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APPLICATION OF THE 'CLIMAFOR' APPROACH TO ESTIMATE BASELINE CARBON EMISSIONS OF A FOREST CONSERVATION PROJECT IN THE SELVA LACANDONA, CHIAPAS, MEXICO

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Abstract. We present a methodology for testing and applying a regional baseline for carbon (C) emissions from land-use change, using a spatial modelling approach (hereafter called the Climafor approach). The methodology is based on an analysis of causal factors of previous land-use change (Castillo et al. 2005). Carbon risk matrices constructed from the spatial correlation analysis between observed deforestation and driving factors (Castillo et al. 2005), are used to estimate future carbon emissions within acceptable limits for a forest conservation project. The performance of two risk matrices were tested by estimating carbon emissions between 1975 and 1996 from randomly selected sample plots of sizes varying from 1,600 to 10,000 ha and comparing the results of the observed emissions from these sample plots with the model estimations. Expected emissions from continued land-use change was estimated for the community applying the risk matrices to the current land cover. The methodology provides an objective means of constructing baseline scenarios including confidence intervals, using the sum of variances of the various data sources, such as measured carbon densities, classification errors, errors in the risk matrices, and differences between the model prediction and observed emissions of sample plots due to sample size. The procedures applied in this study also give an indication of the impact of the variance in the various data sources on the size of the confidence intervals, which allows project developers to decide what data sources are essential to improve his baseline. The modelling approach to estimate the deforestation pattern is based on readily available cartographic and census data, whereas data on carbon densities are required to assess the potential for forest conservation projects to offset carbon emissions.

Keywords: baselines, carbon emissions, deforestation, forest conservation, Mexico, risk matrices

1. Introduction

Assessments of the greenhouse gas benefits of forest conservation projects requires the construction of so-called 'baseline scenarios' that describe the future status of the terrestrial carbon stocks in the absence of a project. However, no standard methods currently exist to estimate the baseline scenario and pilot projects that currently receive carbon (C) credits from avoided deforestation have used a number of different approaches:

- Extrapolation into the future of past trends – e.g. the Norway-Costa Rica AIJ project in the upper Virilla river basin. The baseline assumed that a local deforestation rate of 7.5% of between 1986–1992 would continue between

1997 and 2021 (UNFCCC 2000). An average estimated deforestation rate of 7.5% seemed overstated, because the overall deforestation rate in the same time period rounds 3.2% and deforestation is constantly declining (Dutsche 2000).

- Hypothetical future scenarios – e.g. the Rio Bravo Conservation Management Area, Belize. The baseline is defined by the intent of key stakeholders to purchase the land for conversion to agriculture (Stuart and Moura Costa 1998).
- Prevailing technology or practice – e.g. the ICSB-NEP reduced impact logging project in Malaysia. The baseline assumes that current logging practises would continue without intervention (Stuart and Moura-Costa 1998).
- Simple logical arguments based on adjusting observed trends; quantification of baseline carbon done in proxy areas (Brown et al. 2000).

Many analysts consider the development of methodologies for setting baselines for forestry projects as the most difficult task in drafting rules for the UN Framework Convention on Climate Change (UNFCCC) Kyoto Protocol Clean Development Mechanism (CDM). The existing methods of setting baselines for forest conservation projects in developing countries, such as the examples cited above, often either fail to capture regional variation in the causes of carbon emissions, or are not based on scientific and objective methodologies. None of the methods allow an objective assessment of whether the baseline is appropriate to the area in question or provide a measure of how accurate the prediction is likely to be. Extrapolation of past trends without taking into account spatial variation can cause overestimation or underestimation in the projection of future deforestation trends in the specific project area, as pointed out by Dutsche (2002) for the Virilla river basin project in Costa Rica. Hypothetical future scenarios can take account of local details in land-use patterns but are very hard to standardise and could be abused by those seeking to over-state project benefits (Tipper and De Jong 1998). The assumption that current practises will continue into the future does not take into account political and financial pressures to improve management practises (e.g. low-impact logging technologies, changes in forest legislation) that could also have an impact on carbon emission reductions.

To provide credible emissions reduction units through the conservation or management of forests, verifiable, evidence-based procedures are required to set acceptable baselines. As there is often significant variation in the socio-economic conditions within any region, any standardized approach should take into account regional trends and variations in land use and local differences in the way that rural communities manage their resources. An objective means of assessing the accuracy of a proposed baseline is also required to calculate confidence intervals of predicted future emissions so that allowable future baseline emissions can be set conservatively at the lower level of the confidence interval. Errors in data sources have to be identified and quantified, which in turn will give the project developer insight in what additional information sources are most effective to reduce the level of uncertainty in baseline emission estimations.

Spatial statistical models are considered very appropriate to identify and evaluate the relationship between deforestation and spatially-explicit explanatory variables such as accessibility and pressure on land (e.g. Chomitz and Gray 1995; Cropper et al. 2001; Deininger and Minten 1996; Mamingi et al. 1996; Mertens and Lambin 2000; Nelson and Hellerstein 1997). These models are well suited for predicting where deforestation will occur and generally involve large samples and reasonably reliable data (Mertens et al. 2002). While such models say little about what tools are likely to be effective in preventing deforestation (Cropper et al. 2001), they suggest where deforestation will likely take place in the future if the spatially explicit conditions remain similar.

In this study we illustrate an approach (hereafter called the 'Climafor' approach) that calculate the allowable baseline emission applicable for a forest conservation project, submitted to the Scolel Té trust fund in Chiapas, Mexico. The spatially explicit models that we test in this paper were developed as a standardized baseline approach for an area of 2.7 million ha in southern Mexico (Castillo et al. 2005). The models constructed by Castillo et al. (2005) are correlation-type models whose dependent variable is deforestation in a particular polygon during the time period considered. The independent variables that delimit the polygons are variables that define the accessibility to- and pressure on land.

2. Methods

2.1. MODEL SELECTION

The analysis presented here employs data from an analysis of the causal factors of land-use change and C emissions between 1975 and 1996 for an area of 2.7 million ha in the northeast of Chiapas, southern Mexico (Castillo et al. 2005). The study identified three causal factors that were closely correlated to the observed land-use change (Table I). A detailed description of the study area and the relationships between the selected factors and land-use change are given in Castillo et al. (2005). In this paper we use their results to calculate the future C emissions of the community land that encompass the forest conservation project area.

Deforestation rate matrices were constructed, with one axis comprised of the most important factor determining the accessibility and one axis the main factor determining the pressure on land (Table I). The vulnerable C densities and their 95% confidence intervals of the compound land use classes were used to calculate the C emissions associated with the deforestation (Table II). Each matrix combined three categories of the accessibility factor (in this case closeness to roads and agricultural land) and four categories of pressure on land (density of population active in the primary sector), giving a total of 12 categories of deforestation and

TABLE I

Causal factors of land-use change applied in the analysis.

Causal factor	Definition	Categories
	Accessibility factors	
Distance of forest from roads (DistRd)	Distance from paved and unpaved roads built up to the end of the 1980s (1:50,000 road maps)	0 to 1000, 1000 to 7000, 2000, $>$2000 m
Distance of forest from agriculture (DistAg)	Distance from agriculture, pasture and disturbed land; in 1975 and 1997 (INEGI 1984, 1987, 1988; classified satellite images)	0 to 500, 500 to 1000, $>$1000 m
	Pressure factor	
Farmer density (PopDens)	Population whose primary occupation in 1990 was farming (INEGI 1991)	0, 0 to 15, 15 to 30, $> 30/\text{km}^2$

TABLE II

Vulnerable C-densities (95% Conf. Intervals; from Castillo et al. 2005).

Vegetation type	Vulnerable carbon (tC ha^{-1})
Tropical region	
Non disturbed Forests	222.2 (± 9.9)
Disturbed Forest	100.0 (± 24.3)
Agriculture	0
Temperate region	
Non disturbed Forest	121.9 (± 19.7)
Disturbed Forest	56.6 (± 11.2)
Agriculture	0

related C emissions in each model (represented by the 12 cells of the matrix). Two models were tested: distance to roads combined with population density (hereafter called DistRd-PopDens); and distance from agriculture combined with population density (DistAg-PopDens). For each category in the matrix, the historical loss of forest between 1975 and 1996 and the 95% confidence interval was used as the input values (Tables III and IV). Each model was parameterised with data derived from approximately 75% of the 2.7 million ha study area, and validated with

TABLE III

DistAg-PopDens Risk matrix, expressed in % deforestation between 1975–1996, including the 95% confidence intervals.

PopDens	DistAg (m)		
(hab/km^2)	0–500	1500–1000	>1000
>30	65.2±2.4	54.1±2.8	51.3±3.1
>15–30	58.2±2.2	49.1±2.4	43.1±2.7
>0–15	56.2±2.5	46.8±2.8	40.5±3.5
0	50.8±4.7	38.3±5.1	29.9±4.4

TABLE IV

DistRd-PopDens Risk matrix, expressed in % deforestation between 1975–1996, including the 95% confidence intervals.

PopDens	DistRd (in m)		
(hab/km^2)	0–1000	1000–2000	>2000
>30	59.7±3.2	51.5±3.0	42.7±9.9
>15–30	53.1±2.3	46.1±2.4	40.7±5.9
>0–15	48.6±2.6	38.1±2.4	29.4±3.3
0	38.8±4.0	28.8±3.1	25.7±4.5

the remaining 25% (see for details Castillo et al. 2004). The difference between the estimation and validation outcome was included in the compound measure of variance.

Maps of the spatial distribution of the matrix categories of each model were created in a Geographic Information System (GIS). An example of the DistRd-PopDens model map at the scale of the study area is given in Figure 1.

2.2. TESTING MODEL PERFORMANCE

The applicability of each model to projects of different extend was tested by applying the DistRd-PopDens and DistAg-PopDens matrices to ten randomly selected plots across the Selva Lowland region (Figure 2). The spatial distributions of the 12 risk categories of each matrix were mapped in each sample unit. These maps were then intersected with the 1975–1996 vegetation-change map and total expected deforestation and associated carbon losses for 1975 to 1996 were calculated for each category in the matrix. The results were then compared to observed deforestation

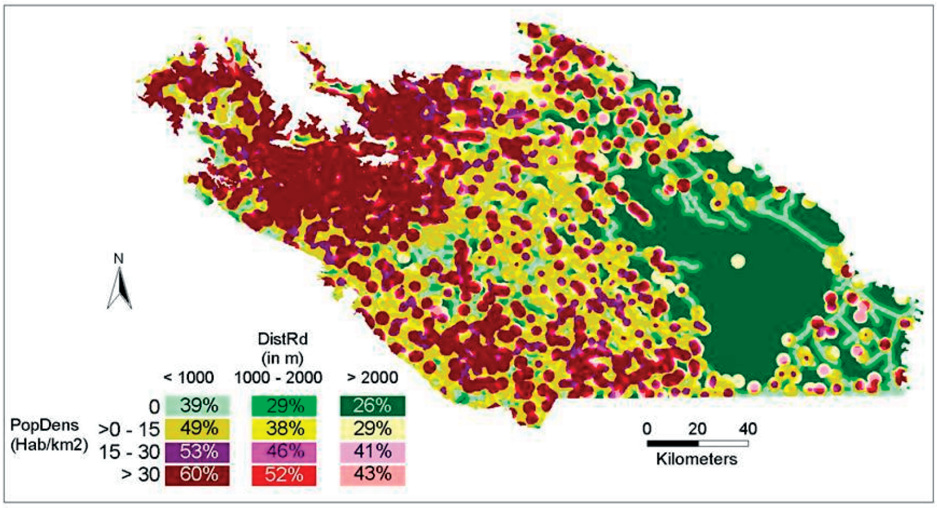

Figure 1. Deforestation risk map, based on distance to roads (DistRd) and population density (PopDens).

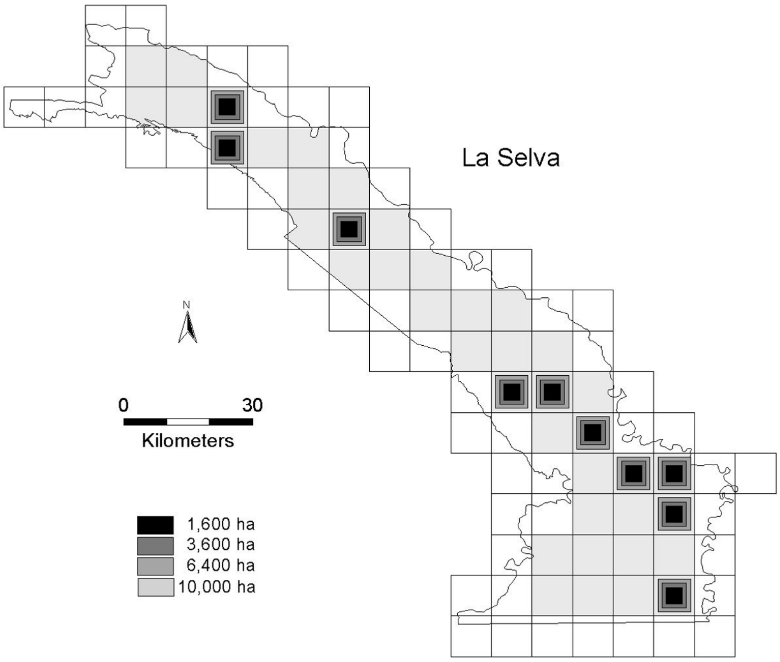

Figure 2. Spatial distribution of 10 × 10 km grid cells for the Selva lowland region, with 10 randomly selected samples of 1,600, 3,600, 6,400, and 10,000 ha nested grid cells.

rates and associated C losses over the same period. The error for each model was expressed as: observed loss of C as a percentage of total vulnerable C stock minus expected loss of C as percentage of total vulnerable C stock. The performance of the model was assessed at four spatial scales: 1,600 ha, 3,600 ha, 6,400 ha, and 10,000 ha. The size of the smallest sample unit (1,600 ha) was chosen to reflect the area of a typical community forest project. The error, therefore, gives an indication of what level of accuracy might be expected if the models are used to predict future C emissions at this scale. Errors from the application of the models to the 10,000 ha area gives an indication of accuracy of predictions at the scale of a larger forest management or conservation project.

2.3. APPLICATION OF THE MODELS TO PREDICT FUTURE EMISSIONS

To illustrate the application of the Climafor approach for project baseline construction, the matrices were used to predict emissions for the next 10 years by overlaying a map of current (1997) vegetation and carbon density with the risk maps generated from each model (Figure 3). The site used to demonstrate the methodology was La Corona, a community of approximately 2,200 ha located in Marques de Comillas, which submitted a proposal to conserve part of their community forest within the framework of the Scolel Té International Carbon Sequestration project. Land-use data from 1997 were available for this community and predicted emissions from 1998 to 2007 were calculated, applying both the DistRd-PopDens and DistAg-PopDens matrices.

2.4. ERROR ESTIMATION

In order to estimate the allowable amount of baseline C emissions for the conservation project, we calculated the lower level of the confidence interval by subtracting the compound error, composed of the square root of the sum of the squares of all coefficients of variance of the data sources (expressed in percentage of their mean). In formula:

$$U_{total} = \sqrt{U_i^2} \tag{1}$$

where U_i is the percentage variance U in data sources i: variances in measured carbon densities, classification errors, variances in the deforestation rates of the risk matrices, and differences between the model prediction and observed emissions of sample plots of different size.

As all variances were calculated with 95% probability, the lower level of the confidence interval gives the expected minimum future emissions that will occur with 95% probability (Schlamadinger and Marland 2000). We used this lower level of the confidence interval to set the threshold of the allowable baseline emissions for the conservation project. The model that predicts the lowest baseline emission is selected as the final allowable baseline emission for the community. We consider

TABLE V

Vulnerable carbon stock in La Corona by vegetation type in 1997.

Vegetation type	Area (ha)	Vulnerable carbon (t)
Forest	1,823	405,140±18,051
Disturbed forest	12	1,219±296
Secondary shrub vegetation	278	0
Agriculture	7	0
Pasture	148	0
Settlement	8	0
Total	2,277	406,359±18,347

this as the most conservative procedure that includes any risk associated with the uncertainty in the applied data at the scale of the application.

3. Results

3.1. CURRENT VEGETATION AND VULNERABLE CARBON DENSITIES OF THE PROJECT SITE

In 1997 the community contained 1,823 ha of closed rain forest, 12 ha of disturbed forest, 278 ha of shrub vegetation and 163 ha of open land, with a total amount of 406,359 ± 18,347 Mg of vulnerable C that is susceptible to disappear soon after forest conversion (Table V). The 1997 vegetation map was overlain with the DistRd-PopDens and DistAg-PopDens risk maps (Figure 3) to calculate the expected future C-emissions over the next 10 years. The expected loss of C over the next 10 years would be 79,722 tC applying the DistAg-PopDens matrix and 57,381 tC for the DistRd-PopDens matrix (Tables VI and VII).

3.2. SOURCES OF VARIANCE IN THE DATA

The absolute difference in average deforestation rate in the validation area derived from the DistAg-PopDens risk matrix and the observed rate varied between 0 and 6% and those derived from the DistRd-PopDens matrix between 0 and 9% (Castillo et al. 2004).

The absolute difference between the regional deforestation rates and the rates derived from the 1,600 ha sample plots varied between 7.1 and 26.7% for the DistAg-PopDens matrix and between 4.4 and 30.3% for the DistRd-PopDens model (Table VIII).

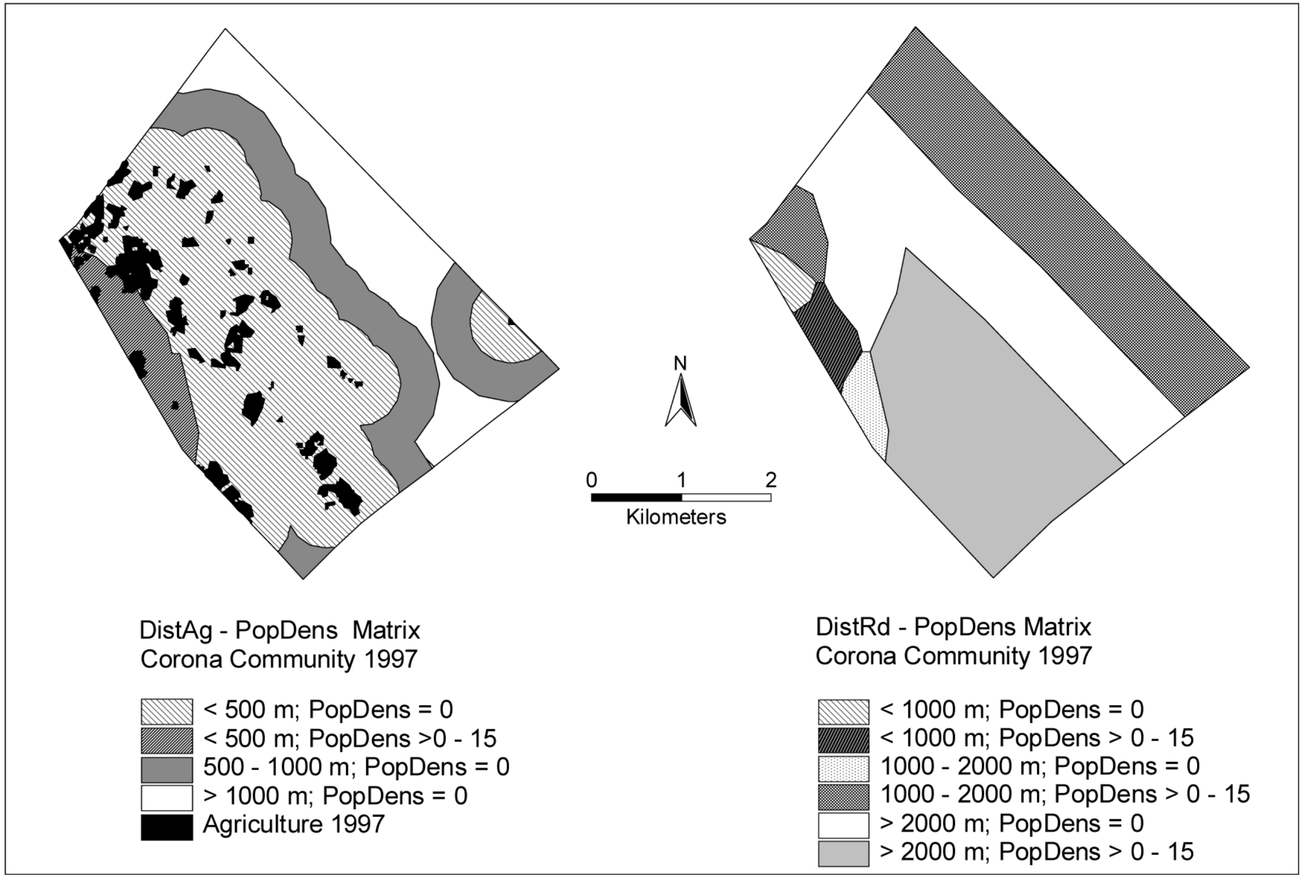

Figure 3. DistAg-PopDens and DistRd-PopDens risk maps for La Corona community.

TABLE VI

Estimated and allowable baseline emissions from deforestation between 1998–2007 (tC) for the La Corona community, based on the DistAg-PopDens matrix and total compound error.

		Estimated emissions (in tC)		Total error (in %)		Allowable emissions (in tC)		
	PopDens	>0–15	0	>0–15	0	>0–15	0	Total
DistAg	<500 m		50,624	25.3%	22.2%	4,095	39,385	43,480
	500–1000 m	0	18,028	27.7%	30.0%	0	12,619	12,619
	>1000 m	0	11,071	24.2%	31.7%	0	7,561	7,561
	Total	5,482	79,722			4,095	59,566	63,661

TABLE VII

Estimated and allowable baseline emissions from deforestation between 1998–2007 (tC) for the La Corona community, based on the DistRd-PopDens matrix and total compound error.

		Estimated emissions (in tC)		Total error (in %)		Allowable emissions (in tC)		
	PopDens	>0–15	0	>0–15	0	>0–15	0	Total
Dist	<1000 m	800	23,067	26.5%	21.5%	588	18,107	18,696
	1000–2000 m	1,540	18,535	21.3%	22.2%	1,212	14,420	15,632
	>2000 m	1,180	15,780	22.7%	34.0%	912	10,414	11,326
	Total	3,520	57,381			2,712	42,942	45,654

We estimated the overall error in the classification of the satellite images at around 10% for all classes (Castillo et al. 2004). We used the area-weighted variance in vulnerable carbon densities (Table II). The compound percentage in variance of the land use classes present in La Corona varied between 22.2 and 31.7% in the DistAg-PopDens matrix and between 21.3 and 34.0% in the DistRd-PopDens matrix (Tables VI and VII).

3.3. ALLOWABLE BASELINE CARBON EMISSIONS FROM THE PROJECT AREA

The total compound variance expressed in percentage can be considered as the level of uncertainty in all data sources combined. Subtracting this percentage from the amount of carbon that is susceptible to disappear between 1998 and 2007 would

TABLE VIII

Difference between de average deforestation rate from 10 random sample areas of 1,600 ha each and the regional model estimates according to DistAg-PopDens and DistRd-PopDens matrices.

		Distance from agriculture (m)		
		<500	500–1000	>1000
Population density (/km^2	>30	–19.8%	–26.7%	18.0%
	15–30	–21.9%	–11.2%	23.7%
	0–15	–16%	–19.4%	12.5%
	0	–7.1%	–19%	20.8%
		Distance from roads (m)		
		<1000	1000–2000	>2000
Population density (/km^2	>30	+4.4%	–5.2%	–22.5%
	15–30	–9.9%	–26.1%	–30.3%
	0–15	–17.6%	–8.4%	–7.3%
	0	+1.6%	–5.6%	–20.7%

result in a conservative estimate of the C emissions, if conditions continue into the future. This result in total allowable baseline emission estimations of 63,661 tC applying the DistAg-PopDens matrix (Table VI) and 45,654 tC for the DistRd-PopDens matrix (Table VII). The DistRd-PopDens gives the lowest estimate of future emissions if given conditions continue and is thus considered as the final allowable baseline emission quota for the community over the next 10 years. Any verified future reduction in this baseline emission ceiling can thus be considered as additional.

4. Discussion

To establish baselines for avoided deforestation, without doubt the greatest – and most critical – challenge is the formulation of acceptable guidelines that will allow calculating conservative future reference emissions. It is these baselines, which will serve as the mechanical means of determining 'additionality' of emissions reductions and of qualifying them as 'surplus' for purposes of offsetting or replacing emission reductions elsewhere. Thus, although the determination of 'what would have happened otherwise' is in part a qualitative inquiry, ultimately, the baseline has to capture the emission consequences in quantitative terms (Stewart et al. 2000). They pointed out that an alternative approach could be to develop performance standards or benchmarks for different types of projects, adjusting the standards to fit local conditions and updating them regularly as methodological refinements are made. In most cases a project can be viewed as a scheme – set in a particular geographical location and within a specific political, economic, social and sectoral context.

Although land use is a difficult sector to predict future trends, it is extremely valuable to have standard procedures to create a sectoral baseline. The challenge in developing and applying such methods for setting baselines will be to develop standard approaches that a wide range of experts, environmental groups, academia and government officials will agree upon. This is to say that they will ensure that carbon mitigation projects only offset emission reductions that are additional and real. The overall goal is to create simplified and efficient baseline-setting standards while not compromising the integrity of the UNFCCC.

There is considerable potential to conserve C stocks through conservation and sustainable forest management activities in Mexico (Masera et al. 1997). Forest management and conservation activities in Chiapas have a high potential to mitigate C emissions at relatively low costs (Tipper et al. 1998; De Jong et al. 2000). If baseline standards could be set that calculate future emissions due to land-use change with the most conservative estimates, this would create an enormous potential to develop forest conservation and management projects in areas such as Chiapas.

In this study we present the Climafor approach for constructing evidence-based regional baseline scenarios through an analysis of the relationship between land-use change and prevailing socio-economic conditions, using readily available cartographic and census data. The approach provides an objective means of selecting the most conservative baseline for an area through an analysis of all sources of error and variance produced when the models are applied to real projects. The results give an indication of what level of accuracy can be expected when these types of approaches are used to predict future carbon losses and can thus be used to set suitable and acceptable C risk buffers around the estimated future emissions. Assigning the most conservative estimation of future emissions as the allowable baseline, will reduce the risks of over-estimating baseline emissions to a minimum.

It should be noted that while this assessment gives an indication of the accuracy of predicting future C emissions, this will depend on the extent that the relationship between deforestation and accessibility and pressure factors observed in the past remain the same for the next years. In areas such as the Highlands where there is little new colonization occurring it may be reasonable to assume that the relationship between deforestation and the causal factors used in the analysis will remain similar long into the future. However, in other areas where in the last decades there have been marked changes in population dynamics, it is possible that observed relationships in the past and the spatial variation in these relationships will change in future. The selection of a model and the period for which the baseline would be applicable to predict C emissions should therefore not solely be based on the results of model performance but should also consider likely changes in land-use patterns in the future. The longer the baseline prediction, the higher will be the error margin. Therefore we selected the future baseline emission timeline for 10 years, as proposed by Dutschke (2002). In the case of Mexico this timeframe is very appropriate, as most data that we used to construct the risk matrices and vegetation maps are readily available every 10 years or less. We suggest that after this period the baseline matrices have to be revised and the new results applied to all projects. If shorter revision periods are considered more adequate, than the modified reference case ought to apply only to new projects. This will balance the interests of investors who want to have a clear idea of their emission benefits with the benefit to the environment of revising baselines in order to avoid over-crediting (SGS 1998).

By providing objective means of constructing baseline scenarios and setting risk buffers based on evidence of causal factors of land use change, uncertainty in and availability of various data sources, the proposed Climafor approach answers many of the questions that were raised in the past, when projects calculated the carbon benefits of conserving existing forests in developing countries.

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