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Management of fallow species composition with tree planting in Papua New Guinea

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Abstract

In response to increasing population pressure and demand for food to feed pig herds, villagers are intensifying land use in Papua New Guinea (PNG). Managing the species composition of fallow vegetation is one intensification technique used. The most important species used is *Casuarina oligodon*. Minor species include *Parasponia rigida*, *Schleinitzia novo-guineensis*, *Albizia* spp. and *Piper aduncum*. Casuarina is a multi-purpose species grown throughout the highlands that provides timber for fencing, firewood and house construction. In four regions of the highlands, villagers transplant self-sown seedlings into food gardens towards the end of the cropping phase to enhance soil fertility. These grow to form dense stands of trees which dominant the fallows.

About 1.3 million people plant some casuarina trees and about one fifth of these manage fallow species composition with casuarina. The technique is most commonly used over an altitudinal range of 1400-2100 m where slopes are steep (over 20°), the landform is hills or mountains, the lithology is sedimentary, vegetation is grasslands, and the annual rainfall is relatively low (2000-3000 mm). Land use intensity in these locations is very low to low. Limited soil analysis indicates that casuarina increases levels of nitrogen and carbon in the soil.

In two of the four regions where casuarina is used most intensively, the practice has been adopted since the 1920s. In another, it has increased greatly since the 1930s. Pollen evidence indicates that casuarina planting increased after 500 AD in parts of the highlands. It is suggested that this represented limited planting to provide timber as nearby forest was depleted, but not widespread fallow management. It is hypothesized that the management of fallows by casuarina planting has been adopted more recently, probably over the past 150 years. It is concluded that there is potential for adoption of the technique in other locations in the PNG highlands. Many aspects of the tree and its use are poorly understood and deserve further systematic study.

Management of fallow species composition with tree planting in Papua New Guinea

Most Papua New Guineans are rural villagers who grow most of their food needs, maintain domestic pig herds and build their own dwellings. The environmental range in which they live and practise agriculture is large (sea level to 2800 m altitude; mean annual rainfall of 1000-8000 mm; a wide range of landforms and soil types). The staple foods are sweet potato, sago, banana, *Colocasia* and *Xanthosoma* taro, yam, and cassava. Soil fertility maintenance is usually based on fallowing (swiddens). However, intensity of land use ranges from very low ($r = 5$) to semi-permanent ($r = 33-66$) and permanent ($r = 67-100$)¹. Population is increasing rapidly and is doubling about every 30 years (2.3 per cent per annum). Timber is the main fuel for cooking and heating by rural villagers. The value of firewood used by all households in Papua New Guinea was estimated by the World Bank Poverty Assessment as US\$105 million (John Gibson, pers. comm., 1997).

Casuarina oligodon, the focus of this paper, is grown in the central highlands. The highlands and high altitude zones cover an altitudinal range of 1200-2800 m with the highest human densities between 1500-2000 m. Population densities in parts of the region are very high. Some 46 per cent of the PNG rural population resides above 1200 m in the highlands. Here sweet potato is the most important staple food. Domestic pigs are common, with about equal numbers of pigs and people. Timber fences are usually built around food gardens to exclude pigs. Because of the cool temperatures, timber is needed to heat dwellings. Trees are often scarce in and around the main highland valleys because of the demand for timber.

Throughout Papua New Guinea, there is very little expansion on to previously unused land and land use is becoming more intensive. This is being achieved by the following: replacement of certain crops with more productive introduced species, particularly sweet potato, cassava, *Xanthosoma* taro, potato and maize; adoption of more productive cultivars, particularly of sweet potato and banana; lengthening of the period of cropping before fallowing; shortening of the fallow period; and development of certain soil fertility maintenance techniques.

The soil fertility maintenance techniques include: fallow species management with tree planting; the transfer of organic matter into food gardens (composting); rotations over time of a leguminous food crop with a root crop; soil retention barriers that reduce soil erosion; and other practices, including mulching, the use of animal manures for fertilizer, terrace construction and transfer of organic matter from drainage ditches on to the soil surface. These techniques have been developed by villagers themselves; that is, they are indigenous technologies.

The focus of this paper is on fallow species management with tree planting. Because *Casuarina oligodon* is the most important species used, it is the main species discussed. First, a brief review is given on other tree species used for this purpose.²

¹ The intensity of land use can be measured by Ruthenberg's r , where r is the proportion of time that land is under crop out of the total cropping plus fallow period (expressed as a percentage)[20]. For example, a value of 5 indicates that land is cropped for five years out of every one hundred, or in practice a one year cropping period is followed by a 19 year fallow.

² In certain environments in PNG, villagers alter the composition of the fallow phase by planting or protecting self-sown seedlings of economically important trees. These include breadfruit (*Artocarpus altilis*), Polynesian chestnut (*Inocarpus fagifer*), galip (*Canarium indicum*), okari (*Terminalia kaernbachii*), marita (*Pandanus conoideus*), karuka (*Pandanus julianettii*), tulip (*Gnetum gnemon*) and bamboo. This is not reviewed here as it is not a soil fertility maintenance technique.

Minor tree species

Parasponia rigida

P. rigida (sometimes identified as *Trema orientalis*) forms root nodules and presumably fixes atmospheric nitrogen. It is an indigenous species growing in the highlands (1500-2000 m), although the exact altitudinal range is unknown. In a number of locations, villagers protect self-sown seedlings in sweet potato gardens so that they survive competition with grass and other regrowth during the fallow phase. People say that they do this because the tree enhances soil fertility. Apart from this, very little is known about how villagers manage *Parasponia* to enhance soil fertility. The practice appears to be more common in the Southern Highlands and Enga Provinces. Occasionally the species dominates the fallow vegetation, for example, in parts of the Sau Valley in Enga Province³.

When fallow vegetation is cleared, branches of *Parasponia* may be trimmed rather than ringbarking the tree. This way trees survive during the cropping phase and grow again during the next fallow phase. Villagers say that it is not possible to propagate the species by planting seed.

Schleinitzia novo-guineensis

This is a fast growing indigenous leguminous tree related to leucaena. The species is common in the fallow vegetation on a number of small islands in Milne Bay Province, including Paneati, Munuwata and Iwa Islands[15]. On Munuwata Island, villagers protect self-sown seedlings as they believe that this species improves soil fertility. The population density on Iwa Island is about 450 persons/km² and there is intense pressure on agricultural land. Here, villagers transplant self-sown seedlings of *Schleinitzia novo-guineensis*, together with those of *Rhus taitensis*, after the first planting of yams have been harvested and prior to the second planting of sweet potato and cassava. Both species are said to improve soil fertility[15].

Very little is known about *Schleinitzia* and its role in soil fertility maintenance. As population pressure on many small islands is placing increased strain on the agricultural system, it is possible that this species may have a useful role to play. The species and its use deserves high research priority.

***Albizia* spp.**

Albizia chinensis is occasionally used as a shade for Arabica coffee and grows over a usual altitudinal range from sea level to 1900 m. An *Albizia* species (possibly *A. chinensis*) is common in fallow vegetation in a number of locations in Morobe Province. These include the headwaters of the Erap Rivers (500-1300 m), the tributaries of the Yakwoi River (1500-1600 m) and the upper Watut Valley (900-1000 m). In these locations, *Albizia* seedlings are said to be transplanted into sweet potato, banana and *Xanthosoma* taro gardens so that they survive during the fallow phase[8]. Sometimes bamboo (for construction) and *Crotalaria* (for soil fertility restoration) are also planted in the gardens. Very little is known about the use of *Albizia* and there is some doubt as to whether it is planted or self-sown.

Piper aduncum

This species is of South American origin. It is now very common in fallow vegetation on hillsides in Morobe Province. It grows up to about 1600 m altitude, and occasionally as high as 1730 m. On the Sogeri Plateau (600-800 m) inland from Port Moresby, an agricultural system has recently been developed by migrants from Morobe Province because of the availability of *Piper* sticks. After fallow

³ In the nearby Tsak Valley, *Trema amboinesis*, (possibly the same species) is reported to dominate fallow vegetation for taro gardens[26].

vegetation has been cleared, *Piper* sticks are cut and hammered into the ground to form a small fence. Soil is shovelled against the back of the fence to make a terrace and reduce soil erosion. After a one year cropping phase with sweet potato as the main food crop, the *Piper* sticks begin to grow and eventually dominate the fallow vegetation, suppressing grass regrowth[2]. The technique differs from others reported here in that trees are not planted primarily to restore soil fertility, but the *Piper* fences and fallows may result in this.

Casuarina

The most important tree species planted to form fallows in PNG is *Casuarina oligodon*. It is a multi-purpose tree species that provides hard easily-split timber for fencing, firewood and house construction. Villagers believe that it increases soil fertility and reduces soil erosion on steep slopes. It provides shade for the major cash crop in the highlands, Arabica coffee. The tree also provides “atmosphere” in highland villages where the sound of the wind in the branches is considered favourably. It is used in a number of contexts, as follows:

- Seedlings are inter-planted with food crops, mainly sweet potato, so that casuarina becomes the dominant species during the fallow phase. This paper concentrates on this usage.
- Planted in selected sites that are used for “mixed gardens”, that is, food gardens containing species other than sweet potato, which require a high level of soil fertility. Casuarinas are used this way in many places in the highlands.
- Planted in and near villages to provide timber and shade. Casuarinas are used for this throughout the highlands and this use has spread to highland fringe areas in recent decades.
- As a shade for coffee trees in villages and plantations. Casuarina is the most important long-term shade for coffee, having displaced leucaena and *Albizia chinensis* which were previously sometimes used as long-term coffee shade. A common sequence after fallow vegetation has been cleared is the establishment of “mixed gardens”. Casuarina and coffee seedlings are interplanted with the food crops once the annuals are established. These annuals, and later banana, provide the initial shade for coffee, and casuarina/coffee take over after some years[7].

Natural stands of casuarina

Casuarina oligodon is indigenous to the highlands of the island of New Guinea (PNG and Irian Jaya). Self-sown seedlings and trees are common on sites adjacent to watercourses. Seedlings colonize bare areas, including road cuttings and locations affected by flooding and landslides[17]. Soils in these sites, for example on the Chim Formation in Chimbu Province, are often low in soil organic matter and nitrogen, but rich in other nutrients. The colonization by casuarina seedlings of a site devastated by a major landslide adjacent to the Chimbu River was documented by Humphreys and Brookfield[17]. Eleven years after the landslide, the site had a complete cover of large casuarina trees.

Villagers report that transported seedlings grow poorly or not at all on certain sites, presumably because of inadequate soil fertility. Self-sown trees are uncommon in open grassland sites, suggesting that it is vulnerable to fires. Information on tree longevity is lacking, but some trees in villages and on coffee plantations are more than 30 years old.

Casuarina grows over an altitudinal range of 700-2600 m in PNG; with trees occasionally growing over a range of 120-2820 m (R. M. Bourke, unpublished data). It is most common over the range 1400-2100 m. The mean diurnal temperature range between 700 and 2600 m is 9-29 °C; and between 1400 and 2100 m is 11-25 °C.

Casuarina as a planted fallow

Throughout most of the PNG highlands, it is common for some casuarina seedlings to be planted in food gardens so that they become a component of a fallow vegetation. This is illustrated in Figure 1 where minor/insignificant use of planted tree fallows indicates that 10-32 per cent of fallow land contains planted casuarina trees. The practice is much more important within four regions in the highlands. The most important in terms of population using the technique is the northern part of

Chimbu Province in Sinasina, Chuave and Gumine Districts and adjacent locations in the Eastern Highlands Province in the Watabung, Unggai and Daulo areas and the edges of the Asaro Valley (Figure 1) (Significant planted tree fallows in Figure 1 indicate that 33-66 per cent of fallow land is dominated by casuarina; very significant indicates more than 66 per cent.) (Source: Mapping Agricultural Systems of Papua New Guinea (MASP)).

North of Mount Hagen, casuarinas dominate fallow vegetation in the middle and upper Kaironk and the upper Asai Valleys in the Simbai area of Madang Province. In Enga Province (around and west of Wabag in Figure 1), villagers plant extensive stands of casuarinas on the edges of the Lai, Ambum, Minyamb, Tsak, Sau, Laigaip and upper Porgera Valleys. (The most important soil fertility maintenance technique in this region is composting and this is done on flatter and more fertile land.) The fourth region where casuarina planting is significant is the Tekin Basin in the Oksapmin area in the far west of the central highlands (Figure 1).

Some 1.3 million villagers in the PNG highlands, representing 36 per cent of the rural population of all Papua New Guinea, plant casuarina trees in food gardens. About one fifth of these villagers (260,000 people) plant casuarina at the significant or very significant level, that is, so that the species dominates more than one third of fallow vegetation. This is 17 per cent of the rural population who live at over 1200 m altitude in PNG. The biggest concentration of people (165,000) using this technique is in northern Chimbu and adjacent locations of Eastern Highlands Province. (Source: MASP)

The physical environment of locations where people plant casuarina fallows at significant and very significant levels was extracted from the Mapping Agricultural Systems of Papua New Guinea and the PNG Resource Information System Databases (Table 1). The most common landform is hills or mountains with weak or no structural control. The most common rock type is sedimentary, including limestone. Field observations suggest that the technique is more common on calcareous mudstone, particularly in north Chimbu and the Tekin Basin.

As expected, the altitudinal range was lower highlands (1200 m) to the boundary of the highlands zone and high altitude zone (2100 m). Planted casuarina fallows are mostly used on steep slopes. While steep slopes are common throughout the highlands (Table 1), the most intensive agricultural land use occurs on gentle slopes or flat land. Casuarina fallows are rarely used in this environment. The dominant vegetation is grasslands, particularly *Miscanthus* cane grass. The practice is more common in the dryer parts of the region (2000-3000 mm annual rainfall) and less common in wetter locations (above 3000 mm).

The measure of land use intensity (r value) for agricultural systems in which there are significant or very significant levels of casuarina fallows ranges from 5 to 29, with a mean of 16. Thus, land use intensity ranges from very low to low. Much higher intensities are used in other locations within the highlands, particularly where soil fertility is maintained by composting where r values of 50-100 are common.

Effect of casuarinas on soil fertility

Throughout the highlands villagers say that casuarinas improve soil fertility. For example, in Chimbu Province, discussions about soil erosion and soil fertility decline often include reference to the use of casuarina fallows to reduce these problems. The limited scientific evidence supports this view.

Parfitt collected soil samples from under casuarina trees of different ages on adjacent sites. He found higher levels of soil nitrogen under 5-6 year old casuarinas than under grass fallows or food gardens and the levels increased with tree age[19]. Another study recorded that soil N and C were higher under casuarina than under sole coffee and that soil N and C increased with the age of casuarina. Levels of N and C were higher under casuarina than under *Albizia* or *Crotalaria*[25].

Leaf litter rates for the first three years of growth were recorded as 3.3 t/ha/year (dry weight)[5]. Higher rates of 7-8 t/ha/year have been recorded by P. Harding for 10-15 year old trees[5]. Estimates of the rate of nutrient returns to the soil from leaf litter were 39, 3 and 10 kg of N, P and K respectively for the first three years of growth; and 84-123 kg N/ha/year for 10-15 year old trees[5].

Use by villagers

There is only limited published information on how villagers select and transplant seedlings, planting density, survival rates, fallow periods and utilization of timber. Men appear to be more involved with transplanting seedlings than women, but detailed observations are lacking. *Casuarina* seedlings often grow abundantly in sandy sites adjacent to streams. Villagers select self-sown seedlings from such sites. They plant them in food gardens towards the end of the cropping phase so that the seedlings attain a height of 80-120 cm by the time the final crop of sweet potato is harvested. They are thus able to compete with natural regrowth and invading pigs as the garden reverts to fallow. It is likely that, in locations where *casuarina* fallows are most dense, many seedlings grow from seed from nearby established trees and transplanting is no longer necessary. In Chimbu Province, the seedlings are transplanted into gardens during the final few plantings of sweet potato[9; 16; 18; 23]. In the Simbai area, seedlings are transplanted to the garden immediately after the food crops have been established[1; 11]. The difference in timing between Chimbu and Simbai reflects the shorter cropping phase of two plantings only in the Simbai area.

The duration of *casuarina* fallows is reported as 3-8 years for the Simbai area[11]; 7-9 years for the Chimbu Valley[23]; as short as 8 years[24]; and 7-10 years in the Baliem Valley of Irian Jaya[3]. In the Chuave area of Chimbu Province, villagers say that soil fertility has been restored sufficiently for another garden phase when *casuarina* trees have attained a diameter of 20-25 cm. This is probably a fallow period of 8-12 years. All of the reported periods are estimates only. However, the 11 study of regrowth vegetation adjacent to the Chimbu River on the site of a major landslide does indicate that *casuarina* trees attain a significant size by 10 years[17].

When villagers judge that soil fertility has been restored sufficiently by the *casuarina* fallow, the trees are ring-barked; the side branches are removed for fencing and firewood; and the trunk is left standing until the timber is needed. Sometimes trees are left alive with a small crown to maintain them until the next fallow phase. Sweet potato and other food crops are planted amongst the standing *casuarina* trees.

There are two known problems with *casuarinas* in the PNG highlands. The first is poor growth caused by boron deficiency which is widespread[6]. In an experiment in the Southern Highlands, where boron deficiency is particularly severe, application of 3 g B/tree more than doubled the height of treated trees compared with adjacent untreated trees over a 20 month period[13]. Another problem of unknown cause results in tree die-back. It is possibly caused by a root pathogen, but this remains speculative.

History of adoption

The question of how long villagers have been managing fallow species composition by planting *casuarina* is an important one. If it is relatively recent, then the technique has potential for use in other locations in the highlands on the assumption that absence indicates that it has not been trialled and rejected. In contrast, if it is a very ancient practice, then there is less potential for adoption elsewhere as there has been sufficient time for the practice to spread throughout the region.

While not conclusive, there is some evidence that the planting of *casuarinas* in the main food gardens is a relatively new practice. (I am distinguishing this technique from planting *casuarina* trees in and near villages or as fallow vegetation for the smaller "mixed gardens".) The practice of planting *casuarinas* in the main sweet potato (or taro) gardens is known to be relatively recent for two of the four regions where the technique is used, the Simbai and Oksapmin areas. In the Simbai area, the systematic planting of *casuarina* trees developed within the life time of the fathers of living men[10], that is, since the 1920s. Similarly, in the Tekin Basin in the Oksapmin area, extensive planting of *casuarinas* was adopted over the past two generations[12], that is, since the 1920s (author's fieldwork, 1979). The practice has become more important in this region since the 1960s.

In the Chimbu region, there is evidence that the practice has increased in importance during this century, although villagers claim that it has been used for a long time, that is, for over four generations. Photographs and observations by Europeans in the 1930s show that *casuarina* planting for fallows was much less extensive than by the late 1950s[9]. A study of seven villages in the Chuave area

of this province recorded a marked increase in casuarina cover between 1952 and 1961[21]. Elsewhere in the same province, in the Sinasina area, planting of casuarinas was recorded in the mid-1960s as an increasing practice prompted by the loss of forest reserves[16].

Casuarina planting has also spread in recent decades outside of the four main regions shown in Figure 1. For example, in the Okapa area of the Eastern Highlands, people started planting casuarina trees in garden land since the mid-1960s, following their introduction as shade for coffee[22]. Writing about the grassland valleys of the northern part of this province, Ataia notes that 30 years ago the valleys were mainly grassland but now trees dot the landscapes, with casuarina being the dominant species[4]. Photographs of the Benabena, Asaro and upper Ramu Valleys taken during the 1930s and 1940s show an almost treeless landscape that contrasts with today's partly wooded landscape. This change is associated with the encouragement of tree planting by Australian Administration officials in the 1950s and 1960s to counter deforestation. Other important factors are the use of casuarina for shade for coffee and movement of hamlets from ridges to the valley floors and lower ridges.

This hypothesis of the relatively recent adoption of widespread planting of casuarina in food gardens differs from the conclusions of Haberle[14]. He conducted a comprehensive review of agricultural change in the PNG highlands over a 2000 period, as interpreted from pollen spores. An increase in casuarina pollen has been recorded at many sites in the highlands from 500 AD onwards. Haberle concluded that agriculturists in the Wahgi Valley (in PNG) and the Baliem Valley (in Irian Jaya) were the first to adopt silvicultural practices between 800-1100 AD; and that other highland regions show similar increases in casuarina pollen between 1000-1400 AD, suggesting there may have been a diffusion of tree fallowing techniques outwards from the main valleys.

I interpret the pollen evidence as indicating that people were planting casuarina trees in and near villages from this period, but they were not planting extensive areas in the main food gardens as is now done in four main regions of the highlands. It is suggested that early tree planting was done to provide timber as supplies became scarce with the removal of nearby forest. The pollen data are from the Wahgi Valley, Tari Basin, Tari Gap, the Baliem Valley and high altitude locations in Enga Province. Today villagers plant casuarina trees in the Wahgi Valley, Tari Basin and the Baliem Valley, but they do not do so in the main sweet potato gardens⁴. Unless widespread planting of casuarina trees has declined prior to recent observations in these locations, and this seems unlikely, then the casuarina trees revealed by the pollen record are likely to represent plantings other than in the main food gardens.

Conclusions

Pollen data showing a rapid increase in casuarina trees after 500 AD are interpreted as showing planting of trees in and near villages from this period. It is generally accepted that sweet potato was introduced into the PNG highlands about 300 years ago[27]. This almost certainly resulted in a significant increase in food production and pig numbers, and numerous associated changes in land use and possibly social organization and human populations. It is hypothesized that, following an extended period of expanded production, environmental constraints began to limit supplies of sweet potato for people and pigs in a number of locations during the 19th and early 20th centuries. In response, villagers in some regions devised a number of innovative practices, including composting, soil erosion control and fallow management with casuarina.

The significant distances between locations where people use casuarina most intensively suggest an independent discovery of the value of casuarina in soil fertility maintenance. Three factors suggest that there is potential for further adoption of the technique within the highlands. These are the limited number of locations where the technique is now important; the recent expansion of casuarina planting in at least three of the four regions where it is most important; and the continuing demand for food for subsistence, stock feed and sale by the increasing human population.

⁴ In the Pitt River area in the north Baliem, villagers do plant casuarina trees near the end of the cropping phase, but this is the only part of the Baliem area where this is done[3].

There are many unknown aspects of casuarina trees and their use by villagers. Regarding the tree itself, it has not been established that *C. oligodon* fixes atmospheric nitrogen (although there can be little doubt that it does); growth rates under village conditions are unknown; the cause of the die-back condition has not been investigated; there have been no studies of different provenances; and the effect of casuarina on soil erosion control, soil fertility restoration and following crop yields has not been documented. Many aspects of human management are also poorly known, including how villagers select and transplant seedlings, planting densities, survival rates, the history of adoption of managed tree fallows and use of the timber. Research into these aspects of the tree and its use are a high priority.

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Table 1. Environments in which planted casuarina fallows are used in the PNG highlands⁵

Environmental factor	Class ⁶	Proportion (%) of planted fallows by area which fall into environmental class ⁷	Proportion (%) of total area of PNG highlands which falls into environmental class ⁸
Landform	Hills/mountains	92	51
Rock type	Sedimentary	77	62
Altitude	1200-2100 m	87	54
Slope	> 20°	83	78
Dominant vegetation	Grassland	80	24
Annual rainfall	2000-3000 mm	77	40

⁵ Source: Data extracted from the Mapping Agricultural Systems of PNG and PNG Resource Information System Databases

⁶ Several categories for each environmental factor have been collapsed to form these classes

⁷ Planted casuarina fallows are used in agricultural systems which occupy 2100 km² in the PNG highlands

⁸ The total area of all land used for agriculture and not used for agriculture in the PNG highlands is 63,800 km².

