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The past protecting the future

Locating climatically stable forests in West and Central Africa

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Abstract

Purpose – In answer to the urgent need to adapt conservation strategies and approaches to climate change, the purpose of this paper is to locate the climatically stable forests in West and Central Africa and to assess whether they overlap with the existing network of protected areas and if not, to prioritize them for protection.

Design/methodology/approach – With ongoing global warming, rain forest will survive where locally soil moisture content remains high compensating for the regional drought stress. As a proxy for a soil moisture-driven model, rainfall $>2{,}000$ mm, altitude >500 m and strong relief (standard deviation in elevation data pixels) were overlapped in a GIS analysis to locate the climatically stable forest within the present continuous forest of Central Africa and within the degraded forest of West Africa. As a means of verification, the biodiversity was measured in and outside the identified areas in Gabon and Equatorial Guinea as high levels of biodiversity are related to the survival and stability of the forest in the past. Biodiversity was calculated (measured as Fisher-α diversity) for all trees (dbh >5 cm) on 66 transects (200×5 m).

Findings – The forest areas identified as climatically stable in the GIS analysis showed a higher biodiversity than the forest outside these areas (student T-test: $P < 0.000035$, stable $= 54.7$ and unstable $= 33.7$), supporting the validity of the model. Mapping the results of the GIS query showed that most of the climatically stable forests in West and Central Africa are located outside the park systems, and that it is already too late to protect the climatically stable forest in West Africa as almost nothing is left of it.

Originality/value – Wedged in between large-scale drought tolerant ecosystems the African rain forest is most vulnerable to global climate change. Knowing which parts are climatically stable and resilient helps to set and focus conservation priorities and efforts. This approach is a powerful tool which has helped to identify areas with a high-conservation priority in Africa.

Keywords Conservation, Climatology, Forests, Africa, Global warming

Paper type Research paper

Introduction

Climate change is affecting the distribution of plant communities at a global scale, causing a shift in their geographical position and a change in their extension (IPPC 2001 Climate change, 2001), and the forest is particularly vulnerable in Africa (UNEP, 2008). Presently, there is no detailed scenario how the rain forest in Central Africa is going to change and where the climatically forest are located. The situation is even more pressing because rain forest is also disappearing at a rapid pace with the socio-economic development of the region, as is visible comparing the extent of rain forest in West Africa and Gabon in Central Africa.

The only primary forest still standing in Ivory Coast and Ghana is within the protected areas, whereas in Gabon the protected areas lay within the primary forest.

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If in West Africa the climatically stable forest had been situated in between the protected areas, it has now disappeared and turned into secondary forest and plantations. Since the forest in the protected areas is not climatically stable, West Africa will be left without any rain forest and having lost all its rain forest biodiversity.

Conservation NGOs, governments and national agencies have not yet realized how alarming the situation is. To protect any rain forest for the future, it is essential to locate the climatically stable forests and give them a protected status. In contrary to West Africa, this is still possible in Gabon, which is a country half the size of France, with slightly more than one million people (mainly restricted to three large cities) and covered for 80 per cent by pristine to selectively logged primary forests.

To locate the climatically stable forests in West and Central Africa, forest history of the last 20,000 years has been applied. Presently, the West- and Central African rain forests are in a sub-maximum expansion. The rain forest was at its largest some 8,000 years ago when both forests were linked and the Dahomey Gap did not exist (Dupont *et al.*, 2002). Before and after this maximum extension, the forest was smaller, considerably smaller during the Last Glacial Maximum (LGM) and less so during the Late Holocene. The loss of rain forest during the LGM some 18,000 years ago was due to global cooling (Maley, 1991; Sosef, 1994; Leal, 2004) and during the Late Holocene Perturbation (LHP) some 2,500 years ago (Maley, 2001) due to a spell of global/regional warming. The principles and mechanisms as how the African rain forest waxes and waned with climate change has been well established as paleo-climate during these periods has been well reconstructed (Maley, 1987, 1991, 1996), a.o. similar phenomena still occur in Gabon today (Leal, 2004). Additional support comes from studying the detailed biogeography of the refuge Begonias (Sosef, 1994) and the distribution ecology of the Caesalpinioideae-Leguminosae (Leal, 2001, 2004), both species groups are indicative for climatically stable forest.

The availability of high-quality data on elevation, climate and vegetation for Africa has made it possible to reconstruct the forest refugia in much more detail than before, i.e. the climatically stable forest. In this study, a first detailed reconstruction is presented which can be used for future reference.

High levels of biodiversity are related to the survival and stability of the forest in the past (Parmentier *et al.*, 2007). Therefore, as verification of the approach and to see whether there was a biological difference, biodiversity in terms of Fisher α-diversity was measured on transects between the refuge and none-refuge areas. The higher diversity values of transects in refuge areas supports the validity that these areas being are climatically stable forests.

Methods

Rationale

The approach adapted in this study to locate climatically stable forest is based on the reconstruction of past dry climate periods and the ecological response of humidity dependent ecosystems as rain forests to the subsequent drought stress (Leal, 2004). Drought stress during the LGM and LHP were very different and hence their effect on the rain forest. Climate during the LGM was dominated by shallow cloud cover more than today due to increased upwelling of cold deep sea water along the west coast of Central Africa, as a consequent the rain forest was least affected in elevated areas (Maley, 1987). Climate during the LHP resembles much closer the present and future global warming (Maley, 2001; Leal, 2004). A prolonged dry season without cloud cover affected mostly the forest in areas with a flat of gentle topography like in the coastal region and on the interior plateaus whereas the forest in rugged areas was less or only temporarily exposed to the then stronger evapotranspiration (Leal, 2004).

Reconstruction

The (Pleistocene) forest refugia of the LGM were reconstructed by overlapping in a GIS analysis (ArcView 3.3), the present rain forest cover (Mayaux *et al.*, 2004), rainfall data extracted from the WoldClim database (www.worldclim.org, Hijmans *et al.*, 2005) and topography data extracted from the SRTM database (www2.jpl.nasa.gov/srtm). A map query to obtain the "wet" forest refuge areas in West and western Central Africa was done by taking a mean annual rainfall of more than 2,300 mm. A more detailed map was created for Gabon by also doing an additional map query for mean annual rainfall more than 1,800 mm to obtain the humid refuge areas.

To reconstruct the forest which was least affected during the LHP, the wet and humid forest refugia were superimposed on scanned and georeferenced national maps when available from the National Geographic Institute of Gabon. The procedure was to reject areas within the identified Pleistocene refuge areas with a gentle topography and to add areas with rugged topography adjacent to Pleistocene refuge areas. Pleistocene refuge areas with a gentle topography were excluded, because these areas probably experienced considerable drought stress during the LHP. Vice versa, rugged areas adjacent to Pleistocene refuge areas probably experienced less-drought stress during the same period (Daws *et al.*, 2002; Leal, 2004).

Biodiversity assessments

Biodiversity was assessed in Gabon in the identified refuge areas and outside by using transects (200 × 5 m) on which all tree species with a diameter at breast height (dbh) above 5 cm were recorded. For each transect the Fisher α-diversity was calculated counting individuals above 5 and 10 cm dbh. The Fisher α-diversity values calculated for transects for all individuals above of 10 cm where compared to other ecological data available for tropical Africa (Parmentier *et al.*, 2007). By calculating only the local (Fisher α-) diversity of the transects, the accumulative effect of an increased diversity with habitat differentiation was avoided.

Results

Reconstruction

The map queries performed identified the traditional upland Pleistocene refuge areas in the West African (Upper Guinea) and western Central Africa (Lower Guinea), except for the lowland forest refugia like Cape Palmas, Cape Three Points in Upper Guinea, and the lower coastal refuges areas in Lower Guinea. Most upland refugia are located on the transition from coastal lowland to the elevated interior plateau. This transition zone has the geomorphology of a dissected escarpment and receives a relatively high mean annual rainfall being situated close to the ocean with its influx of humid air (Figure 1).

The LHP refuge areas coincide with the Pleistocene refuge areas as their transitional position escarpment position between coastal lowland and interior plateau is characterized by rugged topography creating an abundance of narrow valleys.

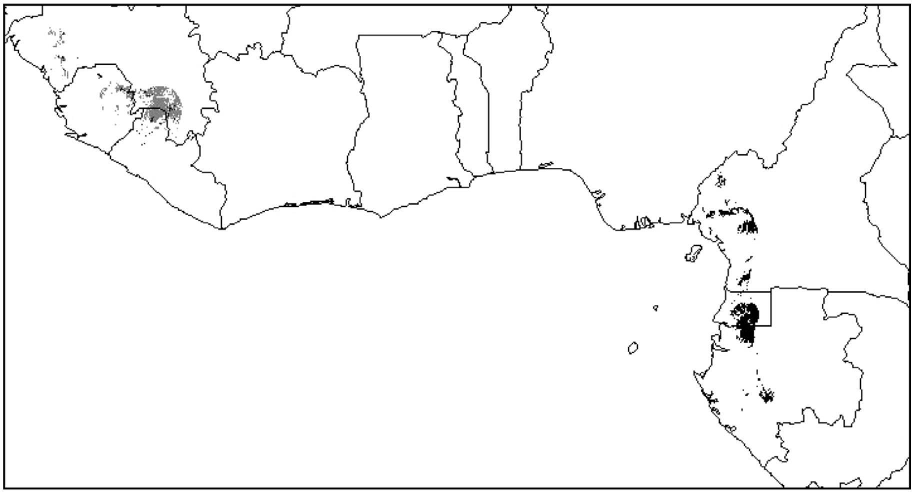

Figure 1.
Map showing the refuge areas with primary rainforest (black), the degraded forest refugia (light grey)

The refuge areas in Upper Guinea consisted mainly of degraded forest and croplands whereas in Lower Guinea there are still large stretches of refuge areas consisting of primary forest. The primary forest in Upper Guinea is mainly limited to protected areas, but which is not part of the identified refuge areas.

Biodiversity assessment

In total, 66 transects were measured, 34 in none-refuge areas and 32 in refuge areas (Figure 2). Sites sampled in the none-refuge areas included high-rainfall areas at the coast, i.e. Mondah and Pongara, in the drier interior, i.e. Mt Kinguié and Langoué and the wet peripheral forests on the Bateké Plateaus. The average Fisher α-diversity on the refuge transects was much higher than on the none-refuge transects (student T-test: $P < 0.000035$, refuge $= 54.7$ and none-refuge $= 33.7$). Low diversity values were present among the refuge transects, mainly from the Mvé Lakené Plateau and Mt Mbilan Plateau in the Monts de Cristal. Three transects from none-refuge areas had high-diversity values, two from northern Waka and one from Langoué.

The low values of the transects from the small plateaus of Mvé Lakené in the Monts de Cristal may have to do with their gentle topography. All transects on the plateau had a lower diversity (32.5, 42.5, 34.6, 31.9) than the one transect on the southern flank of the same plateau (67.3). The one transect on the Mbilan Plateau with a low-diversity value (21.6) was in a marshy area on ironstone, which are restrictive conditions for

Notes: Y-axis: Fischer α-values, X-axis: transects

Figure 2.
Graph showing the Fisher alpha-diversity values for the non-refuge transects (grey bars) and the refuge transects (black bars)

many species. The other two transects on the small plateau had a higher diversity value than the one transect on the flack (56.5, 45.2 and 40.9, respectively).

Discussion

Conservation

Reconstructing the Pleistocene forest refugia in this study has been done by applying the same principles and mechanisms as in the first attempts by Maley (1987, 1991). The first reconstructions were more qualitative in principle than quantitative in detail. Elevation and rainfall data now have improved to such a quality that refuge areas can now be reconstructed in a much greater detail. This reconstruction shows that virtually all climatically stable forest in West Africa has been degraded and no longer exists (Figure 1). The only forest remains in the protected areas and which are most likely to become deforested with ongoing global warming. The absence of this forest will most certainly not be able to counter effect the increasing desertification from the north, which will also have a stronger effect on the northern limit of the rain forest in Central Africa. The conservation strategy for West Africa, would be to reforest the lost climatically stable areas. In western Central Africa, there still exists large stretches of climatically stable forest, but not all of it is protected (Figure 3). Here, the conservation strategy would be to focus and prioritize these unprotected areas to avoid a similar development which has happened in West Africa. One way to help conserve these forests would be to rate them with the highest carbon credit values so that there is an economic incentive.

Biodiversity

Their reconstruction in a greater detail evidently does not signify a stronger proof for their former existence or their climatic stability in the future. Even the observation that the transects in the refuge areas have a higher Fisher α-diversity is not inconclusive, even when they are among the ones with the highest values for the whole of Africa (Parmentier *et al.*, 2007). There is the risk of circular reasoning when dealing with

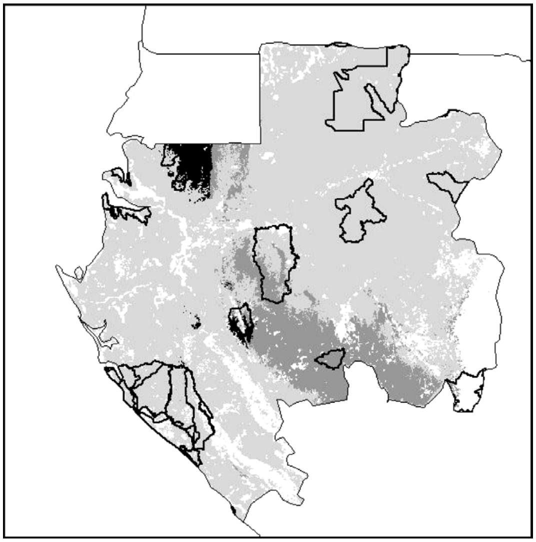

Figure 3.
Map showing the rain forest in Gabon (light grey) with wet primary rainforest refugia (black), the humid forest refugia (dark grey), and the park system (outlined in black)

forest refugia and their biological proof and therefore first an ecological perception on the results is taken.

The ecological observation is that forests in elevated areas with a mean annual rainfall of more than 2,300 mm are more diverse than lowland rain forests which receive less rainfall like sites in the drier interior of Gabon. This observation confirms the general rule that drier areas are less diverse than wetter areas (Givnish, 1999). What is not conforming to the general rule is that these elevated areas are even more diverse than the wettest lowland sites of Gabon. High-rainfall areas in the lowland are throughout the world the areas with the highest biodiversity (Gentry, 1988). The higher diversity in elevated areas cannot be attributed to a higher habitat diversity, because only local diversity on the transects was compared and not the accumulative diversity of the entire site.

The difference in diversity between the lowland and elevated areas can be explained by the difference in drought stress. Drought stress in terms of negative soil matrix potentials (MPa) was not measured on the transects, but in qualitative terms the difference can be deduced by elucidating all the ecological factors which determine soil moisture availability, especially during dry seasons. Length of the dry season is a strong force arranging species composition and associated characteristics, like (Fisher α-) diversity (Ter Steege *et al.*, 2003). The absence of a dry season in the elevated areas of the Monts de Cristal reduces drought stress completely during the months July and August as rain in the form of drizzle continues to fall (personal observation), when in the rest of the country, including sites with the highest mean annual rainfall, there is no rainfall during these months.

Hills in general have the orographic capacity to intercept small amounts of rain which either shortens or lessens the impact of the dry season, even when these hills are located in relatively low-rainfall areas like the Belinga Mountains. Compared to the lowland daily maximum air temperatures are also a few degrees lower in hills because of their altitude, which in turn reduces the strength of the evapotranspiration. The ruggedness of hills also reduces the exposure to evapotranspiration for forest on slopes or in valleys (Daws *et al.*, 2002).

In Gabon-elevated refuge areas experience less-drought stress than the adjacent lowland, due to a shorter or less strong dry season, also evapotranspiration is less strong or less exposed. These are characteristics which can explain the difference in diversity between lowland and elevated refuge areas. If nowadays such elevated areas experience less-drought stress under present climatic conditions, in principle they would also experience less-drought stress when climate becomes drier and more seasonal with future global warming. It would seem that elevated areas are presently more climatically stable than the lowland, that they have been in the past and will so in the future, although this is not proven empirically.

Conclusion

Conservation NGOs and national governments try to conserve their most valuable plant communities/ecosystems which are characterized either by high biodiversity or high uniqueness of species (endemism). A new aspect they have to take into consideration is the stability of the ecosystem/plant community. This study focused particularly on the practicality for conservation. Even if academic debate continues whether these forest refuge areas have ever existed and whether they are indeed climatically stable, this model has shown its value for conservation in identifying forests areas where biodiversity is high to exceptionally high and the reconstruction/prediction of the West African situation is very precarious and needs an immediate response from Conservation NGO's and national governments.

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Miguel E. Leal (PhD) is a tropical forest ecologist and plant taxonomist/systematist in Central Africa assessing biodiversity and collecting plants. In the broader scheme, this information feeds into the program to locate climatically stable or resilient forest as an adaptation to climate change. Miguel E. Leal can be contacted at: Miguel.Leal@mobot.org

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