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A Dendrochronological Study of Teak (*Tectona grandis* L. f., Verbenaceae) in Puerto Rico

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Abstract

In Puerto Rico, an island in the West Indies, large areas of primary forest have been cut and converted to farmland or to secondary forest; subsequently the farmlands declined in fertility and were abandoned. Various tree species were planted in order to restore the degraded land and to provide timber. Teak is a species with great restoration potential in Puerto Rico especially for low altitude areas with deep, well drained soils, and in the past 50 years, teak plantations have been established in such areas. Teak was planted in the subtropical wet forest at Rio Abajo in central Puerto Rico in the 1940s and 1960s and at Sabana during the 1960s. We conducted a dendrochronological study of the species at Rio Abajo and at Sabana in order to investigate patterns of growth and to determine the effect of climate on the growth of teak. We compared the growth of teak and that of mahoe (*Hibiscus elatus* Sw. (Malvaceae)), a tree species used in the manufacture of fine furniture, native to Cuba and Jamaica, which had also been planted at Rio Abajo. The best predictors of growth of teak at Rio Abajo are July and November temperatures. The tree ring chronology shows decreased growth during several hurricane years, followed by increased growth the following year. Both species are growing well, but teak growth is better than that of mahoe, a native species of nearby islands, suggesting that it is a good choice for these and similar areas in the subtropical wet forest life zone of Puerto Rico.

Key words: dendrochronology, teak, *Tectona grandis,* Puerto Rico, mahoe, *Hibiscus elatus*

Introduction

Teak (*Tectona grandis* L. f.) is one of the most valuable and best known tropical timbers (Weaver and Francis 1990, Weaver 1993). The species is native to India, Burma, Thailand, Indochina and Indonesia and has been extensively planted within its natural range as well as in tropical areas of Latin America and Africa (Chudnoff 1984). In Puerto Rico, an island in the West Indies, large areas of primary forest have been cut and converted to farmland or to secondary forest. Subsequently the farmlands decreased in fertility and were abandoned. Various native and exotic tree species have been planted to restore the degraded land and to provide timber (Weaver and Francis 1990). A few teak trees were introduced in the Caribbean region around 1880 and plantations were first established in 1913 (Brooks 1939). Teak was introduced in Puerto Rico from Trinidad before 1940, and by 1990 it occupied approximately 130 ha in various parts of the island. Teak appears to be a species with great restoration and economic potential for Puerto Rico in areas with low altitude and deep, well drained soils (Weaver and Francis 1990).

Teak was planted at Rio Abajo in central Puerto Rico (Figure 1) in the 1940’s and 1960’s and at Sabana in the eastern part of the island. We carried out a dendrochronological study of the species in order to investigate patterns of growth and to determine the effect of climate on the growth of teak at the sites. We compared the growth of teak with that of mahoe (*Hibiscus elatus* Sw. (Malvaceae)), a native of Cuba and Jamaica used in the manufacture of fine furniture, (Francis and Weaver 1988), that had also been planted at Rio Abajo. Although measuring growth rings in tropical species can be difficult because the annual rings may not be distinct, recent dendrochronological studies in India and Java (Pant 1983, Bhattacharyya et al. 1992, Jacoby and D'Arrigo 1990) and Panama (Devall et al. 1995) show great potential for some tropical species, especially teak.

Materials and Methods

Rio Abajo soils are clay loam and clay while Sabana soils are loam, however, both sites are in the subtropical wet forest life zone. The area has a short dry season in February-March (Weaver and Francis 1990). We sampled 30 teak trees and 12 mahoe trees growing in pure stands at Rio Abajo and 31 teak trees from a stand at Sabana. We collected two cores per tree in case some cores were unusable. The cores were air dried, mounted on wooden blocks, and hand sanded with three grades of sandpaper. Cores were then scrutinized for defects and selected for the analysis; cores with indistinct rings, rotten spots, or fungus growth were eliminated. We measured ring widths and crossdated the tree-ring series (Table 1) using software developed by Van Deusen (1987; 1993). Identification of marker rings helped establish correct crossdating, but use of the software was the primary method of crossdating.

After crossdating, we developed a mean chronology for each species. In order to optimize the climate component of the ring widths and the disturbance signal common to most of the trees (see Graybill 1982), we standardized the cores by using the first difference of the inverse hypersine (Van Deusen 1987, 1990). This removed the biological growth trend and achieved homogeneous variances. We obtained total monthly rainfall plus mean monthly temperatures from NOAA for Dos Bocas, a weather station near Rio Abajo and Juncos, near Sabana (Figure 2). Data were collected at Dos Bocas since 1936 and at Juncos since 1909. We used the ALLREGS program, one of the DYNACLIM system of programs (Van Deusen 1993), to screen all possible climate models to determine which factors had the most effect on growth for each of the species. The program ALLREGS computes all possible least-squares regressions of the dependent variable, the standardized chronology, against all of the independent variables (climate). We analyzed the 12 monthly precipitation and temperature variables and one and two year lags of these variables. We also studied this data set to detect any extreme values. We used the program DYNAOLS to study climate models by conducting all possible regressions with ALLREGS. We fit climate models to the chronologies. The program DYNAOLS allows one to perform ordinary least squares and to evaluate regression diagnostics.

To examine the stand growth pattern through time and to detect periods of disturbance/release, a horizontal straight line standardization was used (Veblen et al. 1991, 1992). This approach damps out some of the within and among core variance, but the age-related effect is retained in the ring width index series. Let MSRW represent mean standardized ring width. Percent change in radial growth is computed as MSRW – lag(MSRW)/lag(MSRW) x 100, where lag means an earlier value. A growth release is defined as a 40% or greater change in MSRW sustained for at least five years (Devall et al. 1998).

Results and Discussion

The untransformed chronologies of teak and mahoe are presented in Figure 3 and mean annual radial increment (MARI) values are given in Table 2. The overall growth of teak is somewhat better than that of mahoe. The teak MARI averaged over 30 years is 5.33 mm at Rio Abajo and 5.59 mm at Sabana in contrast to 4.51 mm for mahoe at Rio Abajo. In Table 2 the mean annual radial increments are compared using one-way analysis of variance. When looking at individual ages the growth rarely appears to be different between teak and hibiscus. However, the cumulative effect over 30 years clearly shows that on average the teak grows significantly better than the hibiscus.

Teak – The oldest teak core from Rio Abajo dated to 1941, but 1945 was the first year in which more than one tree was present. Our analysis used first differenced inverse hypersine data; taking the first difference of the ring widths eliminated the first observation, so 1946 was the starting year. Current July and November temperature and November temperature lagged one year (Table 3) were the best predictors of growth of teak (R^2 = 0.53, p < 0.001). The observed and expected values of the standardized ring widths of teak are shown in Figure 4. Predicted growth was obtained from the program DYNAOLS with the climate variables mentioned above. The observed and predicted values are similar and run in the same direction most of the time.

For the five year period 1943-1948 initial growth rates were high as the planted teak expanded to occupy the site (Fig. 5). After 1948 the teak growth leveled, with some short term punctuated growth in the 1960's and early 1970's. From 1978 through 1990 growth decreased somewhat, reflecting age and competition effects from other trees in the stand. This horizontal line chronology shows a normal plantation growth development with no real periods of disturbance/release. For the hurricanes in 1956, 1961, 1964, 1979 and 1989, there is a growth decline in the hurricane year followed by a year of increased growth. There were two years of growth increase after hurricane Donna in 1961.

January temperature of the current year and February and July temperature of the previous year (Table 3) were the best predictors of the growth of teak at Sabana (R^2 = 0.73, p < 0.001). The observed and expected values of the standardized ring widths of teak are shown in Figure 6. The teak at Sabana were mostly planted in the early 1960's and have a high relative growth rate from 1960 to 1966 before dropping off (Fig. 7). As at Rio Abajo, there were no periods of growth release. The teak at Sabana are an exception for the 1961 hurricane, where growth declined in 1962. These were very young trees and probably did not have sufficient root systems, crown development, and reserves to take advantage of the decreased competition the year after the hurricane.

Mahoe – 1948 was the first year in which more than one mahoe tree was present, so 1949 was the starting year. Current October mean temperature, current September precipitation and October temperature of the previous year (Table 3) were the top estimators of growth of mahoe (R^2 = 0.53, p < 0.001). The observed and expected values of the ring widths of mahoe are shown in Figure 8.

Compared to the two teak chronologies, mahoe seems to grow at a slow but steady pace (Fig. 9). The young plantation does not display early rapid growth as found in teak. There are no release events evident in the chronology or in the percent change analysis. The mahoe stand reacts the same as the teak stands in response to hurricanes, with a decrease in growth during the year of the storm followed by a year of better growth.

The principle of limiting factors is important to dendrochronology (Fritts 1976). The range of rainfall reported for teak in its native habitat in southeast Asia is 1200-3400 mm (Salazar and Albertin 1974). The 2000 mm per year of rainfall at Rio Abajo appears to be sufficient for the two species during most of the year, so mean temperature becomes the limiting factor. Current July and November temperature were negatively correlated with the growth of teak, indicating that radial growth of the species is greater when the temperature is lower than average in July and November. Lower temperature could also result in lower potential evapotranspiration which would benefit growth by reducing water stress In contrast, the growth of mahoe was positively correlated with October mean temperature of the current year and of the previous year. The two species exhibit contrasting growth strategies, but both are influenced by temperature at about the same time of the year. At Sabana, temperature, not rainfall, is also a limiting factor.

July temperature proved to predict the teak chronology at Rio Abajo better than other months of the current year or past two years. Growth in this month apparently has a significant influence on the variation in total annual teak increment. Although the months selected were the best in predicting the ring widths over all the years (July and November temperature and November temperature of the previous year), they may not have been the best for any individual year. Rain and temperature during other months also influenced growth. There is less rainfall in July than in the other summer months and June-September is the warmest time of the year (Figure 2). With less rainfall there would be more clear days with increased heat and decreased humidity. It appears that in July, days with lower temperature are more favorable for the growth of teak.

October and November of the previous year were important to the growth of mahoe and teak at Rio Abajo. Bud formation, storage of photosynthates, formation of growth hormones and other growth processes occur the year before radial growth develops, so previous variation in climate can affect the ring width of the current year (D'Arrigo and Jacoby 1992).

Hurricanes passing over or near the island likely are evidenced in the chronologies because they cause leaves to fall and branches to break during the time of the hurricane, causing a decrease in radial growth for that year. However the thinning effect from other trees falling and the nutrients provided from the fallen organic matter cause increased growth the following year. Teak is apparently more sensitive to hurricanes than mahoe, perhaps because mahoe developed in an environment of hurricanes.

Conclusion

Both teak and mahoe are growing well at the two sites, but teak growth is better than that of mahoe, a native of similar nearby islands, suggesting that teak is a good choice for the subtropical wet forest region of Puerto Rico.

Acknowledgments

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Table 1. Correlations of core *i* with all the other cores by species.

Core	Sabana Teak	Rio Abajo Teak	Mahoe
1	31	42	23
2	44	37	43
3	44	54	58
4	32	58	47
5	30	44	46
6	55	32	47
7	27	57	35
8	20	65	16
9	18	61	31
10	42	38	46
11	43	30	32
12	46	52	44
13	22	71	29
14	44	51	45
15	41	48	26
16	34	50	54
17	51	45	40
18	33	42	24
19	32	41	30
20	18	58	26
21	39	51	
22	46	32	
23	20	32	
24	21	43	
25	38	56	
26	41	52	
27	57	35	
28	32	52	
29	57	55	
30	54	71	
31	46	21	
32	22	37	
33	65	33	
34	46	42	
35	21	73	
36	29	53	
37	59	80	
38	48	75	
39	24	56	
40	30	48	
41	28	57	
42	33	33	
43	18	73	
44	20	70	
45	39	38	
46	26	75	
47	18	44	
48	64		
49	43		
50	28		
51	27		
52	81		
53	53		
54	57		

Table 2. Mean annual radial increment (MARI) growth in millimeters.

	Rio Abajo		Sabana			
Age	Teak-MARI	Mahoe-MARI	Teak-MARI	*F*	*P*-value	RMSE
3	7.79	6.37	9.07	2.4	0.095	4.89
5	7.32[a,b]	5.79[b]	8.70[a]	3.9	0.023	4.13
10	5.68	5.09	6.37	1.3	0.288	3.31
15	4.98	4.20	4.82	0.5	0.629	3.05
20	3.94	4.36	3.35	1.6	0.208	2.33
25	3.41[a,b]	3.73[a]	2.41[b]	3.4	0.036	2.21
30	2.98[a,b]	3.45[a]	1.82[b]	4.2	0.022	1.73
35	3.97	3.62		0.1	0.826	3.44
40	2.98	3.41		0.1	0.789	2.89
45	2.44	3.01		0.1	0.833	2.31
30 Year Average:	5.33[a]	4.51[b]	5.59[a]	14.7	<0.001	4.06

Notes: MARI compared using one-way analysis of variance. Where the *F*-statistic is significant at the 0.05 level, Tukey's test was applied to separate means. RMSE is root mean squared error.

Table 3. Correlations between species growth chronologies and climate variables at Rio Abajo in east central Puerto Rico. cor = correlation, est = slope estimate, prob = probability, var = variable.

Sabana-Teak (*Tectona grandis*)					Rio Abajo - Teak					Mahoe (*Hibiscus elatus*)				
cor	var	lag	est	prob	cor	var	lag	est	prob	cor	var	lag	est	prob
-0.65	Jan temp	0	-0.02	<0.01	-0.53	Jul temp	0	-0.01	<0.01	0.29	Oct temp	0	0.22	<0.01
-0.10	Feb temp	-1	-0.11	0.02	-0.34	Nov temp	0	-0.15	<0.01	0.24	Sep rain	0	0.02	<0.01
0.36	July temp	-1	0.21	<0.01	0.08	Nov temp	1	0.12	<0.01	-0.36	Oct temp	1	-0.23	<0.01

Figure 1. Location of the study sites, Rio Abajo and Sabana, on the island of Puerto Rico.

Figure 2. Mean monthly temperature and total monthly precipitation in west central Puerto Rico; data from the NOAA station at Dos Bocas near Rio Abajo.

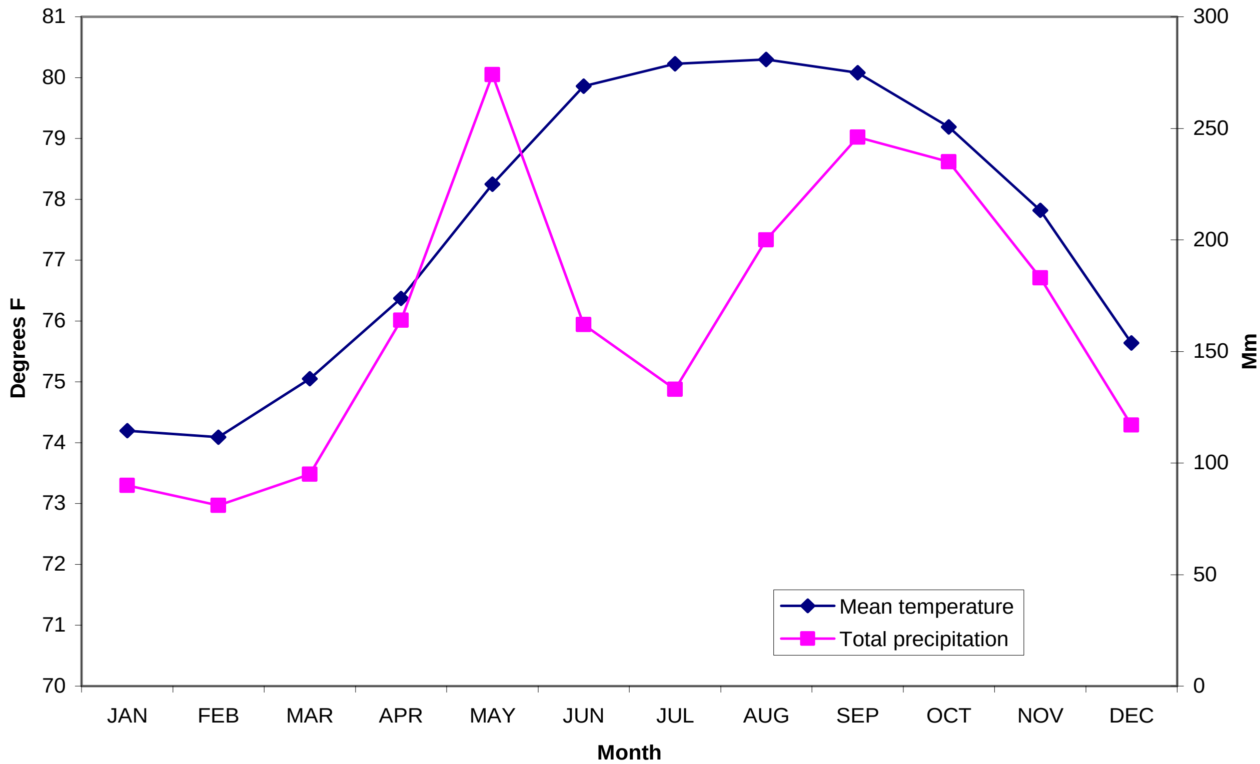

Figure 3. The untransformed chronologies of teak and mahoe from Rio Abajo, Puerto Rico.

Figure 4. Teak at Rio Abajo, the observed (solid line) vs predicted (dashed line) values calculated with the climate variables of July and November temperature of the current year and November temperature of the previous year.

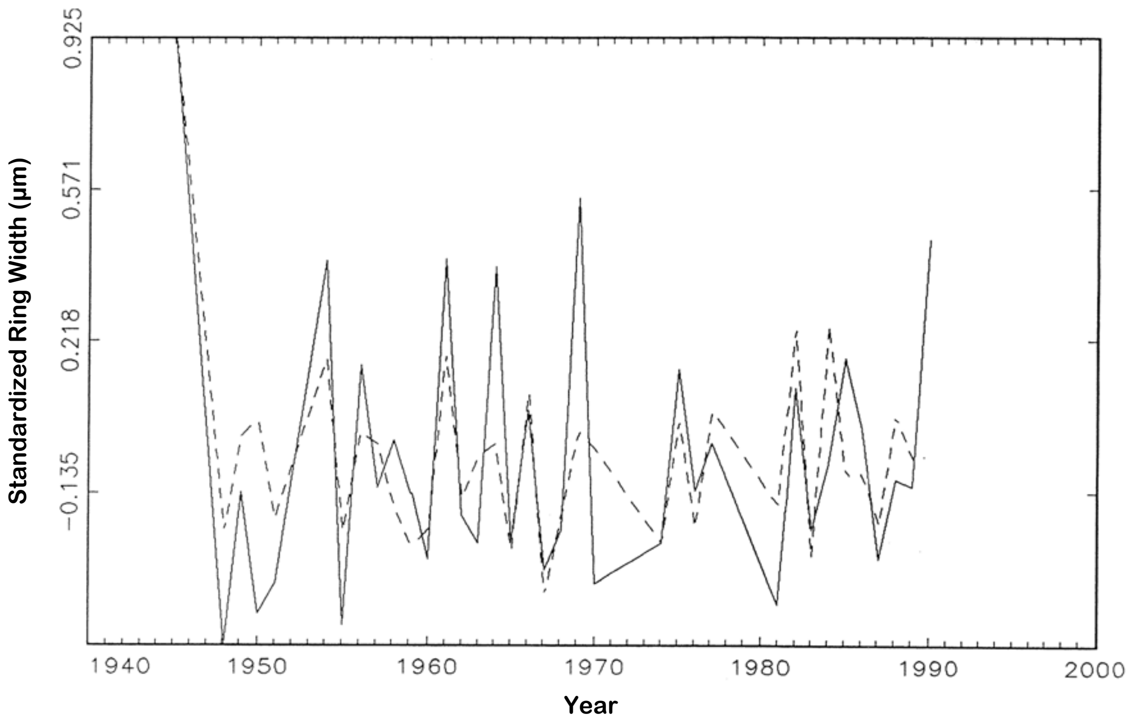

Figure 5. Mean horizontal line standardized ring width chronology illustrating growth pattern of teak at Rio Abajo. Graph of core sample size appears below chronology.

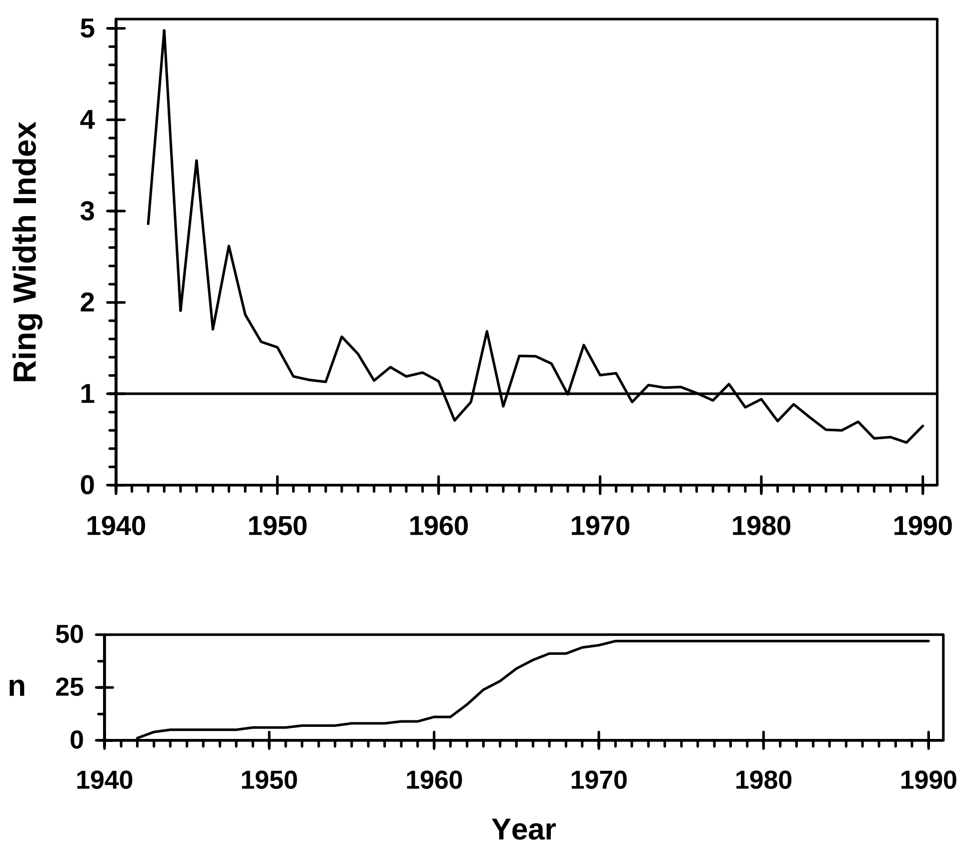

Figure 6. Teak at Sabana, the observed (solid line) vs predicted (dashed line) values calculated with the climate variables of January temperature of the current year and February and July temperature of the previous year.

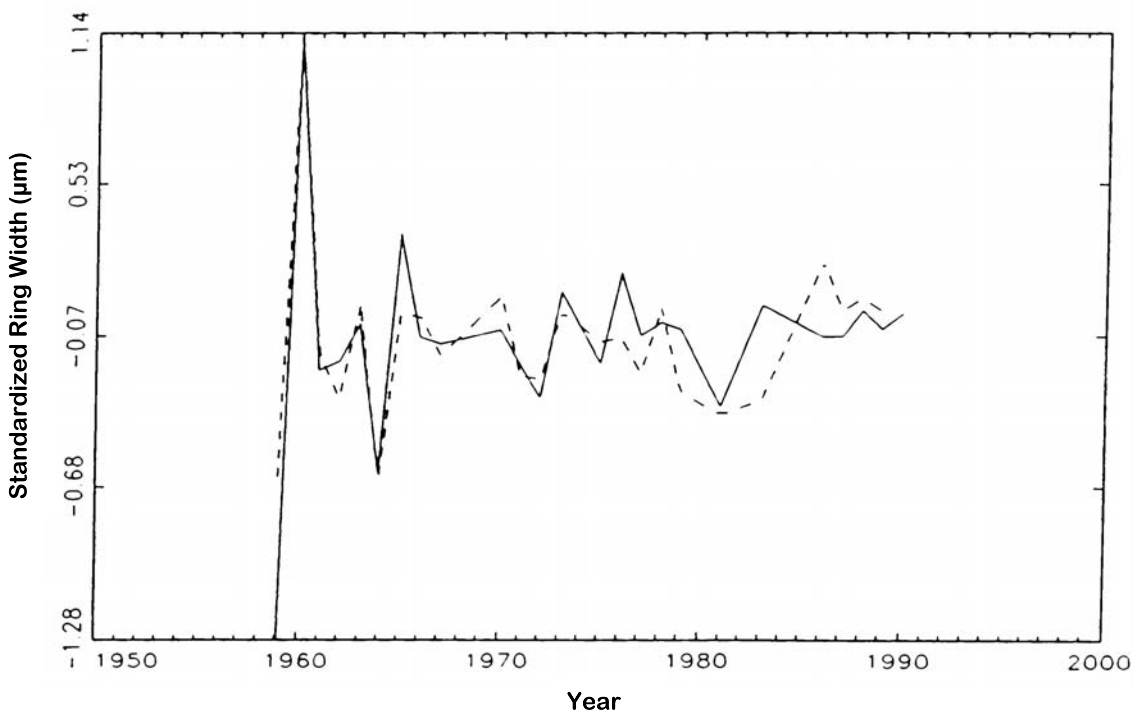

Figure 7. Mean horizontal line standardized ring width chronology illustrating growth pattern of teak at Sabana. Graph of core sample size appears below chronology.

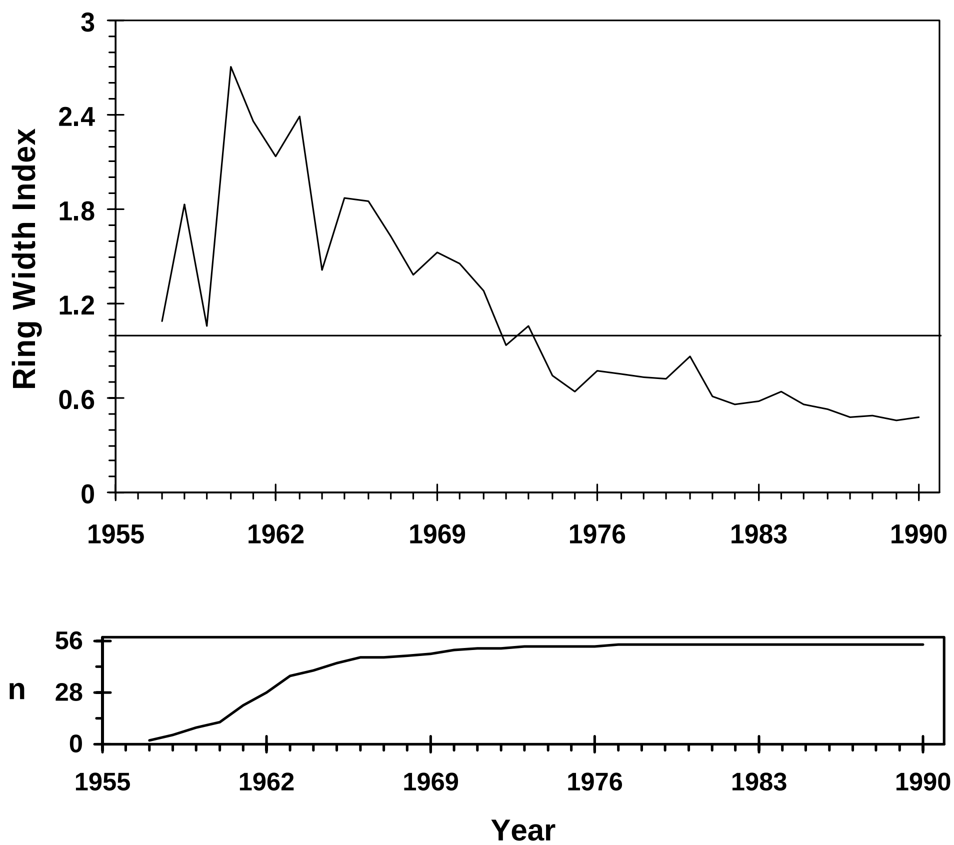

Figure 8. Mahoe, the observed (solid line) vs predicted (dashed line) values calculated with the climate variables of October mean temperature, September precipitation and October temperature of the previous year.

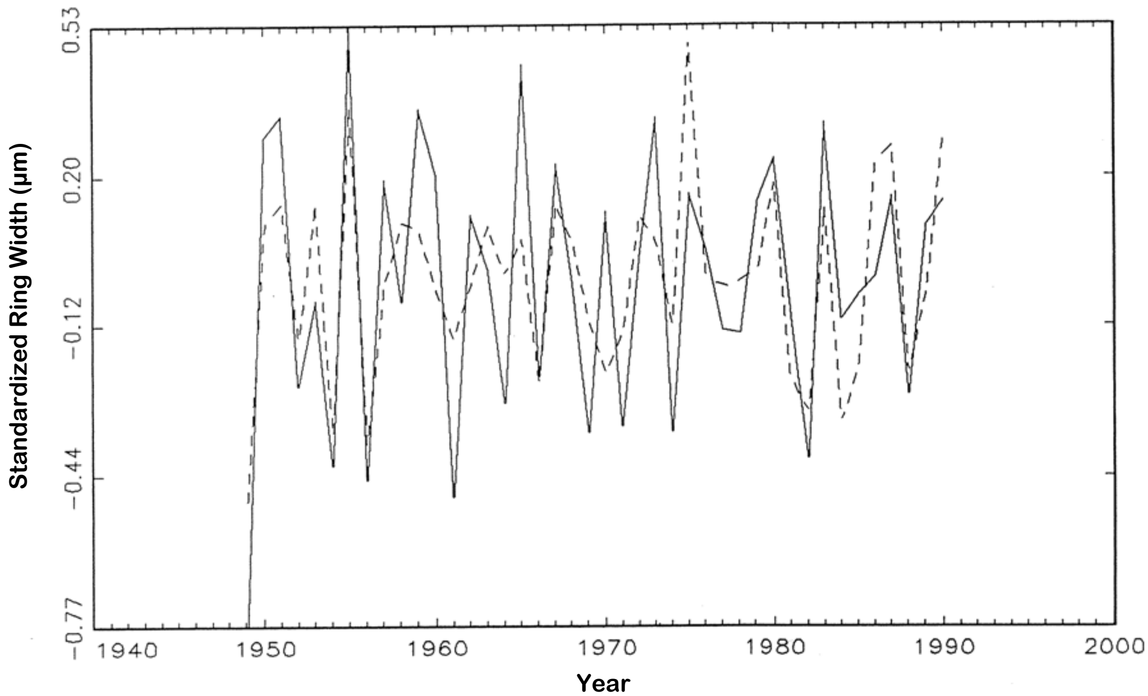

Figure 9. Mean horizontal line standardized ring width chronology illustrating growth pattern of mahoe at Rio Abajo. Graph of core sample size appears below chronology.