A late-Holocene record of human impact from the southwest coast of New Caledonia

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Abstract: A late-Holocene vegetation record is presented from the southwest coast of New Caledonia. Lac Saint Louis is a freshwater swamp at 3 m a.s.l. adjacent to the River Coulee delta. Pollen analysis, charcoal analysis, radiocarbon dating and stratigraphic analyses have been used to reconstruct the vegetation and sedimentary history of the swamp. The sediment record commences at 6000 BP and reflects rapid floodplain development associated with postglacial sea-level rise. This rapid accumulation of sediment ceased around 5500 BP and the site became a freshwater swamp. From 5500 to 3000 BP the pollen record reflects several aspects of this coastal landscape; coastal forest, the swamp surface and the adjacent mangrove zone. At 3000 BP charcoal levels increase significantly in conjunction with abrupt changes in the pollen record. Mangrove pollen declines and pollen indicative of coastal forest is replaced by pollen indicative of coastal savanna. These changes coincide with the commencement of the archaeological record in New Caledonia and mirror similar changes in other late-Holocene records elsewhere on the island, and are interpreted as representing human impact. Yam terraces surrounding Lac Saint Louis may have been built around 2000 BP based on mineral magnetic measurements and charcoal accumulation. The decline in mangrove vegetation adjacent to site may be the result of a late-Holocene fall in sea level. Increased sediment accumulation along the coastal foreshore as a result of forest clearance in the River Coulee’s catchment, however, is also considered.

Key words: New Caledonia, palynology, fire, human impact, sea level, tropical Pacific, late Holocene.

Introduction

A growing body of palaeoenvironmental evidence suggests significant environmental change took place during the late Holocene. While a number of researchers have reached the conclusion that human activities significantly modified Pacific island environments shortly after initial colonization, there are diverging views about whether the changes seen in the palaeoenvironmental record can be attributed solely to human impact.

Until recently, evidence for vegetation change was slight and theories regarding the dominant role of human impact were based primarily on the preliminary study of Hope and Spriggs (1982) from Vanuatu, the Easter Island work of Flennley and King (1984) and the unpublished work of Southern (1986). Extrapolation from the relatively large body of work conducted in New Zealand was also important (see McGlone, 1983 and 1989, for an account of early New Zealand work). In recent years, more sites have been published from islands in Oceania and a number have evidence of vegetation change to a more open landscape coincident with the start of the archaeological record (Athens and Ward, 1993; 1995; Haberle, 1996; Athens, 1997; Parkes, 1997; Hope et al., 1999; Burney et al., 2001; Stevenson et al., 2001). There are also numerous studies that reveal that geomorphic change was as significant as the vegetation change in the late Holocene in these islands. Together these studies suggest that increased hillslope erosion and increased sedimentation in the valleys, as well as subtle changes to coastal foreshores, are all part of the human-impact signal (e.g., Latham et al., 1983; Kirch, 1983; Spriggs, 1986; 1997; M.S. Allen, 1997; Lepofsky et al., 1996; J. Allen, 1997).

Over the years Nunn (e.g. 1990; 1999; 2001) has been an influential critic of palaeoenvironmental studies that see human impact as the major factor leading to late-Holocene environmental change in the Pacific. Instead he cites the influence of climatic variability and sea-level fall as the most likely influences behind coastal landscape change during this period. Much of his argument is centred on the islands of Fiji where he has conducted research into sea-level histories, and where he believes the grasslands and fernlands are related to low rainfall and low soil fertility. In addition, there are some records that have vegetation change and an associated increase in fire substantially preceding the archaeological record. The most controversial of these was work undertaken in the Cook Islands by Ellison, (1994), where a change from forest to open grass/fernland at around 2500 14C yr BP interpreted as resulting from human impact precedes the archaeological evidence for first occupation by 1500 years. While debate has really been
centred around the accuracy of the chronology (Anderson, 1994; 1995; Kirch and Ellison, 1994) some consideration has also been given to whether the vegetation change could have been driven by other factors such as climate. The record from the Cooks is not alone, however, as several other records, primarily from Micronesia, report significant landscape change preceding the archaeological record (Ward, 1988; Dodson and Intoh, 1999; Athens et al., 2002a).

This paper reports research undertaken at Lac Saint Louis, New Caledonia, a small semi-enclosed coastal basin surrounded by terraces for growing yams (Dioscorea spp.). In 1991 a sediment core was collected and a preliminary study examined the record for charcoal, grass pollen and fern spores (Stevenson and Dodson, 1995). An increase in charcoal, grass pollen and some fern spores was found to coincide with the earliest-known archaeological records in New Caledonia. The current paper expands on this preliminary work, analysing all palynomorphs and considering in more detail the stratigraphy of the site.

**Physical environment**

The main island of New Caledonia is narrow and approximately 500 km long and 50 km wide. It lies within the latitudes 20° to 23° south, and between longitudes 164° and 168° east (Figure 1). New Caledonia has a tropical climate influenced by the prevailing easterly air flow (the southeast trade winds). The weather of the island is influenced by the relative position during the year of the south Pacific convergence zone (SPCZ) and subtropical anticyclone belt. The warmest and wettest part of the year is from December to April when the SPCZ is at its southernmost limit. During this period the islands are affected by tropical storms or tropical cyclones that are irregular in number and strength and greatly influence the rainfall of this season.

The great majority of New Caledonia’s precipitation falls on the northeastern coast, the uneven distribution arising from the predominance of the moist southeast trade winds and the presence of the central mountain chain producing orographic rainfall. The east coast routinely receives rainfall in excess of 4000 mm/yr, whereas the west coast may receive less than 1000 mm/yr (Section d’Hydrologie, 1981). Years of rainfall shortage are linked to El Niño–Southern Oscillation (ENSO) (Moriere and Rebert, 1986).

New Caledonia is renowned for its rich and highly endemic flora. The modern flora has over 4500 species of vascular plants, with more than 3200 of these being native (Morat, 1993). The native flowering plants are represented by 3061 species, from 788 genera and 165 families, with a high degree of endemism at each level. Savanna covers over 50% of the island, with its present extent stemming from anthropogenic activity, in particular the land-use practices of European colonizers who cleared large tracts of the west coast for cattle grazing (Barrau, 1980; Schmid, 1987). On the main island the native or natural vegetation in all its forms is confined to the steep slopes of the central mountain chain or unexploited regions within the island’s ultramafic terrain. What remains of New Caledonia’s rainforest covers around 20% of the main island.

**Site description**

Although mapped as a lake, Lac Saint Louis is a freshwater swamp on a coastal plain around 3 m above sea level (a.s.l) (Figures 1 and 2). It is approximately 9 km due east from Noumea. Surrounded by ridges between 10 and 20 m high on three sides (Figures 1 and 2), it now has a small local catchment of around 0.025 km². The average annual precipitation at Saint Louis is between 1300 and 1500 mm per year (Section d’Hydrologie, 1981).

The vegetation surrounding the swamp is characterized as savanna and is dominated by Imperata cylindrica and Melaleuca quinquenervia. On a more regional scale the steep slopes just inland of Lac Saint Louis are covered in lowland rainforest. In 1991 the swamp surface was covered in Eleocharis cylin-drimorphus (Cyperaceae), a reed over 2 m tall. Fire in 1993 removed the reed cover and destroyed the upper layers of root mat (Figure 3).

The inner slopes of the ridges have terrace features characteristic of yam cultivation that are no longer in use and may be of prehistoric origin (Figure 3). At the base of the ridges, on flat land bordering the swamp, contemporary small garden plots are found which have also been abandoned. Gardens growing bananas and vegetables are still in use at the southern
end of the swamp, beyond which the vegetation grades into a mangrove system. The mangrove zone is composed primarily of *Rhizophora* spp. with some *Bruguiera* sp. and *Sonneratia* sp. *Avicennia marina* is found on the inland side of the mangrove zone on higher ground with occasional individuals of *Lumnitzera* sp.

**Methods**

Work at Lac Saint Louis began in 1991 when a 4.2 m sediment core (SL1991) was collected using a D-section corer. The density of the reed cover and water depth hampered a more central location for core collection in 1991 and the sediments below 4.2 m could not be collected due to the stiffness of the material. Detailed field descriptions were made in 1993, post fire, on a series of cores running through the north–south axis of the swamp (Figure 1).

In 1991 the sediment core SL1991 was returned to Australia for processing and dating. Nine bulk sediment samples were selected between 35 and 420 cm depth for radiocarbon dating. Mineral magnetic measurements were also undertaken, with 1 cm samples analysed contiguously between 40 and 220 cm. Sampling for pollen and charcoal was based on the radiocarbon age estimates. Subsamples of 1 cm, were taken every 3 cm from 40 to 219 cm, then processed using standard techniques (Moore *et al.*, 1991). Pollen was counted every 3 cm from 40 to 150 cm, then every 10 cm to 220 cm, while charcoal was counted every 3 cm from 40 to 220 cm.

In 1996 a laboratory error in the 1991 charcoal processing was discovered. Insufficient marker pollen had been added to samples below 117 cm leading to erroneously high influx values for these samples in the original calculations published in Stevenson and Dodson (1995). Because the exact volume of marker pollen added to these samples could not be determined, all the charcoal samples were reprocessed and a new curve produced.

The fossil pollen diagrams are percentage diagrams plotted using the program PSIMPELL (Bennett, 2001). The large, diverse and endemic flora of New Caledonia, in combination with a very modest reference collection, limits the level of identification possible. As a result, there are a number of recurring pollen types that have not been identified, but are instead categorized by number. These appear in the pollen diagrams as Type ‘number’ (e.g., Type 2) and appear collectively in the summary pollen diagram as Unknown Types. They are quite different from the ‘indeterminate’ category that is composed of damaged and crumpled grains and grains that were seen infrequently. Only taxa with a value of 5% or more in at least one sample are plotted as they are considered to carry the bulk of the interpretative information. The remaining taxa contribute to the analysis of species richness.

All statistical analyses were carried out within PSIMPELL. Numerical zonation of the pollen data used optimal splitting by sum of squares analysis. This was based on the basic pollen sum and included only those taxa with a value of 5% in at least one sample. Palynological richness was also carried out. For this routine only the aquatic taxa were excluded. Palynological richness provides a comparative estimate of the expected number of taxa in each sample and is determined by rarefraction analysis (Birks and Line, 1992). This subroutine within PSIMPELL takes a standardized count (which must be less than the actual count) and compares the richness between samples.

Principal components analysis (PCA) was used to compare the pollen records from Saint Louis and nearby Plum Swamp. The methodology involved merging the two data sets, excluding all aquatics and ferns and analysing only those terrestrial taxa with a value of 5% or more in at least one sample. The pollen diagrams are thus reduced to biplots that express the relationship between samples and the taxa contributing most to the analysis. A square-root transformation was applied to the data to reduce the influence of over-represented terrestrial taxa, such as the wind-dispersed Casuarinaceae.

**Results**

**Stratigraphy**

Core 5 (Figure 1) is situated just within the northern swamp boundary. An olive to pale olive sandy clay with gravels and wood between 230 and 180 cm depth appears to be an old soil (Figure 4). Overlying this is an organic mud (silt and clay) that in turn is overlain by sandy clay. The texture of this latter unit is the same as the soil in core 4. Above the sandy clay the core reverts to organic clay, in keeping with the stratigraphy of the cores described below.

Cores 1, 2, 3 and SL1991 are at the northern end of the north–south transect (Figure 1) and all exhibit similar stratigraphic patterns. The basal clays contain fragments of marine shells and change to organic muds and peats in the upper sections (Figure 4). The topmost layers of peat are reddish brown in colour and are found across almost the entire site. Above this is a change to organic sandy clay with a clayey sand layer in core SL1991. Similar sandy clay is found in core 5. Both these sand layers correlate well stratigraphically. Cores 6 and 7 at the southern end of the swamp have a clayey peat constituting the basal sediments in contrast to the organic muds in cores 1, 2, 3 and SL1991. Core 6 also has lenses of light blue quartz sand between 340 and 320 cm, and the sand layer underlying the reddish brown peat in both cores 6 and 7 is quartz stained black by organics. Both cores are sandier at depth than the other cores, but the sand is mainly micaceous. A more detailed stratigraphic description of the pollen core SL1991 appears in Table 1.

**Radiocarbon dating**

The chronology of the site is based on nine conventionally dated samples. The age determinations reveal that the sediments are Holocene in age, with the basal sediments deposited around 6590 ± 110 BP (Beta 43695) (Table 2). Dates between
212 cm and 420 cm have overlapping standard deviations indicating very rapid deposition. The upper 150 cm covers the period from 5370 ± 80 BP (Beta 43690) to present. An age-depth relationship for the core using the uncalibrated ages is shown in Figure 5. Dividing the age determinations into two populations and placing a straight line of best fit through each using regression analysis constructed the relationship. The two lines intersect at around 150 cm and define a substantial change in sedimentation rate from 2 cm/yr to 0.02 cm/yr. Unless otherwise specified, the ages referred to in the text are uncalibrated 14C years BP.

**Mineral magnetics**

Mineral magnetic measurements can be used to detect variation in the type of inorganic sediment and its possible source. In summary, there are no obvious stratigraphic markers that coincide with the peaks in SIRM values (Figure 6). The negative susceptibility values from 107 to 94 cm, 52 to 50 cm and from 44 to 40 cm are within the known range of values for mineral fractions such as quartz, calcite, felspar and kaolinite (Thompson and Oldfield, 1986). Of note are the peaks of SIRM and susceptibility that coincide at 58 and 48 cm. Since both measures have high values this suggests a presence of secondary magnetic minerals, possibly fine topsoil that may also be enhanced by fire (Rummery, 1983; Thompson and Oldfield, 1986; Oldfield, 1991).

**Pollen and charcoal analyses**

Zonation of the pollen diagrams resulted in two significant zones, designated SL-A and SL-B. The diversity in pollen types from the site is large, with over 200 individual pollen and spore types counted. Each zone has an inferred age range derived from the age model and from this point onward positions in the core are referred to as inferred 14C ages rounded to the nearest 50 years.

**Zone SL-A (220–89 cm; inferred age 6250–3000 BP)**

Figure 6 presents two summary percentage diagrams; a total pollen sum showing mangrove pollen versus all other taxa and a basic pollen sum that excludes fern spores and aquatic

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–20</td>
<td>Root mat.</td>
</tr>
<tr>
<td>20–35</td>
<td>Water and plant material with very little sediment.</td>
</tr>
<tr>
<td>35–65</td>
<td>Black/brown organic mud. Large amount of fibre and root material.</td>
</tr>
<tr>
<td>65–89</td>
<td>Dark brown sandy organic mud.</td>
</tr>
<tr>
<td>85–89</td>
<td>Black/brown organic mud.</td>
</tr>
<tr>
<td>89–91</td>
<td>Creamy-coloured sand layer with red nodules.</td>
</tr>
<tr>
<td>91–100</td>
<td>Black/brown organic mud.</td>
</tr>
<tr>
<td>100–140</td>
<td>Very dark greyish brown peat, with fragments of wood between 107 and 126 cm. Micaceous particles throughout.</td>
</tr>
<tr>
<td>140–210</td>
<td>Black/brown organic mud, with an increase in fibrous organic material between 188 and 196 cm.</td>
</tr>
<tr>
<td>210–370</td>
<td>Black/brown organic mud with a slight colour change to very dark brown. Gradual colour change between 340 and 370 cm to very dark grey brown.</td>
</tr>
<tr>
<td>370–420</td>
<td>Very dark grey brown mud. No fibrous organic material. Shell fragments between 390 and 420 cm.</td>
</tr>
</tbody>
</table>

**Table 1** Stratigraphic description of SL1991 (mud = silt and clay)
pollen. Mangrove pollen comprises less than 30% of the total pollen sum in zone SL-A. Figure 7 shows that most of the mangrove pollen is *Rhizophora*. *Bruguiera* occurs throughout zone SL-A, with *Avicennia* only entering the record after 4500 BP. *Excoecaria* comp., a coastal tree tolerant of saline conditions, is found in small amounts in both the SL-A and SL-B sediments, but not after 2000 BP.

Fern spores dominate the total pollen sum prior to 6000 BP (Figure 6). Terrestrial tree and shrub taxa dominate between 6000 and 5000 BP. The most abundant tree and shrub pollen taxa are *Araucaria*, *Cunoniaceae*, *Macaranga*, *Melaleuca*, *Nothofagus* and palms (Figure 7). While *Araucaria columnaris* is a component of coastal forest, *Nothofagus* does not occur at sea level. From a modern pollen rain study the *Nothofagus* percentages are in keeping with it being part of the regional pollen rain (Stevenson, 1998).

The percentages of Cyperaceae pollen gradually increase after 5500 BP, until it comprises around 30% of the total pollen sum by 4000 BP (Figure 7). This is coincident with peat accumulation at the site. Psilate monolete fern spores also increase during this period. The percentages of Cunoniaceae, *Macaranga* and Myrtaceae pollen decrease in the upper part of zone SL-A with an increase in the percentage of *Rhizophora* pollen (Figure 7). Poaceae values of less than 5% are also common in this upper part of zone SL-A. Charcoal is present throughout zone SL-A, although the accumulation rates are very low (Figure 6).

The values of indeterminate taxa are expressed as a percentage outside of the total sum. In zone SL-A the values are high, exceeding 40% for one level, and are constituted in almost equal parts by damaged and degraded pollen as well as pollen that could not be identified (Figure 6). It should be noted that palynological richness values are consistently high throughout SL-A.

Given the rapid sedimentation rate, the low pollen concentration and the similarity in pollen content in the lower part of zone SL-A, it was decided not to count the samples between 160 and 190 cm.

Zone SL-B (89–40 cm; inferred age 3000–800 BP)

Charcoal enters the fossil record in large amounts from around 3000 BP, coincident with a significant change in the pollen composition, most markedly the dramatic decrease in mangrove pollen. These changes are in close accordance with the commencement of the archaeological record, which is estimated to be between 1100 and 1050 BC (Sand, 2000). This tight age range stems from over 40 age determinations from early Lapita sites. The slightly looser age range of 1510 to 1080 BC for the boundary between SL-A and SL-B in this study is inferred from only four bulk dates on sediment spanning between 8 and 10 cm of core material.

The total pollen sum is initially dominated by fern spore taxa, changing to a spectrum dominated by Cyperaceae pollen after 2000 BP. This is coincident with the complete absence of mangrove pollen (Figure 7). *Araucaria* and *Nothofagus* pollen gradually disappear in this zone and the percentages of herb taxa (essentially grass) increase throughout zone SL-B (Figures 6 and 7). *Melaleuca*, Myrtaceae and grass pollen percentages increase across the boundary between SL-A and SL-B and then decrease as the record becomes overwhelmed with Casuarinaceae pollen. A large number of Myrtaceous grains had to be lumped under the general category of *Melaleuca* pollen. The Casuarinaceae pollen curve probably contains a significant percentage of *Melaleuca* pollen, particularly if you consider the similarity in shape of the two curves.

*Casuarina equisetifolia* is commonly found in woodland behind mangroves and is a good colonizer after disturbance. Charcoal levels are low from 2500 to 2000 BP, resembling values prior to 3000 BP. During this time the levels of Casuarinaceae pollen start to increase, and continue to rise significantly even with the resumption of more fire in the landscape after 2000 BP. The percentage values of Casuarinaceae pollen are often hard to evaluate, though, as they are prolific producers of windborne pollen. Based on a modest pollen rain study for New Caledonia (Stevenson, 1998) the values of

### Table 2 Radiocarbon ages from Lac Saint Louis

<table>
<thead>
<tr>
<th>SL1991 depth (cm)</th>
<th>Lab. number</th>
<th>Uncalibrated (14C yr BP)</th>
<th>Calibrated (cal. yr BP) and (2σ range)</th>
<th>Calendar age and (2σ range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>35–45</td>
<td>Beta-45257</td>
<td>620 ± 80</td>
<td>600 (690–510)</td>
<td>AD 1354 (1262–1439)</td>
</tr>
<tr>
<td>52–60</td>
<td>Beta-43688</td>
<td>1710 ± 60</td>
<td>1600 (1710–1520)</td>
<td>AD 341 (141–434)</td>
</tr>
<tr>
<td>92–100</td>
<td>Beta-43689</td>
<td>3370 ± 90</td>
<td>3620 (3840–3400)</td>
<td>BC 1663 (1884–1441)</td>
</tr>
<tr>
<td>142–150</td>
<td>Beta-43690</td>
<td>5370 ± 80</td>
<td>6500 (6720–6310)</td>
<td>BC 4548 (4774–4563)</td>
</tr>
<tr>
<td>212–220</td>
<td>Beta-43691</td>
<td>6210 ± 110</td>
<td>7110 (7420–6760)</td>
<td>BC 5145 (5465–4812)</td>
</tr>
<tr>
<td>273–280</td>
<td>Beta-43692</td>
<td>6380 ± 100</td>
<td>7290 (7460–7030)</td>
<td>BC 5340 (5513–5076)</td>
</tr>
<tr>
<td>330–338</td>
<td>Beta-43693</td>
<td>6590 ± 110</td>
<td>7471 (7570–7270)</td>
<td>BC 5522 (5717–5321)</td>
</tr>
<tr>
<td>372–380</td>
<td>Beta-43694</td>
<td>6480 ± 110</td>
<td>7420 (7570–7160)</td>
<td>BC 5473 (5624–5214)</td>
</tr>
<tr>
<td>412–420</td>
<td>Beta-43695</td>
<td>6590 ± 110</td>
<td>7470 (7670–7270)</td>
<td>BC 5522 (5717–5321)</td>
</tr>
</tbody>
</table>

Calibrated using CALIB 4.3, Stuiver et al. (2000). All samples are bulk sediment samples.
Figure 6  SL.1991 summary pollen diagram. Two pollen sums are shown, the total pollen sum and the basic pollen sum which excludes ferns and aquatics. Numerical values of the basic pollen sum are also shown. The indeterminate percentages are calculated outside of the total sum. The diagram also includes palynological richness, mineral magnetic measurements (SIRM and susceptibility) and charcoal accumulation.
Figure 7 Individual pollen curves for SL1991. Values are derived from the basic pollen sum. Only taxa with a value of 5% in at least one sample are plotted. Dots indicate presence of pollen type at a value of <1%.
Figure 8 A summary of the charcoal curves for Lac Saint Louis, Plum Swamp (Stevenson et al., 2001) and Lake Suprin (Hope and Pask, 1998), shown against inferred age. Note scale change between sites. Also shown are the major vegetation shifts alongside the colonization history.

Casuarinaceae pollen after 2000 BP could indicate one or two individuals close to the core site, or a Casuarina-dominated woodland at greater distance. Semail et al. (2002) report similar pollen curves, where Casuarinaceae pollen dominates after 2000 BP, from the north of New Caledonia. However, the basal dates for these sites are around 2200 BP and charcoal has not been analysed as yet. The values of SIRM and magnetic susceptibility also show a corresponding increase after 1900 BP. Melaleuca, Poaceae and Myrtaceae pollen replace the Casuarinaceae pollen after 1400 BP.

Palynological richness fluctuates throughout zone SL-B, decreasing dramatically after 2000 BP. Unfortunately, there are a number of significant pollen types for zone SL-B that could not be identified. Reflected in the decline of the palynological richness is the decline in the Unknown Type category toward the top of SL-B.

The only food plant pollen encountered was from the two surface samples: Dioscorea (yam) type pollen and Solanaceae pollen. Psidium guajava, a weedy Myrtaceous shrub introduced since European settlement, is also found in these surface samples. In general, however, the surface samples are dominated by Cyperaceae pollen, with the uppermost sample having very low pollen concentration due to the lack of compaction.

Principal components analysis (PCA)
The results of the principal component analysis comparing the Lac Saint Louis data with the Plum Swamp data are illustrated in Figure 8. Only the first and second axes are plotted as these explain 64% of the variation in the data set. Plum Swamp is a backswamp on the Plum River on the southeastern side of Mont Dore at an elevation of around 10 m a.s.l. (Stevenson et al., 2001). The results of the PCA reveal how the sites start out floristically as two quite different vegetation types given their relative positions in the landscape, but move to a common landscape after 3000 BP, defined by varying amounts of Melaleuca, Casuarinaceae and Poaceae.

Discussion

The sediments collected from Lac Saint Louis are Holocene in age and record the rapid rise in sea level following global deglaciation. The stratigraphy and pollen records of Lac Saint Louis also record the change of the site from an open system to a closed freshwater swamp. From 3000 BP landscape transformation is recorded as the conversion of lowland forest to savanna and the decline of mangrove forest from near the site. These transformations are coincident with the commencement of the archaeological record.

The basal sediments from the swamp reflect both marine (the shell and blue quartz sand lenses) and fluvial (micaeous sand) origins of sediment, indicating that at this time Lac Saint Louis was open to the influence of the River Coulee and the Baie Murari. The bulk of these sediments originate from the rapid formation of the River Coulee delta during Holocene sea-level rise. Rapid accumulation of sediment ceased around 5500 BP and peat accumulated from 5450 to 3500 BP, reflecting shallow water conditions. The River Coulee arises in an iron-rich ultramafic catchment and the decrease in mineral magnetic values after 3900 BP no doubt reflects less clay mineral deposition from the river and the transition to a more closed site through barrier and floodplain development. Micaeous sand, which has a terrestrial origin, also ceases to be deposited in the sediments around this time. After 3500 BP peat ceases to accumulate at the site and the deposition of organic clay is indicative of deeper water conditions.

The terrestrial pollen record between 5450 and 4000 BP is dominated by common lowland forest taxa and the River Coulee is likely to have made significant regional contributions to the pollen record during this time. The values of the lowland forest taxa decrease after 4000 BP as the percentages of Rhizophora pollen increase in the upper part of zone SL-A. At the same time, the increase in fern spores and Cyperaceae pollen in the upper layers of the peat are indicative of freshwater conditions at the site.

The high percentages of mangrove pollen and the wood fragments in the sediments just prior to 3000 BP might suggest that the swamp was a mangrove forest. However, there are no macrobotanical remains indicative of mangroves, such as preserved leaves or pneumatophores, and the sediments do not have the characteristic sulphurous odour of mangrove peats and muds. Also the percentage values of Rhizophora in the total pollen sum are more in keeping with an extralocal source for the pollen rather than mangrove forest over the site itself (Grindrod, 1985; 1988; Thanikaimoni, 1987; Clark and Guppy, 1988; Crowley et al., 1990). It is also worth noting that Acrostichum, the distinctive mangrove fern, was not encountered during pollen counting and that, as no Cheno-podiaceae pollen or distinctly degraded pollen was encountered either, the site appears never to have been a high-tide mudflat.

The dramatic changes at 3000 BP in vegetation composition and charcoal concentration are associated with a sand layer that is confined to the landward end of the swamp adjacent to the steeper ridges. As intact coastal forests have sparse ground cover it would appear that fire and the associated forest disturbance at 3000 BP led to some slopewash being deposited in the swamp. The ground surface undoubtedly became more stable following the establishment of grassland on the surrounding ridges. The savanna of New Caledonia takes two main forms, grassland and grassland with an an overstorey of scattered Melaleuca. This savanna environment has been greatly extended during historical times (Barrau, 1980; Schmid, 1987) and it has been speculated that the Melaleuca swamps are the likely origin of this now widespread vegetation type (Mueller-Dombois and Fosberg, 1998).

Human colonization of New Caledonia began around 3000 BP and two sites, Lac Saint Louis and Plum Swamp, record a significant change in vegetation composition and charcoal con-
centrations at, or shortly after, this time. Charcoal records from palaeoenvironmental studies in New Caledonia also reveal that fire is a natural part of the landscape with a very deep time depth (Hope and Pask, 1998; Stevenson et al., 2001); however, the magnitude of these events after 3000 BP have no precedent in the earlier records (Figure 9). Plum Swamp, on the southern side of Mont Dore and around 10 m a.s.l., also records a significant change in late-Holocene vegetation composition. Figure 8 illustrates how the landscapes around Lac Saint Louis and Plum Swamp start out floristically different and then converge to common landscape type after 3000 BP. However, and with the limits of the radiocarbon determinations, these dramatic shifts at the two sites are not synchronous (Figure 9). Synchronous shifts between the sites might be expected if change was being driven by natural climatic phenomena alone.

A puzzling aspect of the record, however, is the decline in mangroves at 3000 BP. Direct impact as a result of fire seems unlikely and, given the timber resources of the island, human exploitation quite unnecessary. Although some evidence exists for a higher than present sea level (±2 m) between 4000 and 2500 BP (Baltzer, 1970; Coulard and Delibrias, 1972; Fontes et al., 1977; Grossman et al., 1998) the decline in mangrove pollen after 3000 BP is not a gradual process.

An alternative possibility is that forest clearance within the River Coulee catchment increased sedimentation rates within Baie Murari. While there is no direct evidence for this alternative impact on the mangrove vegetation, a number of studies from elsewhere in the Pacific support the idea of increased sedimentation along coastal foreshores following human colonization (Kirch, 1983; Spriggs, 1997; M.S. Allen, 1997; Lepofsky et al., 1996; J. Allen, 1997).

One of the other interesting questions at Lac Saint Louis relates to when the yam terraces were constructed. The only terraces dated so far in New Caledonia are the taro terraces at Col de Pirogue. These gave a date of 1200 BP (Sand, 1999). The formation of the yam terraces at Lac Saint Louis is very loosely assigned to the period after 2000 BP based on the increase in SIRM and susceptibility values and the resumption of higher charcoal accumulation levels. The simultaneous high values in SIRM and susceptibility are probably related to the inwashing of fine topsoil. In addition, pottery found scattered on the surrounding ridge tops appears to belong to the Plum tradition (Sand, personal communication), a pottery-making tradition dating to the first millennium AD. The decline in palynological richness after 2000 BP also reflects, at least in part, the declining floristic richness of the vegetation within the pollen source area (cf. Birks and Line, 1992). This could be expected with clearance of the high ground around the site for cultivation. However, the detection of agricultural practices in pollen records from the Pacific is difficult due to the general lack of direct evidence for crop plants. This arises because the dominant Pacific island agriculture is based on tuberous plants (taro, yam, sweet potato) that are insect-pollinated and therefore have poor pollen production and dispersal mechanisms. This situation in the southwest Pacific contrasts to other cultural settings such as Asia and Europe, where crop plants are principally from the wind-pollinated grass family (Poaceae) and by comparison well dispersed. The only crop-type pollen detected in the Lac Saint Louis record was Dioscorea (yam). However, this was only in the surface samples along with several European introductions, including pollen from some of the contemporary garden plots. There were no pollen types indicative of companion planting either.

Figure 9 PCA biplot of Lac Saint Louis and Plum Swamp terrestrial pollen. Hollow symbols represent samples from before 3000 BP (precolonization period) and solid symbols represent samples that are 3000 BP and younger. The figure 1 denotes the basal sample at each site, and the arrowheads the direction of change toward the present. Reprinted from Stevenson et al. (2001) with permission from Elsevier.
The impact on and use of the terrestrial landscape around Lac Saint Louis might therefore be summarized as follows:

1. intentional or unintentional coastal forest clearance associated with fire shortly after colonization;
2. little or no activity around the site itself and in the absence of frequent fire Casuarina colonized the landscape;
3. yam terraces created on the surrounding ridges with fire utilized to clear and maintain an open landscape;
4. yam terraces abandoned sometime after European colonization but fires lit by people continue to be a common feature of the local landscape.

Conclusions

A number of studies from Pacific island locations suggest that the incidence of fire and the structure of lowland vegetation changed soon after human colonization. The record from Lac Saint Louis contributes to this growing body of work, revealing that the landscape within the vicinity of Lac Saint Louis was changed to a savanna environment as New Caledonia was being colonized by people. The site also records a significant change in the relative position of the adjacent mangrove zone. This may have resulted from a late-Holocene fall in sea level, although increasing sedimentation within the Baie Murari is also considered a possibility. The savanna landscape first created 3000 years ago has been maintained through to the present day with the continued use of fire.

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