Deutscher Tropentag 2004
Berlin, October 5-7, 2004
Conference on International Agricultural Research for Development

A resources assessment study of Guadua bamboo (*Guadua angustifolia*) in the Coffee Region of Colombia

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1. Introduction:

Guadua angustifolia, a bamboo species with a high economic and conservation potential, has been studied intensively over the past years in Colombia. It is considered an alternative product for the farmers in the central region of Colombia, dominated traditionally by coffee-production.

Guadua "forests" are found along rivers and creeks and also in patches away from waters.

Most of the Guadua stands in Colombia grow naturally. However, commercial cultivation has been increasing over the past years. Many questions arise about stand establishment, favourable site conditions, silvicultural treatment, technological properties of the culm etc. – and a basic information required for all resources planning and research is the estimation of the existing Guadua stands in terms of area and stand characteristics (like culm density).

Large area assessments of Guadua in the Coffee Region of Colombia are difficult for several reasons: the spatial arrangement, dimensions of the patches, and the relatively low density. To come to regional estimates, ways have to be found to efficiently combine different data sources like field measurements, remotely sensed data, and existing statistics.

According with the knowledge of the autors of the present paper, there were not reports about Guadua inventories with statistical bases for the study area. Some previus works, make reference to mapping approaches of Guadua crown cover, without taking in account estimations of other variables like culms, volume, biomass per hectare and others.

Previus estimations of the crown cover done by the Corporaciones Autonomas de Desarrollo (CARDS), reported 0,85% of Guadua crown cover using mapping approach and 1,14% based in harvesting and reforestation records (Garzón 2002), however the same autor discussed about some inconsistency problems found in the information that avoid to get reliable estimation for the entire Coffee Region.

The objetives of this study were:

a. to define and apply a practical and low cost sampling approach for Guadua patches in the Coffee Region of Colombia.

b. to get valid statistical estimation of the Guadua crown cover in the Coffee Region of Colombia and the different characteristics of the Guadua patches in terms of culms abundance, volume per hectare, etc).

2. Study area:

The study area (1 029 524.77 Ha) was located in the Coffee Region of Colombia, in the departments of Valle del Cauca, Quindio, Risaralda, and Caldas (See Figure 1). The geographical location is defined in UTM zone 18, in the following coordinates: (1064421, 922515) and (1195757, 1122579).

A digital elevation model was used to extract the areas with an elevation over the see level up 900 to 2000 m (Cardona 2002). In these areas the best conditions to grow *Guadua angustifolia* in the region are found.

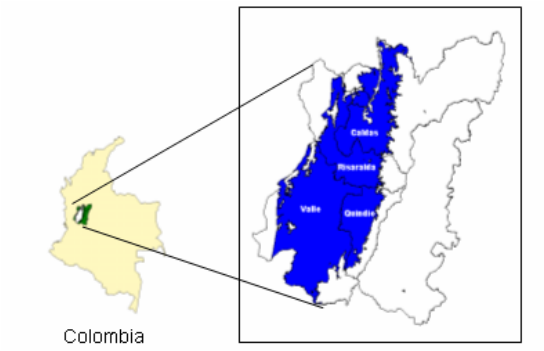

Figure 1: *Location of the Coffee Region in Colombia*

3. Methodology:

To define an optimal sampling approach of Guadua stands in the Coffee Region of Colombia, it is instructive to compare it with the commonalities and differences of forest inventories. A comparison is presented in Table 1. Taking in consideration the factors annotated in Table 1, and budged limitation, the following approaches had been used:

1. The area of Guadua stands (minimum area 0.3 ha) was estimated from (available) aerial photographs. Systematic sampling was employed to collect field data, with a sample size of *n*=89 on a 10km x 10 km grid. Decision for the relatively low sample size was governed by restrictions of resources. The aerial photographs closest to the sample point were taken to center an aerial photo plot of approximately 3 km x 3 km (900 ha) on it. In these plots pure Guadua stands and mixed Guadua stands were delineated for area estimation (Figure 2 and Figure 3).
   A field verification campaign was carried out in 21 of the 89 plots to validate the delineation of the Guadua patches (more details about de validation campaign can be found in Rubiano D 2002 and Morales D and Kleinn C 2004). A confusion matrix (Congalton and Green 1999) was developed with the information of the field verification and the aerial photo plots interpretation, and the estimation of the accuracy of the interpretation obtained was 95.1%.

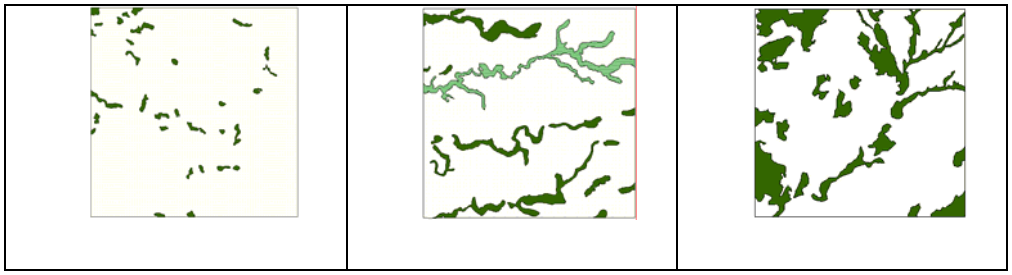

Figure 2: Examples of Guadua crown cover delineation inside the aerial photographs plots .

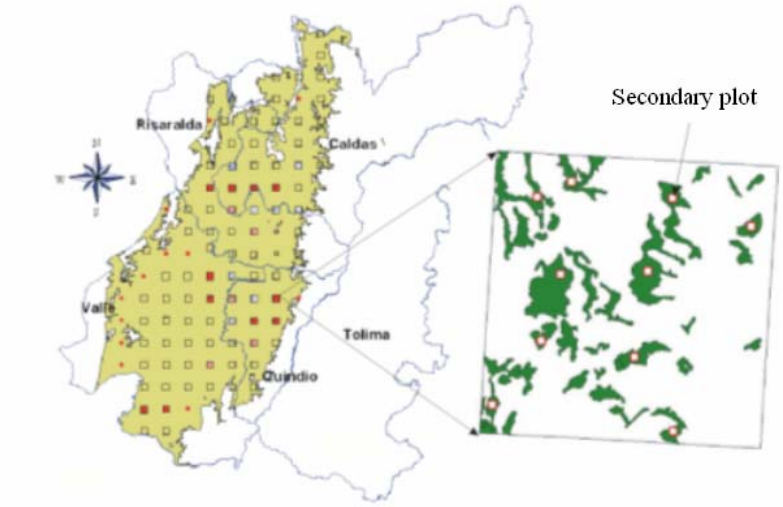

Figure 3: Systematic sampling approach used with the aerial photographs plots for the estimation of Guadua crown cover over the Coffee Region of Colombia and graphical representation of the field sampling design.

Table 1: Characteristics of Guadua stands in the Coffee Region with respect to sample based inventory approaches. To each "situation" (left column), observations and approaches are given (adapted from TROF project 2000).

Situation	Observations & Approaches
Remote sensing issues	
Limited visibility on satellite images	- Identify observable covariates - Link it to land cover/land use or other categories - Higher resolution sensors?
Availability of air photos in appropriate scale	- Provide air photos – costs? - use high resolution satellite images
Relatively rapid dynamics	- use up-to-date imagery - comprehensive field verification
Organizational issues of field work	
Access denied by owners	- low number of field plots - retrieve as much info as possible from remote sensing - apply methods for non-response
Risk for the field crews due "guerrilla" and "paramilitares" problems.	- Low number of field plots - apply "remote measurements" in the field
Scarce/low density/low value per ha.	- Combination with other assessments and activities
Field plot issues	
Resource heterogeneous - with respect to spatial configuration	- use different plot designs
- with respect to density	- use different plot sizes
Local variability varies	- use different sampling intensities - use adaptive designs
Analysis issues	
Known volume/biomass/carbon models possibly not valid	- develop new models - check applicability of present models
Use of general collateral data	- trade statistics etc. do not apply

2. For the field survey, a two stage sampling was applied (Shiver D and Border B, 1956). Thirteen primary plots were randomly selected of the 89 interpreted aerial photographs plots, excluding those without Guadua patches. In each selected primary plot, 10 secondary plots of 10m x 10m each were randomly selected. The location of the secondary plots was done using the delineation of the Guadua stands in the primary plot (Figure 3). There, number of stems, diameter *d* and other attributes were measured (more details in Morales D and Kleinn C 2004). It is important to mention that the study was carried out between June and August 2002.

The "effective area" of Guadual was estimated due the high effect of the edge of the canopy projection. A value of 8.6 m was found like the average distance between the edge of the crown projection in the field and the guadua stands area (effective area) (see Figure 4 and Figure 5).

This factor is very important to take in consideration to make field data extrapolations to the entire area, if plots have been installed just in the effective area of the Guadua stands.

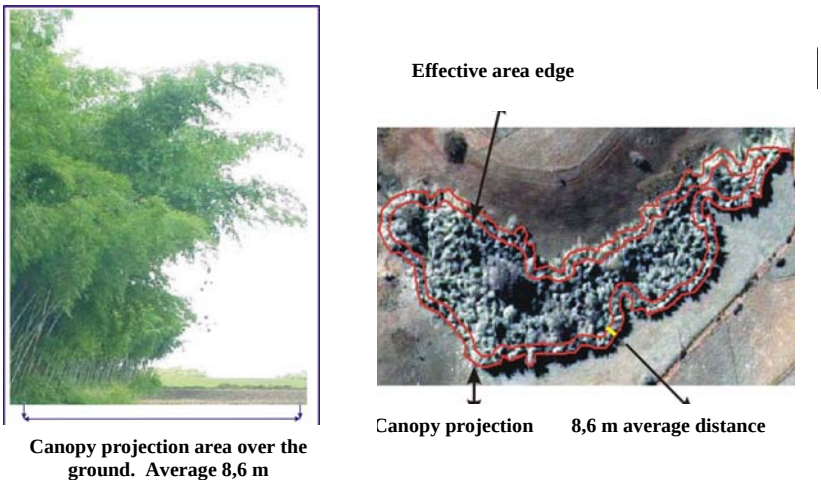

Figure 4: Graphical representation of the influence of the edge of the canopy projection in the estimation of the effective area of Guadua patches in the Coffee Region of Colombia.

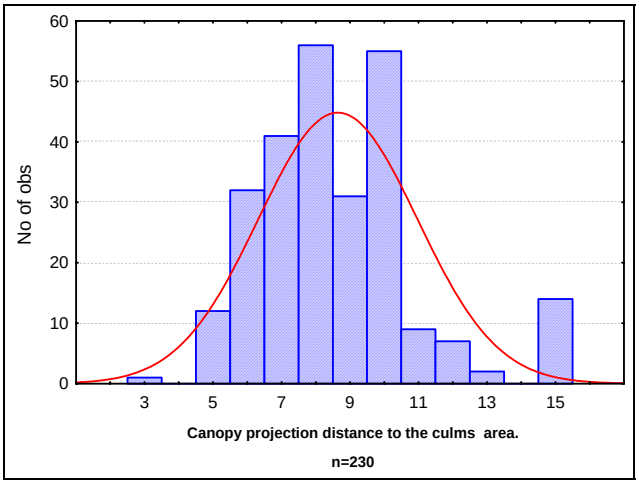

Figure 5: Graphical representation of the sampling of 230 distances of the canopy projection edge located randomly over the Guadua patches in the Coffee Region of Colombia (average 8,6 m) (source Morales D and Kleinn C 2004).

4. Results:

In the tables 2, 3, and 4 the main results of the Guadua inventory in the Coffee Region of Colombia are presented. It is important to keep in mind that all those results come from a low intensity forest inventory.

According with Thuresson (2002) a low-intensity forest inventory may not fulfill all information demands for the users from a forest inventory point of view. However, it can provide fairly advanced data for use in decision-making, and the information from such inventories may promote forest policy work and new inventories.

In table 2, the Guadua crown cover and the effective area estimation is presented. It is important to note that the percentage of the standard error for the crown cover estimation was only 10,76%.

Table 2: Guadua crown cover and Guadua effective area estimation for the Coffee Region of Colombia.

	Average	Standard error	Confidence interval 95%
Crown cover estimation	3,90%	0,42%	**[** 3,07% - 4,73% **]**
Effective area estimation	2,70%	0,32%	**[** 2,07% - 3,33% **]**

In table 3, the principal Guadua stands variables are presented. For the number of culms per hectare, the percentage to the standard error was 6,82%.

Table 3: Estimation of the principal Guadua stands variables in the Coffee Region of Colombia.

	Average	Standard Error	Confidence intervals 95%
Diameter (dbh-cm)	10,8	0,5	**[** 9,9- 11,70 **]**
Culms length (m)	19,1	0,8	**[** 17,5 - 20,7 **]**
Volume (m^3/ha)	1053	116,9	**[** 819,2 - 1286,7 **]**
Biomass (Ton/ha)	81,50	3,4	**[** 74,7 - 88,3 **]**
Culms abundance/ha	6940	473,3	**[** 5993,4 - 7886,6 **]**

The low availability of good models to estimate volume and biomass of Guadua culms was found like a limitant for this study.

For the estimation of the culms volume the following relationship was used:

Culm volume = π/4 (dbh/100) ^2*Culm length* Fc. Where: Fc = shape factor (0,78) (Arbeláez 1996)

In the case of biomass estimation, the relationship developed by Riaño et al. (2002) was used with a factor of 0,5 for carbon estimation (Brown 2001 cited by Riaño et al. 2002):

Dry weight (gr)= -1,007+0,476*(-25474,8+705,09*dbh (mm))

About the healthy and phytosanitary situation of the culms, it was found that 96,1% (percentage of standard error=3,1%), were in good conditions. Just a low percentage (1,4%) of the culms, were found with a problem with *Podischnus agenor* (Oliver) (Rojas 1991, makes a description of the culms damage due this insect).

The culms maturity percentage is one of the most important information related with the Guadua stands management. This information together with the analysis of number of culms per hectare and other variables can help the decision makers to keep the sustainability of the Guadua stands.

To compare the impact of the harvesting or the management of the Guadua stands, a defined regional sustainable standards based in the maturity of the culms percentage, developed by the Coorporaciones Autónomas de Desarrollo (CARDS) in Colombia (Giraldo y Sabogal 1999 and Riaño *et al*. 2002) can be used.

The results about the maturity percentage for the culms in the study area, are presented in Table 4. These results are very similar with the sustainable standards proposed by the CARDS. It shows that the guaduales in the study area are general terms in a sustainable condition.

Table 4: Culms maturity per dbh found in the Guadua stands in the Coffee Region of Colombia.

DBH Classes	Culms maturity				
	Shoots	**Young**	**Mature**	**Dry**	**Total**
4-8	0.39%	1.63%	5.07%	1.14%	8.22%
8-12	1.83%	8.55%	38.14%	4.50%	53.01%
12-16	1.35%	7.38%	24.75%	2.26%	35.75%
16-20	0.12%	1.02%	1.65%	0.14%	2.94%
>=20	0.03%	0.01%	0.03%	0.00%	0.08%
Total	**3.72%**	**18.59%**	**69.64%**	**8.05%**	**100.00%**
% Standard error	**12.8%**	**10.8**	**7.08**	**15.8**	
CARDS *	**5.0%**	**25.0%**	**65.0%**	**5.0%**	

** Taken from Giraldo E and Sabogal A. 1999*

5. Conclusions:

The applied methodology in this study allowed to obtain statistically valid results that can support the decision making in the sustainable management of the resource studied with a low cost.

Fragmented forest patches, can be assessment using common forest inventories approaches, but some adjustment must be done to get reliable results.

The estimation of the effective area in fragmented forest is an issue with a high importance to the extrapolation of the information to the entire area. In the case of bamboo forest this area represented 33.14 % of the total crown cover area estimation.

6. Acknowledgements

To the INCO-DC Program of the European Commission for the financial support of this research (contract No. ICA4-2000-10209) Guadua bamboo project.

To all those that were involved with this project, in special to Marco Chávez (air photo interpretation - CATIE), Juan Carlos Camargo – UTP (contacts and logistic in Colombia), Ximena Londoño (Guadua technical aspects), Gustavo Cardona (Colombian partner), Gabriel Jaime Aranjo and team (field inventory), Diego Rubiano and team (validation of the air photo interpretation in Colombia).

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