MODELLING PENTACLETHRA FOREST – AN IMPORTANT CENTRAL AMERICAN LOWLAND RAIN FOREST TYPE – FOR TIMBER PRODUCTION

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ABSTRACT

Pentaclethra forest is a major component of the Central American Atlantic Moist Forest Ecoregion (CAAMFE). It covers most of the Costa Rican Atlantic Lowland region and parts of Panama and Nicaragua. Although soils are poor, deforestation in this forest type, for pastureland or permanent crops such as citrus, has been extensive during recent decades. The remaining forest stands, are small fragments in protected areas or on privately owned land, of which, the latter is one of the main sources of timber in the countries mentioned. The traditional log-and-leave methods are recognized to be obsolete and a relatively good biophysical information base for the management of Pentaclethra forests has been built up by CATIE and other institutions. This information is appropriate for the development of computer models of stand dynamics in managed forests. In this paper we present a synthesis of studies in Pentaclethra forest aiming to demonstrate the feasibility of silvicultural interventions to promote sound management practices in these forests. A model framework is presented.

INTRODUCTION

Pentaclethra forest (Finegan and Camacho 1999) is a major component of the Central American Atlantic Moist Forest Ecoregion (CAAMFE). Dinerstein et al. (1995) defined the CAAMFE among other Latin American ecoregions, and according to its importance to ecological processes, conservation status, and priority, they classified it as bioregionally outstanding, vulnerable and moderate priority at regional scale respectively. CAAMFE covers an area of about 155,020 Km^2 extending from Guatemala down to Panama. In the Southern region of this area, from Panama through Costa Rica to Southern Nicaragua this ecoregion is dominated by *Pentaclethra macroloba*, a legume tree species with dominance of about 14-25 % of the IVI and 18-44 % of total basal area for trees with dbh ≥ 10 cm.

These forests have been severely devastated for banana plantations, cattle breeding, and unplanned logging leaving the area with small to medium size fragments of forests. Most of the remaining forest fragments are under total protection or in privately owned farms, subject to conversion to other more attractive land use forms. Forest management practices that promote ecologically sound timber harvesting as alternative to logging and abandon, and total protection include silvicultural treatments to improve the economic value of the forest while maintaining ecological processes of the natural forest system. CATIE is a leading institution among those that investigate forest management principles and practical issues within CAAMFE and in Pentaclethra forest in particular. Long-term research areas have been established since 1988 in four areas, two in Northern Costa Rica and two in Southern Nicaragua to monitor forest interventions and response of the forest to these interventions.

Modelling these ecosystems is now undergoing with perspective to produce general tendencies using the information derived along the one decade of observations. Preliminary results on logging and silvicultural effects on species composition, growth trends, regeneration and mortality patterns have been reported elsewhere (Sitoe 1992, Castillo 1997, Finegan and Camacho 1999, Finegan et al. 1999). A general framework for a patch model (based on gap-modelling principles) has been adopted for the site conditions and data available at hand (Sitoe 1998). The model is expected to be able to test hypotheses regarding forest management interventions in relation to the ecosystem integrity in terms of species composition, growth of remnant forest stand, regeneration and mortality as well as give insights of the forest dynamic processes.

Our purpose with this paper is to present *(a)* a review of the long-term research activities in Pentaclethra forest by CATIE's Natural Forest Management Unit; *(b)* a summary of preliminary results; and *(c)* the modelling strategy and framework adopted.

HISTORY OF LONG TERM RESEARCH

Five research sites were established by CATIE in the three countries covered by CAAMPFE. These sites were established with the objective to (a) monitor forest dynamics and biodiversity of primary forests with different intervention (logging and silvicultural treatment) intensities, (b) evaluation of ecologically and economically sound logging operations, and (c) cost-benefit analysis of the activities in a) and b). The following paragraphs are a brief description of the history of the sites. More detailed description of ecological and silvicultural conditions of the sites can be found elsewhere (Finegan and Camacho 1999, Finegan *et al.* and Castillo, 1997). For all sites the permanent sample plots (PSP) followed Synnot (1979) procedures, with quadrangular form, measuring 100 x 100 m and bordered by 40m stripe each side, except for Changuinola.

Los Laureles de Corinto Research Site is located in a private property in Northern Costa Rica at an altitude of about 250 m.a.s.l. It covers an area of 150 ha with primary and secondary forests. Nine (PSP) were established between 1987 and 1990 within the primary forest area. Commercial logging operation was planned and implemented in 1992 in 30 ha, which also included six of the PSP. A liberation silvicultural treatment was applied in three of the logged plots four years after logging.

La Tirimbina Research Site is also in a privately owned land in Northern Costa Rica, about 50 Km north of Laureles de Corinto, in an altitude of about 200 m.a.s.l. La Tirimbina covers an area of about 80 ha with primary and secondary forests. Nine PSP were established between 1988 and 1990 in within the primary forest area. Between 1989 and 1990 all the plots were commercially logged followed (in 1991 and 1993) by silvicultural treatments (liberation, refinement and shelterwood).

Changuinola Research Site is located in Northern Panama in a private land of about 78 ha of which one half are primary forest. Eight 80x80 m plots were established in 1990. These plots have been selectively logged by the landowner in a yearly basis. Liberation silvicultural treatment was applied in 1992 in two plots.

La Lupe and Los Filos Research Sites are located in Southern Nicaragua and presently are being managed by UCA (Universidad Centroamericana). Six PSP were established in La Lupe in 1990 and a liberation silvicultural treatment was applied between 1992 and 1995. In Los Filos, eight PSP were established in 1992 followed by improved logging operation.

RESULTS FROM 1988-1998

Early results from the research sites have been reported in a variety of forms, from thesis dissertations to scientific papers. In this section, we present some of the most relevant results reported from the Southern Nicaragua (La Lupe and Los Filos) and Northern Costa Rica (Laureles de Corinto and La Tirimbina) sites.

All the sites are dominated by *Pentaclethra macroloba* with IVI varying from 14 to 26% and a relative abundance of about 18-44%. The total number of species identified is between 161 and 272. Table 1 presents the general characteristics of the CATIE research sites in Pentaclethra forest. The Costa Rican sites seem to be denser and diverse than the Nicaraguans.

Table 1: *General characteristics of the Pentaclethra forest. IVI – importance value index; BA – basal area ($m^2.ha^{-1}$).*

Site	Area* (ha)	Total species	Species per ha	#Stem per ha	Pentaclethra macroloba		
					IVI %	% stems	%BA
Corinto(1)	9	272	103	435	25.9	24.9	44.3
Tirimbina(2)	9	259	103	504	15.6	14.0	32.0
La Lupe(3)	6	161	94	499	14.2	10.5	17.8
Los Filos(3)	8	180	101	436	14.7	11.0	18.7

* Effective area of the plots.
(1) Brenes, H. Natural Forest Management Unit Data base administrator. Unpublished data
(2) Camacho and Finegan 1999, Finegan et al. 1999
(3) Castillo, 1997

Of the total species identified in the each site, there is an average of fifty commercial (timber) species. These are considered more in detail in silvicultural studies.

The diameter distribution structure conforms the reverse-J, with most of the trees not exceeding 30 cm dbh. This large group of small trees includes juveniles of canopy species, adults of understorey species and palms. The analysis of the vertical structure of the forest shows that trees (dbh≥10cm) grow in a variety of canopy closure conditions with relatively few trees growing in completely open conditions and also few in completely shaded conditions. This means that the majority of the trees receive a certain amount of sunlight either directly or through sunflakes during the daytime.

Diameter to height equations were developed based on literature information. Llerena and Malleux (1984), experimented with several equations while Botkin (193) used a quadratic function and Lieberman *et al.* 1995 used a power function. The power and quadratic functions were used to test the best fit to the data of Corinto Research Site. Analyses were divided in adult size (Zamora *et al.* 1997) because Finegan and Camacho et al found final adult as influencing the stem diameter growth pattern.

From the regression and the residual analysis for the diameter-to-height function we found that the quadratic function performed well for all adult size species groups except the understorey species that exhibited a linear relation. Note that understorey species have stem diameters up to 30 cm. One equation was developed for each adult size and the coefficients are presented in Table 2. The residuals for all the models were checked and were found to be randomly distributed with mean zero and homogeneous variance as required by regression assumptions. The coefficients of determination (R^2) ranged from 0.32 to 0.81. Figure 1 shows the scater plot with the fitted lines for each adult size species group.

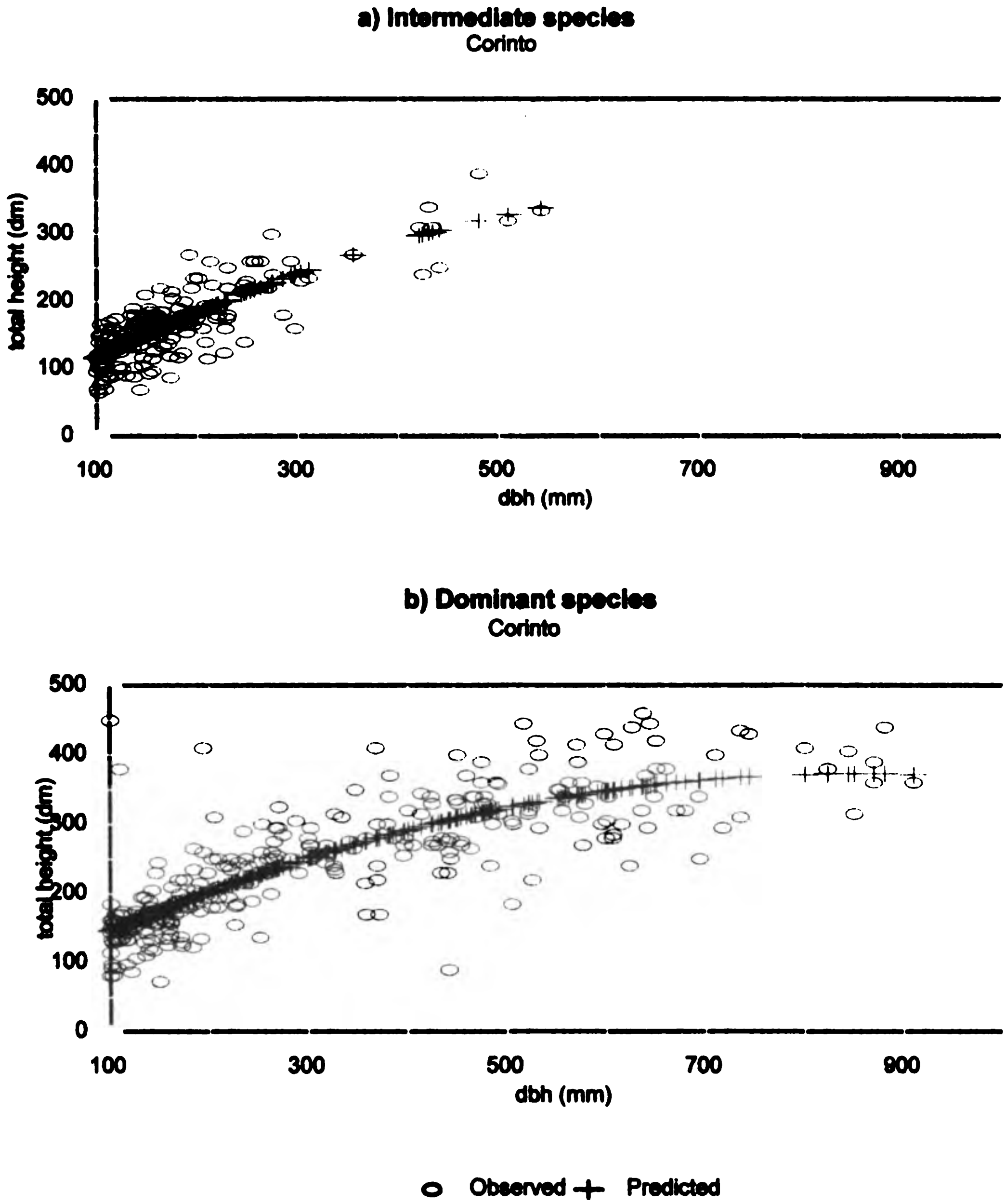

Figure 1: *Scatter plot of the observed and predicted total stem height for Corinto (data from plots 1,2,3 and 4). Statistics of regressions used to estimate predicted heights are presented in Table 2. Figure 2.a was manually set to a different scale (x-axis) to evidence the trend.*

Table 2: *Regression coefficients for the quadratic function of height on dbh. N – number of stems; a – intercept; b_1 and b_2 are linear and quadratic coefficients respectively; R^2 is the model coefficient of determination. All models are highly significative ($P<0.0001$).*

Adult size	N	*a*	b_1	b_2	R^2
Understorey	54	43.62	0.704	-	0.32
Intermediate	165	38.19	0.828	-0.000503	0.65
Sub-canopy	136	-11.98	1.129	-0.000739	0.50
Dominant	280	81.94	0.687	-0.000405	0.66
Unknown	84	25.22	0.875	-0.000501	0.81

MODELLING FRAMEWORK AND STRATEGY

The ultimate purpose of long-term data collection is to empower the researcher through the data set with new knowledge. Specific objectives include finding general trends and patterns of the reaction of the tree species when logging and silvicultural treatments are applied in a forest stand. If trends and generalizations could be made, then they can be formally stated in form of a simulation model. The final goal of the modelling process as stated by the Forest Management Unit is to "*broaden and deepen our understanding of the forest dynamic processes...*" (CATIE 1995, Campos et al. 1997). The defined modelling objective suggests a model to give insights of the forest dynamic processes rather than predictions. A process-based model would be the ideal tool for the stated purpose. However, the development of a process-based model requires costly data not collected traditionally in forestry sciences, where "pragmatic data" are the most important. On the other hand, the empirical models that have been traditionally used in forestry, despite their relative simplicity and accuracy, do not fit well in this objective. Empirical models have been reported as neglecting the ecological aspects while fitting well the observed data to statistical equations (Amateis 1994). This is expected when considering the Levins tricotomy of biological models, in which to gain in accuracy, one should sacrifice one of the other two aspects, generality and realism (Levins 1966, 1993).

Taking into account the objectives stated and the data available, an intermediate term was to be found between empirical and process-based models. The gap-based models offered one of these viable alternatives (Botkin 1993, Shugart 1998). The gap-based models use most of the data traditionally collected in permanent sample plots in forest sciences and offer an acceptable alternative of expressing ecological relations within a forest ecosystem that could be interpreted for forest management purposes. We do recognize the difficulties existing to depart from empirical to process-based models. Recent gap-models use non-traditional input data, and biological processes are better represented in these models. Thus, the model framework we are proposing here has an important goal: to provide a research framework, highlight data requirements and areas for further research.

Figure 2 presents the general model framework adopted based on this approach, and will be used to develop the first modelling approach for our research sites (Sitoe, 1998). The species ecological groups developed by Finegan et al.1999 will be used together with the commercial value of the species to develop the species list. Output from other relevant models could be used to provide input for our model when data could not be collected (e.g. Maximum age could be estimated using the growth simulation technique - Lieberman and Lieberman, 1987). Allometric functions of correlated tree characteristics (e.g. dbh-to-height) will be developed. Topography and soil type will act as micro-site factors within the site while logging and silvicultural treatments will be simulated according to the established rules for forest management. The global model will be composed of the traditional growth, mortality, regeneration and silvicultural sub-models. The model resolution will be at individual tree level simulated in function of species, relative size to the neighbours, initial conditions of the tree and micro site characteristics.

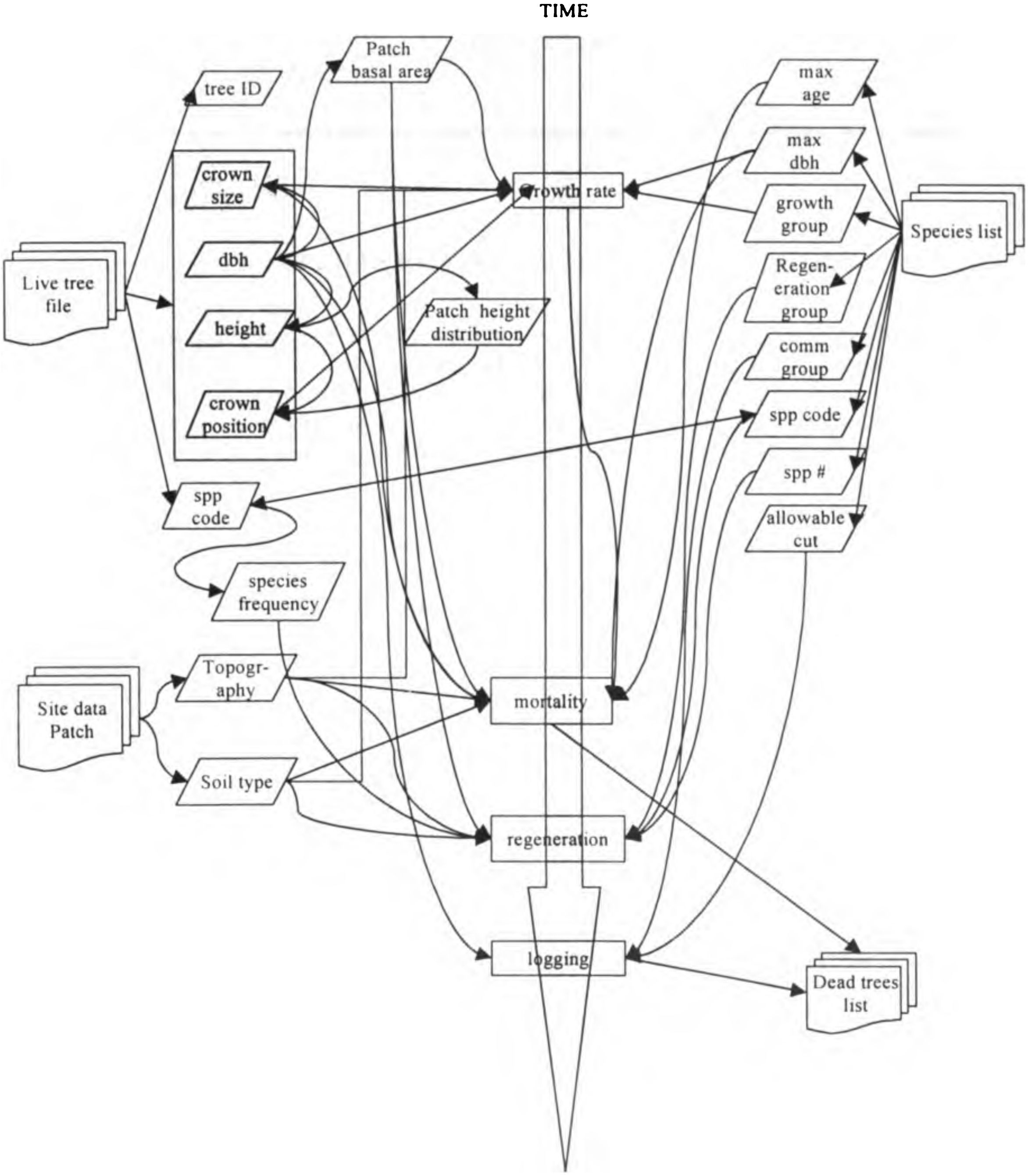

Figure 2. *General framework for a growth and yield model in Pentaclethra forest (Sitoe 1998). The shaded variables are the dynamic state variables, while species list is maintained fixed. At this stage, site characteristics will also be considered fixed. The large downward arrow represents the time and rectangles on it, the "processes" to be modeled.*

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