PES: Payment for Ecosystem Services

The Mbé Watershed

a sustainability assessment

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The Mbé watershed

M.E. Leal[1]

[1] Miguel E. Leal (PhD) is a tropical forest ecologist and botanist with over 10 years of research and field experience in Gabon assessing biodiversity, collecting plants and studying forest history and its future dynamics with climate change.

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Introduction

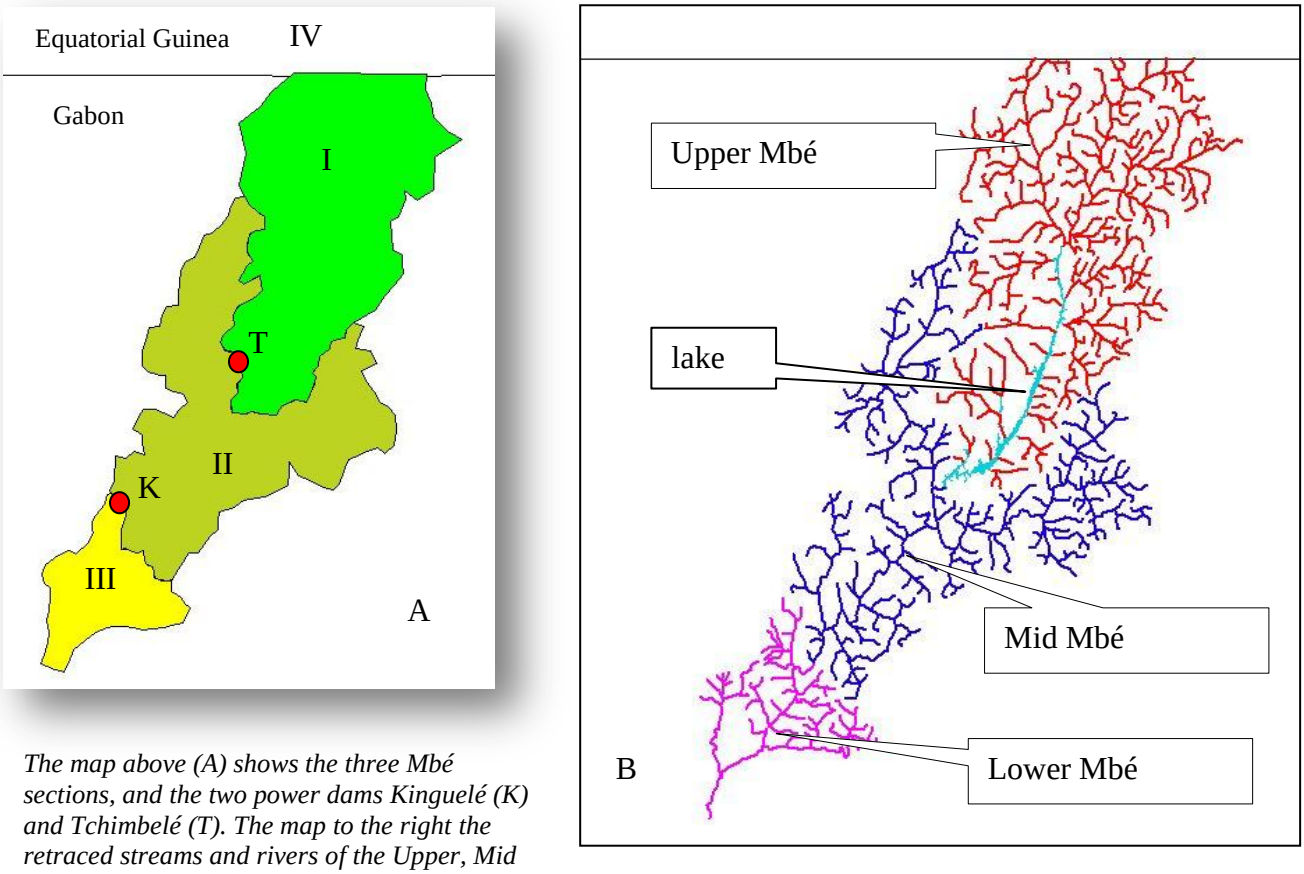
Rainforests offer important ecosystem services. One of better known ecosystem services is reducing the amount of greenhouse gasses in the air by sequestering carbon dioxide from the atmosphere and storing it as biomass (trunks, branches, foliage, shrubs and roots). Other important services are preventing soil erosion and ensuring the continued integrity of watersheds that supply clean water and hydro-electricity.

In the Mbé watershed two power dams are supplying Libreville with electricity and in order to keep up with the demand the two hydro-electric plants require a constant and stable volume of water at the dams and without which Libreville would be become highly dependent on fossil fuels for its energy consumption increasing city's the carbon footprint.

Factors which may deplete the water volume are (i) increased erosion due to forest conversion and forest dieback as well as (ii) increased evaporation rates from higher temperatures attributable to global warming. These benefits may become limited by a loss of forest area and degradation of forest functions through various environmental changes, often occurring because of the public's lack of awareness of the importance of the ecosystem services.

This report assesses the environmental characteristics of the watershed, analyzes the resilience of the forests to climate change, and evaluates the plant biodiversity and the threats to the landscape's capacity to provide ecosystem services to the city of Libreville.

An extreme low level of the lake at Tchimbele

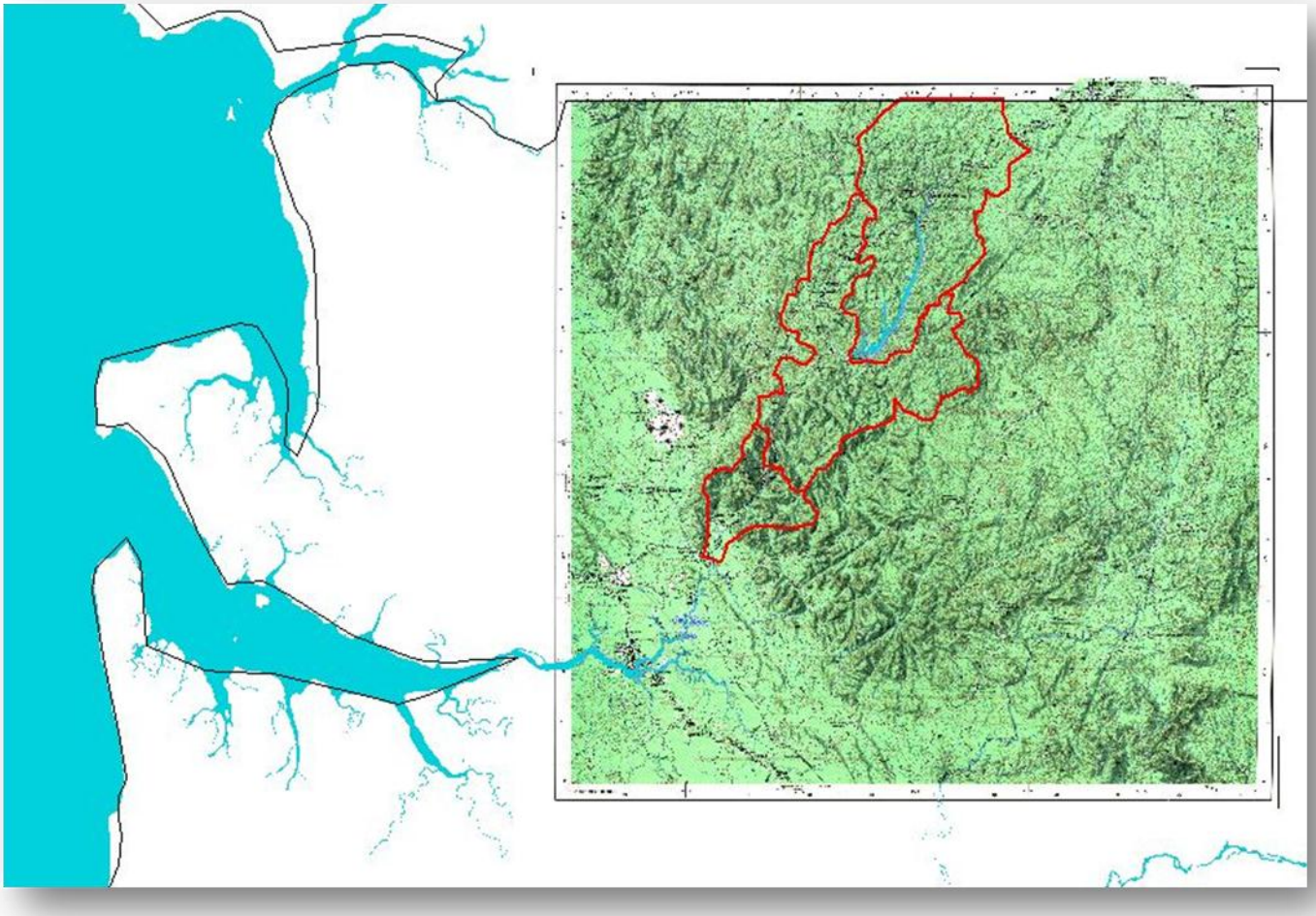


The map above (A) shows the three Mbé sections, and the two power dams Kinguelé (K) and Tchimbelé (T). The map to the right the retraced streams and rivers of the Upper, Mid and Lower Mbé sections (B).

Watershed description

The Mbé watershed is located in the Monts de Cristal rainforest landscape and on the Gabonese side it is divided into three different sections by the two power dams, Tchimbelé and Kinguelé (see above, fig. A): I) the Upper Mbé above the Tchimbelé dam, II) the Mid Mbé in between the Tchimbelé and Kinguelé dams and III) the Lower Mbé below the Kinguelé dam. A fourth section (IV) represents the headwaters of the Mbé River in Equatorial Guinea which is outside the scope of this report.

The outline of the different sections of the Mbé watershed was obtained by tracing all streams connected to the Mbé River on the geo-referenced map of Kango (see next page) in GIS (ArcView 3.3) and creating a new theme by drawing a polygon around the streams of each section. Each section has a different shape and size. The Upper Mbé basin is roughly oval shaped. The Mid Mbé is Y-shaped with the two arms flanking the lower half of the Upper Mbé and the leg of its Y-shape as the continuation of the Mbé River after the Tchimbelé dam until the Kinguelé dam. The Lower Mbé is the smallest basin and the continuation of the Mbé River until it ends in the Komo River.



The map above shows the Mbé sections on the geo-referenced map of Kango in Arcview

Definition of the Monts de Cristal

The Monts de Cristal is not an administrative unit. The name refers to the mountainous landscape of the western edge of the Woleu-Ntem plateau with the coastal lowland. Geographically it is very different as is illustrated in the cross-section below Therefore the rugged zone up to the border with the Equatorial Guinea is considered "the **Monts de Cristal".**

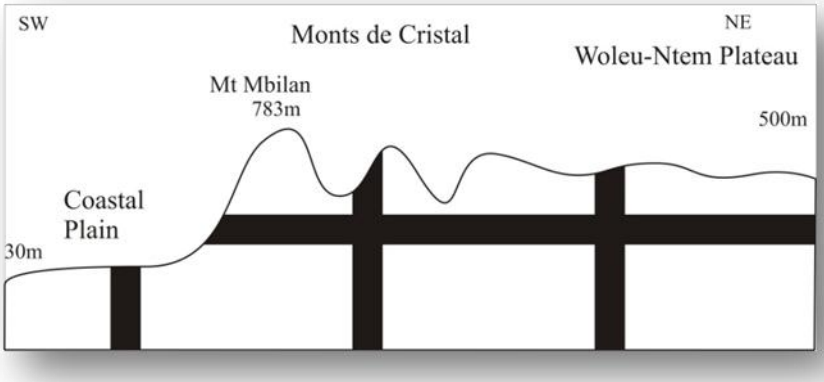
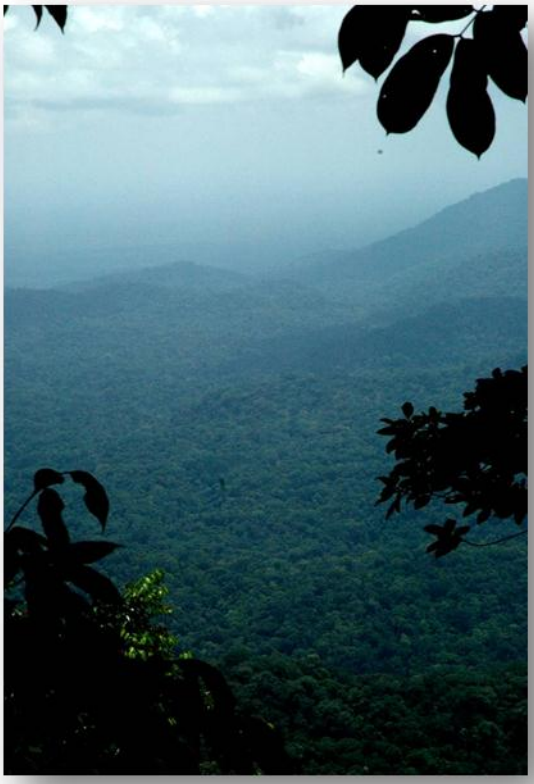


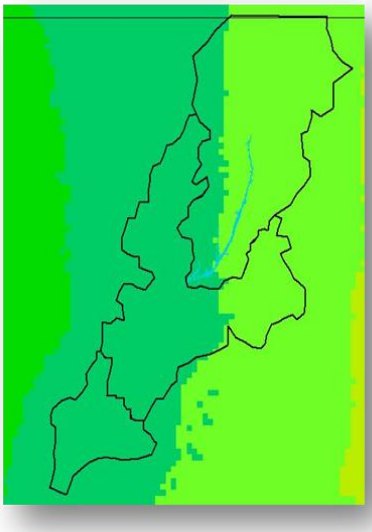
Diagram to the right shows the abrupt transition in altitude and ruggedness between the coastal lowland and interior plateau.



Environment

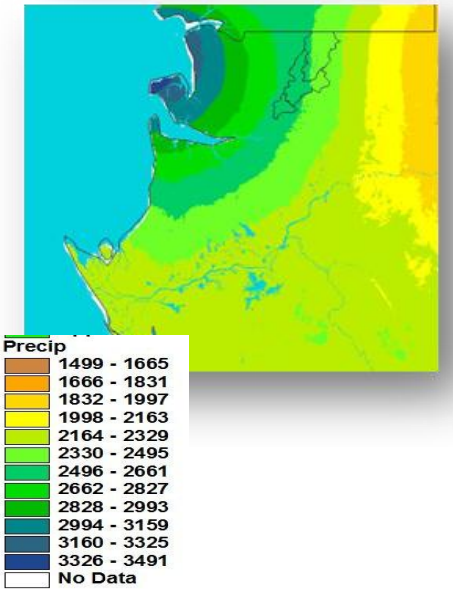
Monts de Cristal is a unique landscape, climatically wet because of its close vicinity to the ocean and very a mountainous and rugged topography (see left). The high level of rainfall and strong ruggedness create a complex pattern of patches with different environmental characteristics which in turn determine species distributions, biodiversity and resilience to climate change. A spatial depiction of the environmental patchiness is obtained by summarizing and distinguishing differences and similarities and grouping these in "land-units". Each land-unit represents a certain combination of environmental characteristics.

The complex landscape of the Monts de Cristal



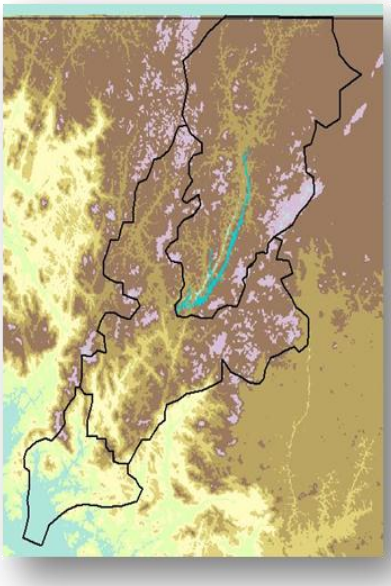
Rainfall

The rainfall gradient over the Monts de Cristal is steep. Over a distance of 225 km mean annual rainfall varies between 3000mm in the west to 1800mm in the east. The landscape receives constant rainfall even during the dry season (July-August) when the rest of Gabon remains dry without any rainfall. This extra input of moisture comes from orographic rainfall which is when clouds are forced up hill (500-1000m) the moisture vapor condenses into raindrops or on leaves of the vegetation.

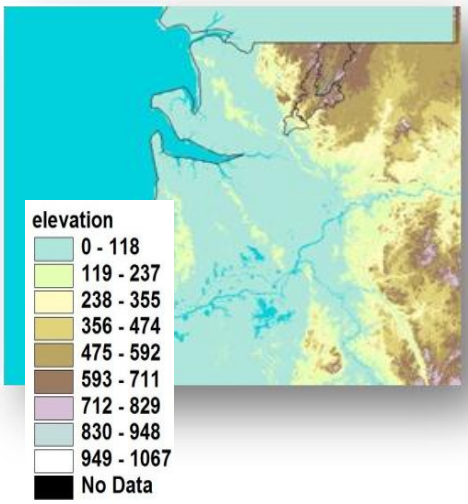


The diagram to the right illustrates mean annual rainfall in the Mbé watershed, and the diagram to the left illustrates mean annual rainfall the within the rest of Gabon.

Altitude

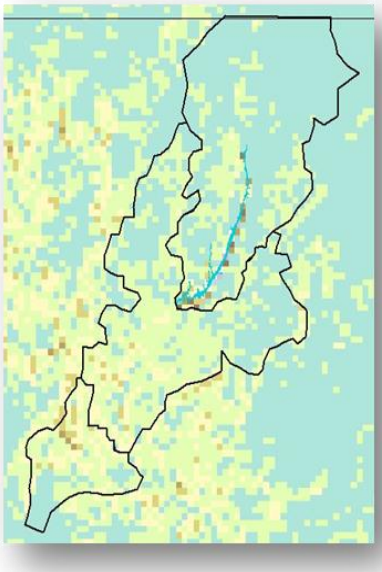


The transition between the coastal lowland and the Monts de Cristal is abrupt similar to an escarpment. In certain places, such as at Mt Mbilan in the Low Mbé, the altitude increases from 124m to 864m over a 4,5km. Beyond this initial rugged zone further onto the interior plateau, the differences between valleys and summits become smaller (500-600m) with only a few tops over 700m.

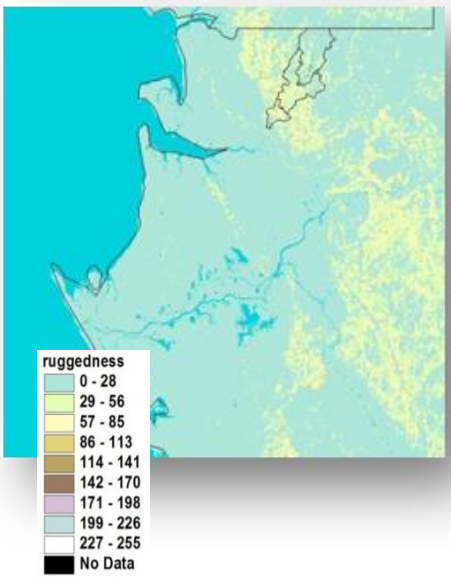


The diagram to the right shows a close up of the elevation levels in Mbé, and diagram to the left, the elevations of this area relative to the rest of the country.

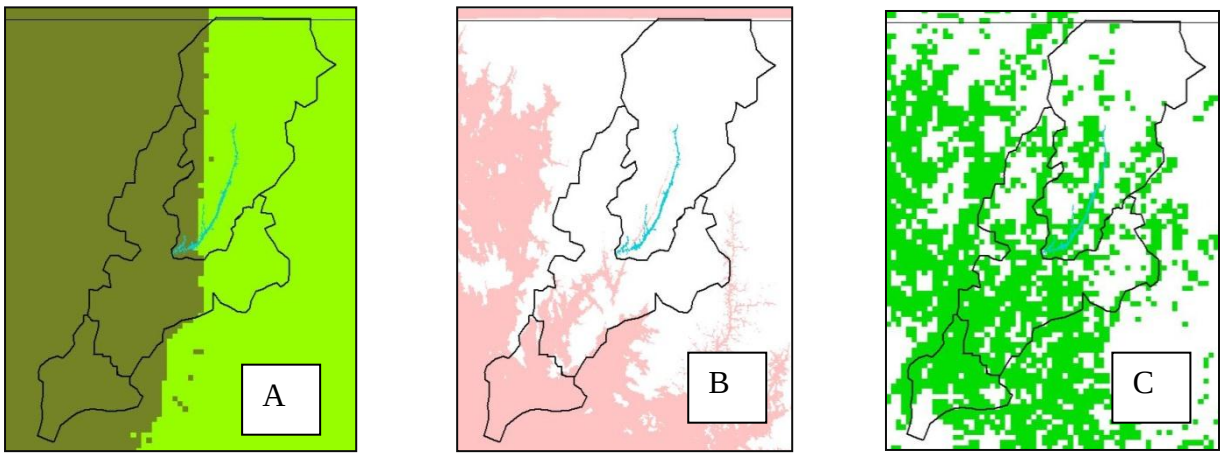
Ruggedness



Ruggedness in coastal region and on the interior plateau is low. The zone in between these two "book-ends" of the landscape, a zone approximately 20-40km wide, has a strong relief, with steep slopes and narrow valleys. In these shady valleys moisture accumulates and evapo-transpiration is low creating local environmental conditions that allow moisture to stay fairly stable. This permits the forests in these areas to withstand periods of regional drought stress in the absence of rainfall.



The diagram to the right illustrates the ruggedness in the Mbé watershed, and the diagram to the left illustrates the ruggedness within the rest of Gabon.



The three maps above illustrate the differences within the Mbé watershed in rainfall: above 2500mm (dark green) and below(light green) (A), elevation: above 500m (white) and below (pink)(B), and ruggedness: strong(dark green) and below (white) (C).

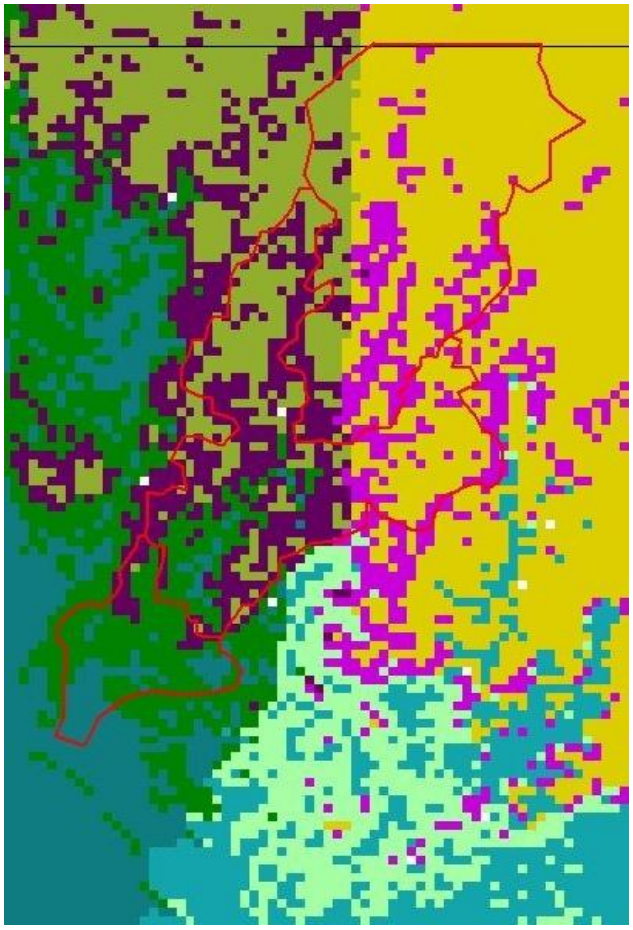
The table to the left shows the eight different land-units overlapping the different environmental characteristics

		rainfall	
altitude	*ruggedness*	>2500mm	<2500mm
lowland	weak		
(500m>)	strong		
highland	weak		
(500m<)	strong		

Land-unit classification

The complexity of the Monts de Cristal and the Mbé watershed is clearly visible from the nation map of Kango (see next page). Classifying the Mbé watershed into "land-units" presents a useful proxy of habitat diversity in this complex landscape, which allows a more detailed analysis of biodiversity and resilience of the forest in the Mbé watershed.

These land-units were created by overlapping in a GIS analysis (ArcView 3.3), rainfall data extracted from the WoldClim database (hppt://www.worldclim.org, Hijmans *et al.*, 2005) and topography data extracted from the SRTM database (http://www2.jpl.nasa.gov/srtm). The following categories were used to classify the Mbé watershed (see above): A) mean annual rainfall above (dark green) and below 2500mm (light green), B) elevation below (pink) and above 500m (white) and C) ruggedness (as the stander deviation in elevation pixels) above (green) and below 30m (white). This analysis results in eight different units (see table above).



The map above is a section of the Kango national map based on aerial photography and illustrates the geographical complexity of the Monts de Cristal.

The map to the left is equivalent but based on remote sensing data layers and includes climate information.

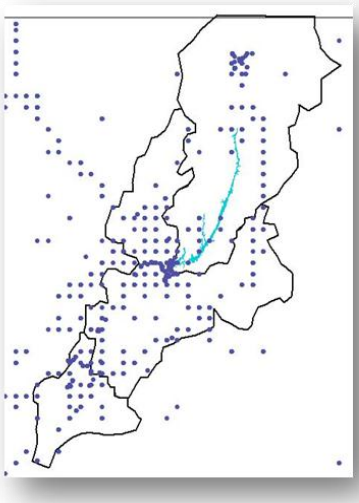
A formal classification of the landscape in discrete characteristics allows defining the three Mbé sections in qualitative and quantitative terms. Each section of the Mbé watershed exhibits a different set of land-units, different in abundance and in distribution. Each of which creates a typical environmental setting which may explain the level of plant biodiversity in each section and its resilience to global warming.

In general, the differences in rainfall are relatively low compared to variations in ruggedness and altitude. The Lower Mbé section is characterized by a strong ruggedness with an altitude below 500m, similar to the leg of the Mid Mbé section. The arms of the Mid Mbé and the lower half of the Upper Mbé sections are each characterized by a strong ruggedness and an altitude higher than 500m. The remainder of the Upper Mbé section has a weak ruggedness and an altitude above 500m.

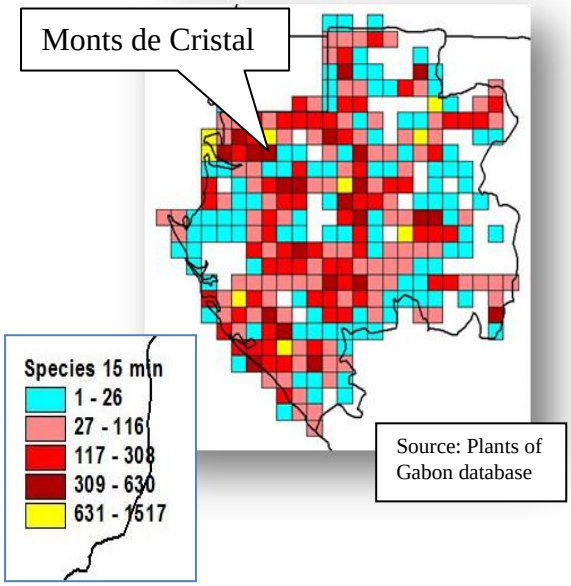
Despite the overlapping environmental characteristics and shared land-units the distribution and abundance allows defining the Lower Mbé as a *rugged lowland*, the Mid Mbé as a *rugged upland* and the Upper Mbé a *gentle upland*.

Biodiversity

The Monts de Cristal are well known for their botanical richness, which is the highest in Gabon and possibly the whole of tropical Africa. The Monts de Cristal are uniquely diverse because of a high habitat diversity and postulated moisture stability during glacial periods in Pleistocene and dry periods during the Holocene which enabled its forests to persist while the rest of the region experienced significant forest die back.



The map below shows the number of plant species per "15 minutes gridcell" in Gabon and on the right where plants have been collected in and close to the Mbé watershed.

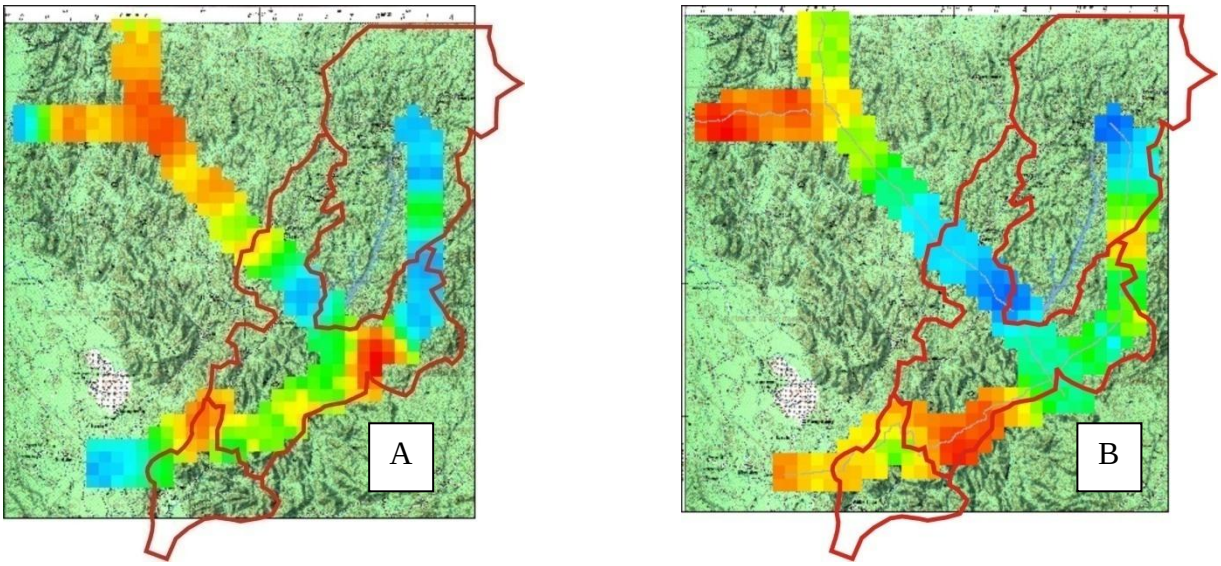


Below is an overview is given of the different sources on plant biodiversity data collected in and around the Mbé watershed: 1) general collecting, 2) mega-transects, 3) short-transects and 4) 1-hectare plots. Each source highlights a certain aspect of the biodiversity in the Monts de Cristal and the Mbé watershed and together they provide a fairly complete view.

Calvoa maculata

General collecting

Monts de Cristal, particularly at Tchimbelé and Kinguelé, has attracted botanists for several decades thanks to its proximity to Libreville and the facilities available near the power dams. The data from general collecting provides us with the most comprehensive information on the plant biodiversity in the Monts de Cristal and the Mbé watershed, as it includes herbs, lianas and epiphytes. A species-list of all plants collected in the area is given in the Appendix attached to this report. A total of approximately 1556 species have been identified, and new species are still being discovered, such as most recently *Calvoa maculata* and *Amphiblemma mvensis*. Also new "records" have been added to the list. New records are species known from other parts of Central Africa, such as *Korupodendron swongeanum*, a former endemic tree species from Cameroon and which have been found in Gabon for the first time.



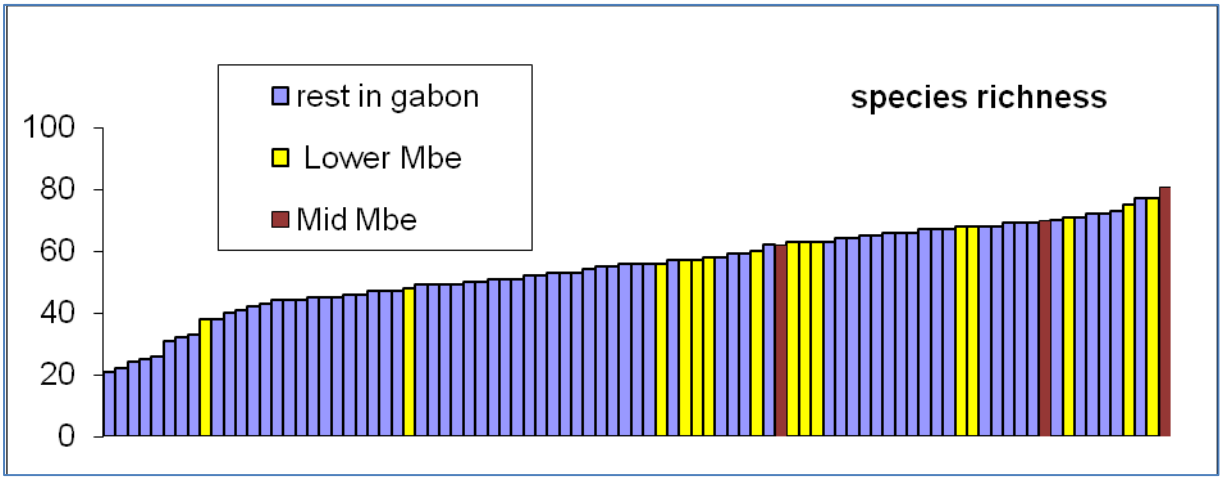
The two maps above show the density of Begonias (A) and Caesalpinioideae (B) along the Mega-transects: Red means a high abundance and blue low. Source: WCS Gabon

Mega-transects

Tetraberlinia moreliana,
a Caesalpinioideae tree species and its pod

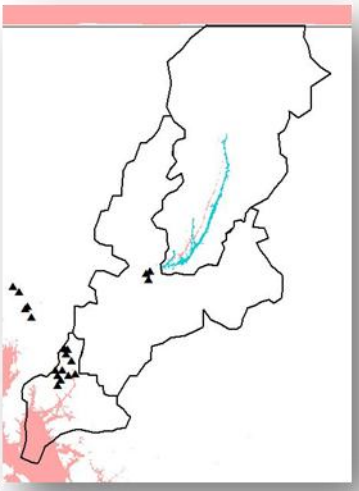
Prior to the establishment of the national parks systems in Gabon so-called "mega-transects" (several kms long and 5m or 10m wide) were laid out throughout Gabon's forests to measure the variation in biodiversity over long distances. In the Monts de Cristal particular attention was given to the abundance of so-called refuge species, *Begonia*s, forest herbs, and *Caesalpinioideae,* canopy tree species. Both plant groups have limited seed dispersal, and areas where they occur in high abundance indicates forest stability during periods of forest dieback over the Quaternary (Pleistocene and Holocene). The sections of mega-transects through the Mbé watershed show that the abundance of both *Begonias* and *Caesalpinioideae* is high in the left arm of the Mid Mbé and in the eastern part of the Upper Mbé whereas in the right arm of the Mid Mbé, *Begonia*s are abundant but *Caesalpinioideae* remain low. There is a high abundance of both plant groups in the leg of the Mid Mbé and in the Lower Mbé, which show that the forest in the rugged sections in the Mbé watershed have been most stable in the past.

Begonia susaniae,
an endemic species from the Monts de Cristal



Source: Leal 2009

This graph illustrates the range in tree biodiversity of all short transect laid out in Gabon

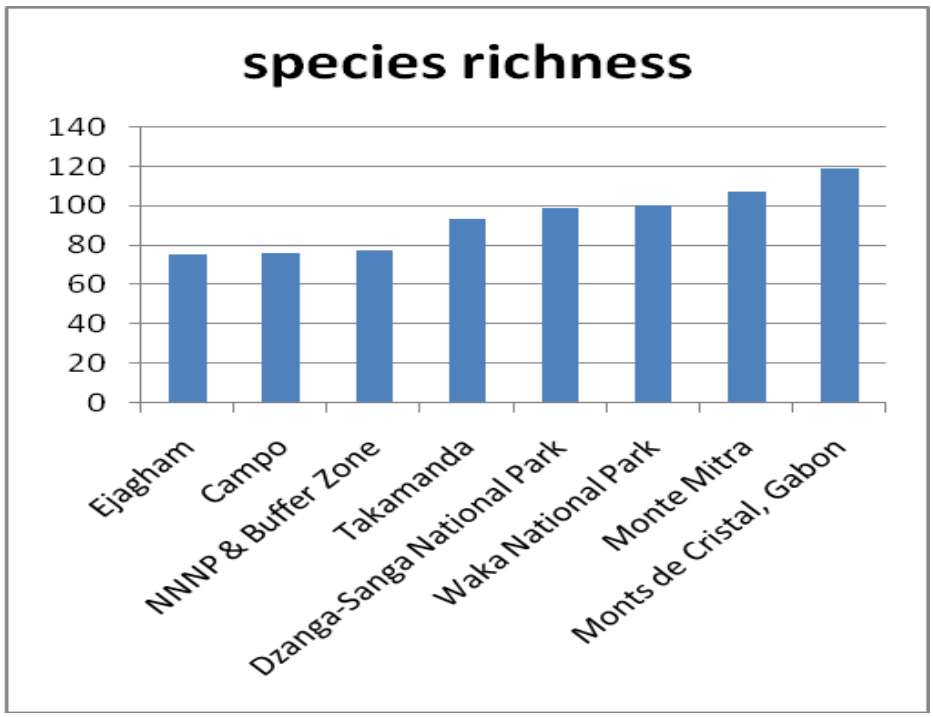


The map above show the locations of the transects in the Mbé watershed

Short transects

Over the last five years MBG has laid out a number of short transects (200x5m) in the less accessible parts of Gabon including the Monts de Cristal and the Mbé watershed. Short transects have the advantage that they can be laid out in areas where larger plots, 1-hectare plots or 50 hectare plots, would not fit, such as on summits and ridges and that they also allow us to do a nested sampling along an altitudinal gradient, geomorphological slope-units, environmental land-units as created above or any other spatial classification. The graph above represents the range of plant species richness from all short-transects carried out by MBG in Gabon (each bar representing one transect). It must be noted that most of the transects have been set up in areas known to have high biodiversity. Therefore, some of the transects in the Mid Mbé may seem average, but they actually are above average (except for two transects). The short-transects in the Mbé watershed display a tree diversity which among the highest in Gabon and tropical Africa.

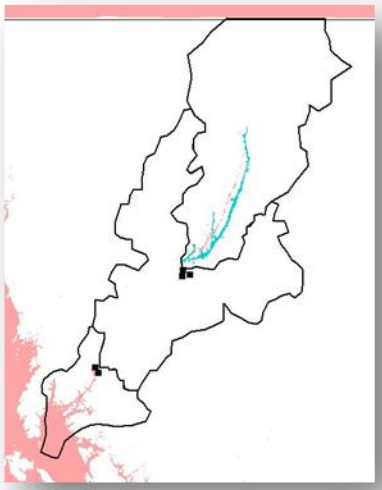
Measuring tree biodiversity



Source: Sunderland et al. 2004

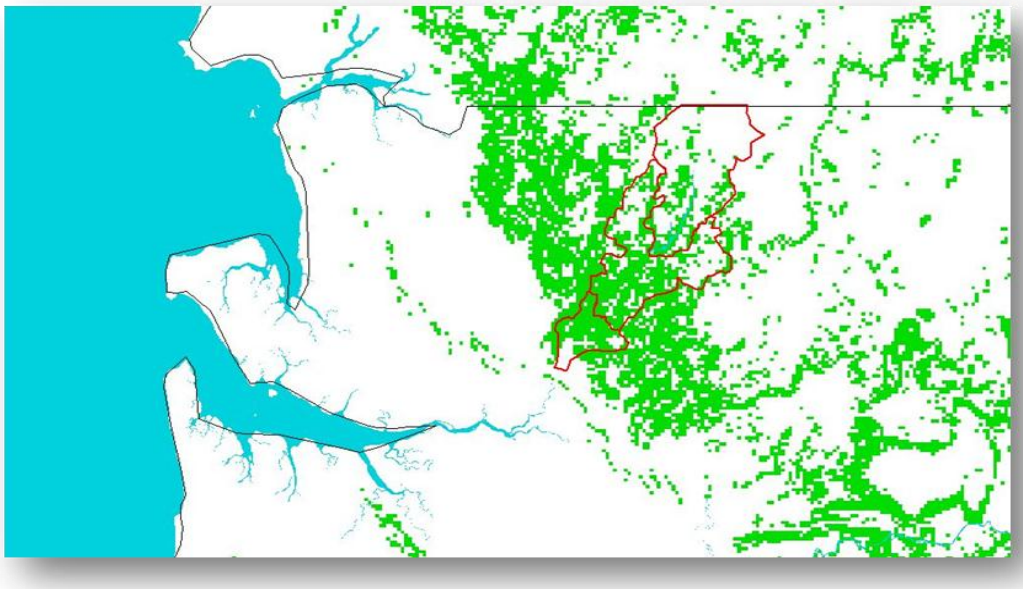
This graph illustrates the range in tree biodiversity in one hectare plot in Gabon and in the region

Plots



One hectare plots are more commonly used standard to measure tree biodiversity. Unlike short transects, these plots are usually laid out in homogeneous landscapes with a flat or gentle topography. Therefore, the data from these plots provides information on tree biodiversity about the less rugged areas of a landscape. There are five 1-hectare plots in the Monts de Cristal, two in the Lower Mbé and three in the Mid Mbé. The availability of similar plots in Gabon and elsewhere in the region allows comparing these plots those from the Mbé watershed. The graph above shows that the plots of the Mbé watershed in the Monts de Cristal have the highest tree species diversity in the region.

The map above shows the locations of the plots in the Mbé watershed and to the left an example of a more homogeneous landscape than the Monts de Cristal



The diagram above shows the location of postulated climatically stable forests in the Monts de Cristal, and the Mbé watershed.

Threats

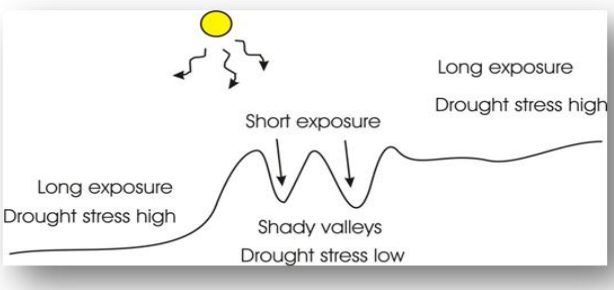
Climate change and forest dieback

In the worst case scenario of the effects of global warming, regional rainfall in tropical Africa may drop below the required minimum to sustain so-called zonal rainforest. As regional drought stress increases the persistence of closed-canopy forest becomes highly dependent on local compensation determined by altitude, topography or relief. These geographical characteristics determine the amount and stability of soil moisture available for plants to survive when rainfall levels decrease.

Accumulation of soil moisture is determined by topography. In rugged areas with steep slopes and steep valley bottoms rainfall is quickly drained, but when the valley bottom is gentle moisture will accumulate and slowly drain away. The latter is the case for the Monts de Cristal. Topography or the profile of the valley also determines the rate of moisture loss from evapo-transpiration. In deep narrow valleys exposure to the sun is reduced and consequently the amount of water lost (see also diagram below). Increasing altitude lowers daily maximum temperatures and hence evapo-transpiration and they are able force orographic rainfall (see also under the section *Rainfall*).

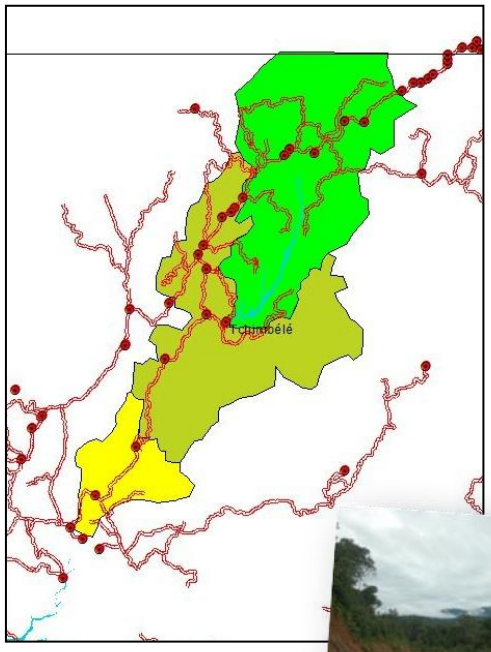
In the map above in green the most rugged landscape with narrow valleys has been located though a GIS map query (see also under *Land-units*). In the green areas forest dieback is least likely to happen with ongoing global warming.

The diagram on the right shows how under clear skies evaporation is lower in sheltered valleys in rugged areas.

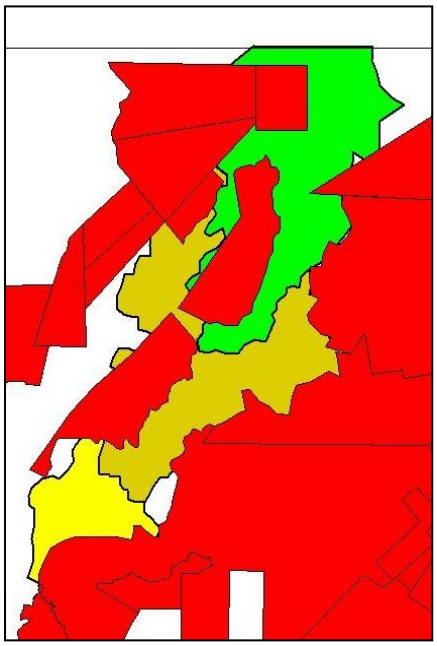


Local impact versus protection

Land clearance for agricultural cultivation by neighboring villages and commercial logging are the two greatest threats to forests outside the protected park in the Monts de Cristal area. To the west of the Mbé watershed, a corridor of villages crosses the left arm of the Mid Mbé and the northern part of Upper Mbé following the major roads in that area as shown on the map to the right (red lines correspond to road and reds dots to villages). Similarly authorized logging concessions comprise a significant portion of the inside the Upper and Mid Mbé, as shown on the map below left (concessions are demarcated in red).



The map to the right shows village corridor (red dots) and main access road (red lines) in and around the Mbé watershed

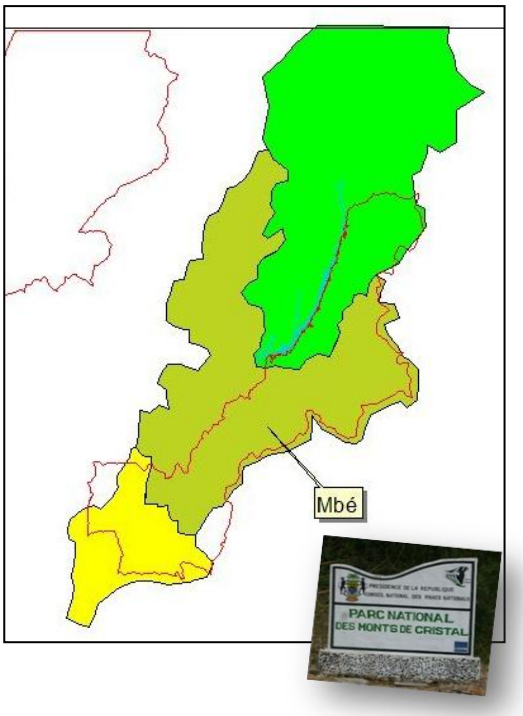


The map above shows the logging consession (red blocks) in and around the Mbé watershed

Deforestation for agricultural cultivation or logging, opens the closed canopy and reduces the overall buffering capacity of the forest to prevent erosion and resist drought stress during the dry season. Increased erosion means more sediments in the run-off water into the Mbé watershed streams and the Tchimbele lake. A fragmented canopy forest will also dry out quicker during period with high levels of solar radiation and consequently maximum air temperatures increase. This will also increase evaporation of water from the Tchimbele lake and lowering its level. A fragmented forest will also be more susceptible to forest dieback from global warming.

The forest in the eastern side of the Mbé watershed is protected by the Mbé NP (map to the right). Although the forest in this part of the Mbe watershed is not directly threatened by logging, logging in the adjancent consessions may forest to dieback in the national park according to model simulations studying the indirect effect of logging on regional climate change (for more details see reference *Roy, S.B., Walsh, P. D. and Lichstein, J. W. 2005*). Logging and forest dieback from global warming reinforce the overall forest dieback in the Monts de Cristal.

The map to the right show the Mbé NP in the Mbé watershed



Conclusion

In this report the environmental characteristics of the watershed were assessed, the resilience of its forests to climate change analyzed, its information on the plant biodiversity compiled and the threats to the landscape's capacity to provide ecosystem services to the city of Libreville identified.

The Mbé watershed has the environmental characteristics such as high mean annual rainfall, rainfall during the dry season and low evapo-transpiration rates to ensure sufficient and sustainable water volume to supply Libreville with electricity. Only a growing demand from Libreville could compromise its capacity, because water volume is at its maximum and most likely to decrease in the future. In terms of plant biodiversity the Mid Mbé and Lower Mbé have the best credentials.

Forest dieback caused by climate change is most like going to affect the Upper Mbé section as its ruggedness is weak and hence its resilience is low. This could cause the disruption of the ecosystem services for the Tchimbelé power plant. The Mid Mbé has the best chance of continuing its ecosystem service to the power plant of Kinguelé. The Upper Mbé also runs the highest risk from local impact from agriculture and logging affecting its sustainability for the future. Only left arm of the Mid Mbé runs similar risk whereas the rest is quite safe from by the impact of local populations.

Literature

Brncic, T. M, Willis, K. J., Harris, D. J. & Washington, R. (2007). Culture or climate? The relative influences of past processes on the composition of the lowland Congo rainforest. *Philosophical transaction of the royal society B , 362,* 229–242.

Cannon, C. H., Morley, R. J. & Bush, A. B. G (2009). The current refugial rainforests of Sundaland are unrepresentative of their biogeographic past and highly vulnerable to disturbance. PNAS Early Edition, www.pnas.org_cgi_doi_10.1073_pnas.0809865106

Cook, K. H. & Vizy, E. K. (2006). Coupled model simulations of the West African monsoon system: Twentieth- and twenty-first-century simulations. Journal of Climate 19: 3681–3703.

Eva, H.D., Belward, A.S., De Miranda, E.E., Di Bella, C.M., Gond, V., et al.., (2004). A land cover map of South America. Global Change Biology, 10, 731-744.

Delire, C., Ngomanda, A. & Jolly, D. (2008). Possible impacts of 21st century climate on vegetation in Central and West Africa. Global and Planetary Change 64: 3–15.

Good, P., Lowe, J. A., Collins, M. & Moufouma-Okia, W. An objective tropical Atlantic sea surface temperature gradient index for studies of south Amazon dry-season climate variability and change. Phil. Trans. R. Soc. B 363, 1761-1766.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., & Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology, 25, 1965 -1978.

ISCCC, (2009). Synthesis report. Climate Change, Challenges, Risks & Decisions, Copenhagen, Denmark.

Leal, M.E. (2009). The past protecting the future, locating climatically stable forest in West and Central Africa. International Journal for Climate Change Strategies & Management,1, 92-99.

Phillips, O. L., Aragão, L. E. O. C., Lewis, S. L., Fisher, J. B., Lloyd, J., López-González, G., at al. (2009). Drought sensitivity of the Amazon rainforest. Science, 323, 1344.

Maley, J. (1987). Fragmentation de la forêt dense humide Africaine et extension des biotopes montagnards au Quaternaire récent: nouvelles données polliniques et chronologiques, implications paléoclimatiques et biogeographiques. Palaeo-ecology of Africa, 18: 307 – 334.

Maley, J., (1991). The African rain forest vegetation and palaeoenvironments during the late Quaternary. Climate Change, 19, 79-98.

Myers, N. Mittermeier, R. A., Mittermeier C,. G. , da Fonseca, G. A. B. & Kent, J. (2000). Biodiversity hotspots for conservation priorities. Nature, 403, 583-585.

Nepstad, D.C., Stickler, C.M. Soares-Filho, B. & Merry, F. (2007). Interaction among Amazon land use, forests and climate: prospects for a near-term forest tipping point. Philosophical transaction of the royal society B

Parmentier, I., Senterre, B., Malhi, Y., Whittaker, R.J., A.T.D.N. (collective author), Alonso, A. , Leal, M.E., et al. (2007). The odd man out? Might climate explain the lower tree alpha-diversity of the African rain forests relative to the Amazonian rain forests? Journal of Ecology 95, 1058 - 1071.

Roy, S.B., Walsh, P. D. and Lichstein, J. W. (2005) Can logging in equatorial Africa affect adjacent parks? Ecology and Society 10: 6 http://www.ecologyandsociety.org/vol10/iss1/art6

Schefuss, E., Schouten, S., Jansen, J. & Sinninghe-Damsté, J., (2003). African vegetation controlled by tropical sea surface temperatures in the mid-Pleistocene period. Nature, 422, 418-421.

Sunderland, T., G. Walters & Y. Issembe (2004). A preliminary vegetation assessment of the Mbe National Park, Monts de Cristal, Gabon. A report for the Central African Regional Program for the Environment (CARPE).

Walker, R., Moore, N. J., Arima, E., Perz, S., Simmons, C., Caldas, M. Vergara, D. & Bohrer, C. Protecting the Amazon with protected areas. PNAS, 106: 10582–10586.