FOREST & LANDSCAPE

THE ROCKEFELLER FOUNDATION

World Agroforestry Centre
TRANSFORMING LIVES AND LANDSCAPES

FOREST & LANDSCAPE WORKING PAPERS EXCERPT FROM 61/ 2011

Potential Natural Vegetation of Eastern Africa (Ethiopia, Kenya, Malawi, Rwanda, Tanzania, Uganda and Zambia)

Volume 1- Introduction

The Atlas

J.-P.B. Lillesø, P. van Breugel, R. Kindt, M. Bingham, Sebsebe Demissew, C. Dudley, I. Friis, F. Gachathi, J. Kalema, F. Mbago, V. Minani, H.N. Moshi, J. Mulumba, M. Namaganda, H.J. Ndangalasi, C.K. Ruffo, R. Jamnadass and L. Graudal

FACULTY OF LIFE SCIENCES
UNIVERSITY OF COPENHAGEN

Title
Potential natural vegetation of eastern Africa. Volume 1. The Atlas

Authors
Lillesø, J.-P. B., van Breugel, P., Kindt, R., Bingham, M., Sebsebe Demissew, Dudley, C., Friis, I., Gachathi, F., Kalema, J., Mbago, F., Minani, V., Moshi, H.N., Mulumba, J., Namaganda, M., Ndangalasi, H.J., Ruffo, C.K., Jamnadass, R. and Graudal, L.

Collaborating Partner
World Agroforestry Centre

Publisher
Forest & Landscape Denmark
University of Copenhagen
Hørsholm Kongevej 11
DK-2970 Hørsholm

Series - title and no.
Forest & Landscape Working Paper no.61-2011

ISBN
ISBN 978-87-7903-550-8

DTP
Melita Jørgensen

Citation
Lillesø, J.-P. B., van Breugel, P., Kindt, R., Bingham, M., Sebsebe Demissew, Dudley, C., Friis, I., Gachathi, F., Kalema, J., Mbago, F., Minani, V., Moshi, H.N., Mulumba, J., Namaganda, M., Ndangalasi, H.J., Ruffo, C.K., Jamnadass, R. and Graudal, L.. 2011. Potential natural vegetation of eastern Africa. Volume 1: The Atlas. Forest & Landscape Working Paper 61-2011

The report is available electronically from
www.sl.life.ku.dk

Introduction

- This book represents **Volume 1** in a seven-volume series that documents the potential natural vegetation map that was developed by the VECEA (Vegetation and Climate change in East Africa) project. The VECEA map was developed as a collaborative effort that included partners from each of the seven VECEA countries (Ethiopia, Kenya, Malawi, Rwanda, Tanzania, Uganda and Zambia).
- In **Volume 1**, we present the potential natural vegetation map that we developed for seven countries in eastern Africa. In Volume 1, we also introduce the concept of potential natural vegetation and give an overview of different application domains of the VECEA map.
- **Volumes 2** to **5** describe potential natural vegetation types, also including lists of the "useful tree species" that are expected to naturally occur in each vegetation type – and therefore also expected to be adapted to the environmental conditions where the vegetation types are depicted to occur on the map. **Volume 2** focuses on forest and scrub forest vegetation types. **Volume 3** focuses on woodland and wooded grassland vegetation types. **Volume 4** focuses on bushland and thicket vegetation types. In **Volume 5**, information is given for vegetation types that did not feature in Volumes 2 to 4.
- **Volume 6** gives details about the process that we followed in making the VECEA map.
- **Volume 7** shows the results of modelling the distribution of potential natural vegetation types for six potential future climates.

Acknowledgements

We are extremely grateful to the Rockefeller Foundation for having provided financial support to the work that has led to the development and publication of the VECEA map and its accompanying documentation.

We also greatly appreciate the comments and suggestions that were made by Paul Smith and Jonathan Timberlake (both of Royal Botanic Gardens Kew) when they reviewed early drafts of volumes 2, 3, 4 & 5.

Thanks to everybody in our institutions who contributed directly or indirectly to the completion of the VECEA vegetation map and its associated documentation. We especially appreciate the assistance by Nelly Mutio (as for organizing logistics for the regional workshop that we organized in 2009 and for assisting in administrative issues), Melita Jørgensen for desktop publishing, and of Jeanette van der Steeg for helping with the final preparation of the maps for Volume 1. Meshack Nyabenge and Jane Wanjara of ICRAF's GIS Unit for supervising the digitizing of several of the old vegetation maps.

Thanks to Ann Verdoodt and Eric Van Ranst (both from the University of Ghent) for compiling and sharing thematic soil maps that were derived from the soil of Rwanda (Birasa, E.C., Bizimana, I., Bouckaert, W., Gallez, A., Maesschalck, G., and Vercruysse, J. (1992). Carte Pédologique du Rwanda. Echelle: 1/250.000. Réalisée dans le cadre du projet "Carte Pédologique du Rwanda" (AGCD, CTB). AGCD (Belgique) et MINAGRI, Kigali).

Thanks to Eugene Kayijamahe, Center for Geographic Information System and Remote Sensing at National University of Rwanda for sharing the digital map "Vegetation of Volcanoes National Park" that allowed us to classify in greater detail this part of the VECEA map.

Thanks to UNEP-GEF for funding the Carbon Benefits Project (CBP) through which information was compiled on indicator and characteristic species for The Vegetation Map of Africa (White 1983). (This work led to the publication in 2011 of an Africa-wide tree species selection tool that is available from: *http://www.worldagroforestrycentre.org/our_products/databases/ useful-tree-species-africa).* Thanks to BMZ for funding the ReACCT project in Tanzania through which funding was made available for field verification of the VECEA map around Morogoro (this was essential in preparing the VECEA map as the base map for Tanzania was essentially a physiognomic map).

Contents

1. Background

The VECEA map of eastern and southern Africa (Ethiopia, Kenya, Uganda, Rwanda, Tanzania, and Zambia) is the product of a project funded by The Rockefeller Foundation and implemented by Forest and Landscape Denmark, World Agroforestry Centre, Nairobi, and botanical experts in the seven countries. The project also benefited from previous support to botanists at the relevant departments at the universities of Makerere/Dar es Salaam by an ENRECA programme provided by Danida and previous support to Ethiopian Flora Project provided by SIDA/SAREC and through grants from the Carlsberg Foundation.

The documentation of the VECEA vegetation map consists of seven volumes. In this volume 1, we present the map, and we briefly discuss the important concepts utilised and applied in the map. In volumes 2 to 5, we provide a detailed documentation and discussion of the five major physiognomic vegetation categories and their variation in vegetation types as well as distribution of tree species in this framework. In volume 6, we describe the original maps that we have utilised for each country and we document and discuss the modelling procedures and processes. In volume 7, we model how vegetation types may develop under different climate change scenarios.

So why did we chose to make a regional vegetation map when similar maps have already been developed (Olson *et al.*, 2001; Whittaker *et al*, 2005)? The most recent is the ecoregional approach developed by World Wildlife Fund (WWF), Nature Conservancy, and Conservation International. In WWF's terrestrial ecoregion scheme[1], White's vegetation map (and memoir) of Africa (White, 1983) - henceforth called the White map - serve as the basis for the ecoregions of the Afrotropics (Olson *et al*; 2001; Burgess *et al.* 2004). In this process the ecoregions map has mainly become a simplified version of the White map. A major objective of the White map is to provide a framework on a continental scale within which more detailed local studies can be conducted and compared and as such the map is suitable as a basis for describing the terrestrial ecoregions of Africa by capturing the broad-scale patterns of biological diversity and the ecological processes that sustain them.

We have taken the opposite approach of WWF's terrestrial ecoregion scheme by deconstructing[2] the White map into its more detailed parts. We have done this by utilising the same smaller maps as those that White utilised and to a large extent described in his text without directly mapping them. The VECEA map thus differs in terms of the spatial resolution, which allows us to break down the landscape into more well defined mapping units.

So why do we think that a higher resolution of the map is important? It is in the nature of the scale of the White map (1:5,000,000) that vegetation units on the map are heterogeneous in character and only broadly delineated and thus it is not possible to utilise the White map for a more detailed understanding of vegetation dynamics and species distributions, which is an understanding that is required if a map should be of importance for field implementation (see below for the intended uses of the VECEA map). Fur-

1: See also *http://www.worldwildlife.org/science/ecoregions/ecoregion-conservation.html*

2: Our method can best be described by paraphrasing the term deconstruction (Derrida, 1967). The White map is an interpretation of reality and we explain it and provide a higher resolution map by revisiting the maps and botanical research that he used to make his map. The VECEA map is thus also an interpretation of reality, but at a higher resolution.

thermore for practically all indigenous species in the region there is insufficient point location data available to make good estimates of their actual and potential distributions across landscapes. A higher resolution of maps and consequently more detailed predictions of species distribution, however, opens up a new discussion of how to interpret vegetation dynamics at the community level (see below for our discussion of Potential Natural Vegetation), but this discussion is unavoidable and necessary for successful field implementation. The great advantage of mapping at a higher resolution is that the interpretation of community dynamics becomes publicly available and can be disputed and tested. This is in contrast to ecoregion maps where managers of restoration projects and tree planters must make their own guesses based on very generalised recommendations.

In comparison with White, we have had the advantage of computer based technologies that has enabled us to provide a higher resolution for a very large geographic area. Based on our analysis, we are in overall agreement with White's methodology and approach and we will provide a detailed discussion of the VECEA map in a number of peer reviewed papers. The process of elaborating the regional map has been iterative. Almost all available relevant vegetation information for the VECEA countries from early 20th century and onwards were collated and digitised. The botanists prepared national maps based on their interpretation of available vegetation maps and botanical information. The preparation of the regional map was a process of harmonisation of nomenclature and interpretation of vegetation types in an interaction between the team members.

The main objective for preparing the map is utilitarian and closely related to the requirement for a more detailed understanding of the indigenous tree species in the region – to improve the productivity of smallholder tree growers utilising the species in agroforestry systems. The utility of the map, however, goes beyond understanding the productivity of indigenous tree species and encompasses a more general understanding of agricultural productivity and conservation of fauna and flora in ecosystems.

In summary, the utility of the VECEA vegetation map, complemented with additional information on vegetation development and other environmental data layers, is that it:

(i) provides an integrated interpretation of landscapes and indicates the position of transitions between areas with significantly different environmental conditions, conditions which are most likely to be important determinative factors for agricultural potential;
(ii) predicts potential distributions of indigenous plant species in the agricultural landscapes and predicts possible genetic variation across distributional ranges;
(iii) can be a tool for predicting potential distributions of species of terrestrial animals, birds, reptiles, and invertebrates in remaining natural vegetation;
(iii) can be a user friendly extension tool for improving the potential options (both from indigenous and exotic species) available to

farmers in their quest for improving livelihoods and income generation;

(iv) provides for possible forecasts of changes in agricultural potential resulting from climate change;

(v) provides a management tool for interpretation of historical, current, and future distribution of ecosystems and ecoregions, including alternative stable states;

(vi) provides a tool for ecological restoration and protection of ecosystems.

A brief background on vegetation mapping in the VECEA region (Ethiopia, Kenya, Malawi, Rwanda, Tanzania, Uganda and Zambia)

Prior to the colonisation of Africa, vegetation exploration and mapping were mainly limited to the coastal areas (Whitlow, 1984, 1985). From the mid-nineteen century the continent was dominated by European colonial powers and the colonial imprint during the period where most vegetation mapping was carried out - at the end of the colonial era and during first decades of the new independent nations – was such that the expatriate botanists from the former colonial powers continued working in the respective spheres of interest. In the VECEA region British botanists worked in Kenya, Malawi, Tanzania, Uganda and Zambia, while Belgian botanists worked in Rwanda, and Italian botanists in Ethiopia. The botanical mapping of Ethiopia was, however, on a very small scale (Friis *et al.*, 2010). In volume 6 we provide details of the main maps utilised for the VECEA map.

The period during which the most substantial mapping was carried out has been called the "golden age of reconnaissance surveys" (Young, 2007), conducted as part of the international drive for development after the Second World War, from 1950 to about 1975. The aim of the reconnaissance surveys was to produce an overview of the natural resources for agriculture available in the countries: climate, water, soils, pastures and forests (Langdale-Brown, 1966, Young, 2007). The Colonial Office – after independence the Land Resources Division – in Britain recruited Soil Surveyors and Ecologists to carry out the surveys. Typically the surveys extended over the whole of a country or a large region at scales between 1:250.000 and 1:1,000.000. In a very general sense, their aim was to show what is there. Project surveys were usually at intermediate, semi-detailed scales such as 1:100.000 or 1:50.000 and covered land provisionally intended for a development scheme. Most of the vegetation maps made during this period had, as the major purpose, to be an aid in agricultural strategic planning, where the distribution of vegetation types were interpreted as a measure of agricultural potential. Other maps were made as general agro-ecological type surveys, a result of forest inventories, surveys of pest habitats such as Red Locust habitats and Tsetse fly habitats (Young, 2007).

An important international botanical organisation AETFAT (Association pour l'Etude Taxonomique de la Flora d'Afrique Tropicale) was established during this period and AETFAT was responsible for the development of two vegetation maps of Africa. The first major vegetation map by Keay

(1959) was preliminary compared to the second map by White (1983). Relatively little mapping has been carried out since the 1980s and the investments in compiling Floras in the region was also comparatively larger during the early years, although Floras are still being updated.

A major objective of the White vegetation map (White, 1983) is to provide a framework on a continental scale within which more detailed local studies can be conducted and compared. White saw it as essential that vegetation maps should be based on vegetation alone. Pattern lines and transition zones shown on the map must correspond to zones of greater or lesser width, where change in the structure and appearance of the vegetation is more rapid than anywhere else on the map. Conversely, the differences in structure of the vegetation (except very locally) between different parts of a mapping unit must be less than those between any part of a particular unit and any part of another unit.

White classified and mapped the vegetation types almost entirely based on physiognomy and floristic composition of the vegetation, and not on climate, although a few comparative climatic terms such as moist and dry are occasionally used in the designation of the mapping units. In parallel to the mapping of vegetation, Frank White developed a chorological map of plant species distributions in Africa. The study of chorology of plants (the study of plant distributions) in Africa has a long history, which has been documented in detail by Friis (1998). Two of the important characteristics of Frank White's chorological classification are (i) the classification is non-hierarchical showing the presence of distinctive floras with a high degree of endemism ('regional centres of endemism' with more than 50% of endemic species – 1000 species), the "transition zones" where the regional centres more or less gradually replace each other, and more complex areas where several regional centres of endemism met ('regional mosaics').

In the legend of the White map, the mapping units are grouped according to physiognomy, whereas in the text, they are grouped according to the floristic regions in which they occur. There are thus two interconnected classifications, which can be used independently but are fully cross-referenced. White denotes the physiognomic vegetation types in a largely non-hierarchical classification of "formations" defined as plant communities characterised by physiognomy, the formations are very unequal in the size of the areas they occupy and, to a lesser extent, in their degree of physiognomic distinctness, but this feature would remain regardless of the way in which they are classified (White, 1983).

The classification system of Frank White (White, 1983)

The classification system of the Vegetation of Africa has evolved from earlier classification, including the 'Yangambi' classification (CSA, 1956). And more particularly that of Greenway (1973; Pratt *et al.*, 1966) but differs in several respects from both. White considered the Yangambi classification as having too few categories and they are heavily biased in favour of West African types. In the nomenclature descriptive English terms were used for the main physiognomic types avoiding the use of imported vernacular names of such as savanna and steppe. African vernacular names for local variants of the major physiognomic types have been used such as 'mopane' and 'miombo'.

The main modifications to Greenway's system are as follows (White, 1970, 1976, 1983, 1993):
(i) mangrove is separated from forest as a major physiognomic type, (ii) bamboo is treated a major physiognomic type and not as a type of thicket, (iii) giant-grass thicket is treated as grassland, (iv) the term scrub is used in a general sense to designate all woody vegetation other than forest, woodland, mangrove and bamboo, though in most contexts more precise terms as bushland or shrubland are preferred, (v) shrubland is recognised as a major physiognomic type, (vi) the physiognomically mixed and distinctive Afroalpine vegetation is treated as a major type, (vii) desert is recognised as a major classificatory unit, but semi-desert vegetation is classified as shrubland, grassland, etc., wherever the physiognomy justifies this, (viii) the physiognomically diverse vegetation of saline and brackish swamp is treated collectively as a major classificatory unit, (ix) in addition to wooded grassland, three other transitional types, namely scrub forest, transition woodland, and scrub woodland are recognised - firstly they enable clearer and less arbitrary distinctions to be made between regional formations and secondly, they facilitate the description of transition zones and complex mosaics, and, as in the case of transition woodland, the interpretation of vegetation dynamics.

The classification systems of VECEA largely follows that of the White map (see volumes 2-5).

2. What is potential natural vegetation?

We will here attempt to clarify how we interpret and implement terms utilised in the classification of vegetation. The central concept "Potential Natural Vegetation" in the VECEA map can be seen as the pivot around which a whole range of contested assumptions circle. These unavoidable assumptions are concerned with the distribution and dynamics of species and vegetation. While it is indisputable that plants are not randomly distributed geographically and in time, there is an ongoing debate about at what scale patterns can be discerned and whether plant species form assemblies that follow similar distribution patterns.

Friis (1998) in his review of the development of chorology explains that one of the earliest disputes in botany was about classifying plant distributions (plant chorology). In the beginning of the 19th century J.F. Schouw divided the globe into areas with more or less defined floras. Some of the most important criteria were based on presence or absence of characteristic species and without making assumptions about the historical development of the flora. Some twenty years later in a large work on plant geography A. de Candolle completely rejected a natural classification of the world into phytochoria because. (i) the plant world was too poorly known, and (ii) scientists did not apply sufficiently logical criteria. During the following century many scholars further contributed to the understanding of plant chorology in Africa and there is now a general consensus on chorology as a useful tool to describe plant species distributions in Africa - contrary to the situation in Europe (Friis, 1998). Frank White has been a major contributor and chorological patterns are an important integral part of White's vegetation map. Although logical, the criteria utilised are still not completely objective in the strictest sense. As Friis points out, White more than once stated that "there is no *a priori* reasons why the pattern lines on a vegetation map based on physiognomy of vegetation should coincide closely with those of a chorological map based on the coinciding distributional limits of species." But the results of his work with the vegetation map of Africa showed that if the chorological map of Africa was based on chorological data alone, rather than on transferring pattern lines from a detailed vegetation map, the pattern lines would not have been significantly different" (Friis, 1998 p. 37).

Early concepts concerned with the definition of community patterns in space are the biome[3], that was introduced to plant ecology by Clements in the first half of the 20th century and ecoregion that was introduced by Crowley, and Bailey in the second half of the same century (see discussion in Pennington *et al.,* 2004). The concepts are largely overlapping and assume that one can discern broad scale patterns in the distribution of ecological communities, which are defined by similar climax plant formations and environmental conditions. A major difference is that an ecoregion is never discontinuous, while a biome is in principle always coincident with the climax vegetation and therefore can consist of disjunct areas (Bailey, 2005). Biomes and ecoregions define very large scale patterns, thus allowing for analysis at a continental or global scale, and are widely used by conservation agencies.

During the first part of the 20th century Clement and later Tansley[4] envisaged that in a given area, the assemblage of plant species would compete and replace each other such that eventually the dominant species would coexist in a stable climax (equilibrium/balance of nature), which would vary with the biotic and abiotic environment including the prevailing climate. This climax concept was soon after contested by Gleason who saw vegetation development as a stochastic process rather than as development as an organism, with communities composed of species with individual adaptations to the biotic and abiotic environment and thus with individual distributions. During the almost one hundred years since these ideas were conceived an enormous amount of studies and theoretical developments have modified our understanding of vegetation dynamics and it is unlikely that any scholar today would understand the term 'climax vegetation' in the same way as Clement and Tansley did. Already Whittaker (1962) in a review of the field of vegetation classification largely corroborated Gleason's view. This concept of the flux of nature led to interest in theories where disturbance is seen as a permanent feature of vegetation such as patch dynamics and patterns and processes in forest (Cadenasso *et al.*, 2003, Whitmore, 1982, van der Maarel, 1996). However, a non-equilibrium view does not preclude that there can be patterns of coinciding distribution of species, such that vegetation types can still be identified (Walker & Del Moral, 2003; Chadzon, 2008).

The concept of Potential Natural Vegetation (PNV) is part of this develop-

3: **Biome**, also called major life zone, the largest geographic biotic unit, a major community of plants and animals with similar life forms and environmental conditions. It includes various communities and is named for the dominant type of vegetation, such as grassland or coniferous forest. Several similar biomes constitute a biome type - for example, the temperate deciduous forest biome type includes the deciduous forest biomes of Asia, Europe, and North America. "Major life zone" is the European phrase for the North American biome concept (*http://www.britannica.com,* accessed November 14, 2011).

4: **Ecosystem**, the complex of living organisms, their physical environment, and all their interrelationships in a particular unit of space. The concept of ecosystems, introduced by Tansley, not only considers the complex of living organisms and their physical environment, but also all their relationships in a particular unit of space (*http://www.britannica.com,* accessed November 14, 2011).

ment of vegetation science. A widely accepted definition of PNV is: Potential natural vegetation has been defined as the vegetation structure that would become established if all successional sequences were completed without interference by man under the present climatic and edaphic conditions, including those created by man (van der Maarel, 2005). The term was coined by Tüxen in the middle of the 20th century (Tüxen, 1956) and has been applied in many parts of the world to categorise plant communities. The concept is closely related to the schools of phytosociology, which originated in Europe and elaborated methods for vegetation analysis and detailed and often hierarchical systems of classification of vegetation by floristic and physiognomic characteristics (see reviews by van der Maarel, 2005; Whittaker, 1980). We do not consider the reintroduction of the PNV concept as a statement about the degree of niche assembly of ecological communities versus a stochastic neutral theory (sensu Hubbell, 2008) but as a tangible hypothesis about species distributions.

We believe that there is truth in the concepts of climax and PNV as well as in the critique and that for practical conservation and management of vegetation and species this discussion should not only be a theoretical discussion, but should be lead to a more informed interpretation of 'real' landscapes. The dichotomy between the continuum concept and the concept of communities as co-occurring species can in principle be solved by considering the two concepts as two different and complementary ways of looking at the same landscape (after Austin, 2005, pp. 66-67): The continuum concept applies to an abstract environmental space, not necessarily to any geographical distance on the ground or to any indirect environmental gradient. The abstract concept of community of co-occurring species can only be relevant to a particular landscape and its pattern of environmental variables, community is a property of the landscape. Such a community concept is compatible with the different concepts of a continuum. The PNV map thus offers a useful tool in lieu of missing environmental relationships. For the forests we have been careful not to map the detailed variation of the forest types, but have kept the physiognomic and chorological classification of White (1983). As pointed out by Langdale Brown and Omaston "The forests are characterised by a great variety of species and communities. Sometimes edaphic or seral relationships between these types are clear, but we cannot yet account for all the differences. Indeed these tropical forests are such complex and longlived communities that in many cases it is not yet possible to be sure what is the climax; even the very nature and constancy of the climax is in doubt." (Langdale Brown & Omaston, 1964 p. 36).

The 'Clementian' traits of interpreting PNVs are in particular (i) the use of rigid hierarchical systems of classification together with a rigid prescription of species composition, and (ii) a static view that there can be only one endpoint to succession. We suggest that the PNV concept should not be interpreted in terms of a static 'Clementian' paradigm and we have been helped in this by the non-hierarchical classification utilised by White. The largest part of the VECEA region is covered by dry vegetation where fire and large browsers (megaherbivores) have profound influence on vegetation development (Bond *et al.*, 2005, Owen-Smith, 1987) and there may in most cases be more than one stable state for the vegetation of a particular area. The use of PNV can thus be an aid in interpreting the dynamics of vegetation and likely alternative stable states. In the Serengeti-Mara area the possibility of alternative stable states has been convincingly documented (Sinclair *et al.*, 2007, McNaughton *et al.*, 1988, Dublin *et al.*, 1990) and the VECEA map could be a tool for identifying alternative stable states in other areas.

With the VECEA vegetation map we suggest that the interpretation of landscapes is done at such a resolution that the implications of analyses can be transferred directly to the landscapes. In making a map with this level of detail we have entered the domain of the contested concepts (climax, continuum, species assembly rules, non-equilibrium communities, etc), which may otherwise be avoided at the biome/ecoregional level of analysis (but not in the implementation and management of patterns and processes in actual landscapes). We do not claim that we have completely solved the conundrum with our map, but we trust that we have created a tool that can be an aid in biogeographical analyses.

When the concepts, biome, plant community, and PNV are defined very loosely (as they are often used in practice) they are almost interchangeable in the sense that they all attempt to describe the variation in vegetation that can be experienced as one moves through a landscape. The use of the two first concepts is rarely questioned - because of the underlying objectives and the scale at which they are used – as they are rarely utilised in a context where they need to be applied in a particular landscape. PNV on the other hand, by nature of its use to describe plant communities on large scale, immediately invokes an interpretation of pattern and process. Like the concept of chorology, the concept of PNV is logical, but the criteria utilised can not be completely objective in the strictest sense. This is to us an acceptable compromise, since nature includes a large degree of history and chance and we suggest that the PNVs are tested and corroborated through empirical tests as well as modelling.

The PNV concept offers a tool that can be utilised in analysing the pattern and processes in landscapes including the biotic and abiotic interrelationships that govern these ecosystem aspects. As such it complements and can be used as an input to modelling of ecosystems and individual species. Although we are confident that the VECEA map provides a realistic picture of where particular vegetation types occur, the map still is a hypothesis about what the actual vegetation type will be. This is an inherent consequence of trying to map anything.

3. Additional observations on the VECEA map

We expect that environmental conditions are more homogeneous within vegetation types than between vegetation types. For this reason, we include histogrammes of altitude, rainfall and temperature for each of the vegetation types (volume 2 – 5). However, given the distribution pattern of historical or current weather stations, gridded climate data are interpolated data layers that do not always approximate the actual climatic conditions. This is especially the case in areas with complex topographies and locations of water bodies – and resulting rain shadow areas - such as occur in eastern Africa. Therefore it is not always possible to check whether the climate layer or the vegetation layer is correct.

For several places in the map, we used vegetation modelling to fill in gaps. Ideally each of these areas should be re-confirmed through field work. During restoration of natural vegetation, which is likely to be implemented in the future in the region, the natural succession processes should be investigated.

More detailed maps have been produced for many places (e.g. Mt. Kilimanjaro) that could be integrated or used to adjust boundaries on the map. Unfortunately, time and resources did not allow us to integrate information from these maps, unless for some areas mentioned in Volume 6 (for example Mt. Elgon).

Also in areas where other detailed maps are not available, additional field work (such as transects) could be used to check and possibly correct the map. The details of the vegetation map allow us to use the map for targeted surveys in a hypothesis-testing method.

The VECEA map could be combined with information from the Africa Soil Information Service (AfSIS), especially for mapping special soil conditions that create edaphically-restricted vegetation types.

Where additional weather data becomes available, it would theoretically be possible to adjust boundaries.

The utility of the map has been greatly enhanced by creating it as an overlay to Google Earth. We made the maps available electronically at *http://sl.life.ku.dk/English/outreach_publications/computerbased_tools.aspx* (click on Vegetation and climate change in Eastern Africa). This overlay could be turned into an interactive tool both with respect to users of the map for tree planting advice (for the White map on Google Earth see *http://www.worldagroforestrycentre.org/our_products/databases/useful-tree-species-africa*), and with respect to improving the map along the lines of "citizen science" (see *http://en.wikipedia.org/wiki/Citizen_science*), where we could systematically test the VECEA map by collection and analysis of data sent by individual citizen science volunteers and networks of volunteers.

References

Austin, M.P. 2005.
Vegetation and the environment: discontinuities and continuities. Pages 52-84 in van der Maarel (ed.). 2005. Vegetation ecology. Blackwell Publishing, Oxford, UK.

Bailey, R.G. 2005.
Identifying Ecoregion Boundaries. Environmental Management Vol. 34, Suppl. 1: 14–26.

Burgess, N., D'Amico Hales, J., Underwood, E., Dinerstein, E. 2004.
Terrestrial Ecoregions of Africa and Madagascar: A Conservation Assessment. World Wildlife Fund Ecoregion Assessments, Island Press, Washington D, U.S.A.

Chazdon, R.L. 2008.
Chance and determinism in tropical forest succession. Pages 385-408. In Carson, W.P. & Schnitzer, S.A. 2008. Tropical Forest Community Ecology. Blackwell Publishing, Oxford, UK.

CSA, 1956.
C.S.A. Specialist meeting on Phytogeography. Yangambi 28th July-8th August 1956. Publication No. 22. Scientific Council for Africa South of the Sahara/Conseil Scientifique pour l'Afrique au Sud de Sahara. London, UK.

Dublin, Holly T., Sinclair, A.R.E., & McGlade, J. 1990.
Elephants and Fire as Causes of Multiple Stable States in the Serengeti-Mara Woodlands. The Journal of Animal Ecology, Vol. 59 (3): 1147-1164.

Bond, W.J., Woodward, F.I. & Midgley, G.F. 2005.
The Global Distribution of Ecosystems in a World without Fire. New Phytologist 165 (2): 525-537.

Friis, I., Sesebe Demissew, & Van Breugel, P. 2010.
Atlas of the potential Vegetation of Ethiopia. *Biologiske Skrifter (Biol.Skr. Dan.Vid.Selsk.)* 58: 307.

Friis, I. 1998.
Frank White and the development of African Chorology. Pages 25-51 in Huxley, C.R., Lock, J.M. & Cutler, D.F. (eds.). 1998. Chorology, Taxonomy and Ecology of the Floras of Africa and Madagascar. Royal Botanic Gardens, Kew, UK.

Greenway, P.J. 1973.
A classification of the vegetation of East Africa. Kirkia 9: 1-68.

Hubbell, S.P. 2008.
Approaching ecological complexity from the perspective of symmetric neutral theory.

Keay, R.W.J. 1959.
Vegetation map south of the Tropic of Cancer. Explanatory notes. With French translation by A. Aubréville. Oxford University Press

Langdale-Brown, I., Osmaston, H.A., & Wilson, J.G. 1964.
The vegetation of Uganda and its bearing on land-use. pp. 157 + maps (scale 1:500,000): vegetation (4 sheets), current land use, range resources, ecological zones, rainfall. Government of Uganda, Kampala.

McNaughton, S.J., Ruess, R.W. & Seagle, S.W. 1988.
Large Mammals and Process Dynamics in African Ecosystems. BioScience 38 (11): 794- 800.
Oldemann, B.A.A. 1978.
Architecture and energy exchange of dicotyledoneous trees in the forest. Pages 535-560 in Tomlinson, P.B. & Zimmermannn 1978. Tropical trees as living systems. Cambridge University Press, Cambridge, UK.
Olson, D.M., Dinerstein, E., Wikramanayake, E.D., Burgess, N.D., Powell, G.V.N., Underwood, E.C., D'Amico, J.A., Itoua, I., Strand, H.E., Morrison, J.C., Loucks, C.J., Allnutt, T.F., Ricketts, T.H., Kura, Y., Lamoreux, J.F., Wettengel, W.W., Hedao, P. & Kasssem, K.R. 2001.
Terrestrial Ecoregions of the World: A New Map of Life on Earth. *BioScience* 51: 933-938.
Owen-Smith, N. 1987.
Pleistocene Extinctions: The Pivotal Role of Megaherbivores. Paleobiology 13 (3): 351-362.
Pennington, R.T., Cronk, Q.C.B. & Richardson, J.A. 2004.
Introduction and synthesis: plant phylogeny and the origin of major biomes. Phil. Trans. R. Soc. Lond. B 359: 1455-1464.
Cadenasso, L.J., Pickett, S.T.A., Weathers, K.C., Bell, S.S., Benning, T.L., Carreiro, M.M. Todd & Dawson, E. 2003.
An Interdisciplinary and Synthetic Approach to Ecological Boundaries. BioScience 53 (8): 717-722.
Pratt, D.J., Greenway, P.J. & Gwynne, M.D. 1966.
A Classification of East African Rangeland, with an Appendix on Terminology. The Journal of Applied Ecology 3 (2): 369-382
Sinclair, A.R.E., Mduma, S.A.R., Grant, J., Hopcraft, C., Fryxell, J.M., Hilborn, R. & Thirgood, S. 2007.
Long-Term Ecosystem Dynamics in the Serengeti: Lessons for Conservation. Conservation Biology Volume 21, No. 3, 580–590.
Tüxen, R. (1956)
Die heutige potentielle natürliche Vegetation als Gegenstand der Vegetationskartierung. Angewandte Pflanzensoziologie 13: 5–55.
van der Maarel, E. 1996.
Pattern and Process in the Plant Community: Fifty Years after A.S. Watt. Journal of Vegetation Science 7 (1): 19-28
van der Maarel, E. 2005.
Vegetation ecology - an overview. Pages 1-51 in van der Maarel), Vegetation ecology (ed). Blackwell Publishing, Oxford, UK.
Walker, L.R. and Del Moral, R. 2003.
Primary succession and Ecosystem rehabilitation. Cambridge University Press. Cambridge, UK.
White, F. 1970.
Classification. Page 78-112 in Chapman, J.D. and White, F. 1970. The evergreen forests of Malawi. Commonwealth Forestry Institute. University of Oxford. Oxford, UK.
White, F. 1976.
The vegetation map of Africa – The history of a completed project. Boissiera 24: 659-666-
White, F. 1993.

The AETFAT Chorological Classification of Africa: History, Methods and Applications. Bulletin du Jardin botanique national de Belgique 62 (1/4): 225-281
White, F. 1983. *The vegetation of Africa*. UNESCO, Paris, France.

Whitlow, R. 1984.
The study of vegetation in Africa: a historical review of problems and progress. Singapore Journal of Tropical Geography 5 (1): 88-101.

Whitlow, R. 1985.
Vegetation mapping in Africa: a critique. Singapore Journal of Tropical Geography 6 (1): 64-77.

Whitmore, T.C. 1982.
On pattern and process in forests. Pages 45-59 in E. I. Newman (ed.). The plant community as a working mechanism. Blackwell Scientific, Oxford, UK.

Whittaker, R.H. 1962.
Classification of Natural Communities. Botanical Review 28 (1): 1-239.

Whittaker, R.H. 1980.
Approaches to classifying vegetation. Pages 3-30 in Whittaker, R.H (ed.). 1980. Classification of Plant Communities (Handbook of Vegetation Science). Springer Verlag. New York, U.S.A.

Whittaker, R.J., Araújo, M.B., Jepson, P., Ladle, R.J., Watson, J.E.M, and Willis, K.J. 2005.
Conservation Biogeography: assessment and prospect. Diversity and Distributions 11: 3–23.

Young, A. 2007.
Thin on the Ground: Land Resource Survey in British Overseas Territories. The Memoir Club, Stanhope, UK.

Forests

- 2-3 Afromontane rain forest (Fa)
- 2-4 Undifferentiated Afromontane forest (Fb)
- 2-5 Single-dominant Widdringtonia cupressoides forest (Fc)
- 2-6 Single-dominant Hagenia abyssinica forest (Fd)
- 2-7 Afromontane moist transitional forest(Fe)
- 2-8 Lake Victoria transitional rain forest (Ff)
- 2-9 Zanzibar-Inhambane transitional rain forest (Fg)
- 2-10 Afromontane dry transitional forest (Fh)
- 2-11 Lake Victoria drier peripheral semi-evergreen Guineo-Congolian rain forest (Fi)
- 2-12 Zambezian dry evergreen forest (Fm)
- 2-13 Zambezian dry deciduous forest and scrub forest (Fn)
- 2-14 Zanzibar-Inhambane lowland rain forest (Fo)
- 2-15 Zanzibar-Inhambane undifferentiated forest (FpK)
- 2-16 Zanzibar-Inhambane scrub forest (FqK)
- 2-18 Scrub forest on coral rag (fc)
- 2-19 Lake Victoria Euphorbia dawei scrub (fe)
- 2-20 Riverine forest (fr)
- 2-21 Swamp forest (fs)

Others

- 5-3 Afroalpine vegetation (A)
- 5-4 Afromontane bamboo (B)
- 5-5 Desert (D)
- 5-6 climatic grasslands (G)
- 5-7 Lowland bamboo (L)
- 5-8 Mangrove (M)
- 5-9 Somalia-Masai semi-desert grassland and shrubland (S)
- 5-10 Freshwater swamp (X)
- 5-11 Halophytic vegetation (Z)
- 5-12 Edaphic grassland on drainage-impeded or seasonally flooded soils (g)
- 5-13 Edaphic grassland on volcanic soils (gv)
- 5-14 Sands(s)

Urban areas

- Tows and villages
- Cities

Roads & tracks

- Primary Route
- Secondary Route
- Unimproved Route

Water

- Canals
- Connectors
- Nonperennial rivers
- Perennial rivers
- Lakes & reservoirs

Woodlands and wooded grasslands

- 3-3 Butyrospermum wooded grassland (Wb)
- 3-4 Moist combretum wooded grassland (Wcm)
- 3-4 Dry combretum wooded grassland (Wcd)
- 3-5 Acacia-Commiphora deciduous wooded grassland (Wd, WdK)
- 3-7 Zambezian Kalahari woodland (Wk)
- 3-8 Wetter miombo (Wmw)
- 3-8 Drier miombo (Wmd)
- 3-8 Miombo on hills and rocky outcrops (Wmr)
- 3-9 North Zambezian undifferentiated woodland (Wn)
- 3-10 Mopane woodland and scrub woodland (Wo)
- 3-11 Terminalia sericea woodland (Wt)
- 3-12 Vitex-Phyllanthus-Shikariopsis-Terminalia woodland / T. glaucescens woodland (Wv)
- 3-13 Zambezian chipya woodland (Wy)
- 3-14 Edaphic wooded grassland on drainage-impeded or seasonally flooded soils (wd)
- 3-15 Riverine woodland (wr)

Bushlands

- 4-3 Somalia-Masai Acacia-Commiphora deciduous bushland and thicket (Bd)
- 4-3 Acacia-Commiphora stunted bushland (Bds)
- 4-4 Evergreen and semi-evergreen bushland and thicket (Be, We - 3-6)
- 4-5 Itigi thicket (bi)
- 4-7 Montane Ericaceous belt (E)

Compound vegetation types

- Fb/Be
- S/D
- Wmr/Fg
- Wcd/wd
- g/wd
- Bd/wd
- g/P
- Bds/S
- Wcd/P
- Be/P
- Be/wd
- Zanzibar-Inhambane mosaic (Zl)
- Catena Wn/g
- Transitional zone Wmd/Wn
- Transitional Wmd/Bd
- wd/P
- Fd/B
- Fa/Fb
- Be/Fe
- Z/w
- Fa/Fb/Fh
- Bd/g
- T/g
- Fa/Fb/Fd
- Wk/g
- Wn/P
- Wmr/Fo
- E/Fc
- X/P