Supporting Information (SI)



## MODEL DESCRIPTION

Here we provide the details on the land-cover transition model and the book-keeping carbon cycle model. The same model structure was repeated for the eight life zones with there respective parameters that can be found in [S1] and [S2].

### A1. Land-cover transition model

Let $D(t)$, $t$ = 1990, 1991, …, 2030 be the deforestation rates at time '$t$' in ha yr$^{-1}$.

Let $A_F(t,\tau),_{\tau=1,2,\ldots,t-1990+1}^{t=1990,1991,\ldots,2030}$ be the area of mature forest (ha yr$^{-1}$) at time '$t$', age-cohort '$\tau$',

let $A_{SF}(t,\tau),_{\tau=1,2,\ldots,t-1990+1}^{t=1990,1991,\ldots,2030}$ be the area of secondary forest (ha yr$^{-1}$) at time '$t$', age-cohort '$\tau$',

let $A_{FA}(t,\tau),_{\tau=1,2,\ldots,t-1990+1}^{t=1990,1991,\ldots,2030}$ be the area of fallow (ha yr$^{-1}$) at time '$t$', age-cohort '$\tau$',

let $A_{AG}(t,\tau),_{\tau=1,2,\ldots,t-1990+1}^{t=1990,1991,\ldots,2030}$ be the area of agriculture (ha yr$^{-1}$) at time '$t$', age-cohort '$\tau$', and let $A_O(t,\tau),\ {}^{t=1990,1991,\ldots,2030}_{\tau=1,2,\ldots,t-1990+1}$ be the area of other land (ha $yr^{-1}$) at time '$t$', age-cohort '$\tau$'.

A first-order Markov model of transition probabilities between land-cover classes can be specified as follows:

$$\begin{bmatrix} A_F \\ A_{SF} \\ A_{FA} \\ A_{AG} \\ A_O \end{bmatrix}^{t,\tau} = \begin{bmatrix} \alpha_{F,F} & \alpha_{SF,F} & \alpha_{FA,F} & \alpha_{AG,F} & \alpha_{O,F} \\ \alpha_{F,SF} & \alpha_{SF,SF} & \alpha_{FA,SF} & \alpha_{AG,SF} & \alpha_{O,SF} \\ \alpha_{F,FA} & \alpha_{SF,FA} & \alpha_{FA,FA} & \alpha_{AG,FA} & \alpha_{O,FA} \\ \alpha_{F,AG} & \alpha_{SF,AG} & \alpha_{FA,AG} & \alpha_{AG,AG} & \alpha_{O,AG} \\ \alpha_{F,O} & \alpha_{SF,O} & \alpha_{FA,O} & \alpha_{AG,O} & \alpha_{O,O} \end{bmatrix} \begin{bmatrix} A_F \\ A_{SF} \\ A_{FA} \\ A_{AG} \\ A_O \end{bmatrix}^{t-1,\tau-1}$$

, where

the matrix $\alpha$ contains the land-cover transition probabilities. The transition matrices can be found in S2.

However, a transition from one land-cover class to another should reset the cohort age to 1, and therefore the above form of the equation is applied as follows:

First, the deforested land every year is partitioned into the 1-yr age classes as follows:

$A_F(t, 1) = D(t) \times K_F$

$A_{SF}(t, 1) = D(t) \times K_{SF}$

$A_{FA}(t, 1) = D(t) \times K_{FA}$

$A_{AG}(t, 1) = D(t) \times K_{AG}$

$A_O(t, 1) = D(t) \times K_O$ ,

Where K is the fraction of deforested land that goes into mature forest, secondary forest, fallow, agriculture or other land cover (S1) and where $K_F$ is equal to zero.

Next, to the 1-yr age cohorts, we add the area that results from the transition from other land-cover classes:

$$\begin{bmatrix} \boldsymbol{A_F} \\ \boldsymbol{A_{SF}} \\ \boldsymbol{A_{FA}} \\ \boldsymbol{A_{AG}} \\ \boldsymbol{A_O} \end{bmatrix}^{\boldsymbol{t,1}} = \begin{bmatrix} \boldsymbol{K_F D(t)} \\ \boldsymbol{K_{SF} D(t)} \\ \boldsymbol{K_{FA} D(t)} \\ \boldsymbol{K_{AG} D(t)} \\ \boldsymbol{K_O D(t)} \end{bmatrix} + \begin{bmatrix} \boldsymbol{0} & \boldsymbol{\alpha_{SF,F}} & \boldsymbol{\alpha_{FA,F}} & \boldsymbol{\alpha_{AG,F}} & \boldsymbol{\alpha_{O,F}} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{\alpha_{FA,SF}} & \boldsymbol{\alpha_{AG,SF}} & \boldsymbol{\alpha_{O,SF}} \\ \boldsymbol{0} & \boldsymbol{\alpha_{SF,FA}} & \boldsymbol{0} & \boldsymbol{\alpha_{AG,FA}} & \boldsymbol{\alpha_{O,FA}} \\ \boldsymbol{0} & \boldsymbol{\alpha_{SF,AG}} & \boldsymbol{\alpha_{FA,AG}} & \boldsymbol{0} & \boldsymbol{\alpha_{O,AG}} \\ \boldsymbol{0} & \boldsymbol{\alpha_{SF,O}} & \boldsymbol{\alpha_{FA,O}} & \boldsymbol{\alpha_{AG,O}} & \boldsymbol{0} \end{bmatrix} \begin{bmatrix} \boldsymbol{A_F} \\ \boldsymbol{A_{SF}} \\ \boldsymbol{A_{FA}} \\ \boldsymbol{A_{AG}} \\ \boldsymbol{A_O} \end{bmatrix}^{\boldsymbol{t-1,\tau-1}} .$$

Finally, for age cohorts older than 1 year, we estimate the within-class transition of land-cover classes:

$$\begin{bmatrix} A_F \\ A_{SF} \\ A_{FA} \\ A_{AG} \\ A_O \end{bmatrix}^{t,\tau} = \begin{bmatrix} \alpha_{F,F} & 0 & 0 & 0 & 0 \\ 0 & \alpha_{SF,SF} & 0 & 0 & 0 \\ 0 & 0 & \alpha_{FA,FA} & 0 & 0 \\ 0 & 0 & 0 & \alpha_{AG,AG} & 0 \\ 0 & 0 & 0 & 0 & \alpha_{O,O} \end{bmatrix} \begin{bmatrix} A_F \\ A_{SF} \\ A_{FA} \\ A_{AG} \\ A_O \end{bmatrix}^{t-1,\tau-1} \text{, for } \tau = 2, 3,,,, t.$$

The initial conditions for this model are the 1990 land cover conditions which can be found in S1 per life zone under $A_F$, $A_{SF}$, $A_{FA}$, $A_{AG}$, and $A_O$. We kept track of existing secondary forest in 1990 by averaging all their age classes and by specifying an average biomass value, as the age of this existing secondary forest was unknown.

From the results of this model, we can also calculate the annual rate of re-clearing of secondary vegetation as:

$$A_{SF,clear}(t,\tau) = A_{SF}(t-1,\tau-1)(\alpha_{SF,FA} + \alpha_{SF,AG} + \alpha_{SF,O}),$$

This re-clearing of the secondary vegetation can be divided into two sub-categories: the clearing of secondary forest that was already present in 1990 $I_{SF,clear}$ (initial conditions) and the clearing of secondary forest newly created after 1990 $S_{SF,clear}$, are given by :

1) $I_{SF,clear}(t) = diag\,(A_{SF,clear}(t,\tau))$, and
2) $S_{SF,clear}(t,\tau) = A_{SF,clear}(t,\tau) - diag(I_{SF,clear}(t))$, where $diag(I_{SF,clear}(t))$ is the diagonal matrix with the vector $I_{SF,clear}$ as the main diagonal.

The annual re-growth of secondary vegetation can be calculated as:

1) For the secondary forest already present in 1990:

   $A_{SF,initial}(t) = diag(A_{SF}(t,\tau))$

2) Secondary forest created throughout the simulation:

   $A_{SF,new}(t,\tau) = A_{SF}(t,\tau) - diag(diag(A_{SF}(t,\tau)))$ , where $A_{SF,new}(t,\tau)$ is the same matrix as $A_{SF}(t,\tau)$ without the elements in the diagonal.

The annual rate of re-clearing of fallow land correspond to:

$A_{FA,clear}(t,\tau) = A_{FA}(t-1,\tau-1)(\alpha_{FA,AG} + \alpha_{FA,O})$.

The annual rate of agricultural conversion (permanent crop) to *Other* land.

$A_{AG,clear}(t,\tau) = A_{AG}(t-1,\tau-1)(\alpha_{AG,O})$ .

The vegetation re-growth in agriculture for permanent crop is given by:

$A_{AG,new}(t,\tau) = A_{AG}(t,\tau) - diag(diag(A_{AG}(t,\tau))$ , where $A_{AG,new}(t,\tau)$ is the same matrix as $A_{AG}(t,\tau)$ without the elements in the diagonal.

## A2. Book-keeping carbon cycle model

As described in Ramankutty *et al.* (2007), the following estimates are based on a complete accounting of annual carbon balance.

The carbon density of mature forest $C_F$, the carbon density of secondary forest $C_{SFi}$ present in 1990 (initial conditions), the carbon density of fallow land $C_{FA}$, and $C_{perm}$ the carbon density in permanent crop agricultural land can be found in [S1].

<u>*Carbon release from cleared vegetation*</u>

The biomass cleared every year is the sum of biomass from deforestation, cleared secondary vegetation, cleared fallow, and of permanent crop to *Other* land cover :

$$Bio_{Clear}(t) = Bio_{defore}(t) + Bio_{SFclear}(t) + Bio_{FAclear}(t) + Bio_{AGclear}(t) \quad tCyr^{-1}.$$

The biomass cleared from deforestation is:

$$Bio_{defor}(t) = C_F\, D(t) \quad tCyr^{-1},$$

The biomass from re-cleared secondary vegetation is:

$$Bio_{SFclear}(t) = \left(\sum_{\tau=1}^{t} C_{SF}(\tau-1) S_{SF,clear}(t,\tau)\right) + C_{SFi} I_{SF,clear}(t) \quad tCyr^{-1}, \text{ where}$$

$C_{SF}$, the biomass in secondary vegetation created throughout of the simulation, is calculated as follows:

$$\boldsymbol{C_{SF}(\tau)} = \begin{cases} \boldsymbol{C_F/(1 + e^{(1.7-0.105(\tau+5))})} \;\; tCyr^{-1}, \boldsymbol{if\ \tau} < 70\ years \\ \boldsymbol{C_F}\ tCyr^{-1}, \boldsymbol{if\ \tau \geq 70\ years} \end{cases}$$

Note that this biomass is calculated for age-cohort $\tau-1$ because the cleared biomass has the biomass of the previous year. To be consequential with the fallow definition *in vigor* for Panama (*regrowing vegetation from agricultural land abandonment with less than five years of age*), the land classified as secondary forest is assumed to be more than five years of age, which are added to $\boldsymbol{\tau}$ (i.e., $\boldsymbol{\tau}$ = 1 for SF is a 5-year old forest). $C_{sf}$ is assumed to be equivalent to the biomass contain in the mature forest after 75 years.

The biomass cleared from the fallow land is:

$$Bio_{FAclear}(t) = C_{FA} \sum_{\tau=1}^{t} A_{FAclear}(t,\tau) \quad tCyr^{-1}.$$

The biomass cleared from the agricultural conversion (permanent crop) to the *Other* land cover is expressed by:

$Bio_{AGclear}(t) = C_{perm} \sum_{\tau=1}^{t} A_{AGclear}(t,\tau)\, \mathrm{F_{perm}} \quad tCyr^{-1}$, where $\mathrm{F_{perm}}$ correspond to the fraction of agricultural land occupied by permanent crop.

<u>*The fate of carbon after clearing*</u>

The biomass cleared is partitioned into biomass burnt instantaneously ($f_{burn}$), biomass left as slash on the site ($f_{slash}$), and biomass transferred to product pools ($f_{prod}$) as follows:

$f_{burn}$ = 0.6; $f_{slash}$ = 0.339; $f_{prod}$ = 0.061    from Gutierrez, R. (1999).

The various carbon fluxes include flux from instantaneous burning ($C_{f,\ burn}$), flux from decay of product and slash pools ($C_{f,\ decay}$), and flux due to carbon uptake by regrowing vegetation ($C_{\ regrowth}$).

The burnt flux is calculated as follows:

$$C_{f,burn}(t) = Bio_{clear}(t)\, f_{burn} \quad tCyr^{-1}.$$

Annual transfers of carbon to the slash and product carbon pools are:

$$C_{in,slash}(t) = Bio_{clear}(t)\, f_{slash} \quad tCyr^{-1}, \text{ and}$$

$$C_{in,prod}(t) = Bio_{clear}(t)\, f_{prod} \quad tCyr^{-1}$$

The slash and product pools experience exponential decay. Thus, the carbon flux dynamics of the slash and product can be expressed using the differential equation:

$$\frac{dC}{dt} = C_{in} - \lambda C,$$

where $C_{in}$ is the transfer of carbon from deforestation, and $\lambda$ is the decay rate. Thus, the carbon dynamics for the various pools can be calculated using:

$$C_{slash}(t) = C_{slash}(t-1)(1-\lambda_{slash}) + C_{in,slash}(t) \quad tC \text{ , and}$$

$$C_{prod}(t) = C_{prod}(t-1)(1-\lambda_{prod}) + C_{in,prod}(t) \quad tC \text{ , and}$$

and the fluxes of carbon from the decay of these pools is calculated as

$$C_{f,decay}(t) = \lambda_{slash} C_{slash}(t-1) + \lambda_{prod} C_{prod}(t-1) \quad tCyr^{-1},$$

where $\lambda_{slash} = 0.1$ and $\lambda_{prod} = 0.1$.

*Carbon uptake from re-growing vegetation*

The carbon flux from uptake by regrowing secondary forests created after 1990 is:

$$\boldsymbol{C_{SF,regrowth}(t)} = \begin{cases} -\sum_{\tau=1}^{t} \boldsymbol{A_{SF,new}(t,\tau)}\left[\boldsymbol{C_F}/(\boldsymbol{1}+\boldsymbol{e}^{(1.7-0.105(\tau+5))}) - \boldsymbol{C_F}/(\boldsymbol{1}+\boldsymbol{e}^{(1.7-0.105((\tau-1)+5))})\right] \boldsymbol{tCyr^{-1}}, \boldsymbol{if\ \tau} < 70\ yrs \\ \boldsymbol{0}\ tCyr^{-1}, \boldsymbol{if\ \tau \geq 70\ yrs} \end{cases}$$

The secondary forest present before 1990 as well as newly formed mature forest were accounted to sequester carbon as follow:

$\boldsymbol{C_{SF,regrowthIC}(t) = -\left[A_{SF,initial}(t)R_{SF} + \sum_{\tau=1}^{t} A_F(t,\tau)R_p\right]\quad tCyr^{-1}}$, where $R_{SF}$ is the growth rate in $\boldsymbol{tCha^{-1}yr^{-1}}$ of secondary forest that were already present in 1990 and $R_P$ is the growth rate in $\boldsymbol{tCha^{-1}yr^{-1}}$ of newly classified mature forests, including plantations (according to ANAM land cover classification) [S1].

The carbon uptake resulting from the net fallow re-growth is calculated as:

$$\boldsymbol{C_{FA,uptake}(t) = -C_{FA}\left[\sum_{\tau=1}^{t} A_{FA}(t,\tau) - \sum_{\tau=1}^{t} A_{FA}(t-1,\tau-1)\right]\ tCyr^{-1}}$$

On agricultural land, annual (temporary) crops are assumed to have an annual balance equal to zero (rice, maize, sugarcane). For permanent crops (banana, plantains, coffee, cocoa), the carbon uptake was only considered on newly created agricultural land and calculated as follow:

$$\boldsymbol{C_{AG,perm}(t)} = \begin{cases} -\sum_{\tau=1}^{t} \boldsymbol{A_{AG,new}(t,\tau) F_{perm} C_{PermRate}}\ \ tCyr^{-1}, \boldsymbol{if\ \tau \leq 5\ years} \\ \boldsymbol{0}\ tCyr^{-1}, \boldsymbol{if\ \tau} > 5\ years \end{cases},$$ where

$F_{perm}$ correspond to the fraction of agricultural land occupied by permanent crop and $C_{PermRate}$ is the growth rate of permanent crops in $tCha^{-1}yr^{-1}$ [S1].

For pasture land, the carbon uptake by the vegetation was only considered on newly created agricultural land, and the vegetation was assumed to be burned every three years.

$\boldsymbol{C_{AG,past}(t) = -\left[A_{AG,new}(t,1) F_{past} C_{past} (1 - R_{burn})\ \ tCyr^{-1}\right]}$ , where $F_{past}$ is the fraction of agricultural land going to pasture, $C_{past}$ correspond to the carbon contained in the pasture biomass and $R_{burn}$ is the burning frequency ratio.

The total uptake by growing vegetation is than calculated:

$$\boldsymbol{C_{regrowth}(t) = C_{SF,regrowth}(t) + C_{SF,regrowthIC}(t) + C_{FA,uptake}(t) + C_{AG,perm}(t) + C_{AG,past}(t)\ \ tCyr^{-1}}$$

Finally, converted in $CO_{2e}$ (by multiplying the C emissions by 44/12) and expressed in M tons (1 megaton=1,000,000 tons), the total net emissions from land-cover change are calculated as:

$$C_{net} = C_{f,burn}(t) + C_{f,decay}(t) + C_{regrowth}(t)\ tCyr^{-1}.$$

DETAILS ON METHODS

In order to evaluate net carbon emissions from land-use change in Panama, we adapted a model from Ramankutty *et al.* (2007) (Ramankutty et al., 2007) which includes: a Markov-based model of land-use change and a bookkeeping carbon cycle model. This model was used to project net annual emissions based on historical information from 1990 and 2000. The simulations were performed using MatLab, version 6.1 and 7.6.

*Markov model of land-use change*

This first-order Markov model served in asserting the land-cover dynamic following deforestation of mature forest (Fearnside and Guimaraes, 1996, Flamm and Turner, 1994, Lambin, 1997, Ramankutty et al., 2007, Wood et al., 1997). This model was constructed using two GIS maps of land use for 1992 and 2000, made available by the National Environment Authority of Panama (ANAM). These maps were based on Landsat TM5 and TM7 images and made in 2002. For the year 1992, a mosaic of eight images was used dating from 1988 to 1992 and from 1998 to 2001 for the year 2000. They constituted the most recent land use analysis for Panama at the time of the study. A life zone map following Holridge's classification (1967) and produced by the Tommy Guardia Geographic Institute of Panama, was used to stratify the country in 8 life zones. Five of the 12 life zones found in Panama were aggregated as they covered small and geographically clustered mountainous areas. The model includes Premontane Moist Forest, Moist Tropical forest, Premontane Wet Forest, Tropical Wet Forest, Premontane Rainforest, Premontane Dry Forest, Tropical Dry Forest, and the aggregated life zones. Only the vector-format of these maps was conserved by ANAM. Only the vector-format was conserved by ANAM. So, the three maps were initially converted from vector to raster with a pixel size of 100 m by 100 m (one hectare) with the Lambert-Azimuthal Equal Area projection, using ArcGIS 9.3 ESRI®. Land use change, including annual deforestation, was evaluated per life zone with matrix calculation on the overlaid maps. Eight contingency tables were built, and transformed into transition probabilities (Equation 1, Appendix 1) (Pastor et al., 1993).

The matrices included five land use classes: Mature forest, Secondary forest, Fallow, Agriculture, and Other (ANAM/ITTO, 2003). Under this classification, the mature forest category includes all forests with more than 80% tree cover as well as plantations. The secondary forest category covers re-growing, previously cleared, and degraded forest having between 60% and 80% tree cover. The fallow category includes re-growing vegetation as part of a shifting cultivation cycle or following agricultural land abandonment, with less than five years of age. The agriculture category was sub-divided into the average percentage area cover with annual crop, permanent crop, and pasture found in Panama's agricultural census (Contraloría, 2001). The "Other" category joined urban areas, inland water (such as lakes or reservoirs), and lowland vegetation liable to flooding (such as albinas). Deforestation was assumed to be zero prior to 1992 for the sake of this modeling exercise.

In order to obtain annual transition probabilities, the eight-root of the matrices were taken when possible. If not, a formula for annualization of matrices was applied (Equation 2, Appendix 1) (Urban and Wallin, 2002). The model was verified using eigenanalysis and bootstrap techniques on the determination of transition matrices (see Equation 3, Appendix 1).

*Bookkeeping carbon cycle model*

To estimate the flux of carbon related to land-use dynamics, we used a simple bookkeeping carbon cycle model (Houghton, 1999, Houghton, 2003, Houghton et al., 2000, Ramankutty et al., 2007). This model tracks the annual emissions and uptake following reclearing and regrowth of fallow and secondary forest as well as carbon fluxes from permanent cultivation growth and clearing. Only changes in land use/cover are considered here; changes in land use management or the effect of natural or human disturbances (e.g. fire, insect outbreak) possibly affecting carbon fluxes were not considered. Emissions released following clearing events were partitioned into three pools: 1) a fraction burned whose carbon emissions were considered as immediately lost into the atmosphere,2) a fraction accounting for the decay of residues left on site that are released at slower rate, and 3) a fraction including the carbon temporarily stored in wood products (Gutierrez, 1999). We assumed the same rates of decay for the dead material left on site and for woody material removed from site as were estimated for the Brazilian Amazon (Houghton et al., 2000) because no information is currently available for Panama. Non-$CO_2$ gases (e.g. methane, nitrous oxide) liberated during the burning process that depend on burning efficiency were not accounted for. Soil carbon changes following land-use change were also ignored in this analysis. It was decided not to account for SOC changes in the model is mainly because of the lack of data availability in Panama. The emissions on soil reported in the greenhouse gases inventory of Panama were basically based on default values and more recent studies showed no statistical differences between forest and pasture, subsistence agriculture, agroforestry systems and plantations (Kirby and Potvin, 2007, Potvin et al., 2004, Tschakert et al., 2007, Schwendenmann and Pendall, 2006). However, none of these studies tracked changes in SOC at the same site through time, which would provide more reliable estimates of changes in SOC with land-use/cover change. Yet, not all transitions have been examined to date (e.g. forest to annual crops).

Average total forest carbon content for the mature forest (including living and dead aboveground and belowground biomass) and the reclearing of secondary forest already present in 1990 was obtained per life zone from Panama's national report to the Forest Resource Assessment of Panama (Gutierrez, 2005) available online at :http://www.fao.org/forestry/fra/50896/en/pan/ (click on Panama). The regrowth and reclearing of secondary forest formed since 1990 were accounted as following a logistic function in proportion to the mature forest mean carbon stock relative to the age of the forest, where exponential growth in trees is considered in the first years (Potvin and Gotelli, 2008) and where we assumed the carbon to be recovered completely after 75 yrs (Alves et al., 1997, Brown and Lugo, 1990) (Equation 4, Appendix 1). Secondary forest regrowth was simulated starting at the age of 5 years in order to correspond to the land use classification, and in particular to distinguish it from the fallow category. Only net changes in annual fallow areas were accounted for; using values from (Gutierrez, 2005). For the reverting mature forest class was assigned a plantation growth rate (Gutierrez, 2005). Mean carbon stock value for the different types of agriculture were used in order to account for the net changes from forest lands to agriculture, without accounting for the changes between the different agricultural land uses themselves. Finally, the annual emissions were obtained per life zone and then summed up to obtain the total national annual emissions. All the equations to the model can be found in SI Model Equations and in Appendix 1 of this document. The variables and parameters used are available in S1.

***Sensitivity analysis***

We used sensitivity analysis to identify the key parameters having the greatest impact on the overall results by testing specific changes on each parameter. The key results are reported in the main text. For the sensitivity test performed on the land-cover classification accuracy in determining deforested area, the range of value tested comes from (Grassi et al., 2008) which report a range of error of 5 to 20% for mid-resolution imagery and (Foody, 2002) where the commonly recommended overall accuracy is 85% (or less then 15% error). For the quality of the land-cover maps, all the matrices of the Markov model were modified to account for the fact that the time interval between individual images are generally greater than 8 years (Sloan, 2008).The REL was then set to 10-year difference but the model was tested for sensitivity using a 9-year or 8-year time interval. For the snapshot effect, a proportional compensation on four transition probabilities of the Markov matrix was applied, with changes made to the transition from fallow to agriculture and from agriculture to fallow, with proportional change on the transition of fallow to fallow and agriculture to agriculture so that the column would sum up to 1 (Caswell, 2001).

***Uncertainty Analysis***

*Correction of the original data used in the FRA (2005)*

The original forest inventory data used for Panama’s national report to the FRA (2005) was expressed for the most part in merchantable volume. The data reported in the FRA (2005) were first converted to aboveground living biomass using Brown (1997). Then, different adjustments were performed to account for roots, litter and woody debris depending on the forest class. The belowground biomass was calculated as a fraction of the aboveground living biomass according to default values detailed in the IPCC GPG (2003) corresponding to 0.24 for moist and 0.27 for dry mature forest (Premontane Dry and Tropical Dry Forests), and 0.42 for secondary and fallow classes. The woody debris was calculated as a fraction of the total living biomass according to default value detailed in the IPCC GPG (2003) corresponding to 0.11 for all classes. The biomass data was converted to carbon stock information by multiplying by 0.5. The values presented in table S3 are expressed in terms of tons of C per hectare. Then, as applied in the FRA (2005), the litter was accounted by adding 2.1 for mature forest, 1.7 for secondary forest and, 0.9 for fallow, which was derived from expert knowledge and default factor obtained from the IPCC GPG (2003) (Gutierrez, 2005).

We performed a quantitative analysis of uncertainty using Monte Carlo techniques to propagate uncertainty in the components of the model. It allows us to generate an assessment of uncertainty in the overall results by using key parameters and input variables identified with the sensitivity analysis and to calculate confidence intervals (Verbeeck et al., 2006). For the input parameters uncertainties were given by uniform, normal, lognormal and gamma distributions (S3). A normal distribution was used when suitable for the estimation of symmetrical uncertainties that is where the specified mean value can be assumed more probable than the other values in the range (IPCC, 2000). In this case, the mean and variance was used to generate the normal distribution for mature forest. The lognormal distribution was used for secondary forest; otherwise the high SD relative to the mean would have generated negative values. The gamma distribution was preferred for the fallow carbon stock and was determined with two parameters calculated from (Granger Morgan and Henrion, 1990). Uniform distribution was used when all values in a given range have equal probability, such as the transition matrices and the value used for the fate of carbon. In this case minimum and maximum values were used. For the Markov model, as each column of the matrix has to sum up to one, the main diagonal was defined as the difference of 1 with the sum of the other randomly defined transition probabilities. The ranges of uncertainty around the input parameters was obtained from a thorough review of the literature of Panama (and elsewhere when unavailable in Panama), from the IPCC Good Practice Guidance and, from expert knowledge when no data were available. We simulated the model per life zone by running 10,000 iterations using a Simple Random Sampling (SRS) of parameter values within defined ranges. While in other studies, correlations between parameters emerged as very influential component of uncertainty (Smith and Heath, 2001, Peltoniemi et al., 2006), for this model key parameters and input variables are assumed to be correlated through time but independent between the different iterations of the Monte Carlo analysis. We made no distinction between the uncertainty due to lack of knowledge and the uncertainty caused by natural variability. In order to make this distinction, a second-order Monte Carlo analysis should be applied (Hoffman and Hammonds, 1994, Verbeeck et al., 2006). However, we recognize our inability to partition these two components because of the lack information currently available.

We evaluated the 95% confidence intervals per life zone. To propagate the error on the overall results, we added the mean and the variance obtained for each life zone and calculated the total mean and the 95% confidence intervals (Hammonds et al., 1994, Granger Morgan and Henrion, 1990). We did not address possible additional uncertainty due to the model structure as this uncertainty should be examined by alternative models or by the addition of parameters that were not included in the model (Hammonds et al., 1994).

***Scenario Analysis***

We used this model to see the effect of different possible strategies to reduce emissions from deforestation that could be of interest to the government of Panama. After ample discussions with civil servants and assisting to different workshops given on REDD in Panama, five scenarios of deforestation reduction were selected. These scenarios include 1) the Mesoamerican Biological Corridor of Atlantic Panama phase II conservation project (CBMAP II scenario), 2) the National System of Protected Areas including 54 protected areas (SINAP scenario), 3) the Palo Seco forest reserve, a priority protected area for ANAM and the Darien biogeographical region where high level of deforestation are in effect (Palo Seco & Darién scenario, 4) the replication of Ipetí-Emberá REDD community project in other communities of Darien region (Replication of Ipetí-Emberá scenario), and 5) a reduction of 50% of the annual deforestation (Stern Review). We tested the different scenarios from the year 2000 to 2030, starting the reduction of deforestation in 2010.

Appendix 1. *Equations*

*Equation 1. Obtention of transition probabilities*

Eight contingency tables were built, and transformed into transition probabilities (Pastor et al., 1993).

1)

$$p_{i,j,\tau} = n_{i,j} / \sum_{j=1}^{m} n_{i,j}$$

where $p_{ij,t}$ is the probability of one hectare to change from land use *i* to *j* during the time *t*

*Equation 2. Annualization of matrices*

2) $$p_{i,j} = p_{ij,\tau}/t$$

where $p_{i,j}$ is the off-diagonal probability,

$p_{i,i} = 1 - sum(\, p_{i,j}\,)$ for j=1 to n,

where $p_{i,i}$ is the diagonal probability

*Validation of the annualization of the transition matrices*

The validity of the annualization of the transition matrices using Equation 2 described above, was verified by running the model starting in 1990 to compare the value from the simulations with the area cover by each land use in 2000. An eigenanalysis was performed between the annual matrices and the ten-year matrices to verify the effect of annualizing the matrices (Tanner et al., 1994). The eigenvalues, right and left eigenvectors as well as the Damping ratio sensitivity of the transition probability matrices were calculated (Caswell, 2001, Wootton, 2001) (Equation 3 below) , and were consistent between the annual and the ten-year matrices.

Equation 3.

$$\frac{d\rho}{dp_{jk}} = \frac{1}{|\lambda_2|}\left[\frac{d\lambda_1}{dp_{jk}} - \frac{\rho}{|\lambda_2|}\left(x\frac{dx}{dp_{jk}} + y\frac{dy}{dp_{jk}}\right)\right] \; where \; \frac{d\lambda_1}{dp_{jk}} = \frac{v_j w_k}{(v_1, w_1)}$$

$$\frac{dx}{dp_{jk}} \; and \; \frac{dy}{dp_{jk}} \; are\ the\ real\ and\ imaginary\ parts\ of \; \frac{d\lambda_2}{dp_{jk}} \; respectively$$

$(v_1, w_1)$ is the inner product of the right and left eigenvectors.

*Equation 4. Logistic equation*

The function used to calculate the standing stock of the secondary forest is

$Csf = Cveg / (1+e^{1.7-0.105(t)})$

where *t* is time in years,

*Cveg* is the standing stock in mature forest,

*Csf* the standing stock in secondary forest

The reverting rate is calculated as $\Delta Csf = f(t) - f(t-1)$.

S1. Parameter and carbon values used in the model

| | Value | Unit |
|---|---|---|
| ***Premontane Moist Forest*** | | |
| Mature forest | 164.4 | tC/ha |
| Secondary forest | 117.5 | tC/ha |
| Fallow | 51.9 | tC/ha |
| Area deforested | 491 | ha |
| Fraction of the deforested land to secondary forest | 0.310 | - |
| Fraction of the deforested land to fallow | 0.216 | - |
| Fraction of the deforested land to agriculture | 0.195 | - |
| Fraction of the deforested land to other | 0.279 | - |
| Initial condition $\boldsymbol{A_F}$ | 17574 | - |
| Initial condition $\boldsymbol{A_{SF}}$ | 7872 | - |
| Initial condition $\boldsymbol{A_{FA}}$ | 34458 | - |
| Initial condition $\boldsymbol{A_{AG}}$ | 170415 | - |
| Initial condition $\boldsymbol{A_O}$ | 7515 | - |
| ***Moist Tropical forest*** | | |
| Mature forest | 177.5 | tC/ha |
| Secondary forest | 128.4 | tC/ha |
| Fallow | 56.7 | tC/ha |
| Area deforested | 21700 | ha |
| Fraction of the deforested land to secondary forest | 0.312 | - |
| Fraction of the deforested land to fallow | 0.307 | - |
| Fraction of the deforested land to agriculture | 0.353 | - |
| Fraction of the deforested land to other | 0.028 | - |
| Initial condition $\boldsymbol{A_F}$ | 1221316 | - |
| Initial condition $\boldsymbol{A_{SF}}$ | 224564 | - |
| Initial condition $\boldsymbol{A_{FA}}$ | 407206 | - |
| Initial condition $\boldsymbol{A_{AG}}$ | 1070153 | - |
| Initial condition $\boldsymbol{A_O}$ | 40704 | - |
| ***Premontane Wet Forest*** | | |
| Mature forest | 176.8 | tC/ha |
| Secondary forest | 138.2 | tC/ha |
| Fallow | 61.1 | tC/ha |
| Area deforested | 5597 | ha |
| Fraction of the deforested land to secondary forest | 0.258 | - |
| Fraction of the deforested land to fallow | 0.309 | - |
| Fraction of the deforested land to agriculture | 0.427 | - |
| Fraction of the deforested land to other | 0.006 | - |
| Initial condition $\boldsymbol{A_F}$ | 637773 | - |
| Initial condition $\boldsymbol{A_{SF}}$ | 162373 | - |
| Initial condition $\boldsymbol{A_{FA}}$ | 215423 | - |
| Initial condition $\boldsymbol{A_{AG}}$ | 344750 | - |
| Initial condition $\boldsymbol{A_O}$ | 556 | - |
| ***Tropical Wet Forest*** | | |
| Mature forest | 178.6 | tC/ha |
| Secondary forest | 126.4 | tC/ha |

| | | |
|---|---|---|
| Fallow | 55.9 | tC/ha |
| Area deforested | 11544 | ha |
| Fraction of the deforested land to secondary forest | 0.489 | - |
| Fraction of the deforested land to fallow | 0.103 | - |
| Fraction of the deforested land to agriculture | 0.406 | - |
| Fraction of the deforested land to other | 0.002 | - |
| Initial condition $A_F$ | 1069260 | - |
| Initial condition $A_{SF}$ | 186597 | - |
| Initial condition $A_{FA}$ | 185863 | - |
| Initial condition $A_{AG}$ | 164522 | - |
| Initial condition $A_O$ | 1358 | - |
| ***Premontane Rainforest*** | | |
| Mature forest | 171.8 | tC/ha |
| Secondary forest | 121.6 | tC/ha |
| Fallow | 53.8 | tC/ha |
| Area deforested | 3135 | ha |
| Fraction of the deforested land to secondary forest | 0.459 | - |
| Fraction of the deforested land to fallow | 0.161 | - |
| Fraction of the deforested land to agriculture | 0.378 | - |
| Fraction of the deforested land to other | 0.002 | - |
| Initial condition $A_F$ | 532993 | - |
| Initial condition $A_{SF}$ | 53129 | - |
| Initial condition $A_{FA}$ | 33067 | - |
| Initial condition $A_{AG}$ | 51911 | - |
| Initial condition $A_O$ | 326 | - |
| ***Premontane Dry Forest*** | | |
| Mature forest | 169.1 | tC/ha |
| Secondary forest | 114.0 | tC/ha |
| Fallow | 50.4 | tC/ha |
| Area deforested | 10 | ha |
| Fraction of the deforested land to secondary forest | 0.141 | - |
| Fraction of the deforested land to fallow | 0.129 | - |
| Fraction of the deforested land to agriculture | 0.149 | - |
| Fraction of the deforested land to other | 0.580 | - |
| Initial condition $A_F$ | 12212 | - |
| Initial condition $A_{SF}$ | 134 | - |
| Initial condition $A_{FA}$ | 2097 | - |
| Initial condition $A_{AG}$ | 35817 | - |
| Initial condition $A_O$ | 8941 | - |
| ***Tropical Dry Forest*** | | |
| Mature forest | 165.6 | tC/ha |
| Secondary forest | 114.0 | tC/ha |
| Fallow | 50.4 | tC/ha |
| Area deforested | 67 | ha |
| Fraction of the deforested land to secondary forest | 0.363 | - |
| Fraction of the deforested land to fallow | 0.152 | - |
| Fraction of the deforested land to agriculture | 0.227 | - |
| Fraction of the deforested land to other | 0.258 | - |

| | | |
|---|---|---|
| Initial condition $A_F$ | 5076 | - |
| Initial condition $A_{SF}$ | 3110 | - |
| Initial condition $A_{FA}$ | 22670 | - |
| Initial condition $A_{AG}$ | 236178 | - |
| Initial condition $A_O$ | 7518 | - |
| ***Mountainous life zones*** | | |
| Mature forest | 163.8 | tC/ha |
| Secondary forest | 116.0 | tC/ha |
| Fallow | 49.1 | tC/ha |
| Area deforested | 418 | ha |
| Fraction of the deforested land to secondary forest | 0.369 | - |
| Fraction of the deforested land to fallow | 0.198 | - |
| Fraction of the deforested land to agriculture | 0.417 | - |
| Fraction of the deforested land to other | 0.016 | - |
| Initial condition $A_F$ | 184522 | - |
| Initial condition $A_{SF}$ | 7737 | - |
| Initial condition $A_{FA}$ | 7854 | - |
| Initial condition $A_{AG}$ | 14022 | - |
| Initial condition $A_O$ | 0 | - |
| ***Parameter used for all life zones*** | | |
| Rate of accumulation for mature forest (here representing plantations) | 4.3 | tC/ha/yr |
| Rate of accumulation for secondary forest | 3.4 | tC/ha/yr |
| Pasture | 4.8 | tC/ha |
| Permanent crops (for all Moist and Wet life zones)* | 50 | tC/ha |
| Rate of accumulation for permanent crop (for all Moist and Wet life zones) | 10 | tC/ha/yr |
| Permanent crops (for Dry Tropical Forest and Dry Premontane Forest)** | 21 | tC/ha |
| Rate of accumulation for permanent crop (for Dry Tropical Forest and Dry Premontane Forest) | 2.6 | tC/ha/yr |
| Fraction of the carbon that is emitted through burning | 0.6 | - |
| Fraction of the carbon that goes in the slash pool | 0.34 | - |
| Fraction of the carbon that goes in the product pool | 0.06 | - |

* Assumes a five-year harvest cycle/maturity (Table 3.3.2, IPCC Good Practice Guidance from Schroeder (1994)).

** Assumes an eight-year harvest cycle/maturity (Table 3.3.2, IPCC Good Practice Guidance from Schroeder (1994)).

S2. The land-cover change transition matrices

*Premontane Moist Forest*

| | | 1992 | | | | |
|---|---|---|---|---|---|---|
| | | forest | secondary | fallow | agriculture | other |
| 2000 | forest | 0.967134 | 0.003631 | 0.000445 | 0.000202 | 0.002480 |
| | secondary | 0.010529 | 0.965731 | 0.030695 | 0.002212 | 0.000639 |
| | fallow | 0.010150 | 0.021784 | 0.866151 | 0.036966 | 0.002456 |
| | agriculture | 0.002362 | 0.005690 | 0.099860 | 0.960112 | 0.017421 |
| | other | 0.009823 | 0.003164 | 0.002848 | 0.000508 | 0.977004 |

*Moist Tropical forest*

| | | 1992 | | | | |
|---|---|---|---|---|---|---|
| | | forest | secondary | fallow | agriculture | other |
| 2000 | forest | 0.976649 | 0.017081 | 0.007086 | 0.000442 | 0.005424 |
| | secondary | 0.008015 | 0.932271 | 0.039189 | 0.001931 | 0.003213 |
| | fallow | 0.006863 | 0.034633 | 0.901479 | 0.053949 | 0.004955 |
| | agriculture | 0.007930 | 0.015849 | 0.049009 | 0.942816 | 0.006391 |
| | other | 0.000543 | 0.000167 | 0.003237 | 0.000863 | 0.980017 |

*Premontane Wet Forest*

| | | 1992 | | | | |
|---|---|---|---|---|---|---|
| | | forest | secondary | fallow | agriculture | other |
| 2000 | forest | 0.987180 | 0.012279 | 0.004157 | 0.002287 | 0.037590 |
| | secondary | 0.003303 | 0.952479 | 0.029267 | 0.010406 | 0.002518 |
| | fallow | 0.003959 | 0.022488 | 0.941115 | 0.024752 | 0.002518 |
| | agriculture | 0.005479 | 0.012633 | 0.025038 | 0.962206 | 0.026619 |
| | other | 0.000080 | 0.000122 | 0.000423 | 0.000350 | 0.930755 |

*Tropical Wet Forest*

| | | 1992 | | | | |
|---|---|---|---|---|---|---|
| | | forest | secondary | fallow | agriculture | other |
| 2000 | forest | 0.988332 | 0.006412 | 0.006245 | 0.005035 | 0.041016 |
| | secondary | 0.005702 | 0.962927 | 0.031197 | 0.016539 | 0.013476 |
| | fallow | 0.001207 | 0.020696 | 0.938911 | 0.026491 | 0.004050 |
| | agriculture | 0.004736 | 0.009903 | 0.023484 | 0.951596 | 0.021649 |
| | other | 0.000023 | 0.000062 | 0.000162 | 0.000339 | 0.919809 |

*Premontane Rainforest*

| | | 1992 | | | | |
|---|---|---|---|---|---|---|
| | | forest | secondary | fallow | agriculture | other |
| 2000 | forest | 0.993634 | 0.007636 | 0.007173 | 0.004643 | 0.004601 |
| | secondary | 0.002925 | 0.949103 | 0.025739 | 0.013292 | 0.000613 |
| | fallow | 0.001024 | 0.025984 | 0.931488 | 0.019928 | 0 |
| | agriculture | 0.002404 | 0.017190 | 0.035434 | 0.962018 | 0 |
| | other | 0.000013 | 0.000087 | 0.000166 | 0.000119 | 0.994785 |

*Premontane Dry Forest*

1992

| | | forest | secondary | fallow | agriculture | other |
|---|---|---|---|---|---|---|
| 2000 | forest | 0.990182 | 0.011194 | 0.005198 | 0.001617 | 0.004653 |
| | secondary | 0.001384 | 0.913433 | 0.014497 | 0.003401 | 0 |
| | fallow | 0.001269 | 0.014179 | 0.922413 | 0.023327 | 0.001398 |
| | agriculture | 0.001466 | 0.020896 | 0.038674 | 0.959687 | 0.002863 |
| | other | 0.005699 | 0.040299 | 0.019218 | 0.011969 | 0.991086 |

*Tropical Dry Forest*

| | | 1992 | | | | |
|---|---|---|---|---|---|---|
| | | forest | secondary | fallow | agriculture | other |
| 2000 | forest | 0.970173 | 0.004534 | 0.001610 | 0.000124 | 0.002368 |
| | secondary | 0.010816 | 0.960193 | 0.018734 | 0.003080 | 0.001955 |
| | fallow | 0.004531 | 0.011961 | 0.922894 | 0.013609 | 0.010335 |
| | agriculture | 0.006777 | 0.021704 | 0.054905 | 0.981456 | 0.036113 |
| | other | 0.007703 | 0.001608 | 0.001857 | 0.001730 | 0.949229 |

*Aggregated life zones*

| | | 1992 | | | | |
|---|---|---|---|---|---|---|
| | | forest | secondary | fallow | agriculture | other |
| 2000 | forest | 0.995792 | 0.040158 | 0.010810 | 0.003330 | 0 |
| | secondary | 0.001552 | 0.929546 | 0.021861 | 0.016274 | 0 |
| | fallow | 0.000833 | 0.017991 | 0.927769 | 0.009100 | 0 |
| | agriculture | 0.001756 | 0.011167 | 0.034899 | 0.961339 | 0 |
| | other | 0.000068 | 0.001137 | 0.004660 | 0.009956 | 1 |

S3. Data used in the Monte Carlo analysis.

| | | |
|---|---|---|
| ***Premontane Moist Forest*** | | |
| ***Mature forest*** | | |
| Source | Total C stock (in tC/ha) | |
| PNUD/FAO, 1972 | 207.0 | |
| PNUD/FAO, 1972 | 163.2 | |
| PNUD/FAO, 1972 | 180.2 | |
| PNUD/FAO, 1972 | 160.3 | |
| NA | 141.3 | |
| NA | 138.2 | |
| **Mean** | | **165.0** |
| **SD** | | **25.7** |
| **Probability distribution function** | | **Normal** |
| ***Secondary forest*** | | |
| **Mean*** | | **115.6** |
| **SD**† | | **18.0** |
| **Probability distribution function** | | **Lognormal** |
| ***Rastrojo***‡ | | |
| **Mean** (parameter A for scale) | **38.6** | 2.8 |
| **SD** (parameter B for the shape) | **23.0** | 13.7 |
| **Probability distribution function** | | **Gamma** |
| ***Moist Tropical forest*** | | |
| ***Mature forest*** | | |
| Source | Total C stock (in tC/ha) | |
| PNUD/FAO, 1972 | 207.9 | |
| PNUD/FAO, 1972 | 163.2 | |
| PNUD/FAO, 1972 | 159.4 | |
| PNUD/FAO, 1972 | 134.6 | |
| PNUD/FAO, 1972 | 138.2 | |
| PNUD/FAO, 1972 | 192.2 | |
| PNUD/FAO, 1972 | 167.2 | |
| PNUD/FAO, 1972 | 150.3 | |
| PNUD/FAO, 1972 | 132.2 | |
| PNUD/FAO, 1972 | 193.2 | |
| PNUD/FAO, 1972 | 146.6 | |
| PNUD/FAO, 1972 | 303.6 | |
| PNUD/FAO, 1972 | 175.3 | |
| PNUD/FAO, 1972 | 242.2 | |
| PNUD/FAO, 1972 | 254.6 | |
| PNUD/FAO, 1972 | 182.5 | |
| Aserradero Los Cuatro Hermanos, 1998 | 161.9 | |
| EXTRAFORSA, 1992 | 133.9 | |
| Maderas Pacaro, S. A., 1991 | 192.5 | |
| Corporación Síntesis, S. A., 1996 | 200.4 | |
| Castillo, A., 1991 | 213.4 | |

| | | |
|---|---|---|
| Aserradero Chagres, S. A., 1991 | 190.9 | |
| Pegui, S. A., 1992 | 197.9 | |
| Mederas del Tesca, S. A., 199_? | 200.7 | |
| Aserradero Los Cuatro Hermanos, S. A., 1992 | 157.2 | |
| Madera de Subcurtí, S. A., 1992 | 186.0 | |
| ANCON, 1998 | 161.7 | |
| Grupo Melo, S. A., 199_? | 156.7 | |
| Maderas del Darién, S. A., 199_? | 165.5 | |
| Laminados Mon, S. A., 1993 | 180.8 | |
| Yaviza en Marcha, S. A., 199_? | 176.5 | |
| Kirby & Potvin (2007) | 317.0 | |
| Magallon, F. Master Thesis (2002) | 181.0 | |
| **Mean** | | **185.4** |
| **SD** | | **43.0** |
| **Probability distribution function** | | **Normal** |

***Secondary forest***

| Source | Total C stock (in tC/ha) | |
|---|---|---|
| ANAM, 1998 | 161.1 | |
| ANAM, 1998 | 161.1 | |
| ANAM, 1998 | 172.2 | |
| ANAM, 1998 | 171.4 | |
| INRENARE, 1998 | 148.2 | |
| PNUD/FAO, 1972 | 147.1 | |
| PNUD/FAO, 1972 | 103.0 | |
| PNUD/FAO, 1972 | 109.8 | |
| PNUD/FAO, 1972 | 97.5 | |
| PNUD/FAO, 1972 | 74.3 | |
| PNUD/FAO, 1972 | 83.1 | |
| **Mean** | | **129.9** |
| **SD** | | **36.8** |
| **Probability distribution function** | | **Lognormal** |

***Rastrojo***‡

| Source | Total C stock (in tC/ha) | |
|---|---|---|
| PNUD/FAO, 1972 | 60.2 | *not used* |
| **Mean** (parameter A for scale) | **38.6** | 2.8 |
| **SD** (parameter B for the shape) | **23.0** | 13.7 |
| **Probability distribution function** | | **Gamma** |

## *Premontane Wet Forest*

***Mature forest***

| Source | Total C stock (in tC/ha) |
|---|---|
| PNUD/FAO, 1972 | 212.8 |
| PNUD/FAO, 1972 | 169.8 |
| NA | 74.1 |
| Centro Científico Tropical, 1995 | 135.5 |

| | | |
|---|---|---|
| Inversiones Hope, 199_ | 305.7 | |
| **Mean** | | **179.6** |
| **SD** | | **86.8** |
| **Probability distribution function** | | **Lognormal** |
| ***Secondary forest*** | | |
| Source | Total C stock (in tC/ha) | |
| Centro Científico Tropical, 1995 | 82.0 | |
| Centro Científico Tropical, 1995 | 113.4 | |
| PNUD/FAO, 1972 | 84.2 | |
| **Mean** | | **93.2** |
| **SD** | | **17.5** |
| **Probability distribution function** | | **Lognormal** |
| ***Rastrojo***[‡] | | |
| **Mean** (parameter A for scale) | **38.6** | 2.8 |
| **SD** (parameter B for the shape) | **23.0** | 13.7 |
| **Probability distribution function** | | **Gamma** |
| ***Tropical Wet Forest*** | | |
| ***Mature forest*** | | |
| Source | Total C stock (in tC/ha) | |
| PNUD/FAO, 1972 | 207.0 | |
| PNUD/FAO, 1972 | 180.2 | |
| PNUD/FAO, 1972 | 160.3 | |
| PNUD/FAO, 1972 | 151.8 | |
| PNUD/FAO, 1972 | 184.3 | |
| PNUD/FAO, 1972 | 132.9 | |
| PNUD/FAO, 1972 | 216.5 | |
| PNUD/FAO, 1972 | 161.5 | |
| Reforestadora el Zapallal, S. A., 1998 | 188.8 | |
| JICA, 1995 | 176.5 | |
| Naturaleza y Desarrollo, S. A., 1998 | 188.9 | |
| INRENARE/OIMT, 1997 | 187.0 | |
| **Mean** | | 178.0 |
| **SD** | | 23.3 |
| **Probability distribution function** | | **Normal** |
| ***Secondary forest*** | | |
| Source | Total C stock (in tC/ha) | |
| JICA, 1985 | 125.1 | |
| JICA, 1985 | 106.7 | |
| JICA, 1985 | 124.4 | |
| JICA, 1985 | 132.3 | |
| PNUD/FAO, 1972 | 145.0 | |
| PNUD/FAO, 1972 | 119.2 | |
| JICA, 1985 | 98.2 | |
| **Mean** | | **121.5** |

| | | |
|---|---|---|
| **SD** | | **15.6** |
| **Probability distribution function** | | **Lognormal** |
| ***Rastrojo*** | | |
| Source | Total C stock (in tC/ha) | |
| PNUD/FAO, 1972 | 40.3 | |
| PNUD/FAO, 1972 | 5.1 | |
| **Mean** (parameter A for scale) | **22.7** | 0.8 |
| **SD** (parameter B for the shape) | **24.9** | 27.3 |
| **Probability distribution function** | | **Gamma** |
| *Premontane Rainforest* | | |
| ***Mature forest*** | | |
| Source | Total C stock (in tC/ha) | |
| PNUD/FAO, 1972 | 159.9 | |
| PNUD/FAO, 1972 | 133.2 | |
| PNUD/FAO, 1972 | 192.3 | |
| PNUD/FAO, 1972 | 214.1 | |
| PNUD/FAO, 1972 | 150.4 | |
| PNUD/FAO, 1972 | 141.0 | |
| **Mean** | | **165.1** |
| **SD** | | **31.6** |
| **Probability distribution function** | | **Normal** |
| ***Secondary forest*** | | |
| Source | Total C stock (in tC/ha) | |
| PNUD/FAO, 1972 | 102.7 | |
| PNUD/FAO, 1972 | 82.5 | |
| PNUD/FAO, 1972 | 82.9 | |
| PNUD/FAO, 1972 | 147.2 | |
| **Mean** | | **103.8** |
| **SD** | | **30.4** |
| **Probability distribution function** | | **Lognormal** |
| ***Rastrojo*** | | |
| Source | Total C stock (in tC/ha) | |
| PNUD/FAO, 1972 | 48.4 | |
| PNUD/FAO, 1972 | 17.0 | |
| **Mean** (parameter A for scale) | **32.7** | 2.2 |
| **SD** (parameter B for the shape) | **22.1** | 15.0 |
| **Probability distribution function** | | **Gamma** |
| *Premontane Dry Forest* | | |
| ***Mature forest*** | | |
| **Mean**[§] | | **147.3** |
| **SD**[¶] | | **1.8** |
| **Probability distribution function** | | **Normal** |

| | | |
|---|---|---|
| ***Secondary forest*** | | |
| **Mean**[‖] | | **115.7** |
| **SD**[**] | | **36.6** |
| **Probability distribution function** | | **Lognormal** |
| ***Rastrojo***[‡] | | |
| **Mean** (parameter A for scale) | **38.6** | 2.8 |
| **SD** (parameter B for the shape) | **23.0** | 13.7 |
| **Probability distribution function** | | **Gamma** |
| ***Tropical Dry Forest*** | | |
| ***Mature forest*** | | |
| Source | Total C stock (in tC/ha) | |
| PNUD/FAO, 1972 | 167.1 | |
| PNUD/FAO, 1972 | 163.2 | |
| PNUD/FAO, 1972 | 166.4 | |
| **Mean** | | **165.6** |
| **SD** | | **2.1** |
| **Probability distribution function** | | **Normal** |
| ***Secondary forest*** | | |
| Source | Total C stock (in tC/ha) | |
| ANAM/USAID/STRI, 1999 | 169.5 | |
| PNUD/FAO, 1972 | 87.3 | |
| PNUD/FAO, 1972 | 133.4 | |
| **Mean** | | **130.1** |
| **SD** | | **41.2** |
| **Probability distribution function** | | **Lognormal** |
| ***Rastrojo***[‡] | | |
| **Mean** (parameter A for scale) | **38.6** | 2.8 |
| **SD** (parameter B for the shape) | **23.0** | 13.7 |
| **Probability distribution function** | | **Gamma** |
| ***Mountainous life zones*** | | |
| ***Mature forest*** | | |
| Source | Total C stock (in tC/ha) | |
| PNUD/FAO, 1972 | 192.3 | |
| PNUD/FAO, 1972 | 129.1 | |
| PNUD/FAO, 1972 | 189.1 | |
| PNUD/FAO, 1972 | 140.3 | |
| PNUD/FAO, 1972 | 189.1 | |
| PNUD/FAO, 1972 | 140.3 | |
| PNUD/FAO, 1972 | 108.1 | |
| **Mean** | | **155.5** |
| **SD** | | **34.2** |
| **Probability distribution function** | | **Normal** |
| ***Secondary forest*** | | |

| Source | Total C stock (in tC/ha) | |
|---|---|---|
| PNUD/FAO, 1972 | 123.1 | |
| **Mean** | | **123.1** |
| **SD**[†] | | **27.1** |
| **Probability distribution function** | | **Lognormal** |
| ***Rastrojo***[‡] | | |
| PNUD/FAO, 1972 | 60.8 | *not used* |
| **Mean** (parameter A for scale) | **38.6** | 2.8 |
| **SD** (parameter B for the shape) | **23.0** | 13.7 |
| **Probability distribution function** | | **Gamma** |
| *Parameter used for all life zones* | | |
| | **Minimum** | **Maximum** |
| ***Fate of carbon*** | | |
| fburn | 0.2 | 0.6 |
| fslash | 0.339 | 0.7 |
| fprod | 0.061 | 0.1 |
| *Premontane Moist Forest* | | |
| *f,sf * †* | 0.010529 | 0.013102 |
| *f,fa* | 0.01015 | 0.012468 |
| *f,ag* | 0.002362 | 0.003128 |
| *f,o* | 0.009823 | 0.012203 |
| *sf,f* | 0.003631 | 0.004503 |
| *sf,fa* | 0.021784 | 0.026674 |
| *sf.ag* | 0.00569 | 0.007413 |
| *sf,o* | 0.003164 | 0.003943 |
| *fa,f* | 0.000445 | 0.000567 |
| *fa,sf* | 0.030695 | 0.037563 |
| *fa,ag* | 0.09986 | 0.204721 |
| *fa,o* | 0.002848 | 0.003512 |
| *ag,f* | 0.000202 | 0.000254 |
| *ag,sf* | 0.002212 | 0.002926 |
| *ag,fa* | 0.036966 | 0.064931 |
| *ag,o* | 0.000508 | 0.000649 |
| *o,f* | 0.00248 | 0.00308 |
| *o,sf* | 0.000639 | 0.000815 |
| *o,fa* | 0.002456 | 0.00312 |
| *o,ag* | 0.017421 | 0.021641 |
| *Moist Tropical forest* | | |
| *f,sf* | 0.008015 | 0.009948 |
| *f,fa* | 0.006863 | 0.008558 |
| *f,ag* | 0.00793 | 0.009886 |
| *f,o* | 0.000543 | 0.00068 |
| *sf,f* | 0.017081 | 0.021144 |
| *sf,fa* | 0.034633 | 0.042516 |
| *sf.ag* | 0.015849 | 0.019794 |
| *sf,o* | 0.000167 | 0.000228 |
| *fa,f* | 0.007086 | 0.008834 |

| | | |
|---|---|---|
| *fa,sf* | 0.039189 | 0.047954 |
| *fa,ag* | 0.049009 | 0.065669 |
| *fa,o* | 0.003237 | 0.003993 |
| *ag,f* | 0.000442 | 0.000614 |
| *ag,sf* | 0.001931 | 0.002725 |
| *ag,fa* | 0.053949 | 0.064698 |
| *ag,o* | 0.000863 | 0.001096 |
| *o,f* | 0.005424 | 0.006757 |
| *o,sf* | 0.003213 | 0.004011 |
| *o,fa* | 0.004955 | 0.006179 |
| *o,ag* | 0.006391 | 0.007964 |
| ***Premontane Wet Forest*** | | |
| *f,sf* | 0.003303 | 0.004128 |
| *f,fa* | 0.003959 | 0.004949 |
| *f,ag* | 0.005479 | 0.006848 |
| *f,o* | 7.98E-05 | 9.98E-05 |
| *sf,f* | 0.012279 | 0.015349 |
| *sf,fa* | 0.022488 | 0.02811 |
| *sf.ag* | 0.012633 | 0.015791 |
| *sf,o* | 0.000122 | 0.000152 |
| *fa,f* | 0.004157 | 0.005196 |
| *fa,sf* | 0.029267 | 0.036584 |
| *fa,ag* | 0.025038 | 0.050076 |
| *fa,o* | 0.000423 | 0.000529 |
| *ag,f* | 0.002287 | 0.002858 |
| *ag,sf* | 0.010406 | 0.013007 |
| *ag,fa* | 0.024752 | 0.040397 |
| *ag,o* | 0.00035 | 0.000438 |
| *o,f* | 0.03759 | 0.046987 |
| *o,sf* | 0.002518 | 0.003147 |
| *o,fa* | 0.002518 | 0.003147 |
| *o,ag* | 0.026619 | 0.033273 |
| ***Tropical Wet Forest*** | | |
| *f,sf* | 0.005702 | 0.007128 |
| *f,fa* | 0.001207 | 0.001508 |
| *f,ag* | 0.004736 | 0.005921 |
| *f,o* | 2.29E-05 | 2.86E-05 |
| *sf,f* | 0.006412 | 0.008015 |
| *sf,fa* | 0.020696 | 0.02587 |
| *sf.ag* | 0.009903 | 0.012379 |
| *sf,o* | 6.22E-05 | 7.77E-05 |
| *fa,f* | 0.006245 | 0.007807 |
| *fa,sf* | 0.031197 | 0.038996 |
| *fa,ag* | 0.023484 | 0.04294 |
| *fa,o* | 0.000162 | 0.000202 |
| *ag,f* | 0.005035 | 0.006293 |
| *ag,sf* | 0.016539 | 0.020674 |
| *ag,fa* | 0.026491 | 0.04847 |
| *ag,o* | 0.000339 | 0.000424 |
| *o,f* | 0.041016 | 0.05127 |

| | | |
|---|---|---|
| *o,sf* | 0.013476 | 0.016845 |
| *o,fa* | 0.00405 | 0.005063 |
| *o,ag* | 0.021649 | 0.027062 |
| ***Premontane Rainforest*** | | |
| *f,sf* | 0.002925 | 0.003656 |
| *f,fa* | 0.001024 | 0.00128 |
| *f,ag* | 0.002404 | 0.003005 |
| *f,o* | 1.29E-05 | 1.62E-05 |
| *sf,f* | 0.007636 | 0.009545 |
| *sf,fa* | 0.025984 | 0.03248 |
| *sf.ag* | 0.01719 | 0.021488 |
| *sf,o* | 8.66E-05 | 0.000108 |
| *fa,f* | 0.007173 | 0.008967 |
| *fa,sf* | 0.025739 | 0.032173 |
| *fa,ag* | 0.035434 | 0.051178 |
| *fa,o* | 0.000166 | 0.000208 |
| *ag,f* | 0.004643 | 0.005803 |
| *ag,sf* | 0.013292 | 0.016615 |
| *ag,fa* | 0.019928 | 0.029957 |
| *ag,o* | 0.000119 | 0.000149 |
| *o,f* | 0.004601 | 0.005752 |
| *o,sf* | 0.000613 | 0.000767 |
| *o,fa* | 0 | 0 |
| *o,ag* | 0 | 0 |
| ***Premontane Dry Forest*** | | |
| *f,sf* | 0.001384 | 0.00173 |
| *f,fa* | 0.001269 | 0.001587 |
| *f,ag* | 0.001466 | 0.001832 |
| *f,o* | 0.005699 | 0.007124 |
| *sf,f* | 0.011194 | 0.013993 |
| *sf,fa* | 0.014179 | 0.017724 |
| *sf.ag* | 0.020896 | 0.026119 |
| *sf,o* | 0.040299 | 0.050373 |
| *fa,f* | 0.005198 | 0.006497 |
| *fa,sf* | 0.014497 | 0.018121 |
| *fa,ag* | 0.038674 | 0.049881 |
| *fa,o* | 0.019218 | 0.024022 |
| *ag,f* | 0.001617 | 0.002021 |
| *ag,sf* | 0.003401 | 0.004251 |
| *ag,fa* | 0.023327 | 0.029159 |
| *ag,o* | 0.011969 | 0.014961 |
| *o,f* | 0.004653 | 0.005816 |
| *o,sf* | 0 | 0 |
| *o,fa* | 0.001398 | 0.001748 |
| *o,ag* | 0.002863 | 0.003579 |
| ***Tropical Dry Forest*** | | |
| *f,sf* | 0.010816 | 0.01352 |
| *f,fa* | 0.004531 | 0.005664 |
| *f,ag* | 0.006777 | 0.008471 |
| *f,o* | 0.007703 | 0.009629 |

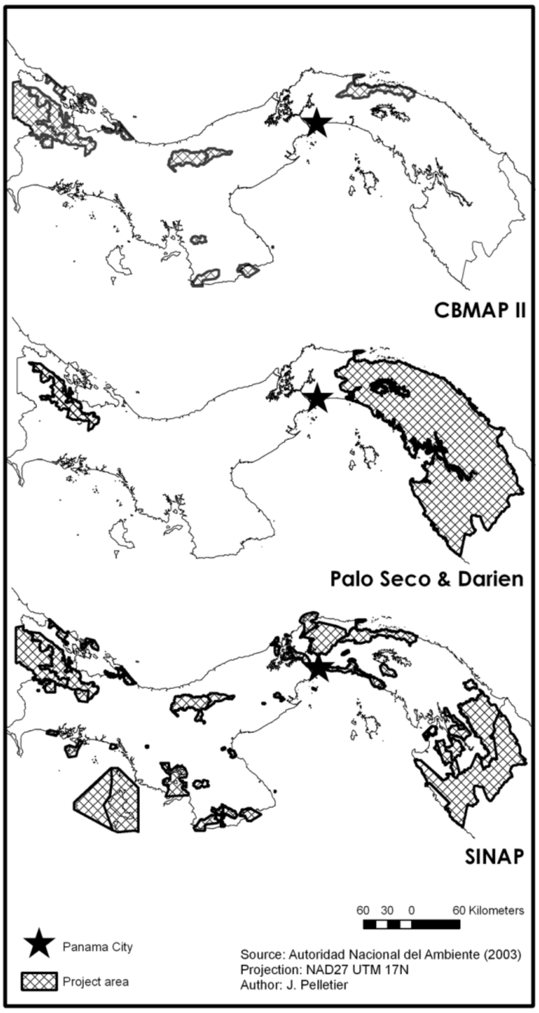
| | | |
|---|---|---|
| *sf,f* | 0.004534 | 0.005667 |
| *sf,fa* | 0.011961 | 0.014952 |
| *sf.ag* | 0.021704 | 0.02713 |
| *sf,o* | 0.001608 | 0.00201 |
| *fa,f* | 0.00161 | 0.002013 |
| *fa,sf* | 0.018734 | 0.023418 |
| *fa,ag* | 0.054905 | 0.08294 |
| *fa,o* | 0.001857 | 0.002321 |
| *ag,f* | 0.000124 | 0.000156 |
| *ag,sf* | 0.00308 | 0.00385 |
| *ag,fa* | 0.013609 | 0.018384 |
| *ag,o* | 0.00173 | 0.002163 |
| *o,f* | 0.002368 | 0.00296 |
| *o,sf* | 0.001955 | 0.002444 |
| *o,fa* | 0.010335 | 0.012919 |
| *o,ag* | 0.036113 | 0.045142 |
| ***Mountainous life zones*** | | |
| *f,sf* | 0.001552 | 0.001939 |
| *f,fa* | 0.000833 | 0.001041 |
| *f,ag* | 0.001756 | 0.002195 |
| *f,o* | 6.77E-05 | 8.47E-05 |
| *sf,f* | 0.040158 | 0.050197 |
| *sf,fa* | 0.017991 | 0.022489 |
| *sf.ag* | 0.011167 | 0.013959 |
| *sf,o* | 0.001137 | 0.001422 |
| *fa,f* | 0.01081 | 0.013512 |
| *fa,sf* | 0.021861 | 0.027327 |
| *fa,ag* | 0.034899 | 0 |
| *fa,o* | 0.00466 | 0.005825 |
| *ag,f* | 0.00333 | 0.004163 |
| *ag,sf* | 0.016274 | 0.020343 |
| *ag,fa* | 0.0091 | 0 |
| *ag,o* | 0.009956 | 0.012445 |
| *o,f* | 0 | 0 |
| *o,sf* | 0 | 0 |
| *o,fa* | 0 | 0 |
| *o,ag* | 0 | 0 |

* Mean was scaled relative to the difference observed between Mature forest and secondary forest in the Moist Tropical Forest, in proportion to the mean obtained for the mature forest of the same life zone.

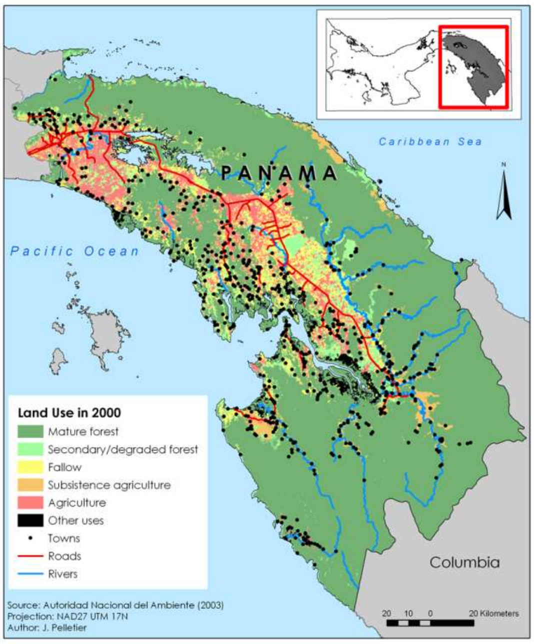
† SD is calculated as proportional to the SD in mature forest for the same life zone.
‡ The mean and SD used was calculated from all available fallow inventory data from the FRA (2005).
§Mean was estimated according to the difference observed between Moist Tropical forest and Premontane Moist forest, in proportion to the mean obtained for the mature forest in the Tropical Dry Forest

¶ SD was calculated in proportion to SD found in mature tropical dry forest.
|| Mean was estimated relative to difference observed between mature and secondary forest in the tropical dry life zone, in proportion to the mean obtained for the mature forest of the same life zone. .

** SD was calculated in proportion to SD found in secondary tropical dry forest




S4. Area covered by the scenarios of deforestation reduction CBMAP II, Palo Seco & Darien, and SINAP scenarios. The Palo Seco & Darien scenario covers the same area as the CBMAP II, though the area was selected randomly on a per pixel basis in the Darién biogeographical region (pixel of 100 m per 100 m).




S5. Population centroids located in the Darién biogeographical region in proximity of mature forests in 2000 and accounted for in the Replication of Ipetí-Emberá project scenario.

# METODOLOGIA

Regresar

- Recopilación de información topográfica y temática para apoyar la clasificación de imágenes

Se recopilaron documentos escritos, fotográficos y cartográficos los cuales sirvieron como guía y soporte para el análisis digital previo de las imágenes de satélite.

A nivel topográfico se tomó como base, el mapa general 1:250,000 del Instituto Geográfico Nacional "Tommy Guardia", actualizado al año 2000 en formato convencional, el cual fue escaneado por el proyecto, para tenerlo en formato digital; a la vez, se adquirió la base de datos del mismo mapa editado por la empresa EoN System, S.A.. El Departamento de Información Ambiental de la Dirección de Evaluación y Ordenamiento Ambiental de la ANAM, facilitó todos los mapas escaneados 1:50,000 principalmente aquellos mapas donde están comprendidas las Áreas Protegidas del país.

A nivel forestal se utilizaron los inventarios forestales de: La Yeguada, Donoso, Alto Chucunaque, Manglares de Chiriquí, Azuero, y Chame, Registros de Plantaciones forestales, así como el mapa de cobertura boscosa de 1992, y el mapa de Vegetación del año 2000, El mapa de distribución de Catvales del Proyecto Cativales OIMT/ANAM y el mapa Uso Actual de la Tierra, 1997 del Programa de Desarrollo Sostenible de Darién.

- Digitalización Mapa Base y áreas protegidas

Se digitalizó y actualizó en base a las imágenes de satélite la red de drenaje, costas, límites de distritos, provincias y comarcas ya que estos detalles principalmente del área oriental no coincidían con las imágenes georeferenciadas tomando en cuenta que estas imágenes son la base principal de este estudio.

Se digitalizó a escala 1:50,000 en pantalla, utilizando el AutoCad R-14 todas las áreas protegidas tomando en cuenta la descripción de cada una de ellas según lo establecido en Leyes, acuerdos o reglamentos que las crea, posteriormente fueron convertidas en formato Shape File del programa ARCVIEW para elaborar el producto final.

- Selección y obtención de imágenes de satélite

Se realizó un inventario de las imágenes de satélite existentes en diferentes instituciones u ONG's (Autoridad Nacional del Ambiente (ANAM), Autoridad del Canal de Panamá (ACP), Asociación Nacional de la Conservación de la Naturaleza (ANCON)). Seguidamente se solicitó la adquisición de las imágenes de satélite actualizadas al verano del 2000 - 2001 tomando en cuenta aquellas que tuvieran porcentajes bajos de nubes (de 5% a 10%) y que las mismas tengan todas las bandas: para las LANDSAT TM5 (Siete bandas) y para la LANDSAT TM7 (ocho bandas). con una resolución de 25m x 25m por píxel (650 m² de superficie interpretable. (Véase cuadro 1).

- Georeferenciación de las Imágenes de satélite

Al terminar el proceso de selección y adquisición de las imágenes se procedió la entrada de los datos utilizando el Software ERDAS IMAGINE, utilizando la extensión Img.

Para que los elementos del terreno captados por el sensor estuvieran la misma posición en las imágenes, se procedió a la georeferenciación de las mismas, tomando en cuenta los mapas topográficos 1:50,000; en áreas donde no existe mapa topográfico se utilizó una imagen de Radar previamente georeferenciada y verificada esta georeferenciación en campo con GPS. Para cada escena de imagen se localizaron aproximadamente 120 puntos claramente identificables en la imagen y en el mapa topográfico uniformemente distribuidos sobre todo el territorio cubierto por las imágenes. Una vez georeferenciadas todas las imágenes, se procedió a elaborar un mosaico digital de las imágenes que se utilizaron para la elaboración del mapa. (Véase mosaico digital).

- Determinación de las categorías de cobertura boscosa y uso del suelo

Para definir la clasificación de los bosques y uso del suelo para analizarlos en las imágenes de satélite, se realizó una serie de consultas con personal de la ANAM (Servicio Nacional de Desarrollo y Administración Forestal, del Sistema Nacional de Áreas Protegidas de la ANAM) y personal del proyecto donde se presentaron y discutieron propuestas sobre las categorías del bosque y uso del suelo que debería contener el mapa a generar, tomando en consideración la respuesta espectral de las mismas. Las categorías definidas y consensuadas por el personal antes mencionado, fueron las siguientes:

Bosque natural (Bn): Es toda formación boscosa con una estructura cerrada, constituida por especies leñosas y no leñosas, arbóreas, arbustivas, herbáceas y otras, formando un conjunto de especies diversas que conviven en un determinado espacio. Se incluyen como bosques naturales los bosques maduros o primarios, secundarios, intervenidos y los manejados. (*Basado en el Reglamento de la Ley Forestal, resolución J.D. 05-98 del 22 de enero de 1998*).

1. Bosque maduro (Bm): Son formaciones cerradas constituidas predominantemente de especies propias de la fase final de la sucesión ecológica, poseen estratos verticales diferenciados con un dosel superior continuo, debajo del cual aparece un sotobosque igualmente diferenciado. Para los bosques del país bajo condiciones normales la cubierta de árboles y del sotobosque es mayor al 80%. Bajo esta definición se incluyen también los bosques clasificados por algunos investigadores como *bosques primarios* Estosbosques naturales comprenden aquellos donde los procesos de intervención, alteración y fragmentación no han tenido influencia antropogénica visible.

2. Bosques secundarios maduro (Bsm): Son formaciones naturales cerradas. La vegetación se encuentra en estado de sucesión secundaria, producto de la remoción completa o parcial de la vegetación primaria, debido a causas antropogénica o naturales. Estos bosques genéricamente comprenden diferentes etapas de sucesión vegetal que van desde formaciones tempranas, hasta bosques secundarios tardíos.

3. Bosque intervenido y/o secundarios (Bi): Son formaciones naturales cerradas, con alteraciones visibles y no visibles, en la cobertura de copa, estructura y composición del bosque causada por la intervención humana o por fenómenos naturales. Estos bosques pueden ser homogéneos y mixtos (La clasificación se fundamenta básicamente en criterios de experto, más que en parámetros definidos)

Bosque de Orey (BO). Son formaciones naturales cerradas. Con predominancia de la especie Orey (*Camphosperma panamensis*). Dicha predominancia es mayor al 60%. Son bosques típicos de las zonas inundables del Litoral Atlántico.

4. Bosque de Orey homogéneo (BOh): Cuando la especie presenta una dominancia mayor al 60 %.

5. Bosque inundable mixto (BOm): Superficie de terreno que se encuentran inundables todo el año y presentan diferentes especies arbóreas, arbustivas, ratreras y herbáceas sin el predominio de una de ellas.

6. Bosque de Cativo (Bc): Son formaciones naturales cerradas. Con predominancia de la especie Cativo (*Prioria copaifera*). Estas formaciones crecen y se desarrollan en sitios inundables y secos del Bosque húmedo Tropical (BhT), aspectos que condicionan su dominancia y de acuerdo al porcentaje de representación se establecen claramente dos tipos.

7. Bosque de cativo mixto (Bcm): formaciones naturales cuando el bosque cuando el bosque se encuentra mezclado con otras especies, donde la predominancia del cativo es inferior al 60 %. Se dan con mayor frecuencia en sitios secos.

8. Bosque de cativo homogéneo (Bch): Cuando la especie presenta una dominancia mayor al 60 %. Se dan con mayor frecuencia en sitios inundables.

9. Manglares (M): Son formaciones naturales cerradas. Conformadas por diferentes especies arbóreas que se desarrollan en zonas costeras y reciben la influencia del agua salada por períodos cortos, producto del flujo y reflujo de las mareas. Estos ecosistemas reciben la denominación de "Humedales".

10. Plantaciones forestales (Plf): Formaciones boscosas constituidas por una o más especies arbóreas nativas o exóticas, establecidas mediante plantación o siembra. La FAO define las plantaciones forestales como "rodales establecidos mediante plantación y/o siembra en el proceso de forestación o reforestación". Pueden ser de especies introducidas (todos los rodales plantados) o rodales de especies autóctonas sujetos a un manejo.

11. Rastrojos: Son formaciones naturales cerradas, cuyo estado de sucesión secundaria se encuentra en una etapa inicial de desarrollo. Se encuentran plantas de tipo herbáceos, bejucos, arbustos y las especies presentes no tienen gran valor comercial, pero ejercen funciones de mejoramiento de suelos y generan las condiciones ambientales necesarias para la colonización de especies propias de etapas más avanzadas. Las especies son de crecimientos rápidos, con un dosel superior denso y homogéneo. Estos bosques se denominan también como bosques

pioneros y de acuerdo con las normas legales son formaciones menores a 5 años de edad.

12. Uso agropecuario (Agr): Todas aquellas áreas que son utilizadas paracultivos agrícolas anuales, semi permanentes o permanentes y pastoreo, al igual que áreas cubiertas de herbazales, rastrojos e incluso algunos remanentes boscosos dispersos.

13. Uso Agropecuario de Subsistencia (UAS): Son áreas utilizadas para actividades agrícolas y pecuarias de subsistencia, que incluyen áreas cubiertas de rastrojos y remanentes boscosos dispersos. Estas se ubican principalmente a orilla de los ríos, caminos de penetración y en los polos de colonización.

14. Vegetación baja inundable (Vbi): Es aquella vegetación dominada por especies herbáceas (heliconias, cortaderas, bejucos, etc), y palmas, que puede incluir pequeñas áreas cubiertas de rastrojos y remanentes boscosos dispersos, la cual se encuentra en áreas planas cubiertas de agua dulce o salobre la mayor parte del año. En algunos lugares se les conoce con el nombre de "pantano" "laguna" o "swampo".

15. Albinas (Alb). Es un área plana o semiplana, se ubica cerca de la costa y son bañada por las mareas. La vegetación es escasa, producto de la alta concentración de sales, generalmente se encuentran especies de mangles y de tipo arbustivo.

16. Otros Usos (Ous): Son aquellas áreas pobladas de tipo urbanas, semiurbanas y urales, industriales, mineras, salinas, camaroneras y suelos desnudos.

**Observaciones**

Todos los bosques naturales del País son latifoliados, existiendo muy pocas formaciones naturales discontinuas o con bajos niveles de cobertura de copa. En términos generales, la cobertura de copas para todos los tipos de bosques es superior al 70%. Para bosques secundarios muy jóvenes o rastrojos, este porcentaje podría ser inferior en zonas de bosque seco tropical (bs-T), *Gutiérrez, R. 2000. Clasificación de Bosques en la República de Panamá.*

- Manipulación y despliegue de las imágenes

  - Despliegue de las imágenes: con el módulo de visualización del programa ERDAS se realizó el despliegue de las imágenes banda por banda, para proceder a su análisis.

  - Selección de áreas de interés de las imágenes: para la selección de las áreas de estudio se utilizó el módulo AOI (áreas de observación de interés) de ERDAS para delimitar el área seleccionada de cada escena

  - Creación de máscaras de áreas no deseables en las imágenes: este proceso se basó en crear una imagen binaria que contiene valores de 1 y 0; donde 1(uno) fueron las áreas de interés (áreas que fueron clasificadas) y 0(cero) áreas cubiertas de nubes, mar y otros sectores que excluimos de la clasificación digital en la imagen.

- Análisis y realces de las imágenes:

  - Revisión de histogramas: La revisión del histograma permitió deducir el contraste presente en las imágenes, donde la presencia de picos en el histograma indicaron las determinadas clases de coberturas en las imágenes. Con esta revisión fue posible deducir si habían bandas que necesitaban comprensión del contraste y expansión para mejorar su resolución.

  - Realce de las imágenes: se mejoró la calidad visual de la imagen con la finalidad de realzar los contrastes de los datos para su análisis digital y visual, de tal forma que, fueran más evidentes los rasgos de interés que presentaba cada imagen.

  - Creación de Composiciones a color (Verdadero y Falso Color): A partir de la información multiespectral que generan los sensores espaciales, se puede obtener distintas composiciones de color; aplicando cada uno de los tres colores primarios (azul, verde, rojo) a una banda distinta de la imagen; este proceso permite visualizar simultáneamente imágenes de distintas regiones del espectro, lo que facilitó la delimitación visual de algunas coberturas. Para elaborar el mapa de cobertura boscosa y uso del suelo se utilizaron las combinaciones de bandas 4,5,3 / 4,5,7 para falso color infrarrojo, para discriminar las diferentes coberturas vegetales y resaltar las características estructurales del terreno

- Aplicación del Índice de Vegetación: Este Índice permitió discriminar las áreas cubiertas con vegetación y suelos desnudos o con vegetación escasa.

- Clasificación digital de las imágenes

La clasificación digital no busca una definición absoluta de cada cubierta que puede ser aplicable a cualquier imagen sino mas bien, una caracterización particular, válida para una determinada imagen y un área concreta.

Se definió con rigor cada una de las categorías que se discriminarían teniendo en cuenta la propia variabilidad en la zona de estudio; por lo que se seleccionó una muestra de pixeles de la imagen que representaban adecuadamente a las categorías de interés.

Se aplicó una clasificación no supervisada (no necesita conocimiento del área de estudio) donde se procedió a realizar una búsqueda automática de grupos de valores homogéneos dentro de la imagen. Posteriormente, se aplicó la clasificación supervisada (conocimiento previo del terreno), a partir del cual se seleccionaron muestras para diferentes categorías, lo que complementó el análisis final.

Para este proceso se utilizó composiciones a color 4,5,7; 4,5,3 y 4,5,2 tratadas por índices o cocientes de vegetación, componentes principales y filtros que realzan los diferentes rasgos de la imagen. También se aplicó máscaras para separar áreas de interés que presentaban características significativas.

La respuesta espectral de las Plantaciones forestales (Teca, principalmente) no es reflejada en las imágenes debido a que éstas son tomadas en su mayoría en verano, ya que en esta época del año la teca es caducifolia). Para poderlas clasificar se levantó en campo a través del GPS todos los polígonos de las plantaciones mayores de 50Ha. y así sobreponerlas en la imagen clasificada.

- Verificación de campo

Los resultados de la clasificación digital y visual fueron comprobados en el campo por medio de giras a sectores que presentaron dificultades en la clasificación. Las áreas que mostraron diferencias con las clases resultantes, se procedió a capturar las coordenadas de estos puntos con el GPS y se tomaba foto de los mismos. Además se realizaron sobrevuelos en el área de Donoso, Chepo, Cuenca del Canal para verificar la imagen clasificada con respecto a la realidad.

Estos datos fueron utilizados para realizar las correcciones de la clasificación original de las imágenes.

- Reclasificación o agrupamiento de clases y filtrado de la imagen clasificada

Se procedió a corregir la imagen clasificada con los datos tomados en el campo, reclasificando las clases según las observaciones de campo, posteriormente se aplicó un filtrado para generalizar polígonos demasiados pequeños.

- Vectorización automática de la imagen clasificada corregida

La vectorización fue la transferencia de datos tipo raster o imagen a un dato tipo vectorial o de polígonos. Este proceso se realizó utilizando el programa ERDAS

- Cuantificación de las diferentes categorías que contiene el mapa de cobertura boscosa y uso del suelo

Los datos numéricos de superficie de las diferentes categorías de coberturas analizadas en las imágenes de satélite fueron obtenidos mediante análisis y cálculos automatizados utilizando el software ARCVIEW 3.3 y se sobrepuso la división política (provincias, distritos y comarcas) generadas por el proyecto para obtener la superficie de cada categoría de cobertura boscosa y uso del suelo por distrito y provincia.

Regresar

Subir Top

Para calcular la superficie ($Km^2$) de cobertura boscosa a nivel nacional (por distrito y provincia) se sumaron las siguientes categorías:

- Bosque Maduro
- Bosque Secundario joven
- Bosque de Cativo homogéneo

- Bosque de Cativo mixto
- Bosque de Orey homogéneo
- Bosque Inundable mixto
- Plantaciones
- Manglares.

El mapa fue elaborado en ARCVIEW 3.3 a escala 1:250,000 (comprende 12 hojas) generando una base de datos, complementada con una base planimétrica (red vial, drenaje, poblaciones, límites de provincias, distritos y comarcas) y áreas protegidas

Para calcular la superficie de cobertura boscosa y uso de suelo en todas las áreas protegidas del país, se sobrepuso los límites de cada área, al mapa de cobertura boscosa y se procedió a realizar los cálculos de cada cobertura, determinando así, la superficie boscosa en cada área protegida.

El mapa de cobertura boscosa y uso del suelo: 2000 estará a la disposición de todas las Direcciones Nacionales de la Autoridad Nacional del Ambiente, así como a cualquier usuario que tenga a bien requerido

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