Project WWF Grassland IKI:

"Taking Land Use Change Out of Savannahs and Grasslands through Policy Engagement, Land Use Planning and Best Management Practices"

# A Carbon Map for the Project Region in Paraguay

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## 1. Introduction

A complete carbon map shows the carbon stored in all types of biomass and soil within each spatial unit. It is a useful tool for spatial planning and environmental protection purposes which intends to include the protection of natural carbon sinks. In addition, such maps can be used to determine the amount of direct land use change (LUC) emissions caused by an expansion into unused, natural land. In addition, the use of maps which determine forest biomass carbon has already become a common tool for countries preparing for UN-REDD+ (e.g., Gibbs et al. 2007). In the UN-REDD+ context, carbon maps can be used to determine a baseline for the payments for forest preservation and to monitor deforestation over time.

When comparing different carbon maps, one has to be careful to compare only maps including the same carbon pools. The different carbon pools are above ground living biomass, below ground living biomass, dead organic matter (all types of dead biomass) and the soil. Three examples of global carbon maps for tropical above ground forest biomass can be found in the works of Saatchi et al. (2011), Baccini et al. (2012) and Avitabile et al. (2015). Mitchard et al. (2013) compare the Saatchi et al. (2011) and Baccini et al. (2015) maps. These global maps focus on determining global carbon stocks in tropical forest above-ground biomass by using active sensors. Ruesch and Gibbs (2008) calculated a global map of biomass carbon stored in above- and below-ground living biomass using the International Panel on Climate Change Good Practice Guidance for reporting national greenhouse gas inventories (IPCC-Guidelines) with a resolution of 1 km for the year 2000. Scharlemann et al. (2009) use the map of Ruesch and Gibbs (2008) and combine it with a soil organic carbon map based on the Harmonized World Soil Database (HWSD) version 1.1 (FAO/IIASA/ISRIC/ISS-CAS/JRC 2009) to calculate a global carbon map with a nominal spatial resolution of 1km.

The European Union Renewable Energy Directive (EU-RED) requires a determination of direct land use change emissions caused by biomass production for biofuel production. A carbon map can serve as a benchmark for calculating these direct land use change emissions. Lange and Suarez (2013) and Söder (2014), calculated such a benchmark carbon map in line with the EU-RED requirements for the Llanos Orientales in Colombia and the Brazilian Cerrado respectively. These carbon maps include all carbon pools.

The purpose of this case study is to produce a carbon map including all carbon pools for the project region of the WWF Grassland IKI project “Land Use Change in Savannahs and Grasslands – Approaches by Policy Engagement, Land Use Planning and Best Management Practices”. The project region consist of western Paraguay encompassing the ecoregions the Pantanal, the Cerrado, the Chaco Húmedo, Chaco Seco and the Médanos. This report describes the methodology and data sets used to produce the carbon map.

## 2. Methodology

The method used for calculating carbon maps in this section builds upon the EU-RED framework for calculating carbon emissions from direct land use change as presented in Carré et al. (2010) which builds upon the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006). A similar description of the method can be found in Lange and Suarez (2013) and Söder (2014).

To determine the carbon stock $(CS_{il})$ per unit area *i* associated with a particular land use *l,* one must summarize the carbon stock stored in the soil $(SOCact_{il})$ and biomass $(Cbio_{il})$ and then multiply the result by the hectares per unit area $(A_i)$ (see equation 1). [1]

$$CS_{il} = (SOCact_{il} + Cbio_{il}) \times A_i \qquad (1)$$

The following two sections present the method and data separately for the carbon stocks in biomass and soil.

### a. Carbon in Biomass

#### i. Methodology

For the calculation of carbon stock stored in biomass $(Cbio_{il})$ it is assumed that it can be subdivided into a carbon stock stored in above-ground biomass $(C_{AGB})$, below-ground biomass $(C_{BGB})$ and dead organic matter $(C_{DOM})$[2]. The carbon stock stored in below ground biomass is often calculated by applying a constant ratio factor $(R)$ to the carbon stock stored in above-ground biomass.

$$Cbio_{il} = C_{AGB} + C_{BGB} + C_{DOM} \qquad (2)$$

[1] Normally, one uses one hectare as the unit area.

$$C_{BGB} = C_{AGB} \times R \quad (3)$$

Different methods are available for deriving the carbon stock stored in biomass. A comparison of different methods can be found in Goetz et al. (2009) or Wertz-Kanounnikoff (2008). The most basic method for producers is to produce ground-based inventory data on the land cover classes present on their land, combined with field surveys on the related carbon stocks (Wertz-Kanounnikoff 2008).

The most commonly used method is to use a land cover map based on satellite images and to combine it with available carbon values representing the average carbon value for each land cover class in the map. This method corresponds to the Tier 1 method of the IPCC 2006 adopted by the European Commission for the EU-RED (Carré et al. (2010)). In practice this methodology is problematic in case that suitable average carbon values are not available. Carbon values provided by case studies in the scientific literature do not necessarily adequately represent the biomes in the region (because case studies were conducted in other regions), or overestimate the carbon stored in premature stands (Gibbs et al. 2007, Wertz-Kanounnikoff 2008, Goetz et al. 2009). In addition, the classification systems of the land cover map and the case studies need to match in order to derive reasonable average carbon values per land cover class. It follows that the accuracy of the resulting carbon maps depends on the availability of regional carbon values for the land cover classes in the map.[i]

In this study we use a combination of ground-based inventory data and a land cover map combined with carbon values by calculating the average carbon values for each land cover class in the land cover map from ground based inventory data. The next section introduces the land cover map and the data set on ground based inventory data.

### ii. The land cover map

For the study regions we use a land cover map derived by DLR (Deutsches Zentrum für Luft- und Raumfahrt) mainly based on Landsat imagery. A detailed description of the methodology and datasets underlying this map can be found in another report of the SULU project (Da Ponte 2017). The land cover map encompasses the project region of the Sulu project in the west of Paraguay. The ecoregions present in the study area are the Pantanal, the Cerrado, the

Chaco Húmedo, Chaco Seco and the Médanos. The map derived by Da Ponte (2017) includes the following land cover classes:

Table 1: Land Cover Classes in the DLR Land Cover Map

| | |
|---|---|
| Hydrophilic Forest | Forest classified along depressions of water streams with high values of NDWI in the surface. Forests related to the presence of water (temporary or not) like waterbodies and high-water tables. |
| Dry forest | Dense continuous forest lands. Chaco Forest, Cerrado Forest and/or a transition between these two ecosystems. |
| Agricultural fields | Identified mainly due to its shape (recognized) and spectral difference with other classes. Has been recognized mainly as artificial pastures. |
| Savannas and Shrublands | Dry lands with continuous grasslands or cover by disperse trees not classified as forest |
| Flooded savannas | Lands prone to flood with continuous grasslands or cover by disperse trees not classified as forest |
| Marshland | Riparian grasses almost permanently flooded. (High values of NDWI) |
| Wetland (temporary flooded) | Estimated based on Sentinel 1 water masks showing water for more than 10% of available acquisitions |
| Waterbodies | water bodies with permanent open water surface |
| Urban areas | settlements, and other built-up area (obtained from the GUF ( 12 m resolution)) |

### iii. Carbon values

Data to calculate average carbon stocks for each land cover class in the map are available from the National Forest Inventory (Inventario Florestal Nacional de Paraguay IFN conducted under the National Program on UN-REDD (Programa ONU_REDD) of Paraguay and the National System of Monitoring and Forest Information (Sistema Nacional de Monitoreo e Información Florestal SNIF). The study was realized by the National Forest Institute (Instituto Forestal Nacional, the Environmental Secretary of Paraguay (Secretaía del Ambiente de la Republica del Paraguay) and the Federation for the self determination of the indigenous people (Federación por la Autodeterminación de los Pueblos Indígenas FAPI).

The data of the forest inventory are available as georeferenced sample points which contain the result of the local analysis at the particular sample. Relevant information for the carbon mapping is the following data within the IFN (all values in tons per hectare):

1. Total carbon in living tree biomass (above and below ground) (Carbono de biomasa total de arboles vivos);
2. Total carbon in living coppice biomass (underwood) (Carbono de biomasa de sotobosque);
3. Total carbon in dead organic matter of dead trees (above and below ground)(Carbono de necromasa total de arboles muertos en pie);
4. Total carbon in dead organic matter of dead ground wood (Carbono de necromasa total de madera muerta caida);
5. Total carbon in dead organic matter of dead stumps (Carbono de necromasa de tocones);
6. Total carbon in dead organic matter of dead leaves and branches ( Carbono de biomasa de detritus e hojarazca);
7. Total carbon in the first 50 cm of the soil (Carbono orgánico en suelo hasta 50 cm de profundidad.

In order to determine total carbon in living biomass, we summarize the carbon values for living tree and underwood biomass (1. and 2.). For the calculation of total carbon in dead organic matter (DOM) we summarize the carbon values of dead trees, ground wood, stumps and leaves and branches (3.-6.). For the generation of the map, we use only the sum of all stocks for carbon in total biomass.

### iv. Combining the land cover map with the carbon values

In order to relate the values of the sample points with the land cover classes of the land cover map we use ArcGIS software to overlay both datasets. As a first step, we extract for each sample point of the IFN the underlying spatially explicit land cover class. We do this by using the DLR land cover map of 2016 since it is closer to the date of generation of the IFN (~2015). As a second step, we derive basic statistics for each land cover class over all sample points within the respective land cover class (see table 2 for the mean values for all types of biomass carbon stocks and table 3 for additional statistics for the carbon stock in total biomass). The basic statistics include the mean (average) carbon value over all sample points and the median value as a more outlier robust estimate. In order to provide information on the variety of carbon values across IFN sample points, we also include the standard deviation.

The forest inventory intents to quantify carbon in forests and it is therefore questionable whether the IFN values can be used to estimate average carbon values for the non- forest land cover classes as well. However, several of the sample IFN sample points fall within no-forest land cover classes. Within these land cover classes forest stands are not fully absent but do not represent the dominant vegetation cover (e.g. like palm stands in the flooded savannahs). Thus, on the one hand, taking the values of the IFN also for the non-forest land cover classes could be seen as a precautionary approach in order to capture also areas of higher carbon within these land cover classes. On the other hand, the IFN captures also carbon in the coppice biomass and therefore captures not only carbon stored in trees. In addition, when analyzing the resulting average carbon values of the IFN for these land cover classes it shows that they are much lower compared to the forest land cover classes (see table 3 e.g. 55.1 $tCha^{-1}$ for hydrophilic forest compared to 13.5 $tCha^{-1}$ for savannahs and shrublands). Moreover, comparing them with the IPCC 2006 standard values for grassland (8 tC/ha) and shrubland (~56tC/ha), average values resulting from IFN for the non-forest land cover classes seem to reasonably capture carbon in non-forest biomass even though they might slightly overestimate carbon values for pixels with pure low grassland vegetation.

The IFN does not take samples on agricultural fields. For this land cover class we take the biomass carbon value from the IPCC 2006 for (planted) grassland vegetation since the DLR identifies most of these fields as artificial pastures. We assume that these grasslands are mature and not recently planted. Since the IPCC differentiates the carbon values for grassland vegetation by climate regime, we use the IPCC Climate map (Fischer et al. 2008) to identify the pixels with tropical wet and tropical try climate.

As a final step we link the average carbon values of table 2 (by summarizing the mean carbon values for living biomass and dead organic matter which corresponds to $Cbio_{il}$ in equation 2) with the land cover map of DLR of 2016 and 2018 and thus derive two maps showing average carbon stocks in above and below ground living and dead biomass for 2016 and 2018.

Table 2: Average Carbon Stocks in Different Biomass Types

| All values in tC $ha^{-1}$ | Biomass | | | Total |
|---|---|---|---|---|
| | Living | | Dead | |
| Land Cover Class | Above Ground | Below Ground | Organic Matter | |
| Hydrophilic forest | 33.6 | 14.3 | 7.2 | 55.1 |
| Dry forest | 27.7 | 11.6 | 6.4 | 45.7 |
| Savannahs and shrubland | 8.7 | 2.7 | 2.2 | 13.5 |
| Flooded savannahs | 17.2 | 1.4 | 1.9 | 20.5 |
| Wetland and marshland | 14.8 | 0.0 | 3.0 | 17.9 |
| Agricultural fields | Total Carbon (IPCC 2006: 4 (tropical dry) 8 (tropical wet) | | | |

Table 3: Basic Statistics on the IFN Sample Values for Carbon Stocks in Total Biomass for the DLR Land Cover Classes

| Land Cover Class | Number of IFN Sample Points | mean | median | standard deviaton |
|---|---|---|---|---|
| Hydrophilic forest | 5 | 55.1 | 48.4 | 11.5 |
| Dry forest | 132 | 45.7 | 40.1 | 23.7 |
| Savannahs and shrubland | 4 | 13.5 | 12.5 | 2.1 |
| Flooded savannahs | 54 | 20.5 | 17.6 | 11.4 |
| Wetland and marshland | 4 | 17.9 | 17.9 | 1.3 |

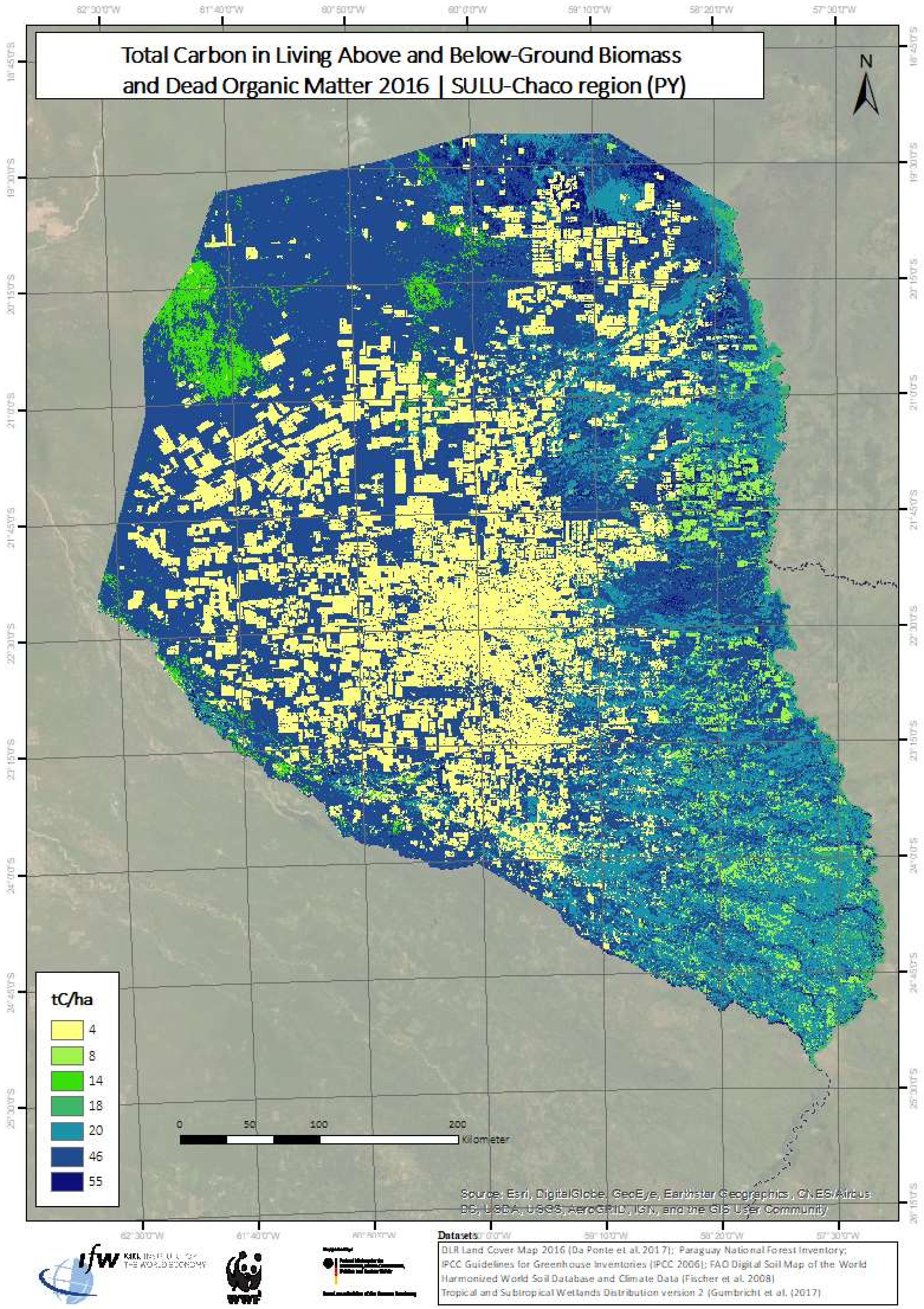


Figure 1: Carbon Map for Carbon Stocks in Total Biomass 2016

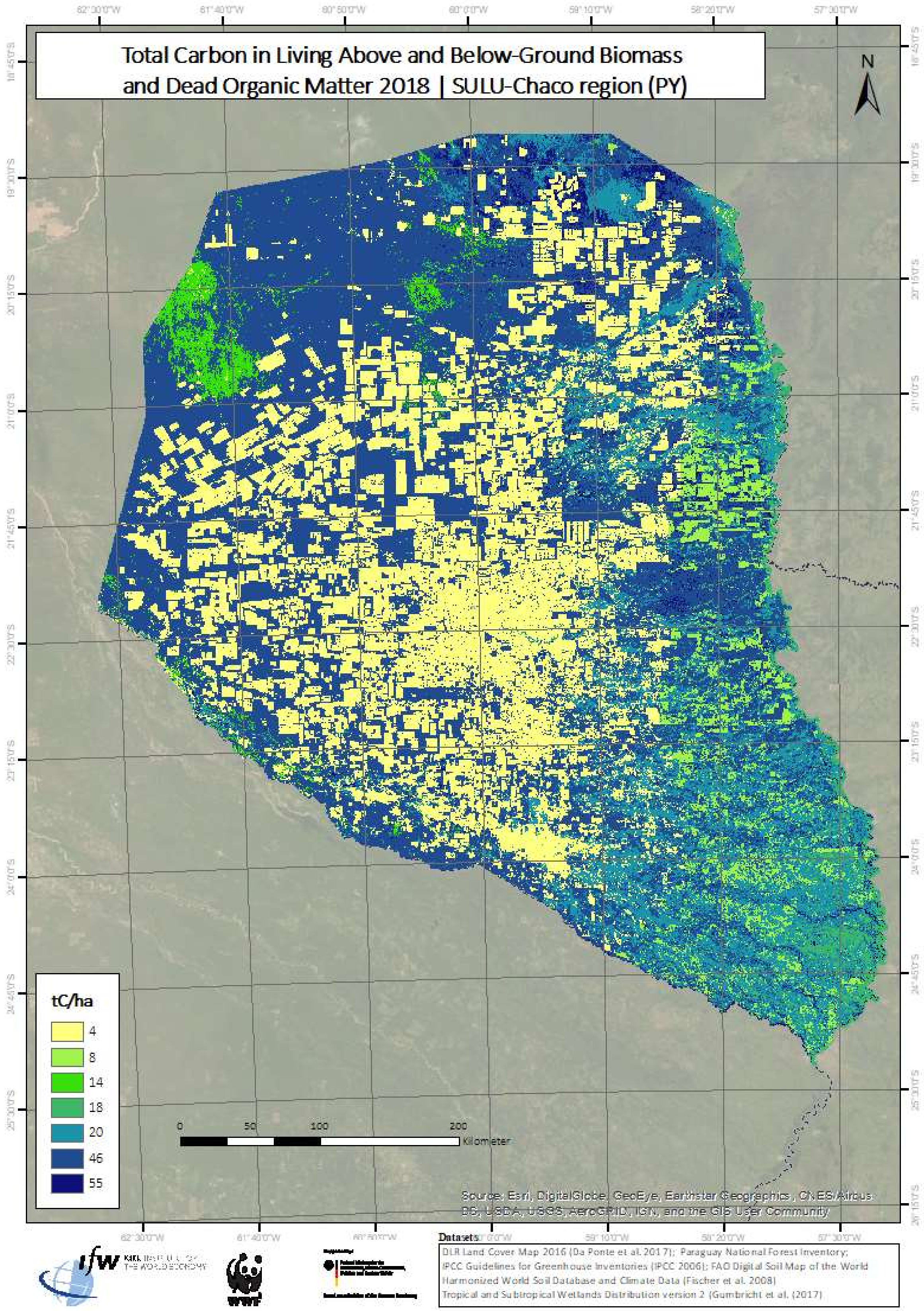


Figure 2: Carbon Map for Carbon Stocks in Total Biomass 2018

#### b. Soil Carbon in Mineral Soils

##### i. Methodology

After calculating the carbon stocks in living and dead biomass, calculation of the carbon in the soil, which is not part of the living biomass of roots, remains necessary. The carbon stock stored in the soil changes once the land is used for agricultural production. Thus, for the calculation of the present carbon stock stored in the soil, information from the land cover map must be combined with a soil map. Here, we only consider the Tier 1 approach of the IPCC 2006 which modeled soil carbon stocks influenced by climate, soil type, land use, management practices and inputs.

The method for calculating carbon stocks stored in the soil is based on the assumption that the actual carbon stock stored in the soil ($SOCact_{il}$) is the product of the carbon stock under natural land cover ($SOCref_i$) and the influence of land use ($Flu_l$), management ($Fmg_l$) and input factors ($Fi_{\ l}$), which can increase or decrease the carbon content under natural land cover.[3]

$$SOCact_{il}\left(\frac{tC}{ha}\right) = SOCref_i\left(\frac{tC}{ha}\right) \times Flu_l \times Fmg_l \times Fi_{\ l} \qquad (4)$$

For all natural vegetation cover without human interference these factors are all one and therefore the reference (natural) soil carbon content and the actual soil carbon content are equal. Thus, for the given land cover map, the calculation of equation 4 is only necessary for the agricultural fields. For these fields the hypothetical carbon stock under natural land cover $SOCref_{il}$ must be adjusted with the soil use factors which indicate how much the land use type, the management practice and the inputs change the carbon stock stored in the soil compared to a natural land cover. The categories for the land use type factor include annual cropland, perennial cropland, pasture or forest plantations. The categories for the management factor mainly account for the tillage regime, while the input factor accounts for the amount of fertilizer/manure applied to the production. However, since we lack spatially explicit information on the management regime on the artificial pastures (e.g. fertilizer input or other improvements as well as the potential degree of degradation) we assume an average

[3] The EU Background Guide gives more details and data about land cover classes not explicitly covered by the IPCC 2006 e.g. savannahs and degraded land.

management system. According to the IPCC 2006 this implies factors of one as well (see table 4). This results in the assumption, that agricultural activities do not change the natural carbon content in the soil in the project regions (neither decrease it e.g. by tillage activities or degradation nor increases it via fertilizer input or irrigation).

Table 4: Relative Carbon Stock Change Factors for Grassland taken from IPCC (2006)

TABLE 6.2
RELATIVE STOCK CHANGE FACTORS FOR GRASSLAND MANAGEMENT

| Factor | Level | Climate regime | IPCC default | Error [1,2] | Definition |
|---|---|---|---|---|---|
| Land use ($F_{LU}$) | All | All | 1.0 | NA | All permanent grassland is assigned a land-use factor of 1. |
| Management ($F_{MG}$) | Nominally managed (non –degraded) | All | 1.0 | NA | Represents non-degraded and sustainably managed grassland, but without significant management improvements. |
| Management ($F_{MG}$) | Moderately degraded grassland | Temperate /Boreal | 0.95 | ± 13% | Represents overgrazed or moderately degraded grassland, with somewhat reduced productivity (relative to the native or nominally managed grassland) and receiving no management inputs. |
| | | Tropical | 0.97 | ± 11% | |
| | | Tropical Montane[3] | 0.96 | ± 40% | |
| Management ($F_{MG}$) | Severely degraded | All | 0.7 | ± 40% | Implies major long-term loss of productivity and vegetation cover, due to severe mechanical damage to the vegetation and/or severe soil erosion. |
| Management ($F_{MG}$) | Improved grassland | Temperate /Boreal | 1.14 | ± 11% | Represents grassland which is sustainably managed with moderate grazing pressure and that receive at least one improvement (e.g., fertilization, species improvement, irrigation). |
| | | Tropical | 1.17 | ± 9% | |
| | | Tropical Montane[3] | 1.16 | ± 40% | |
| Input (applied only to improved grassland) ($F_I$) | Medium | All | 1.0 | NA | Applies to improved grassland where no additional management inputs have been used. |
| Input (applied only to improved grassland) ($F_I$) | High | All | 1.11 | ± 7% | Applies to improved grassland where one or more additional management inputs/improvements have been used (beyond that is required to be classified as improved grassland). |

[1] ± two standard deviations, expressed as a percent of the mean; where sufficient studies were not available for a statistical analysis a default, based on expert judgement, of ± 40% is used as a measure of the error. NA denotes 'Not Applicable', for factor values that constitute reference values or nominal practices for the input or management classes.

[2] This error range does not include potential systematic error due to small sample sizes that may not be representative of the true impact for all regions of the world.

[3] There were not enough studies to estimate stock change factors for mineral soils in the tropical montane climate region. As an approximation, the average stock change between the temperate and tropical regions was used to approximate the stock change for the tropical montane climate.

Note: See Annex 6A.1 for estimation of default stock change factors for mineral soil C emissions/removals for Grassland.

### ii. Carbon Values

In order to derive the carbon values for $SOCref_i$ we again use the data of the IFN. The values of the IFN on soil carbon were derived for the first 50 cm of the soil. This deviates from other methods like the IPCC 2006 and the EU-RED which base their measures of soil carbon stocks only on the first 30 centimeters of the soil.

As an underlying soil map we use the FAO Digital Soil Map of the World which differentiates more soil classes in the region as for example the Harmonized World Soil Database (HWSD). We again extract the soil class for each sample point of the IFN by overlying the IFN Sample Points with the FAO soil map and then calculate the average carbon values for each soil class. It turns out that the IFN contains only sample points for 22 of the 59 FAO soil classes in the project region even though these classes encompass 87.4 % of the project region area. In order to fill the gaps we also calculate average carbon values for the broader classes of the HWSD by again overlaying the IFN sample point with the HWSD map. The final soil carbon map contains average carbon values for all soil classes of the FAO soil map covered by sample values of the IFN and average carbon values of the HWSD soil classes for the areas not covered.

Table 5: Basic Statistics on the IFN Sample Values for Carbon Stocks in the Soil for the FAO Digital Soil Map of the World

| FAO Soil Class | Number of IFN Sample Points | mean | median | standard deviaton |
|---|---|---|---|---|
| FLe | 6.0 | 36.8 | 36.8 | 40.3 |
| GLe | 10.0 | 61.7 | 66.9 | 9.0 |
| RGe | 3.0 | 77.7 | 77.7 | 0.0 |
| RGe-CMe | 9.0 | 81.6 | 50.6 | 56.9 |
| SNg-VRe | 18.0 | 39.3 | 38.2 | 26.8 |
| SNj-SNh | 3.0 | 39.5 | 39.5 | 0.0 |
| SNj/g | 18.0 | 55.0 | 50.6 | 17.2 |
| LVh-GLe | 3.0 | 67.0 | 67.0 | 0.0 |
| SNg-GLe | 11.0 | 29.6 | 0.0 | 35.6 |
| SNh-SNg | 16.0 | 50.1 | 52.0 | 8.3 |
| LVh-CMe | 24.0 | 66.2 | 63.7 | 20.3 |
| GLe-VRe | 12.0 | 61.2 | 43.9 | 61.0 |
| RGe-LVh | 34.0 | 51.6 | 51.5 | 16.6 |
| SNh/g | 12.0 | 49.8 | 49.0 | 11.6 |
| SNg-GLm | 2.0 | 52.8 | 52.8 | 0.0 |
| RGea | 9.0 | 85.7 | 71.1 | 56.6 |
| LVnj-GLe | 6.0 | 50.8 | 50.8 | 10.8 |
| RGe-LVj | 3.0 | 45.1 | 45.1 | 0.0 |
| ARh | 3.0 | 39.9 | 39.9 | 0.0 |
| LVh-GLe/LVh-CMe | 7.0 | 59.1 | 46.8 | 22.9 |
| SNj-GLe | 1.0 | 40.6 | 40.6 | 0.0 |

Table 6: Basic Statistics on the IFN Sample Values for Carbon Stocks in the Soil for the Harmonized World Soil Database

| HWSD Soil Class | Number of IFN Sample Points | mean | median | standard deviaton |
|---|---|---|---|---|
| FLd | 10.0 | 75.8 | 73.6 | 9.2 |
| SNg | 82.0 | 43.5 | 47.4 | 25.3 |
| RGe | 3.0 | 52.0 | 52.0 | 0.0 |
| CMx | 68.0 | 56.4 | 52.4 | 17.7 |
| SNh | 10.0 | 39.5 | 37.3 | 9.8 |
| RGe | 6.0 | 102.0 | 102.0 | 60.4 |
| CMe | 16.0 | 67.7 | 73.4 | 16.1 |
| ARh | 3.0 | 39.9 | 39.9 | 0.0 |
| SNm | 9.0 | 86.2 | 60.7 | 53.8 |
| LPe | 3.0 | 27.6 | 27.6 | 0.0 |

### c. Soil Carbon in Organic Soils

The FAO and HWSD do not explicitly identify peat swamp areas. Thus, for these areas the methods applied for the mapping of soil carbon underestimates carbon stocks. According to EU-RED and IPCC, the carbon content is to be calculated for the first 30 centimeters of the soil as this is the layer where most of the carbon is stored in mineral soils. The 50 centimeters applied in this case study should therefore be sufficient to fully capture the carbon in mineral soils. This does not apply for peat swamp areas which can have a thickness of several meters. In addition, the EU-RED method based on the IPCC 2006 assumes that the carbon content of a soil stabilizes again after 20 years of agricultural production following a land use change (excluding emissions from tillage and inputs). Land use factors of the IPCC 2006 are only valid under this assumption. The 20 years are an arbitrary assumption for calculation purposes but not totally unrealistic for mineral soils. However, peatland soils converted to agriculture can keep on causing emissions for hundreds of years and certainly do not fully stabilize after 20 years. Thus, we deviate from the method above for the peat swamp areas. We identify these areas by using the map on "tropical and subtropical wetland distribution version 2" from wetland international (Gumbricht et al. 2017). The same source provides information on peat depths. For these areas we do include the carbon content of the full peatland depth (maximum of 10 meters) in order to fully capture the high carbon contents of these areas.

In order to determine the carbon content per hectare we rely on the method of Page et al. (2011) :

$$C_{peat}{}^{-ha} = Volume^{-ha} * Bulk\ Density * percentage\ carbon\ content \qquad (5)$$

$$Volume^{-ha} = peat\ depth * 1\ hectare$$

For the calculation we take peat depth from Gumbricht et al. (2017) and in line with Page et al. (2011) assume an average bulk density of 0.09g $cm^{-3}$ as well as a percentage carbon content of 56%. This results in an approximated carbon stock per meter peat depth of 504 tC $ha^{-1}$. Most of the peat areas in the study region exceed only one meter of peat depth.

The resulting carbon stocks for the peat swamp areas in the project areas are included into the final map showing the soil carbon content (figure 3).

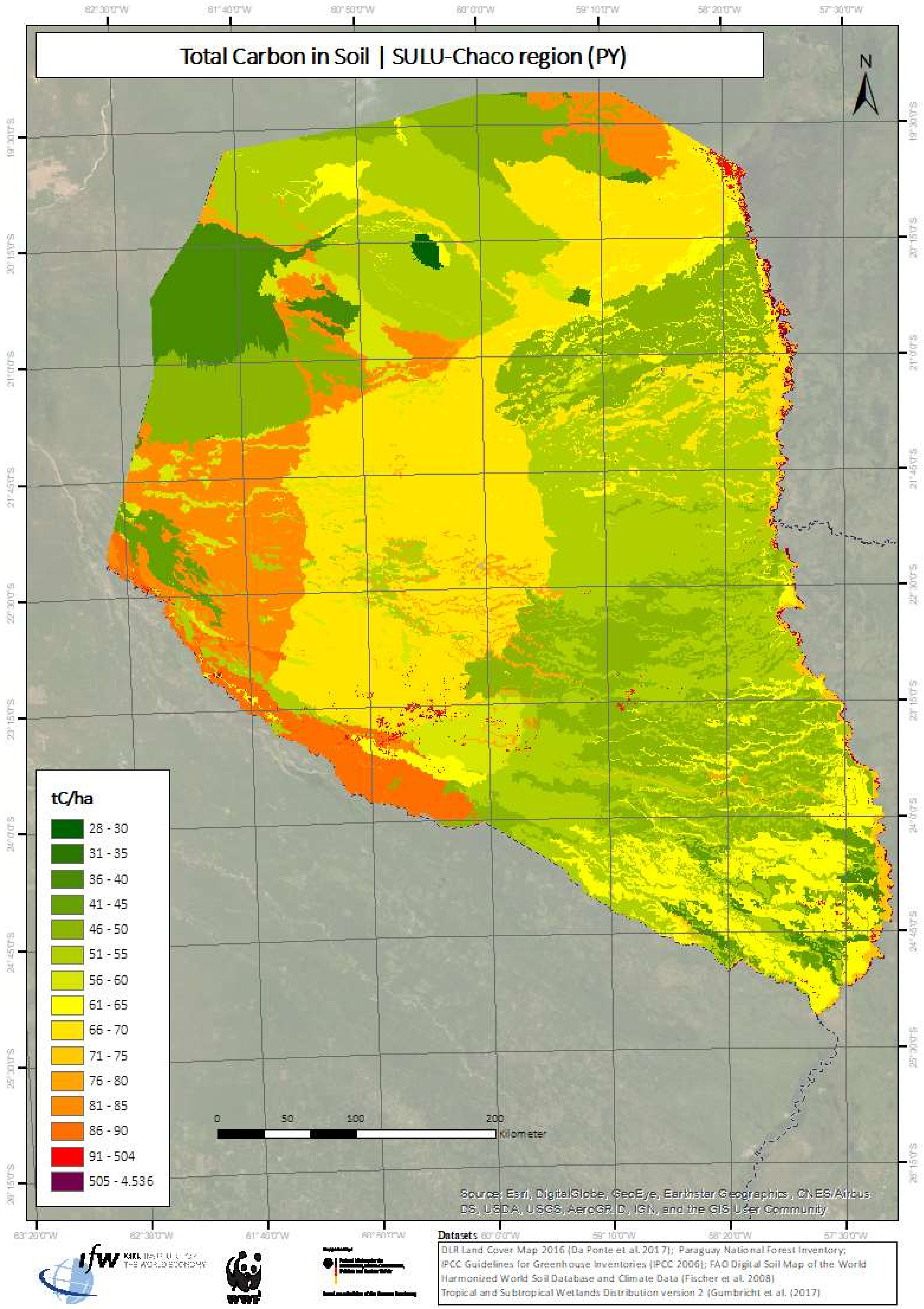


Figure 3: Carbon Map for Carbon Stocks in the Soil

### d. The Total Carbon Map

The final carbon map is calculated by overlaying and summarizing the map of carbon stocks stored in total biomass and the map of actual carbon stocks stored in the soil. The result is a carbon map that indicates the high and low carbon stock areas.

## 8. Conclusions

The calculated carbon maps account for all carbon pools, in living and dead biomass above and below ground and in organic and mineral soils. Outstanding in this mapping exercise is the availability of several sample points of carbon measurement directly taken in the study region which gives the chosen carbon values for each land cover class in the carbon map a higher credibility than taking values from only one spot or from other regions with similar biomes.

In 2018, carbon stored in biomass has a share of 43% in total carbon in the map, showing the importance of incorporating carbon stocks in the soil, especially in areas with peatland soils. The map accounts for the importance of peatland soils by incorporating the newly available data on peatland soils from Gumbricht et al. 2017.

Total carbon in the study region sums up to 2210 million tCO2eq in 2016 and 2168 million tCO2eq in 2018, indicating a potential loss of carbon of 42 million tCO2eq. Such calculation does not account for continuous losses of CO2eq emissions from organic soils or a forgone future CO2eq storage potential within drained organic soils. Therefore, it is important to notice, that the methodology only captures carbon stocks in 2016 and 2018 and does not explicitly account for carbon dynamics. Carbon dynamics might be important when addressing CO2eq losses from land use change. This is mentioned at different points in this report, e.g. when the absence of seasonal flooding after a conversion to grazing land changes the carbon storage in soils of flooded savannahs and maybe also the flooding patterns in the surrounding areas. In addition, carbon losses from drained organic soils can be substantial over the years and would need to be accounted for when using these maps to estimate emissions from potential land use change. The strength of these maps lies within the possibility to identify areas with high carbon and to account for them in spatial planning activities.

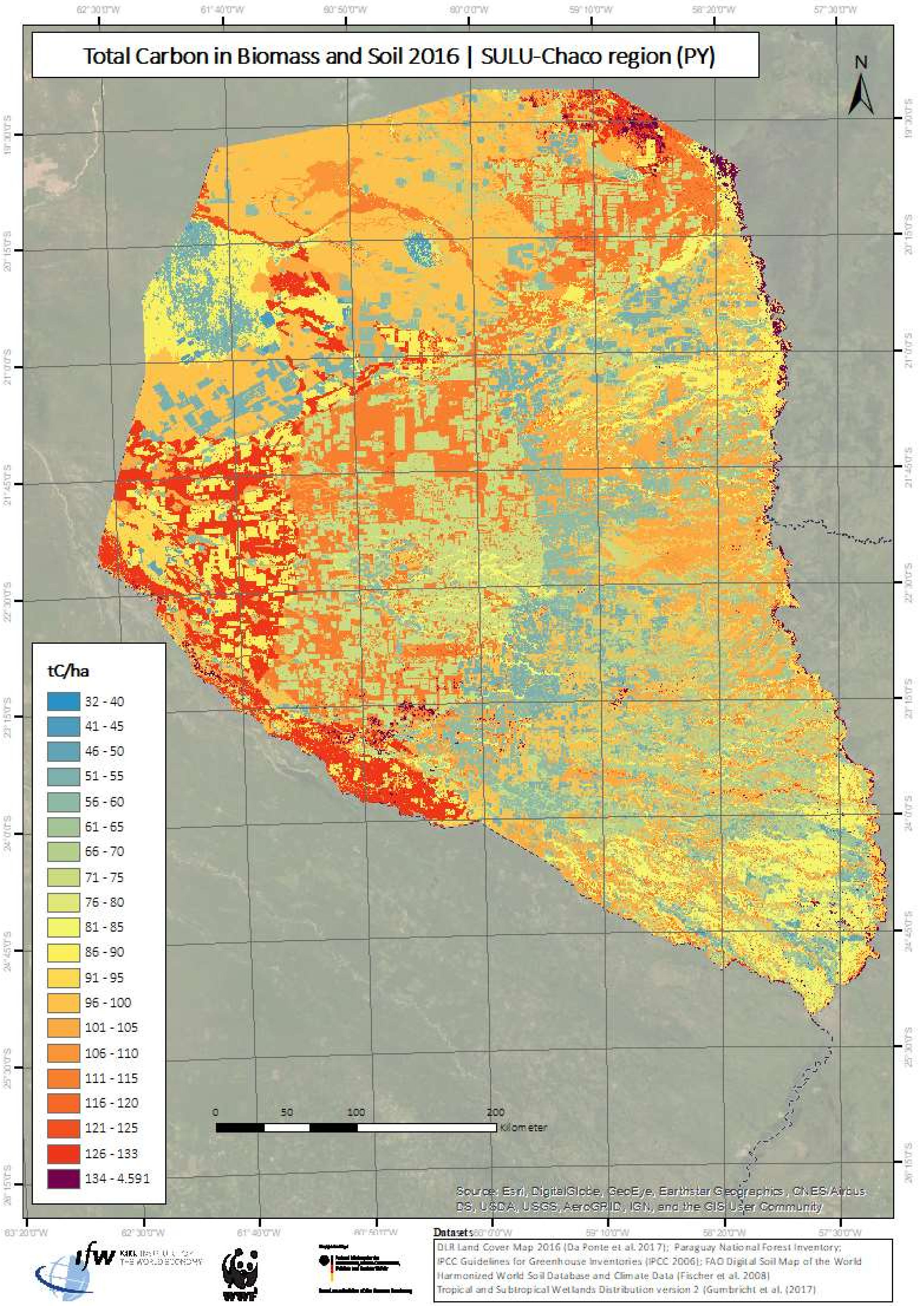


Figure 4: Carbon Map for Carbon Stocks in Total Biomass 2016

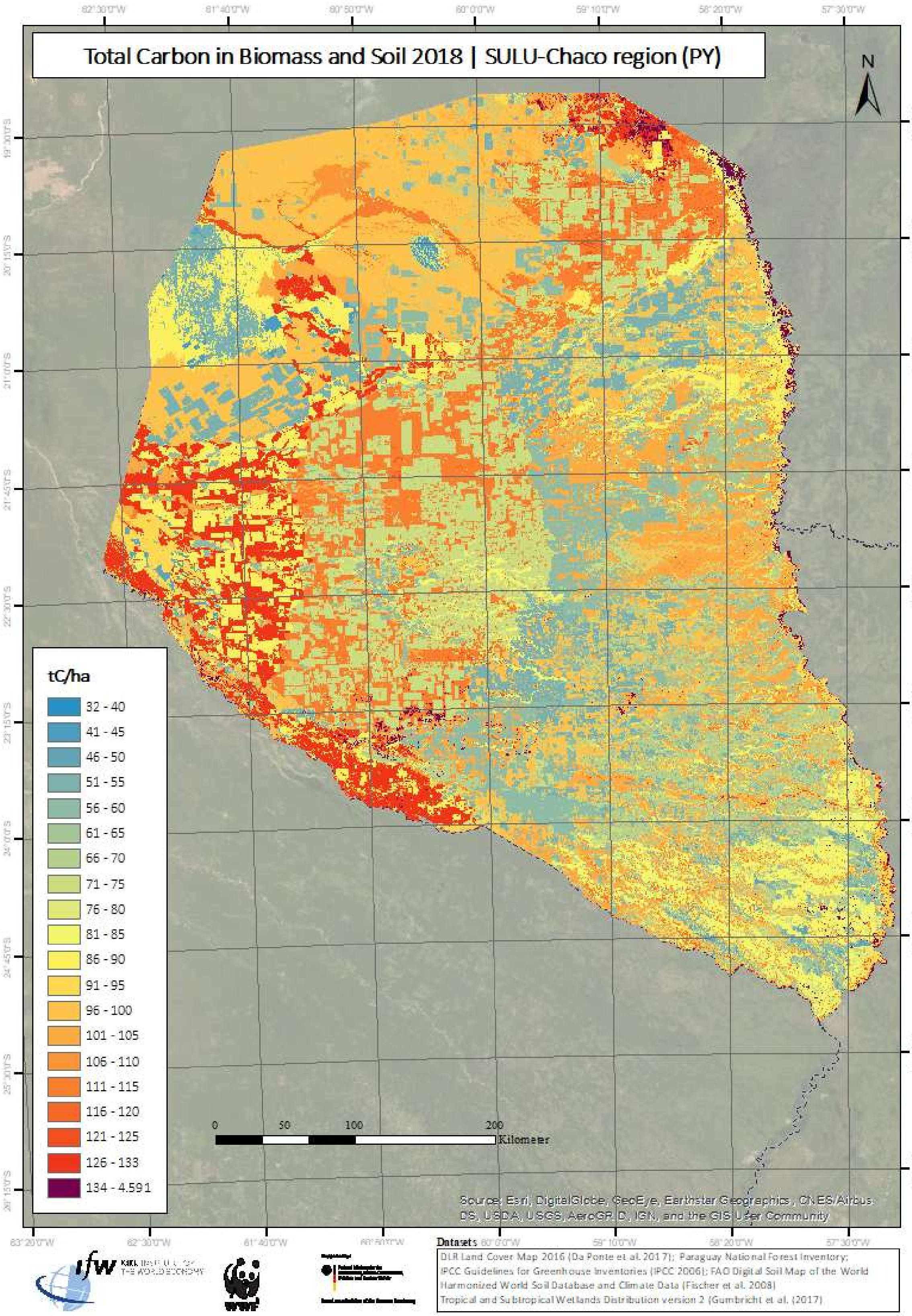


Figure 5: Carbon Map for Carbon Stocks in Total Biomass 2018

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[i] In addition to the method used in this case study, there has been a rapid development of techniques for determining above-ground biomass carbon, particularly for tropical forests via remote sensing techniques based on active signals such as Synthetic Aperture Radar technologies (SAR) and/or Light Detection and Ranging (LIDAR) (Engelhart et al. 2011). The signal of SAR penetrates through clouds and returns the ground terrain as well as the level of the top of the canopy cover which in turn gives the basis for deriving the height of the biomass cover. Thus, SAR provides a 2-dimensional image of the ground. If slightly different angles are used, this 2D image can be converted into a 3D image. The knowledge about typical biomass heights of different land covers can then be used to derive a land cover map (Mette et al 2003, Kellndorfer et al, 2004, Shimada et al 2005). Recent applications to tropical forests can be found, e.g., in the works of Gama et al. (2010), Engelhart et al. (2011), Kuplich et al. (2005), Michard et al. (2009), Pandey et al. (2010) or dos Santos et al. (2009).

Instead of using radar signals, the Light Detection and Ranging (LIDAR) method uses pulses of laser light and analyzes the signal return time (Engelhart et al. 2011). While this method cannot penetrate through clouds, it is possible to estimate the height and density of the biomass cover resulting in a detailed 3D image (Patenaude et al 2004). The biomass density and height is linked to biomasses, and thus, the 3D image can be converted into above-ground carbon estimates by applying allometric height–carbon relationships (Hese et al 2005). Applications to tropical forests can be found, e.g. in the works of Saatchi et al (2011), Duncanson et al. (2010), Zao et al. (2009), Avitabile et al. (2016).