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16. In general, if R is the gas constant, T is the absolute temperature, and D and Q are, respectively, the diffusion coefficient and activation energy of a certain nuclide in a given diffusing medium, then $D = D_0\, e^{-Q/RT}$, where D_0 is a temperature-independent parameter. In particular, if C_0 is the initial concentration of that nuclide within a sphere of radius a, then the average nuclide concentration $\overline{C}$ within that sphere at some later time t is given by

$$\overline{C}/C_0 = \frac{6}{\pi^2}\sum_{1}^{\infty}\frac{e^{-(n^2\pi^2Dt/a^2)}}{n^2}$$

[see L. O. Nicolaysen, *Geochim. Cosmochim. Acta* **11**, 41 (1957)]. We used measured values of $D_0 = 2.2 \times 10^{-2}$ and $Q = 58$ kcal/mole for diffusion of Pb in zircon [see Sh. A. Magomedov, *Geokhimiya* **2**, 263 (1970)] and a computer program to calculate the times when $\overline{C}/C_0 = 0.99$ for $T = 100°$, 150°, and 200°C.
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Ramón and Maya Ruins: An Ecological, Not an Economic, Relation

Abstract. *Economically important trees such as* ramón *have been shown to have a high density in the civic-ceremonial core zone of ancient Maya ruins. The distribution of such trees is probably the result of their requirements for growth and reproduction, which are optimal on the ruins, and not because they are the descendants of trees planted by the Maya aristocracy.*

The role that the *ramón* tree (*Brosimum alicastrum*) played in Maya culture has been the subject of intriguing speculation. Early reports (*1*) noted that *ramón* is a common tree on all Maya ruins, leading Puleston (*2*) to propose that *ramón* was a subsistence alternative for the Classic Maya of the central southern lowlands. Puleston also suggested that its occurrence in the ceremonial precincts and on housemounds at Tikal, Guatemala, was evidence of its cultivation in residential areas. Some Mayanists appear to have accepted this proposal (*3*); others (*4*) doubt that the Maya would have depended entirely on such a resource. Folan *et al.* (*5*) have suggested that the Maya aristocracy maintained and controlled the distribution of economically important fruit, fiber, bark, and resin trees in the city centers. They also contend the present trees are descendants of those planted by the ancient Maya and that their distribution today corresponds to that in Classic times.

Ramón and other economically important species were used by the indigenous people in the past as well as today. But the trees grow on Maya ruins because their requirements for growth and reproduction are probably optimal on the ruins, not because the Maya may have cultivated them 1000 years ago. The data from Tikal and from Cobá in the Yucatán, Mexico, we suggest, are probably biased to the *ramón* and associated species (*5*). If all tree species had been considered, as at Lamanai, Belize, then the frequency and density or dominance of useful trees would probably be no greater than those of nonuseful trees.

Table 1. Comparison of the distribution and dominance of *ramón* at three Maya ceremonial centers. Abbreviation: N.A., not available.

Designation of vegetation units	Area sampled (ha)	Number of *ramón* per hectare	Total trees per hectare	Important trees (percent of total)
		Tikal		
0 to 0.5 km	5	63		
0.5 to 1.0 km	5	49		
2.5 to 3.0 km	5	4	N.A.	N.A.
4.5 to 5.0 km	5	71		
		Cobá		
A	19.3	56		
B	25.7	13		
E	49.3	1.3		
H	45	6	N.A.	N.A.
I	50	8		
K	50.5	4		
		Lamanai		
High structures	15	106	780	53
Outcrop	20	33	780	32
Low structures	25	17	655	17
Highbush	30	12	685	6

We have already described six forest associations commonly occurring at Lamanai (*6*). *Ramón* occurred in nine transects in only two of the associations—on ruins and in highbush forest. In the latter it was present in only two of eight sampled transects. Three more transects are now included in the data: two ruin sites and a naturally occurring limestone outcrop 12 km south of Lamanai. Even though *ramón* was present in all 12 transects, it was dominant only in two stands.

A correlation matrix (*7*) with important values (*8*) was used to determine whether there were naturally occurring groupings in the 12 transects. A dendrogram (Fig. 1) identifies high and low structures among the ruins and highbush forest. On the basis of the measure of similarity the forest-covered limestone outcrop, where there was no evidence of structures, is closer to the high structures than to the low ones.

Six species can be described as being associated with high structures. They are *Brosimum alicastrum* (*ramón*), *Protium copal* (*copal*), *Bursera simaruba* (*chacha*), *Pimenta dioica* (*naba kook*), *Talisia oviliformis* (*kinep*), and *Allophyllus camptostachys* (*bikhach*). Four species, *Spondias mombin* (*hu hu*), *Crysophila argentea* (*akuum*), *Guazuma ulmifolia* (*pixoy*), and *Stemmadenia donnelsmithii* (*chalkin*), were more common on the low structures and throughout the highbush forest (*9*).

The density of *ramón* trees is greatest on the steep sides of the highest structures, where the soil rarely exceeds 15 cm in depth and covers identifiable structures or collapsed structural limestone material. Because of the softness of the local limestone, roots have caused extensive damage to structures. Soil moisture content is low even during the rainy season, and drainage is rapid from the steep sides of the structures. Because the limestone base is close to the soil surface, there are high concentrations of exchangeable Ca (24,500 ppm) and Mg (500 ppm) as well as high cation exchange capacity and pH (7.5).

Soil depth increases to approximately 25 cm on low structures and plazas. Soil moisture content also increases, and the pH of the upper few centimeters is more acidic (6.0). Soil depth on the outcrop and in the highbush forest soils varies from < 15 cm to > 40 cm. The decline in density of *ramón* can be attributed to a more stable substrate and increased competition from other establishing species.

Numerous housemounds occur throughout the region, and they can be easily identified by the presence of the *naba kook* tree with its peeling yellowish bark. The mound soils are also shallow, well drained, and have a high exchangeable Ca and Mg content. Other species on the mounds include *copal*, *kinep*, and an occasional *ramón*. These species were rarely found off the housemound.

A comparison of data on *ramón* distribution from Tikal, Cobá, and Lamanai (Table 1) shows that, although Lamanai is by far the smallest of the three, the density of *ramón* on high structures is greater than that at Tikal and Cobá. Puleston (*2*) gave figures for *ramón* only. To support the association of *ramón* with structures of the elite Maya, as suggested by Puleston, Folan *et al.* (*5*) used 15 trees that were considered of economic importance and counted only individuals of the 15 species. Data presented for two survey lines show that *ramón* was the dominant tree, accounting for approximately 50 percent of total tree composition. Declining numbers of *ramón* and other economically important species are correlated with diminishing size and number of structures at all three sites. The total number of trees per hectare was greater on the high structures and the limestone outcrop. On high structures at Lamanai 53 percent of the trees were economically important species; the percentage declined rapidly toward the highbush forest. If we assume that the vegetation at both Tikal and Cobá was undisturbed at the time of sampling, then the figures presented by Puleston and Folan *et al.* appear to be biased in favor of *ramón*. If all tree species were identified and counted, the importance of *ramón* and the other economically important species on Maya ruins would be considerably lower.

Loten (*10*) established that there were approximately 400,000 m^2 of plaster-covered limestone at Lamanai during the height of its importance. This would have included large ceremonial structures, raised plazas, residences, and causeways. It is reasonable to assume that the Maya planted useful trees on the lower plazas and causeways, but it is doubtful that they would have planted great numbers in the ceremonial centers.

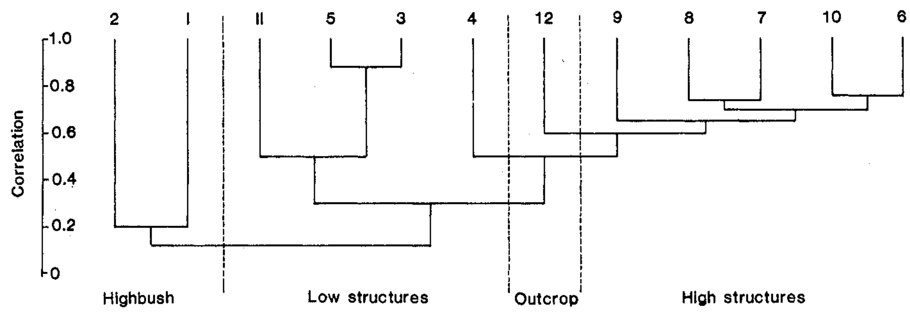

Fig. 1. Correlation matrix (clustering by minimum distance matrix) and dendrogram of the 12 transects. (Cluster analysis of variables is based on a measure of similarity.)

At Lamanai, the large structures are a series of additions superimposed on a base structure. The amount of fill between additions may vary from < 0.5 to > 3 m. If trees were clustered at the ceremonial centers, as Folan *et al.* (*5*) suggest, then we would expect to find evidence of their presence, such as tree roots penetrating the hill of buried structures. To date we have seen no such evidence.

The black and red soil categories identified at Cobá (*5*) probably reflect only age differences, with the younger black soils occurring on the vegetated structures, as at Lamanai. The black soils could hardly be more than 1000 years old, whereas the surrounding red soils are the result of many thousands of years of exposure to tropical environmental conditions. The association of black soils and economically important trees is based on the presence of necessary conditions for optimal growth.

It has been suggested that the Maya elite controlled most of the trees necessary to supply basic nutritional needs as well as the fiber, bark, and resin associated with ceremony (*2, 5*). This would have required the planting of trees all over the structures. If this were the case, the collapse of the social system would have caused plantations of economic species to compete with wild plants, which would rapidly change the character of the plantations. As an alternative, we propose that succession followed a progressive course. Structures free of vegetation would be rapidly colonized after abandonment by a variety of calcicole species which in time would modify environmental factors. The modifications would allow additional species to establish themselves; soil development would also occur during this period. With the establishment of vegetation, soil pH would decrease toward neutral. Organic materials—a humus layer overlying a crumb structure—would accumulate. The degree of buildup would affect soil aeration and water movement, the end result being a stable and self-perpetuating climax community. Botanically what we see today at ancient Maya ruins like Cobá, Tikal, and Lamanai is not a replication of planting patterns of 1000 years ago, but the ecological end result of species competition and selection.

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9. Local names for the seven species are Maya, except *ramón* and *copal*, which are Spanish. The local Maya names are *ox* and *pom*, respectively.
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