméa (Southern Province)	Monitoring, education, surveillance and avifauna census in the terrestrial areas
Forest, Timber and Environment Service of the Northern Province Koné (Northern Province)	Monitoring of plantations, natural forests and public nurseries Forest and environmental regulations, surveys and controls Education of public and in schools Local and regional cooperation Funds for timber industry and private projects Road building and maintenance
Agriculture and Forest Dept. of Territory of New Caledonia Nouméa (Southern Province)	Public and state funds Application of international conventions Timber statistics (Local production + importation) Other forest and environmental issues
Agriculture and Forest Dept. of Territory of New Caledonia Nouméa + Tontouta Airport (Southern Province)	Introduction of plants and exportation of animals

Table 4. Target forest types and species for conservation actions

Actions		
Improving knowledge and conservation of habitats of special interest, addressing: ecology; regeneration; threats; growth; development; awareness raising among visitors, landowners and users; census; plantations; regulations; conservation areas; ecotypes and provenances; monitoring; and education.		
Target forest type	Conservation rate [(1)]	Major target species and genera
Forests and trees on the ultramafic mountains and mining areas	30 %	*Agathis lanceolata*, *Agathis ovata*, *Araucaria montana*, *A. nemorosa*, *A. rulei*, *A. scopulorum*, *A. bernieri*, *A. biramulata* *Arillastum gumiferum*
Chalky forests	0 %	*Araucaria columnaris*, *Intsia bijuga*, *Manilkara pancheri, Santalum austrocaledonicum*
Trees and other plants of the sclerophyll forests	3 %	*Terminalia cherrieri*, plus species from the genera *Cupaniopsis*, *Diospyros*, *Eugenia*, *Phyllanthus*, *Syzygium*
Rain forests and high altitude forests on schist	5 %	*Agathis spp., Araucaria schmidii*, *Calophyllum caledonicum*, *Crossostylis spp.*, *Elaeocarpus spp.*, *Kermadecia spp.*, *Montrouziera cauliflora*, *Schefflera spp.*
Mangroves	0 %	Genera *Avicennia*, *Bruguiera*, *Exoecaria*, *Rhizophora*, etc.

1) Conservation rate is an indicative assessment of the current level of conservation in an ecosystem, derived from Conservation rate = Protected area/Total area

Information sources

This study is based on the following papers.

Kettle CJ, Ennos RA, Jaffre T, Gardner M, Hollingsworth PM. 2008. Cryptic genetic bottlenecks during restoration of an endangered tropical conifer. Biological Conservation 141:1953–1961.

Kettle CJ, Hollingsworth PM, Jaffre T, Moran B, Ennos, RA. 2007. Identifying the early genetic consequences of habitat degradation in a highly threatened tropical conifer, *Araucaria nemorosa* de Laubenfels. Molecular Ecology 16:3581–3591.

Papineau C. 2002. State of forest and tree genetic resources in New Caledonia. Prepared for Regional Workshop on Forest and Tree Genetic Resources for Oceania, FAO/SPRIG (AusAID)/PREP/PIFTSP (SPC), Apia, Samoa, 12-16 April 1999. Forest Genetic Resources Working Paper, No. FGR/33E. Forest Resources Development Service, Forest Resources Division. FAO, Rome (unpublished).

Forest Genetic Resources Training Guide

MODULE 1 Species conservation strategies

1.1 *Leucaena salvadorensis*: genetic variation and conservation
1.2 *Talbotiella gentii*: genetic variation and conservation
1.3 *Shorea lumutensis*: genetic variation and conservation

MODULE 2 Trees outside of forests

2.1 Conservation of tree species diversity in cocoa agroforests in Nigeria
2.2 Devising options for conservation of two tree species outside of forests

MODULE 3 Tree seed supply chains

3.1 Genetic bottlenecks in the restoration of *Araucaria nemorosa*
3.2 Tree planting on farms in East Africa: how to ensure genetic diversity?

MODULE 4 Forest management

4.1 Impacts of selective logging on the genetic diversity of two Amazonian timber species
4.2 Does selective logging degrade the genetic quality of succeeding generations through dysgenic selection?
4.3 Conserving *Prunus africana*: spatial analysis of genetic diversity for non-timber forest product management

MODULE 5 How local is local? – the scale of adaptation

5.1 Selecting planting material for forest restoration in the Pacific north-west of the USA
5.2 Local adaptation and forest restoration in Western Australia

Other modules to be published among the following:

Plantation forestry, Tree domestication, Forest restoration, Genetic modification