Sandalwood (*Santalum austrocaledonicum* Vieillard) in New Caledonia: Taxonomy, Distribution, Ecology

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Abstract

Sandalwood is represented in New Caledonia by a single species, *S. austrocaledonicum*, which is divided into three varieties showing different geographic distributions: the Nouméa area for the *pilosulum* variety, the foot of ultramafic rock formations for the *minutum* variety and the Loyalty Islands, the Isle of Pines and a few locations in New Caledonia for the *austrocaledonicum* variety. It is mainly limited to secondary vegetation stands with diverse flora, but can also be found in sclerophyll forest and in low altitude scrub, which could well be its original environment.

It grows in extremely varied soils, with a pH of 4 to 8 or more, containing a variety of exchangeable bases (Ca, K, Na); these soils may be rich in magnesium, nickel and chrome. Its foliar mineral composition features relatively high concentrations of nitrogen and potassium, low to medium-level concentrations of phosphorus and highly variable levels of calcium.

As in other Pacific islands, sandalwood, which is highly sought after for its wood and essential oils, has undergone intensive harvesting in New Caledonia. This overexploitation, along with the destruction of its original biotopes (sclerophyll forest and low-altitude scrub) by both agricultural and grazing activities and fire, has contributed to the growing scarcity of this species through the disappearance of numerous stands.

At the present time, the *minutum* variety, which may well be an edaphic scrubland variety, can only be found in a single location and must be considered as an endangered species. Urgent action is therefore necessary for its survival.

Introduction

Sandalwood is a shrub or medium-sized tree, infrequently exceeding 20 m in height, often with a diameter of less than 50 cm. It belongs to the genus *Santalum* of the *Santalaceae* family. In the first stages of its development, it is a non-specific obligate semi-parasite of herbaceous or ligneous host plants whose sap it sucks in through its roots.

Sandalwoods have been sought after since ancient times for the precious wood and the oils extracted from the heartwood used in perfume-making, or in the social life of certain peoples (*e. g. S. album* L. for funeral rites in India), the species have been heavily exploited. For this reason, *S. fernandezianum* F. Philippi, endemic to Juan

Fernandez, is presently considered extinct due to over-exploitation (Mabberley 1987).

Throughout the Pacific, sandalwood has been the target of unbridled exploitation which in fact turned into nothing more than looting by the sandalwood ships which plied the seas in search of this valuable wood. The practices of this era are widely documented in Shineberg (1973).

The different species have survived this overexploitation due to the plant's strong ability to regenerate from seed. Many populations have been destroyed or reduced by the combined effect of intensive harvesting and fire. It is necessary to implement protective measures in order to rehabilitate endangered populations whose still unknown genetic potential could, in the future, prove useful for the establishment of plantations.

The number of species of the genus *Santalum* is currently estimated at twenty. Its dispersal centre is Australia and New Guinea, which respectively have 7 and 2 species and thus belong to the "Australo-Papuan" phytogeographic unit (van Balgooy 1971). It is, however, widespread throughout the Pacific (Vanuatu, Fiji, Samoa, Tonga, French Polynesia, Hawaii) and extends westward as far as India with *S. album* L.

Taxonomically, the genus *Santalum* has been divided into three sections (Wagner, Herbst & Sohmer 1990) covering all currently known species:

- *Santalum* section for the following areas: India, Indonesia, Australia, New Guinea, New Caledonia, Vanuatu, Fiji, Tonga, Hawaii.

- *Hawaiensia* section: only in Hawaii.

- *Polynesica* section: for French Polynesia (Society Islands, Marquesas), Henderson, Juan Fernandez.

Sandalwood Taxonomy And Distribution In New Caledonia

The genus *Santalum* (Santalaceae) was the subject of a recent survey in New Caledonia (Hallé 1988). This author recognises only one species: *S. austrocaledonicum* Vieillard. On the basis of morphological variations linked to individual plants from several populations, he distinguishes three varieties for which it is presently difficult to state clearly whether the variations observed are genotypical or phenotypical in nature.

Taxonomy

S. austrocaledonicum (*Santalum* section) is a 2 to 3 m shrub or a small 6 to 12 m tree, with a short upright trunk, whose diameter rarely exceeds 50 cm. The bark is grey and shows lengthwise fissuring. The branches, which are usually short and upturned at the ends, carry a dense, shining, light-green foliage which gives the tree a rounded habit (Sarlin 1954).

The opposite leaves offer a great variety of forms. Initially, long and thin (5 - 9 cm x 0.5 cm) during the juvenile period (from seedling to 1 - 2 m at the age of 3), they

widen while decreasing in length in the adult form: 2 - 4 cm x 0.8 - 2 cm on average for the lamina with a petiole 0.6 - 1 cm long.

The inflorescences, with terminal or axillary panicles, are shorter than the leaves and somewhat thicker. The colour of the flowers varies from yellowish green to sandy white at the end of anthesis. The fruits, which are considerably less numerous than the flowers (1 for every 10 flowers on average), are elliptical or subglobose at maturity. In certain cases, they can have four sides of varying prominence.

In addition to the standard variety, *S. austrocaledonicum*, var. *austrocaledonicum*, two other varieties have been described (Hallé 1988): the *minutum* and *pilosulum* varieties, with the author basing the distinctive characteristics on the size of the lamina, the glabrousness and pilosity of young shoots and the perianth section, and finally the morphology of the interstaminate disk lobes. Comparative data for characteristics separating the varieties are shown in Table 1.

TABLE 1. Elements of comparison for the three varieties of *Santalum austrocaledonicum* Vieillard (Hallé 1988). Leaf: blade (B), petiole (P) (size and length in cm). Interstaminate lobes (size in mm). Aspect of inflorescence and perianth: glabrous (G), or villous (V).

Varieties	Leaf		Inflorescence		Perianth		Interstaminate lobes
	B	P	G	V	G	V	
austrocaledonicum	5 x 2	0.6-1.6	x		x		1.3 x 0.8
pilosulum	"	"		x		x	"
minutum	2 x 0.8	0.3-0.5	x		x		1.3 x 0.4

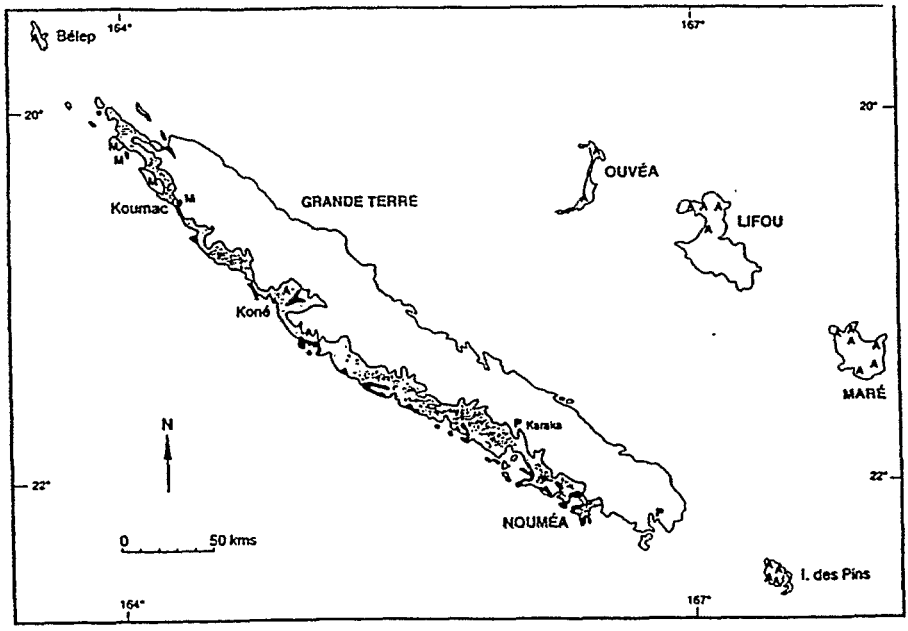
Distribution

Sandalwood has been observed in New Caledonia, the Loyalty Islands, the Belep Islands and on the Isle of Pines, with each variety occupying well-defined areas of distribution (Hallé 1988), as described below:

- *S. austrocaledonicum* var. *austrocaledonicum:* It is common to both the Loyalty Islands and Isle of Pines and can also be found in a few scattered locations in New Caledonia. According to the same author, this variety, although rare, may be found on certain islands in Vanuatu. In that case, it may be sympatric with the only species commonly recognised in this archipelago: S. *yasi* Seem. (*Santalum* section), which can also be found in Fiji and Tonga (Smith 1985). More recently, the species found in New Caledonia is noted as the only representative of the genus in Vanuatu (Daruhi 1991). Given the inability to make a definite determination because of the lack of observation of more complete material from Vanuatu, the problem of knowing whether or not *S. austrocaledonicum* is endemic to New Caledonia remains unresolved.
- *S. austrocaledonicum* var. *pilosulum* is endemic and is geographically limited to Nouméa and the surrounding area at low altitudes, only occasionally being found outside this area, at an altitude of 800 m (Karaka region: north-east slope of Mt. Do between Boulouparis and Thio).
- *S. austrocaledonicum* var. *minutum* is endemic and is sparsely distributed only in north-west New Caledonia (Koumac, Tiébaghi, Poum, Tanlé).

An overall survey of sandalwood's geographic distribution is given on the map in Figure 1.

FIGURE 1. Sandalwood distribution (Hallé 1988), A: var. *austrocaledonicum* and P: var. *pilosulum* within the sclerophyll forest:
Past Present
M: var. *minutum* in low-altitude mining scrub.



Phenology

The first flowering in *S. austrocaledonicum* appears after 6-7 years. It in fact occurs throughout the year, at least for the *austrocaledonicum* and *pilosulum* varieties, with, however, two main periods: from December to February and from June to August. The fruit takes 3 months to reach maturity and fruiting is usually abundant on each tree (Bailly 1986). One often sees both ripe fruit and young inflorescences on the same tree, as is the case for many species of the New Caledonian flora. Few observations, except those from the infrequent herbarium specimens, are available for the *minutum* variety, which is sparsely distributed and rarely harvested.

Ecology of Sandalwood

Climatic Conditions

Generally, under natural conditions, the various sandalwood species prefer mainly ligneous or ligno-herbaceous formations, which are evergreen, not too dense and heavily populated with secondary or climax vegetation in regions with low annual rainfall (Beadle 1981; Smith 1985; Wagner *et al.* 1990), from sea level to an altitude of 3000 m (Hawaii).

TABLE 2. Associated species of *Santalum austrocaledonicum* Vieillard, in different types of vegetation in New Caledonia. Braun-Blanquet's coefficient of abundance-dominance from + to 5; the species occupying more than 1/20 of the surface : scattered individuals +; not very abundant; abundant 2, the species occupying more than 1/20 of the surface; 1/20-1/4 = 2; 1/4-1/2 = 3; 1/2-3/4 = 4; more than 3/4 = 5. Locations as follows:- A1: Pinda; A2: Pouembout; B1: P/Forestier; B2: Ouen Toro; B3: Mont Venus; C1: Ouen Toro; D1: Paita; D2: Maré; E1: Boulinda; F1: Poum.

Associated Species / Type of Vegetation	Locality (see legend)									
	A		B			C	D		E	F
	1	2	1	2	3	1	1	2	1	1
Santalum austrocaledonicum Vieill.	1	+	+	1	+	+	1	+	+	+
A. Characteristic species of the sclerophyll forest										
Terminalia novocaledonica Daniker	2									
Archidendropsis paivana (Fourn.) Nielsen			3							
Omocarpum orientale (Sprengel) Merr.			+							
Diospyros pustulata F. White	2		2							
Alaeodendron curtipendulum Endl.	+		2							
Drypetes deplanchei (Brongn. & Gris) Merr.	2									
Cleistanthus stipitatus (Baillon) Muell. Arg.	1		1							
Fontainea pancheri (Bailon) Heckel	2									
Homalium deplanchei (Viell.) Warb.	2		1							
Captaincookia margaretae Hallé			2							
Psydrax odorata (Forster f.) AC.Sm. & Darwin	1		+						1	
Olea paniculata R.Br.	+						+	+		
Premna serratifolia L.	2	1		+						
Planchonella cinerea (Pancher) Royen	2									
Jasminum didymum Forster & Forster f.	1			1	3					
Gardenia urvillei Montr.	+	+	1		+					
Pleurostylia opposita (Willd.) Alston	+			+						
Casearia deplanchei Sleumer	+	+							1	
Casearia silvana Schltr.	1				3					
B. Characteristic species of secondary scrub										
Acacia spirorbis Labil.	+				3	5	+		3	1
Codiaeum peltatum (Labil.) Green, P.	1	2	1		1					
Croton insularis Baillon	1	2	2	1						
Lantana camara L.			+	+		+		+		
Leucaena leucocephala (Lam). De Wit			+	1	4	2	2			
Casuarina collina Poisson			+	+	5					
Dodonaea viscosa (L.) Jacq.			1	1	+			2		
Wikstroemia indica (L.) Meyer			+	+		1	+		+	
Acronychia laevis Forster & Forster f.		+	1				+	+	1	

In New Caledonia, *S. austrocaledonicum* behaves as a low-altitude heliophilic species. It is found in areas where the average annual rainfall is between 600 and 1750 mm. The "Karaka" site at an altitude of 800 m according to the herbarium sample collected by Brousmiche in 1881 (Hallé 1988) is, therefore, an exception and remains problematic.

Plant Formations

The most abundant sandalwood stands are located within the secondary formations of the sclerophyll forest in New Caledonia and in the dense rainforest growing on limestone in the Loyalty Islands and on Isle of Pines. These two types of forest have some floristic ties (Jaffré, Morat & Veillon 1994), attributed in part to rainfall conditions, which, in the Loyalty Islands, are between those of the sclerophyll forest and those of the dense rainforest found at low- and medium-altitudes in New Caledonia. Moreover, the very permeable nature of the substrate, which is composed of upraised coral limestone ("Katcha"), is a factor which heightens aridity during the dry season. These conditions are even more accentuated where plant cover is less dense, as is the case with the secondary formations where sandalwood is located.

These secondary formations are the result of human activity (burnt areas, former fallow land). They have very diverse flora and represent either stages of secondary formation or of the forest's regression. Sandalwood behaves as a secondary species and can be associated with grasses (*Panicum maximum, etc.*) on the plains, with ruderal species (Compositae, Convolvulaceae, Leguminosae, *etc.*), in both forest regrowth and former fallow land, or even with gregarious pioneer species (*Acacia spirorbis, Dodonaea viscosa, Croton insularis, etc.*) in secondary thickets (Table 2).

Even if secondary growth appears to clearly facilitate sandalwood's establishment and development, it does not seem to adapt well to heavily damaged environments. Thus it is rarely found in secondary formations with *Psidium guajava* (guava) or *Imperata cylindrica* (alang alang) or in soils which have been depleted through overuse, as has been observed in certain parts of Lifou (Jaffré & Veillon 1987). It grows rarely and develops poorly in the *Melaleuca quinquenervia* ("niaouli"), formations or in skeletal soil which suffers from frequent fires or erosion.

Smaller populations are located in a few of the rare fragments of sclerophyll forest still in existence on the west coast of New Caledonia. In the Poya region (Nékoro, Pindaï), it is associated with endemic species characteristic of this sclerophyll forest (Table 2) and is one of the species of the canopy which usually reaches a height of no more than 15 m.

In the Loyalty Islands and on the Isle of Pines, there is no sandalwood at all within the climax dense rainforest.

Limited populations, sometimes single trees, have been noted in the low-altitude scrub at Tanlé and on the mountainous formations of Poum, Tiébaghi, Koumac and Boulinda. Eight herbarium samples were taken from this type of formation by eight different collectors between 1961 and 1994.

C. Characteristic species of the herbaceous vegetation										
Panicum maximum Jacq.				1		5				
Solanum nigrum L.						+	+	+		
Bidens pilosa L.						1		2		
Sida acuta Burm. f.						+		1		
Imperata cylindrical (L.) Pal.						+		2		
Aristida novaecaledoniae Henrard						+				
Hyptis pectinata (L.) Poit.						+				
Desmanthus virgatus (L.) Willd.						+				
Rivina humilis L.						+				
D. Characteristic species of the secondary succession and weeds										
Glochidion billardieri Baillon	+	+		+			+	+		
Melochia odorata L.f.			+				1	2		
Acalypha pancheriana Baillon								1		
Breynia disticha Forster & Forster f.			+	+				2		
Passiflora suberosa L.	+	+	+	1	3	2	+	1		
Stachytarpheta australis					+		1	+		
Mariscus javanicus (Houtt.) Merr. & Metcalf								2		
Tridax procumbers L.								1		
Ageratum conyzoides L.								1		
E. Characteristic species of secondary thickets ultramafic substrate										
Baeckea lerratii Schltr.									1	
Codia montana Forster & Forster f.									1	
Hibbertia wagapii Gilg.									1	
Rauvolfia semperflorens (Muell. Arg.) Schltr.									1	
Guioa pectinata Radlk.									1	
Scaevola montana Labill.			+				+		1	
F. Serpentinophyllous species of the mining scrub										
Phyllanthus peltatus Guillaumin										1
Cassinia trifoliata (Baillo) Radlk.	+									1
Nephrodesmus sericeus (Hochr.) Schindler										+
Xanthostemon pubescens (Brongn & Gris) Sebert & Pancher										1
Setaria jaffrei Morat										+
Hibbertia deplancheana Bureau ex Guillaumin										1
Iteiluma pinifolium (Baillon) Aubrev.										+
Ochrosia mulsantii Montr.										1
Hunga gerontogea (Schltr.) Prance										1

It has not been possible to identify the exact variety for the sterile-state specimen collected from the Boulinda formation (Hallé 1988). It came from a thicket of *Acacia spirorbis* associated with several shrub species (Table 2).

Specimens from the Poum and Tiébaghi formations, as well as the samples collected just recently in Koumac at an altitude of about 50 m, belong to the *minutum* variety. One of the samples from Poum, for which a survey of companion species has been made, was located in typical scrub associated with species from the serpentinophyllous flora at the base of the scrub. The variety of sandalwood associated with scrubland is at the very least endangered because of the fires which ravage the hillsides. Thus, a survey of the remaining populations or isolated trees is urgently needed in order to attempt propagation so as to save this variety whose genetic and economic potential is totally unknown.

Edaphic Conditions

The results of analyses of soil samples taken from around the bases of sandalwood trees in many different plant formations on different geological substrates are given in Table 3. They attest to the diversity of chemical conditions of the soil in which this species can develop. In this regard, sandalwood behaves like an ubiquist.

TABLE 3. Soil analyses for samples taken around the base of Sandalwood trees.
Composite soil[1] = calcareous rocks covered with ultramafic colluvium;
Composite soil[2] = dark clayey soil om magnesium rich basalt.

Locality	Mont Vénus	Ouen Toro	Ouen Toro	Mont Ravel	Pindaï	Poue-mbout	Maré	Boulinda
Substrate	Crust Calcareous	Schists	Phtanite	Flysch	Composite soil[1]	Composite soil[2]	Rocks Calcareous	Rocks Ultramafic
ELEMENT								
C ‰	27.6	58.2	154.4	41.3	53.6	28.1	71.0	17.2
N ‰	2.19	4.07	9.39	3.40	5.44	2.18	6.42	1.06
C/N	12.60	14.45	16.44	12.14	10.22	13.26	11.06	16.22
pH	8.1	5.7	4.1	6.7	7.3	6.9	6.7	5.6
Exchangeable bases me/ 100 g								
Ca^{++}	23.0	6.7	6.1	17.0	27.0	30.6	14.92	0.92
Mg^{+}	2.68	4.90	3.6	14.2	3.6	20.7	9.19	1.48
K^{+}	0.61	0.61	0.36	0.74	1.02	0.22	0.35	0.14
Na^{+}	0.28	0.32	0.52	0.46	0.36	1.21	0.47	0.15
CE	21.2	16.5	31.8	29.2	27.8	51.6	25.8	3.37
Total elements								
P (ppm)			72	279	292		7480	70
Ca %			0.20	0.53	0.77		0.87	<0.01
Mg %			0.23	0.92	0.32		0.37	1.40
K %			0.43	0.30	0.11		0.02	<0.01
Na %			0.02	0.07	0.02		0.01	1.29
M %			0.11	0.27	0.23		0.68	1.29
Ni %				0.05	0.28			0.19
Cr %					0.75			8.01
Co %					0.02			0.11

Thus, the *pilosulum* variety, located in the Nouméa area, can be found in highly alkaline soil (pH 8.1), formed from limestone crusts, in slightly acidic soils from schists and in highly acidic soils (pH 4.1) originating in phthanite.

In the Loyalty Islands, the *austrocaledonicum* variety grows in brown, calcic soils and in ferrallitic soils which are acidic, allitic and mature, and on coral limestone ("Katcha"). Their pH is neutral or slightly acidic and they differ sharply from soil in New Caledonia because of their high levels of phosphorus (Becquer, Bourdon & Petard 1993).

In the forest of Pindaï (Poya region), the same variety is found on the limestone substrate covered by ferrallitic deposits of ultramafic origin, resulting in a soil which is relatively rich in nickel and chrome as well as in exchangeable calcium and potassium. In the Pouembout and Nékoro forests, it grows in black, very clayey, tropical soils, which are very rich in magnesium with a neutral or highly acidic pH and which rest on basalt.

On the ultramafic rocks at the base of the Boulinda formation, the sample whose variety has not been determined grows in soil with moderate acidity (pH 5.6) and which is very poor in phosphorus, potassium and calcium. Its magnesium level is sharply above its calcium level and it has heavy concentrations of chrome, manganese, and, to a lesser degree, nickel.

The soil at the *minutum* variety site should be, given the vegetation and the latest soil samples (*i. e.* scrub on immature colluvial soil on serpentine peridotite), very poor in phosphorus, potassium and calcium, similar to the above-mentioned soil but richer in magnesium and nickel and less rich in chrome and manganese.

Nitrogen levels for the different soils analysed are variable and most often are moderately high. The C/N ratio is from 10 to 16, showing high mineralisation of the nitrogen. Potassium is found in most of the soils analysed at satisfactory levels except for those on ultramafic rocks which form a very special substrate. In the Loyalty Islands, soils generally have low reserves of potassium (Latham & Mercky, 1983) but sandalwood, because of the large size of its creeping root system, benefits from potassium in upper horizons which are enriched by organic material.

Sandalwood Nutrition

An outline of the mineral needs and tolerances of S. *austrocaledonicum* is derived from consideration of the foliar mineral composition of trees growing on different substrates. The concentrations of different elements is compared with those observed with different companion species on the same substrates (Table 4). The results assembled demonstrate that in New Caledonia, sandalwood shows relatively high levels of nitrogen and potassium and extremely variable levels of calcium (0.68% to 3.57%). Phosphorus levels are low to moderate.

On ultramafic rock, even under natural conditions, sandalwood develops less well than it does on sedimentary substrates and foliar levels of mineral elements are relatively low. However, they do remain higher than those of the species which have adapted best to this very special environment. Manganese and nickel levels are moderately high.

TABLE 4. Foliar mineral composition of *Santalum austrocaledonicum* and associate species on different substrates. (n = number of analyses)

Localities (substrates) / Species	'n'	N	P	Ca	Mg	K	Na	Mn	Ni	Co	Cr
		%						ppm			
Ouen Toro (phtanites)											
S. austrocaledonicum	5	2.25	0.104	1.03	0.51	2.23	0.21	32	9.4	-	-
Range (±)		0.23	0.020	0.23	0.03	1.13	0.39	17	2.0		
Acacia spirorbis	1	2.70	0.078	1.00	0.29	0.88	0.84	27	1.0	-	-
Ouen Toro (schists)											
S. austrocaledonicum	6	2.20	0.131	2.17	0.63	2.86	0.96	200	12	-	-
Range (±)		0.42	0.040	0.47	0.12	0.62	0.45	76	8.5		
Acacia spirorbis	1	2.65	0.090	0.95	0.27	0.98	0.42	66	3	-	-
Psydrax odorata	1	1.64	0.068	1.39	0.34	1.09	0.21	394	1	-	-
Cleistanthus stipitatus	1	1.89	0.097	1.25	0.21	0.81	0.08	144	1	-	-
Mont Coffyn (calcareous crust)											
S. austrocaledonicum	3	2.47	0.077	1.92	0.38	3.63	0.49	50	15	-	-
Range (±)		0.41	0.008	0.24	0.08	0.65	0.22	16	7.8		
Mont Ravel (flychs)											
S. austrocaledonicum	3	2.51	0.117	3.42	0.56	3.04	0.63	70	19	-	-
Range (±)		0.11	0.008	0.20	0.03	0.54	0.18	7	2.5		
Acacia spirorbis	5	2.69	0.084	1.77	0.41	0.92	0.33	54	14	-	-
Range (±)		0.26	0.020	0.47	0.08	0.24	0.07	21	5.3		
Pouembout (dark clayey soil)											
S. austrocaledonicum	2	1.96	0.241	1.93	0.93		1.85	113	3.5	-	-
Range (±)		0.11	0.006	0.13	0.07		0.28	12	0.7		
Diospyros pustulata	1	1.28	0.090	2.20	0.34	0.97	0.24	97	8	<2	<2
Pindaï (composite soil)											
S. austrocaledonicum	3	2.36	0.073	3.11	0.43	2.67	0.89	53	27	-	-
Range (±)		0.52	0.006	0.46	0.03	0.59	0.32	32	23		
Psydrax odorata	1	1.33	0.040	3.13	0.21	0.50	0.24	92	6	<2	<2
Diospyros pustulata	1	1.04	0.042	2.59	0.17	0.94	0.02	14	7	<2	<2
Ile des Pins											
S. austrocaledonicum	1	2.50	0.155	1.48	0.78	2.23	0.83	190	13	<2	<2
Acacia spirorbis	1	2.70	0.096	0.90	0.29	0.83	0.23	68	5	<2	<2
Boulinda											
S. austrocaledonicum	1	2.50	0.112	0.68	0.52	1.00	0.75	320	40	13	12
Acacia spirorbis	1	2.80	0.049	0.36	0.33	0.58	0.58	230	11	2	3
Psydrax odorata	1	1.40	0.040	1.75	0.47	0.60	0.06	1600	14	24	1
Koumac											
S. austrocaledonicum	1		0.020	0.30	0.31	1.09	1.34	229	52	8	5
Ouenarou (oxydic ultramafic soil)											
S. austrocaledonicum	6	1.35	0.259	0.39	0.71	2.20	0.55	441	154	9.3	7.8
Range (±)		0.26	0.150	0.19	0.22	0.91	0.34	165	49	2.8	2.1

Comparison of the foliar mineral composition of sandalwood and *Acacia spirorbis* shows that, except for nitrogen whose levels are particularly high in *Acacia spirorbis* (Leguminose), major mineral elements are more abundant in the sandalwood.

Foliar analyses tend to show that the needs of *S. austrocaledonicum* are relatively high for nitrogen and potassium and much less so for calcium even though it often grows in calcareous soils.

Conclusion

Despite the recent review of the *Santalum* genus in New Caledonia, it is still not known whether the species *S. austrocaledonicum* is endemic to the Territory, whether the varieties described correspond to different entities from the physiological and genetic point of view or if they have the same economic potential.

Although it is limited to the drier parts of the Territory, sandalwood is found in various soils and plant formations. However, it is clearly more frequent in secondary formations than in climax formations. It seems indifferent to the acidity of the soil and is adapted to limestone substrates as well as to acidic rocks that are poor in calcium. Its foliar mineral concentrations show an important need for nitrogen and potassium and a more limited need for phosphorus.

At the present time it is difficult to give precise details about sandalwood's original associations in the Loyalty Islands and on the Isle of Pines as it now only exists in secondary formations. In New Caledonia, on the other hand, it seems to have its origins in the sclerophyll forest and the low-altitude scrub which originally covered, before man's arrival, the lower slopes and plains of the west coast. The gradual reduction of these stands to a state of isolated fragments through fire and human activity has surely contributed to the restriction and modification of the species' distribution. As a precious wood of commercial value, sandalwood has also been subjected in the past to over-exploitation which brought about the eradication of the most accessible populations both in the Loyalty Islands and in New Caledonia.

Given the species' current scarcity in New Caledonia, where several populations have been reduced to a few isolated trees, it must be protected by setting aside the fragments of sclerophyll forest and low-altitude mining scrub which still harbour it.

Furthermore, the establishment of plantations in appropriate environments (artificial plantations or strengthening of existing formations) would allow the most endangered populations to increase in number : particularly the *minutum* variety which could well be edaphic, linked to the scrub of north-west New Caledonia. Such operations would contribute to the Territory's economic development through production of wood or essential oils while ensuring the reforestation of the driest regions and the preservation of the species' genetic potential.

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