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Review

Population-based theories as an approach to natural resources management in developing countries: A narrative review of Machakos District in Kenya

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Many human societies across the world have collapsed or almost gone into extinction because of the scarcity of natural resources. Others however, have survived by either migrating to seek for natural resources elsewhere or by transition and/or adaptation to new environmental conditions. This narrative review paper examines how a society of Machakos District in Kenya has managed to escape from a potential collapse driven by natural resources' scarcity. The review found that most societies in developing countries have failed to: (i) successfully repack natural resources management information into stories that motivate collective action, and (ii) invest in institutional improvement, innovation and technological changes through the influence of political leaders and economic elites. This paper recommends that for developing countries to successfully avoid societal collapse due the scarcity of natural resources, there is need to follow similar pathways like the society of the Machakos District in Kenya.

Key words: Natural resources management, developing countries, societal collapse, population growth, Malthus, Geertz, Boserup.

INTRODUCTION

By the year 2050, the earth will have nine billion inhabitants who are more likely to live on a depleted natural resource base whose scarcity is currently being aggravated by deteriorating environmental and climatic conditions (United Nations, 2015). These unprecedented environmental and climatic conditions make it very difficult for the scientific community to precisely assess if and how the global climate change scenarios will develop into a regular two degrees up or run into an Eocene-like scenario (Lovelock, 2006). On the contrary, what scientists are quite clear about is that natural resources will continually face harvesting pressure which is driven

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by population growth, rural poverty, land degradation, climate change and use of unsustainable sources of energy, especially in developing countries as has been acknowledged by several scholars (Wunder et al., 2008; Zulu, 2010; Lele, 1991; Place and Otsuka, 2001; FAO, 2010a, b; Nankhuni and Findei, 2004; Sunderlin et al., 2005).

Malthus' (1798) population based theory has already acknowledged that human population tends to grow faster than the capacity of earth to produce the food that humans require. The increasing population growth would unpredictably lead to the collapse of the world; known as the "Mathusian catastrophe", especially in absence of adaptation. In most developing countries in Africa, a similar idea has been supported by the Neo-Mathusian population based theory in the sense that there has been increasing crises which have been hugely manifested by: high rates of population growth, repeated famines, wars, food crises, environmental degradation, soil erosion, crop failure and disastrous floods. Such crises may probably lead to an unprecedented human catastrophe if left unchecked.

On the contrary, Boserup's (1965) population based theory has opposing viewpoints towards both theories of Mathusian and Neo-Mathusian. Boserup strongly believed that people have the resources, knowledge and technology to increase food supplies in case of unprecedented crises such as increasing population pressure, famine, wars, etc. As a result, she suggested, the collapse of human populations might be unlikely. Although, she highlighted that the changes in technology would allow for improved crop strains and increased yields, she admitted that overpopulation can lead to unsuitable farming practices which may contribute to land degradation.

The key point in this review paper is not about the collapse of societies but rather on how societies have managed to survive in the light of dwindling natural resources as emphasised by Butzer and Endfield (2012). As a result, the general theories of development pathways (rural economics) and adaption theories of 'Boserupian', 'Geertzian', 'neo-Boserupian' and Brox (1990) will all be used as ideal models to support the case study of the Machakos District in Kenya. The significance of this review paper is therefore to highlight that as long as humans have knowledge and technology, population-based collapse is unlikely.

This narrative review is structured as follows: i) a discussion of some key concepts on societal change, ii) anoverview of population-based theories on natural resource scarcity including Malthus'(1798),Neo-Mathus,Boserupe and Geertz on population theory and development pathways, iii)a description of the case of Machakos District in Kenya as a model for escaping societal coiiapse particularly in developing countries and ,iv) suggestions on approaches or pathways to escape societal collapse due to natural resource scarcity.

Existing secondary data were extracted from relevant documents such as books, existing reports, publications, journals and internet articles. The relevant documents were accessed, perused and the relevant information/text was compiled, sorted and analyzed based on the objectives of the paper.

CONCEPTS OF SOCIETAL CHANGE

Assessing societal change implies focusing on a system and a set of characteristics driving human interactions with their surrounding environment. Increasing human pressure on the surrounding environment could lead to the extinction of a society. This means that extinction of societies should not be perceived as something intrinsically bad. Theoretically, a society may go extinct as a result of the incapacity to gather sufficient financial benefits to fight against vulnerability factors. As Malthus (1798) already observed, the rich and powerful members of societies will often successfully shift resource availability at the expense of the poor and vulnerable people. This is because the rich and powerful members of the society are the most decisive group and they are able to set up remedial actions to overcome a given issue of resource scarcity. In addition, they represent the primary actors who 'act', 'move', respond' or even 'choose' which remedial actions to put in place. However, the implementation of such collective remedial actions in response to a given stress or shock as compared to a single individual is multi-facetted and time-consuming (Diamond, 2005). This emphasises the fact that societies are often heavily locked into institutional pathways (governance rules, tax systems, organisations, etc.) that require a lot of time and effort to make them work.

The descriptions of evolving societies and their relationships with their natural resources can be either spatially and or temporally related. The spatial dynamic of such actions has to be linked to the role of external markets, the growth of urban centres, and the migration of population and so on. The 'population-based' theories of natural resource scarcity focuses particularly on land degradation following the neo-Thünian ('land rent') story of societal changes (De Groot, 2003) (Figure 1). The figure depicts the situation of a society with growing urban centres and markets (central in the picture), around which expanding and intensive zones of extractive land use are found. The picture symbolizes the US in the 1800s, or 'developing societies' in the present age. Virtually all countries in the world have gone through these stages or are still in it in some points. The full story is based on ideal-type ecological and geographical environments which may help in the explanation of the transition from extensive to intensive farming systems. If the process continues from intensive farming systems to the agriculture frontier and then the extraction frontier, all the frontiers will more likely collapse. As a result, there is

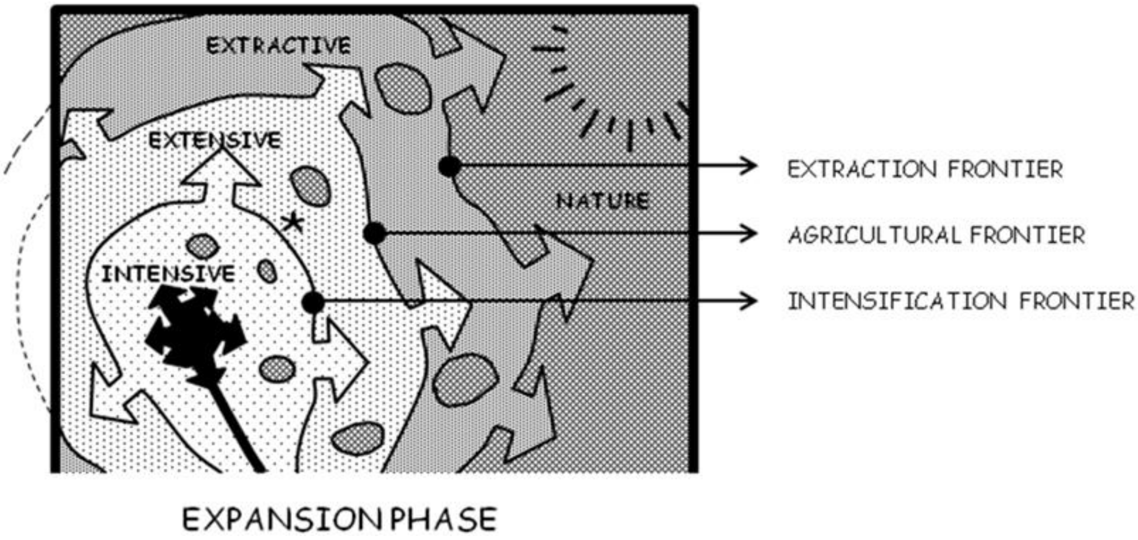

Figure 1. A neo-Thünian symbolization of an expansion phase with land use frontiers moving outward from the expanding urban markets while the round areas depict left-over natural areas (a wetland, water reservoir, etc.) (Adapted from De Groot, 2003).

no more space for further expansion and everything has become internal and the system is finally closed up.

The population-based theories of Malthus on natural resource scarcity fall within the end expansion of figure 1 since it takes into account increasing population growth against land production as the main driver of land collapse. On the contrary, Wilkinson (1973) has stressed that avoiding population collapse and the massive starvation were possible in primitive' societies, despite the fact that population levels had began to approach carrying capacities. Among the reasons evoked is the fact that the Malthus' theory has neglected many external and non-population factors that may be important in natural resources management (Burger and Zaal, 2009), particularly technological and institutional development, as well as cultural and social adaptation.

An overview of population-based theories

Although several population-based theories are available, the first population-based theory was elaborated by Malthus (1798) in his influential essay in which he highlighted that exponential population growth is inherent in all societies, and massive starvation is the general mechanism that keeps populations in check. The focus of his works was on the depletion of natural resources which may lead to the decrease of productivity of human labour. The latter tended to fall below-subsistence wages for the poor and causing their death. Although, he admitted that the reduction of the populations (through birth control) may give rise to cycles of partial recovery, this population reduction may only represent a moral way to escape from the cascade of misery. As an extension of Malthus theory, Homer-Dixon (1999) integrated the political and institutional visions as a way of explaining the collapse of the society by elite groups' capture of natural resources. Indeed, increasing capture of natural resources by elite groups is more likely to drive the collapse of the society since less natural resources is available to meet the livelihood needs of poorer members of the society. However, Geertz (1963) based on studies on rice agriculture in Indonesia, coined the term 'agricultural involution' which is a concept that completely opposes both the Malthus theory and Homer-Dixon (1999) theories as highlighted below.

In the historical process of 'agricultural involution' due to population growth, agriculture becomes ever more labour-intensive, e.g. going from rain-fed to irrigated rice, from broadcast to transplanted rice, ending in systems that are highly productive per hectare but with very low returns to labour. The system remains ecologically sustainable, however, without collapse. If society would control population levels, it could continue forever, with the masses stuck on a very low survival level, supporting a small group of the elite. Gellner's (2006) 'agricultural society' follows an analogous development pathway. The work of Boserup (1965) stands in the same tradition of societal pathways under circumstances of rising population pressure. Her studies end in a somewhat more optimistic conclusion, however. In the Geertzian involution image, there is no real technological progress; people basically continue what they have been doing, only with more and more labour input per hectare. The Boserupian image is one of adaptation rather that involution; mainly driven by ecological necessity.

The modest optimism of Boserup made her the symbol of opposition against the Malthusian 'prophesies'. The

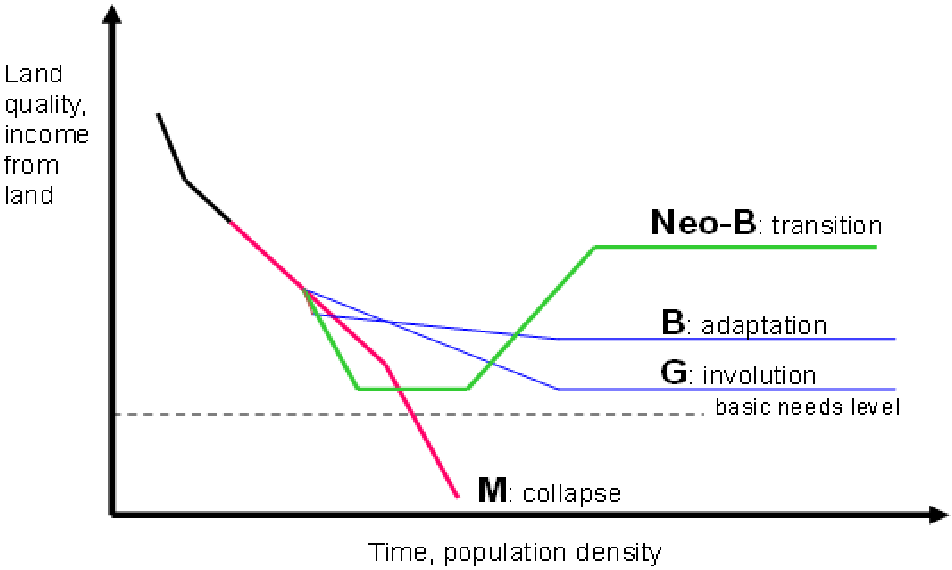

Figure 2. Four ideal-type development pathways in an agricultural society (like Malawi) under rising population pressure. M = Malthusian; G = Geertzian; B = Boserupian; neo-B = neo-Boserupian.

true optimists came later, however. We may call them the 'neo-Boserupians', because they remain within the same family of looking at population-driven change in a relatively closed society. A characteristic product here is Tiffen et al. (1994) book "More People, Less Erosion", a title that boldly positions itself against the Malthusian outlook. The book creates a basis for our insights in the present paper and tells the story of Machakos District in Kenya, that was regarded as a moonscape in the making in the 1930s but 50 years later carried a tripled population with tripled incomes per capita.

The key of this 'miracle of Machakos' was the terrace, thousands of kilometres of which had been constructed, largely by female hands, to cover the whole of the rolling landscape. We will come back to Machakos in the next section. Here it suffices to mark the great difference with the original Boserupian theory not only in terms of outcomes but also in underlying mechanism. The terrace was the cornerstone of a fully innovated farming system, with new crops, new irrigation, new cattle and manure management, new agroforestry and so on. This is transition rather than Boserup's adaptation.

Figure 2 gives an overview of the four population-based theories. The horizontal axis is a combined one ('time, population density'), expressing an assumption of a steady population growth over time. This implies that we are looking at a finite time period; populations cannot grow forever. The vertical axis is also a combined one ('land quality, income from land') implying that we look at basically agricultural regions where soils, forests, water and other natural resources determine the amount of effort needed by 'developing societies' for a decent harvest and improved livelihoods.

Stressing further on Figure 2, the four development pathway's curves start from the 'original affluence', especially from the Malthusian and neo-Boserupian collapse transition. At this point in time, incomes tend to be low because of the low investments provided to set this pathway in motion. As a result, irrigation systems need to be constructed, trees planted, new animal husbandry systems tried out. Among the actions needed at institution level, there is a need to implement negotiated new rules, redefined gender roles along with organised collective actions. These trends are quite crucial to explain the Mathusian assumption on 'poverty trap'. In that regards, individual actors or the whole societies may find themselves locked in. On way down from the original affluence, actors are initially wealthy enough to invest in innovation, but the motivation to do so tends to be low, since things are still going well enough. By the time the incomes have declined to the basic needs level, the situation is reversed; the motivation for change is high but the capacity to act has become zero (Hobbes et al., 2011).

From Figure 2, it can be implied that societies can follow one path after another, e.g. displaying a long Geertzian decline after a rapid neo-Boserupian upswing. For instance, agriculture in Bangladesh (Turner and Ali, 1996) shows a Geertzian long-term trend but interrupted by Boserupian 'ups' e.g. due to the green revolution. It also implies that different groups within a society may follow different pathways under the overall pathway of the society as a whole. One well-known issue is that in strongly neo-liberal societies that lack effective equity mechanisms, the tendency of markets to work to the net advantage of the rich (e.g. due to their greater negotiation power) may result in increasing poverty of the poor (M or G) in spite of overall economic growth (B or neo-B). A final point to note here is that these development pathway ideal-types are scale and time independent.

In the section below, the story of 'Machakos society' will be used as key case studies to successfully illustrate how to escape societal collapse from natural resource scarcity in the developing countries.

The story of Machakos District in Kenya as a model for avoiding societal collapse

In this section, we will identify and discuss the underlying factors that may have determined the avoidance of the Malthusian collapse or Geertzian involution of the society in Machakos District. As said, the focus is on relatively closed societies, by passing strongly externally driven cases such as those described by Conelly (1992), in which migrant farmers in the Philippines moved rapidly from unsustainable slash-and-burn agriculture to a sustainable system of terraced rice and fruit tree fields due to a road that connected them to a growing market and strong government interventions to protect forests. However, no society is ever fully closed. We will therefore distinguish between internal and external factors.

Based on Tiffen et al. (1994), Burger and Zaal (2009) and Murton (1999) determining factors behind the 'miracle of Machakos' can be grouped as follows:

Motivational evidence/information

Soil erosion (topsoil washed out, gullies forming, etc.) was easy to see by the Machakos society. In other words, images of Malthusian futures were easy to identify, and the Machakos society was never in a state of denial as so often happens in 'developing societies' especially with less visible problems such as pollution or climate change.

Capacitating knowledge

How to make terraces was thoroughly debated and experimented between government organisations, non-governmental organisations and the farmers themselves. In the colonial period, terracing was forced labour and much resented. After independence from colonial rule, people first dropped terracing but picked it up again, this time voluntarily and massively. Debates between scientists and farmers on the best system continued (the farmers' style won) but all the while, farmers knew perfectly how to do it. Additional elements such as agroforestry were sometimes more time-consuming to grasp but knowledge was never a real bottleneck.

Population density

Much emphasised by Tiffen et al. (1994), high population density was not only the problem but also the solution. High population density resulted in low transaction cost, spreading of ideas, high school attendance due to short walking distances, and so on.

Social organisation

The hills of Machakos had been a refuge area of the Akamba people against the Masai. Contrary to many other ethnic groups in 'developing societies', the Akamba look on their land as a place to stay and to invest in. Successful urban Akambas returned to the district after pensioning, then often starting new farming activities, e.g. an experimental orchard or fishpond. Terracing was surrounded by a community atmosphere that endorsed and stimulated the work, often performed collectively in labour exchange groups, going around working on the farms of all members. A final cultural factor is that the Akamba woman, although officially second in command to her husband, is not shy to run the farm whether he is in or out. She knows how to organise a female self-help group and add a male secretary to satisfy the higher-level institutions and politics. The relevance of this gender phenomenon is that all over the world (e.g. in micro-finance), female motivations tend to be more future-oriented.

Nearby urban growth

It is a one-hour drive from Machakos District to Nairobi, Kenya's rapidly growing capital. The city was a ready market for basically all of Machakos old and new products (maize, vegetables, fruit, milk, etc.) and supplier of its external inputs when needed (fertilizer, knowledge, ideas, equipment, etc.). In neo-Thünian terms, Machakos found itself in the expanding zone of intensive land use around Nairobi. Moreover, labour migration to the city supplied many households in the district with substantial remittances that could be invested in the farm. Nevertheless, Murton (1999) is adamant on the urban factor in the miracle of Machakos: "Wealth comes from the city".

World market growth and connections

Good connections with traders and proximity of an airport enabled Machakos farmers to participate enthusiastically in the global coffee boom of the 1960s, bringing much income to the district. Later, Machakos beans and other vegetables found their way to European supermarkets.

In this list, factors 5 and 6 are external, and it is quite likely that Tiffen et al. (1994) neo-Boserupian enthusiasm for internal factors, that is, a society taking itself out of poverty, is not free of bias. We also find a mixture of internal and external factors in the conclusions of Turner et al. (1993), based on studies of twelve cases of successful, sustainable agricultural intensification throughout the 'developing societies' of Africa. Many of those are less spectacular than Machakos District, but they all represent Boserupian and neo-Boserupian pathways of farming regions under population pressure.

At this point it may be worthwhile to take a brief look at the well-known collapse and sustainability factors to natural resources (Diamond, 2005). On the collapse side, Diamond mentions population, resource scarcity and climate change, followed by one positive external factor (trade relations that bring wealth and ideas), one negative external factor (especially welfare, exhausting society), and finally the response of society to resource scarcity. The sustainability factors elaborate on the latter in particular, focusing on timely knowledge and internalisation of the problem, leadership and rapid investments in solutions. So, in all this, what can 'developing societies' learn from the Machakos?

Suggested pathways to escape societal collapse due to natural resource scarcity

On the basis of lessons learnt from the Machakos "success" story, several suggestions can be drawn to avoid the population catastrophe's theory driven by natural resources scarcity. Some scholars have pointed out that the failure of western societies were driven by poor behavior assessment and understanding of the natural environment, as well as lack of long term vision and/or institutions. The lack of accountability of those factors could have played a crucial role in the collapse of historical civilizations. To avoid the collapse of historical civilizations, Good and Reuveney (2009) have suggested considering a theory based on endogenous population growth and renewable resources, as well as employing components of modern optimal social resource management/growth. In other words, they encourage that society should be built around a family of social welfare functions and appropriate policy instruments from the perspective of moral philosophy as well as a society driven by complete information flow, full understanding of the operating forces, infinite foresight, and efficient social institutions.

Arguing critically on Good and Reuveney's (2009) model of society collapse avoidance, it can be emphasized that in such a model of society, policy-makers and state managers have full knowledge of the advantages and disadvantages of taking a given decision for the benefit of the society as a whole. This implies that the manager's decision should rather lead to maximize or aggregate utility for the benefits of the whole society (Gross national product (GNP) rather than for maximizing the individual utility (equivalent to GNP per capita). In that regard, the manager has to take care of the benefits of the future generations by using a discount rate between almost 0 and 10 per cent. Failing to achieve that will more likely lead to the collapse of almost all model runs highlighted above.

The latter viewpoint is somehow controversial because some scholars have found that societies that prefer individual utility over aggregate utility tend to perform better. This has to do with the fact that societies focusing on promoting individual utility tend to lower population as a component in their utilitarian function. Even if these societies avoid collapsing, their collapse avoidance is relatively at a low discount rate levels estimated around 0.1%. This discount rate level is lower than the daily discount rate of people and from the 'social discount rate which is usually estimated at 5% (Arrow and Lind, 2014). The latter daily discount rate is used by governments in the cost-benefit analyses of public investments.

Focusing only on the discount rate's application, escaping from the societal collapse seems a hopeless solution. But if the focus is shifted to noneconomic attributes, the situation seems hopeful. People give to charities, decide to marry, and invest in their communities and in their children without involving cost-benefit and discount reasoning. Governments do the same when they establish human rights and workplace safety regulations and when they invest in healthcare systems, biodiversity conservation or, for that matter, the army. The decision-making pattern we encounter here goes under many names such as 'safe minimum standard' or 'two-tiered value theory' (De Groot, 1992). The basic notion of all of them is that we have to decide on fundamental and equity issues first, using our deliberative institutions, and only then decide on our efficiency issues, e.g. through markets and cost-benefit analyses that apply discount rates.

As Good and Reuveney (2009) put it, collapse is economically rational. This can be illustrated by visualising that at a discount rate of 7%, having a 3 US$ meal now that burdens future generations (100 years) with a cost of 2,600 US$ is economically rational, even desirable, because 3 times 1.07 to the power of 100 is more than 2,600. Such long-term discounting is sometimes justified by the assumption that future generations will be richer than ours, that is, they will have no problem putting up the 2,600 dollar compensating our meal. We find this assumption difficult to maintain. Thus we side with such authors as Voinov and Farley (2007), who feel that fundamental long-term issues should be decided without the application of discount rates. This outcome puts the decision-making level of natural resources management investments in 'developing societies' squarely in the first, non-economic tier.

Of course it has to be mentioned that the response to the challenge of natural resources scarcity, interlinked as it is with fundamental and system-level institutions is an inherently slow process. This strongly reinforces the general risk that on the way down from moderate to severe resource scarcity, motivations for environmental recovery in 'developing societies' may rise but they will require an ever-larger part of national gross domestic product (GDP). This, as we have seen, is because rehabilitation is usually much more costly than timely protection. Therefore, even though 'developing societies' do not currently need much new science and technology on the short term, there is need for massive effort to get existing knowledge on natural resources management across to the public, to business and public leaders and to key institutions, in ways that really motivate people to take remedial action. On the latter, Nobel prize winner Kahneman (2011) informs us that people act on stories to which they can connect, not on deliberation. Natural resources management information in 'developing societies' will have to be repacked into stories that show for example how natural resource scarcity will affect children's lives.

On the other hand, the need for investment in technological and institutional change is eminent in all literature. Maybe in land management, energy systems, fisheries or forest management, the efforts will have to be massive. These investments should not be looked at through a merely economic lens. Before economics come in, commitments need be political, expressing the universally human capacity to move for the common good of sustainably managing natural resources. This necessitates the creation of and defence for common good institutions by the political and economic elites at any level of society. The success of 'developing societies' will increasingly depend on political leaders and economic elites that build and defend common good institutions. According to Turner et al. (1993), the earth is a refuge for its inhabitants, not merely a marketplace.

CONCLUSIONS

Developing countries will continue to face the issue of natural resources scarcity that concurrently threaten the livelihoods of the growing human populations. However, the situation is not hopeless since human beings have the capacity to adapt and innovate in ways of survival as initially suggested by Malthus and the Neo-Malthus population based theories. Contrary to the latter theories, the Geertzian, Boserupian; Neo-Boserupian and the Machakos District in Kenya have all evidenced that societies in developing countries need to be motivated, socially well-organised and possess capacitating knowledge to act positively. Such positive action would make societies in developing countries to successfully: i) utilise the available workforce and opportunities, and ii) take economic and noneconomic decisions based on natural resources management. Avoiding societal collapse of developing societies calls for crafting and investing in institutional building. Such institutional construction may successfully lead to the preservation of a healthy planet that will continue to provide for its inhabitats and sustain the livelihoods of the billions of human beings who depend on it.

Conflict of interest

There was no financial/relevant interest that may have influenced this study.

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Comparison of plant communities between primary and secondary tropical forests of Mount Oku, Cameroon

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Globally, human populations are rapidly converting large blocks of tropical old-growth forests into small forest patches, embedded within human-modified landscapes, consisting mostly of agricultural fields and pasture lands. Mount Oku commonly known as Kilum-Ijim, situated at the North-western Cameroon is recognized as a globally important center of endemism and a hotspot for biodiversity conservation but now undergoes unprecedented degradation. The aim of this study was to compare the diversity between primary and secondary forests in mount Oku (Cameroon) and determine whether species richness and composition are distinguishable in the two forest types. The vegetation was sampled in 102 plots according to a stratified sampling design so as to cover the altitudinal gradient from 1833 to 2772 m. Forty plots were located in primary forest and 62 in secondary forest. A set of 6 plant traits/characteristics associated with dispersal, establishment, and persistence functions were gathered. A total of 385 vascular plant species were present in the 102 plots. 243 species were common to primary and secondary forest plots, 69 were present exclusively in primary forest plots and 73 in secondary forest plots. The Indicator Species Analysis showed that 38 and 28 species were indicator of primary and secondary forests, respectively. The mean species richness per plot was 45.5 and 44.1 in primary and secondary forests, respectively. Only tree species richness was significantly higher ($p < 0.001$) in the primary forest. The maximum height of vegetation and density of trees were respectively 19.42 m, 101 stems/ha in primary forest and 11.93 m, 36 stems/ha in secondary forest and show significant difference ($p<0.001$). Primary forest plots were characterized by phanerophytes, while secondary forest plots were characterized by geophytes and chamaephytes, able to propagate vegetatively and resist disturbances. Finally, there is need to urgently protect the last remnants of ancient forest for their biological value.

Key words: Afromontane forest, biodiversity, endemism, human activities, mount Oku, species composition, species richness.

INTRODUCTION

Tropical rainforests are vanishing more rapidly than any other biome (Achard et al., 2002; Laurance et al., 2009). In the last decades, their deforestation has led to an unprecedented loss of old-growth or primary forest habitats and, concomitantly, to an increase of the proportion of secondary forests (Tabarelli et al., 2012). At a global scale, deforestation of tropical forest leads to biodiversity loss and could cause catastrophic species extinctions (Dent and Wright, 2009). The leading causes of deforestation are well known and vary across continents (Geist and Lambin, 2002): human population increase, conversion of forest to agricultural lands, timber extractions for local or industrial uses and exportation. Faced with the urgent need to save the biodiversity of tropical rain forests, a myriad of studies monitoring forest cover changes, diversity losses and species extinctions bloomed in all the continents (Brancalion et al., 2013, Uddin et al., 2015). In large proportion of them, the rainforest is still considered as a whole ancient, old-growth or primary forest patches and is not distinguished from secondary habitats.

Recently, an increasing attention has been placed on tropical secondary forests (Barlow et al., 2007; Thier and Wesenberg, 2016) since they provide various ecosystem services, host a non-negligible part of the biodiversity, including endemic animals and plants displaced from destroyed primary habitats, and may act as buffer zones protecting primary forests (Brearley et al., 2004). From biodiversity conservation and a sustainable management perspective, it is important to know how much primary and secondary forests diverge in terms of species richness and identities. Our knowledge of the value of the secondary forests for biodiversity conservation remains limited (Barlow et al., 2007) and the roles and value of the secondary forests are still argued (Gibson et al., 2011). Indeed, the responses of the different taxa to land use patterns and the percentages of species restricted to primary forests vary markedly across the world.

In central and west Africa, tracts of tropical rainforest have survived on scattered mountain top in relatively intact conditions (Laurance et al., 2006). This is the case of the Kilum-Ijim forest on Mount Oku (Cameroon), which is the largest remaining tract of the Central African cloud forest. In this paper, there is focus on this cloud forest, which is recognized as a global biodiversity hotspot (Myers et al., 2000). The Kilum-Ijim forest area has continuously decreased during the last century due to land use changes. Today, primary or old-growth forest habitats remain only on the summit of Mount Oku. In the last two decades, new patches of secondary forest appeared on the site, consecutively due to forest protection projects and abandonment of cultivated areas.

The main objective of this study is to compare the diversity of primary and secondary forest types and determine whether species richness and composition are distinguishable between these two forest types. Regarding the intensive agricultural practices and forest use methods (clear cuttings, wildfires, conversions to cropping areas, grazing of forest interior by cattles and goats, over hunting, bark harvesting of *Prunus africana*, etc) that occurred during the last three decades on Mount Oku, it is hypothesized that primary and secondary forests strongly differ in terms of plant richness. This difference should be *a fortiori* pronounced among dominant plant traits occurring in the two types of forest. The underground question of this paper is to know if the (almost inevitable) loss of primary forest could be partly offseted by the expansion of secondary habitats encouraged by local nature conservation projects in term of ecosystem services.

MATERIALS AND METHODS

Study area

The study was carried out on the Mount Oku, a mountain area of the Bamenda Highland located in north-west region of Cameroon (6°12'N and 10°32'E). This site hosts the Kilum-Ijim forest, which is the largest tract remaining of Central African cloudy forest, a biodiversity hotspot threatened by contemporary land-use changes. Peaking at 3 011 m, Mount Oku is the second highest peak in the mainland of West Africa (Asanga, 2002). The climate is characterized by a rainy season which extends from May to September and a dry season from October to April (Hawkins, 1965). Rainfall mainly occurs between July and September and varies from 1780 to 2290 mm per year. It peaks at 3050 mm per year on the summit, commonly described as cold, very cloudy and misty. In most parts of the mountain, mean temperatures vary between 13 and 22°C.

A crater lake is present at the centre of the mountain area. The geological substrate mainly consists of Tertiary basaltic and trachytic lava, covering the granitic Basement complex rocks. Locally, superficial deposits of volcanic ash occur (Cheek et al., 2000). The dominant soils are clay (mainly Gibbsite) soils but altitude and climate can generate soils with high organic matter contents (humic soils). Before the spectacular increase of human population and the development of agriculture in the past century, it is believed that the whole of the Bamenda Highland area was covered with forest (Cheek et al., 2000). The forest area covered 20 000 ha in 1978 but, today, it is reduced to about 9 500 ha (Momo et al., 2012).

The vegetation of Mount Oku has been mainly described by conservation project reports, species listing and notes (Hawkins, 1965; Cheek et al., 2000, 2004; Letouzey, 1985; Maisels and Forboseh, 1997; Asanga, 2002; ENGREF, 1987). The Kilum-Ijim forest is a mountain cloudy forest. Its canopy is dominated by upper montane forest species such as: *Podocarpus latifolius*, *Syzygium staudtii*, *Schefflera mannii*, *Carapa grandiflora*, *Nuxia congesta*, *Prunus africana* and *Bersama abyssinica*. In the last decades, post-agricultural forests appeared on fallow lands and are mainly characterised by heliophilous and fire-resistant trees and shrubs (*Gnidia glauca*, *Hypericum revolutum*, *Hypericum roeperianum*, *Maesa lanceolata* and *Erica mannii*), and open habitat herbs(*Hyparrhenia* sp., *Sporobolus africanus* and *Pennisetum clandestinum*).

Since 1987, the Kilum-Ijim forest has been benefited from

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biodiversity conservation projects (Maisels and Forboseh, 1997) and the creation of community forests (Gardner, 2001; Nkengla, 1999). Despite these efforts in implying villagers and forest community managers, results are mitigated and forest stands are still cleared, converted to crop land, burned, grazed by domestic animals, overhunted and overexploited for their medicinal plants (Stewart, 2003, 2009; Asanga, 2002). Many species, including large mammals, have been lost on Mount Oku during the last century due to hunting (Maisels et al., 2001).

Sampling design and data collection

Based on the results of an earlier study using remote sensing analyses, the authors distinguished between primary and secondary forest patches on Mount Oku (Momo et al., 2012). Primary forests were defined as forest patches that were already referenced in ancient documents (Hawkins, 1965; ENGREF, 1987; Cheek et al., 2000; Macleod, 1987) and continuously present on a series of Landsat satellite images from 1978 (the oldest image available) till now. Secondary forest patches appeared after 1978 on these same satellite images and/or experienced heavy recent disturbances (clearcuts, fire).

The vegetation was sampled in 102 plots following a stratified sampling design so as to cover the altitudinal gradient from 1833 to 2772 m. 40 plots were located in the primary forest and 62 in the secondary forest, which is representative of the dominance of the secondary forest representing 66% of the Kilum-Ijim forest area. In each plot, vascular plant species were sampled in a system of nested quadrats: trees (> 10 m height) and shrubs (2-10 m) were sampled in a 40 x 40 m area, low shrubs and tall herbs (1 to 2 m) in a 40 x 20 m area and low herbs (<1 m) in a 20 x 20m area located in the corner of large plot. Their cover-abundance was scored using the following scale: i= one individual with very low cover (0.1%); += few individuals with low cover (0.5%); 1= many individuals but cover <5%; 2a = 5-25%; 3 = 25-50%; 4 = 50-75%; 5 = 75-100%. Species nomenclature follows Lebrun and Stork (1991-1997).

The following local environmental variables were measured in each plot: vegetation height (m), trees density (number of stems.ha^{-1}), number of rodent traps, bare soil cover (%), altitude and slope. For this purpose, several Landsat satellite images taken between 1978 and 2007 were integrated in a Geographic Information System (GIS), and changes in land-use types were compare. Forest fragmentation over this period was assessed by comparing the number, the area and the perimeter of forest fragments, and a forest fragmentation index was derived. Finally, the respective effects of natural (altitude, slope) and human (human density, distance to villages) factors on deforestation were quantified using structural equation models (Momo et al., 2012).

An orientation index was calculated following Chabrerie et al. (2013). Landscape elements (forests, savannas, crops) were digitalized from satellite images (Landsat MMS 1978 and ETM+ 2007, freely available at www.landcover.org) using a Geographic Information System (GIS; ArcGis® v.8.3, ESRI). The area of the different landscape elements and the percentage and area of cleared forest between 1978 and 2007 were calculated at a radius of 500 m around each sampling plot. This radius is commonly used to assess the effect of landscape structure on forest plants communities (Jamoneau et al., 2011). The following human population variables were extracted from administrative data (Direction Nationale du Recensement, 1991-1994; Bureau central du recensement de la population, 2010) and completed by field surveys: distance of the nearest house and human population density within a radius of 5 km around the plots.

A set of 6 plant traits/characteristics (including 39 trait categories) associated with dispersal, establishment and persistence functions were gathered and summarized in Appendix 1. Data were extracted from plant databases, thesis, books and completed by field measures: life forms (Raunkiaer, 1934), diaspore types (Dansereau and Lems, 1957; Doucet, 2003), dispersal modes (Dansereau and Lems, 1957; Guillaumet, 1967), leaf types (Ohsawa, 1995), altitudinal tolerance (Senterre, 2006) and biogeographic history (White, 1978; White, 1979; White, 1983). These plant characteristics are likely to respond to the changing environment that occurred on Mount Oku for decades, that is, an intensification of agriculture practices and deforestation.

Data analysis

To explore gradients of species composition, the species cover-abundance matrix was subjected to a nonmetric multidimentional scaling (NMS) using PC-Ord® v.5 (MjM Software Design, Gleneden Beach, Oregon, USA). NMS used the relative Sørensen's index as distance measured between plots. A three-dimensional solution was found with a maximum of 400 iterations and 50 runs with randomized data (final stress = 21.50; final instability = 0.00001). The NMS was coupled with a Detrended Correspondence Analysis (DCA) according to the recommendations of Økland (2003). In order to align NMS and DCA ordination diagrams to maximise their comparability, the recommendations of McCune and Grace (2002) were followed and a rotation of the NMS and DCA clouds of points by the same elevation variable along the first ordination axes was applied. Rotation rigidly maintains the Euclidean distance among points in the ordination diagrams. Spearman correlation tests were used to assess concordances between NMS and DCA axes and between NMS axes and environmental variables. Multi-response permutation procedures (MRPP) and indicator species analysis (ISA) from Dufrêne and Legendre (1997) were used to examine differences in species composition among primary and secondary forest plots. ISA were also run for each trait on the plots x trait category abundance matrices to highlight traits which were filtered by primary and secondary forest environments. Mann-Whitney U-tests ($p < 0.05$) were used to test differences in species richness between primary and secondary forest plots. Finally, the effects of local and landscape variables on total, tree and herb richness were tested using generalized linear models (GLMs) and Poisson error distribution of response variables. Only the most significant models were retained. Univariate analyses and GLMs were built using SPSS (version 17.0).

RESULTS

Species composition

A total of 385 vascular plant species were present in the 102 plots. 243 species were common to primary and secondary forest plots, 69 were present exclusively in primary forest plots and 73 in secondary forest plots. The first DCA axis was highly positively correlated with the first NMS axis ($r = 0.918$; $p < 0.001$) and the second DCA axis was highly negatively correlated with the third NMS axis ($r = -0.925$; $p < 0.001$). The third DCA axis was slightly correlated with the three NMS axes (axis 1: $r = -0.213$; $p = 0.032$; axis 2: $r = 0.278$; $p = 0.005$; axis 3: $r = -0.238$; $p = 0.016$). Consequently, only NMS axes 1 and 3 were retained in subsequent analyses. The NMS ordination diagram (Figure 1) showed that primary and secondary forest plots were clearly separated along the third NMS axis.

The first NMS axis was highly positively correlated with elevation, distance of the nearest case, forest and

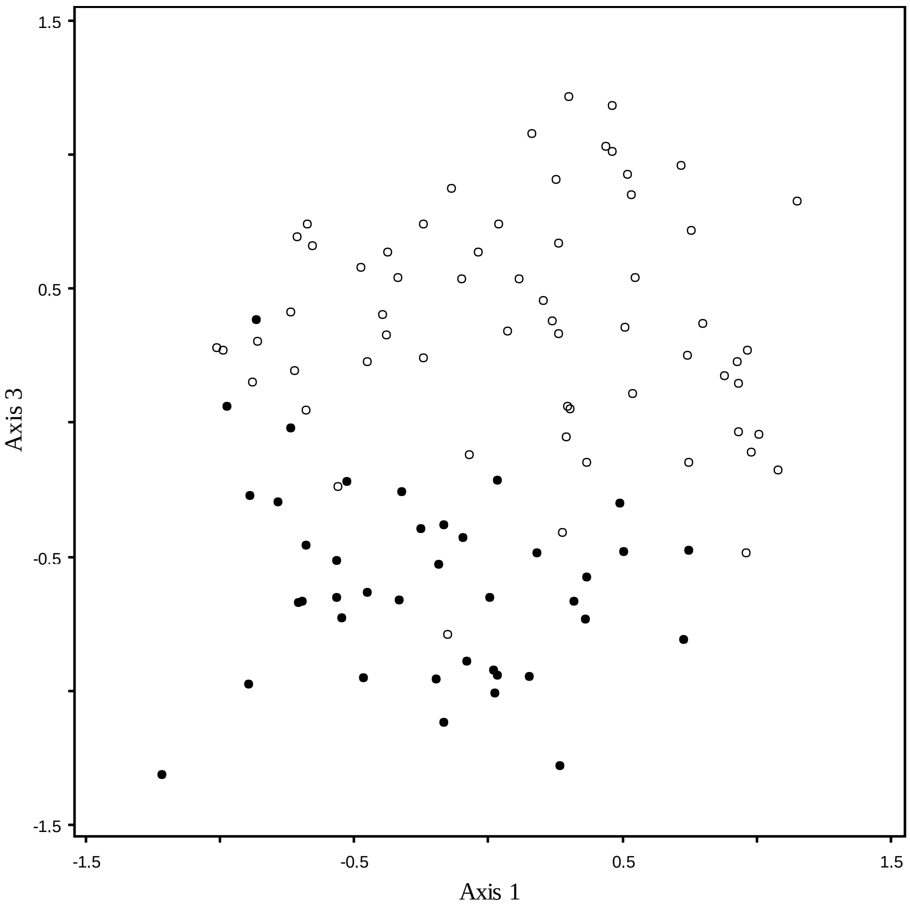

Figure 1. Ordination diagram defined by the first and third axes of the non-metric multidimensional scaling showing the 102 plots; symbols: black circles = plots in primary forest (n=40), white circles = plots in secondary forest (n=62).

secondary forest areas ($p < 0.001$) and negatively with crop and savannas areas, human population density, tree density and number of rodent traps (Table 1). It can therefore be considered that this axis represented an increasing elevation gradient coupled with a decreasing gradient of landscape management intensity. Bare soil cover and distance to the nearest home increased, while vegetation height and tree density decreased along this axis. The ordination diagram of plots separates at first, the oldest forests was inherited from primary formations on one side, and on the other side, secondary forest and shrub recolonization of fallow and savana.

The ISA showed that 38 and 28 species were indicators of primary and secondary forests, respectively (Table 2). The primary forest plots were characterized by afromontane forest trees (*Carapa grandiflora*, *Nuxia congesta*, *Syzygium staudtii, Schefflera mannii*, *Bersama abyssinica* and *Podocarpus latifolius*), shrubs (*Ardisia kivuensis*, *Allophyllus bullatus, Mimulopsis solmsii*, *Xylamos monospora, Rytigynia neglecta*) and herbs (*Commelina cameroonensis*, *Laportea alatipes*, *L. ovalifolia*, *Mimulopsis solmsii*) including ferns (*Asplenium friesiorum*). Only one species was indicator of the canopy of secondary forests. Secondary forests were dominated by two heliophilous edge species, *Gnidia glauca* and *Hypericum revolutum*.

Plant traits

The ISA performed on the plant trait matrices highlighted trait categories which were filtered whether by primary or secondary forest conditions (Table 3). Primary forest plots were characterised by phanerophytes with large leaves (40 to 200 cm^2), reproducing with sarcochorous diaspores (*Syzygium staudtii*, *Carapa grandiflora*, *Schefflera mannii*, *Allophylus bullatus*, *Podocarpus latifolius*, *Pittosporum viridiflorum* and *Pavetta hookeriana*), that is, diaspores with fleshy parts, adapted to endozoochory. The fruits of these species were known to attract birds and/or small rodents. Primary forest hosted mainly submountain and lower mountain species. The spatial distributions of these species were limited to a narrowed geographic area (Cameroon, East Africa,

Table 1. Spearman correlation tests between NMS axes and environmental variables. Only variables showing significant correlations are indicated. * p<0.05, ** p<0.01, *** p<0.001.

Variables	**NMS axis 1**		**NMS axis 3**	
	R	**p**	**R**	**p**
Vegetation height (m)	-0.494	<0.001 ***	-0.569	<0.001 ***
Tree density (n.stem.ha-1)	-0.423	<0.001 ***	-0.605	<0.001 ***
Bare soil cover (%)	0.495	<0.001 ***	-0.017	0.869
Number of rodent traps	-0.237	0.017 *	-0.409	<0.001 ***
Elevation (m)	0.732	<0.001 ***	0.038	0.708
Distance to the nearest village	0.363	<0.001 ***	0.013	0.900
Human population density (r=3 km)	-0.307	0.002 **	-0.065	0.515
Distance to the nearest case	0.399	<0.001 ***	-0.008	0.934
Forest area	0.458	<0.001 ***	-0.121	0.224
Crop area	-0.361	<0.001 ***	0.157	0.115
Savannas area	-0.299	0.002 **	0.122	0.222
Primary forest area	0.086	0.392	-0.373	<0.001 ***
Secondary forest area	0.444	<0.001 ***	0.077	0.445
% deforested area (1978-2007)	0.012	0.908	0.315	0.001 **

Table 2. Results of indicator species analysis (ISA) conducted on plant species in the four vegetation layers in (a) primary (n=40) and (b) secondary forest plots (n=62). Only species with *p*-values <0.05 are shown. *p*-values from Monte Carlo tests are based on the proportion of randomized trials with expected IV>observed IV.

Primary forest			**Secondary forest**		
Species	**IV**	**p**	**Species**	**IV**	**p**
Tree layer			**Tree layer**		
Nuxia congesta	82.2	0.001	*Gnidia glauca*	25.8	0.002
Syzygium staudtii	76.8	0.001			
Carapa grandiflora	47.4	0.001			
Schefflera mannii	31.6	0.002			
Bersama abyssinica	22.4	0.002			
Allophylus bullatus	19.4	0.008			
Podocarpus latifolius	14.8	0.010			
Pittosporum viridiflorum	13.5	0.013			
Pavetta hookeriana var. *hookeriana*	10.0	0.021			
Corynanthe pachyceras	7.4	0.045			
Shrub layer			**Shrub layer**		
Carapa grandiflora	79.3	0.001	*Nuxia congesta*	66.0	0.006
Ardisia kivuensis	76.0	0.001	*Maesa lanceolata*	65.4	0.002
Allophylus bullatus	74.6	0.001	*Vernonia hymenolepis*	60.0	0.001
Rytigynia neglecta	62.3	0.014	*Gnidia glauca*	58.9	0.001
Clausena anisata	49.1	0.014	*Hypericum revolutum*	58.8	0.001
Xymalos monospora	48.0	0.006	*Rapanea melanophloeos*	46.3	0.003
Psydrax dunlapii	37.9	0.001	*Schefflera abyssinica*	30.4	0.009
Bersama abyssinica	35.4	0.012	*Bridelia speciosa*	22.1	0.037
Piper capense	28.5	0.005	*Erica mannii*	11.3	0.044
Cassipourea malosana	27.4	0.001			
Arundinaria alpina	26.8	0.001			
Zanthoxylum rubescens	16.9	0.021			
Rauvolfia vomitoria	14.6	0.018			

Table 2. Contd.

Dracaena fragrans	12.5	0.011			
Corynanthe pachyceras	12.3	0.029			
Under-shrub layer			**Under-shrub layer**		
Ardisia kivuensis	80.3	0.001	*Hypericum revolutum*	57.7	0.001
Allophylus bullatus	70.4	0.001	*Vernonia hymenolepis*	42.9	0.001
Carapa grandiflora	58.6	0.001	*Nuxia congesta*	38.9	0.008
Rytigynia neglecta	51.6	0.033	*Gnidia glauca*	37.1	0.001
Mimulopsis solmsii	45.2	0.001	*Maesa lanceolata*	24.6	0.041
Bersama abyssinica	42.9	0.001	*Maytenus undata*	13.8	0.047
Psydrax dunlapii	26.8	0.004	*Psorospermum aurantiacum*	12.9	0.044
Dracaena fragrans	25.0	0.001			
Cassipourea malosana	22.5	0.001			
Piper capense	22.0	0.040			
Rubus pinnatus	10.0	0.024			
Rauvolfia vomitoria	9.6	0.033			
Aframomum sp.	7.5	0.048			
Herb layer			**Herb layer**		
Commelina cameroonensis	62.5	0.001	*Geranium arabicum*	58.0	0.001
Achyrantes aspera	48.0	0.018	*Cynoglossum amplifolium*	44.3	0.001
Laportea alatipes	35.2	0.007	*Pteridium aquilinum subsp. aquilinum*	42.6	0.003
Laportea ovalifolia	28.9	0.002	*Alchemilla cryptantha*	40.6	0.014
Impatiens sakeriana	27.3	0.002	*Desmodium repandum*	38.4	0.032
Piper capense	25.3	0.012	*Agrocharis melanantha*	31.2	0.018
Momordica foetida	21.3	0.012	*Platostoma rotundifolium*	28.4	0.007
Sida rhombifolia	19.9	0.010	*Rhamnus prinoides*	25.5	0.017
Mimulopsis solmsii	15.9	0.027	*Cynoglossum coeruleum*	22.9	0.012
Psydrax dunlapii	15.2	0.036	*Pilea tetraphylla*	17.7	0.014
Cyathula cylindrica var. *cylindrica*	15.0	0.005	*Hibiscus noldeae*	16.8	0.025
Raphidiocystis phyllocalyx	13.5	0.016	*Centrosema pubescens*	16.1	0.012
Zehneria minutiflora	13.2	0.049	*Crassocephalum biafrae*	14.5	0.022
Dovyalis sp.	12.5	0.010	*Helichrysum cameroonense*	14.5	0.023
Diplazium sp.	10.0	0.016	*Laggera crispata*	12.9	0.036
Asplenium friesiorum	10.0	0.023	*Pentas pubiflora*	12.9	0.036
Landolphia sp.	7.5	0.042	*Lecanthus peduncularis*	12.6	0.049

Table 3. Results of indicator species analysis (ISA) conducted on plant trait and biogeographical categories (see details in Appendix) in (a) primary (n=40) and (b) secondary forest plots (n=62).

Primary forest			**Secondary forest**		
Trait	**IV**	**p**	**Trait**	**IV**	**p**
Life form			**Life form**		
Phanerophyte	53.4	0.008	Chamephyte	54.2	0.041
			Geophyte	63.0	0.003
Diaspore type			**Diaspore type**		
Sarcochore	56.6	0.003	Acanthochore	59.7	0.001
			Barochore	59.0	0.003
			Pogonochore	73.2	0.001

Table 3. Contd.

Dispersal type			**Dispersal type**		
Endozoochory	56.7	0.003	Epizoochory	65.0	0.001
Leaf type			Leaf type		
Mesophyll	61.0	0.001	Notophyll	55.6	0.003
Altitudinal tolerance			**Altitudinal tolerance**		
Submountain	57.8	0.045	Lower and middle altitudes	62.1	0.009
Submountain to lower mountain	58.1	0.004	Lower mountain	57.7	0.012
			Large latitudinal range	55.4	0.012
Phytogeographic type			**Phytogeographic type**		
Guineo-Congolian	76.2	0.001	Paleotropical and Afro-Malagasy	65.0	0.001
Common to Cameroonian and east African mountain	53.5	0.016	Multiregional African	74.2	0.001
Only in Cameroonian mountain	67.8	0.001	Afro-tropical mountain	63.1	0.001

Table 4. Mean (± Standard Error) values of species richness in primary (n=40) and secondary (n=62) forest plots. Z is the value of the Mann-Whitney's test. Significant *p*-values are shown in bold.

Variables	Primary forest		Secondary forest		Mann-Whitney test	
	Mean	**S.E.**	**Mean**	**S.E.**	**Z**	**p**
Species richness						
Total	45.5	2.4	44.1	1.5	-0.202	0.840
Tree layer	5.4	0.4	2.4	0.3	-5.307	0.001
Shrub layer	16.8	0.8	15.2	0.7	-1.291	0.197
Under-shrub layer	14.3	1.1	12.4	0.7	- 1.194	0.232
Herb layer	22.7	1.8	24.8	1.3	-1.286	0.198

Guineo-Congolian areas).

Secondary forest plots were characterized by geophytes (*Pteridium aquilinum*) and chamaephytes (*Alchemilla* sp.) able to propagate vegetatively and to resist to disturbances (bush fire) or survive under grazing pressure. The tree and shrub layers of the secondary forests were often dominated by the barochorous species, *Gnidia glauca*, explaining this significant trait in the ISA. Other secondary forest species used animal vectors (epizoochory) or wind (pogonochore diaspores producing plumed appendages) to disperse. Species in secondary forest plots were able to occur in a wide range of altitudinal levels and biogeographic areas (multiregional African, afro-tropical mountain species).

Species richness and some variables between primary and secondary forest plots

The mean (±1SE) species richness per plot was 45.5 (±2.4) and 44.1 (±1.5) in primary and secondary forests, respectively (Table 4). Only tree species richness showed significant differences (Z=-5.307; p < 0.001) between the two types of forests.

The total plot species richness was influenced positively by tree density and human population density and negatively by deforestation (Table 5). The tree species richness decreased along the elevation gradient and increased with the area of primary forest neighbouring plots (Table 5). The herb species richness increased with human population density and secondary forest area in the neighbouring landscape.

Table 6 shows mean values of local and landscape variables in primary (n=40) and secondary (n=62) forest plots. The maximum height of vegetation and density of trees were respectively 19.42 m, 101 stems/ha in primary forest and 11.93 m, 36 stems/ha in secondary forest and show significant difference (p<0.001). Anthropogenic activities were high in primary forest as shown by the number of rodent trap (p<0.05) and the proximity of

Table 5. Generalized linear models the effects of local and landscape variables on species richness. [1]: parameter estimate; [2]: standard error; [3]: degrees of freedom; [4]: significant *p*-values are shown in bold. Dependent variables: RTOT: total species richness in plots; Rtree: tree species richness; Rherb: tree species richness; Explanatory variables: DA: Tree density (n. stems.ha^{-1}); ALTI: altitude; HAB: human population within a 5km radius around plots; F7807: deforested area (ha) between 1978 and 2007 within a 500 m radius around plots (=forest area in 1978-forest area in 2007); FP: area of primary forest (ha) within a 500 m radius around plots; FS: area of secondary forest (ha) within a 500 m radius around plots.

Dependent variables	Explanatory variables	Par. est.[1]	S.E.[2]	D.F.[3]	Khi-2	P -value[4]
RTOT	Intercept	3.4878	0.0471	1	5491.48	<0.001
	DA	0.0014	0.0003	1	22.34	<0.001
	HAB	0.0009	0.0001	1	45.63	<0.001
	F7807	-5.2E-07	1.1E-07	1	23.68	<0.001
Rtree	Intercept	6.4318	0.6946	1	85.73	<0.001
	ALTI	-0.0024	0.0003	1	54.59	<0.001
	FP	0.0165	0.0040	1	16.81	<0.001
Rherb	Intercept	3.2309	0.0558	1	3347.50	<0.001
	HAB	0.0009	0.0001	1	44.10	<0.001
	FS	0.0034	0.0009	1	13.29	<0.001

Table 6. Mean values of local and landscape variables in primary (n=40) and secondary (n=62) forest plots. Z is the value of the Mann-Whitney's test. * p<0.05, ** p<0.01, *** p<0.001.

Parameter		Primary forest		Secondary forest		Mann-Whitney test	
		Mean	S.E.	Mean	S.E.	Z	p
Local variables	**Code**						
Maximum height of vegetation (cm)	HMAX	1942.5	72.0	1193.5	56.2	-6.402	0.000 ***
Density of trees (n. stems/ha)	DA	101.0	7.6	36.0	4.7	-6.056	0.000 ***
Bare soil cover (%)	SOL	3.3	1.0	4.4	0.9	-1.339	0.181
Number of domestic bee hives	RUCH	0.6	0.1	0.5	0.1	-0.234	0.815
Number of rodent traps	PIEG	0.9	0.2	0.4	0.2	-3.433	0.001 **
Altitude (m)	ALTIMC	2302.1	23.0	2352.2	27.9	-1.539	0.124
Slope (°)	PENTE	12.9	1.1	12.9	0.7	-0.446	0.656
Orientation index =180°-Absolute value (orientation-180°)	OrientSud	68.5	7.6	74.3	6.0	-0.665	0.506
Landscape variables							
Number of villages in a radius of 5 km	NBVIL5KM	4.9	0.2	4.1	0.1	-3.539	0.000 ***
Distance of the nearest village (m)	DVIL	2388.6	85.1	2564.5	113.2	-1.145	0.252
Number of inhabitants in a radius of 5 km	HAB5KM	373.8	24.8	325.7	11.9	-1.395	0.163
Distance of the nearest house (m)	DCASE	1803.2	105.5	1985.6	108.2	-0.898	0.369
Percentage of primary forest loss (ha; 100x(forest 1978-primary forest 2007)/forest 1978) r=500 m	PDEFP7807	64.4	2.9	74.8	2.9	-2.670	0.008 **
Forest area in 2007 (r=500 m)	F2007	42.4512	15.7707	40.707	24.1658	-0.158	0.875
Savanna area in 2007 (r=500 m)	S2007	26.1477	12.9258	27.0103	17.6999	-0.24	0.81
Crop area in 2007 (r=500 m)	C2007	8.1452	13.3525	8.6936	10.7118	-0.786	0.432
Primary forest area in 2007 (r=500m)	FP	23.1	2.0	15.5	2.0	-2.876	0.004 **
Secondary forest area in 2007 (r=500 m)	FS	18.7	1.8	24.9	2.5	-1.083	0.279

villages.

DISCUSSION

Forests generally become fragmented through intensification of human activities. The results of this study suggested cropland and pasture expansion as the major reasons for the observed fragmentation along with high dependence on forest resources such as thinning, bee keeping and hunting (Uddina et al., 2015). In fact, Momo et al. (2012) show that between 1978 and 2007, the number of forest fragments increased from 2627 to 5183, their average area decreased from 7.4 to 1.8 ha, and perimeter from 912 to 446 m, and the forest fragmentation index increased by 285.7%, so despite the recent progression of forest cover (since the year 2001), the proportion of ancient forest has continuously decreased from 1978 to 2007, indicating that deforestation is still ongoing. The loss of forest is particularly serious in this mountainous area, because the landscape is fragile with steep slopes and loss of soil cover can mean that recovery of the ecosystem can be very slow or even impossible as in other mountainous zones (Halada, 2010).

The ordination diagram of plots separates at first, the oldest forests inherited from primary formations on one side, and on the other side, secondary forest and shrub recolonization of fallow and savanna. In the study zone, 63.1% of species are common to the different types of forests while Zapfack et al. (2002) showed that the primary and secondary forests have only 42% of similarity in terms of species composition. Where forest plants are present in secondary as well as primary forests, it can be assumed that they colonised the secondary forest sites from the primary forests andhedgerows that surround most fields. Why have some forest plants been so successful in colonising secondary forests from source populations in primary forests? To answer this question, let us consider the different land-use histories of primary and secondary forests. Clearing of the original forests, combined with the sustained use of a site for agriculture for the better part of a century, would eliminate the forest plants present at the time of clearing. Thus, when a farm field is abandoned, primary forest plants can colonise it only if they can get there from nearby forests (Lôbo et al., 2011). The re-growing secondary forest has significantly altered forest structure and often significantly altered canopy species composition as well, as compared to the original forest. So, there is really no more primary forest on Mount Oku. In fact, the primary nature of tropical forests is also quite debated because many studies show the existence of very ancient human traces in these forests (Denevan, 1992).

Only one species was indicator of the canopy of secondary forests. Secondary forests were dominated by two heliophilous and pioneer edge species, *Gnidia glauca* and *Hypericum revolutum*. These two species are commonly found in high altitude communities that have been damaged, cleared or burned (Cheek et al., 2000; Asanga, 2002). They characterised the altitude coppices described by Letouzey (1985) and the first stages in the succession back to mountain forest (Asanga, 2002). Common disturbances that give rise to secondary forests include fragmentation of habitats, deforestation and change in land use practices (Chokkalingam and De Jong, 2001). Changes in plant species composition of Mount Oku forests in the last century could be partly related to the drastic reduction of seed disperser mammals (Maisels et al., 2001). Now, 80% of tree species occurring in the Mount Oku forest are adapted to animal dispersal. Out of these, 97.5% are dispersed by birds or monkeys and 2.4% by rodents (Maisels and Forboseh, 1997). Only 20% of the trees are wind-dispersed. Some forest species are much better than others at dispersing seeds to abandoned fields. Thus, one reason secondary forests differ in species from primary forests is that they contain species with better dispersal capabilities. Secondary forests contain herbaceous plants with tiny spores that drift long distances in wind, such as fern plants. But not all forest species capable of dispersing in abandoned farmlands are well represented in secondary forests. Some shade-tolerant forest species are uncommon in secondary forests, perhaps because they cannot tolerate the sunny, open conditions of rundown, abandoned fields.

According to Yongo (2002), tropical forests are characterised by the presence of high phanerophytes. The low percentage of phanerophytes obtained in this study as compared to other sites reinforces our belief that we are in predominantly disturbed forest. Although, disturbed forests of Mount Oku still harbor a flora composed mainly of phanerophytes, with a significant proportion of chamaephyte, this high proportion of chamaephytes results in the exposure of understorey to light rays, following the opening of the canopy. It shows that secondary forests generally with fewer tree species, are dominated by widespread pioneer trees and have a simpler structure (Whitmore, 1998; Aide et al., 2000).

The species richness per plot was slightly higher in primary forests, and it can be assumed that the proximity of many secondary forest plots to primary forest stands will likely result in increased richness in these plots due to potentially high seed input from mature forests (Mesquita et al., 2001; Kennard et al., 2002). Secondary forests contain a subset of the forest plants found in primary forests; plants may be uncommon in secondary forests because of seed size and seed dispersal ability. Small seeds give rise to small seedlings, which compete poorly with the dense vegetation of abandoned farm fields. Generally, these secondary forests regenerate largely through natural processes after partial abandonment of alternative land use (agriculture, pasture, etc.) on formerly forested lands (Smith et al., 1999).

Conclusion

Finally, this study suggests that expansions of cropland coupled with high dependency on forests by human population are the major drivers of the forest fragmentation and degradation with implications for biodiversity, ecosystem services and people's livelihoods. A total of 385 vascular plant species were present in the 102 plots. 243 species were common to primary and secondary forest plots, 69 were present exclusively in primary forest plots and 73 in secondary forest plots. The Indicator Species Analysis showed that 38 and 28 species were indicator of primary and secondary forests, respectively. The mean species richness per plot was 45.5 and 44.1 in primary and secondary forests, respectively. Only tree species richness was significantly higher ($Z=-5.307$; $p < 0.001$) in primary forest. The maximum height of vegetation and density of trees were respectively 19.42 m, 101 stems/ha in primary forest and 11.93 m, 36 stems/ha in secondary forest and show significant difference ($p<0.001$). Primary forest plots were characterized by phanerophytes, while secondary forest plots were characterized by geophytes and chamaephytes. This study improves the information base at national scale, and may contribute to understand global change in forest. Such information is required for informed decision making and planning conservation. So, there is need to urgently protect the last remnants of ancient forest for their biological value.

Conflict of Interests

The authors did not declare any conflict of interests.

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Appendix 1. The plant traits and biogeographic characteristics and their categories.

Plant characteristics	Codes	Categories	Functions	References
Life form	B-Ph	Phanerophyte	Holding space and time	Raunkiaer,1934
	B-Ch	Chamephyte		
	B-L	Liana		
	B-H	Hemicryptophyte		
	B-Th	Therophyte		
	B-G	Geophyte		
Diaspore type	G-Acan	Acanthochore	Ability to disperse, to regenerate and to establish in the ecosystem	Dansereau and Lems, 1957; Doucet, 2003
	G-Ballo	Ballochore		
	G-Baro	Barochore		
	G-Pogo	Pogonochore		
	G-Ptero	Pterochore		
	G-Sarco	Sarcochore		
	G-Sclero	Sclerochore		
	G-Sporo	Spore		
Dispersal type	D -Ane	Anemochory	Ability to migrate, to colonize, dispersal distance	Dansereau and Lems, 1957; Guillaumet, 1967
	D-Auto	Autochory		
	D-Endozoo	Endozoochory		
	D-Epizoo	Epizoochory		
Leaf type	F-Mg.Ma	Megaphyll (leaf area > 20 dm^2) and Macrophyll (2-20 dm^2)	Adaptation to macro and microclimatic conditions	Ohsawa, 1995
	F-Me	Mesophyll (40-200 cm^2)		
	F-No	Notophyll (20-40 cm^2)		
	F-Mi	Microphyll (2-20 cm^2)		
	F-Na.Le	Nanophyll (0,2-2 cm^2) and leptophyll (< 0,2 cm^2)		
Altitudinal tolerance	A-lowalti	Lower and middle altitudes	Response to climate and tolerance to altitude	Senterre, 2006
	A-SM	Submountain		
	A-SM+MI	Submountain to lower mountain		
	A-MI	Lower mountain		
	A-MI+MS	Lower mountain to upper mountain		
	A-alpine	Upper mountain to subalpine		
	A-large	Large latitudinal range (> 2 altitudinal levels)		
Phytogeographic type	P-Cos	Cosmopolitan	Flora stability and age, response to natural disturbances and to human presence (species exchanges between continents), response to isolation and forest degradation (endemic species)	White, 1978; White, 1979; White, 1983
	P-Pan	Pantropical		
	P-Pal	Paleotropical and afro-malagasy		
	P-Afr	Afro-tropical		
	P-P-A	Multiregional african		
	P-GC	Guineo-Congolian		
	P-MoAfr	Afro-tropical mountain		
	P-MoCam.EAfr	Common to cameroonian and east African mountain		
	P-MoCam	Only in cameroonian mountain		

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Floristic diversity of Vallikkaattu Kaavu, a sacred grove of Kozhikode, Kerala, India

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Flora of Vallikkaattu Kaavu, a sacred grove of Kozhikode District, Kerala, India with their botanical name, family, conservation status, endemic status, medicinal status and habit has been presented in detail. This sacred grove associated with the Sree Vana Durga Bhagavathi Temple located 20 km north of Kozhikode at Edakkara in Thalakkalathur Panchayat, is the largest sacred grove in Kozhikode District with an extent of 6.5 ha. Floristic studies of this sacred grove recorded 245 flowering species belonging to 209 genera and 77 families. Among the 245 species, 75 are herbs, 71 are trees, 55 are shrubs and 44 are climbers. Out of the 245, 44 are endemics - 16 endemic to Southern Western Ghats, 3 endemic to Southern Western Ghats (Kerala), 13 endemic to Western Ghats, 9 endemic to Peninsular, India, 2 endemic to India and 1 endemic to South India (Kerala). Thirty four threatened plants were reported, out of which 3 are Critically Endangered, 5 are Endangered, 4 are Near Threatened, 1 is at Low Risk and Near Threatened, 16 are Vulnerable and 3 are with Data-Deficient status. Species with Not Evaluated status and Least Concern status were also listed. Endemic plants like *Sonerila rheedei*, *Litsea ghatica*, *Lagenandra meeboldii* and *Ischaemum tumidum* var. *calicutensis,* threatened and endemic plants like *Anaphyllum wightii* and *Kunstleria keralensis* and *Acorus calamus* with endangered status were recorded. *Myristica* swamps having dense prominent stilt and breathing roots represented mainly by *Gymnacranthera farquhariana* and the endemic and threatened species, *Myristica fatua* var. *magnifica* and *M. malabarica* were also recorded from this sacred grove. Out of the 245 species listed, 236 are medicinal, constituting 96% of the total flowering plants reported from this sacred grove.

Key words: Endemic, threatened, critically endangered, vulnerable, *Gymnacranthera farquhariana*, *Myristica fatua* var. *magnifica*.

INTRODUCTION

Sacred groves are considered a reservoir of biodiversity, gene pool and treasure house of many endemic, endangered and economically important plants used in Ayurveda, tribal and folk medicines and their importance in conserving biodiversity has been well recognized. The sacred groves blessed with many native plants comprise of patches of forests or natural vegetation ranging from few trees to forests which have been conserved by local

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people time immemorial dedicating them to local deities. They do play significant role in soil and water conservation and nutrient cycling in the terrestrial ecosystem. In India, they are reported from the Himalayas, North-east India, highlands of Bihar, Orissa, Madhya Pradesh, Andhra Pradesh, Karnataka, Tamil Nadu and Kerala. In Kerala, they are known variously as “Kaavu”, “Sarppakkaavu”, “Pambinkaavu” or “Nagakkaavu” which are dedicated to gods/goddesses or to certain ancestral/natural spirits. The sacred groves in general, act as nursery and storehouse of many local Ayurveda, tribal and folk medicines (Bhakat and Pandit, 2003). Extensive studies have been done on the floristic diversity of sacred groves of the Western Ghats and Kerala State during the past three decades (Gadgil and Vartak, 1975, 1976, 1981; Unnikrishnan, 1995; Chandran and Gadgil, 1993a,b; Chandran et al., 1998; Nambeesan, 1999; Induchoodan, 1992, 1996; Pushpangadan et al., 1998; Unni and Anupama, 2004; Anupama, 2009; Sreeja and Unni, 2010a; Sreeja, 2008, 2013). Many sacred groves of Kozhikode District have been reported as storehouse of valuable medicinal plants used in Ayurveda, tribal and folk medicines (Sreeja and Unni, 2010b, 2011). Studies show that some sacred groves of Kakkodi Panchayat in the Kozhikode district (Kerala) have undergone drastic degradation due to human interventions (Sreeja et al., 2010). Sacred groves being rich in a variety of medicinal plants, their conservation warrants extensive floristic studies and implementation of immediate measures for conservation, failing which many threatened medicinal plants might be lost forever.

Studies on sacred groves of Kerala shows there are 761 sacred groves rich in biodiversity with a floristic wealth of over 722 species belonging to 217 families and 474 genera (Balasubramanyan and Induchoodan, 1996). Even the smallest groves harbour some old and magnificent specimens of trees and climbers (Induchoodan, 1992, 1996; Chandrasekara and Sankar, 1998a, b; Anupama, 2009). Studies done by the Centre for Water Resources Development and Management (CWRDM), Kozhikode, Kerala (2007) showed the floral diversity of 577 sacred groves of Kerala with 737 plants out of which 609 are Dicotyledons, 122 are monocotyledons, 4 are Pteridophytes, and 2 are Gymnosperms. A very interesting constituent of sacred groves of Malabar is the typical *Myristica* swamps found in evergreen swampy groves of Kozhikode, Kannur and Kasaragod. Sacred groves of Kerala have distinct tiers of trees, shrubs, herbs, climbers, stranglers, epiphytes, parasites, and wild relatives of many cultivated plants (Rajendraprasad, 1995). The vegetation of sacred groves has been broadly classified into two types *viz*., evergreen and moist deciduous (Basha, 1998). A new species of the leguminous climber *Kunstleria keralensis* has been reported from one of the sacred groves of Kerala (Mohanan and Nair, 1981). Chandrasekara and Sankar (1998 a, b) recorded 73 species from three sacred groves of Kerala of which 13 are endemic to Southern Western Ghats, 3 are endemic to Western Ghats and 1 is endemic to Peninsular India. Induchoodan (1996) identified 364 important sacred groves in Kerala with a floristic wealth of 722 species. Pushpagadan et al. (1998) reported that the biological spectrum of sacred groves of Kerala closely resembles that of tropical forest biodiversity. A rare species of cinnamon, *Cinnamomum quilonensis* have been reported from the sacred groves of Alappuzha in Kerala (Mohanan and Nair, 1981). Twenty five threatened plants have been recorded from coastal sacred groves of Thrissur (Sujana et al., 2006). A study undertaken on the floristic composition, vegetation dynamics, ecology as well as the rituals in 173 sacred groves of 13 districts of Kerala by the Jawaharlal Nehru Tropical Botanic Garden and Research Institute (JNTBGRI), Thiruvananthapuram reported the presence of 411 species of angiosperms belonging to 276 genera and 92 families, out of which 57 were endemic to Kerala/Western Ghats including five endangered species *viz*., *Vateria macrocarpa*, *Phaeanthus malabaricus*, *Rauvolfia micrantha*, *R. serpentina* and *Taprobanea spathulata*.

Anupama (2009) studied the ecology of 7 select sacred groves of Malabar *viz.,* Kammadathu Kaavu (Kasaragod), Parappool Kaavu, Poongottu Kaavu and Thazhekkaavu (Kannur) and Bhayan kaavu, Poyil Kaavu and Thurayil Kaavu (Kozhikode) with emphasis on major physicochemical aspects of their soils and floral diversity with special reference to angiosperms. A total of 171 plants have been recorded consisting of 10 Monocotyledons, 159 Dicotyledons and 2 Gymnosperms. Reports on floral diversity of six sacred groves of Kakkodi Panchayat of Kozhikode District (Sreeja, 2008; Sreeja et al. 2010) reported the presence of 131 species of plants belonging to 118 genera and 60 families, out of which 127 were Angiosperms, 2 were Gymnosperms and 2 were Pteridophytes.

MATERIALS AND METHODS

This study was done in Vallikkaattu Kaavu of Kozhikode District (11°08’ and 11°50’ N latitude; 75°30’ and 76° 08’ E longitude) located on the southwest coast of India with a humid tropical climate, mean annual rainfall of 3266 mm and temperature range of 22 to 36°C. History and details of this sacred grove was collected through field visits, personal interview with members of the Temple Trust and confirmed scrutinizing the temple records. Plants were collected seasonally based on their flowering season, herbaria prepared following the wet method of Fosberg and Sachet (1965) and identified with the help of Flora of the Presidency of Madras by Gamble and Fischer (1915-1936) and other Floras, Manuals, Revisions, etc. and confirmed by matching with the Herbaria of University of Calicut (CALI), Foundation for Revitalization of Local Health Traditions(FRLH), Bangalore and Jawaharlal Nehru Tropical Botanic Garden and Research Institute (TBGT), Thiruvananthapuram, Kerala and The Madras Herbarium (MH) of the Botanical Survey of India, Coimbatore. Medicinal uses of these plants were collected through personal interviews with local medical practitioners and renowned Ayurveda physicians of Kottakkal Arya Vaidya Sala, Malappuram, Kerala and confirmed with the authentic

Table 1. Flora of Vallikkaattu Kaavu.

S/N	Botanical name	Family	Cons. St.	End. St.	MS	Habit
1	*Naravelia zeylanica*	Ranunculaceae	-	-	M	C
2	*Magnolia champaca*	Magnoliaceae	NT/K	-	M	T
3	*Polyalthia korintii*	Annonaceae	-	-	M	S
4	*Uvaria narum*	Annonaceae	-	-	M	C
5	*Anamirta cocculus*	Menispermaceae	-	-	M	C
6	*Coscinium fenestratum*	Menispermaceae	EN/Cr/K	-	M	C
7	*Cyclea peltata*	Menispermaceae	-	-	M	C
8	*Tiliacora acuminata*	Menispermaceae	-	-	M	C
9	*Tinospora cordifolia*	Menispermaceae	-	-	M	C
10	*Tinospora sinensis*	Menispermaceae	NT/K	-	M	C
11	*Cleome rutidosperma*	Capparaceae	-	-	M	H
12	*Hydnocarpus pentandra*	Flacourtiaceae	V/G	W.G	M	T
13	*Xanthophyllum arnottianum*	Polygalaceae	-	W.G	M	T
14	*Calophylum inophyllum*	Clusiaceae	-	-	M	T
15	*Hopea parviflora*	Dipterocarpaceae	EN	SW.G	M	T
16	*Hopea ponga*	Dipterocarpaceae	EN	SW.G	M	T
17	*Vateria indica*	Dipterocarpaceae	EN/Cr	W.G	M	T
18	*Vatica chinensis*	Dipterocarpaceae	-	-	-	T
19	*Hibiscus hispidissimus*	Malvaceae	-	-	M	S
20	*Hibiscus rosa-sinensis* var. *rosa-sinensis*	Malvaceae	-	-	M	S
21	*Sida rhombifolia*	Malvaceae	-	-	M	H
22	*Bombax ceiba*	Bombacaceae	-	-	M	T
23	*Sterculia guttata*	Sterculiaceae	-	-	M	T
24	*Grewia nervosa*	Tiliaceae	-	-	M	S
25	*Grewia tiliifolia*	Tiliaceae	-	-	M	T
26	*Grewia umbellifera*	Tiliaceae	-	W.G	M	C
27	*Elaeocarpus tuberculatus*	Elaeocarpaceae	-	-	M	T
28	*Hugonia mystax*	Linaceae	-	-	M	C
29	*Biophytum reinwardtii* var. *reinwardtii*	Oxalidaceae	-	-	M	H
30	*Impatiens cordata*	Balsaminaceae	-	SW.G	M	H
31	*Aegle marmelos*	Rutaceae	NE/K	-	M	T
32	*Glycosmis macrocarpa*	Rutaceae	V/G	-	M	S
33	*Glycosmis pentaphylla*	Rutaceae	-	-	M	S

book by Udayan and Balachandran (2009), authentic websites and journals. Present conservation and endemic status of plants was listed referring to authentic publications and web sites (Sasidharan, 2004, 2006, 2011; FRLHT, 2004; IUCN, 2012).

Vallikkaattu Kaavu, associated with the Sree Vana Durga Bhagavathi Temple, located 20 km north of Kozhikode at Edakkara in Thalakkalathur Panchayat of Kozhikode District is the largest sacred grove in Kozhikode District with an area of 6.5 ha. Major portion of this sacred grove is a hillock and a perennial stream flowing through it drains into a pond closer to it. The *Kaavu* and the temple which were owned earlier by three Hindu families and the H. R and C. E. Department, Government of Kerala took over its control in1948 and is being administered by a Board of Trustees consisting of five members - two members from the hereditary families and three from the Department, which meets once a month and takes decisions on matters related to the temple administration. Main deity of the temple is Sree Durga Bhagavathi and the sub-deities are Ganapathi, Ayyappan, Bhadrakaali and Sree Vettakkorumakan. The daily *Poojas* are *Malar Nivedyam* and *Nivedya Pooja. Thrikaala Pooja* is performed as offerings which is done during the Vaisakha (May) and Karkkidaka (July-August) months, Navaraathri (October) days and the period Mandala (November-December). The main *Vazhipaadus* (offerings) are *Raktha Pushpaanjali, Pushpaanjali, Thrimadhuram, Muttarukkal, SharkkaraPaayasam, Maala, Ennavilakku* and *Neyvilakku. KudukkaChoru* is an important *Vazhipaadu* done for being blessed with progeny.

RESULTS AND DISCUSSION

Detailed list of plants in Vallikkaattu Kaavu, a sacred grove of Kozhikode District with their updated botanical name, family, conservation status, endemic status, medicinal status and habit is presented in Table 1.

This sacred grove recorded 245 flowering plants belonging to 209 genera and 77 families. Among these 245 species, 75 species are herbs, 71 trees, 55 shrubs

Table 1. Contd.

34	*Zanthoxylum rhetsa*	Rutaceae	-	-	M	T
35	*Gomphia serrata*	Ochnaceae	-	-	M	S
36	*Aglaia elaeagnoidea*	Meliaceae	-	-	M	T
37	*Aphanamixis polystachya*	Meliaceae	V/K	-	M	T
38	*Naregamia alata*	Meliaceae	-	P.I	M	H
39	*Dichapetalum gelonioides*	Dichapetalaceae	-	-	M	S
40	*Gomphandra tetrandra*	Icacinaceae	-	-	M	S
41	*Nothapodytes nimmoniana*	Icacinaceae	V/K	-	M	S
42	*Cansjera rheedei*	Opiliaceae	-	-	M	C
43	*Celastrus paniculatus*	Celastraceae	V/K	-	M	C
44	*Lophopetalum wightianum*	Celastraceae	-	-	M	T
45	*Salacia reticulata*	Hippocrateaceae	DD/K	-	M	S
46	*Ziziphus oenoplia*	Rhamnaceae	-	-	M	C
47	*Ziziphus rugosa*	Rhamnaceae	-	-	M	S
48	*Ampelocissus latifolia*	Vitaceae	-	-	M	C
49	*Cissus repens*	Vitaceae	-	-	M	C
50	*Leea indica*	Leeaceae	-	-	M	T
51	*Lepisanthes tetraphylla*	Sapindaceae	-	-	M	T
52	*Anacardium occidentale*	Anacardiaceae	-	-	M	T
53	*Holigarna arnottiana*	Anacardiaceae	-	SW.G	M	T
54	*Mangifera indica*	Anacardiaceae	-	-	M	T
55	*Connarus monocarpus*	Connaraceae	-	-	M	C
56	*Abrus precatorius*	Fabaceae (Subfamily: Faboideae)	-	-	M	C
57	*Aeschynomene indica*	Fabaceae (Subfamily: Faboideae)	-	-	M	H
58	*Clitoria ternatea* var. *ternatea*	Fabaceae (Subfamily: Faboideae)	-	-	M	C
59	*Dalbergia horrida* var. *horrida*	Fabaceae (Subfamily: Faboideae)	-	SW.G	M	C
60	*Derris scandens*	Fabaceae (Subfamily: Faboideae)	-	-	M	C
61	*Derris trifoliata*	Fabaceae (Subfamily: Faboideae)	-	-	M	C
62	*Desmodium heterophyllum*	Fabaceae (Subfamily: Faboideae)	-	-	M	H
63	*Gliricidia sepium*	Fabaceae (Subfamily: Faboideae)	-	-	M	T
64	*Kunstleria keralensis*	Fabaceae (Subfamily: Faboideae)	V	SW.G(K)	M	C
65	*Mucuna pruriens* var. *pruriens*	Fabaceae (Subfamily: Faboideae)	-	-	M	C
66	*Pongamia pinnata*	Fabaceae (Subfamily: Faboideae)	-	-	M	T
67	*Smithia sensitiva*	Fabaceae (Subfamily: Faboideae)	-	-	M	H
68	*Bauhinia acuminata*	Fabaceae (Subfamily: Caesalpinioideae)	-	-	M	S
69	*Bauhinia phoenicea*	Fabaceae (Subfamily: Caesalpinioideae)	-	W.G	M	C
70	*Caesalpinia pulcherrima*	Fabaceae (Subfamily: Caesalpinioideae)	-	-	M	S
71	*Saraca asoca*	Fabaceae (Subfamily: Caesalpinioideae)	V	-	M	T
72	*Acacia caesia*	Fabaceae (Subfamily: Mimosoideae)	-	-	M	C
73	*Adenanthera pavonina*	Fabaceae (Subfamily: Mimosoideae)	-	-	M	T
74	*Entada rheedei*	Fabaceae (Subfamily: Mimosoideae)	-	-	M	C
75	*Mimosa pudica*	Fabaceae (Subfamily: Mimosoideae)	-	-	M	H
76	*Xylia xylocarpa*	Fabaceae (Subfamily: Mimosoideae)	-	-	M	T
77	*Calycopteris floribunda*	Combretaceae	-	-	M	C
78	*Quisqualis indica*	Combretaceae	-	-	M	C
79	*Terminalia bellirica*	Combretaceae	-	-	M	T
80	*Terminalia catappa*	Combretaceae	-	-	M	T
81	*Terminalia paniculata*	Combretaceae	-	P.I	M	T
82	*Syzygium caryophyllatum*	Myrtaceae	-	-	M	S
83	*Barringtonia acutangula*	Lecythidaceae	-	-	M	T
84	*Careya arborea*	Lecythidaceae	-	-	M	T
85	*Melastoma malabathricum*	Melastomataceae	-	-	M	S

Table 1. Contd.

86	*Memecylon randerianum*	Melastomataceae	-	SW.G	M	T
87	*Memecylon umbellatum*	Melastomataceae	-	-	M	S
88	*Osbeckia virgata*	Melastomataceae	-	-	M	S
89	*Sonerila rheedii*	Melastomataceae	-	SW.G	M	H
90	*Ludwigia hyssopifolia*	Onagraceae	-	-	M	H
91	*Ludwigia perennis*	Onagraceae	-	-	M	H
92	*Begonia malabarica*	Begoniaceae	-	-	M	H
93	*Centella asiatica*	Apiaceae	-	-	M	H
94	*Canthium angustifolium*	Rubiaceae	-	-	M	S
95	*Canthium rheedii*	Rubiaceae	-	P.I	M	S
96	*Catunaregam spinosa*	Rubiaceae	-	-	M	S
97	*Chassalia curviflora*	Rubiaceae	-	-	M	S
98	*Ixora coccinea*	Rubiaceae	-	-	M	S
99	*Ixora malabarica*	Rubiaceae	V	SW.G	-	S
100	*Mitracarpus hirtus*	Rubiaceae	-	-	M	H
101	*Mussaenda frondosa*	Rubiaceae	-	P.I	M	S
102	*Neolamarckia cadamba*	Rubiaceae	-	-	M	T
103	*Ophiorrhiza pectinata*	Rubiaceae	-	-	M	S
104	*Pavetta indica* var. *indica*	Rubiaceae	-	-	M	S
105	*Acmella paniculata*	Asteraceae	-	-	M	H
106	*Artemisia nilagarica*	Asteraceae	-	-	M	S
107	*Chromolaena odorata*	Asteraceae	-	-	M	S
108	*Eclipta prostrata* var. *prostrata*	Asteraceae	-	-	M	H
109	*Elephantopus scaber*	Asteraceae	-	-	M	H
110	*Emilia sonchifolia*	Asteraceae	-	-	M	H
111	*Mikania micrantha*	Asteraceae	-	-	M	C
112	*Spilanthes ciliata*	Asteraceae	-	-	M	H
113	*Tridax procumbens*	Asteraceae	-	-	M	H
114	*Vernonia cinerea*	Asteraceae	-	-	M	H
115	*Wedelia trilobata*	Asteraceae	-	-	M	H
116	*Mimusops elengi*	Sapotaceae	-	-	M	T
117	*Diospyros ebenum*	Ebenaceae	DD	-	M	T
118	*Diospyros paniculata*	Ebenaceae	V/G	-	M	T
119	*Jasminum angustifolium* var. *angustifolium*	Oleaceae	-	-	M	C
120	*Jasminum malabaricum*	Oleaceae	-	W.G	M	C
121	*Olea dioica*	Oleaceae	-	I	M	T
122	*Allamanda cathartica*	Apocynaceae	-	-	M	C
123	*Alstonia scholaris*	Apocynaceae	-	-	M	T
124	*Chonemorpha fragrans*	Apocynaceae	-	-	M	C
125	*Holarrhena pubescens*	Apocynaceae	-	-	M	T
126	*Ichnocarpus frutescens*	Apocynaceae	-	-	M	C
127	*Kammetia caryophyllata*	Apocynaceae	-	SW.G	M	C
128	*Nerium oleander*	Apocynaceae	-	-	M	S
129	*Rauvolfia tetraphylla*	Apocynaceae	-	-	M	S
130	*Tabernaemontana alternifolia*	Apocynaceae	LR-NT	SW.G	M	T
131	*Thevetia peruviana*	Apocynaceae	-	-	M	S
132	*Wrightia tinctoria*	Apocynaceae	-	-	M	T
133	*Tylophora indica* var. *indica*	Asclepiadaceae	-	-	M	C
134	*Cryptolepis buchananii*	Periplocaceae	-	-	M	C
135	*Hemidesmus indicus* var. *pubescens*	Periplocaceae	-	P.I	M	C
136	*Fagraea ceilanica*	Loganiaceae	-	-	M	S

Table 1. Contd.

137	*Strychnos nux-vomica*	Loganiaceae	-	-	M	T
138	*Nymphoides hydrophylla*	Menyanthaceae	-	-	M	H
139	*Cordia wallichii*	Boraginaceae	-	P. I	M	T
140	*Heliotropium keralense*	Boraginaceae	EN/Cr/G	SW.G(K)	M	H
141	*Evolvulus alsinoides* var. *alsinoides*	Convolvulaceae	-	-	M	H
142	*Ipomoea aqutica*	Convolvulaceae	-	-	M	H
143	*Ipomoea hederifolia*	Convolvulaceae	-	-	M	C
144	*Ipomoea obscura*	Convolvulaceae	-	-	M	C
145	*Solanum americanum*	Solanaceae	-	-	M	H
146	*Solanum torvum*	Solanaceae	-	-	M	S
147	*Bacopa monnieri*	Scrophulariaceae	-	-	M	H
148	*Scoparia dulcis*	Scrophulariaceae	-	-	M	H
149	*Torenia bicolor*	Scrophulariaceae	-	W.G	M	H
150	*Oroxylum indicum*	Bignoniaceae	EN/K	-	M	T
151	*Andrographis paniculata*	Acanthaceae	-	-	M	H
152	*Asystasia gangetica* var.*gangetica*	Acanthaceae	-	-	M	H
153	*Justicia gendarusa*	Acanthaceae	-	-	M	S
154	*Strobilanthes ciliatus*	Acanthaceae	-	SW.G	M	S
155	*Thunbergia erecta*	Acanthaceae	-	-	M	S
156	*Callicarpa tomentosa*	Verbenaceae	-	-	M	S
157	*Clerodendrum inerme*	Verbenaceae	-	-	M	S
158	*Clerodendrum infortunatum*	Verbenaceae	-	-	M	S
159	*Clerodendrum paniculatum*	Verbenaceae	-	-	M	S
160	*Duranta erecta*	Verbenaceae	-	-	M	S
161	*Lantana camara* var. *camara*	Verbenaceae	-	-	M	S
162	*Premna serratifolia*	Verbenaceae	-	-	M	S
163	*Stachytarpheta jamaicensis*	Verbenaceae	-	-	M	S
164	*Tectona grandis*	Verbenaceae	-	-	M	T
165	*Vitex altissima*	Verbenaceae	-	-	M	T
166	*Hyptis suaveolens*	Lamiaceae	-	-	M	S
167	*Leucas biflora*	Lamiaceae	-	-	M	H
168	*Leucas lavandulifolia*	Lamiaceae	-	-	M	H
169	*Ocimum tenuifloram*	Lamiaceae	-	-	M	H
170	*Pogostemon wightii*	Lamiaceae	-	SW.G	-	S
171	*Persicaria chinensis*	Polygonaceae	-	-	M	S
172	*Persicaria glabra*	Polygonaceae	-	-	M	H
173	*Peperomia pellucida*	Piperaceae	-	-	M	H
174	*Piper longum*	Piperaceae	NT/K	-	M	H
175	*Piper nigrum* var. *nigrum*	Piperaceae	LC/K	-	M	C
176	*Gymnacranthera farquhariana*	Myristicaceae	-	-	M	T
177	*Myristica fatua* var.*magnifica*	Myristicaceae	EN	SW.G	M	T
178	*Myristica malabarica*	Myristicaceae	V	W.G	M	T
179	*Cassytha filiformis*	Lauraceae	-	-	M	C
180	*Cinnamomum malabatrum*	Lauraceae	-	SW.G	M	T
181	*Cinnamomum verum*	Lauraceae	-	-	M	T
182	*Litsea coriacea*	Lauraceae	-	P.I	-	T
183	*Litsea ghatica*	Lauraceae	-	W.G	M	S
184	*Persea macrantha*	Lauraceae	V/K	-	M	T
185	*Dendrophthoe falcata*	Loranthaceae	-	-	M	S
186	*Santalum album*	Santalaceae	V/G	-	M	T
187	*Scleropyrum pentandrum*	Santalaceae	-	-	M	T
188	*Acalypha hispida*	Euphorbiaceae	-	-	M	S

Table 1. Contd.

189	*Antidesma bunius*	Euphobiaceae	-	-	M	T
190	*Antidesma ghaesembilla*	Euphorbiaceae	-	-	M	T
191	*Antidesma montanum*	Euphorbiaceae	-	-	M	T
192	*Aporosa acuminata*	Euphorbiaceae	-	-	M	T
193	*Aporosa cardiosperma*	Euphorbiaceae	-	-	M	T
194	*Briedelia stipularis*	Euphorbiaceae	-	P.I	M	S
195	*Glochidion zeylanicum*	Euphorbiaceae	-	-	M	T
196	*Macaranga peltata*	Euphorbiaceae	-	-	M	T
197	*Mallotus philippensis*	Euphorbiaceae	-	-	M	T
198	*Meineckia longipes*	Euphorbiaceae	-	P.I	-	S
199	*Phyllanthus airy-shawii*	Euphorbiaceae	-	-	M	H
200	*Tragia involucrata*	Euphorbiaceae	-	-	M	H
201	*Trewia nudiflora*	Euphorbiaceae	-	-	M	T
202	*Laportea interrupta*	Urticaceae	-	-	M	H
203	*Antiaris toxicaria*	Moraceae	-	-	M	T
204	*Artocarpus heterophyllus*	Moraceae	-	-	M	T
205	*Artocarpus hirsutus*	Moraceae	V/G	SW.G	M	T
206	*Acampe praemorsa*	Orchidaceae	-	-	M	H
207	*Dendrobium aphyllum*	Orchidaceae	-	-	M	H
208	*Luisia tristis*	Orchidaceae	-	-	-	H
209	*Nervilia aragoana*	Orchidaceae	V/K	-	M	H
210	*Curcuma amada* var. *amada*	Zingiberaceae	-	I	M	H
211	*Curcuma ecalcarata*	Zingiberaceae	-	W.G	M	H
212	*Zingiber nimmonii*	Zingiberaceae	-	W.G	M	H
213	*Zingiber zerumbet*	Zingiberaceae	-	-	M	H
214	*Costus speciosus*	Costaceae	-	-	M	H
215	*Smilax zeylanica*	Smilacaceae	V/K	-	M	C
216	*Curculigo orchioides*	Hypoxidaceae	-	-	M	H
217	*Molineria trichocarpa*	Hypoxidaceae	-	-	M	H
218	*Monochoria vaginalis*	Pontederiaceae	-	-	M	H
219	*Floscopa scandens*	Commelinaceae	-	-	M	H
220	*Caryota urens*	Arecaceae	-	-	M	T
221	*Cocos nucifera*	Arecaceae	-	-	M	T
222	*Corypha umbraculifera*	Arecaceae	DD	-	M	T
223	*Acorus calamus*	Araceae	EN/K	-	M	H
224	*Amorphophallus commutatus* var.*commutatus*	Araceae	V/G	W.G	M	H
225	*Amorphophallus nicolsonianus*	Araceae	-	SW.G(K)	M	H
226	*Anaphyllum wightii*	Araceae	NT	SW.G	M	H
227	*Colocasia esculenta*	Araceae	-	-	M	H
228	*Lagenandra meeboldii*	Araceae	-	W.G	M	H
229	*Pistia stratiotes*	Araceae	-	-	M	H
230	*Pothos scandens*	Araceae	-	-	M	C
231	*Typhonium roxburghii*	Araceae	-	-	M	H
232	*Cyperus bulbosus*	Cyperaceae	-	-		H
233	*Cyperus haspan*	Cyperaceae	-	-	M	H
234	*Hypolytrum nemorum*	Cyperaceae	-	-	-	H
235	*Kyllinga nemoralis*	Cyperaceae	-	-	M	H
236	*Scleria laevis*	Cyperaceae	-	-	M	H
237	*Bambusa bambos*	Poaceae	-	-	M	S
238	*Centotheca lappacea*	Poaceae	-	-	M	H
239	*Coix-lacryma-jobi*	Poaceae	-	-	M	H

Table 1. Contd.

240	*Cynodon dactylon*	Poaceae	-	-	M	H
241	*Dendrocalamus strictus*	Poaceae	-	-	M	S
242	*Digitaria radicosa*	Poaceae	-	-	-	H
243	*Ischaemum tumidum* var. *calicutensis*	Poaceae	-	S.I (K)	-	H
244	*Paspalidium geminatum*	Poaceae	-	-	-	H
245	*Pennisetum pedicellatum*	Poaceae	-	-	-	H

Cons. St., Conservation status; End. St., endemic status; MS, medicinal status; M, medicinal; C, climber; H, herb; S, shrub; T, tree; I, India; P.I., Peninsular India; S.I(K), South India, Kerala; SW.G, Southern Western Ghats; SW.G(K), Southern Western Ghats, Kerala; W.G, Western Ghats; DD, data deficient; EN, endangered; EN/K, endangered, Kerala; EN/Cr/G, critically Endangered, Globally; EN/Cr/K – Critically Endangered, Kerala; LC/K – Least Concern, Kerala; LR-NT – Low Risk, Near threatened; NE/K, not evaluated, Kerala; NT, near threatened; NT/K, near threatened, Kerala; V, vulnerable; V/G, vulnerable, globally; V/K, vulnerable, Kerala.

and 44 climbers. Among these species, 44 are endemics out of which 16 are endemic to Southern Western Ghats, 3 are endemic to Southern Western Ghats (Kerala), 13 are endemic to Western Ghats, 9 are endemic to Peninsular India and 2 are endemic to India and 1 is endemic to South India (Kerala). There were 34 threatened plants listed, out of which 3 are Critically Endangered, 5 Endangered and 4 Near Threatened, 1 is at Low Risk and Near Threatened, 16 are Vulnerable and 3 are with Data-Deficient status. Species with not evaluated and least concern status were also listed. Endemic plants like *Sonerila rheedei*, *Litsea ghatica, Lagenandra meeboldii*, *Ischaemum tumidum* var. *calicutensis*, threatened and endemic plants like *Anaphyllum wightii* and *Kunstleria keralensis* and *Acorus calamus* with endangered status were recorded. *Myristica* swamps having dense prominent stilt and breathing roots represented mainly by *Gymnacranthera farquhariana* and the endemic and threatened species *Myristica fatua* var. *magnifica* and *M. malabarica* were also recorded from this sacred grove. Out of the 245 species listed from this grove, 236 are medicinal constituting 96% of the flowering plants reported from this sacred grove.

Conflict of Interests

The authors have not declared any conflict of interests.

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