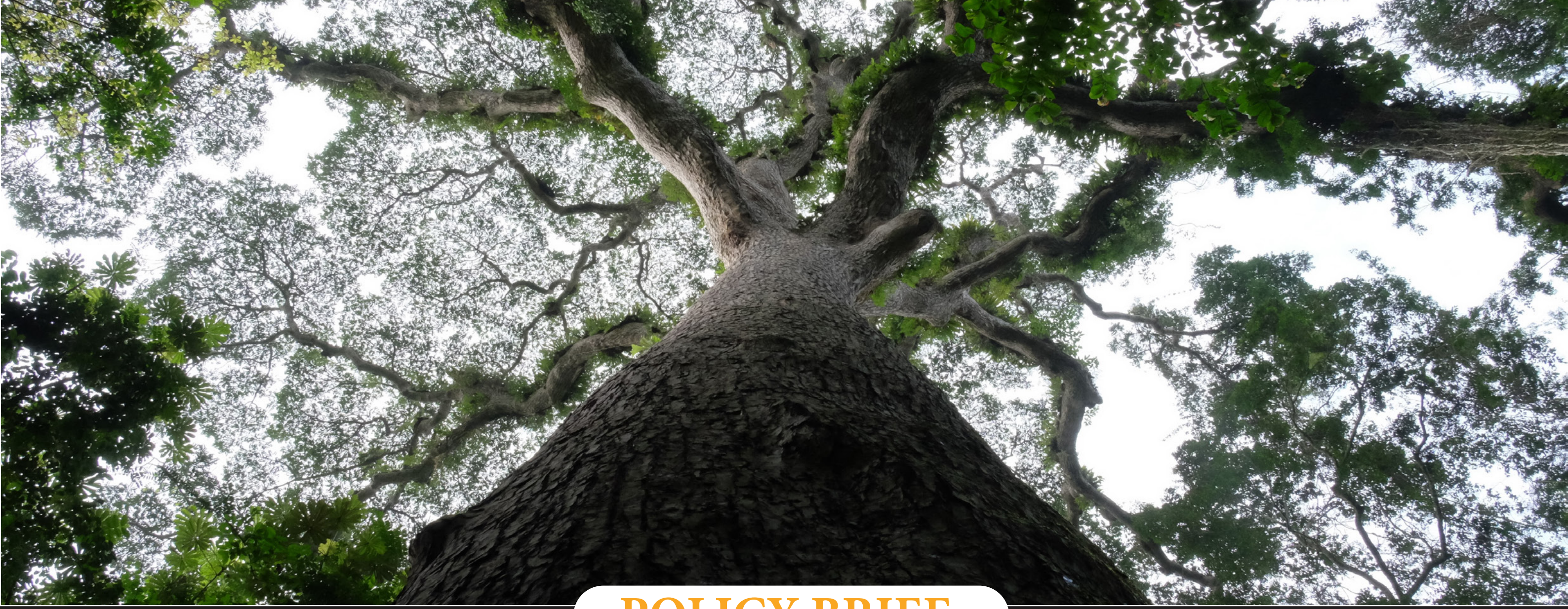

POLICY BRIEF

Tropical forest carbon management:

ON-THE-GROUND MONITORING OF INTACT TROPICAL FORESTS

THIS BRIEF

This policy brief is part of the POLCARTIM project coordinated by the Royal Museum for Central Africa (Tervuren, Belgium) and executed in collaboration with the Belgian Science Policy (BELSPO) and with support from the Belgian Biodiversity Platform. The project is funded by BELSPO under the BRAIN-be Programme. POLCARTIM focuses on providing policy support concerning rainforest carbon stocks and timber trade. The presented study is part of AFRIFORD (BR/132/A1/AFRIFORD) and HERBAXYLAREDD (BR/143/A3/HERBAXYLAREDD) and was published as the February 2019 cover story of Nature Plants.

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KEY POLICY RECOMMENDATIONS

- In view of developing tropical forest policy, accurately assess and account for carbon dynamics, with focus not only on carbon stocks but also on the amount of time that carbon stays within the trees.
- Quantification of tropical forest ecosystem services by considering forests as a whole, with all forest strata providing specific services..
- Expansion of the permanent forest inventory plot network in the tropics to more carefully assess, possibly with adapted measurement techniques, carbon stocks and carbon turnover and thus the climate change mitigation potential of tropical forests

SUMMARY

- The carbon stock of the world's forests is estimated at 861 ± 66 Pg C of which tropical forests represent 55%, while the boreal belt holds 32% and the temperate forests 14% (Beeckman, 2016). On average 42% of this carbon is found in live biomass, both below- as aboveground (Pan et al., 2011), although the largest part of the forest biomass consists of wood and bark. It is estimated that 400 Pg carbon is stored in wood globally (Chave et al., 2009).

- As such, trees play a key role in carbon management and climate change mitigation strategies. A recent study showed that while tropical forest canopy trees represent the bulk of the carbon reservoir, the understory provides long-term stability in forest carbon cycling (Hubau et al., 2019). A small tree contains little carbon, but they live long and are very numerous. Large trees, on the other hand, are less abundant and have faster life-cycles, but each contains more carbon. Therefore, tropical forest ecosystem services should be quantified by considering forests as a whole, with all forest strata providing specific services

- Accounting for the differences in species richness, carbon age and carbon fluxes among different forest strata is critical for effective conservation management, but this is currently largely overlooked. Carbon age and fluxes can be deduced from the growth rhythm of trees, but information on growth is scarce, especially in tropical forests. Therefore, the maintenance and extension of permanent forest inventory plot networks across the tropics is vital for detailed monitoring of growth and carbon fluxes.

CONTEXT

- Although certain trade-offs exist, carbon sequestration (rate of carbon uptake) and biodiversity conservation efforts can go hand-in-hand ([Deklerck et al., 2019](#)). Biodiversity reinforces the resilience of forests and as such their long-term carbon sequestration potential. **Tropical forests contain half of the biomass-carbon on our planet. They are essential for climate regulation, by sequestering 55% of the global terrestrial carbon uptake.**

- Furthermore, tropical forests have removed about 15% of anthropogenic CO2 emissions throughout the course of the early 2000s. However, these **tropical forests are under a constant deforestation pressure, due to increasing land demands for urbanization, agriculture (through permanent or shifting cultivation) and industrial timber exploitation.** This is especially critical in the Congo Basin, where there has been an acceleration in deforestation in recent years ([The World Bank, 2013](#)). Although political instability, poor infrastructure and poor governance have passively protected the Congo Basin forests, these factors also contribute towards the lack of accountability in terms of carbon sequestration efforts.

- Investing in carbon storage (storing carbon in the forest) and sequestration represents important strategies for climate change mitigation. Forests have the potential to provide both long-lived carbon stocks and long-term carbon sinks. To successfully conserve the forest carbon stock and increase carbon uptake, we must conserve carbon-rich forests and extend the forested land area. Decision makers and forest managers should therefore be informed on the long-term behavior of carbon within forests.

- **Critical questions are: (i) how long does the carbon remain in the forest (carbon persistence), and (ii) where does it stay in the system the longest?**

THE UNDERSTORY CONTRIBUTES SIGNIFICANTLY TO THE FOREST CARBON SINK.

The oldest carbon in the system is often assumed to be located in large trees. **Canopy and emergent trees contain a large proportion of the stand-level tropical forest biomass but large trees alone do not represent the entire forest in terms of growth rates, tree lifespan, and carbon persistence**. A recent study showed that small trees in African tropical forests can also be very old (Hubau et al., 2019; **Figure 1 and Figure 2 below**). Mean carbon age (period that carbon is fixed in a tree) in understory trees (74 years) is greater than in sub-canopy (54 years) and canopy (57 years) trees, and similar to carbon age in emergent trees (66 years). Furthermore, while the understory represents a small share (11%) of the carbon stock, it contributes disproportionally to the forest carbon sink (20%) and it is more diverse compared to the canopy in terms of species composition (Burton et al., 2013).

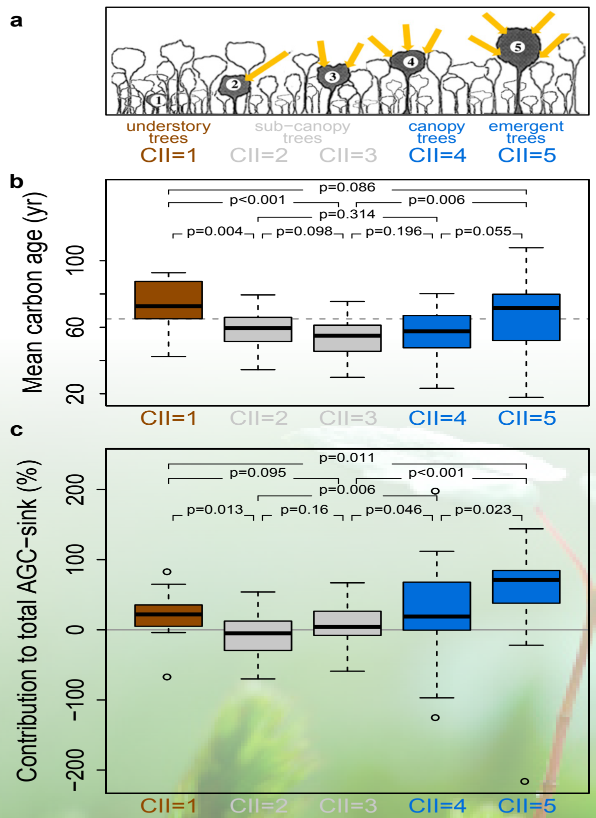

Figure 1. Estimation of mean carbon age and contribution to aboveground carbon sink per forest stratum based on growth data from 23 permanent forest inventory plots in Central Africa. Panel a visualizes forest strata, based on the Crown Illumination Index (CII), with yellow arrows indicating reception of sunlight. Understory trees (brown; CII 1) receive no direct sunlight, sub-canopy trees (grey) receive lateral (CII 2) or restricted vertical (CII 3) light, canopy trees (blue; CII 4) are almost completely exposed to vertical light and emergent trees (blue; CII 5) have a crown that is completely exposed to vertical and lateral light. Boxplots in panels b and c show the distribution of plot-level mean carbon age and the contribution to the total plot-level AGC-sink per CII class. Boxes represent 50% of the plot-level average ages; the dashed lines represent 95% of the data. P values represent the outcome of a statistical test, with P values < 0.05 indicating a significant difference between strata. Panel b shows that carbon age in the understory (CII=1) and in emergent trees (CII=5) is significantly higher than in the sub-canopy (CII= 2 and 3). Panel c shows that understory trees (CII 1) contribute significantly more to carbon uptake than the sub-canopy. This Figure was published by Hubau et al. (2019).

This discovery has important consequences for tropical forest policy aimed at carbon storage in the tropics. Small trees contain little carbon, but they live long and are very numerous and diverse. Large trees are relatively less abundant, and have faster life-cycles, but each tree contains more carbon. As such, the death of a large tree signifies an important carbon source. The long-term persistence of carbon and other ecosystem functions depends on smaller trees too, which compared to their stature contribute disproportionately more to long-term carbon storage, sequestration and climate resilience. Therefore, tropical forest ecosystem services should be quantified by considering forests as a whole, with all forest strata providing specific services. Bhély Angoboy Illondea, a Congolese researcher who took part in the study by Hubau et al. (2019) summarizes as follows: "**This is an important reminder to scientists and managers to focus on longevity as well as size. One tends to only see the big trees in the forest, but appearances are deceptive.**"

Figure 2: Keeping up appearances: the small tree with the tag was more than a 100 years older than the big tree. The small disc belonged to the trunk of an African tree with a diameter of only 7 cm, but with an age of no less than 329 years. The big disc in the back belonged to the trunk of a tree in the crown layer of the same forest. This large tree reached an age of (only) 203 years, and is therefore more than a century younger. Scientists of the Royal Museum for Central Africa (Tervuren, Belgium) were able to trace the growth speed and the age of the small tree with precision thanks to the scars of the nail that was knocked into the trunk to attach the tag in 1948. The zone between the black discoloration and the bark is only a few millimetres wide, but the tree took 70 years to form these growth rings. © RMCA Jo Van de Vijver..

CRUCIAL SET-UPS FOR CARBON MANAGEMENT IN AFRICA

THE NEED FOR MONITORING IN PERMANENT SAMPLE PLOTS

To allow for long-term monitoring of carbon stocks and fluxes, there is a need for repeated measurements of the same trees across multiple years and decades. Permanent forest inventory plots are demarcated areas within tropical rainforests, ranging between 0.2 and 50 ha. All trees in these plots are tagged and numbered so they can be measured repeatedly (Figure 3). The collection of temporal data allows to efficiently monitor forest dynamics such as tree growth, tree mortality and species turnover. This provides vital information on carbon fluxes and on the response of forests to climate change fluctuations, which is crucial information for sustainable forest and carbon management. This information has currently been lacking, due to a lack of accountability of carbon sequestration in the Congo Basin region. Although many (scattered) projects are being set-up by key players as UN (FAO, UNDP, UN environment), USAID, Forest Carbon Partnership Facility of The World Bank and the Central African Forest Initiative with their DRC REDD+ National Fund, a more coherent effort is needed among donors and implementing partners in order to gather more national political motivation, which is needed to reinforce carbon monitoring on the African continent.

STRENGHTEN THE CONGO BASIN

Maintenance of such a large forest inventory plot network requires international collaboration. However, the plot network does not cover all African forests equally. Even though the Democratic Republic of the Congo hosts more than half of the Congo Basin, it is still underrepresented in the plot network (Figure 4), and there is a need for dedicated funding to expand this in the inner Congo Basin. Continued on-the-ground monitoring of intact tropical forests, and especially of those areas that are currently under-investigated, is required to quantify carbon persistence and recycling within the forest and to track the impacts of accelerating environmental change

PLOT NETWORKS

In Africa the largest network of permanent inventory plots in intact tropical rainforest currently includes more than 240 repeatedly measured plots (Hubau et al., 2020; Figure 4). These plots are mostly about one hectare in surface area and spread across 11 countries (Sierra Leone, Liberia, Ghana, Nigeria, Cameroon, Gabon, Central African Republic, Republic of Congo, Democratic Republic of the Congo, Uganda and Tanzania). These plots are part of a single large international network called AfriTRON (African Tropical Rainforest Observation Network), from which all data are curated by ForestPlots.net. This long-term cyberinfrastructure initiative hosted by the University of Leeds (United Kingdom) documents permanent plot records and corresponding scientists from the world's tropical forests. Another example is the Forest Global Earth Observatory Network (ForestGEO), which targets especially large plots (more than ten hectare) and currently maintains 4 plot sites in African tropical forests. Additional plots are managed by the Tropical Ecology Assessment and Monitoring Network (TEAM), which aims at understanding how tropical forests respond to climate change and disturbed landscapes.

Forest company plots are also an option and an example here is The Tropical managed Forest Observatory (TmFO), which is a pan-tropical network coordinated by the Centre de coopération Internationale en Recherche Agronomique pour le Développement (CIRAD). It is aimed at understanding the effects of logging on tropical forest ecosystems and encompasses more than 600 permanent forest plots (Latin America, Africa and South-East Asia). In Africa this network maintains permanent sample plots in Gabon and Central African Republic. These plots represent a unique opportunity to monitor the effects of logging on carbon and species dynamics.

There have been strong efforts to develop national inventories in Central Africa. However, this data belongs to the country in question and is often difficult to access. The FAO discerns summary statistics in their Forest Resource Assessment (FRA-2015) based on data provided by countries every 5 years. These inventories are performed with the help of the FAO and these permanent sample plots could be considered to become part of the scientific network

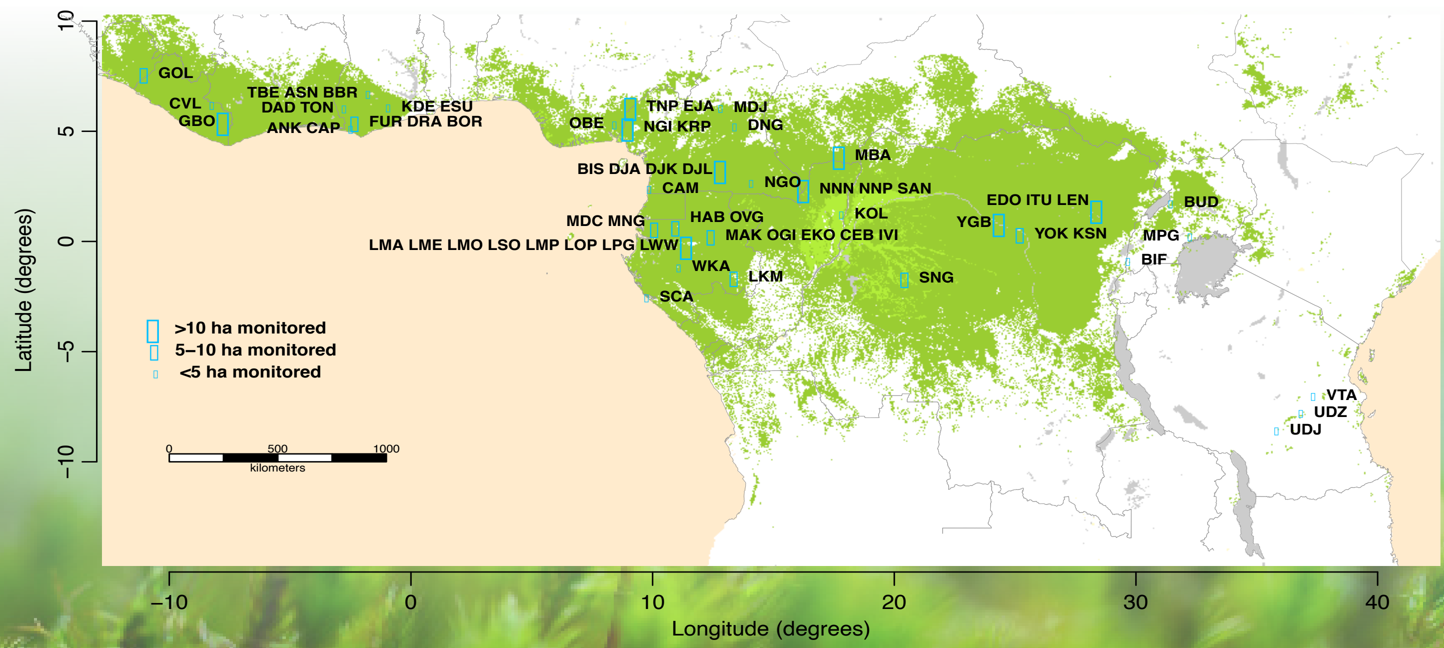

Figure 4: Map showing the locations of the 244 permanent inventory plots in African tropical forests (Hubau et al., 2020). Dark green represents all lowland closed-canopy forests, submontane forests and forest-agriculture mosaics; light green shows swamp forests and mangroves, blue circles represent plot clusters, referred to by three-letter codes. Clusters <50 km apart are shown as one point for display only, with the circle size corresponding to sampling effort in terms of hectares monitored.

KEY FINDINGS

CARBON IN THE UNDERSTORY

- Mean carbon age (i.e. period that carbon is fixed in a tree) in understory trees is greater than in sub-canopy and canopy trees (74 years versus 54 years respectively), and similar to carbon age in emergent trees (66 years).
- While the understory represents a small share (11%) of the carbon stock, it contributes disproportionally to the forest carbon sink (20%).
- While the canopy represents the bulk of the carbon reservoir, the understory provides long-term stability in forest carbon cycling.

PLOT NETWORKS

- There are many different plot types and different networks dedicated towards similar goals. However, the Congo Basin and its tropical forests are still underrepresented in terms of number of permanent sample plots.
- Dedicated funding is needed to fill the gap in permanent sample plots in the Congo Basin.

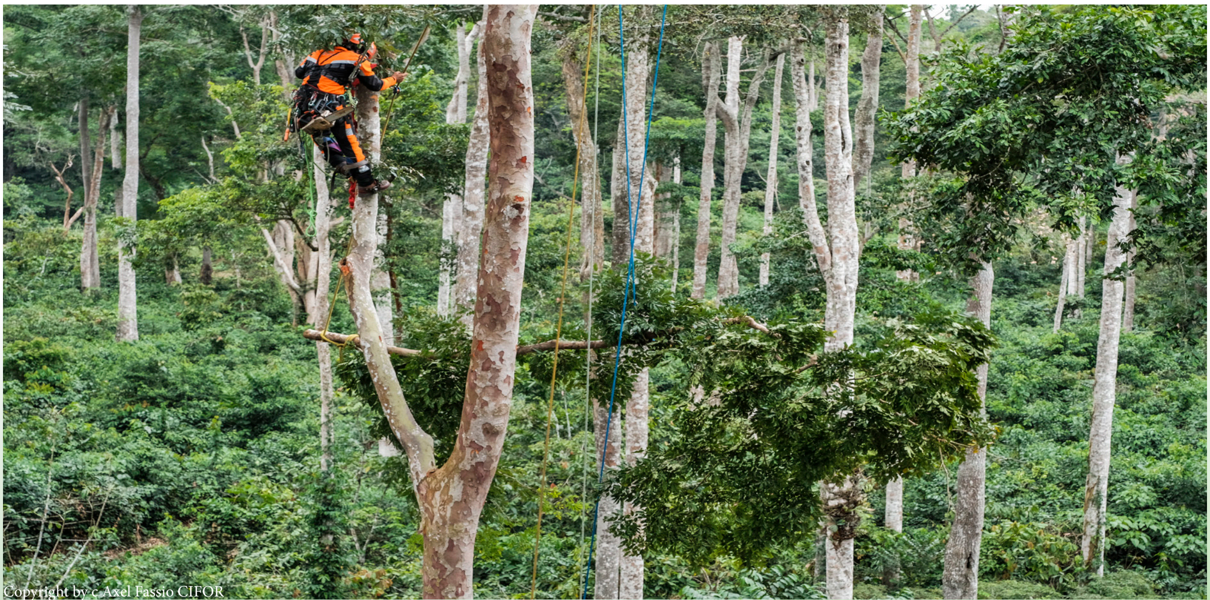

Figure 3: Canopy Research: An equatorial rainforest consists of huge trees demanding adapted sampling techniques.

POLICY RECOMMENDATIONS

CARBON DYNAMICS AND CARBON MONITORING

- Carbon dynamics of tropical forests should be accurately assessed and monitored to allow optimal carbon management for these forests, which impacts climate mitigation strategies. The focus should be both on carbon stocks and carbon persistence within the ecosystem.

- Dated wood of standing trees provides key information about the occurrence of extremely low growth rates or steady state conditions of certain ecosystem components, such as in understory trees. When stand-level carbon assessments in the rainforest are needed, we recommend classical diameter measurements in permanent sample plots. This assessment gives a reliable estimation of the carbon stock. A repeat census in such plots after an interval of at least five years provides consistent information about carbon sequestration by the forest community.

- Tropical forest ecosystem services should be quantified by considering forests as a whole, with all forest strata providing specific services. There is a direct correlation between carbon stocks and dynamics and ecosystem services (for example: environmental protection and the production of goods). As such we also need to protect the understory and this is particularly important in Central Africa, where the demand for fuelwood and charcoal could severely affect the understory.

- Continued on-the-ground monitoring of tropical forests, and especially in those areas that are currently under-investigated, is required to quantify carbon persistence and recycling and to track the impacts of accelerating environmental change. This is of great urgency, as our planet's last great tropical forests are threatened more than ever before in human history.

PERMANENT FOREST INVENTORY PLOT NETWORK

- The existing permanent forest inventory plot networks should be expanded to increase this on-the-ground monitoring.
- When performing measurements in permanent inventory plots it is important to mark the tree with a numbered metal etiquette and an aluminum nail.
- The measuring point on the tree should be marked with paint and should normally be at breast height, or 50 cm above irregularities such as buttresses. The point of measurement should be recorded in the metadata

RESOURCES

1. Hubau W., De Mil T., Van den Bulcke J., ..., Lewis S. and Beeckman H. The persistence of carbon in the African forest understory. Nature plants, 5, 133-140 (2019).
2. Hubau W., Lewis S., Phillips O.L., ..., Woods J.T and Zemagho L. Asynchronous carbon sink saturation in Africa and Amazonian tropical forests. Nature, 579, 80-87 (2020).

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