The potential for conservation of carbon stocks and carbon sequestration in the Trésor rainforest reserve, French Guiana: a quick scan

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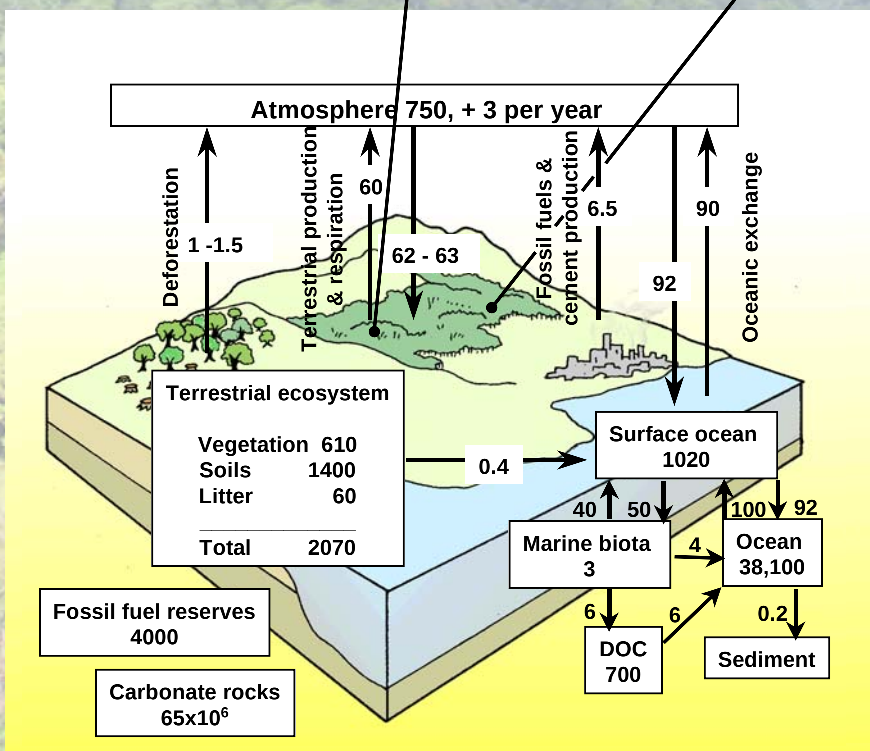

Carbon in Trésor
Wageningen, 2006

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On request of the Trésor foundation, Utrecht, Netherlands

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(Illustration on front cover: What is the role of Tresor (photo) in the global carbon budget?)

Carbon in Trésor

Alterra, Wageningen University and Research Centre, Wageningen, Netherlands

ABSTRACT

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A quick scan study is presented here to give a first estimate of the total carbon balance of the Trésor voluntary rainforest reserve in French Guiana, as well as an overview of the current knowledge of biogenic carbon flows in Amazon forests and savannas. It is observed that carbon stocks vary highly across the Amazon forests, and even more if also savannas are considered. Reported carbon sequestration capacities are also highly variable and uncertain, but over a smaller range. In this report, we estimated a total carbon content of between 561 and 829 kilotonnes of carbon on the 2479 hectares of the Tresor reserve. The sequestration capacity is estimated at between 0.5 and 3 kilotonnes of carbon per year.
A general assessment is also given on the potentials to gain carbon offset credits for the reserve under the Kyoto protocol or possible future regimes. It is concluded that possibilities are currently small, although France, a full carbon accounting country, and hence French Guiana is likely to have an interest in conserving carbon in its rainforests. Finally a series of recommendations is given on the kinds of research needed or recommended to bring the reserve in a good position to contribute to climate change mitigation and potentially benefit from the carbon market. Priorities are: definition of a baseline, monitoring of carbon contents in permanent sample plots, and map the full potentials of the reserve in all ecosystem services.

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[Carbon in Trésor/October/2006]

Contents

1 Introduction

The Tresor natural reserve is a voluntary reserve not far southeast of Cayenne, French Guiana. It is located at the south-facing slope, foothills and adjacent plains of the Montagne de Kaw, a coastal range of hills. The climate is tropical-humid, with high rainfall caused by orographic effects. The well-drained parts of the reserve (top of hill, slope and foothills) are covered in tropical rain forest, while the lower, poorly drained parts, are covered with savanna-like vegetation and intermittently flooded forest along the Orapou river. From hill top to river the height difference is 267 m

The reserve has been installed in 1995 through the initiative of Utrecht University funded by Dutch private money. The objectives were oriented at conservation of the ecosystems and species contained in it, in the face of threats of gold mining. Now, the Tresor foundation is seeking a broader basis for maintaining the reserve, and wishes to explore the potential value of the area in conserving and accumulating carbon, in the face of climate change. Ultimately, it is useful to assess the potential to generate income from 'carbon offsets' within the framework of future climate change mitigation treaties ('post-Kyoto').

This short report contains the following elements:

1. This introduction
2. An outline of the basic methodology required to estimate the carbon balance of the Tresor reserve.
3. An overview of the state of the art knowledge on carbon stocks and storage in Amazon tropical rain forests and savannas. We will address the uncertainties in research and the issues in translating information gained in other parts of the Amazon to French Guiana and the Tresor reserve in particular.
4. discussion of the information available from within French Guyana itself, in particular data already gathered in the Tresor reserve
5. a 'best guess' of the carbon stocks and uptake capacity of the reserve.
6. An overview of the current discussions on forest conservation as a mechanism within the UNFCCC to generate income
7. Recommendations for future research to improve estimates of the carbon balance and prepare for seeking carbon offset credits.

2 Methodology to estimate the carbon budget of the reserve

Carbon in an ecosystem is stored in plant biomass (wood, roots, branches, leaves), animal biomass (usually quantitatively insignificant), coarse litter (from dead trees to leaf litter) and Soil Organic Material (SOM)[1]. The size of these components as well as the carbon sequestration rate of the whole ecosystem can vary strongly between vegetation types, although it has been observed that Net Primary Productivity (NPP) of live biomass varies more strongly than Net Ecosystem Productivity (NEP), which includes the turn-over of dead material and SOM. Nevertheless, a reliable estimate of the reserve's carbon budget and carbon dynamics can only be made if the spatial variability in vegetation types and the carbon budget of each vegetation type is known.
The Tresor reserve is a mosaic of very different vegetation types (figure 1). Various ways to classify the types have been proposed, but here we assume the types as listed in table 1 (Ek et al. (2000)).

The carbon budget of each type requires an assessment of a) total carbon in all ecosystem components and b) recordings of changes in these components, or of the net flux of carbon into or out of the ecosystems. Total carbon stocks can be assessed through inventories in situ. Alternatively there are (satellite) remote sensing methods based on laser detection or radar that provide a proxy for vegetation structure and biomass. Finally, simple models exist, such as 'CO2-FIX' (Masera et al. (2003)). Most of these methods require calibrated relationships between direct observations (tree basal area, absorbed radiation) and biomass or carbon. To monitor changes in stocks, or the carbon fluxes, either repeated inventories or repeated remote sensing are required.
Because usually only measurements are available of live, above ground biomass, it is often necessary to either estimate the dead components and SOM from allocation models, or to estimate net ecosystem carbon productivity from NPP and mean carbon residence time. Both approaches depend on an underlying model, requiring assumptions with substantial uncertainties.
Alternatively, direct observation methods exist, in which the exchange of carbon dioxide with the atmosphere (the source or sink of carbon for net ecosystem productivity) is monitored, using micrometeorological methods (eddy correlation or atmospheric budgeting). The advantage of these direct observation methods is that exchange of the whole ecosystem, for areas of about 1 km^2, is monitored with high time resolution, without omission of hard-to-measure components such as soil carbon. The disadvantage is usually that rather large, homogeneous vegetated areas are required, but also relatively high cost and high infrastructural requirements. Also, these direct observations do not offer an estimate of the total carbon *stock*.

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[1] A list of acronmyms and abbreviations is provided in Appendix 1

Finally, if local inventories or direct measurements are not available, estimates of carbon stocks and balances have to be estimated from information on comparable ecosystems from the literature. This is the case for the Tresor reserve.

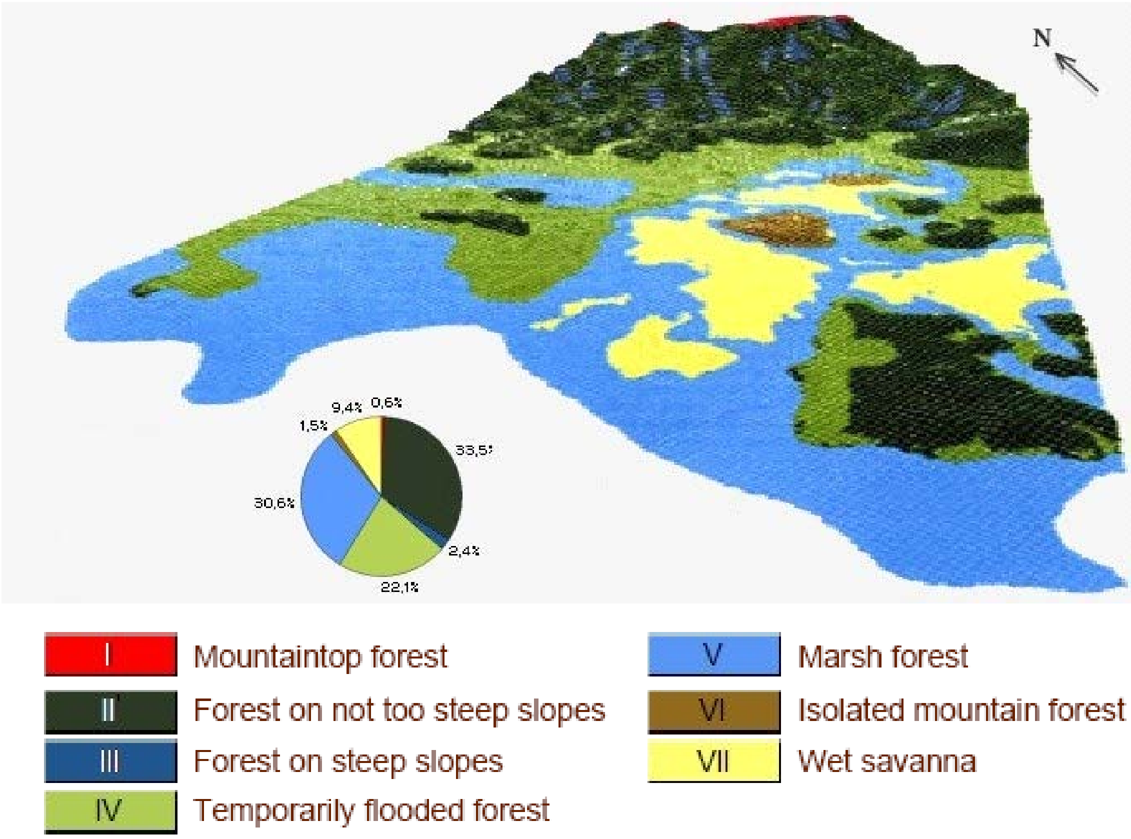

Figure 1 – Bird's eye view of the reserve, showing topography and distribution of vegetation types. From: Ek et al, (2000) and http://www.tresorrainforest.org/

3 Latest insights on carbon stocks and sequestration in the Amazon

Rain Forests

Ter Steege (2001) reports on biomass in forests of Guyana. Although soils in French Guiana, especially Tresor, are more fertile than in Guyana (Ter Steege, pers. Comm.), the forest types described by Ter Steege (2001) can act as a very coarse guide. Forests on lateritic soils are estimated to contain about 286 T C ha^{-1} in above-and below ground components, dead and alive, together. Malhi et al. (2006) showed biomass being highest in the moderately seasonal, slow growing forests of central Amazonia and the Guyanas (up to 350 T dry weight ha^{-1}) and declining to 200-250 T dry weight ha^{-1} at the western, southern and eastern margins of the Amazon. Including dead biomass and belowground biomass would increase these values by approximately 10% and 21%, respectively, giving an estimate for the Guyanas of about 470 T ha^{-1}, which with 50% carbon in biomass, is equivalent to about 235 T C ha^{-1}. This is comparable to the estimate by Ter Steege (2001).

Traditionally, tropical rain forests have been considered 'climax' ecosystems, that is, they were assumed fully developed and, on average, not increasing any more in biomass and carbon. However, the first direct eddy correlation measurements in an undisturbed south-west Amazon forest showed that these forests were accumulating carbon at a rate of about one tonne per hectare, per year (Grace et al. (1995)). The explanation offered was that the rise of CO_2 concentrations in the atmosphere acts as fertilizer. Subsequent studies, in several sites, showed a similar phenomenon, with uptake rates being even higher: Malhi et al. (1998) and Carswell et al. (2002) reported rates of 5 TC ha^{-1} y^{-1}, for Central and Eastern Amazonia, respectively, while Araujo et al. (2002) reported even higher rates also for central Amazonia. The latter study, as well as Kruijt et al. (2004) also showed high uncertainty in these measurements, mainly related to poor performance of the methodology at night. The only exception so far using direct flux measurements was shown by Saleska et al. (2003), for a site near Santarem, state of Para, where the forest was reported to be carbon-neutral or even emit carbon at a modest rate. This site was reported to be more disturbed than the others, with much coarse litter present. Taken together, these results point at high spatial variability. They highlight the fact that even 'pristine' tropical forests are never in equilibrium, but always either recently disturbed by tree fall or climatic effects, and emitting carbon, or restoring from disturbance, and absorbing carbon.

Other lines of evidence come from an Amazon-wide effort to re-establish and recensus the many forestry inventory plots across the region, as well as implement new ones, using standard methodologies, where needed (RAINFOR, Malhi et al. (2006)). Although these plots only provide data on dynamics of above ground biomass, and sometimes necromass, and not of roots and SOM, the paired censuses in many more sites than the direct eddy-correlation provide rich and independent data on the magnitude and spatial variation of above-ground carbon dynamics. Malhi et al. (2006) showed a gradient in biomass accumulation from east (0.5 TC $ha^{-1}y^{-1}$) to west (1.5 TC $ha^{-1}y^{-1}$). Also, turn-over and species richness appeared higher in the western Amazon than in the east. The gradient was most strongly correlated with nutrient availability, but also (inversely) with the length of the dry season. Chambers et al. (2004)) performed a detailed study of all flux components in an Amazon forest near Manaus, Brazil. Their conclusion was that net carbon uptake was small.

It can be questioned to what extent these biomass plots are representative for the Amazon forests. It is likely that research plots, also with the direct eddy correlation studies, are situated preferentially in well-developed places, such that recently disturbed areas are underrepresented. It is possible that, if these areas would be sampled representatively, the estimated sink strengths would vanish. Summarising, the uncertainty and variability analyses done on both direct flux studies and inventories highlight the importance of accounting for the disturbance history.

Another aspect of tropical forest carbon storage is whether the soils can and do ultimately store the carbon produced in the biomass. Chambers et al. (2001) argues from a theoretical point of view that Amazon forests can at best accumulate 1 tonne of carbon per hectare and per year.

Savannas

Data on carbon stocks and carbon uptake in savannas are relatively scarce. Recently Grace et al. (2006) published an extensive review, however. Their general conclusion is that savannas can be quite productive, but although the capacity to store carbon underground is often expected to be high, the overall productivity of savannas is lower than tropical rain forests. Below ground there seem to be important differences between the Central Brazilian Cerrados and the Savannas in the north of South America, where the former have more carbon in both live biomass and soil organic matter. The savannas in the Orinoco Llanos and the wet savannas in Lamto, Ivory coast, seem to be most similar to those in the Tresor reserve. This corresponds to an estimated carbon content in live biomass of 5-10 T C ha^{-1} above ground and a similar amount below ground. The amount of SOM varies more than one order of magnitude between all savannas. The only relevant estimate for this study is from the Lamto area, where the carbon content was low, only 18 T ha^{-1}. As this is a wet savanna type, on gley soils, usually associated with peat formation, this seems very low. For annual NPP Grace et al. (2006) mention between 3.5 and 6.5 T C $ha^{-1}y^{-1}$ for these savannas. They also mention that these are likely to be underestimates because below-ground productivity is usually poorly estimated. At the same time it needs to be realized that NPP is not the same as NEP, and hence that the NEP of savannas is likely to be low, especially for those ecosystems that have not recently been disturbed or been subject to fire.

Flux measurement studies similar to those in tropical rain forest exist, but are so far either not applicable to the Tresor situation (e.g., Brazilian Cerrado sites, dry African sites), or not yet producing publications (measurements in the Ilha do Bananal, S.E. Amazon, Brazil, run by the University of Sao Paulo).

Other forest types

Other forest types mentioned in Ter Steege (2001) are not directly comparable to the Tresor area. Values mentioned are, for soils with impeded drainage (swamps) between 400 and 650 TC ha^{-1}, because of the peat layer present. Forests on alluvial soils, near rivers, are estimated at 374 TC ha^{-1}.

Ecosecurities (2002) present an attempt to summarise the biomass contents of forests of the Guyanas. There are no data cited for French Guiana, but apart from Ter Steege (2001) they cite a report from Suriname Tjon (1996), that contains estimates for less well-studied forest types such as swamp forests, savanna and creek forests. Estimating below-ground carbon at a similar amount as above-ground biomass, the estimate for 'high' swamp forests total carbon is only 140 TC ha^{-1}. It is likely that Ter Steege (2001) is correct in assuming organic peat layers, leading to the much higher estimates.

The Ecosecurities (2002) study mentions a value for 'creek' forest, which is likely to be similar to the 'alluvial clay' forests from Ter Steege (2001), also equivalent to about 140 TC ha^{-1} for total carbon. Again, this is much lower than Ter Steege's estimate. In this case, probably the Ecosecurities estimate is closer, because Ter Steege refers to a forest with high numbers of large *Mora excelsa* trees.

Malhi et al. (2004) report on two plots, one seasonally inundated and one swamp, which have an NPP of about 4 T $ha^{-1}y^{-1}$, which is at the high end of productivity in Amazon forests and comparable to the estimates for savannas by Grace et al. (2006). However, these plots are in the more fertile western Amazon. Because of high turn-over rates net ecosystem carbon productivity is expected to be still modest.

Methane emissions

It is important to account for the fact that waterlogged ecosystems, such as swamps and flooded forests, will emit Methane gas from their often anoxic soils along with the absorption of carbon dioxide. Methane emissions are only a small part of the carbon balance, but since methane is 40 times more effective as a greenhouse gas than CO_2, care should be taken to claim benefits from carbon sequestration by inundated forests and savannas. This is not to say that draining them would positively affect the greenhouse gas balance because methane emissions would be reduced. In reality, emissions from drained, decomposing peat and organic soils usually have a larger impact in terms of global warming than the methane emissions from undisturbed swamp.

4 Data sets from French Guiana

Chave et al. (2001) reported on biomass contents and productivity in plots at two research sites in French Guiana: Nouragues, 100 km inland and Piste de Saint-Elie, near the coast in western French Guiana. After thorough uncertainty analysis, assuming 50% of carbon to be below-ground and assuming a carbon content in biomass of 45% the estimated 95% confidence interval ranged from 220 to 325 T C ha^{-1} for the inland site. At the coastal site the estimated carbon content was slightly but not significantly higher, on average about 315 TC ha^{-1}Malhi et al. (2006), however, give a substantially higher estimate for the same site: between 330 and 400 T C ha^{-1}.
Chave et al. (2001) also estimated carbon accumulation at the coastal site, where repeated censuses were available, from 1981 and 1991. Converted to total carbon (above and below-ground), the estimated net ecosystem carbon productivity (NEP) was 1.9 TC $ha^{-1}y^{-1}$ for a plot which included a recovering tree fall gap, and 0.7 TC $ha^{-1}y^{-1}$ for an undisturbed plot. Given that tree fall is a natural disturbance phenomenon, our interpretation of this is that a likely average range for NEP in this area is between 0.5 and 1.5 TC $ha^{-1}y^{-1}$.

There is also one eddy-correlation tower site in French Guiana, near Kourou, which is in the same region as Piste Saint Elie. The first results of this tower seem to point in the same direction as the biomass plots: forests are accumulating carbon at a rate of between 1 and 1.5 TC $ha^{-1}y^{-1}$.

The plots at Nouragues and Piste Sainte Elie are likely to differ substantially from Tresor in soils and vegetation. Both sites are on older, igneous bedrock with a layer of weathered material (loam, sand) on top Ek et al. (2000). In contrast, the Tresor reserve, although based upon the same geological formations, is covered in lateritic crust (top of the hills) and alluvial sediments (bottom of reserve). Tresor is reported to be richer in minerals than the other two sites (Chave, pers. Comm.). Also, because of orographic effects, Tresor is exceptionally wet. Annual rainfall is reported to be as high as 4000 mm y^{-1}.

Apart from data of study sites in the region, one inventory plot inside the reserve, on the lateritic plateau, has been described in 2003, allowing a one-time biomass calculation. As the trees were not marked, repetition of these measurements, hence calculation of carbon accumulation, is not possible Ter Steege et al. (2003). We made a first-order estimate from these plot data[2], resulting in the high estimate of 475 TC

[2] The methodology followed was as follows:
- We used a list of individuals >10 cm Diameter at Breast Height (DBH), with genus and (mostly) species
- We converted the DBH into tree volume, using the simple equation from (Chave, J., C. Andalo, et al. (2005). "Tree allometry and improved estimation of carbon stocks and balance in tropical forests." Oecologia **145**(1): 87-99). for tropical moist forests without tree height as input. This comes down to a regression of total tree mass on DBH for tropical plots (continued on next page)

ha^{-1} . This estimate exceeds the range of estimates in the sample of 10 plots from Nouragues (416 TC ha^{-1}). It is possible that the one-sample Tresor plot is only high by chance. However, this does suggest that conditions for productivity are favorable, even at the lateritic plateau.

Other data available on the Tresor reserve include data on the species richness, through various inventories and temporary inventory plots. This includes studies on the main vegetation types (Ek et al. (2000)), on the slopes and gullies (Ek et al. (2004)), and on the savannas (Ek et al. (2003)). Also some detailed analyses are available on the physical geography (geology, geomorphology, soils, hydrology) of the reserve (Doomen (2003)). These data are very valuable for assessing the carbon contents of the reserve if they can be used to link the reserve to other studies in the tropics, where more information may be available on carbon dynamics. Clearly lacking is, however, detailed information on soil organic contents and peat.

- For each species, we assigned an estimated oven-dried wood density, extracted from various sources (data base Chave et al pers comm, internet sources), and in case no density could be assigned at species or genus level, we assumed the plot average.
- For each tree volume we multiplied tree volume with density and added this up over the 1 ha plot.
- finally we assumed 45% carbon in dry biomass, and further assumed that 50% of above- plus below-ground carbon is above ground, hence we multipled above ground carbon by a factor of 2

5 Best guess and uncertainty for carbon stocks and carbon sequestration in Tresor

Ek et al. (2000) give an overview and a classification of the vegetation types in the Tresor reserve. Also this report is the only source that informs about the relative representation, in terms of surface areas, of the different vegetations in the reserve. For the purposes of estimating the carbon budgets of the reserve, we have summarized this information together with estimated carbon content and ecosystem carbon productivity, in Table 1.

Table 1 – proportional representation of ecosystem types in Tresor and associated estimates for carbon content and productivity.

Combined types#	Proportion represented (ha)#	Carbon content ($T\ ha^{-1}$)$	Total carbon Tresor (kT)$	Net carbon sequestration rate ($T\ ha^{-1}y^{-1}$)$	Total sequestration Tresor ($T\ y^{-1}$)$
Plateau forest	14	300-450	4.2 - 6.3	0 - 0.5	0 - 7
Forest on slopes	890	400-500	356 - 445	0.5 - 1.5	445 - 1335
Temporarily inundated forest	548	140-300	76.7 - 164.4	0 – 1.0	0 - 548
Swamp forest	758	140-250	106.1 - 189.5	0 – 1.0	0 - 758
Forest on isolated hills	37	350-450	13 - 16.7	1.0 -1.5	37 - 55.5
Savannas	232	20-30	4.6 – 7	0 – 1.0	0 - 232
TOTAL	2479		561 – 829		480 - 2940

# from Ek et al. (2000), types combined
$ estimate in this report, based on literature mentioned.

The specification and justification for these forest types is the following:

- *Forests on the lateritic plateau* are the only ones that are represented by a biomass sample plot (see previous section). Although Ter Steege (2001) assigns rather low carbon content estimates to this forest type, both the plot in Tresor and the data from Chave et al. (2001) suggest much higher biomass. Because of likely past disturbance, however, this forest may be recovering in places and for that reason may be accumulating carbon.
- *Forests on slopes* contribute most to the reserve and contain both gentle and steep slopes, but the former are quantitatively completely dominant. This forest is described as mature, like the plateau forest, but better developed (taller, possibly higher mean Diameter at Breast Height (DBH)). This seems in agreement with the qualitative assessment that the 'foothill forests' are most productive and most well developed (V. Lukkien, pers comm.). Because these forests are situated along the slope, they are likely to receive most of the exceptionally high rainfall in the reserve, and to be very dynamic. This may lead to high productivity, but also high turn-over rates, and substantial

lateral (down-hill) movement of soil and organic material, Therefore we have to be careful in not overstating this forest's biomass and productivity.

- *Temporarily inundated forest,* according to Ek et al. (2000), is also well represented. It is rather hard to classify this in terms of productivity. The description mentions limited stature of trees (up to 30 m), and relatively high proportions of thin trees. They are likely of medium productivity, but could potentially store large quantities of carbon in their soils. However there is no mention of peat layers in the available documentation. For this reason we consider the estimate from Ecosecurities (2002), for 'Creek forest' of Surinam as most representative. The productivity and turn-over figures mentioned by Malhi et al. (2004) for western Amazonian inundated forests may be used with care.
- *Swamp forest* is described as being not very different from swamp forests found throughout the Guyanas. The presence of a peat layer is not mentioned in the available Tresor documentation. Therefore, the estimate by Ecosecurities (2002) for Surinam is likely to be representative.
- *Forest on isolated hills* is described as mature and very well developed, with several tall emergent trees. Therefore we may rank it at the high end with respect to biomass contents at least as productive as the slope forests. The areal extent of this forest type is, however, very limited.
- *Savannas*, finally, constitute a substantial part of the reserve. The studies available for Tresor on this vegetation (Ek et al. (2003); Doomen (2003)) show several different types, but also show that all but a few small patches are permanently or almost permanently waterlogged. Soils analysis shows relatively acidic, clayey, soils, with moderate organic carbon content. Only one exception was found, along the river, where organic content was high. In all savannas of Tresor, the vegetation was low, dominated by grasses and short palms. No traces of charcoal were found anywhere, so we must assume that the savannas are stable, not disturbed and controlled by the high water levels. It seems most appropriate to represent this part of Tresor, for the purpose of carbon estimation, by data from the Venezuelan Orinoco savannas and savannas from Ivory coast (Lamto).

In comparison to other tropical forests, the Tresor reserve shows extreme spatial variation in carbon content. Because of the sloping terrain and the high rainfall, it can be expected that the values at the high end of this variation are also high for rainforests in the region. The savannas have low carbon content as they consist of grassland and low palms, and do not seem to accumulate much carbon in their soils.

In terms of net ecosystem carbon sequestration, the mean estimate for the whole reserve is between 0.1 and 1.1 Tonne per hectare per year, based upon only very scare evidence. Grace et al. (2006) estimated a possible net carbon sequestration rate for undisturbed tropical forests and savannas, purely on the basis of response to rising atmospheric CO_2 concentrations, mean NPP and mean residence times. This rate is of order 0.1 to 0.4 TC $ha^{-1}y^{-1}$, suggesting that for Tresor it would be prudent to assume the lower-end estimate. Having said that, even in Tresor past disturbances have occurred and other climatic change factors than purely CO_2 increase are surely affecting productivity. Therefore, and also in the light of the much higher estimates from direct flux measurements in the Amazon, an estimated average annual carbon uptake rate of 1 T $ha^{-1}y^{-1}$ is not outside of the range of possibilities.

6 Possibilities to gain income from carbon offsets under Kyoto in Tresor

In December 1997 Parties to the United Nations Framework Convention on Climate Change (UNFCCC) agreed through the Kyoto Protocol (KP), amongst many other things, that industrialised countries and countries with economies in transition to a market economy – together known as "Annex I Parties" as listed in Annex I to the Kyoto Protocol – were to reduce their overall emissions of six greenhouse gases by at least 5% below 1990 levels between 2008 and 2012, with specific targets varying from country to country.

UNFCCC and its KP, is rather fragmented and sometimes considered flawed. The main reason for this is that the Emission Reduction Commitments under the KP were already agreed when Parties considered how Land Use Change and Forestry (LULUCF) could be used to achieve those targets. This gave Parties the opportunity to fix via the elaboration of certain rules.

The result is the current set of complex rules and various caps and limitations in the use of LULUCF and subsequent inefficient and costly monitoring and reporting obligations. Partly the complexity is driven by characteristics of the biosphere such as its dynamics, high natural variability, the large uncertainty, i.e. a legally binding commitment is combined with a very dynamic and almost uncontrollable system.

Currently, the only options applicable to the first Commitment Period (2008-2012) that have relation to tropical countries are the Afforestation and Reforestation options under the Clean Development Mechanism (CDM, e.g .Grace et al. (2003)). Thus the preservation of existing stocks of carbon through conservation of tropical forests cannot lead to approved carbon credits during the period 2008 – 2012.

However the article 3.9 of the KP states that processes to elaborate on regimes for the second Commitment Period can start in 2005. One of these processes is an agenda item that was introduced to the COP at its 11th session in Montreal 2005: "Emissions from deforestation in Developing Countries". The community is convinced of the importance of such a mechanism, as it is acknowledged that about 20-25 of global emissions come from deforestation, therefore, here lies an attractive, albeit short-term, option to reduce further increases of CO_2 in the atmosphere.

This means that discussions have started on how to include conservation of existing stocks tropical forests. Reducing Emissions from Deforestation and Degradation (REDD) is now a hot topic in the discussions; but only for after 2012. One of the latest proposals on implementing REDD is the so-called 'Compensated Reduction' scheme. Such a scheme would operate at the country (signatory to Kyoto) base, which would receive compensation (credits) when it would be established that deforestation rates in such a country have fallen below, and stay below, a previously defined historical level. Because this is at a country scale this would require a high level, frequent monitoring system, probably based upon a combination of remote sensing and ground observations. Further, there will have to be mechanisms within the countries to achieve lowering deforestation rates without negative environmental or social side-effects. Quite likely, this will be through schemes in which land owners successful in protection are compensated from the national level. This will require substantial investment from beforehand, either from government or private sources, to achieve forest protection and to provide economic alternatives for the population.

In the specific case of French Guiana, the situation might be different, as this country is part of French territory: an Annex 1 signatory to the Kyoto Protocol. France has to report their full carbon balance to the UNFCCC, including emissions from deforestation in French Guiana. This means that for French Guiana, possible new mechanisms will not apply, but instead, local stakeholders and land owners might already benefit from protecting forest from disappearing. France has included forest management in its accounting system, hoping to achieve benefits from it, and as such should be interested to support conservation actions. In this report we do not detail which mechanisms or subsidies exist within France and its overseas territories to stimulate forest protection by private entities, but it is likely that funds are available. One has to note, however, that in the total carbon emissions of France, deforestation in French Guiana is only a minor part (about 1.8%), hence it is likely that French government has other priorities. On the other hand, it is also recognised that this rate in increasing at an alarming rate (about 57% increase of 1.1% in 1990), hence in need of limitation.

Whatever the exact procedures will be on accounting for carbon conserved through avoiding deforestation, it is very likely that there will always be a requirement to specify a baseline against which avoided emissions can be calculated. In other words, those claiming the credits will have to give a plausible estimate of what the deforestation emissions would have been without the conservation actions taken. Methods to achieve this include investigating and monitoring the following:

- To assess the baseline, patterns and processes of land-use conversions and other disturbances in the surroundings of the reserve, impacts of national policies and economy
- 'leakage' resulting from the conservation and other management: displacement of disturbance activities out of the reserve to elsewhere.
- the areal extent of vegetation as well as carbon stocks and dynamics in them under the management actions taken,

There are several examples of tropical forest reserves already under this kind of management, where investors are assuming that credits will be allowed at some point in the future, albeit in 'Annex 2' (developing) countries. For the Noel Kempf park, Bolivia, for example, carbon is conserved under such a scheme. Carbon stocks have been inventoried, and studies are being made of deforestation rates surrounding the park, using remote sensing information.

In the case of Tresor and French Guyana, deforestation rates and land use change pressure is not high. However, especially in the coastal range where Tresor is located, gold mining is a very important driver of disturbance (Fig. 2). Additionally, there is pressure from smallholder agriculture and also, day tourism from nearby Cayenne. (V. Lukkien, pers comm.). To make conservation a cost-effective alternative for gold mining, is of course not an easy task, and will require the combination of several activities and a combined portfolio of ecosystem services, including carbon protection, biodiversity, wetlands, hydrological services, tourism and support of local communities to develop alternative means of existence.

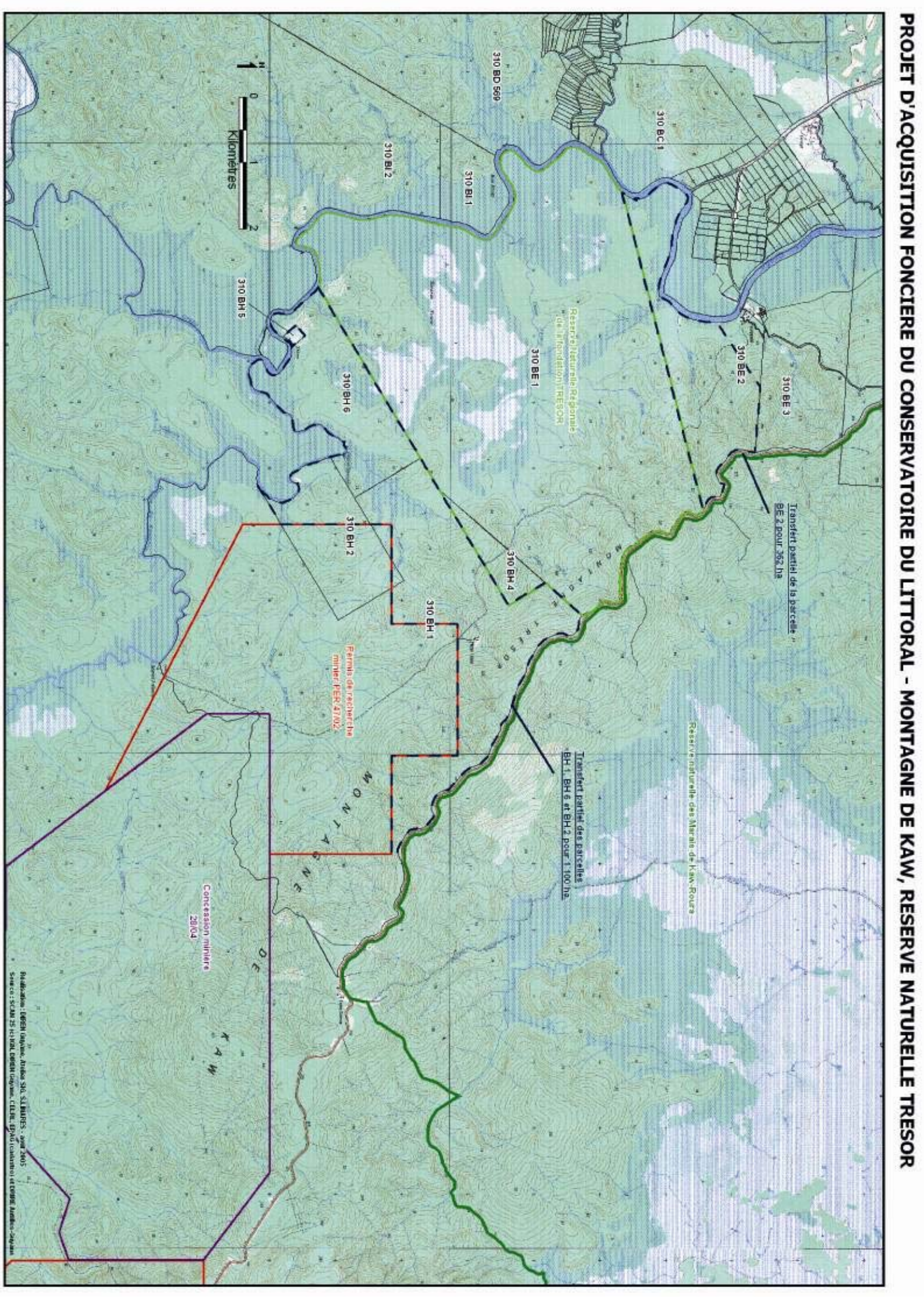

Figure 2 - map of the Trésor reserve and surroundings, showing its boundaries and adjacent (prospective) concessions.

7 Conclusions and advice on further research to narrow down carbon estimates

Despite substantial research efforts throughout the Amazon, the variability in natural vegetation types: forests, wetlands, savannas, and the species richness in these types, is enormous, such that there is far too little information available to estimate carbon contents of an area purely on the basis of a vegetation description. Apart from this, the amount of decomposing carbon in soils can be quite independent of the above-ground vegetation, making it even more difficult to assess carbon stocks on the basis of a small number of soil surveys.

Nevertheless, although variability in vegetations is large, the observed range of carbon contents in vegetations across the Amazon as well as their carbon uptake rates is not infinite, and an order-of-magnitude estimate can be made. In this report, we estimated a total carbon content of between 561 and 829 kilotonnes of carbon on the 2479 hectares of the Tresor reserve. Apart from this, and not documented in this report, other reports abundantly demonstrate the very high value of the reserve in terms of diversity, in species, ecosystem types, habitats and landscapes, that require careful protection not to be lost.

Under current regulations in the Kyoto protocol, and given that French Guiana is French national territory there are no possibilities to generate income from conserving the carbon stocks in the Tresor reserve, except if French government, who has to report its territorial carbon balance to the UNFCCC, could be motivated to assist Tresor in conserving carbon. As stated in the previous section, in order to generate potential revenue from the reserve under any scheme, its ecosystem functions are in need of quantification. In the case of carbon, this means both quantifying what is available (stocks and flows) and quantifying what would disappear if no action would be taken (baseline). Additionally, possible negative side-effects of (conservation) action also need to be quantified (leakage).

Baseline and leakage studies would have to be set up systematically in French Guiana, especially in the NE region where Tresor is. Stocks and flows studies need to be done in the reserve itself or at least in its close vicinity.

More specifically, we recommend research action as listed below in or around the reserve, within each section listed in order of priority.

Baseline and leakage studies

- monitoring of current and reconstructing past deforestation rates and patterns, mining activities, and improving the understanding of their drivers. This knowledge should be implemented in a predictive land-use model (e.g., CLUE-S, Verburg et al. (2002) that could extrapolate in space and time what would happen to the forest reserve under different external driver scenarios.

- The same modeling tool could then be implemented to assess the effects of sustained conservation of the reserve, on surrounding or regional deforestation rates, through displacement of people and funds.
- Research in alternative land use scenarios and community development could contribute to reduce leakage.
- Specific geographical, demographic or socio-economical studies in the mechanisms of land-use processes, and in the interaction of social processes with ecology and climate, could be performed to strengthen the overall assessments and modeling, and to generate critical mass for external research investments.

Carbon studies

- As stated in section 4, there exists one inventory plot on the basis of which a carbon stock could be calculated. However, the trees in this plot were not labeled or georeferenced, hence, it is not possible to re-census this plot to assess carbon accumulation. Also, dead material, litter fall, or below-ground information was not collected. Quantifying these components can make a critical difference in reducing the uncertainty in the carbon content of a plot. We recommend to install a number of well-designed permanent sampling plots, at least three to five in each dominant vegetation type. Guidelines as mentioned in the IPCC 'Good practice guidance'(Nabuurs et al. (2004)) or the RAINFOR protocol (Malhi et al. (2006)) should be followed. If plot establishment inside the reserve is less desirable from a conservation point of view, locations should be selected in nearby forest or buffer zones.
- To support these plot studies, information on wood densities and relationships between tree Diameter at Breast Height (DBH) and total biomass needs to be collected especially for those species that have not been documented so far (Chave et al. (2005)).
- In addition, at least some first-order information should be obtained on below-ground carbon. Assessment of the root-shoot ratios in the most important vegetation types (using excavation plots –not a small task!) and sampling of soil organic carbon content and possible existence and extent of peat layers should be instigated.
- Once this kind of knowledge has been generated, the reserve is in a good position to start estimating the carbon stocks and dynamics using simple models such as CO2-FIX (Masera et al. (2003))
- To assess the full-ecosystem carbon balance, including vegetation and soils, it is possible to install eddy correlation measurements (see section 2 and 3). This would be particularly useful in the savanna areas, as only short towers would be needed and information on these types is particularly scarce.
- As the steep slopes and gullies presents a very dynamic environment, lateral transport or accumulation of carbon should be assessed: downhill dead woody biomass, washing down of topsoils, leaching of dissolved organic carbon in ground water enhance the dynamic turnover of biomass and carbon, and can be important if the carbon balances of the separate vegetation/landscape parts are to be understood properly.

- Surveying the magnitude of current respiration and decomposition rates from soils in the various vegetation components is a useful, quick and non-destructive way to assess the relative strengths of soil carbon pools.
- Using analysis of stable and unstable carbon isotopes (^{13}C, ^{14}C) in organic matter the turn-over rates of carbon in soils can be assessed.
- Remote sensing methods to assess above-ground carbon stocks should be assessed. This assessment should range from broad-scale, visual sources such a Landsat, IKONOS and Spot, to more technical methodologies such as Synthetic Aperture Radar (SAR) and laser/Lidar (Light Detection And Ranging) data, that attempt to estimate vegetation volume and biomass.
- **In general** it is important to foster scientific studies in or near the park to generate critical mass and attract external investment of research(ers) who are attracted by a data-rich research object.

Studies on ecosystem services

- Apart from the carbon balance and its direct potential economic benefits, the importance of other services from the reserve, in (bio)diversity, climate and hydrology (regulating regional water availability and temperature variability) need to be assessed, through a variety of methodologies.

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Appendix 1 – list of abbreviations

CDM – Clean Development Mechanism
COP – Conference of the Parties
DBH – Diameter at Breast Height
NPP – Net Primary Production
NEP – Net Ecosystem Productivity
SOM – Soil Organic Matter
UNFCCC – United Nations Framework Convention on Climate Change
KP – Kyoto Protocol
REDD - Reduced Emissions from Deforestation and Degradation
T C ha^{-1} – Tonne of Carbon per hectare
LULUCF – Land Use Change and Forestry