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Carbon and Co-Benefits from Sustainable Land-Use Management

Deliverable 22: Quantification of carbon benefits in conservation project activities through spatial modeling: East Kalimantan, Indonesia as a Case Study

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The goal of this phase of the Carbon and Co-Benefits Initiative project is further refine and test an approach that can be used to estimate the impact of forest protection activities on net greenhouse gas (GHG) emissions. For instance, in many protected areas, the threat of deforestation may be high in some sections, while near zero in others. To estimate the effect of protecting such an area on the net reduction of GHG emissions, it is important to determine the likelihood or risk that a given area will be deforested. Projected rates of deforestation can subsequently be combined with the risk assessment and with estimates of the carbon stocks in the forests to produce estimates of the net GHG emissions that would occur if the area was not protected. The specific goal of the work reported here is to demonstrate this approach to East Kalimantan in Indonesia. The selected study area is one of the four Indonesian provinces in Kalimantan, the Indonesian part of island of Borneo, where large portion of the Indonesian forest is located[2].

To develop a framework for reporting carbon benefits from forest protection activities, a spatial modeling approach of deforestation and quantitative analysis of future modeled deforestation (projected baseline) was used. One of the key motives for using spatial modeling within the scope of carbon projects is that future land use change can be associated with specific forest types and thus carbon stocks. The three specific objectives were: (1) to test different deforestation driver combinations in the spatial modeling process, using statistical validation techniques, to identify the most critical drivers that explain the patterns of deforestation in the study areas; (2) to stratify the threat of deforestation based on the spatial modeling into low, moderate and high threat classes; and (3) to model potential CO_2 emissions from the simulated deforestation in protected areas, under a scenario of no enforcement of protection. Eighteen protected areas exist is East Kalimantan and the baseline CO_2 emissions in all, modeled without protection, were estimated and used to demonstrate how emissions reductions under protection could be quantified.

In this work GEOMOD was used to simulate a transition from forested to non-forested categories in East Kalimantan. The model depicts the location and quantity of the simulated land-use change, or in this case change from forest to non-forest. Geographic Information Systems (GIS) technology (raster base with a 250 m cell size) was used in the two distinct steps in spatial modeling. The first step simulated the existing landscape mosaic in 2003 based on different biophysical, socio-economic and demographic factors. For example, elevation; slope; and distance to already deforested areas, existing roads, rivers, towns and sawmills were used to model the impact of human activities that lead to deforestation. The results show that the factors that trigger deforestation in East Kalimantan between 1995 and 2003 were distance from sawmills, distance from already deforested areas, and elevation. The second modeling step defines areas of future deforestation threat by extrapolating the results from the first step. The third step estimates CO_2 emissions reductions for protected areas if no deforestation would have been allowed within them beyond 2003. We assumed that the protected areas were established to prevent further deforestation. The potential carbon benefits from such an action would be the difference between the baseline emissions and the assumed zero emissions that would result by well-regulated protection.

The result of analysis showed that approximately 135 million t CO_2 would be emitted between 2003 and 2013 from existing protected areas in East Kalimantan if the rate of deforestation of 0.0134 % per year continued unabated. Protected areas would lose approximately 190 thousand ha of their forest area, resulting in greater potential loss of biodiversity in these tropical forests.

The work presented here has four very important outcomes that could guide the USAID, Indonesian Ministry of Forestry and other stakeholders on actions against deforestation. First, the analysis identifies the main proxy driving forces of deforestation in East Kalimantan. Second, the study identifies which protected areas are under high and very high threat and indicates where action should take place to protect these areas. Third, the study estimates the potential CO_2 emissions from the protected areas as a result of not protecting them. Finally, the study identifies areas that would be very important to protect to maximize the carbon benefits of avoided deforestation activities. The study identifies areas that have very high carbon values that are not protected yet and are under high threat for deforestation.

[2] This work reported here is the second such analysis on estimating the impact of forest protection activities on net greenhouse gas (GHG) emissions supported by this cooperative agreement—the first analysis was performed on a region within the Republic of Congo and reported in Deliverable 10, September 2006.

INTRODUCTION

The goal of this phase of the Carbon and Co-Benefits Initiative project is to develop and test an approach used to estimate the impact of forest protection activities on net greenhouse gas (GHG) emissions. For instance, in many protected areas, the threat of deforestation may be high in some sections, while near zero in others. To estimate the effect of protecting such an area on the net avoidance of GHG emissions, it is important to determine the probability that a given area will be deforested (Brown, 2002, 2003; Brown et al., 2007). Likely rates of deforestation can then be applied to areas projected to be under high to medium threat (high potential). These rates of deforestation can subsequently be combined with estimates of the carbon stocks in the forests to produce estimates of the net GHG emissions that would occur if the area was not protected (i.e. baseline emissions). Previous work following this approach has been completed for areas in Belize, Bolivia, Brazil and Mexico (three different states); with support from US EPA and US AID (see Brown et al. 2007),and in the Republic of Congo (Petrova et al., 2006) under this cooperative agreement. To expand the geographic range further, the goal of the work reported here is to demonstrate this approach by applying each of the key steps to a study area in East Kalimantan, Indonesia. This study was carried out in cooperation with the World Resources Institutes (WRI), People and Ecosystem program. WRI has extensive knowledge on forest and forestry processes and monitoring in Indonesia. The analysis uses Geographic Information System (GIS) technology that imparts several advantages over traditional techniques, including spatial analysis of threat distribution, the ability to overlay other spatial data, such as distribution of biomass, critical watershed, and ranges of endangered species to optimize development goals when designating new protected areas.

Indonesian tropical forests are ranked third (behind Brazil and Democratic Republic of Congo) for their unique biological richness. Forest types include dipterocarp forests, widespread across low and mid elevation; tidal forest, such as mangroves, peat swamp forest; and mountain forest. Indonesia’s total land area is approximately 193 million ha, of which 84% was forested in 1950’s (based on Hannibal, 1950). According to the estimates made by National Forest Inventory of Indonesia from 1986-91 satellite data, the total forest area amounts to only 69% of the land area, excluding Java (GOI/FAO, 1997: 17-18). Kalimantan is covered by approximately 32% of the total national forest area, followed by Irian Jaya (29.9 %), Sumatra (20.8%), Sulawesi (9.7%), Maluku (5.5%) and other (2.1%) (GOI/FAO, 1997: 36). This large decrease of forest cover from the 1950s to the late 1980s was due mostly to the rapid growth in the commercial exploitation of forests from mid 1960s to early 1970s. The annual deforestation rate between the 1970s and the 1990s is estimated at approximately 1.2 million ha (Sunderlin and Resosudarmo, 1996). Today Indonesia is losing nearly 2 million ha of its forest every year (FWI/GFW, 2002).

Deforestation in Indonesia is a result of the economical and political system in the country. Over the past 30 years, the country vastly exploited its forest to position itself as one of the top major producer of logs, plywood, woodpulp, and paper as well as plantation crops, such as palm oil, rubber and cocoa. This economic achievement was completed without applying sustainable management to forests. The major contributors to the fast deforestation in the country are poorly managed allocated forestlands to logging and timber industries, plantations and estates, smallholder’s tree crop plantations, and government regulated or spontaneous transmigration. The potential impact of these human activities on forest carbon stocks, and thus GHG emissions, varies. For example, forest clearing generally produces the highest quantity of GHG emissions, whereas logging will produce lower amounts, depending on the type of logging.

Although fires have burned forest lands in Indonesia for thousands of years, they have become more frequent and widespread in recent times due to human-induced changes in the forests. During the El Niño of 1982-83, fires burned about 3.7 million hectares of forest degraded by commercial logging and agriculture in Kalimantan. In 1987, another 2 million ha of forest, 70 percent of which was mature forest, went up in smoke in Kalimantan, Sumatra, East Timor, Sulawesi, and Java. In 1991, fires burned more than 50,000 ha of forest (Butler, n. d.). These fires produce large amount of GHG emissions but yet they are hard to quantify. The present analysis does not take into consideration the spread of fires because of complexity and unpredictability of these natural disaster events. Because of the lack of data on extent of deforestation caused by fires, we were unable to separate deforestation caused by direct human activities from that caused by forest fires.

OBJECTIVES

This analysis focused on three objectives. The first objective was to test different deforestation driver combinations in a spatial model to identify the most critical drivers that explain the current patterns of deforestation in the study areas. The second objective was to stratify the threat of future deforestation, based on the spatial modeling, into low, moderate and high threat classes. The third objective was to demonstrate how the CO_2 emissions reductions can be estimated for potential protected areas and other areas under high threat for deforestation.

STUDY AREA

The study area of East Kalimantan province of Indonesia (**Fig. 1**) was selected after a site visit (May - June 2006) and discussions with Fred Stolle, South Asia Regional Manager at WRI. Previous analysis done by WRI showed that East Kalimantan had experienced large forest lost between 1985 and 1997 while at the same time it was the province with the largest portion of the total forest in Indonesia.

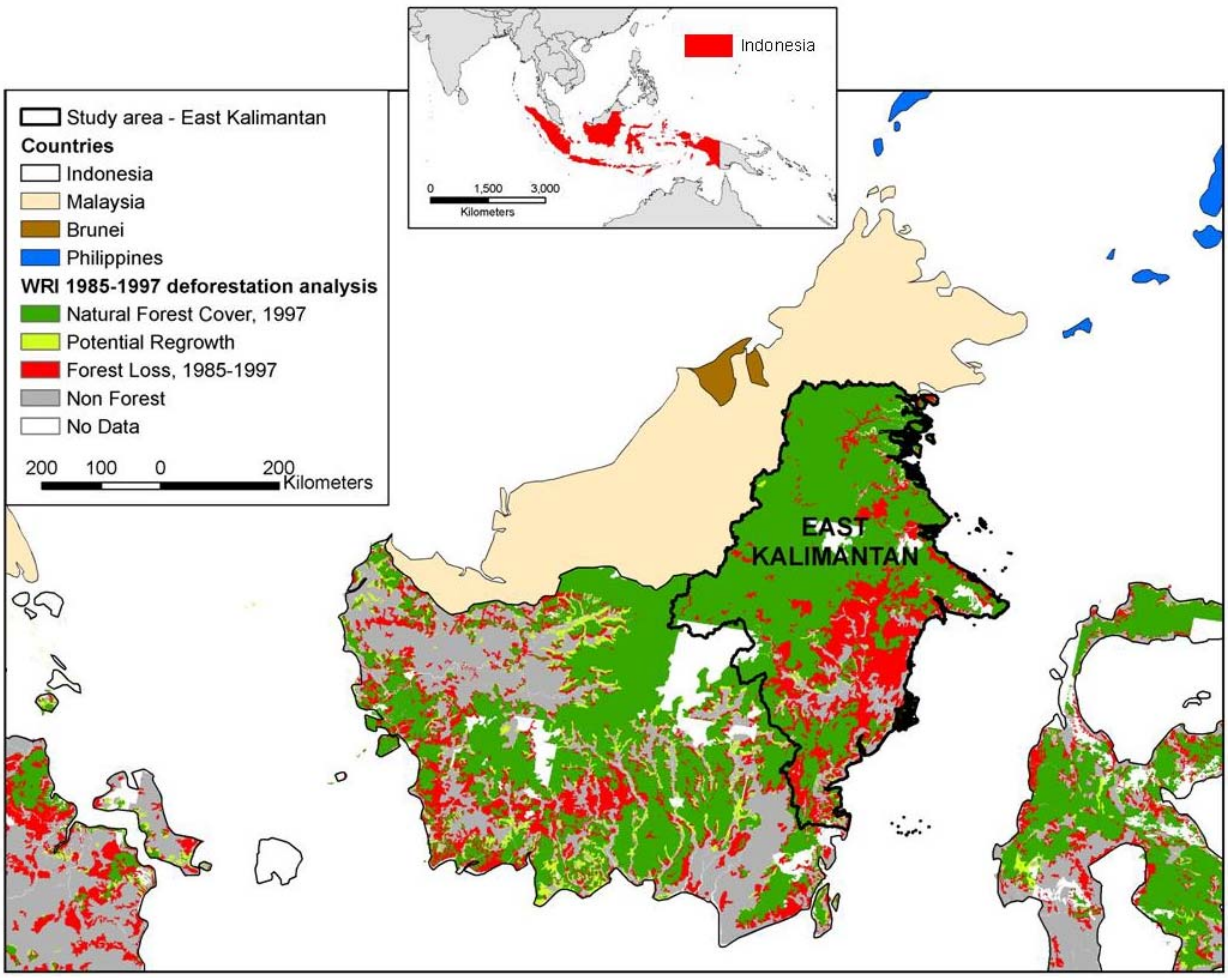

Figure 1. Map of forest lost in the Indonesian part of island Borneo from 1985 to 1997 according to the WRI (Global Forest Watch & Forest Watch Indonesia. 2002) and location of the study area – East Kalimantan.

The province of East Kalimantan is located on the island of Borneo in equatorial area between 113° 44' and 119° 00' East Longitude and between 4° 241' North and 2° 25' South Latitude. The elevation ranges from 0 m to 2438 m above the sea level with high elevation located mostly in the northwestern part of the province. East Kalimantan is the largest province in Indonesia still covered by natural forest, 32% of the total forest in Indonesia in early 1990s (GOI/FAO, 1997: 36). The tropical forests in East Kalimantan range from lowland to montane forest with areas of swamp and mangrove forest, all well known for their high biodiversity. The forest contains more than 800 tree species listed as threatened by the International Union for the Conservation of Nature (IUCN) and endangered animal species such as orangutans, proboscis monkeys, sun bears, gibbons and birds (The Nature Conservancy, 2006).

The protected areas (eighteen in total) in East Kalimantan according to the World Conservation Monitoring Centre (WCMC) database cover approximately 3.7 million ha, which is almost 20% of the total area of East Kalimantan (approximately 19 million ha). A large portion (2.3 million ha) of protected areas is located at mid and high elevation (above 300 m), usually inaccessible to logging and other human-induced activities. A small portion (1.4 million ha) of the protected areas is located in lowland forest, accessible to logging operations, shifting cultivation and tree crop plantation. Furthermore, some of the protected areas overlap with areas of timber and crop plantation or logging concessions (**Fig. 2**).

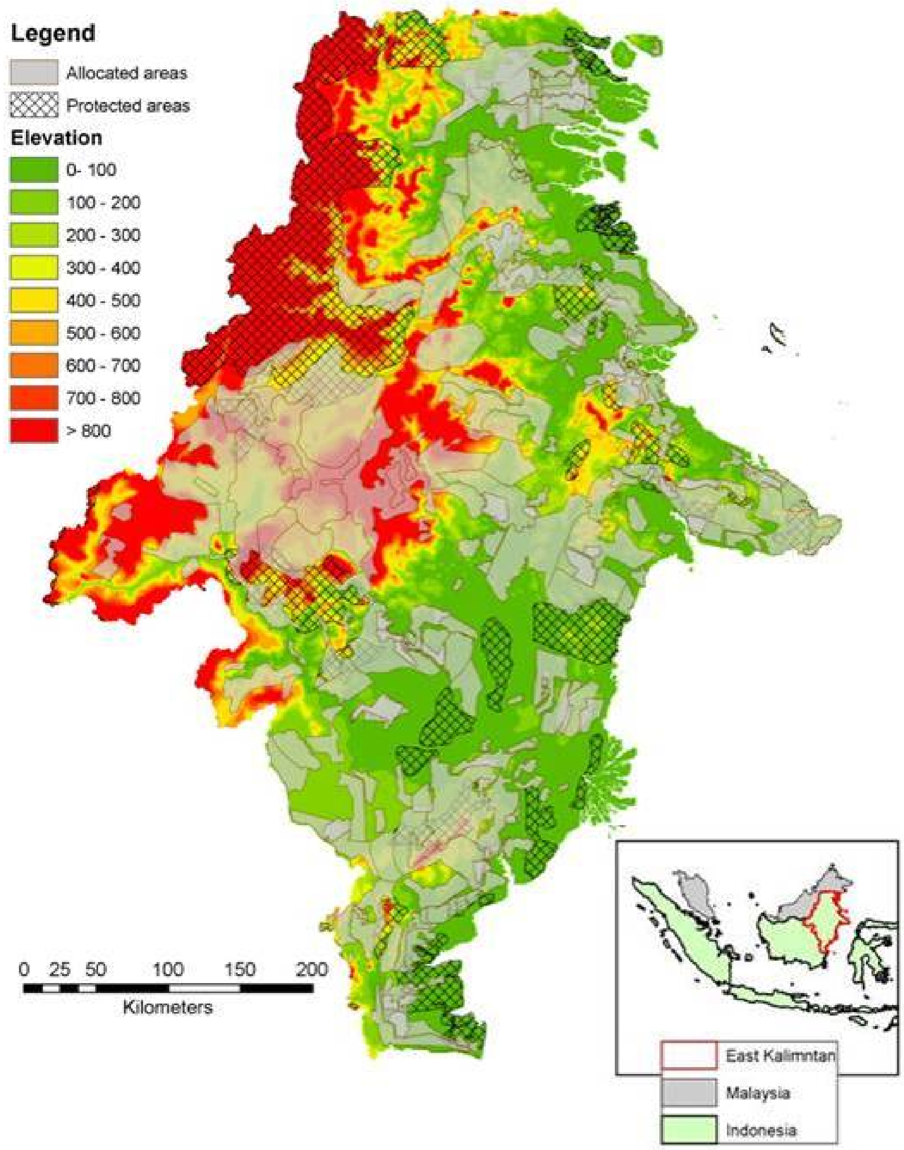

Figure 2. Location of protected areas and allocated lands (plantations for timber & tree crops and logging concessions) and elevation range in East Kalimantan.

DATA AND METHODS

A large variety of GIS data bases were available for the study area (see Deliverable 19). The temporal resolution of analysis was confined by the availability of the land cover maps from 1997 and 2003. The spatial resolution of 250 m pixel size was chosen to satisfy the purpose of the spatial modeling based on extent of the study area and the nature of the analysis. The following datasets were used in the analysis:

- Land cover map of 1997 and 2003 (source: Ministry of Forestry, Indonesia)
- Roads (source: Ministry of Forestry, Indonesia)
- Rivers (source: GeoCommunity - GIS Data Depot)
- Settlements (source: South Asian START Regional Center (SARCS)
- Location of sawmills (source: Ministry of Forestry, Indonesia)
- Protected areas (source: Ministry of Forestry, Indonesia)
- Digital elevation model (DEM) (source: Global Land Cover Facility, University of Maryland)

Although the both land cover datasets were obtained from the Ministry of Forestry in Indonesia, there were discrepancies in the land cover categories and classified area. The land cover map for 1997 was classified into 18 categories and the total classified area was approximately 230 thousand hectares less than the total area classified into 24 categories for 2003 (**Table 1** and **Fig. 3**). To assure equal number of classified pixels, the water and cloud pixels as well as all classified pixels from one map that did not have corresponding classified pixels from the other map were masked out from both maps. The resulting two maps contained approximately 15.7 million hectares, classified respectively as forest (11.1 million ha) and non-forest (4.6 million ha) for 1997, and forest (10.3 million ha) and non-forest (5.4 million ha) for 2003.

Table 1. Area for each land cover class according to the Ministry of Forestry land cover classification for 1997 and 2003.

Land cover class	Area (ha) 1997	Area (ha) 2003
Forest	12,666,790	10,700,600
Non-Forest	4,970,970	4,866,960
Water	50,970	725,840
Clouds	638,380	2,264,500
Total	**18,328,110**	**18,557,900**

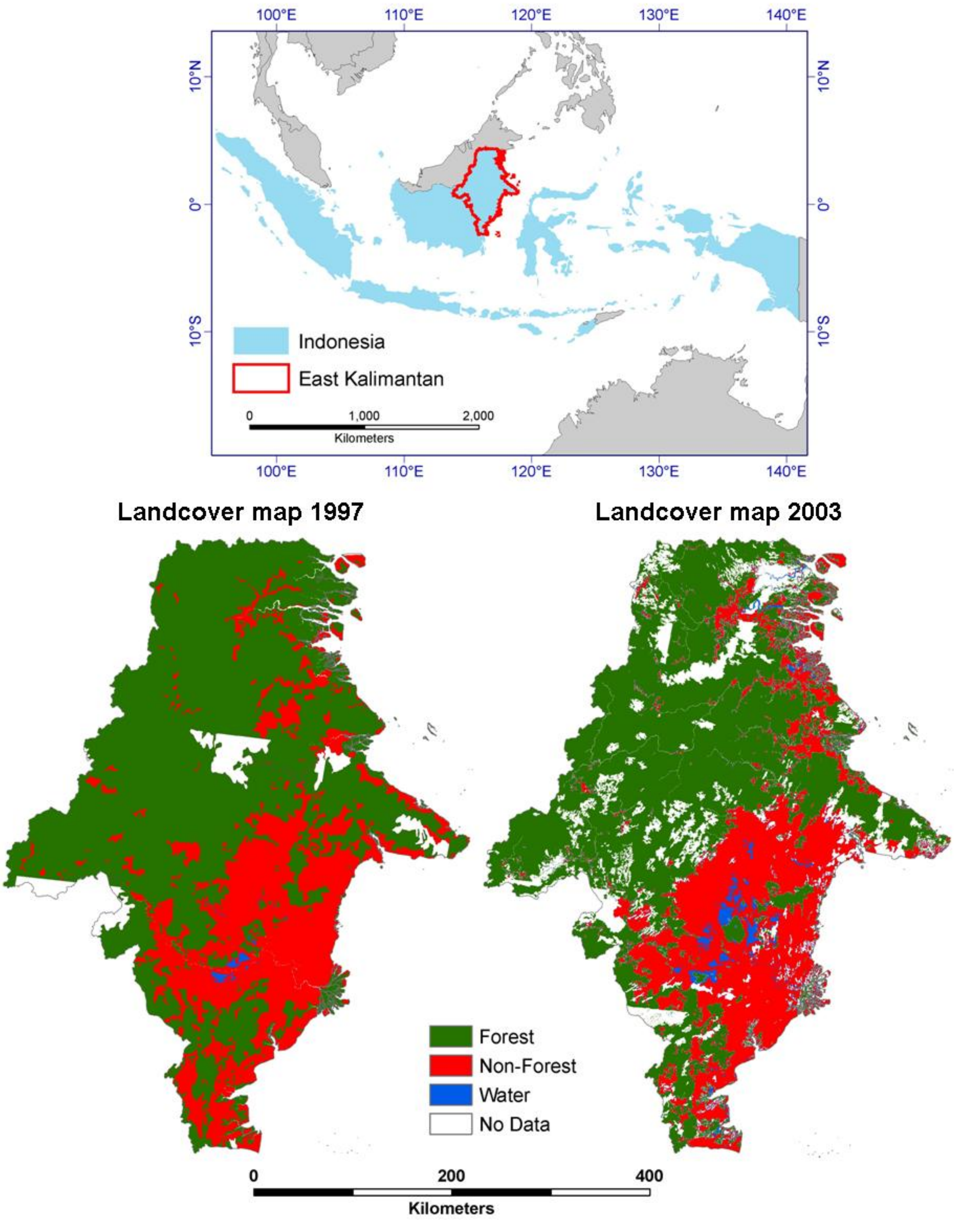

Figure 3. Top – Indonesia and location of the study area - East Kalimantan; bottom – classifications of land cover for 1997 (left) and 2003 (right) for the study area according to the Ministry of Forestry's classifications (no data are areas under clouds or outside the images).

There are many models developed to understand landscape dynamics, and they can be grouped into three major groups: analytical, simulation and regression models (Kaimowitz and Angelson, 1998). Although all model's results are associated with some degree of uncertainty, the spatially-explicit models are recommended, because they can project the location and pattern of future deforestation based on prior knowledge (Brown et al., 2007). In this work, the spatial model called GEOMOD was used to simulate a transition from forest to non-forest category while depicting the specific location and quantity of the simulated non-forest category (Hall et al, 1995, Hall et al., 2000). This analysis followed the framework described in Petrova et al. (2006) (**Fig.4**). The first step involves simulation of the existing landscape mosaic based on different biophysical, socio-economic and demographic factors. The second step takes the results from the first step and extrapolates them into the future and defines areas of future deforestation threat. One of the key motives for using spatial modeling within the scope of carbon projects is that future land use change can be associated with forest carbon stocks to estimate corresponding CO_2 emissions in the third step of the framework. The spatial landuse change modeling and carbon emission modeling was performed with the capabilities of the GIS software - Idrisi Andes (Eastman, 2006).

A brief overview of the approaches and methods are presented in this report, while detailed description of decision rules implied in the methodology are explained in details in Petrova et al. (2006).

1. Step One of Spatial Modeling

Calibration and validation of the spatial model are of high importance for the credibility of the modeled output (Brown et al., 2007). These two procedures are performed at step one of spatial landuse change modeling.

1. 1. Calibration procedure

Calibration is the procedure that uses information from an initial or prior time to calibrate the spatial model. The purpose of this procedure is to create suitability for change (SFC) map from driver maps created either using prior knowledge (*empirical* driver maps) or assuming that with increasing the distance from features (roads, rivers, cities, etc.) the distribution of the deforestation decreases (*heuristic* driver maps).

Seven driver maps (distance from already deforested land, cities, sawmills, rivers, roads and allocated land) were created using the heuristic decision rule, and five driver maps (distance from cities, sawmills, rivers and roads, and slope) were created according to the empirical decision rule (for more details see Petrova et al., 2006). These maps were used in 102 weighted average combinations to produce 102 SFC maps.

1. 2. Validation procedure

Validation is the procedure for assessing the predictive power of the model by comparing the simulated map to the reference map. The GEOMOD simulated deforestation pattern in the study area from 1997 to 2003, using SFC maps produced from the calibration procedure and quantity of non-forested pixels in the map of 2003. Validation of the predicted maps in two categories, forest and non-forest, was performed by comparing the simulated map for 2003 and the reference map of 2003. Kappa for location statistic, measuring the goodness-of-fit for validation, was calculated for each of the 102 simulated maps of 2003 (Pontius, 2002, Pontius and Pacheco, 2004). Detailed explanation of the applied validation procedure is given in Petrova et al. (2006).

2. Step Two of Spatial Modeling

This step determines the rate of land use change, and simulates a future deforestation pattern based on the potential land use change (PLUC) map. In addition, the PLUC map is used to create a threat map of future deforestation.

The annual rate of deforestation between 1997 and 2003 was calculated according to Puyravaud, 2003:

$$Rate = \left(\frac{1}{t_2 - t_1}\right)\ln\left(\frac{A_2}{A_1}\right),$$

where A_1 is the forest area at the initial time (t_1), according to the land cover map of 1997 and A_2 is the forest area in the later time (t_2), according to the landcover map of 2003. Assuming that the deforestation will continue at the same rate, the quantity of the forest class for 2008 and 2013 was calculated.

The SFC map that yielded the highest Kappa for location statistic was used to create the PLUC map that shows the most suitable areas for deforestation beyond 2003. The PLUC map was created by masking out all areas of non-forest category in the reference map of 2003 from the SFC map. This step allowed GEOMOD to simulate a future deforestation pattern in the study area based on the PLUC map and the extrapolated quantity of forest for 2008 and 2013. Furthermore, the PLUC map was used to create a threat map with three categories: low, moderate and high threat of future deforestation. Detailed information on the step two of spatial modeling is given in Petrova et al. (2006) and Brown et al. (2007).

3. Step Three: CO2e emissions modeling

To estimate carbon emissions from simulated deforestation, a map of carbon stocks for the forest in the map of 2003 was created using a 1980 map of the spatial distribution of carbon density in biomass and soils for the forest in tropical Asia (Brown at al, 1993). It was assumed that this map of biomass carbon density was still applicable to the current situation given that no further data are available. To estimate potential CO_2 emissions for each five-year period, deforestation was allowed to happen in the protected areas for a period of ten years beyond 2003. Maps of actual carbon in 2008 and 2013 were created, using the Brown et al. (1993) carbon map. Comparison between the carbon stocks in cases when deforestation was allowed and when deforestation was not allowed in the protected areas for 2008 and 2013, permitted us to estimate the net CO_2 emissions that would occur under a projected business-as-usual or baseline case[3].

[3] CO_2 emissions were calculated by multiplying the C stock difference by 3.667

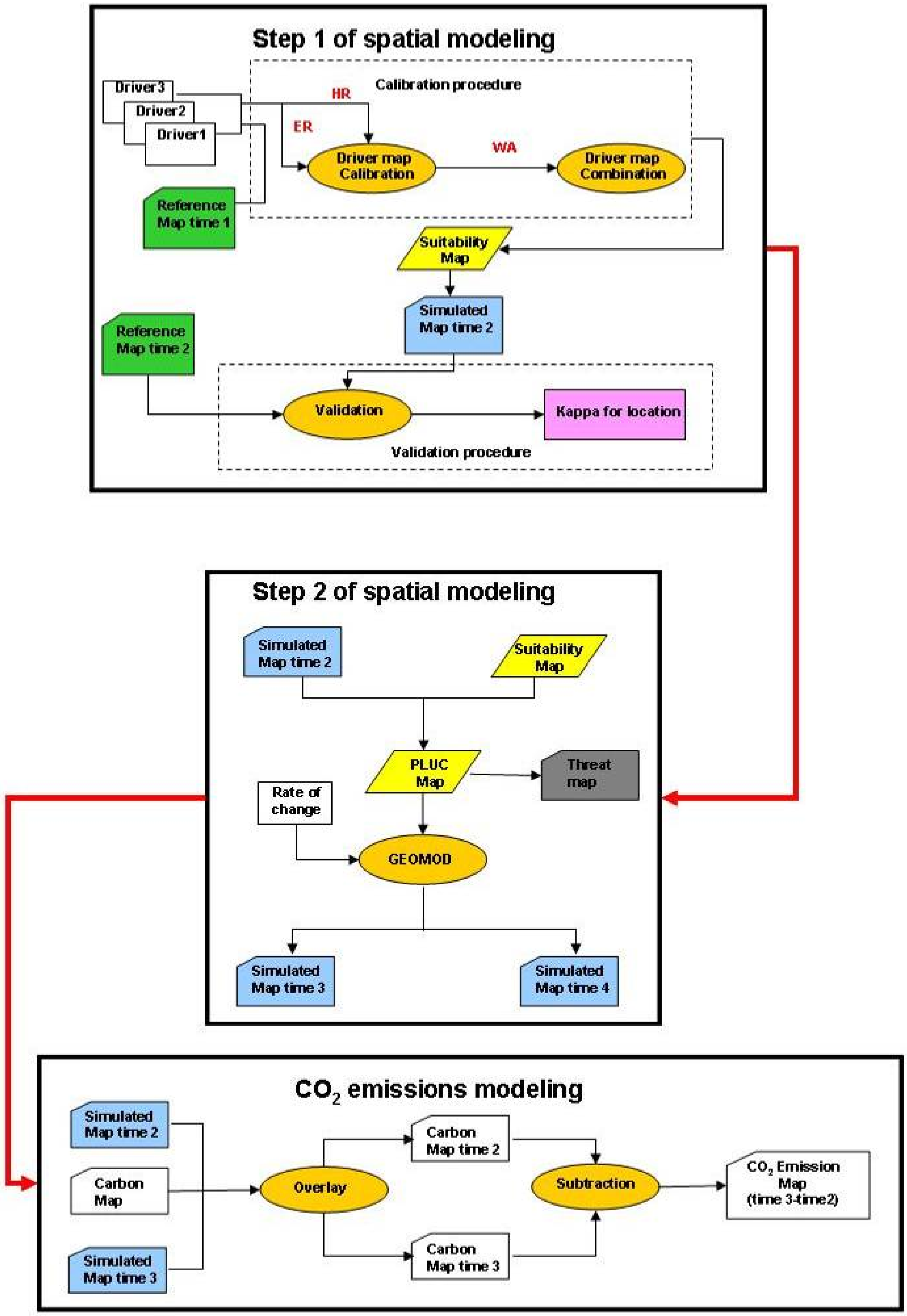

Figure 4. Flow chart of the steps used to simulate changes in land use/land cover using GEOMOD. Step 1 simulates the existing landscape and compares it to the reference land use map of time two. Step 2 simulates future land uses based on the Potential Land Use Change map (PLUC). Step 3 creates a carbon emission map over time based on a carbon map and simulated land use maps. (All spatial procedures are shown in the flow chart with orange oval shapes, simulated land use maps in blue shapes, reference land use maps in green shapes, threat map of future deforestation in gray shapes, and PLUC and suitability maps in yellow shapes). ER=empirical rules, HR = heuristic rules, WA=weighted average.

RESULTS AND DISCUSSION

1. Step One of Spatial Modeling

The results from the validation procedure showed that the most important drivers of deforestation for the period of 1997 to 2003 were accessibility (distance from the already deforested area, distance from cities, and distance from sawmills and roads) and topography (elevation) (**Table 2).** Two accessibility driver maps, distance to already deforested area and distance to sawmills, and elevation driver map were represented in each of the seven combinations that yielded Kappa for location statistic of 0.63 (when the values are rounded). The results showed that distance to cities and distance to rivers driver maps are also important drivers of deforestation, but they do not play a dominant role in explaining the deforestation pattern in 2003. The three diver maps (distance to already deforested area, distance to sawmills, and elevation) were tested alone, to see whether one of them can predict the deforestation pattern in 2003 better than their combination. These results yielded Kappa for location statistic less than 0.62. This suggested that although each of these drivers predicted the deforestation pattern better than random model's prediction, their combination gives the best modeling result. GEOMOD used the SFC map (**Fig. 5**), created by weighted average combination from the dominant driver maps (third row in **Table 2**), to simulate distribution of forest and non-forest categories in 2003 (**Fig. 6**).

Table 2. Top seven combinations of driver maps used to create suitability maps for the calibration procedure, and their corresponding Kappa for location statistics from the model validation procedure according to step one of the spatial modeling (HR=heuristic rule).

Kappa for location statistic	Driver maps combinations used to create suitability maps					
	Accessibility driver maps					Topography
	Cities (HR)	Deforested area (HR)	Sawmills (HR)	Rivers (HR)	Roads (HR)	Elevation (HR)
0.6324	x	x	x	x		x
0.6320	x	x	x			x
0.6282		**x**	**x**			**x**
0.6280		x	x	x		x
0.6265	x	x	x	x	x	x
0.6262		x	x	x	x	x
0.6258	x	x	x		x	x

The SFC map (**Fig. 5**) shows that most of East Kalimantan is very suitable for further deforestation based on the past rates and patterns. The simulated map of deforestation (**Fig. 6 - B**) depicted the trend of the deforestation in 2003. The large similarity in the pattern between the simulated and reference map of 2003 is due to large portion of the area that was deforested in 1997 and stayed deforested in 2003. The reason that some areas are shown on the simulated map as deforested while they were forested on the reference map of 2003 is that these areas were classified as deforested on the map of 1997.

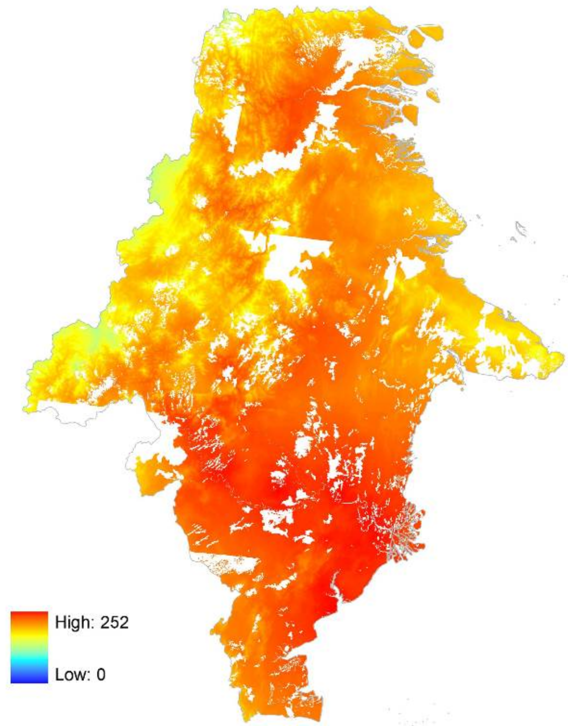

Figure 5. Suitability-for-change (SFC) map created by using weighted average combination from the dominant driver maps (third row in Table 3).

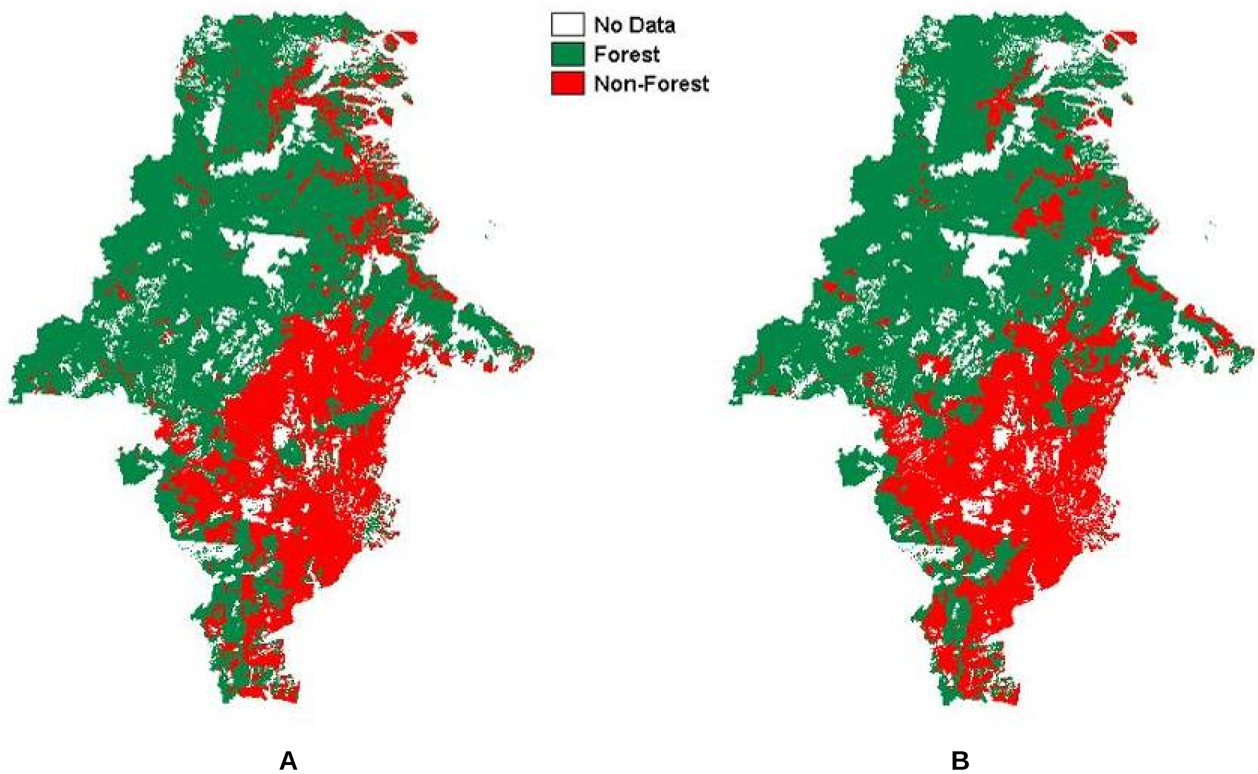

Figure 6. Reference map for 2003 (A) and simulated map for 2003 (B) of East Kalimantan in two categories: forest and non-forest.

2. Step Two of Spatial Modeling

The forested area was approximately 11.2 million ha in 1997and decreased by approximately 0.9 million ha to approximately 10.3 million ha in 2003, according to the land cover maps. The deforested area in 1997 was approximately 4.6 million ha. The deforestation rate for this period was calculated to be 0.0134/yr. The area of forest for 2008 and 2013 was estimated, respectively, to be 9.6 million ha and 8.9 million ha. The amount of deforested area for 2008 and 2013 was correspondingly estimated to be 6.1 million ha and 6.7 million ha. **Figure 7** shows the cumulative quantity of deforested area as a percent of the forested area in 2003. This quantity of deforestation was used by GEOMOD to predict the location of non-forest category in the simulated maps of 2008 and 2013.

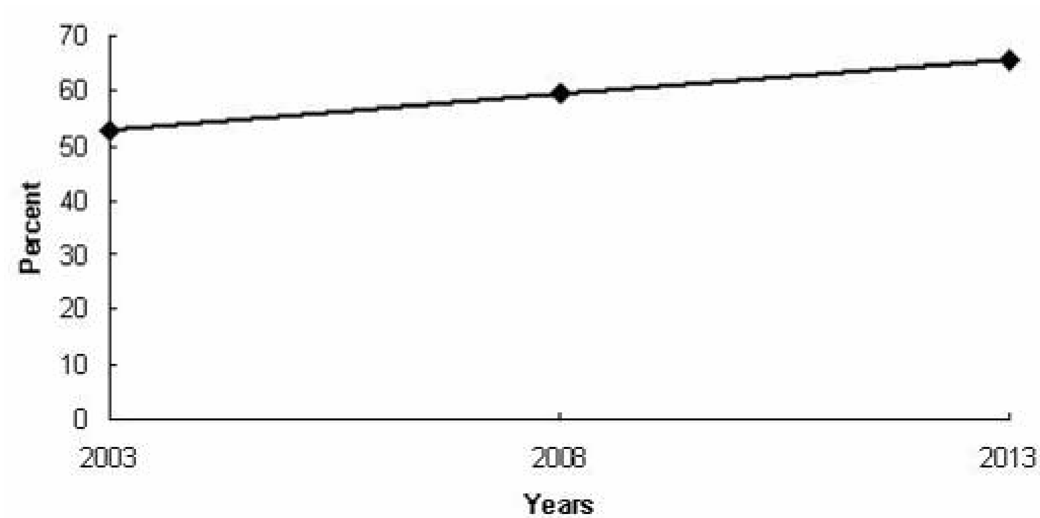

Figure 7. Cumulative quantity of deforested areas as a percent of the initial forested area

Potential land-use change (PLUC) map (**Fig. 8**) was created by masking out all deforested pixels in the reference map from the SFC map (**Fig. 5**), and deforestation beyond 2003 was simulated using GEOMOD. The model simulated the locations of potential deforestation in 2008 and 2013 by selecting pixels with highest value in the PLUC map in descending order according to amount of deforested area calculated for these years. The value of the pixels in the PLUC map was aggregated into three classes, representing future deforestation threat: high, moderate and low threat class (**Fig. 9**).

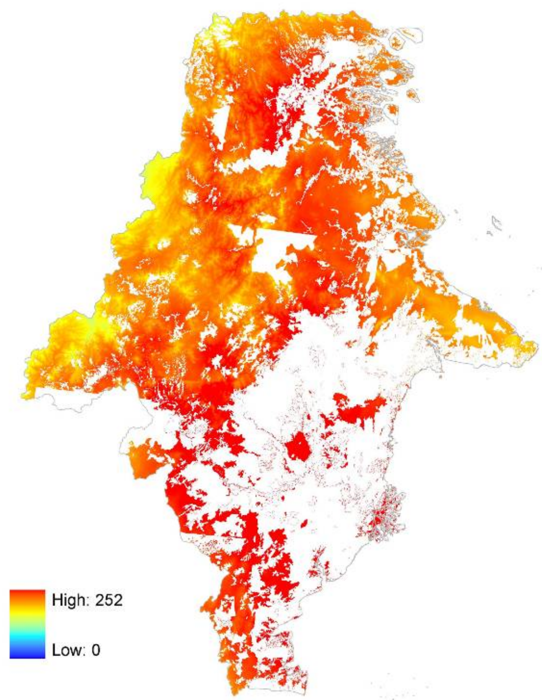

Figure 8. Potential land use change (PLUC) map. The higher numbers on the scale show that these areas are most likely to be deforested beyond 2003.

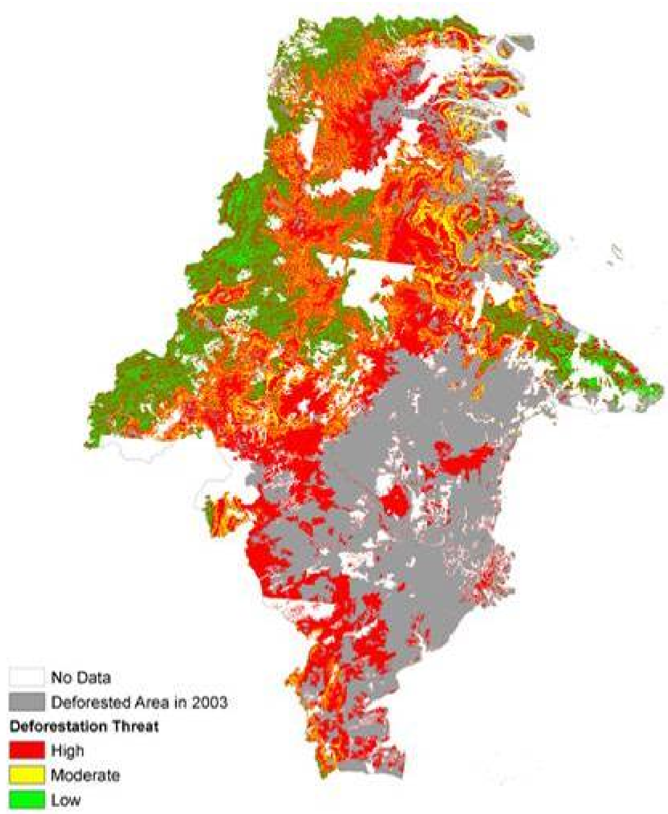

Figure 9. Threat map of future deforestation and already deforested area in 2003.

3. Step Three: CO_2e emission modeling

The carbon stocks for the forest category in 2003 varied from 73 to 383 t/ha across the study area (**Fig. 10**). The total carbon stocks in the forest within the protected areas for 2003 were estimated to be approximately 438.9 million t C. According to the GEOMOD, when deforestation was allowed within the protected areas these stocks decreased by 3.4% during the first five years period (2003-2008), and by an additional 4.3% during the last projected five years period (2008-2013).

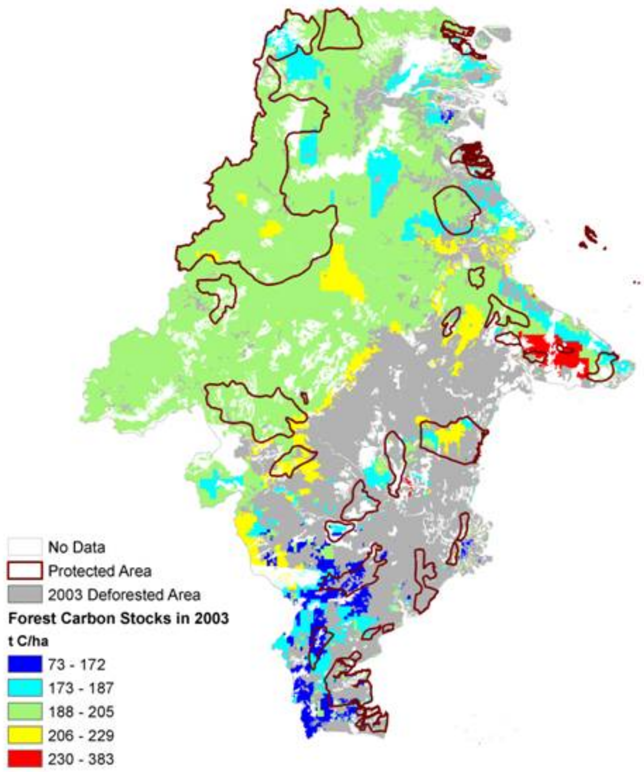

Figure 10. Map of carbon stocks in above and below ground biomass pools for the forest in 2003 (from Brown et al., 1993), location of protected areas, and already deforested area in 2003

4. Estimating the potential carbon benefits from protecting forest areas

Comparison between both land cover maps showed that approximately 1.7 million ha of forest in 1997 were converted to non-forest category in 2003 (**Fig. 11**). The comparison also showed that about 9 thousand ha of non-forest in 1997 were converted to forest by 2003. Further analysis is needed to determine whether this is due to misclassification in the land cover classes or actual re-growth of trees after the devastating fire season of 1997-1998. Deforested areas within the protected areas increased from 396 thousand ha in 1997 to 690 thousand ha in 2003, showing that protection is not well enforced.

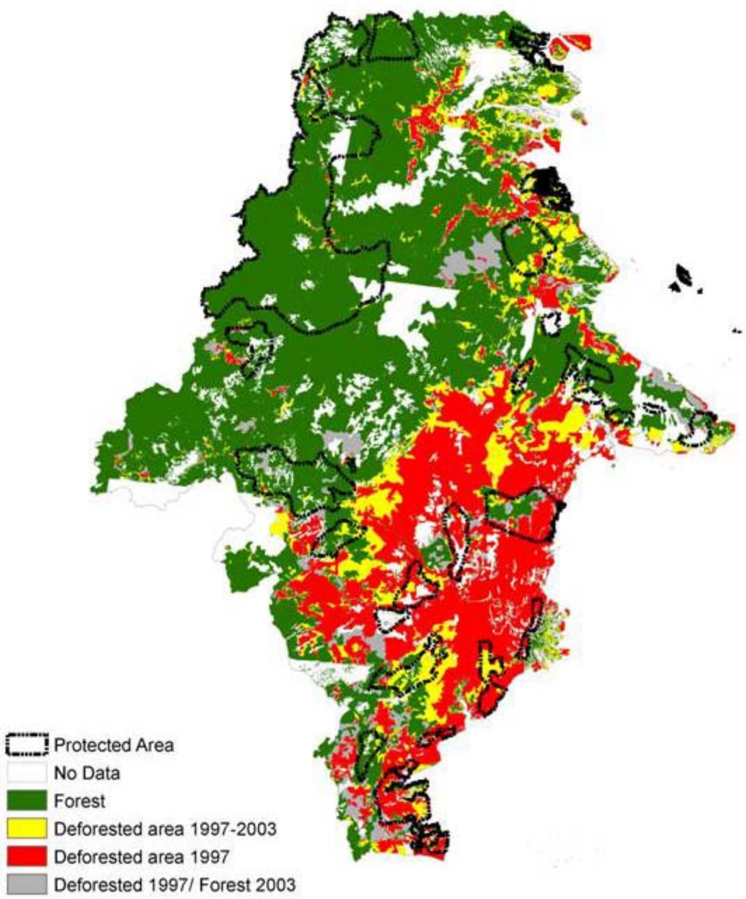

Figure 11. Map of deforested area (yellow) between 1997 and 2003 according to the reference maps and location of protected areas

According to the land cover map of 2003, the forests within the protected areas were estimated to cover approximately 2.5 million ha and approximately 7 thousand ha were already deforested areas. When the spatial explicit deforestation rates were applied across the whole study area, the forested areas decreased to 2.4 and 2.3 million ha respectively in 2008 and 2013, with concomitant gain of non-forest area of 115 thousand ha in 2008 and 116 thousand ha in 2013. The total deforested area increased to 924 thousand ha by 2013 (**Table 3**). The total area (ha) and the forested area (ha) for protected areas as well as the decrease (ha) of forest area for the 10 years simulation period are given in **Table 4**. Protected area Bukit Soeharto with only 140 ha forest left in 2003 was projected to be entirely deforested during of the first 5 years of the 10 years simulation period (**Table 4)**.

Table 3. Distribution of forest and non-forest class within protected areas for 2003 land cover map and for 2008 - 2013 projected maps, when deforestation is allowed to happen within the protected areas (simulating no rigorous enforcement).

Land cover classes	Reference 2003	Simulated 2008	Simulated 2013
	Area (ha)	Area (ha)	Area (ha)
Forest	2,529,550	2,415,000	2,298,670
Non-Forest	693,390	807,940	924,270

Table 4. Forest area (ha) for protected areas in East Kalimantan and projected loss in forest area (ha) per 5-year and 10-year simulated periods.

Protected area	Total area (ha) *according the GIS dataset*	Forest area (ha) 2003	Forest area (ha) decrease 2003-2008	Forest area (ha) decrease 2008-2013	Total forest area (ha) decrease 2003-2013
Apar Besar	215,870	44,960	11,700	14,332	26,034
Apo Kayan NR/BR	89,880	65,880	840	815	1,655
Batu Kristal	3,470	2,530	130	140	270
Bukit Soeharto	77,630	140	140	0	140
Gunung Berau	151,640	105,040	8,147	9,538	17,685
Gunung Lumut	46,340	35,310	1,992	2,176	4,168
Hutan Kapur Sangkulirang	202,620	97,520	3,181	4,683	7,865
Kayan Mentarang	6,470	120,200	411	2,660	3,071
Kutai	124,340	86,650	12,162	13,823	25,985
Long Bangun	333,650	268,610	6,939	11,138	18,077
Muara Kaman Sedulang	80,740	3,670	1,165	883	2,047
Muara Kayan	73,300	14,230	8,067	3,727	11,794
Muara Sebuku	51,770	27,370	1,318	3,868	5,186
Pantai Samarinda	30,282	1,900	607	607	1,214
Perairan Sungai Mahakam	114,420	4,920	1,293	1,275	2,568
Sesulu	125,580	40,860	9,140	12,855	21,994
Sungai Berambai	73,100	44,740	3,727	6,528	10,255
Sungai Kayan Sungai Mentarang	7,705,680	1,440,650	12,953	16,949	29,902
Grand Total	3,716,730	2,426,550	83,920	105,994	189,914

Combining the change in forest cover during the simulation period with estimates of the forest carbon stocks resulted in estimated potential baselines of CO_2e emissions for each protected area (**Table 5**). This table provides a closer look into one of the most important environmental service of forests—carbon storage, one service that can be valued with today's interest in reducing emissions of greenhouse gases. Under a poorly enforced protection program, more than 135 million t CO_2 or about 13.5 million t CO_2 per year could be emitted from these eighteen "protected areas" in this one province. At a current price of CO_2 is around 12-15 U$ per metric ton based on the European market, and the assumption that this price would remain constant during the next 10 years (most expert actually expect that the price would climb to 30 US$ per ton CO_2), the opportunity cost of NOT protecting these eighteen areas would amount to a loss of more than$162 million dollars a year.

In 2006 the governments of Indonesia (National and lower level governments) had a total budget of US$35 million available for all protected areas in Indonesia and approximately US$5 million for East-Kalimantan province (State Ministry of Indonesia, 2006). The protection of National Parks is not only protecting the environmental services but could potentially generate more revenue than is now allocated to National Parks.

Table 5. Simulated t CO_2e emitted per 5-year and 10-year period for the protected areas in East Kalimantan assuming that their protection was not rigorously enforced.

Protected area	t CO_2e emitted 2003-2008	t CO_2e emitted 2008-2013	Total t CO_2e emitted 2003-2013
Apar Besar	8,081,550	9,798,400	**17,879,950**
Apo Kayan NR/BR	606,680	588,970	**1,195,640**
Batu Kristal	97,420	97,420	**194,840**
Bukit Soeharto	105,180	0	**105,180**
Gunung Berau	5,715,410	6,707,760	**12,423,170**
Gunung Lumut	1,269,420	1,383,770	**2,653,190**
Hutan Kapur Sangkulirang	2,269,110	3,415,280	**5,684,390**
Kayan Mentarang	292,430	1,892,950	**2,185,380**
Kutai	9,329,500	10,570,900	**19,900,400**
Long Bangun	5,001,940	8,027,390	**13,029,330**
Muara Kaman Sedulang	824,970	627,700	**1,452,670**
Muara Kayan	5,791,640	2,672,430	**8,464,070**
Muara Sebuku	981,940	2,812,450	**3,794,390**
Pantai Samarinda	423,720	449,350	**873,070**
Perairan Sungai Mahakam	871,720	869,860	**1,741,580**
Sesulu	5,832,060	8,153,030	**13,985,090**
Sungai Berambai	2,921,560	5,111,660	**8,033,220**
Sungai Kayan Sungai Mentarang	9,312,300	12,138,190	**21,450,490**
Grand Total	**59,728,540**	**75,317,500**	**135,046,040**

The National Parks of Kutai and Apar Besar have some of the highest simulated deforestation rates (Table 4) and have very little of their area still forested in 2003 (**Figure 12)**. As the simulation indicates, Apar Besar would have less than 9% of its total area forested by 2013, and Kutai would drop from 70% forested in 2003 to 49% forested in 2013. The loss of such large amount of forest in these two protected areas will have a dramatic effect on biodiversity values, especially on such keystone species like the orangutan which is still abundant in Kutai National park.

The results of this work for East Kalimantan are of direct policy importance to Indonesia. They show the Ministry of Forestry and relevant stakeholder what can happen to National Parks and the vital environmental services (including carbon and biodiversity) if the parks were weakly protected and a business-as-usual rate and pattern of deforestation continues. This model gives clear indication and warning on which National Parks are under threat and thus can be used by the Ministry of Forestry and other stakeholders to target forest governance and law enforcement. Policy option might include the allocation of more funds to certain protected areas and the deployment of more forest guards in areas or educational program for locals in the vicinity of the National Parks. The scenario as presented shows the consequences of business-as-usual model. With the right policies and interventions, the projected scenarios do not have to happen.

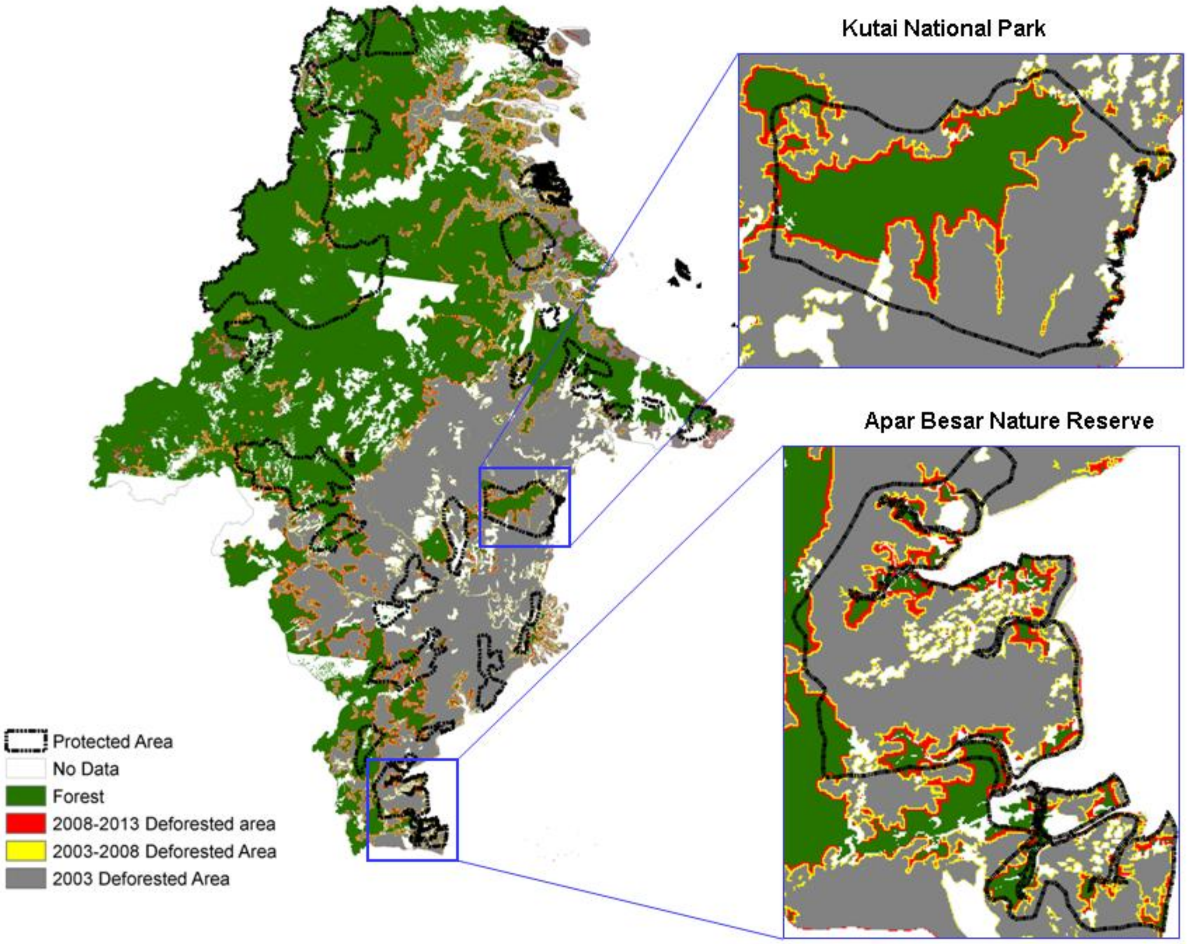

Figure 12. Potential deforestation per 5-year period for East Kalimantan and zoomed-in view of the potential deforestation within the Kutai National Park and Apar Besar Nature Reserve according to 'Baseline Case' scenario (no protection from deforestation).

4.1 Sources of uncertainty in the analysis

Like all modeling studies, there are several sources of uncertainty in the analysis, particularly with respect to the estimation of area and carbon stocks. Sources for these uncertainties include the different number of land cover classes in the initial land-cover dataset for 1997 and 2003, and their aggregation in two classes of forest and non-forest, as well as the uncertainty in the quality of vector data. Some of these errors were propagated through the modeling process. The estimates for carbon stocks in the forest are also uncertain because we used estimates for the 1990s from Brown et al. (1993), which were based on a spatial model calibrated with field data. In addition, the fire scars from 1997-1998 fire season were not incorporated in the analysis, which could explained the 9 thousand ha that were shown as non-forest category in the land cover map of 1997 and as forest category in 2003. The analysis was done at resolution of 250 m (resulting in an area of 6.25 ha per pixel) and may miss small scale changes.

Finally, we assumed that the rate and pattern of deforestation between 1997 and 2003 would remain the same for the simulated 10 year period. The temporal dimension for deforestation baselines is a significant analytic and policy issue—how far into the future can, and should, the baseline be projected? Rates and patterns of land-use change are subject to biophysical factors regulating human use of the land that change marginally over time, but socioeconomic and political factors are more dynamic and less predictable through time. Thus, the farther business-as-usual baseline scenarios are projected into the future, the less reliable they are likely to be. We have used a 10-year projection period that has been suggested is a reasonable time frame for projecting deforestation baselines forward (Brown et al., 2007). The use of a 10-yr period is based on the following: historical data are often collected over the decadal time frame (e.g., population data), and may indicate future projections over the same time period given the dynamics of development and growth in most countries; and from a policy perspective, a decade is roughly two political election cycles (averaging 4-6 years generally, varying by political system).

5. Applications of deforestation modeling

Policy makers and scientists are concerned about deforestation and its negative consequences such as climate change, biodiversity loss, decrease in timber supply, and soil degradation. Spatial models such as GEOMOD help policy makers to understand why, where, when and how much forest would be lost to other land uses if current forest management practices continue. Establishing protected areas is a way to preserve environmental and culture values through reasonable management practices. Many protected areas are established mainly to conserve biodiversity or cultural values. However, a spatial modeling of deforestation combined with other spatial data such as forest carbon stocks, ranges of endangered or threatened species, areas of cultural value, poverty indicators, and key watersheds could be used in the planning stage for identifying the location of protected areas to maximize ecosystem services. Here we demonstrate how such an analysis could be done focusing on the question of “where to protect forests under high threat for deforestation and with high potential carbon emissions”. If such areas were rigorously protected, the carbon benefit to the atmosphere would be large.

The carbon map (**Fig**. **10**) shows that most of the forests in East Kalimantan contain carbon stocks within the range of 190 and 205 t C/ha. For this demonstration, the carbon stocks in the forest in Kalimantan were classified into four categories – medium (less than 190 t C /ha), medium high (less than 205 t C/ ha and greater than 190 t C/ ha), high (less than 230 t C/ ha and greater than 205 t C/ha), and very high (greater than 230 t C/ha). Combining the four-category-carbon map with the three-category-threat map (**Fig. 9**) allowed for the identification of forested areas with high carbon stocks under high deforestation threat (**Fig. 13**).

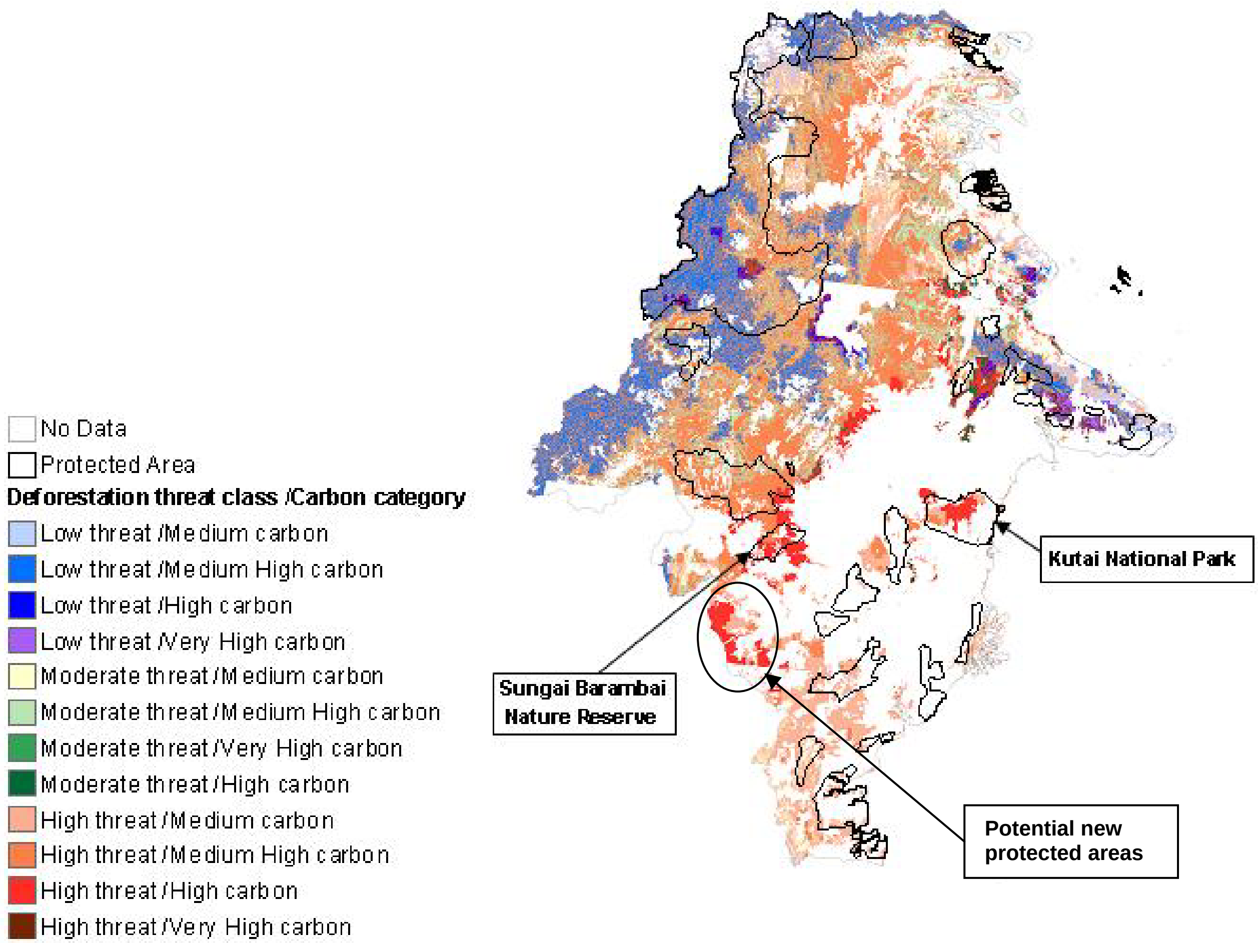

Figure 13. Map of deforestation threat categories combined with forest carbon stock categories.

This analysis allowed us 1) to identify existing protected areas in East Kalimantan that potentially have high carbon protection against deforestation is well enforced and 2) to identify forested area that could create high carbon benefits if these areas were protected. The map on **Figure 13** shows that all of the remaining forests in Kutai National Park and Sungai Barambai Nature Reserve are under high deforestation threat and have medium high to very high carbon stocks (greater than 190 t C/ha). Protecting these forests from further deforestation would result in high amount of carbon benefits to the atmosphere. This map also shows where potential new protected forests in southwest (red color on the map) could be established for maximizing the carbon benefits of avoiding further deforestation.

CONCLUSIONS

The study presented here has four important outcomes that can guide the US AID, Indonesian Ministry of Forestry, NGOs, and other stakeholders on actions against deforestation:

- It identified the main driving forces of deforestation in East Kalimantan. The identification is important for creating policies to mitigate deforestation.
  - One of the most important factors found in this study is the location of saw mills. The Ministry could e.g. better plan permits and/or revoke permits to control deforestation process.
- It identified which National Parks and/or protected areas in East Kalimantan are under severe threat to be deforested further and so indicates where action is required

- It identified the potential opportunity cost by NOT protecting the protected areas. And by doing so gives an overview of the size of the incentives for stakeholders to mitigate deforestation.
- Lastly, it identified areas that would be important to protect to maximize the carbon benefits from avoiding deforestation—these were areas that have very high carbon stocks and are not protected yet and are under high deforestation threat.

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