PHYSICAL ACCOUNTS OF THE FOREST IN THE BASIN OF PIEDRAS BLANCAS, MEDELLIN (COLOMBIA)

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SUMMARY

The physical account for «Piedras Blancas» is a pilot study in order to structure a useful methodology for the Department of Antioquia and possibly for a national level. In these accounts, the biomass of the restocking, stems, leaves and fruits are calculated, as well as the total and commercial biomass.

KEY WORDS: Physical account
Biomass
Forest
Modeling

INTRODUCTION

Colombia is a rich country in natural resources, 70 % of its area is forested with primary forests unique in the world. Those forests have been destroyed rapidly. Natural growth rates and afforestations can not assure sustentability in the future. Physical accounts of the forest will provide information on the existence, destruction and possible recovery of the forest, which is essential for any management or conservation plan of the forest resource.

For this reason, the present work aspires to develop a methodological framework for the physical accounts of the forest in terms of biomass, in an area with information of high environmental quality. This method may be used in the short term at departmental and national levels as another contribution to the efforts carried out in the country regarding the physical accounts of natural resources and of the forests specifically.

MATERIALS AND METHODS

Description of the study area

In accordance with the *Mi Río* Institute (1995), the basin of *Piedras Blancas* has an orientation South-North, and it is located at the East of the municipality of Medellin. It is approximately at 14 km in the old road to Guarne. It has an extension of 41.87 km^2, of which 5.49 km^2 belong to Guarne municipality and 14.43 km^2 to the Copacabana municipality. The rest of the basin belongs to the rural area of Santa Elena.

According to Jaramillo (1989), the soils present two lithological materials: amphibolites and serpentines; alluvial deposits are also present. From the point of view of the origin of the soils, the most important in the whole basin is the volcanic ash, since it covers landscapes of rocks and the important slope deposits. It is also part of the alluviums as material carried and deposited by rivers.

These soils are deep to moderately deep, limited by the phreatic stratum, gravels, stones, rocky bloomings and slight toxicity to the plants for aluminum; with well or moderately well drainage in the hillsides and with imperfect drainage in the depressions. It also has diffuse glide erosion, furrows, cow paws and located mass movements. The erosion degree becomes severe in some units The surface of these soils is made of stones of different diameters and rocky bloomings. During the dry seasons there are cracks of certain width and depth.

From the hydrological point of view there are two main rivers: *El Rosario* or *Perico* river, and *El Salado*, both flow from the mountainous range that joins the *Alto Tres Puertas* summit with the *Alto de las Cruces* above the 2,500 m. The other branch, *El Avila*, flows from the range *La Gurupera* located in the South-Western area of the basin. Starting from the confluence of the first two inflowing in the contour interval of 2,393 m, the stream takes the name of Piedras Blancas, runs for the oriental highland in serpentine form until the contour interval of 2,350 m where a dam was built to supply the aqueduct of Medellin. From there, understream in the so called pathway through the rural sector of the Copacabana municipality, the stream crosses the urban area and oulets in Medellin river in the contour interval of 1,418 m. It has a longitude is of 15 km.

The forest cover of the high part of the basin of the steam Piedras Blancas, have been quantified and described by EEPPMM (1989), based on 1987 aerial photographs. Table 1 shows the results.

Physical accounts of the forest

Biomass

Biomass is the quantity of alive organic material accumulated by surface unit in a certain moment. It is expressed as weight of dry material for area unit ($kg.m^{-2}$, $mg.\ ha^{-1}$. It is also defined as the dry matter in an ecosystem (Saldarriaga *et al.,* 1988). In the studies of the biomass of a forest, one can consider both alive phytomass as dead phytomass (Cuartas, 1993).

Table 1

Summary of the vegetable coverings in the basin of Piedras Blancas

Name	Convention	Area (ha)	% (regarding the total)
PLANTATIONS			
Cypress	Cy	574.29	19.26
Pátula	Pa	337.85	11.33
Other pines	Op	125.98	4.23
Eucalyptus	Eu	24.35	0.82
Acacia	Ac	0.19	0.01
Subtotal		1,062.66	35.65
NATURAL VEGETATION			
Natural forest	F	102.01	3.42
High stubble	Hs	552.40	18.53
Low stubble	Ls	691.54	23.19
Subtotal		1,345.95	45.14
GRASSES			
Weedy grasses	Wg	158.89	5.33
Wrong drainaged grasses	Wdg	16.37	0.55
Natural grasses	Ng	214.22	7.18
Subtotal		389.48	13.06
OTHER USES			
Cultivations	C	101.75	3.45
Erosion	E	10.25	0.34
Nursery		4.55	0.15
Arboretum		11.45	0.38
Dam		15.48	0.52
Lagoon		0.98	0.03
Cienega		3.15	0.10
Highways		35.70	1.20
Subtotal		183.31	6.17
TOTAL		2,981.37	100

Source: Empresas Públicas de Medellín, 1989.

The weight of the stem and the branches is approximately 95 to 98 % of the air biomass and approximately 75 % of the total biomass (Crown, 1978; mentioned by Quarter, 1993). According to Kusela and Nyssonen (1981), the 55 % of green weight correspond to the trunk and the other 45 % corresponds to branches, foliage, roots and stump. De las Salas (1973) mentioned by Cuartas (1993), in a tropical forest of the region of the Carare-Opon estimated the production of biomass for hectare of 185 tons. Bedoya *et al*

(1990), determined a dry weight of the aerial biomass in forests of the San Francisco (Antioquia-Colombia) municipality of 134 $ton.ha^{-1}$. In the region of the Araracuara (Amazons), Cuartas (1993) establishes a total aerial biomass of 61.826 $t.ha^{-1}$ and for the palms of 1.505 $t.ha^{-1}$

Estimating models

For the estimation of the models was generated a database. It included, among others, the following variables: breast height diameter (bhd), breast height girth (bhg), total height (th), base diameter (bd), base girth (bg), height at each tenth of the height of the tree (hi), diameter and girth at each tenth of the total height (di – ci), slice thickness (st), log weight (lw), slices weight (sw), area of slices (aos), densities, moisture content, volume of slices, etc. Several models, in the different coverings for the estimate of the density, rise, volume and biomass were evaluated.

In restocking a database was generated with: humid weight for each plant type in each parcel (Whtp), weight dry for plant type for parcel (Wdtp), total biomass for parcel (Btp), height (Ht), longitude of the root (Lr), humid weight of the aerial part (hWap), humid weight of the root (Whr), dry weight aerial part (Wda), weight dry root (Wdr) and diameter (d). Several models were evaluated in order to estimate the total biomass by parcel (m^2).

The evaluated models of density were: humid density over bark (hdob), humid density under bark (wdub), dry density over bark (ddob) and dry density under bark (ddub). Different models of rise and volume were evaluated. The one that adjusted better was integrated to obtain an equation of reliable volume. Models were generated to estimate total biomass of the tree and of each component (leaves, branches, fruits, stem). A model was generated with the restocking for the total biomass per square meter.

Initial existence of biomass

Total biomass

Stands to be sampled were selected based on its age using a map made by EPM with the different stand ages. The largest range of existent possible ages was included for this area, so an adjusted sample could be obtained in the present situation for the two main coniferous species of the studied area *(Cupressus lusitanica* and *Pinus patula)*. Once in the stand, individuals were selected at random in all the diameter classes of the population (diameters larger than 10 cm to the breast height). The number of sampled individuals was seventy (70). This number was considered as a representative sample of the population.

Selected trees were characterized. In order to measure aerial biomass total height, crown height, girth at the base and bhd were measured. The crown was divided in second fifths of its height and in each fifth four (4) distances were measured to the first branches. Once the crown was measured each individual was cut and its total height was measured again. Different elements of the tree were separated: stem, branches, acicules and cones, and each component was weighed separately (humid weigh) in order to determine the dry weight. Samples of branches, acicules and cones were dried in stove in order to obtain their moisture content (MC). Radicule biomass was not used because of its expensive and cumbersome procedure.

On each individual's stem, girths and diameters were measured at each tenth of their height; that is to say, in logs of equal longitude to the tenth of their total height. The first log was remeasured, given that when cutting this log, a different size appeared compared with the other ones. Punches were used in two points for each log to measure bark thickness. Once the log was weighted two slices or external disks of each log were cut with approximately the same thickness. A mark with the number of the tree and the location of the slice was carved in order to identified each log after being weighted wet and dry. The other extracted elements of each tree were weighted and dryed in ovens at 105 2 C until a constant weight and moisture content was obtained.

The procedure of the slices obtained in the field consisted in measuring eight thickness of each slice in order to find the thickness average. The contour of each slice was drawn in paper with the bark and without the bark in order to measure the correspondent areas. After the extraction of the bark, the slice and the bark were weighted in humid. After this, both of them were heated into the oven at 105 2 C until obtaining a constant weight. All this job was done with the purpose of obtaining the moisture content (MC) in green and in dry slice volumes over bark and under bark, and densities, among others. With this information a database was elaborated. This allowed to develop different regression models in order to obtain the best relations of biomass.

In the natural forest: estimations of biomass in natural forest were based on the selection of individuals of the oak grove and of the high fallow. Selection was made using an random method based on its diameter class. As it became impossible to determine the age of the individuals, the more representative diameter classes (diameters larger than 10 cm) were sampled in the present forests. For the specie *Quercus humboldtii* (oak), representative individuals of all the diameter classes of the existent population in the study area were chosen. The number of sampled individuals was thirty (30), including eight (8) oaks. When the current state of the specie *Quercus humboldtii* and the literature revision is considered, the sampled number seems to be large enough to build the biomass models. The procedure carried out for the coniferous forests was basically the same.

Low stubble: 10 circular plots of 1 m^2 were established at random. This cover was made mainly of ferneries and low habit vegetation. The total of the vegetable material alive was extracted and weighted. Then a significant sample was taken into the kiln to a temperature of 70 2 C until arriving to a constant weight to determine moisture content. The total weight dry of each plot was obtained. Average values were used in order to estimate the total dry biomass of the low fallow. As explained before, moisture content and total dry weight was calculated.

Restocking: 39 plots similar to the previous ones were established, 29 in the stands of the coniferous and 10 in the natural forest previously sampled. In each plot, the total vegetable alive material was extracted. Pine, cypress, latifoliates, cringing, ferns and gramineous origins were discriminated.

Individuals from 0 to 10 cm of diameter were chosen; with the base diameter as a reference and the bhd or normal diameter as reference in the individuals bigger than 1.30 m of height. In both cases, aerial and radicule part were extracted; however, in individuals approximately between 7 and 10 cm of bhd presented serious difficulties when extracted. This procedure was carried out on some few individuals in order to obtain an applicable relation to those of same size.

The individuals were properly marked (name, stand number, plot number) in order to be measured. Aerial part weight, radicle part weight, height and base diameter were taken for conifer and latifoliades with base diameter larger than 0.05 cm. For smaller diameters total weight was the only measured in cringing, ferns and gramineous.

Those plants growing with pine regeneration, cypress and latifoliates, had individual measurement of its diameter, total height, radicle longitude and weight in humid of the aerial part and of the radicle. Then the plants were taken to the kiln to a temperature of 70 2 C until arriving to a constant weight, to obtain the moisture content (MC) in order to calculate the total dry weight. In large individuals samples were taken out (branches, trunk, leaves and root) in order to dry them in the kiln.

Existences of biomass in commercial timber

Estimates of commercial volumes were found by using rise equations. These equations allow to describe the decrease of stem diameter with the increment of distance from the tree base. According to the demands of the transformation technology for the different types of products, restrictions for commercial volumes were diameter and longitude. The model that suited the best was the one proposed and reported by González *et al.* (1994); which has been adjusted to several tree species data used in afforestation programs in Colombia, with a very satisfactory result.

$$V \quad \frac{\;}{4} \; {}_{h1}^{h2} \; b_0 \quad b_1 D \;\; 1 \;\; \frac{h}{H} \;{}^{2}\; dh$$

where:

h^1 y h^2	=	heights among which the volume will be considered
b_0 y b_1	=	rise equation coefficients
D	=	dbh
H	=	total height of the tree
h	=	merchantable volume height

$$h \quad \frac{H(b_0 \quad b_1 D \quad d)}{b_1 D}$$

where:

H	=	total height
b_0 y b_1	=	rise equation coefficients
D	=	dbh
d	=	exploitable diameter

Normal diameter average values and total height values were used at each lot in the coniferous cover. The coefficients of the rise equation of the *Pinus patula* were used with pines. In natural forests the information of the database of Cáceres and Uribe (1997) was used, to be wider and to have the calculation of the equation of growth, with which the MAI is calculated.

Obtained volumes were multiplied by the average density of each covering. Given the lack of models of dry density statistics were acceptable.

Increases

Mean annual increment (MAI)

– MAI in total biomass

For coniferous, the total biomass MAI was calculated starting from the sum of: the first derivative of the volume equation used for each species, multiplied by the mean dry density of each species (0.43 for cypress and 0.45 for pátula), obtaining the biomass of the bole; plus the total dry weight of branches, leaves and fruits, from the best fitted models of biomass in each component. In the stands of *Pinus patula* the equations proposed were used for the area by the National University and Empresas Públicas de Medellin (1995), and for *Cupressus lusitanica,* those of Carmona and Jaramillo (1998). These equations included the number of trees, basal area, age and area (ha) variables. The information of the stands was given by Empresas Públicas de Medellín.

Cupressus lusitanica

$$\mathrm{Ln}\ V = 2.17954 + 0.759057\ (\mathrm{Ln}\ G) + 0.0512832\ (IS) - 6.08515\ (t^{-1})$$

$$\mathrm{Ln}\ G = 2.49297 - 8.98174\ (t^{-1}) + 0.0739675\ (IS) + 0.000154253\ (N)$$

Pinus patula

$$\mathrm{Ln}\ V = 1.6876 + 0.0743(IS) - 4.259(t^{-1}) + 0.7221(\mathrm{Ln}\ G) + 0.000109(N)$$

$$\mathrm{Ln}\ G = 2.89561 + 0.069307(IS) - 19.0698376(t^{-1}) + 0.000482(N)$$

Where:
G = basal area ($m^2 \cdot ha^{-1}$)
V = total volume ($m^3 \cdot ha^{-1}$)
t = age (years)
IS = site index (17 for *P. patula* and 15 for cypress)
N = number of trees
Ln = Neperian logarith

Calculation was made per hectare and for stand, without finding significant difference between the total MAI obtained of the sum of the MAI of each stand and the MAI of the average per hectare.

Due to the lack of volume and biomass equations for other pine species, the coefficients of the models of the patula pine were used for the calculation of the MAI in this covering.

In natural forest the MAI was calculated as in the coniferous case; the equation of volume of González *et al.* (1994) was used. It was obtained based on the differences between the final biomass and the initial in a period of one year. The initial volume was calculated for diameters and for total heights with the Cáceres and Uribe database, and multiplied by the mean dry density (0.58) in order to obtain the biomass of the trunk. With the models of branches, fruits and leaves previously developed for this covering, it was added the corresponding weight. The final volume was calculated in the same way that the previous one, with the obtained diameter of the sum of the initial diameters plus the annual diametric increment found by the same authors for these forests and with the final height calculated starting from the relation normal diameter-initial total height.

In low stubble, there is a total lack of information about the growth of this covering and due to the characteristics and composition (conformed mainly by ferns that impede the growth and developments of other species), no value of mean annual increment was considered. The same was taken in restocking, that is to say, the present vegetation under the coverings of the plantations and the natural forest, since the development of this vegetation is minimum, given the conditions of deficit of light, space and nutrients.

– MAI in commercial timber

With the information of the existence t in total biomass (tb) and commercial (cb) of the stem and of the total MAI of the same one in the coniferous, the future commercial biomass was calculated (bc_{t+1}) starting from its proportion with regard to the future total biomass of the stem (the existences plus the annual mean increment) (bt_{t+1}):

$$bc_{t+1} = (bt_{t+1} \quad bc_t) / bt_t$$

Thus, commercial MAI = $bc_{t+1} - bc_t$

In the case of the natural forest, annual mean increment of the commercial biomass was estimated using the equation of González *et al.* (1994); multiplying the result for the average value of the density of the timber of these forests, with the following variables: initial diameters, initial heights and diameters at the end of a period of one year, with which the final height was calculated.

Planting: at the moment, there is no afforestation at the basin. For this reason, the increases of the forest considered are only the increments in biomass and in commercial timber.

Decreases

Mortality: the death of trees can affect structure, composition and the dynamics of the forests, creating some conditions that begin the succession process. Four causes of mortality exist: changes in metabolism (senescence), accumulation of toxic substances, pathogen, parasites or consumers and changes in the atmosphere and for mechanical or chemical impacts for natural forces (Lugo and Scatena, 1996).

Studies of mortality reported for tropical areas, vary among different regions and inside the same ones, according to the type of vegetation, with values between 0.65 % and 3.27 % (Phillips and Gentry, 1994; Gentry and Therborgh, 1990; Lieberman *et al.,* 1990;

among others). Some authors report a great variation intra and inter regional. For example: the forests of Tambopata in Peru, have annual mortalities between 0.6 and 2.85 % (Phillips *et al.*, 1994; Phillips and Gentry, 1994). In other tropical forests, as those located in Barro Colorado's island (Panama), Hubbell and Foster (1990) found that the rate of mortality was of 3 % during three years of study. They agreed that most of this happened during the year in which the meteorological phenomenon *El Niño* was present; other authors like Putz and Milton (1990), found for the same place, a variation between 1.83 and 1.06 % in the rates of mortality.

Given the lack of information on this topic for the natural forests of Piedras Blancas (oak groves and high stubble) and for the period of time required for its quantification (minimum three mensurations in annual periods), a rate of mortality was taken according to that reported in the literature of 1 %. No value was used for plantations because in general, the dead or damaged trees are used by peasants of the region.

Extraction: in the period of evaluation, the forests of Piedras Blancas were not cut, thus extraction was zero.

Ecosystemic Functions

The forest works as CO_2 sink; the forests play a main role in the global cycle of the carbon because its ability to store large quantities of CO_2 in the vegetation and in the soil, exchanging it with the atmosphere through breathing and photosynthesis. Trees and other forms of biomass can act as carbon sinks, but in their maturity or in their level of optimum growth plans should be introduced to handle biomass because otherwise, years of CO_2 storage will get lost, when being rotted or burned without control.

Averages of coal content of coal values were used in this study, reported by the USDA and Barres mentioned by Ramírez *et al.* (1997), 51.5 % for the coniferous ones and 48.5 % for the natural forest.

Field work was designed to build models of total and commercial biomass per hectare for cypress, pátula and the natural forest; with the models of growth of these coverings and with the data for the area given by EEPPMM of each lot of plantations (mean diameter, mean height, density of trees for hectare and age); total aerial biomass was calculated by hectare and the mean annual increment for coverings. With these results, the percentage of carbon was calculated in the total and commercial biomass, when multiplying by the previously mentioned conversion factor. The fixed quantity of CO_2 was obtained this way as a result of the multiplication of the percentage of coal by 3.67 (one Mg of fixed carbon is equal to 3.67 Mg of CO_2 fixed).

RESULTS AND ANALYSIS

Estimated models

In order to select the best model influenced points with major leverage larger than 2p/n were eliminated (where p = number of independent variables and n = number of data); elimination of these data increased significance and adjustment of the models in some cases. Statistical tests (T, Chi square Kolmogorov Smirnov) validated the ability of the models to represent observed data.

Rise models

Several reported models were evaluated, that of González presented the best adjustment for the coverings, with the following results:

Pátula	di = 3.55254 + 1.05529 (DBH) (1 – hi/th)	[1]
Cypress	di = 1.52359 + 1.14617 (DBH) (1 – hi/th)	[2]
Natural forest	di = 0.0128913 + 1.10152 (DBH) (1 – hi/th)	[3]

where,

di	=	diameter to the i-eth height (cm)
DBH	=	diameter at the 1.30m (cm)
hi	=	i-eth height (m)
th	=	total height (m)

Different rise models were evaluated with two or more independent variables. Those that were found to be insignificant were eliminated and the model was evaluated again; in some cases this led to the elimination of the model itself.

Adjusted models presented large F values, high significance level and a sum of squares larger than residuals confirm the significance of the regression. As an approach to evaluate the goodness of the model the coefficient of determination R^2 was used, which also served to make a preselection of the models. Finally, it was kept in mind the simplicity of the model in order to be used to evaluate the volumes.

The integration of the previous models generated an equation of volume that allowed to obtain commercial volumes. Later on with the average of the dry density in each covering, the commercial biomass was obtained.

Models of biomass

Diameter (dbh) and total height (th) variables were used for three reasons: they are commonly evaluated, they are easy to be measured and they present a high correlation with biomass changes. These models were developed not only for total biomass of the tree but also for each component stem, fruits, branches and leaves.

Models of biomass for restocking growing under conifers were built based on humid weight by plant type for parcel ($g.m^{-2}$). Other variables were difficult and expensive to obtain requiring scales of precision and other instruments due to the size of many individuals. Data collection is simplified significantly when being carried out for plant types. When using the model, the total biomass is obtained in mega grams per hectare. As a result, in low stubble no differences by plant type were found since biomass for this covering was compound mainly by ferns. For this reason the average of the dry weight of each parcel, was taken to the units of mega grams by hectare ($Mg.ha^{-1}$). An optimum model was not found for the restocking of natural forest. The same procedure used in the low stubble was applied finding a mean between these values and those of the parcels under the plantations of coniferous.

– Models for stem biomass

Pinus patula	$Dws = 0.0407032 + 0.0000171476\ (DBH^2\ \ th)$
Cupressus lusitanica	$LnDws = -10.3001 + 0.922163\ \ Ln\ (DBH^2\ \ th)$
Natural forest	$LnDws = -1.40947 + 0.783327\ \ Ln\ (DBH^2\ \ th)$

Where,

Ln	=	Neperian logarithm
Dws	=	dry weight stem (Mg)
DBH	=	diameter to 1.30 m (cm)
th	=	total height (m)

– Models of branch and fruit biomass

Pinus patula	$Ln(Dwb) = -11.6799 + 0.706731\ \ Ln\ (DBH^3\ \ th)$
	$Ln(Dwc) = -15.3478 + 0.879784\ \ Ln\ (DBH^3\ \ th)$
Cupressus lusitanica	$Ln(Dwb) = -10.7015 + 0.851743\ \ Ln\ (DBH^2\ \ th)$
	$Ln(Dwc) = -5.17904 + 0.0000564046\ (DBH^2\ \ th)$
Natural forest	$Ln(Dwbf) = -9.2737 + 0.57775\ \ Ln\ (DBH^3\ \ th)$

Where,

Ln	=	Neperian logarithm
Dwbf	=	dry weight of branches and fruits (Mg)
Dwb	=	dry weight of branches (Mg)
Dwc	=	dry weight of cones (Mg)
DBH	=	diameter to 1.3 m (cm)
th	=	total height (m)

– Models to leaf biomass

Pinus patula	$Dwl = 0.0101471 + 2.01088\ E - 8\ (DBH^3\ \ th)$
Cupressus lusitanica	$Dwl = 0.0177636 + 9.77067\ E - 7\ (DBH^2\ \ th)$
Natural forest	$Ln(Dwl) = 0.00600316 + 0.00000111229\ (DBH^2\ \ th)$

Where;

Ln	=	neperian logarithm
Dwl	=	dry weight of leaves (Mg)
DBH	=	diameter to 1.30 m (cm)
th	=	total height (m)

– Models to total biomass

Pinus patula	$TB = 0.154464 + 5.43698E - 7\ (DBH^3\ \ th)$
Cupressus lusitanica	$Ln(TB) = -8.73498 + 0.811107\ \ Ln\ (DBH^2\ \ th)$
Natural forest	$TB = 60.8912 + 0.0420401\ (DBH^2\ \ th)$

Restocking

$$TB = 0.085119 + 0.00524338 \quad w \quad 0.00448449 \quad HwP + 0.00417368 \quad HwL + 0.0119302 \quad HwF + 0.00287417 \quad HwG + 0.00429277 \quad HwC$$

Where,

TB = total biomass (Mg)
HwG = Humid weight gramineous (g)
HwF = Humid weight ferns (g)
HwL = Humid weight latifoliates (g)
HwP = Humid weight patula (g)
HwC = Humid weight cringings (g)
HwC = Humid weight cypress (g)

The best model was selected for each component (branches, stem, leaves and fruits) and for the total biomass in each covering, obtaining good statistical (sum of squares of the model larger than the residual ones, high values of F and R^2, among other). This indicates that it is possible to estimate biomass of these coverings with the models fitted with an acceptable precision. See Table 2.

Table 2

Statistical of the models of total biomass

Species	R^2 (%)	SSM	SSR	F
Pátula	86.89	2.61	0.37	166.63
Cypress	91.14	11.98	1.12	288.99
Natural forest	84.48	518,106.0	91,310.7	158.87
Regeneration	99.71	24,575.7	54.807	1,419.95

For modeling of restocking under the plantations, the variable diameter, height, dry weight of the aerial part and of the radicule, were not significant, and thus excluded.

Models of density: patula models are unstable, since the sum of squares of the residual overcomes that of the model, what suggest the necessity to have a larger samples to obtain better results. This result corroborates other studies findings, the density in this species doesn't vary proportionally with height.

In natural forest several models of density were rehearsed without obtaining acceptable results. This maybe explained to have worked with eight species represented in very few individuals and/or by not existing variation of the density with regard to the height.

Initial existence of biomass

Estimate of total biomass

In Table 3, the results of biomass obtained for *Pinus patula, Cupressus lusitánica,* other pines, natural forest, low stubble and restocking are presented.

Table 3

Estimate of the total biomass of different types of vegetable covering and restocking in Piedras Blancas

Covering	Biomass (Mg)	Total biomas ($Mg.ha^{-1}$)
Cypress	102,889.80	179.16
Pátula	42,298.82	125.20
Other pines	19,948.93	158.35
Natural forest	52,594.93	80.37
Low stubble	5,221.13	7.55
Restocking	48,524.84	28.67

The covering of larger biomass accumulated per hectare was the cypress, followed by other pines, patula, natural forest and lastly restocking and low stubble, probably due to the advanced age of the cypress plantations and other pines with an age average of 41 and 39 years respectively, while the average of those of the patula pine is 27 years. The number of trees for hectare of each stand for each species presents large variations, so inferences cannot be made with this variable.

Increases

Annual mean increment (MAI)

The MAI for the total and commercial biomass, described in the methodology, it is observed in the Table 4. The covering with more increment for hectare probably because the patula earlier stages at growth in these plantations; continued by other pines, cypress and finally for the natural forest.

Table 4

Annual mean increment in total and commercial biomass for four vegetable coverings in Piedras Blancas

Covering	Area ha	Total biomass (Mg)		Commercial biomass (Mg)	
		ha	Total	ha	Total
Cypress	574.29	3.99	2,291.42	2.86	1,642.47
Pátula	337.85	4.90	1,655.47	3.34	1,128.42
Other pines	125.98	4.36	549.27	2.86	360.30
Natural forest	654.41	1.42	929.26	0.96	628.23

Decreases

Mortality

The natural forest presents a decrease of 0.90 $Mg.ha^{-1}$ of biomass for mortality, that is to say, an annual loss of 588.97 Mg of total biomass and 314.12 Mg of commercial biomass, equivalent to a decrease of 0.48 $Mg.ha^{-1}$.

In the table 6 of the Physical account of the forest, presents the results of the loss for mortality of the natural forest; in the plantations the mortality is zero.

Ecosystemic functions

The forest like drain of CO_2. See Table 5.

Table 5

Estimation of the CO_2 stored and fixed by three types of vegetable covering in Piedras Blancas

Species	Total quantity of CO_2 stored (Mg)	Commercial quantity of CO_2 stored (Mg)	Total quantity of CO_2 fixed ($Mg.año^{-1}$)	Commercial quantity of CO_2 fixed ($Mg.año^{-1}$)
Cypress	194,466.9	133,628.13	4,330.89	3,104.35
Pátula	79,946.88	48,906.80	3,128.91	2,132.77
Other pines	37,704.48	25,932.40	1,038.15	680.99
Natural forest	93,616.35	50,261.86	1,654.04	1,118.22

Physical account of the forest in the basin of Piedras Blancas

Tables 6 and 7 present the count of the forest in total and commercial biomass and in the tables 8 and 9 the ecosystemic storage function and fixation of CO_2 in the basin.

Table 6

Physical account of the forest of total biomass in Piedras Blancas

Covering	Area	Initial stock t-1		Increases t		Decreases t			Stock at the end of the period t	
		Biomass		Mean Annual Increment (MAI)		Plantation	Mortality ha	Utilization ha	Biomass	
		Per ha ($Mg \cdot ha^{-1}$)	Total (Mg)	Per ha ($Mg \cdot ha^{-1}$)	Total (Mg)				Per ha ($Mg \cdot ha^{-1}$)	Total (Mg)
Cypress	574.29	179.16	102,889.80	3.99	2,291.42	–	–	–	183.15	105,181.21
Pátula	337.85	125.20	42,298.82	4.90	1,655.47	–	–	–	130.1	43,954.29
Other pines	125.98	158.35	19,948.93	4.36	549.27	–	–	–	162.71	20,498.21
Natural forest	654.41	80.37	52,594.93	1.42	929.26	–	0.9	–	80.89	52,935.22
Low stubble	691.54	7.55	5,221.13	–	–	–	–	–	7.55	5,221.13
Restocking	1,692.53	28.67	48,524.84	–	–	–	–	–	28.67	48,524.84

Table 7

Physical account forest of biomass in commercial timber in Piedras Blancas

Covering	Area	Initial stock t-1		Increases t		Decreases t			Stock at the end of the period t	
		Commercial Timber		Mean Annual Increment (MAI)		Plantation	Mortality ha	Utilization ha		
		Per ha ($Mg \cdot ha^{-1}$)	Total (Mg)	Per ha ($Mg \cdot ha^{-1}$)	Total (Mg)				Per ha ($Mg \cdot ha^{-1}$)	Total (Mg)
Cypress	574.29	123.11	70,700.84	2.86	1,642.47	–	–	–	125.97	72,343.31
Pátula	337.85	76.59	25,875.93	3.34	1,128.42	–	–	–	79.93	27,004.35
Other pines	125.98	108.91	13,720.48	2.86	360.30	–	–	–	111.77	14,080.78
Natural forest	654.41	43.15	28,237.79	0.96	628.23	–	0.48	–	43.63	28,551.91

Table 8

Physical account of the forest for the function ecosystemic storage and fixation of CO_2 in the total biomass

Covering	Area	Initial stock t-1		Increases t		Stock at the end of the period t	
		Storage of CO_2		MAI of CO_2		CO_2 stored	
		Per ha ($Mg \cdot ha^{-1}$)	Total (Mg)	Per ha ($Mg \cdot ha^{-1}$)	Total (Mg)	Per ha ($Mg \cdot ha^{-1}$)	Total (Mg)
Cypress	574.29	338.62	194,466.9	7.54	4,330.89	346.16	198,797.75
Pátula	337.85	236.63	79,946.88	9.26	3,128.91	245.90	83,075.80
Other pines	125.98	299.29	37,704.48	8.24	1,038.15	307.53	38,742.63
Natural Forest	654.41	143.05	93,616.35	2.53	1,654.04	143.98	94,223.95

Tabl 9

Physical account of the forest for the function ecosystemic storage and fixation of CO_2 in the commercial biomass

Covering	Area	Initial stock t-1		Increases t		Stock at the end of the period t	
		Storage of CO_2		MAI of CO_2		CO_2 stored	
		Per ha ($Mg \cdot ha^{-1}$)	Total (Mg)	Per ha ($Mg \cdot ha^{-1}$)	Total (Mg)	Per ha ($Mg \cdot ha^{-1}$)	Total (Mg)
Cypress	574.29	232.68	133,628.13	5.41	3,104.35	238.09	136,732.48
Pátula	337.85	144.76	48,906.80	6.31	2,132.77	151.07	51,039.57
Other pines	125.98	205.85	25,932.40	5.41	680.99	211.25	26,613.39
Natural forest	654.41	76.80	50,261.86	1.71	1,118.22	77.66	50,823.83

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RESUMEN

Contabilidad física del bosque de la cuenca de Piedras Blancas, Medellin (Colombia)

La contabilidad física para «Piedras Blancas», es un estudio piloto que busca estructurar una metodología útil y aplicable para el Departamento de Antioquía y en lo posible a nivel nacional. En esta contabilización, la biomasa de las repoblaciones forestales, fustes, follaje y frutos son calculados, así como la biomasa total y comercial.

PALABRAS CLAVE: Contabilidad física
Biomasa
Bosque
Modelización

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