A spatial analysis of plant biodiversity in the forest homegardens across an agro-climatic gradient in the Western Ghats of Karnataka, India

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Abstract:

Tropical Forest Homegardens (FHG) are crop systems based on the combination of woody and herbaceous species, generating diverse productions mainly for farmer's subsistence. This study was performed on 40 FHG, in Uttara Kannada district in Karnataka and attempted to describe HG through an agro-climatic gradient in the Western Ghats. Within the study area, three geographical subunits (Coast, Ghats, and Edge of the Ghats) were identified from precipitation and altitude data. A total of 319 plant species where encountered in the Forest Homegardens from which 303 were found in the Homegardens and 126 in Areca Orchards. The coastal zone is characterized with smaller FHG and less Areca Orchards than in the two other zones. Besides this, a richness and diversity (Shannon-Weaver) gradient was found from the coast to the edge of the Ghats. The similarity in composition of species, measured by Sorensen index, was greater between the Edge of the Ghats and the Ghats than between these two and the coastal zone. In addition to the fact that the small FHG have higher species density it seems that when the farmers are vegetarians, densities are even larger.

Keywords: Homegardens, diversity indices, agrobiodiversity, Uttara Kannada, Western Ghats

Résumé :

Les Jardins Agroforestiers (JAF) sont des systèmes de cultures tropicaux basés sur l'association d'espèces ligneuses et herbacées, générant des productions variées majoritairement à destination de l'autoconsommation. L'étude qui suit a été réalisée sur 40 JAF, dans le district de l'Uttara Kannada de l'Etat du Karnataka et a pour but de brosser le portrait des JAF au travers d'un gradient agroclimatique dans la chaine de montagne des Ghâts. Au sein de la zone d'étude, trois sous-unités géographiques (Côte, Ghâts, Est des Ghâts) ont été définis à partir des données de précipitations et d'altitudes. Un total de 319 espèces de plantes a été rencontré dans les JAF dont 303 ont été retrouvées dans les jardins d'habitations et 126 dans les plantations d'aréquiers. La zone côtière se distingue par des JAF de plus petite taille et moins de plantations d'aréquiers que dans les deux autres zones. En parallèle, un gradient de richesse et de diversité spécifique a été mis en évidence depuis la zone côtière jusqu'à la bordure Est de Ghâts. La similarité de composition spécifique, mesuré par l'indice de Sorensen, est plus grande entre la zone Est des Ghâts et celle des Ghâts qu'entre ces dernières et la zone côtière. Outre le fait que les JAF de plus petite taille présentent une densité d'espèces plus importante il semble que, lorsque les exploitants sont végétariens, les densités seront d'autant plus grandes.

Mots clés : Jardins Agroforestiers, indices de diversité, agrobiodiversité, Uttara Kannada, Ghâts occidentaux

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I really hope that this work will be useful for the Vanastree members and the ecoinformatic research team and that it will initiate further investigation on the topic.

To my parents

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Abbreviations:

FHG: Forest Homegarden

HG : Homegarden

OR : Areca nut Orchards

Brahmin : Havyaka Brahmins caste

GSB : Gaur Saraswat Brahmins caste

SC : Scheduled Caste

ST : Scheduled Tribe

SOC :Soil Organic Carbon

PCA : Principal component analysis

UK :Uttara Kannada district

Glossary:

District : Administrative division of the Indian states .

Taluk : Administrative division of the districts

Gram panchâyat : Administrative division of the Taluks

Introduction

The Western Ghats is a chain of mountains that lies along the western coast of the Indian peninsula at 30 to 80 kilometres from the Arabian Sea. With an average height of 1500 this chain of mountains, stretches on 1600 km from the North to the South through the state of Maharashtra, Goa, Karnataka, Kerala and Tamil Nadu (Nayar, 2011).

The Western Ghats form a physical barrier on which the southwest winds, bringing the monsoon, are colliding. Thus, on the coastal plains it is possible to observe an annual rainfall of about 5000 mm. These can even be higher on the foothills. On the other hand precipitations in the eastern side of the chain, on the Deccan Plateau, are smaller and do not exceed 1000 mm . Although the climate of the region is mainly characterized by a rainfall gradient from west to east, it is also possible to see that the arrival and removal dates of the monsoon are a function of the latitude. Indeed at Cape Comorin (southern tip of the peninsula) monsoon arrives late May and withdrew early December while at the latitude of Mumbai rains begin mid-June and will stop at the end of September. Moreover, it is also reported a precipitation gradient in the western Ghats related to elevation (Pelissier, 1995).

In this extremely diversified physical environment, production systems called forest homegardens (FHG) have been developed. They are characterized by their small size, their proximity to homes and a high number of crops generating diversified productions for self-consumption. The arrangement of Forest Homegarden is complex and usually involves different production units as well as several layers of vegetation. Currently, in the context of an increasing awareness on the impacts of human activities on the environment, including the erosion of biodiversity, these traditional farming systems seem to be able to provide solutions for sustainability.

The aim following study is to provide a picture of forest homegarden through an agro-climatic gradient in the Western Ghats of Karnataka. A special attention will be given to the characterization of plant agrobiodiversity in these production systems as well as the latter's relationship with food security. To begin with we will define the biological specificity of the Western Ghats and on the characteristics of forest homegardens. Then, we will present the objectives and hypotheses of the investigation conducted in the Uttara Kannada district in the state of Karnataka. This will be followed by a description of the materials and methods used and the results of the investigation. We will concluded by highlighting the most important results and their perspectives.

I. The Western Ghats: a biodiversity hotspot

Developed for the first time in 1988 by the British ecologist Norman Myers, the aim of the defining biodiversity hotspots in the world is to protect areas with both an exceptional concentration of endemic species but also a significant loss of habitats (Myers et al., 2000).

More precisely to be qualified as a hotspot the area must have at least 1500 endemic vascular plants, that is to say 0.5% of the total number of species in the world and must have lost more than 70% of the initial habitat. In 2004, 34 hotspots were defined in the world. Thus, Western Ghats together with Sri Lanka is part of one of them (**Figure 1**). Initially the area covered nearly 189611 km^2 of vegetation against 43611 km^2 nowadays. This area is home to 5916 species of plants and 51% of them are endemic to this region. Moreover among the 650 tree species that can be found in the western Ghats 352 species (54%) are endemic (Bawa et al., 2007; Nayar, 2011).

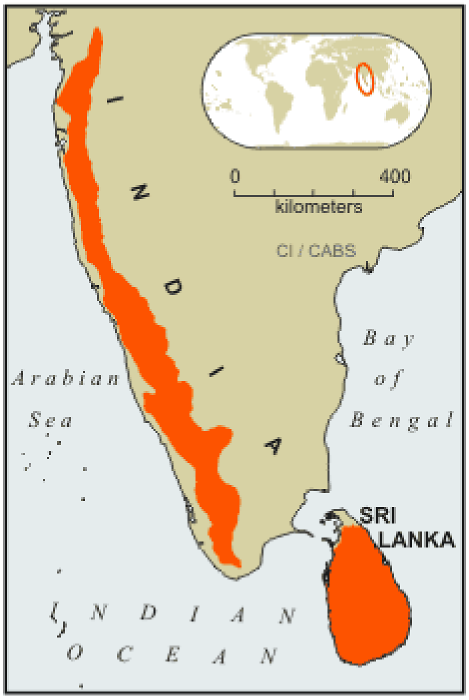

Figure 1 : Map of the area classified as a biodiversity hotspot (www.conservation.org)

Moreover, the plant diversity of this area is also associated with an incredible animal diversity. Indeed, it has been documented more than 140 species of mammals (12.9% endemic), 458 species of birds (7.6% of endemism). The maximum rate of endemism is reached by the 178 amphibian species with 73% of endemism. Thus, recently a new family of frogs has been identified in this unique region (Conservation International, 2013). There are various factors that are potentially explaining the biological and ecological characteristic of the Western Ghats. Given the high heterogeneity in the topography, the climate and soils in this region, this would have allowed the development of species with different needs. Moreover, in the past this area would have been geographically isolated from the arrival of new species coming from the Himalayan region (Gadgil et al., 2011; Nayar, 2011).

Later we will see that this unique area also has an extraordinary diversity of cultivated plants that are economically essential for local populations. This biological diversity seems concomitant with the richness of human cultures and traditions.

II. Agroforestry practices in the Western Ghats

II.1. Agrobiodiversity in the Ghats

Within the exceptional biodiversity in the Ghats, it is possible to define a subset of species that constitute the agrobiodiversity. The broadest definitions of agrobiodiversity would include all components of biodiversity (animals, plants and microorganisms) that promotes agricultural and food production. This term covers the diversity of ecosystems, as well as intra-and inter-specific diversity (FAO, 2004; Thrupp, 2000).

Given the extent of this definition we will only focus on the part of the plant agrobiodiversity directly used by farmers to meet their needs. However it is important to note that in many cases, Ghats's farms have an animal production (dairy cattle, poultry, etc...) that are essential for meeting the food needs of the family.

To illustrate the importance of agrobiodiversity in the Ghats, we will focus on examples taken from the state of Kerala. In fact in the Ghats, Kerala contributes largely to the total biodiversity, including agricultural biodiversity. The role of agriculture in the state of Kerala is predominant. Nearly 2.13 million ha are dedicated to this activity, which represent 54.8 % of the total area of the state. On farmland 142 species belonging to 104 genera and 43 different families have been identified (Nayar, 2011). Many of the agricultural production systems are based on a combination of various plant species, giving them a strong agro-biodiversity. A study conducted in the center of the state, revealed that a total of 127 different species were grown. These species were classified into 10 categories according to their uses: basic food, fruits and nuts, beverages and stimulants, spices, timber, firewood, ornamental plants, multipurpose timber medicinal plants, and practices related to coconuts or rubber. The average number of species per farm ranges from 34 to 38 with species densities included between 4.9 and 5.5 species/100m^2. However, it is important to emphasize the heterogeneity of occurrence frequency of species. It seems that the coconut (*Cocos nucifera L.*) and banana trees (*Musa spp.*) were found in all farms. In addition, papaya trees (*Carica papaya L.*) were found in 88% of the farms, areca palm (*Areca catechu L.*) in 81 %, mango trees (*Mangifera indica L.*) in 78 %, jackfruits (*Artocarpus heterophyllus Lam.*) and cassava (*Manihot esculenta Crantz.*) in 56%, and cocoa (*Theobroma cacao L.*) in 13 % (Mohan, 2004). The Farm Information Bureau of Kerala has identified the 25 classes of most common cropping systems. These classes include monoculture systems such as rice, coconut, rubber, and coffee but can also be more complex and diverse as the association Coconut - Arecanut - Cashew (*Anacardium occidentale L.*) - fruit trees - black pepper (*Piper nigrum L.*). However among these 25 cropping systems 17 include Coconuts (Nayar, 2011).

Despite a wide variety of crops and used plants nowadays it was nevertheless possible to observe a simplification of cropping systems in the recent years. Actually there has been a decrease in the total number of species and an increase in cash crops. Farms also tend to be expanded and plantations are increasingly arranged into rows (Nair and Sreedharan, 1986; Peyre et al., 2006).

II.2. The forest Homegarden definition

In the Ghats, as well as in other tropical regions of the world, it is often reported the existence of production systems with particular characteristics. These systems are called “Homegardens”. Since these production systems present a high variability between regions and over the time, it is relatively difficult to find an accurate definition in the literature. However, the following definition allows us to better understand the characteristics of these "gardens". These agroforestry systems are intensively managed and located near the farmer’s home. These systems results from a deliberate association of multipurpose trees, shrubs and herbaceous plants (annual and/or perennial) and in some cases with livestock (Mohan, 2004). Most of the time these production systems are small and have a high proportion of the productions dedicated to self-sufficiency (Mohan et al., 2007). In his agroforestry systems classification Torquebiau (2000) prefers to use the term “forest-gardens” or “agroforestry homegardens” to avoid the eventual confusions, especially with domestic gardens for vegetables. Thereafter we will use the term forest homegarden or the abbreviation FHG to refer to these cropping systems.

II.3. Forest homegarden spatio-temporal characteristics.

As noted above, by lack of literature in other states, the later examples of Kerala FHG will be used to describe the logical structure of these traditional farming systems. Although at the first glance it seems that the FHG have any structuration, a closer examination shows that the cultivated species are not planted randomly. Thus it has been reported that each species had a well-defined place in order to optimize the use of space. First, it is possible to distinguish a multi- layered configuration of the canopy. In the study of Jose and Shanmugaratnam (1993) almost all FHG have 3 to 4 vegetation layers. Indeed, up to 2 metres high the plants that can be found include vegetables, tubers and other herbaceous plants. The second layer between 2 to 10 m, is characterized by the banana, papaya, cocoa or mango leaves. The top vegetation layer, between 10 and 25 m, consists of coconut, areca or even jackfruit. However, it is interesting to note that in the lower levels of vegetation it is possible to see young trees that will later occupy the upper floors. Thus all these results reflect a vertical and temporal organisation of the production.

In addition, FHG also have a horizontal structure. Most of the time the coconut trees, generally spaced by 7.5 m, are determining the basic line structure of these gardens (**Figure 2**). Then other species are placed around coconuts. Thus, cocoa trees are usually planted in the center of four coconuts. Creeper plants such as black pepper, yams, or beans are planted at the foot of the coconut trees, their trunks forming a support for their development. We can also see similar patterns in areca orchards. Smaller trees and ornamental plants are usually planted near the house whereas the trees with large canopies will be placed in the margins of the farm.

Most of the time brighter parts in the garden are maintained and used to grow annual crops (*Amorphophallus sp. Colocasia sp*, cassava, vegetables) because of their larger light requirements. Given that Bananas are more shade-tolerant, they will be planted wherever there is space (Jose and Shanmugaratnam, 1993).

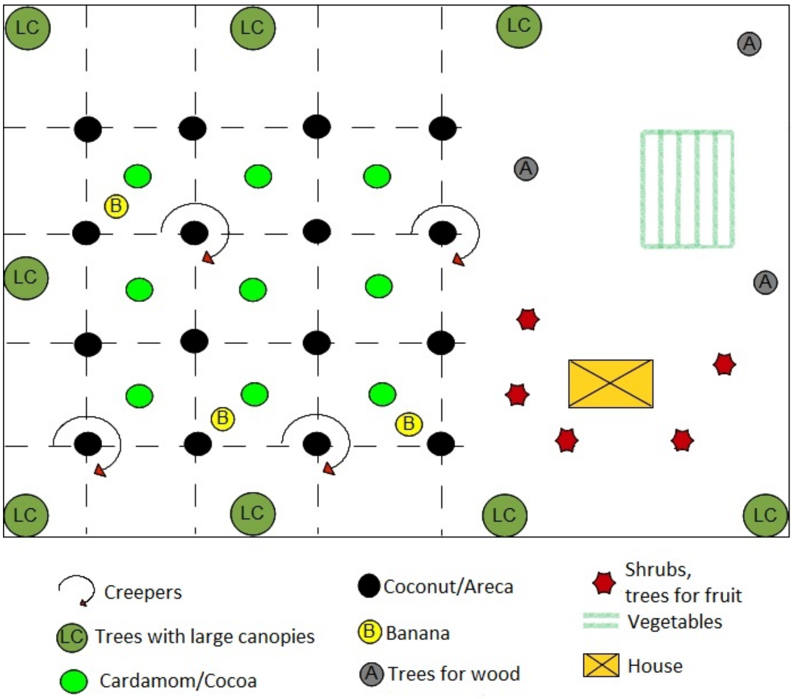

Figure 2 : Mapping of an agroforestry garden according to Jose and Shanmugaratnam, 1993

In some areas the horizontal differentiation leads to distinguish different production units within agroforestry farms. By taking examples from farms in the state of Karnataka, sometimes areca orchards are spatially separated from the other production areas surrounding the house. Since areca trees have significant water needs, it is common to see these orchards in the low lands most of the time near the paddy fields (Ranganathan et al., 2008). In addition, there is a production unit called “Soppina betta” or “Betta”, meaning forest of leaves. These “Bettas” are patches of forest that have been assigned by the State of Karnataka to farmers in possession of areca orchards in order to facilitate the productions. These lands are a source of leaves which is essential to improve soil fertility in plantations. Farmers also have the right to cultivate a certain number of species (black pepper, areca, cashew, ...) and to enjoy the productions for their own consumption of the species from defined list (Government of Karnataka, 1976; Nayak et al., 2000).

Given the main role of trees in these production systems, the management of the evolution in time of plant communities plays a fundamental role. FHG begins in a particular stage of the natural succession possess and will be guided by farmers in order to meet their needs from one season to another and over the years. Human intervention consists in the promotion of the installation of a plant association by selecting species that are naturally growing on the farm or by the implantation of species adapted to the environmental conditions occurring on the farm. Ultimately, the management lead to the establishment of a dynamic stage of development with a so-called "climax" (**Figure 3**) plant community. During the early years, while the trees such as coconut are growing, plants with greater light requirements are being cultivated. Thereafter, when the shadow will be more present because of the trees development, farmers will grow in the lower layers plants with smaller light requirements. Ideally, the dynamic equilibrium will be achieved by managing “the future” “present” and “ past” trees (Jose and Shanmugaratnam, 1993; Mohan et al., 2007).

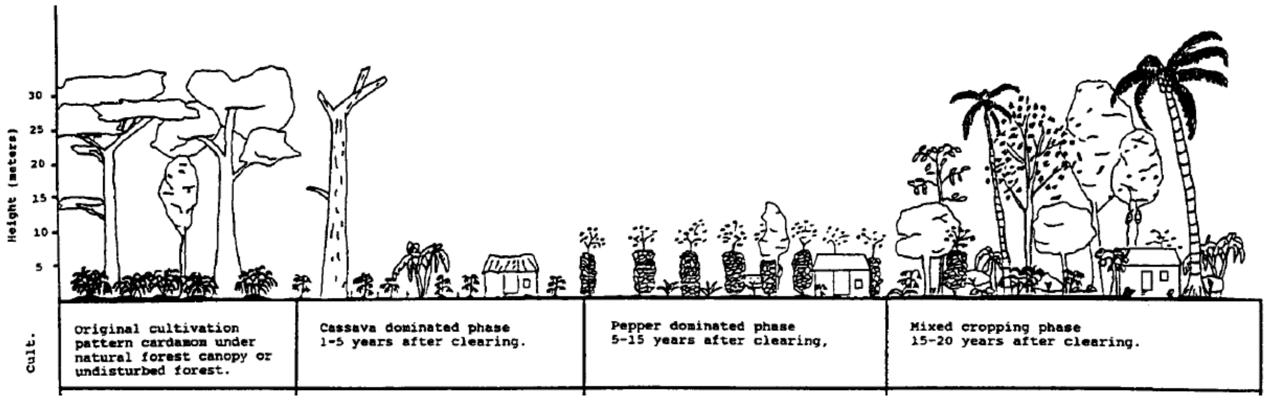

Figure 3 : Schematic view of the establishment of an forest homegarden in the state of Kerala (Moench, 1991)

Nevertheless, it is important to remind that this model of FHG is not static and changes over the years. Indeed, we recently witnessed a simplification and homogenisation of crop systems, shifting from a subsistence agriculture to market a agriculture. However there is more than one way to achieve this transition and some of them seem to be more sustainable than the others (Peyre et al., 2006).

III. The importance of forest homegardens for food security

III.1. Definition of the food security

According to the “World food summit plan” FAO (1996) Food security is reached when people at any time, have physical and economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences and this for an active lifestyle. Four fundamental pillars determine the framework of food security: food availability, stability of food supply, food access and food utilization for a given person (In Magcale-Macandog et al., 2010). As part of this we will try to get some thoughts on the relationship between food security and agrobiodiversity at the farms scale.

III.2. The Relationships between food security and the forest homegarden characteristics

III.2.1. The Size of forest homegardens: a major determinant

As explained above one of the criteria used to define the concept of "homegardens" is the small size of these production systems. This is particularly true in the area of the Western Ghats. Indeed, in the state of Kerala, the average farm size is 0.27 ha. It was also reported that nearly 53% of the 5.9 million farms in this state had an area of less than 1 ha (Nayar 2011). This proportion is even higher in Uttara Kannada district of Karnataka state, where more than 70% of farms appear to have less than 1 ha (Government of Karnataka, 2013).

Given the constraint that can represent a limited access to land for the farmers, many investigations have been conducted to characterize what is the effect of farm size on the management of the crop system in order to better understand and answer to food security and sustainability issues. Given the average size of FHG, in most of these studies it is considered that farms of more than 1 ha are already "large" or called "commercial". The term "small FHG" is general used when lands do not exceed more than 0.40 ha, although this definition depends of the authors (Kumar, 2011; Mohan et al., 2006, 2007; Saha et al., 2009; Vlkova et al., 2011).

In Kerala, it has been revealed that the densities of plants (herbs + shrubs + trees) and trees were greater in the small FHG than in the large ones. This decrease depending on the size of the farm can be interpreted as the result of the adoption of another cropping systems management by the farmers. In order to generate sufficient income to support their needs, farmers with smaller FHG will be forced to adopt a more intensive management by increasing the density of the plantations that is to say the number of individuals per area unit.

In the same study it is also highlighted that there is a greater density of different species in smaller FHG. Thus, species richness densities decrease (number of species. ha^{-1}) depending on the size of FHG has been determined as following a negative exponential function (**Figure 4**). However it is important to note that the total species richness tends to increase slightly with the size of the farms. Species diversity is, in turn, higher in smaller FHG. It seems that the size of FHG affects even more specific abundance rather than species richness. These results could be explained by the desire of farmers having less land to ensure maximum availability of different crops (richness) and as balanced as possible in terms of quantity (diversity) for their own consumption (Kumar, 2011; Vlkova et al., 2011).

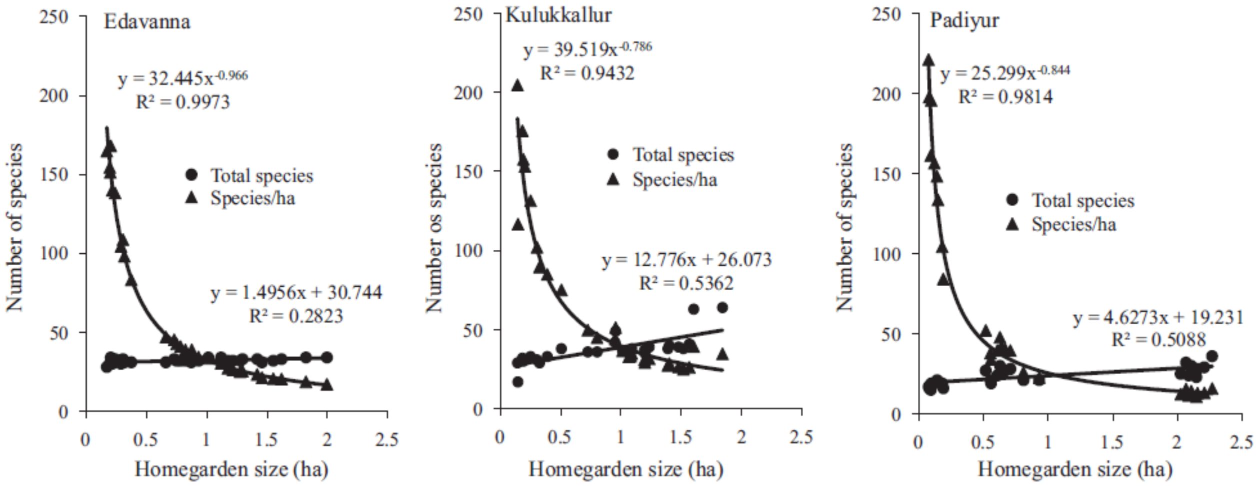

Figure 4 : Specific richness (herbs + shrubs+ trees) as a function of FHG size in three different taluks in the state of Kerala (Kumar 2011).

To provide a more thorough analysis on the specific composition present on farms, many authors agree that there are strong similarities between the different farms and this irrespective of their sizes. Indeed, the similarity of composition, estimated with the Sorenson index, may reach in some cases up to 90% of common species between FHG (Mohan et al., 2007; Saha et al., 2009; Vlkova et al., 2011). Nevertheless, through the Importance Value Index (IVI) aggregating both the relative frequency , relative density and relative dominance of species, it has been shown that the plant category of "vegetable-medicinal-ornamental" was more agroecologicaly important in small FHG. One of the reasons that could be advanced is the fact these plants are mainly grown for home self-consumption and are thus even more essential for small production units. In contrast, spice trees seemed to be more important in large FHG (Mohan et al., 2007). Profit and economic dominance analysis of crops have shown that economically important plants were also agro-ecologically dominant in the farms.

A gross margins (Incomes-operating expenses) comparison between different FHG size classes showed that small farms generate higher margins per area unit (80.28 Rupees/m^2 against 40.6 Rupees/m^2 for large FHG). However, the total profit of large farms is greater than smaller FHG. It should be noted that in large FHG the abundance of ornamental and wild plants is higher and it is more difficult to assess the incomes that these plants are generating but they still remain important for farmers. In the same study it was determined that the species most contributing to the farm profit are coconuts, areca and banana. Unlike small farms with nearly 50 % of the production dedicated to self-consumption, the larger FHG seem to invest more in these three species. By carrying out a sensitivity analysis, simulating a price decrease of these three species or the increase of labour costs, it has been shown that the economy of large FHG was more affected than smaller ones. This result highlights the fact that the farm economy resilience to market disturbances is dependent on the richness and diversity of species and that resilience decreases with farm size (Mohan et al., 2006).

III.2.2. The role of plant density and species richness in soil fertility

As outlined above smaller FHG farmers will have a more intensive management of the production system. It is characterized by the presence of a greater plant density (herb + shrub + tree) and tree density (number of individuals.ha -1) but also species densities (number of individuals.species^{-1}.ha^{-1}). Studies aimed to highlight the relationship between plant diversity and the amount of soil organic carbon, have shown that sequestration is a function of plant density and species density occurring on these farms. Thus the higher the species density the greater the organic carbon in the first meter of soil will be. By the way no statistical difference could be detected on the effect of plant density (grass + shrub + tree). Unlike this tree density has a positive effect on the accumulation of organic carbon in soil, while the species density of tree seems to have no effect. If we consider the total species richness, as measured by the Margalef index, it has been observed that the FHG with higher species richness also have larger amounts of organic carbon in the top 50 cm of soil (**Figure 5**)(Saha et al., 2009).

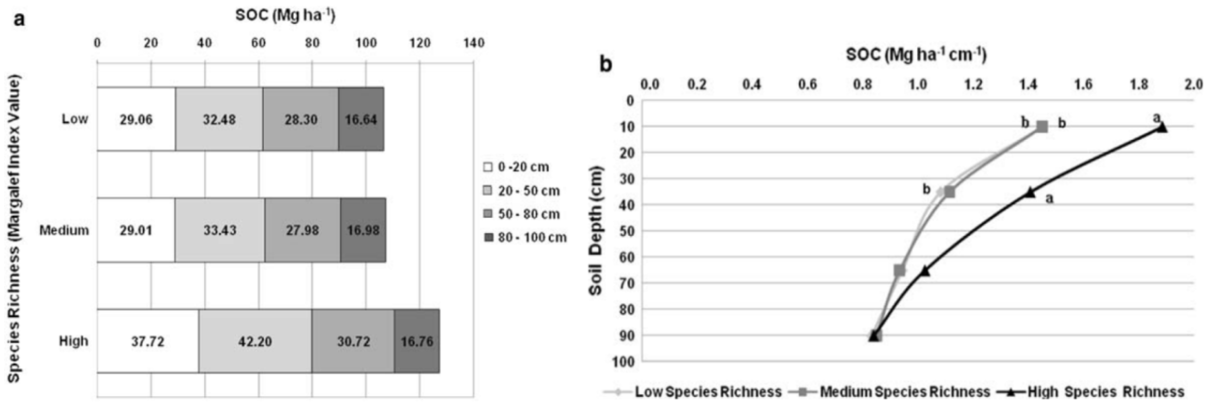

Figure 5 : Soil organic carbon (SOC) content across soil depths in homegardens with different species richness in Thrissur District, Kerala,India. a) Soil organic carbon in mg.ha^{-1}, b) Soil organic carbon in mg.ha^{-1}.cm^{-1} for a given depth class. depth indicated is the mid-point of the sampled depth. Species Richness classes are based on Margalef Index values (MI): low (<5.2), medium (5.2 to 6) High (> 6). The letters a and b indicate statistically significant difference (P> 0.05) between the values of soil organic carbon of different species richness classes for each (Saha et al., 2009).

One interpretation that could be stated to explain these results is that the use of resources (light, nutrients) would be more complete if the number of species included in the system is important. Therefore this would lead to an improvement of the primary production and by the way a better carbon sequestration in the soil. Organic matter will be accumulated in the upper layers of soil in the one hand because of the accumulation of litter on the overground, and on the other hand by the presence of higher roots density in these horizons.

All these results have strong implications for the management of fertilization and irrigation. Indeed, it is well recognized that the soil organic matter is one of the main drivers entering into account in fertility. Actually, this organic matter will induce biological activity in the soil. In fact, the diversity of live activities and micro-organisms will affect the major nutrients dynamics and bioavailability for crops. In addition, one of the characteristics of the organic matter will also be an improvement of soil aggregates structuration, thereby changing the physical properties of the soil. The soil structure stabilization will provide greater resistance to erosion caused by water or wind (Robert, 2002). In addition, the soil organic carbon content is known to play a fundamental role in the water retention capacity of soils (Hassan, 2008).

However, it is important to remind that the soil organic fertility not only depends on the amount of organic matter but also on the quality of the latter. Plant species generating the litter will give physicochemical characteristics to the organic matter and that will in turn affect the decomposition in the soil. It has been highlighted that the lignin and polyphenols rate in the litter, which depends of the biochemical composition of plant species, will slow down and stabilizes their decomposition. This arises from the lignin resistance to enzymatic attacks. It can also create a physical interference for the degradation of the whole litter and is supposed to improve the carbon stabilization. For example, litter from tree species such as *Mangifera indica L.* (Mango), *Arthocarpus heterophyllus* (jackfruit), or *Anacardium occidentale L.* (cashew) have a relatively rapid decomposition, thus promoting a better mineral recycling. In opposition to these species *Ailanthus triphysa Dennst.*, *Artocarpus hirsutus L.* and *Swietenia macrophylla* (mahogany) will produce woody and less labile litter, thus accumulating in the soil. The latter litter, more persistent, can be used to make mulch (Isaac and Nair, 2006).

III.2.3. The relationship between species richness and food security

As we have noticed earlier, FHG have strong similarities in terms of species composition by the willingness of farmers to have a maximum number of species and by the way a high diversity of productions reported that fruits coming from crops and fruit trees represent a secondary source of food which is essential during the lean months. We can give the example of fruit trees such as jackfruit, coconut trees, mango and avocado which fruits are an additional source of nutrients during the April-May and December-January periods. So while waiting for the harvest of the main crops (rice, maize) these products are essential during the summer months , during which food is lacking (Magcale-Macandog et al., 2010). It appears that cassava is in these periods, a good substitute for rice or corn. Similar observations have been made in studies carried out on FHG in Kerala (Mohan et al., 2006). The diversity of plants and trees grown on the farm also allow the farmers to produce food and incomes all over the year. In the case of tree productions (fruits, timber, fire wood or construction wood), it happens that the productions are sold in local markets and thus represent an additional source of income which can be better distributed in the year (Magcale-Macandog et al., 2010).

Compared to corn monoculture systems, it has been determined that agroforestry systems increase the total profits of farms from 43 to 137%. This result can be explained by the improvement of nutrient and water cycling and better light capture. In addition, crop yields would also be more stable from one year to another. Agroforestry systems seem to be the place of positive interactions between the different crops, thus ensuring higher total productivity. Moreover, the product diversity provides greater resilience of these systems to market fluctuations and climatic hazards (Magcale-Macandog et al., 2010; Mohan et al., 2006; Thrupp, 2000).

Note, that the high level of plant diversity found in these farms plays a fundamental role in wildlife conservation. To illustrate this we can take the example of areca orchards in the Western Ghats. Indeed, these plantations, known for their significant crop richness, also host a remarkable diversity of wild birds. It is possible to observe in these plantations nearly 90% of the birds species found in the surrounding native forests. Birds species richness has to be related to the vertical structure complexity of these plantations (Ranganathan et al., 2008).

In turn, native species diversity conservation is also a potential source of ecosystem services and benefits that could help to increase agricultural production. Through its activity, biodiversity will be responsible for the realisation of ecosystem processes and functions such as the primary production process or the function of nutrient cycling in the soil (Cardinale et al., 2012). These ecosystem functions will provide services and profits for farmers. The ecosystem services that may be mentioned are carbon sequestration, pollination or pest biological control by natural predators. In the previous example, the conservation of a wide diversity of birds allows a better regulation of insect pests but could also promote seed dispersal, which can be very helpful for farmers.

Thus the potential of agro-biodiversity conservation of FHG, especially small ones, can be in this sense a way to maintain a sustainable productivity and food security (Jose and Shanmugaratnam, 1993; Thrupp, 2000).

IV. Study objectives and hypotheses

The definition of the following project comes from a partnership between two organizations named Vanastree and ATREE (Ashoka Trust for Research in Ecology and the Environment).

Vanastree is a self-funded non-governmental organization; its main office is located in Sirsi in Uttara Kannada district in the heartland of the Western Ghats forest. The main aim of this organization is to promote food security and biodiversity conservation in farms. Literally “Vanastree“ means in the local language (Kannada) “women from the forests”. In fact, the philosophy of this organization is to improve the social network between farmers in the region but also to improve the awareness of the importance of the women role on farms. To achieve these goals, members of Vanastree are organizing local festivals and had set up a seed bank, which is on the one hand a way of crops genetic resources conservation while favouring on the other hand, the contact between the organization members. These meetings are also providing a great opportunity for members to exchange and sell their seeds, but also to share their traditional farming practices knowledge.

In addition to the seed bank Vanastree promotes, by these seed exchanges, an *in situ* conservation of seeds. So far the organization is composed of 150 women organized in about 20 seed groups, distributed in small villages in Sirsi’s neighbourhood. Thus, this project has been defined in order to document more precisely agrobiodiversity and agricultural practices on farms. Vanastree also seeks to better understand the link between agricultural biodiversity and farmer’s food security to improve the efficiency in their collective actions. According to previous observations made by Vanastree members it seems that farms in Uttara Kannada district have very different characteristics depending on their geographical location. This is probably linked to the high level of pedoclimatic but also social heterogeneity that can be found in the region. Currently very few studies have been conducted on this topic in Uttara Kannada. Therefore this work can be considered has a pilot-test to further investigations on some elements of the production systems. To achieve these objectives a partnership was been established with the eco-informatics department of ATREE.

ATREE is a research institute in the area of biodiversity conservation and sustainable development, with executive offices located in Bangalore. This institute was established to promote interdisciplinary and integrative approaches involving research, education, and policy management for the environment preservation. The aim of this research structure is to give answers on the conservation of biodiversity in relation to climate change and the desire to achieve a sustainable development. Therefore, through the creation of a biodiversity atlas in the state of Karnataka the data involving the plant species distribution present in Uttara Kannada farms will be used by ATREE.

The aim of the study is to document the spatial variability of the species composition and the characteristics of FHG through different geographic zones in Uttara Kannada district. In addition we will try to determine bioclimatic and social-economic factors that could cause any of these differences.

V. Material and methods

V.1. The study area

To investigate the spatial variability of the biodiversity occurring in the FHG of Uttara Kannada we chose an area oriented from west to east. This area was also defined because it spreads transversely to the mountain range of the Western Ghats and therefore involves various environmental conditions that may affect the presence or absence of crops. The exact definition of this area was performed with geo-localized data (annual rainfalls, altitude and soil types) by using the QuantumGIS software 1.8.0 (India Biodiversity Portal, 2008; QGIS Development Team 2013). First of all four GPS points were selected (P1 : (74.239088 , 14.655675) , P2 : (75.089088 , 14.805675) , P3 : (75.189088 , 14.505675) , P4 (74.389088 , 14.355675)) defining a striped study area, which is perpendicular to the annual isohyets lines and by the way to the ridge of the Ghats. This allowed us to define the northern and southern limits of the study area. The western and eastern boundaries were given by using the coastline on one side and the administrative boundary of the Uttara Kannada on the other side. Thereafter, the study area was divided into three sub-units. Since the water factor is a major element for crop productivity, we decided to define them based on the annual rainfall maps. To separate the coastal zone from the two other sub-units we also took into account the altitude. Thus, the three following subunits were defined: the coastal zone, the central zone the western Ghats and the last sub-unit on the eastern edge of the Ghats (**Figure 6**).

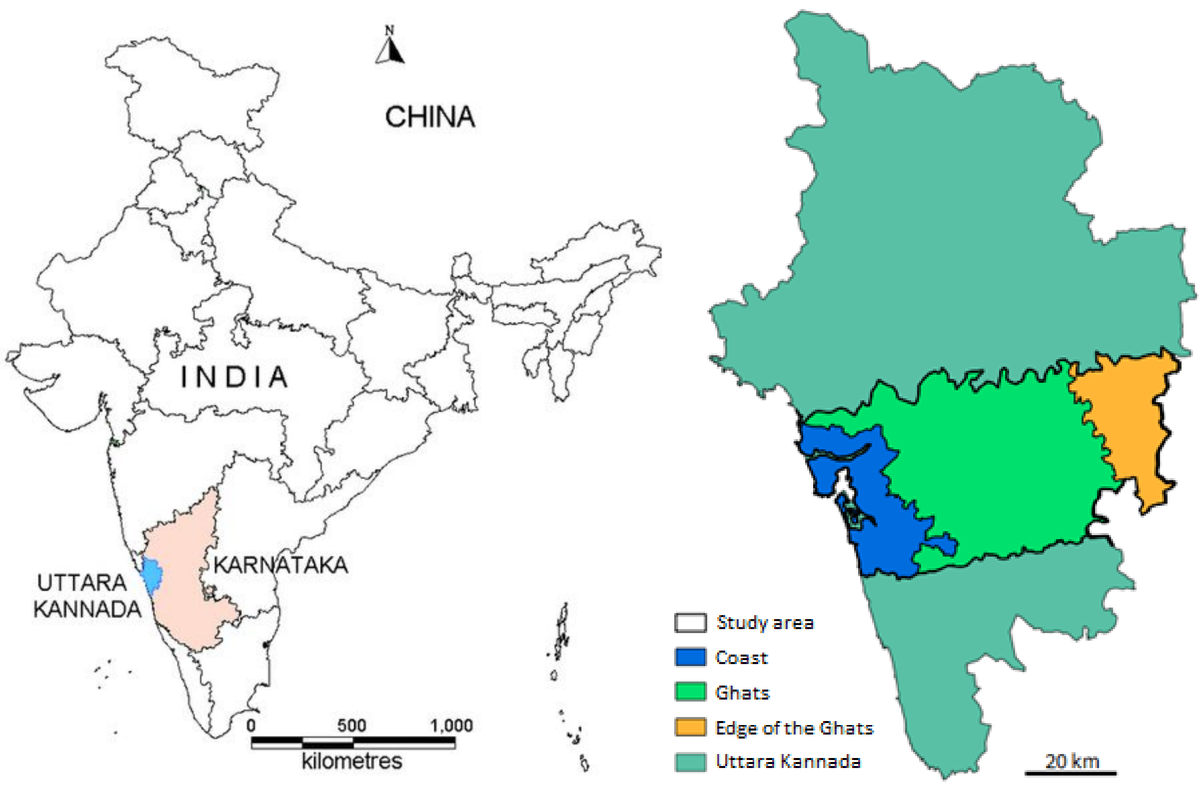

Figure 6 : On the left side: map of India highlighting Uttara Kannada district. On the right side: the study area according to the Gram Panchayat administrative division in Uttara Kannada district (Ramachandra et al., 2013).

Annual rainfalls in the coastal zone vary from 4000 to 3200 mm, in the central units of the Ghats from 3200 to 2400mm and in the Edge of the Ghats from 2400 to 1200mm. However, it is important to emphasize that the precipitation gradient is not isolated from the topography of the environment and also from the pedoclimatic factors. Indeed, soil types and temperature, can also forming gradients that may affect the presence and abundance of certain plant species on the farms. Thus, the western half of the study area has lateritic (Altisol) and coastal alluvial soils (Entisol) while the eastern zone is composed of red sandy soil (Alfisol) (See attached maps in the appendix).

V.2. Sampling of the Forest homegardens

V.2.1. Adjustment of the Forest homegarden definition

The first step of the sampling consisted in the implementation of a pilot-test including ten farms in the central zone of the Ghats. As mentioned by Ranganathan et al. (2008), it has been observed that in some cases the agroforestry farms have several subunits. Thus the first unit that have been identified was the areca orchards which are most of the time an association of many spice plant species. The second production unit consists of land close to homes with high plant biodiversity for food but also ornamental and medicinal purposes. Hereafter, this unit will be called “homegarden”. Moreover, some farmers arranged garden patches in their paddy fields for the vegetable production. These gardens are only temporary, as during the monsoon these fields will be fully used for paddy cultivation. Generally these “temporary gardens” are complementary to the vegetable production of the “Homegarden”. In most of the time the “temporary garden” and the “homegarden” are not considered as two different entities for farmers. In addition, the units called “Soppina betta” that have already been mentioned above, were also present on some farms. Nevertheless it is important to note that this complete production mosaic has not always been distinguished.

In the light of these preliminary results, it has been decided to analyse separately the “areca orchards” and "homegardens”. By taking into account the farmer’s remarks, "temporary gardens" have been included in the “homegardens”, thus considered as a single unit. This separation between homegardens and areca plantations still let us the freedom to gather them subsequently in global analyses of “Forest homegardens” (FHG).

Besides the small patches of temporary gardens, paddy fields were not taken into account in the analysis. It is the same for “Soppina betta” because on one hand the land does not belong to the farmers and secondly they do not have the free will to cut some tree species.

V.2.2. The Farm selection

The first step was the establishment of a list of farms as greatest as possible. To realise this, we used Vanastree’s contact list. This database, collected over ten years, including both Vanastree members but also those farmers that have ever been in direct or indirect contact with this organization. Thus Vanastree contacts on the coast provided us the addresses of farmers that had never been in contact with the organization formerly. Finally, the complete list was composed of 146 farmer addresses spread over 37 villages in the study area.

Given that the three study areas have different sizes and have a different number of farms, it would have been interesting to apply a proportional stratified random sampling over areas. However the only Vanastree list did not allow us to access the total number of holdings in each of these three areas. It was therefore impossible to make a stratified random sampling based on the number of farms in the three areas. Given that the aim of our study was to document and analyse biodiversity in a west-east gradient within the limits of time and the available data, the chosen method for our sampling was to select villages where we had contacts while best crisscrossing inside the three subunits of the study area.

By Assuming that the larger the study zone the more we can expect having strong variability in our samples, we decided to choose the total number of farms in each zones in proportion to their surfaces. Since we only had nine weeks (until 4/22/13 15/06/13) of fieldwork, due to the arrival of the monsoon, we decided to sample 40 farms. By using the QGIS software it was estimated that the coastal zone accounted for nearly 18% of the study area, the central zone of the Ghats for 65% and 17% for the eastern edge of the Ghats. Therefore the number of farms to sample in each of these three subunits was 7 farms on the coast, 26 in the central Ghats and 7 in the eastern zone. To reduce the risk of uneven spatial distribution we first randomly chose the villages and within selected villages we picked out randomly two farms whenever it was possible. In fact in some cases there was only one farm in the selected village list and in other cases the farmers were not available for an interview (**Figure 7**).

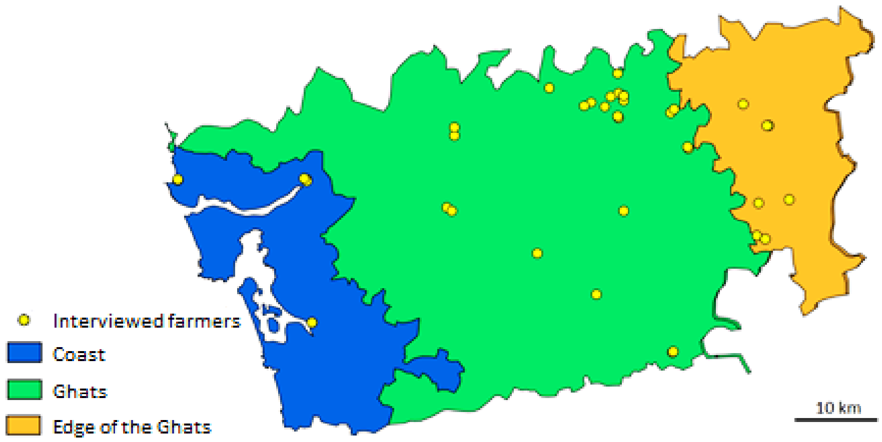

Figure 7 : Map of the sampling spatial distribution in the study area.

V.2.3. The forest homegardens selection criteria and the data collection

Since FHG are characterized by small production units, we selected the farms having less than 3 acres(1.21 ha), including “homegarden” and “areca orchards” whenever these two production units were spatially separated. According to the literature, the large farms seem to lose their high biodiversity characteristics with more cash crops and therefore fewer crops for self consumption. (Kumar, 2011; Mohan et al., 2006, 2007).

Once the farms were selected we conducted the interviews in two major steps. The first step was to define with farmer's help the limits of their homegardens and areca orchards. In the given limits of the production units, we began the identification all the species used by farmers from one corner to the opposite one by criss-crossing in-between. These species represent all the plants that are not considered as weeds by farmers, and that they wanted to keep. However, species only used as ornamental plants or religious purposes were not taken into account. Indeed, despite the importance of these plants on farms, this decision was taken on the one hand due to the identification and counting difficulty in and on the other hand because these plants were supposed to play a less important role in food security. In order to calculate the species richness occurring on the farm on the whole year we asked the farmers what were the species planted during the monsoon and winter periods. To avoid the farmers forgetting to mention some species we used a list of common cultivated species that had already been drawn up by Vanatree members. For all listed species farmers has been asked if it was a naturally occurring plant on the farm or whether it was planted species (domestic). In order to access the species abundance of woody plants the number of individuals, planted in open ground and larger than 1 m height, were counted (Mohan et al., 2007). The abundance of herbaceous plants has not been considered in the analysis, primarily due to the counting difficulties, and secondly because these abundances values are highly transitory in the year. Given that we carried out the fieldwork only during the summer periods it was by this way impossible to access to the annual number of individuals per species.

The second step was composed of an interview using a semi-structured questionnaire. The questions addressed the following topics: informations on famers, the economic characteristics of their FHG, labour, seed management, fertilization and crop protection practices, irrigation and evolution of FHG in the last 5 years.

V.3. Ecological indices

In order to assess plant biodiversity in FHG, species have been divided into different categories. The first subdivision was the separation between the woody species (trees and shrubs) and herbaceous species. Furthermore, for each species encountered, we asked the farmers to distinguish the planted species (domestic) from the naturally occurring species. This plant biodiversity segmentation helped us subsequently clarify the species richness results.

In addition, the Shannon-Weaver index was calculated for woody species in order to estimate species diversity. The reasons which led us to this index choice were firstly the willingness to take into account both species richness and evenness and secondly the possibility of comparing our values with those obtained in other studies. Indeed, the majority of authors who have studied FHG in the state of Kerala, used the same index (Marcon, 2013; Mohan et al., 2006, 2007; Saha et al., 2009; Vlkova et al., 2011). The Shannon-Weaver diversity index equation that has been used is as follows:

$$H = -\sum_{i=1}^{S} pi\ \ln(pi)$$

S represents the number of plant species occurring in the studied area and *pi* the probability that a randomly selected species belongs to the species *i*.

Sørensen index was calculated to determine the percentage of the species composition similarity for different categories of FHG. This index represents the percentage of common plants between Two given FHG. To calculate the similarity index between a FHG A and a FHG B, the equation is as follows:

$$\mathrm{Ss} = \frac{Number\ of\ common\ species}{\frac{(Sa+Sb)}{2}} * 100$$

Ss represents the Sørensen similarity index, *Sa* the species number of species in the garden A, Sb the species number in the garden B.

The FHG have been divided on the one hand according to the three study zones and on the other hand depending on the farmer's diet. Initially the index was calculated for each pairs of FHG then FHG couples were grouped together according to the two subdivisions in order to obtain the average values. These values were then compared to each other (Mohan et al., 2007; Vlkova et al., 2011).

V.4. Statistical analysis

The data exploration and analysis were carried out in different steps according to the protocol established by Zuur et al. (2010). First we determined especially with boxplots, the outlier values. This led us to exclude one of the FHG from our analysis. The first argument that led us to this choice was that *a posteriori* the total area of the FHG has been determined greater than 3 acres whereas in this study we have chosen to focus only on FHG having less than 3 acres. Moreover, the richness values obtained in this FHG were almost the double than those observed in other farms with especially a very high number of exotic species.

In a second step we checked the normality assumptions by using the Shapiro-Wilk or Kolmogorov-Smirnov tests and the variance homogeneity assumption with the Bartlett test in order to determine the adapted hypothesis tests to compare means. Thus, when the normality assumption was not met we used the Mann-Whitney or the Kruskal-Wallis tests. On the contrary when these assumptions were met ANOVA or linear regressions were applied by taking care to begin with models involving interactions between factors and eventually simply them when interactions or factors were not significant. Besides, we have removed from the models the correlated variables to avoid the multicollinearity effect. The variables selection was performed using correlation matrices (Pearson index), correlations circles from principal component analysis but also the variance inflation factors (VIF). All statistical analyses and index calculations (Shannon-Weaver diversity index and Sørensen similarity index) were performed using R 3.0.1(R Development Core Team 2013).

VI. Results and discussion

VI.1. Description of the farms in the region

VI.1.1. Interviewees

Through the studied Ghats section, the social profile of farmers turned out to be very heterogeneous. The first observation that has been done is the relative dominance of the Havyaka Brahmins caste (called Brahmin latter). In fact among the 39 surveyed farms nearly 56 % of the interviewed farmers belonged to this caste. With 13 % the Hallakis were the second most represented caste. The representation percentages of the other castes (Marathi, Namdari, Scheduled Caste (SC), Scheduled Tribe (ST), Siddi) are less than 8%. Moreover, it was also possible to note that these castes proportions are depending of the three defined zones. Thus, on the coastal zone, Hallakis represent more than 71% against about 29 % for the GSB caste (Gaur Saraswat Brahmins). On the contrary, in the Ghats and the Edge of the Ghats, Brahmin caste is dominant and reaches a representation percentage of about 71 % (**Tableau 1**). As we will see later this highly heterogeneous spatial distribution of castes to which farmers are belonging, in our sample, appears to have a significant impact on the cropping system management. One of the major differences between these castes lies especially in their diet habits. Thus all farmers belonging to the Brahmin caste are said to be vegetarians, while nearly 95% of the farmers belonging to another castes are not. Consequently we can observe that there are significantly more vegetarians in the Ghats and Edge of the Ghats zones comparatively to the coastal zone.

Table 1 : Numbers and percentages of farmers belonging to each caste, according to the three zones. The abbreviation Brahmin refers to the Havyaka Brahmins caste, GSB to the Gaur Saraswat Brahmins caste. SC and ST refer respectively to the Scheduled Castes and Scheduled Tribes.

	Coast		Edge of the Ghats		Ghats					
Castes	Hallaki	GSB	Brahmin	Namdari	Brahmin	SC	Marathi	Namdari	Siddi	ST
Number of farmers	5	2	5	2	17	3	2	1	1	1
Percentages per zones	71,4	28,6	71,4	28,6	68,0	12,0	8,0	4,0	4,0	4,0

Concerning the age of interviewed farmers, we found a greater homogeneity across the study area. Indeed, the proportions of age classes appeared to be very similar between the three spatial subunits. It is possible to denote that the 50-60 age class was the most common, followed by the 40-50 age class. The predominance of a relatively old population could be explained by the fact that we interviewed the main owners and managers of the farm.

VI.1.2. The labour

Over the entire study area farmers, up to nearly 80%, are complaining of the lack of labour availability. This lack of availability causes in turn crop management and soil organic fertility maintenance even more difficult. This phenomenon seems to be more pronounced in the FHG larger than 0.4 ha.

VI.1.3. The production units functions and the crop incomes

As explained above, Uttara Kannada FHG have different production units. These have very distinct functions. All zones considered it was determined that 74% of the farmers believe that the homegarden is primary source of food for the household (**Figure 8**). To a lesser extent the homegarden are also a source of income through the sales of seeds and certain fruits and vegetables. Homegardens are also the privileged place for the cultivation of medicinal or religious plants.

Regarding the areca orchards, all the farmers state that their main function is to generate income through the selling of the areca nuts. This result is confirmed by the fact that in 65% of the FHG the areca orchards are the primary source of income for the household. The secondary function of this production unit is the food generation with especially fruits and vegetables as well as spices. These results highlight a strong production and function complementarity between the homegarden and the areca orchards, allowing both a production for self-consumption and an income generation.

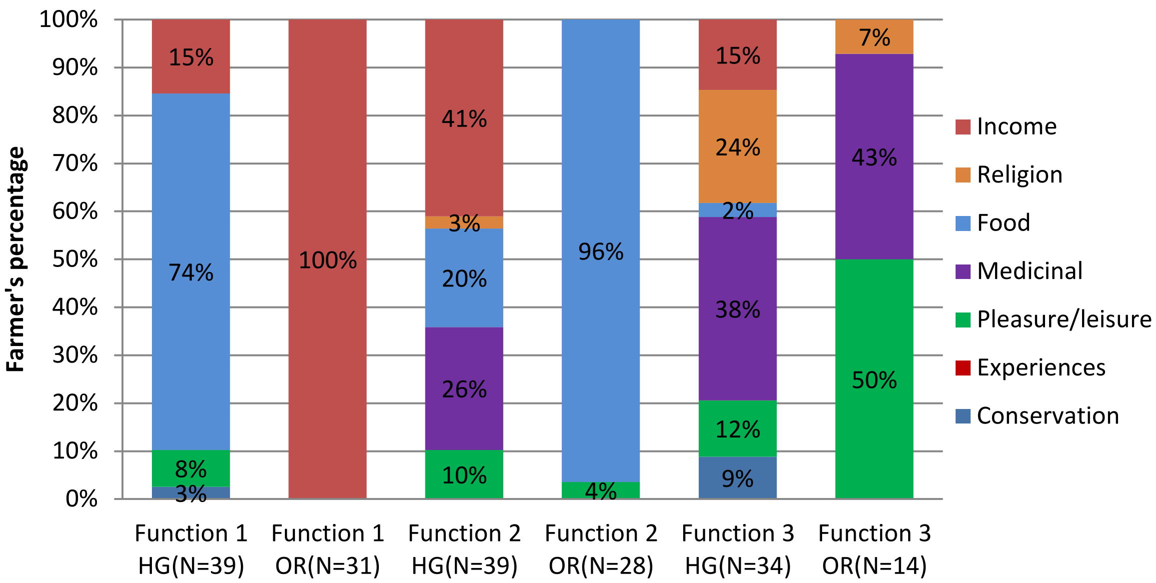

Figure 8 : The primary, secondary and tertiary functions of the homegarden (HG) and the areca orchards (OR) established according to the classification drawn by the interviewed farmers.

Moreover it has also been highlighted that the coastal farms had significantly less incomes than in the two other zones. This result has to be linked with the fact that 68% of the coastal farms do not have areca plantations while this is only the case in 12% in the Ghats and 0% in the edge of the Ghats (p-value = 0.038). In addition, farms that do not have areca plantations have significantly less income than farms with these plantations (p-value = 0.004).

In her FHG financial analysis carried out in Kerala, Mohan et al.(2006) also highlighted the economic importance of areca and banana trees. These two species are, in our study area, the basic frame of these areca orchards.

VI.1.4. The fertilisation

Fertilization in FHG is in most cases based on organic fertilization without the use of synthetic fertilizers. The sources of organic matter are very diverse and are from both animal and vegetable origin. For example, among the 39 farms, in 38 of them cow dung is being spread on the areca plantations and homegarden lands and this even though no animal are present on the farm. Concerning the origin of the organic matter, it is important to emphasize the role of “Bettas” as a source leaves. The survey results are showing that the fertilization practices differ according to the three subunits. Indeed on the Coast only 29 % of farms have Bettas while there is respectively 84 and 86 % in the Ghats and in the edge of the Ghats. Bettas are certainly less current on the coastal zone due to lower forest availability in comparison to the two other zones. Beside this about 57 % of the farmers are using synthetic fertilizers, while this proportion equals to 29% in the edge of the Ghats and 0% in the Ghats. This last point is difficult to explain because the analysis shows no correlation between the absence of fertilization via Bettas and the synthetic fertilizers use.

VI.1.5. The crop protection

Regarding the protection of crops, as well as fertilization, it has been observed that the farmers using synthetic pesticides were a minority in comparison to the use of natural preparations or copper sulphate solutions. Thus there was 38% and 48% of operators using respectively cows urine and ash as repellent against insect pests in their homegardens. In addition we can also mention the example of neem oil extracted from the fruits and seeds of the tree *Azadirachta indica*. This oil has repellent properties and can be used against a wide range of insects such as aphids, nematodes and some beetles.

Bordeaux mixture as well as a solution called “Biofight” based on phytoalkaloides properties are being used in 75% of the areca orchards to fight against fungal attacks. One of the most cited fungal disease by the interviewees was the “Koleroga” caused by the Oomycete called *Phytophthora palmivora*. Indeed, this organism is the agent causing the brown rot of the buds or fruits, on the areca, the coconut and cocoa trees. It has been reported that the koleroga disease is causing each year major crop damages and by the way income losses in the Malnads region (newzfirst 2013). The survey results clearly confirm the strong occurrence of the fungus in the study area because at least 20% of the farmers, all zones considered, complained specifically about the Koleroga on their areca trees.

Note that the pesticides use is also depending of the zones. Similarly to fertilization practices, on coastal zone nearly 60% of the farmers are using synthetic insecticides solutions, while these percentages are respectively 29% and 0% in the edge of the Ghats and in the Ghats.

By considering the fertilization practices and crop protection results it seems that the coastal zone differs from the two other zones with a higher use of external inputs rather than the adoption of practices that promote an optimal use of environment resources and the repellent properties of some plant species.

VI.1.6. the irrigation

During the interviews we asked the farmers whether they believe having enough water supplies for their crops. The results statistical analysis has showed that water problems are mostly located on the north of the study area (p-value = 0.007). In addition, a precipitation regime effect was also been highlighted, hence the lack of water is especially occurring in the North East of the study area.

One of the main reasons that could be at the origin of this lack of water is the quality of the irrigation system on farms. To confirm this hypothesis we focused our analysis on the of irrigation systems in the homegarden as it is in this production unit that water problems were the most frequent. We classified the irrigation systems into three categories. The first consisted of farms where irrigation was done manually (with pots); irrigation pipe systems constitute the second category while the Jets, sprinklers or drip systems were the third one. The results have confirmed that water problems are significantly higher when irrigation systems are manual or semi-manual (pipe). As we might expect farms with mechanical irrigation systems also had higher incomes.

However it is important to note that there seems to be no statistical relationship between the farm latitudes and the presence or absence of mechanical irrigation systems. This result suggests that the precipitation patterns and the quality of irrigation systems are not the only factors responsible for the lack of water.

VI.1.7. the seed management

Given the importance of seed management for the production autonomy in a farm, we asked each farmer to estimate the percentage of seeds purchased on markets opposed to seed from exchanges or seeds saved from previous harvests. In addition we also wanted to determine the main and second sources of the seeds/seedlings. The Analysis of these data reveals that on average, farmers in the Ghats zone have a higher percentage of seeds saved from previous harvests than in the coastal zone (p-value = 0.0011) (**Figure 9**). In addition , it was determined that 38 % of the farmers rely on the seeds exchanges in the Ghats while these percentages were respectively 14 % and 0% on the coast and in the edge of the Ghats (p-value = 0.0766). In our sample, the Ghats zone seems to be discernible from a seed management point of view. Indeed, the farmers of this zone tend to have greater independence concerning the seed purchasing on the local markets. In this way the seed saving practice seems to give more independence and a greater food security for farmers.

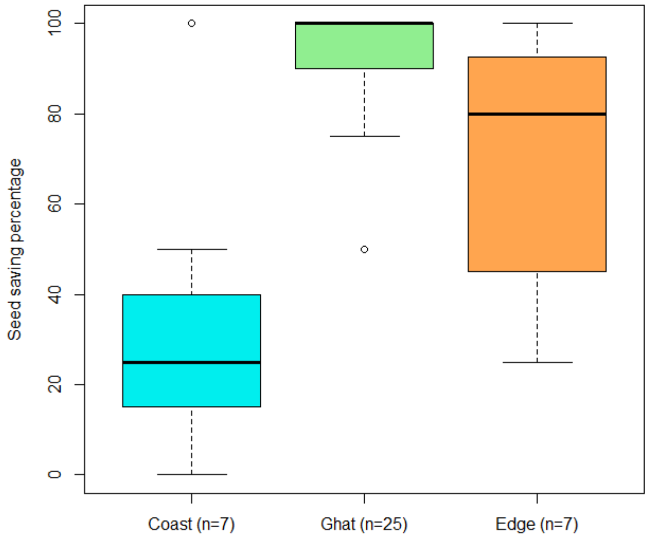

Figure 9 : Annual seed saving percentage on the farms according to the three zones.

VI.2. Plant agrobiodiversity in forest homegardens

VI.2.1. Richness in the study area

The species richness analysis results show that throughout the study area it has been differentiated 319 plant species among which 303 were found in the homegardens and 126 in areca orchards. On average, nearly 65 plant species per farm were found throughout the study area. Given the sampling collection difficulties during the fieldwork, unfortunately 28 species remain undetermined. Indeed concerning the vast majority of these 28 species there was only one or two individuals per farm. The species found in FHG are used as vegetables, fruits for desserts, spices, refreshing beverages, timber, firewood, animal feed, organic fertilizer, and development support for other plants, creation of shaded areas or also the prevention of soil erosion. There are also religious, medicinal and ornamental vocation plants,

In comparison to other studies it is important to note that the number of species found in the study area is higher than the numbers that have been obtained in the majority of FHG biodiversity studies. For example, in a study that has been performed in the Thrissur district of Kerala it has been reported 153 species on 75 farms with an average of 36 species per farm (Mohan et al., 2007). In the same district 106 species have been identified on a total of 24 farms by Saha et al. (2009). Nevertheless our results richness remain below the 463 identified species through a survey of 839 FHG, spread over three districts of Kerala (Kumar, 2011).

In the homegardens the five most represented species are respectively *Solanum melongena*, *Cucumis sativus*, *Amaranthus cruentus*, *Capsicum annuum* and *Luffa acutangula*. These five species are present in over 90% of farms and are mainly used for consumption, although the *Capsicum annum* fruit is also commonly sold in local markets. Regarding areca orchards five most common species found in addition to *Areca catechu* are bananas trees

(*Musa spp*.), Black pepper (*Piper nigrum*), the coconut (*Cocos nucifera*), cardamom (*Ellattaria cardamomum*) , and jackfruit (*Artocarpus heterophyllus*). Among these species, arecanut, black pepper and cardamom are primarily cash crops.

VI.2.2. The sampling effort

With reference to the species-area sampling curve we examined whether our sampling density was sufficient in relation to the size of the study area. Since this study is part of a pilot-test to larger investigations, the species accumulation curve based on the number of sampled farms theoretically allows us to assess to the minimum sample size (Oksanen, 2013; Walter, 2006). The curves in **Figure 10** show that the species accumulation seems to tend towards an oblique asymptote and not a horizontal asymptote. This result reflects that it would have been preferable to choose a sample size of at least two times higher especially for the study of the homegardens (HG). According to the accumulation curve the adopted sample size seems more suited to the study of areca orchards, because the curve trend suggests that a horizontal asymptote is almost reached. Moreover, the examination of these three curves, with additional statistical analysis, suggests that species richness in areca plantations is less important than in the homegardens. It is possible to notice that the study of forest homegardens (HG+OR), that is to say, the homegardens (HG) and areca orchards (OR), is almost equivalent to the homegarden in terms of species richness. The species richness proximity between FHG and homegarden is explained by the fact that the majority of plant species occurring in the areca orchards is also found in the homegardens.

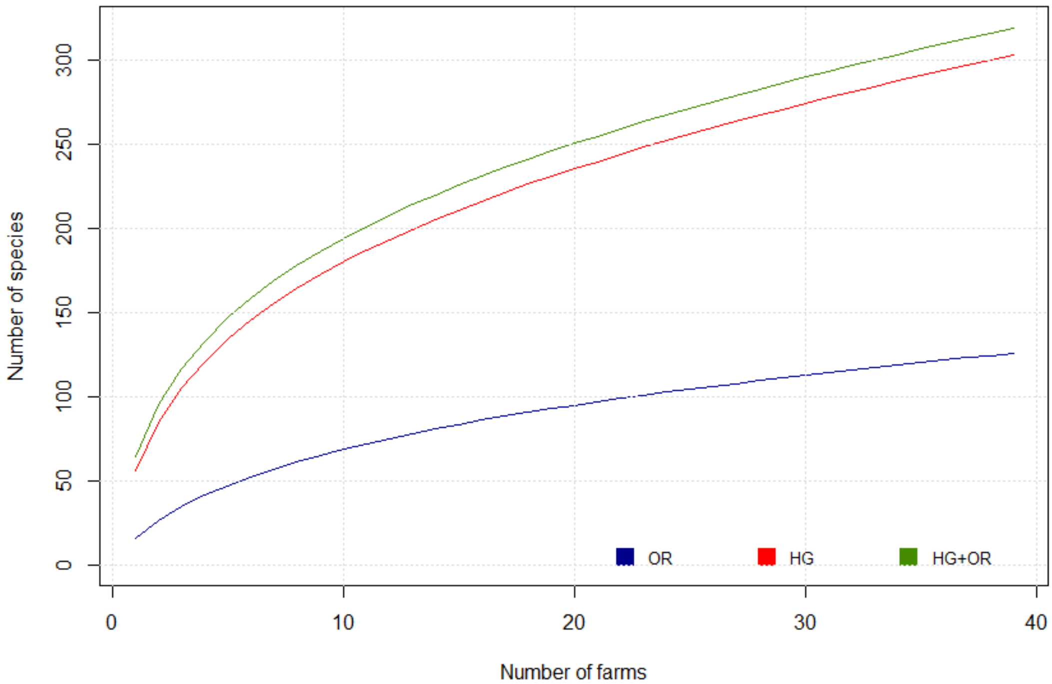

Figure 10 : Specific accumulation models in function to the number of sampled farms for different production units according to Kindt's exact method. The abbreviation OR corresponds to areca orchards, HG to the homegardens, while (HG+OR) refers to the forest homegarden unit which is the gathering of the two latter units.

VI.2.3. Species richness

The species richness statistical analysis shows that the coastal area has significantly fewer species than the Ghats zone and the latter less than the eastern part of the Ghats. This result suggests that there is a growing plant agrobiodiversity gradient through the Western Ghats Mountains. To refine this observation we examined the species richness of different plant types. Thus, the two criteria that were chosen to split the species are on the one hand an opposition between woody (trees, shrubs) and herbaceous species and on the other hand the distinction between species those have been planted by farmers (domestic) and plants naturally occurring on the farm (wild). The results of these statistical analyses are summarized in **Figure 11**.

These results highlight the fact the species richness difference between the three zones is uniformly distributed among the different species. We can see that the dominant classes, all zones considered, are the herbaceous and woody domestic plants. Therefore that shows that farmers are play a fundamental role in the constitution of plant agrobiodiversity present on farms. However, the number of wild herbaceous species also follows a positive gradient from the coast to the east of the Ghats.

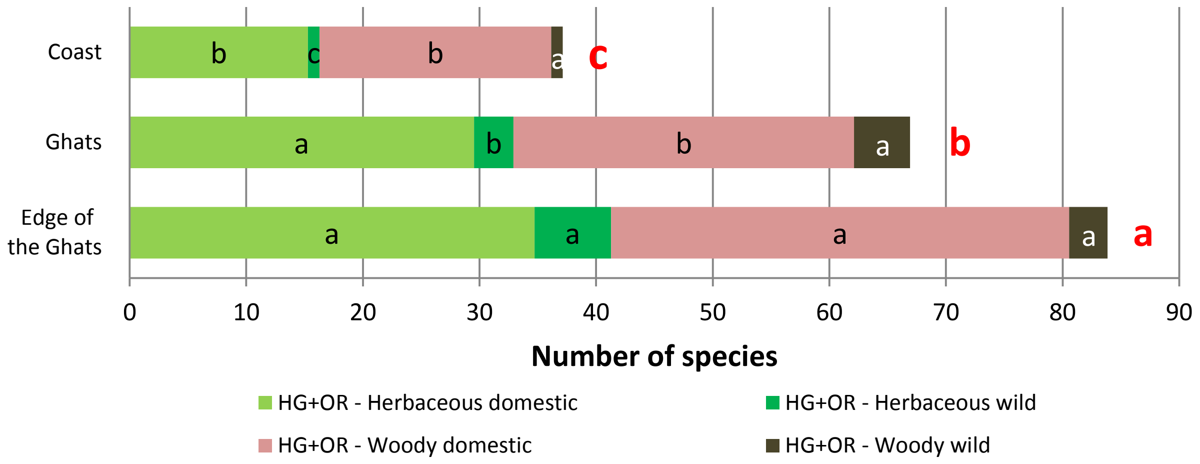

Figure 11 : Results of the mean species richness comparisons in forest homegardens according to the three zones and the different plant categories (n= 39). The abbreviation HG + OR refers to the species found in the homegardens or in areca orchards species. The abbreviation "Domestic / Wild" refers to whether or not species has been planted by farmers and "Woody / Herbaceous" to lignified species (trees, shrubs) or herbaceous species. Statistical groups are resulting from the means multiple comparisons of species richness categories between the three study zones. Groups in red correspond to a multiple comparison of the total plant richness between the zones. According to the Tukey's HSD test, the species categories with the same letter are not significantly different (P> 0.05).

The reasons could be at the origin of these results are numerous. The main reason is certainly the presence of a richer biological farm environment in the Ghats and in the edge of the Ghats, therefore causing an increasing inflow of seeds on the farms. These flows can be accomplished by natural means, such anemochory or zoochory but also by agricultural practices. Indeed, the leave's transportation practice from the Bettas to the FHG is also a potential source of seeds. Moreover, the biological and physical farm environmental condition could also play a fundamental role on the availability of certain plant species for farmers. The example of the species *Murraya koengii* used as spices, illustrates this because in some farms it was a domestic species, while in others they were considered as wild species. In addition, it seems that it will be more difficult to grow plants with large water requirements, such as certain vegetables (squash , carrots , salads, ...), on sandy soils as we were able to meet on the coast (BLE – CIVAM, 2011).

By continuing the segmentation of species richness in the FHG it has been revealed that areca plantations have significantly fewer species than the homegarden. In supplement to the above results, it seems that homegardens mainly contribute to the woody and herbaceous domestic species richness (**Figure 12**). The domestic herbaceous species numbers seems to be mainly due to the presence of many annual vegetable crops grown around the house. In addition, the number of domestic herbaceous species in the homegarden is significantly higher in the Ghats and in the edge of Ghats compared to the coastal zone. Echoing to the caste and dietary habits analysis of farmers in the three areas, one of the explanations could be suggested is that vegetarians, being dominant in the Ghats and edge of the Ghats, tend to grow more vegetable plants for their own consumption to meet their dietary needs.

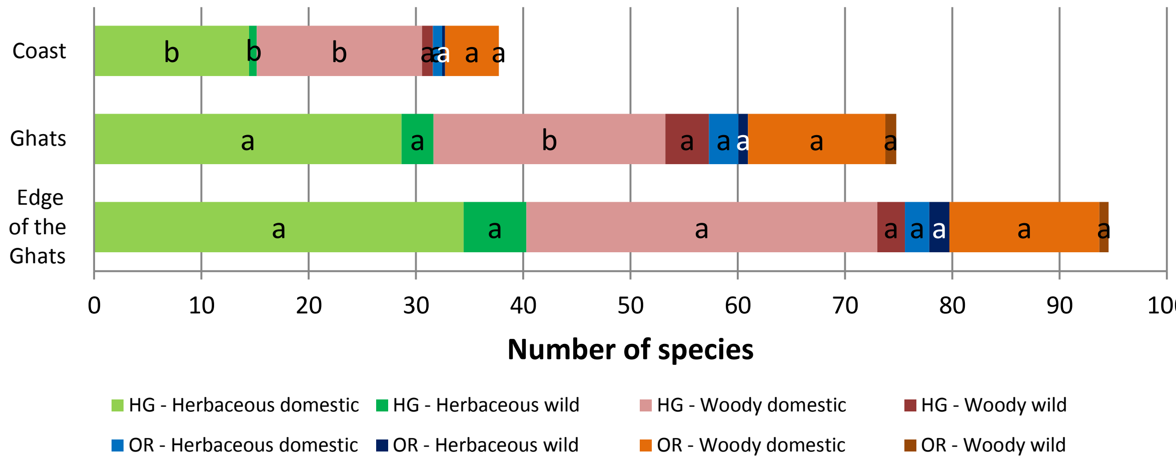

Figure 12 : Results of the mean species richness comparisons between the three zones and according to the different production units and plant categories (n= 39). The abbreviations JH and AR refer respectively to in the homegarden and areca orchards. The abbreviation "Domestic / Wild" refers to whether or not species has been planted by farmers and "Woody / Herbaceous" to lignified species (trees, shrubs) or herbaceous species. Statistical groups are resulting from the means multiple comparisons of species richness categories between the three study zones. According to the Tukey's HSD test, the species categories with the same letter are not significantly different (P> 0.05).

VI.2.4. Species diversity

Besides the species number in the three study areas, it is also important to determine whether there are abundance inequalities between the different species. To refine the above stated results we analysed the Shannon diversity index evolution along in the three zones for tree and shrub species. This index was calculated for the homegarden, the areca plantations and finally the gathering of these two latter production units. Homegardens were found to have a mean Shannon diversity index that equals to 2.40, which is significantly higher than the areca orchards Shannon index equalling to 1.24 (**Figure 13**). This result has to be linked to the fact that the areca orchards are mainly constituted of cash crops. Therefore, to maximize their profit, farmers are planting species that are supposed to generate high gross margins, such as areca, cardamom, black pepper or bananas. This will result in the species abundance increasing of a few species, hence a lower Shannon diversity.

The unit resulting from the gathering of the homegarden and areca orchards has been found to have the intermediate value of 1.72. Since the FHG unit has a statistically different value than the units from which it is composed, this suggests that there is no clear dominance of one of the two units at the farm level. One explanation that could be given is that the production areas and the total species abundances are likely to be equivalent between the homegarden and the areca orchards.

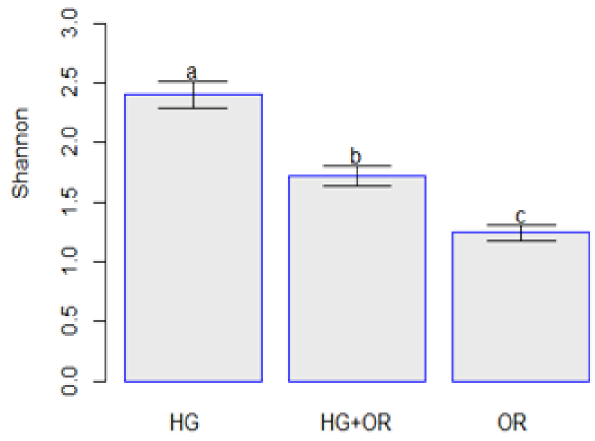

Figure 13 : Results of the mean Shannon diversity index comparisons according to the three production units, all zones considered (N = 31). The abbreviation OR corresponds to areca orchards, HG to the homegardens, while (HG+OR) refers to the forest homegarden unit which is the gathering of the two latter units. The error bars represent the standard errors the means (SE). According to the Tukey's HSD test, the species categories with the same letter are not significantly different (P> 0.05).

Thereafter we tried to determine whether there are differences in diversity between the three defined zones. The Shannon diversity index analysis leads us to conclude that there is significant difference only in the case of homegardens. Indeed the eastern part of the Ghats presents a higher mean Shannon index than the one observed in the coastal zone. This result suggests a relatively higher production specialization in the homegarden of the coast compared to the edge of the Ghats. This may be related to the fact that coastal farmers have significantly lower incomes than in the two other zones, forcing them to cultivate a smaller number of species with higher gross margins.

Shannon-Weaver diversity values that have been found in the gathering unit of the homegarden and areca orchards are similar to those found in studies conducted in Kerala (Mohan et al., 2007; Saha et al., 2009). Besides this studies carried out on the woody plants diversity in the Uttara Kannada district revealed a mean Shannon index that equals to 15.52 (Daniels et al., 1992). This shows that despite the high diversity found in FHG, it is still lower than that found in the surrounding natural environment.

VI.2.5. Species similarity

Following the species richness and diversity analysis we also tried to understand the species compositions similarities between the FHG throughout the study area. For this purpose the Sorensen similarity index has been calculated for each farm. On the whole study area the mean Sorensen index is 0.52 and reaches a maximum of 0.73 (**Tableau 2**). The calculated similarity values turns out to be relatively low compared to those found in the literature. Indeed, in a FHG study processed in the Thrissur district in Kerala the Sorensen index ranges from 70% to 95 % (Mohan et al., 2007). Similar values were obtained on the Phong My commune FHG in Vietnam (Vlkova et al., 2011). The possible reasons behind this difference are firstly a lower sampling areal density (sampled farms.ha^{-1}) and secondly the presence of a potentially stronger physical and social gradient in the study area.

In addition, the results of this Sorensen index analysis highlight that the Ghats and Edge of the Ghats FHG have stronger similarities between themselves than with the coastal FHG. These are completing the species richness and diversity results and outline that the FHG on the coast are also discernible from the two other zones in terms of species composition.

To clarify these observations, an examination of the similarity matrix for each pair of FHG has led us to recalculate the indices means based on farmer's diet. Indeed, when a farm is composed of non-vegetarian farmers the Sorenson indices are significantly lower than otherwise. Since coastal farms consist of 86% of non-vegetarians these results come to explain the lower Sorenson similarities between Ghats or edge of the Ghats FHG and the coastal FHG. However, it is quite difficult to interpret the fact that farms composed of non-vegetarians have low similarity between them. This last result suggests that there is potentially finer farms segmentation in the Non-vegetarians category.

Table 2 : Sorenson similarity index percentages according to the three studied zones and the farmer's diet. The Values in brackets represent the standard errors of the means.

	Coast	Ghats	Edge of the Ghats	Vegetarians	Non vegetarians
Coast	47,45 (1,55)	43,0 (0,55)	41,8 (0,88)	/	/
Ghats	/	56,4 (0,46)	54,2 (0,47)	/	/
Edge of the Ghats	/	/	59,4 (2,14)	/	/
Vegetarians	/	/	/	57,7 (0,46)	48,6 (0,47)
Non vegetarians	/	/	/	/	47,8 (0,82)

VI.3. The various factors involved in the biodiversity variability

As it has been highlighted above, many factors are involved to explaining plant biodiversity on farms. In the following part we have attempted to determine which factors or indicators are the most explaining FHG species richness variability in the study area. To reach this end, the survey results as well as geo-spatial data such as altitude, GPS coordinates, annual rainfall or soil type have been used to determine a large number of variables potentially explaining species richness.

Analysis of Pearson index correlation matrices and the PCA correlation circles have showed that longitude is the variable that best explain the variability of the richness. Given that the Pearson correlation coefficient equals to 0.72 (r), we performed a simple linear regression with longitude as an explanatory variable. This model has a determination coefficient (R^2) that equals to 0.51 and thus informs us that nearly half of the variability in species richness can be explained by the only longitude.

Concerning the physical factors, it has been determined that soil type, annual rainfalls and altitude, are strongly correlated with longitude. Since longitude and species richness are correlated these variables are consequently also correlated with the latter. Given that the correlations between these factors and longitude are more important than those with species richness, it is difficult to determine whether these variables are actually explanatory factors.

After the variable number reduction, based on the correlations, a PCA was performed using as variables the FHG species richness, the longitude, the FHG area and the total incomes (**Figure 14**). By examining the correlation circle we can see that the incomes are highly correlated with the FHG size and the species richness. In addition to the correlation circle the results of Pearson's correlations matrices and the linear regression models are confirming that the FHG size and the incomes are more correlated with species richness than to the longitude. This last point suggests that these two variables are more likely to be real explanatory variables for the species richness and that they are not only related to the longitude variable. Similarly, we were able to show that compared to the incomes variable, FHG size seems to be the main species richness driver.

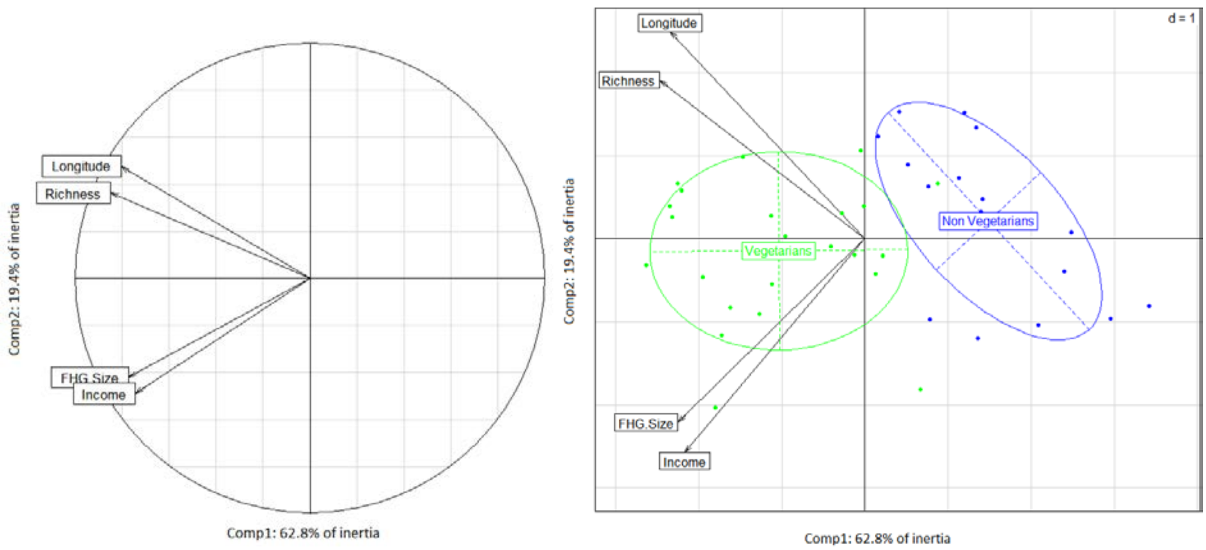

Figure 14 : PCA results by using four variables: the FHG size (Size), the crop income (CI), the species richness and the longitude. To the left is shown the correlation circle of the ACP and to the right the PCA biplot with the dietary ellipsoids representation.

Therefore all of these results suggests that the larger the FHG, the higher the number of crop that the farmers could cultivate. Having larger FHG will have in the one hand a positive impact on the total incomes and on the other hand on species richness. Since the FHG size is more correlated with the income than the species richness, it can lead us to believe that when farmers have more land, they will first tend to grow cash crops. This will certainly have an impact on land use, because the cash crops are mostly located in areca orchards.

In addition, small farms have a greater number of species per area unit than those having a larger size (**Figure 15**). Here we find similar result to those reported the studies processed in the Kerala State. Thus, small farms tend to intensify and diversify their productions to meet their food needs while larger farms would grow a greater amount of cash crops (Mohan et al., 2007).

In addition, it is possible to see that this phenomenon is not independent of farmer's diet and therefore the social class to which they belong. Indeed, on average vegetarians (Brahmins) have significantly larger FHG than non-vegetarians (Non-Brahmins). This last point is probably the main reason why vegetarians also have significantly higher incomes. The results of the ANCOVA, using as explained variable the area allocated per species (specific area), as covariate the FHG size and as factor the farmer's diet; also confirm that for an equal area, vegetarian farmers have a species number significantly higher than non-vegetarians. Therefore it can be concluded that it seems that vegetarians (Brahmins) have more intensive plantation management with higher species concentrations per area unit.

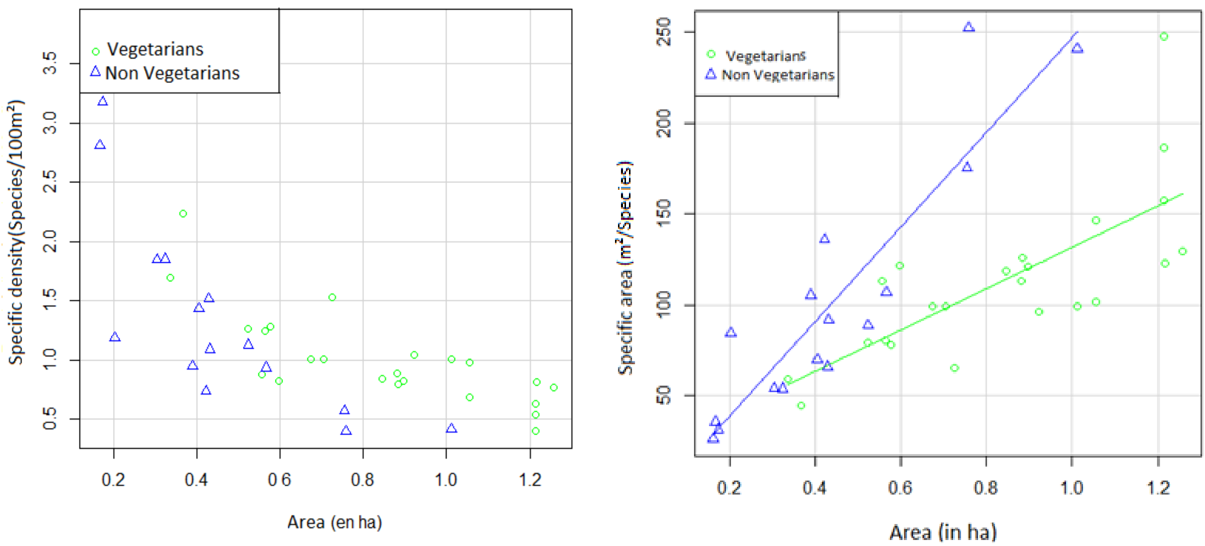

Figure 15 : To the left is shown the species density per 100 m² and to the right the area allocated per species (m² / species) according to FHG sizes. The green triangles represent the vegetarian farmers and blue circles the non-vegetarians.

It is important to bear in mind that the castes spatial distribution in the study area is heterogeneous. Indeed, in our sample, on the coastal zone no farmer belongs to the Brahmin's caste (vegetarian). Since the FHG sizes closer to the coast are smaller than the Edge of the Ghats or the Ghats FHG, this could be a reason why the analysis has highlighted that Brahmins have significantly larger FHG. The reasons for this land distribution heterogeneity can be very diverse and we can eventually think to dietary needs or historical events. We could by this way draw the hypothesis that coastal farmers would more likely tend to eat seafood by fishing and therefore would not be vegetarians.

Conclusion and perspectives

As we have seen through the fieldwork results that there is strong plant biodiversity heterogeneity in the study area. In fact, it has been possible to distinguish the three study zones in terms of richness, diversity and species composition. This heterogeneity between zones is the consequence of a large number of social, economic and physical factors variations.

Thus, it has been highlighted that the coastal FHG have a total richness and woody species diversity significantly less important than in the Ghats or in the Edge of the Ghats. In addition we were able to demonstrate that there are also low species composition similarities between the Ghats zones and the coastal zone.

Coastal FHG are generally smaller and have less areca orchards. These two points will have a negative impact on the annual income of these farms. In contrast with the two other zones, we found that no gardeners belonged to the Brahmin's caste and only one of them was vegetarian. This last point, in addition to the FHG size, seems to be negatively linked to the species density and species richness. Furthermore, the analysis of crop protection and fertilization management seems to highlight the fact that the use of synthetic products is more common in the coastal zone.

In opposition to the coastal zone, the Ghats and edge of the Ghats zones have more similarities between them. This result is reflected in a higher species composition similarity between FHG than between FHG located on the coast and also by the fact that caste's representation proportions are very similar. Regarding the crop protection and fertilization practices, the farmers of these two areas are using less synthetic pesticides and are mainly managing their fertilization with organic matter amendments from animal or plant (Soppina betta) origins. Although no significant difference has been found, the edge of the Ghats FHG have are on average larger than the Ghats FHG. This last point could partly explain that the Edge of Ghats FHG have a significantly higher species richness compared to the Ghats zone.

Although geo-referenced data on soil types and on the annual rainfall had allowed us to characterize these three zones, it still remains difficult to determine the real impacts of each of these physical factors and their possible interactions on plant biodiversity management by gardeners. In order to determine the effect of soil, further investigations are needed, especially by conducting soil tests on farms. Given the time frame it is also important to remember that this plant diversity study only focuses on the plant species used by farmers. Hence, this means as that the number of species found here underestimates the total plant richness. Moreover, we have highlighted through the species accumulation curves based on the number of sampled farms that the sample size was limited to be fully representative of the study area. Another way of improvement that can be stated is that it would have been better to access a larger farms list coming from the Uttara Kannada district Agriculture Department, in order to avoid any sampling bias.

However, with a total of 319 species encountered in the FHG across the study area it is nevertheless possible to see that these production systems represent a high potential for plant species conservation and protection in the mountain range of the Western Ghats. The species use and multiplication in the FHG seem to be a way of active preservation able to provide a source of income and food for farmers. Although the species richness and diversity in these production systems do not equal those found in the surrounding forests, they are not comparable to those in monoculture systems. In this sense these manmade environments represented by the FHG will also be less hostile to local wildlife.

In addition we have also been able to show that species richness and species composition was strongly related to the social castes to which farmers are belonging (or their diet). This suggests that there is not one FHG model and that each FHG has the function to answer to the changing farmer needs and expectations. Currently this last point is particularly important because we are witnessing for a few years to a gradual transformation of the production systems from subsistence farming to market farming. Thus a better understanding of these cropping systems patterns and variability will be essential to optimize their sustainability.

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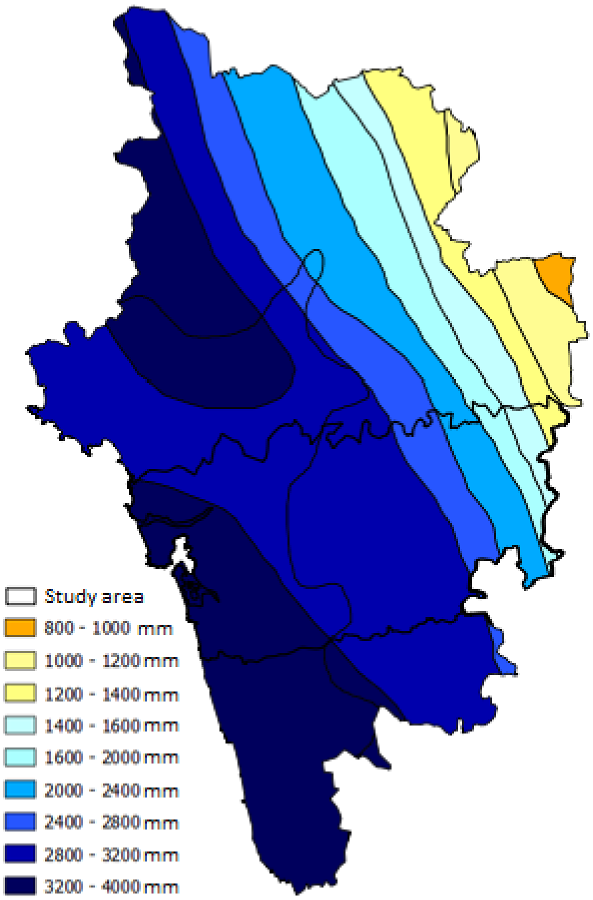
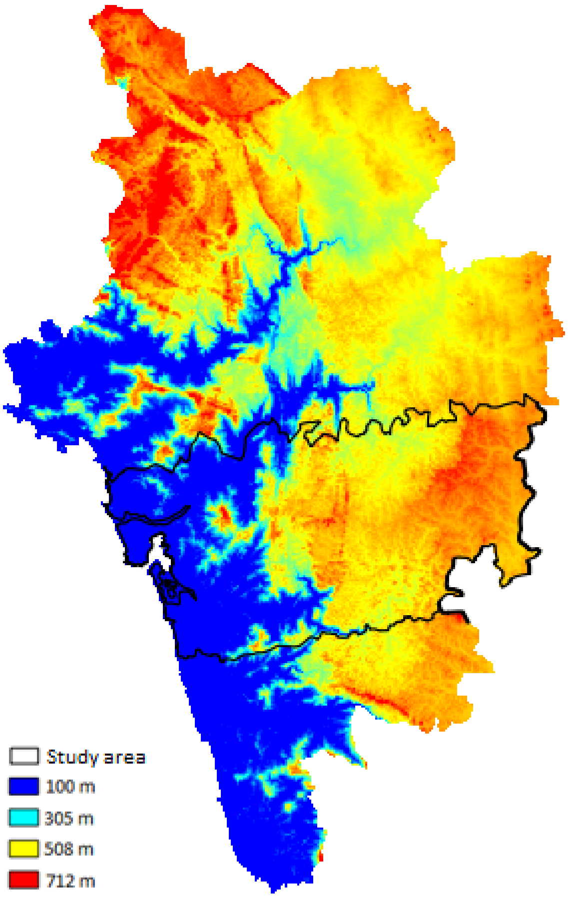
Appendices:

Uttara Kannada GIS maps (1/1000000)

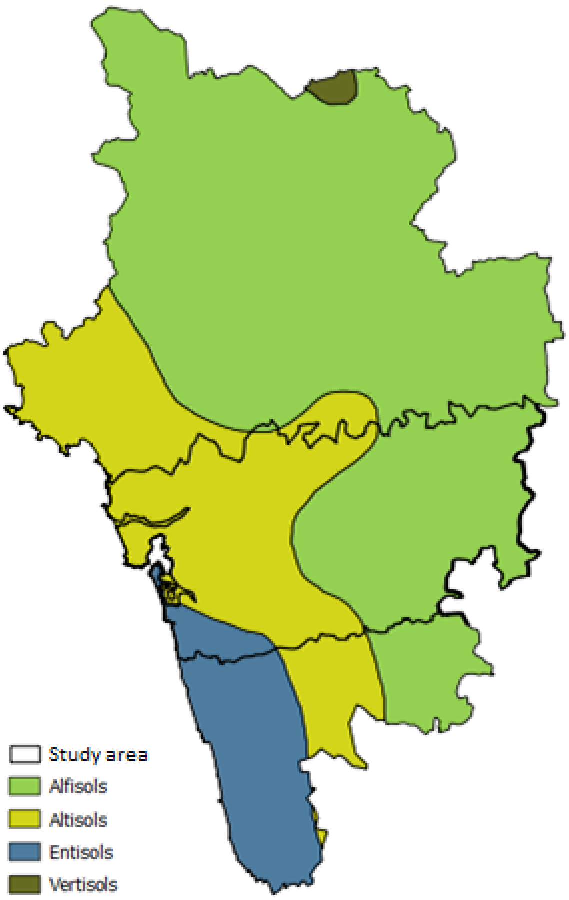
Annual precipitation map:



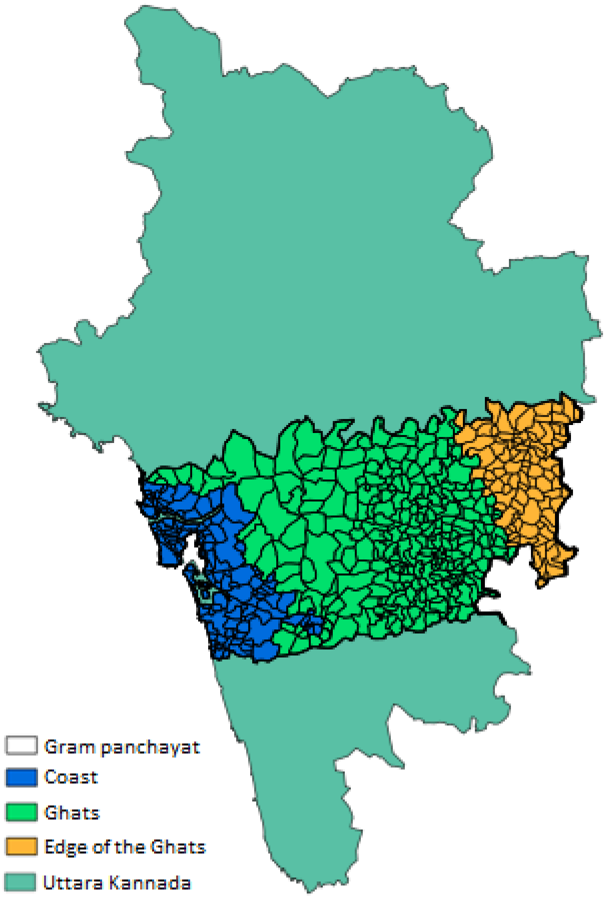
Topographic Map:



Soil maps



Administrative division of the study area



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