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Diversity, local uses and availability of medicinal plants and wild yams in the Mahafaly region of south-western Madagascar

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Diversity, local uses and availability of medicinal plants and wild yams in the Mahafaly region of south-western Madagascar

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Dedication

To my family (parents, sisters and brothers) and my husband for their love and support.

Preface

The research presented in this work is part of the SuLaMa project which promotes participatory research to support sustainable land use management on the Mahafaly Plateau in south-western Madagascar (http://www.sulama.de/index.php/en).

The present work is subdivided in five chapters, including three scientific papers (Figure i-1). In chapter 1, I revise the concepts and methods used in assessing biological diversity and the importance of forest provisioning services to the local communities, and outline the problems concerning the ecosystems on the Mahafaly Plateau. Chapter 2 presents the general diversity of medicinal plants and wild yam species used by the local population in the Mahafaly region, the socioeconomic and cultural factors determining their utilization, and local knowledge about their usage. Chapter 3 estimates the current availability of wild yam resources in the study region, based on the environmental factors that drive their spatial distribution and abundance. In chapter 4, I explore the possible alternative methods for the regeneration and conservation of wild yams in the Mahafaly region, based on small experiments and following the concepts of a participatory research approach. Finally, chapter 5 contains general conclusions, where I consider the importance of the results vis à vis the main objectives of the SuLaMa project, and highlight the importance of the chosen plants as model species for a better understanding of the role of provisioning ecosystem services in the livelihood of local communities in the Mahafaly region. Based on these results, further recommendations for future research and practical applications are given.

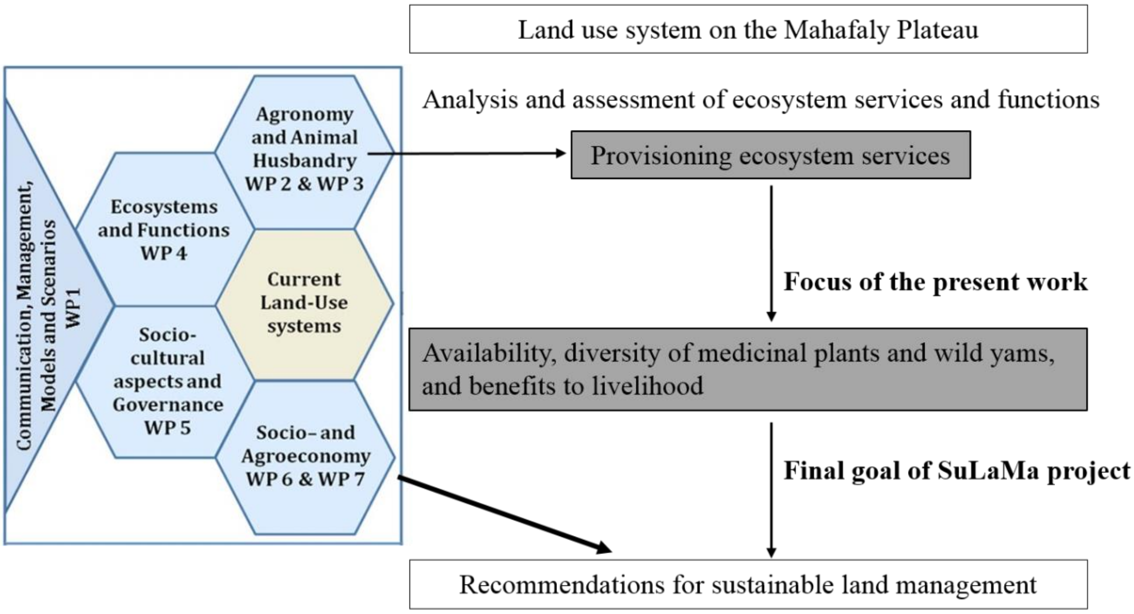

Figure i-1 Focus of the present work within the framework of SuLaMa project.

Table of Contents

List of Figures

List of Tables

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English summary

This study was undertaken to assess the diversity of plant resources utilized by the local population in south-western Madagascar, the social, ecological and biophysical conditions that drive their uses and availability, and possible alternative strategies for their sustainable use in the region. This work is a part of SuLaMa (Sustainable Landmanagement in south-western Madagascar), an interdisciplinary and a participatory research project to support sustainable land use management on the Mahafaly Plateau in south-western Madagascar.

The study region, 'Mahafaly region', located in south-western Madagascar, is one of the contry's most economically, educationally and climatically disadvantaged regions. Poor infrastructure and basic services in this area lead to an insufficient supply systems. With an arid steppe climate, the agricultural production is limited by low water availability and a low level of soil nutrients and soil organic carbon. Local people mainly depend on smallholder agriculture and livestock keeping. The absence of income alternatives and the low level of economic development in the area limit the livelihood strategies of the population, leading to persistent food insecurity. Local communities, therefore, rely on forests resources to fulfill their basic needs. The region comprises the recently extended Tsimanampetsotsa National Park, with numerous sacred and communities forests, which are threatened by slash and burn agriculture and overexploitation of forest resources.

In view of the increasing pressure on ecosystem services and functions, the present study analyses the availability of important provisioning services from forest habitats, and their importance for the livelihood of the local population in this region. Wild yams (*Dioscorea* spp) and medicinal plants were selected as key provisioning services that are frequently collected from forest habitats and used in various ways by the local people in the Mahafaly region to improve food security and health care.

To study the use of wild yams and medicinal plants, an ethnobotanical survey was conducted from June to December 2012 recording the diversity, local knowledge and use of wild yams and medicinal plants utilized by the local communities in five villages within the Mahafaly region. 250 households were randomly selected followed by semi-structured interviews on the socio-economic characteristics of the households. To collect plant specimens for botanical identification and to record harvesting site field surveys, forest transect walks were conducted. Data allowed us to characterize sociocultural and socioeconomic factors that determine the local use of wild yams and medicinal plants, and to identify their role upon the livelihoods of local people. By extrapolating the information from the household surveys, an area of 350 km² was delimitated to be the 'main harvesting area' in the Mahafaly region, allowing us to quantify the abundance of the locally used wild yam species in this region. Environmental variables, soil characteristics and harvest intensity of yam tubers were collected in the field using a systematic sampling approach. Based on abiotic and biotic factors, the species-environment relationships and the current spatial distribution of the wild yams were investigated and predicted using ordination methods and a niche based habitat modelling approach.

Species response curves along edaphic gradients allowed us to understand the species requirements on habitat conditions and the importance of the human-induced changes on species availability, especially when dealing with highly used resources. We thus investigated various alternative methods to enhance the wild yam regeneration for their local conservation and their sustainable use in the Mahafaly region.

Altogether, six species of wild yams and a total of 214 medicinal plants species from 68 families and 163 genera were identified in the study region. Results of the cluster and discriminant analysis indicated a clear pattern on resource uses, and resulted in two groups of households differing in wild yam and medicinal plants collection intensity, knowledge on the local use and wealth status. The latter was characterized by differences in livestock numbers, off-farm activities, agricultural land and harvests. A generalized linear model highlighted that economic factors significantly affect the collection intensity of wild yams, while the use of medicinal plants depends to a higher degree on socio-cultural factors.

The gradient analysis on the distribution of the wild yam species revealed a clear pattern for species habitats. *D. alatipes* occurred in dry spiny forest on calcareous soils at remote places, while *D. bemandry* and *D. fandra* were found in forest habitats on sandy soils with high harvest intensities and near villages. The NPMR (Nonparametric Multiplicative Regression analysis) models explained 37-88% of the species abundance variation. Results further indicated the importance of vegetation structure, human interventions, and soil characteristics to determine wild yam species distribution. The prediction of the current availability of wild yam resources showed that abundant wild yam resources are scarce and mostly located in restricted areas of open spiny forests and dry spiny forest thickets, where harvest intensity is high.

Field experiments on yams (six wild yam species and one local variety of *D. alata*) cultivation revealed that germination of seeds was enhanced by using pre-germination treatments before planting, and vegetative regeneration of the upper part of the tubers (corms) showed a higher sprouting percentage than the setts of tubers. *In-situ* regeneration was possible for the upper parts of the wild tubers but the success depended significantly on the type of soil. The use of manure (10-20 t ha^{1}) increased the yield of the *D. alata* and *D. alatipes* by 40%. The regeneration and the sprouting performance highly depended on the yam species and the cultivation practice. The cultivation of wild species was very labour intensive in comparison to *D. alata*. We thus suggest the promotion of other cultivated varieties of *D. alata* found in the regions neighbouring the Mahafaly Plateau.

Medicinal plants and wild yams are used to fulfill the basic health and food requirements in the livelihood system of local people in the study region. Our work highlighted the need to introduce and promote sustainable yam harvest practices as well as the importance of anthropogenic factors in determining their availability. The predictive map on the current wild yam species distribution showed the range of suitable wild yam habitats in the Mahafaly region. However, the results on yam species distribution need careful interpretation prior extrapolation, since the studied region depicted only a limited set of environmental conditions in the Mahafaly region. Nevertheless, the model of resource use found from our findings and our methodological approach could be used to assess the forests provisioning services and their interlinkage with human systems in the Mahafaly region. As we focused only on specific plants, the overall role of forest resources for the local communities might even be more important and their successful conservation needs to involve the local communities as stakeholders in sustainable management planning.

Several initiatives and participatory actions (e.g. domestication of wild species, on field cultivation of local variety yams, environmental education and promotion of sustainable harvest methods) are needed to ensure the sustainable use of these resources and to sustain the livelihoods of local people. Such actions will help to reduce the ongoing pressure on natural resources and conserve their habitats from human disturbances. Conservation should focus on conserving biodiversity as providers of goods and services for local communities and include Rapid Vulnerability Assessment (RVA) and long-term monitoring of the identified highly used resources.

Deutsche Zusammenfassung

Die vorliegende Dissertation wurde durchgeführt, um die Diversität der von der Bevölkerung des Mahafaly Plateaus genutzten Pflanzenressourcen zu erfassen, die sozialen, ökologischen und biophysiologischen Bedingungen, die deren Nutzung und Verfügbarkeit bestimmen, zu verstehen und mögliche Alternativen für deren nachhaltige Nutzung in der Region aufzuzeigen. Diese Arbeit ist Teil des interdisziplinären und partizipativen BMBF-Forschungsprojektes SuLaMa (*Sustainable Landmanagement in south-western Madagascar*), dessen Ziel die Unterstützung von nachhaltigem Landmanagements auf dem Mahafaly Plateau in Südwest-Madagaskar ist.

Das Untersuchungsgebiet, die Mahafaly Region, liegt im Südwesten von Madagaskar. Es ist eine der ökonomisch, klimatisch und im Bildungswesen am meisten benachteiligten Regionen des Landes. Fehlende Infrastruktur und Grundversorgung führen in dieser Region zu einem mangelhaften Versorgungssystem. In dem ariden Steppenklima wird die landwirtschaftliche Produktion durch die begrenzte Wasserverfügbarkeit und den geringen Gehalt an Bodennährstoffen und organischer Substanz limitiert. Die einheimische Bevölkerung ist abhängig von der kleinbäuerlichen Landwirtschaft und Tierhaltung. Fehlende alternative Einkommensquellen sowie das niedrige Niveau der ökonomischen Entwicklung in dieser Region schränken die Möglichkeiten der Bevölkerung, ihren Lebensunterhalt zu verdienen, ein. Dies führt zu einer ständigen Ernährungsunsicherheit, weshalb ein Großteil der lokalen Bevölkerung auf Waldressourcen angewiesen ist, um ihre Grundbedürfnisse zu decken. Teil der Region ist der in jüngerer Vergangenheit erweiterten Nationalpark Tsimanampetsotsa, mit einer Vielzahl an der lokalen Bevölkerung heiligen Waldflächen ebenso wie von ihr gemeinschaftlich genutzten Waldflächen , die jedoch durch Brandrodung und Raubbau der Waldressourcen zunehmend gefährdet sind.

Die vorliegende Studie untersuchte die Verfügbarkeit von wichtigen Ökosystemdienstleistungen der Wälder und ihrer Bedeutung für den Lebensunterhalt der lokalen Bevölkerung vor dem Hintergrund des steigenden Drucks auf die Ökosystemdienstleistungen und -funktionen. Wilder Yams (*Discorea* spp) und Heilpflanzen wurden als Kernelemente des Waldes für die lokale Bevölkerung ausgewählt, da sie zur Verbesserung der Ernährungssicherheit sowie zur medizinischen Versorgung regelmäßig von dieser gesammelt und auf verschiedene Weisen verwendet werden.

Um die Verwendung von wilden Yams und Heilpflanzen zu untersuchen, wurde eine ethnobotanische Erhebung von Juni bis Dezember 2012 in fünf Dörfern in der Mahafaly Region durchgeführt und die Diversität, das lokale Wissen sowie die Verwendung dieser Pflanzen erfasst. 250 Haushalte wurden zufällig ausgewählt, um anhand von teilstrukturierten Interviews deren sozio-ökonomischen Merkmale zu ermitteln. Im Rahmen von Feldbegehungen entlang von Transekten wurden Pflanzenproben für die botanische Bestimmung gesammelt sowie die Sammelplätze der lokalen Bevölkerung erfasst. Die erhobenen Daten erlaubten die Charakterisierung der soziokulturellen und sozioökonomischen Faktoren, welche die Intensität der Verwendung von

wilden Yams und Heilpflanzen beeinflussen. Hierbei wurde die jeweilige Rolle in der Sicherung des Lebensunterhaltes der Bevölkerung identifiziert. Durch Extrapolation der Informationen aus der Haushaltsbefragung konnte ein 350 km² umfassende Fläche als Haupt-Sammelgebiet in der Mahafaly-Region eingegrenzt werden. Dies ermöglichte die Quantifizierung der Häufigkeit von lokal genutzten wilden Yams Arten in dieser Gegend. Anhand von systematischen Feldaufnahmen wurden die Umweltfaktoren, die Bodeneigenschaften und die Intensität der Yams-Knollenernte erfasst. Die Art-Umwelt-Beziehung und die gegenwärtige räumliche Verteilung des wilden Yams wurde, basierend auf abiotischen und biotischen Faktoren, untersucht und mit Hilfe von Ordinationsverfahren und eines Nischen-basierten Habitat-Modells vorhergesagt. Darüber hinaus wurden Art-Wirkungskurven entlang von Bodengradienten erstellt. Die Auswertungen ermöglichten es, die Umwelt- und Habitatansprüche verschiedener Yams-Arten sowie die Bedeutung der durch den Menschen induzierten Veränderungen auf die Artverfügbarkeit, besonders bei stark genutzten Ressourcen, zu verstehen. Vor diesem Hintergrund wurden verschiedene alternative Methoden zur Verbesserung der Regeneration von wildem Yams für die örtliche Bestandserhaltung und die nachhaltige Nutzung in der Mahafaly Region untersucht.

Insgesamt wurden sechs wilde Yams-Arten und 214 Heilpflanzenarten aus 68 Familien und 163 Gattungen im Untersuchungsgebiet identifiziert. Die Ergebnisse der Cluster- und Diskriminanzanalyse deuteten ein klares Muster in der Ressourcen-Nutzung an und ergaben zwei Gruppen von Haushalten, die sich in der Intensität der Sammlung von wilden Yams und Heilpflanzen, dem Wissen über deren Nutzung und ihrem Wohlstand unterschieden. Letzteres wurde durch den örtlichen Viehbestand, nichtlandwirtschaftliche Haushaltsaktivitäten, die verfügbare landwirtschaftlichen Nutzfläche sowie Ernteerträgen bestimmt. Ein generalisiertes lineares Modell stellte heraus, dass ökonomische Faktoren die Sammelintensität von wilden Yams signifikant beeinflussten, wohingegen die Nutzung von Heilpflanzen stärker von soziokulturellen Faktoren abhängt.

Die Redundanzanalyse zeigte ein klares Muster in der Verbreitung von wilden Yams-Arten in den verschiedenen Lebensräumen. *D. alatipes* kam vorwiegend in abgelegenen, Dornbuschwäldern auf Kalkböden vor, während *D. bemandry* und *D. fandra* in dorfnahen Wäldern auf sandigen Böden mit hoher Ernteintensität zu finden waren. Mit Hilfe eines nichtparametrischen multiplikativen Regressionsmodells (NPMR = *Nonparametric Multiplicative Regression Analysis*) konnten 37-88% der Variation in der Häufigkeit der Arten erklärt werden. Die Ergebnisse deuteten zudem auf die Bedeutung der Vegetationsstruktur, Nutzungsintensität sowie der Bodeneigenschaften bei der Bestimmung der Vorkommen wilder Yams-Arten hin. Die Vorhersage der Verbreitung von wilden Yams-Ressourcen zeigte, dass reichhaltige Vorkommen selten und meist begrenzt in offenen Dornwäldern und Dorndickichten vorkommen, wo die Ernte sehr arbeitsintensiv ist.

Feldversuche zum Yams-Anbau (sechs wilde Yams-Arten und eine lokale Sorte, *D. lata*) zeigten, dass die Keimfähigkeit durch Vorbehandlung des Saatgutes verbessert werden konnte und die vegetative Regeneration der oberen Knollenteile (Kormus) eine höhere Keimrate hatte als die Minisetts der Knollen. Die *in-situ* Regeneration aus den oberen Teilen von wilden Knollen war möglich, wobei der Erfolg signifikant vom Bodentyp abhing. Die Verwendung von Dünger (10-20 t ha^{-1}) erhöhte die Erträge von *D. alata* und *D. alatipes* um 40%. Die Regeneration und Keimfähigkeit hingen stark von der Yams-Art und der Anbaumethode ab. Der Anbau wilder Arten war sehr arbeitsintensiv im Vergleich zu *D. alata*, weshalb der Anbau von weiteren heimischen *D. alata*-Sorten aus benachbarten Regionen gefördert werden sollte.

Heilpflanzen und wilder Yams werden zur Deckung der grundlegenden Gesundheits- und Ernährungsbedürfnisse der Bevölkerung in der Mahafaly Region genutzt. Die Studie hebt die Bedeutung von anthropogenen Faktoren auf die Verfügbarkeit von wilden Yams sowie die Notwendigkeit hervor, nachhaltigere Methoden zur Yamsernte einzuführen und zu fördern. Die prädiktive Karte der gegenwärtigen Verbreitung wilder Yams-Arten zeigte eine Reihe geeigneter Habitate in der Mahafaly Region. Die Ergebnisse ihrer Verbreitung sollten jedoch vor der Extrapolation vorsichtig interpretiert werden, da die untersuchte Region nur einen Ausschnitt der Umweltbedingungen in der Gesamtregion darstellte. Dennoch könnte die Bereitstellung von Dienstleistungen des Waldes und deren Verzahnung mit der Bevölkerung durch die gefundenen Tendenzen in der Ressourcennutzung und dem in dieser Studie angewendeten methodischen Ansatz abgeschätzt werden. Aufgrund der Fokussierung auf spezifische Pflanzenarten in dieser Studie könnte die übergeordnete Rolle natürlicher Waldressourcen für die lokale Bevölkerung sogar noch von größerer Bedeutung sein. Ihre erfolgreiche Erhaltung erfordert daher die Einbeziehung der Kommunen als Akteure in die nachhaltige Managementplanung.

Die nachhaltige Nutzung dieser Ressourcen und die Erhaltung der Lebensgrundlage der einheimischen Bevölkerung erfordern die Durchführung verschiedener Initiativen und partizipatorischer Aktionen (z.B. die Domestizierung von wilden Arten, die Kultivierung lokaler Yams-Sorten, Umweltbildung und die Förderung nachhaltiger Erntemethoden). Solche Aktionen könnten bei der Reduzierung der anhaltenden Belastung der natürlichen Ressourcen und dem Habitatschutz helfen. Der Naturschutz sollte sich dabei auf die Erhaltung der Biodiversität als Lieferant von Ökosystemdienstleistungen für die einheimischen Kommunen unter Einbeziehung des *Rapid Vulnerability Assessment* (RVA) sowie auf langfristige Kontrollen und Monitorings der stark genutzten Ressourcen fokussieren.

1 General introduction

1.1. Assessing biodiversity, forests provisioning services and their sustainable use: concepts and methods used in rural areas in developing countries

1.1.1. Importance of biological diversity and forests provisioning services for local communities

The most widely accepted definition of biological diversity was given by the Convention on Biological Diversity (CBD), which is the 'variability among living organisms from all sources, including, inter alia, terrestrial, marine and other aquatic systems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems' (CBD, Article 2; http://www.cbd.int/convention/articles/default.shtml?a=cbd-02). However, there is still much debate regarding how biodiversity is measured and valued (Christie et al., 2007; Humphries, 1995). Indeed, the CBD recognizes that all levels of biodiversity provide a range of fundamental goods and services essential in supporting human health, wellbeing and the provision of livelihoods (Constanza et al., 1997; Daily, 1997). This concepts was followed by the Millennium Ecosystem Assessment (MEA, 2005), which defined ecosystem services as the benefits people obtain from ecosystems, categorized in provisioning (e.g. food and water), regulating (e.g. flood and disease control), cultural (i.e spiritual and cultural benefits) and supporting (i.e nutrient cycling, seed dispersal) services. Thus, biodiversity contributes to many aspects of human well-being, for instance by providing raw materials and contributing to health, but their values are specific to locations as they include many dimensions (social, cultural, economic or environmental). Assessing those specific values is important for the conservation and sustainable use of natural resources, and to ensure that local communities are benefiting from those conservation efforts.

In rural areas, the most important perceived benefits are often the so called 'provisioning services' such as food, fuel wood, fiber, medicinal plants (Iftekhar and Takama, 2007). They are usually extracted from their natural habitats (e.g. savannah, bushland, forest). The rural communities, especially in developing countries, have a high dependency and direct reliance on natural resources. Here, analysing the parameters and factors that drives this dependency is fundamental for conserving natural resources and securing the livelihoods and well-being of rural communities. However, much of these direct uses and other values of biodiversity are often unaccounted for leading to a subsequent over-exploitation of natural services (de Groot et al., 2012). Thus, for rural areas in developing countries, priorities must be given to the locally most important set of provisioning services from the forests.

There exist different methods to assess the importance of provisioning services for the wellbeing of local communities and their livelihood systems. For example, environmental economists have developed a range of methods, using e.g. market prices or production functions, which place monetary values on the biodiversity and its ecosystem services, allowing its benefits to be directly compared with other development systems (de Groot et al., 2012). However, there exist also non-economic methods that are often used to assess the importance of biodiversity to local communities in rural areas of developing countries. Such methods range from structured survey techniques (e.g. questionnaires, and interviews) to more participatory approaches (e.g. participatory rural appraisal and participatory action research). Surveys mostly aim at recording the relevant resources utilized, indigenous knowledge, perception and expectations, and provide useful information on the community accesses to natural resources or, to what purpose and how important these are to them (Brouwer et al., 2013). The quality of the outcome often relies on the choice of variables designed in the questionnaires and the characteristics of the target population which influence their responsiveness to the survey (Kish, 1995). The use of questionnaires is widespread in natural resource management and conservation areas and is usually elaborated through face to face interviews (Christie et al., 2008) to avoid problems of low literacy and education levels. A combination of techniques, such as participatory action research, ethnobotanical surveys, participatory transect walk with local communities, monitoring of population declines, or participatory mapping (Castro et al., 2014; Milcu et al., 2013; Paudyal et al., 2015) often increase the scientific value of the outcome (Chan et al., 2012).

Interdisciplinary approaches are important in this context because resource use is often culturally determined and they enable a better understanding of the dynamic nature and the relationships between people and their environment. Such approaches support the development of policies with appropriate implementation programs (World Bank, 2008). Yet, the relationship between humans, ecosystem services and biodiversity is complex (ICSU-UNESCO-UNU, 2008), which makes the assessment and the valuation often challenging.

1.1.2. Importance of human dimensions in quantification and conservation of forests provisioning services

People are part of ecosystems and shape them, from local to global scales, and at the same time fundamentally dependent on the capacity of these ecosystems to provide services for human wellbeing and societal development (MEA, 2005; Norström et al., 2014). Thus, trends in the quantification of ecosystem services has moved in recent years from concern about the quantity of the harvested species, to a wider concern on harvesting effects on ecosystems.

Hence, research seeks to understand the relationship of natural resources availability and their use with ecological, social, socioeconomic and cultural factors (Cloquell et al., 2006; Lambin and Geist, 2006; Liu et al., 2007). A number of methods have been employed in household case studies to link biophysical and socioeconomic data in geographic and temporal representations (Evans and Moran, 2002; Lambin, 2003; Rindfuss et al., 2004). However, an increasing need for more spatially explicit approaches in quantifying ecosystem services and their sustainable use as spatial flows can provide a more complete understanding of ecosystem services. In this context, modelling approaches for mapping and quantifying the ecosystem capacity include biophysical conditions (e.g. vegetation, habitat types, soil charactersitcs, etc.), anthropogenic features (e.g. land use) to depict service flows, and users (user location and level of demand; Bagstad et al., 2014). Hitztaler and Bergen (2013) integrated spatial, ecological and ethnographic data to predict and quantify resource uses and landscape pattern in central Kamcharka in Russia. This kind of spatial approach can be very useful for conservation management, for example, to indentify harvesting hot-spots and their spatial disturbance. Another methodological approach was the spatial study of target wildlife species in Indonesia, in order to facilitate and strengthen conservation efforts by the Indonesian government to stabilize wildlife populations (Abram et al., 2015). Some literatures go further by using modelling approaches for studying changes in management strategies and well-being in order to study the distribution of species within a landscape and subsequently predict suitable habitats for species conservation action plans. In this regard, Whitehead et al. (2014) presented a conservation approach that spatially represented social values and development preferences based on species distribution models for threatened species to represent biological values.

Human impact upon ecosystem services refers to ‘direct’ and ‘indirect’ drivers. Examples of direct drivers include over-exploitation, change in land use, and other instances in which human action has a clear impact on ecosystems. Indirect drivers are more diffuse such as demographic, economic, cultural changes, sociopolitical transformations which all affect ecosystems and the quality of their services (REF). In rural areas of developing countries, where both poverty and biodiversity loss are highly linked, research efforts tend to focus on direct drivers that change the availably and quality of ecosystem services. In this context, scientists are often focusing on the sustainable use and conservation of non-timber forest products (Vitoule et al., 2014).

A general indicator of the sustainable use of one or several species may be the continuous presence of a species above a certain abundance threshold sufficient to guarantee its future viability in terms of demographic persistence and ecological persistence. Recent trends in this topic address the socioecological system and resilience (SESs), defined as ‘the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks’ (Folke et al., 2010). The approach taken by SESs modelers and by ecosystems service and conservation researchers links biodiversity directly to the supply of ecosystem services.

1.2. Research area

Mahafaly Plateau is located south-western Madagascar, belonging to the country’s Atsimo-Andrefana region. It is one of the most disadvantaged regions of Madagascar in terms of economy, education and climate, with more than 88% of rural households classified as poor. The gross domestic income per capita was US$ 265 in 2013 and people living below the porverty line are less than $US 200 per capita per year (Neudert et al., 2014). In addition, local infrastructure is very poor leading to an insufficient supply of basic facilities such as schools and health services (Andriatsimietry et al., 2009).

The Mahafaly region is characterized by an arid steppe climate, with an annual mean temperature of 24°C, and a dry season usually lasting from March to October. Rainfall can be highly variable (Richard et al., 2002), with its onset shifting about two months as registered during the last few years (Ratovomanana et al., 2013). The SuLaMa project has defined a study area of 10,000 km² that comprises six communes and 185 permanent settlements or 'Fokontany' (Brinkmann et al., 2014). It also includes the recently extended Tsimanampetsotsa National Park (from 42,200 to 203,000 ha in 2007; 24°03′-24°12′ S, 43°46′ - 43°50′ E; Ratovomanana et al., 2007), with numerous sacred and communities forests. The national park is managed by Madagascar National Parks (MNP), in partnership with WWF Madagascar and GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit). The management of the park area is divided in three zones (core, controlled occupation and controlled utilization; Mamokatra, 1999). The last zone is managed by local communities, where collection of forest resources and ancestral rites such as traditional funerals are allowed through an officially recognized community-based organization (COBA).

The habitat is dominated by deciduous spiny forests with drought tolerant woody species of Didieraceae and Euphorbiaceae and xerophytic bushland and savannah. The area harbours the highest level of plant endemism both at the generic (48%) and species (95%) levels of Madagascar (Mamokatra, 1999). There exist two main ecological regions, whereby the 'Littoral zone' situated in the western part of the Tsimanampetsotsa National Park (Figure 1-1) is dominated by dry forests on sandy soils (Figure 1-2a), while the 'Plateau' is characterized dry spiny forests on tertiary limestone or ferruginous soil (Figure 1-2b; Du Puy and Moat, 1998). Rainfall is very irregular, and varies greatly from the Littoral zone to the Plateau, but the most reliable records indicate long term averages of less than 500 mm throughout the region (UPDR, 2003).

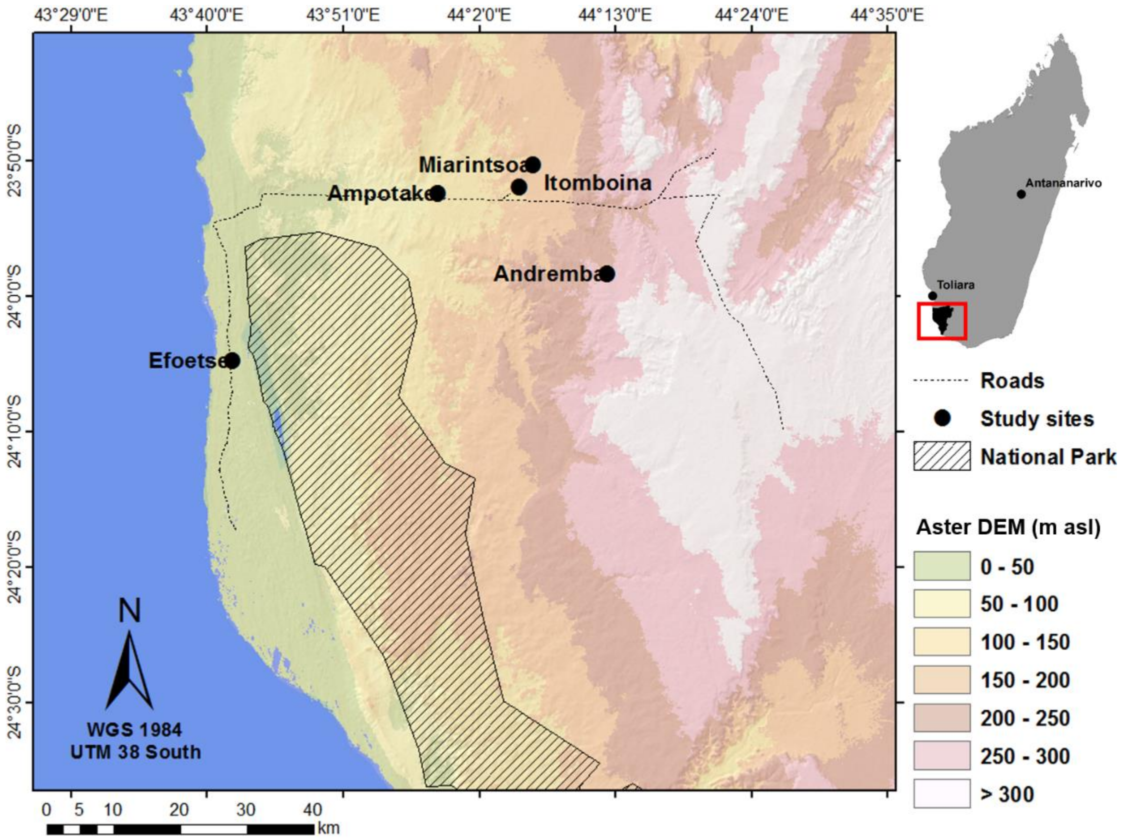

Figure 1-1 Topographic map of the study area in SW-Madagascar. On the west of the national park is the 'Littoral zone' and the east the 'Plateau'.

Ethnically the region is dominated by 'Vezo' in the coastal villages, and 'Tanalana and Mahafaly' elsewhere (Figure 1-2 c, d). The Vezo mainly depend on fishing with a combination of agriculture and animal husbandry while in the remainder of the Mahafaly region, people are cattle herders who largely depend on smallholder agriculture and livestock keeping (Eggert, 1979). The local concepts of wealth in this region refer primarily to the number of livestock owned by a household. Cattle are kept to accumulate capital in the absence of banks and to reflect a person's social status (SuLaMa, 2011). While rice is the staple food throughout Madagascar, it is widely replaced by cassava (*Manihot esculenta* Crantz) in the country's South-West due to cassava's tolerance to infertile soils and low levels of precipitation. Thus, agriculture in the Mahafaly region is mainly based on cassava, maize (*Zea mays* L.) and minor crops such as sweet potatoes (*Ipomoea batatas* L.) and legumes such as *Vigna unguculata* L. and *Vigna radiata* L. In this region, subsistence agriculture is entirely rainfed, without external inputs or other soil amendments (Faust et al., 2014). Thus, agricultural production is heavily limited by water throughout the year, followed by low level of soil nutrients and soil organic carbon. Agriculture and animal husbandry face natural hazards such as droughts, cyclones and locust infestations (SuLaMa, 2011; Brinkmann et al., 2014). Climate change has increased the variability of rainfall events, restricting agriculture even more. Additionally, the absence of income alternatives and the low level of economic development in the area limit the livelihood strategies of the population, leading to a high level of food insecurity (SuLaMa, 2011, WFP, 2013). Agriculture and livestock keeping are often not sufficient to survive and people have to rely on the supplementary exploitation of forests resources, charcoal production, collection of wild food, and other non-timber forests products, and non-farm activities like fishing, temporary migration, and handicraft. In addition, people continue to practice slash-and-burn farming of cash crops and collect forest products for urban consumers such as wood for fuel wood and construction material.

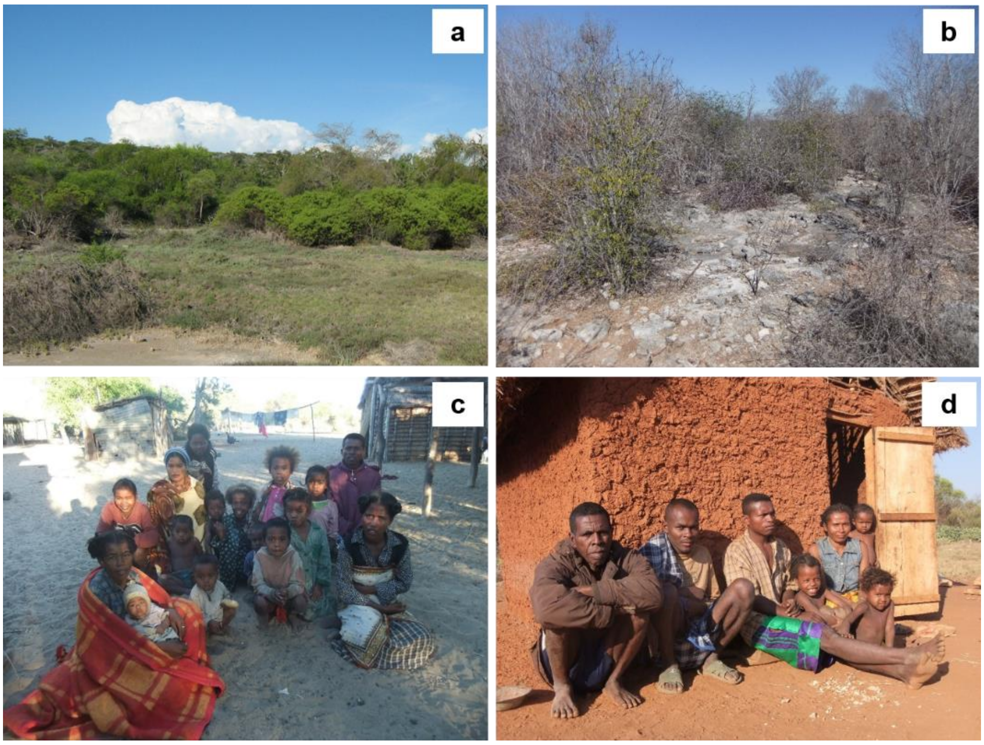

Figure 1-2 Type of natural habitats and inhabitants (a+c) of the Littoral zone and (b+d) in the Plateau, and local people (‘c’ in the Littoral zone and ‘d’ in the Plateau zone) of the Mahafaly region in SW-Madagascar.

These circumstance combined with the population growth, have strongly increased the disturbance of the ecosystems services and functions in the Mahafaly region. Moreover, the pressure on forests resources in and outside the Tsimanampetsotsa National Park area increased and lead to forest degradation with high forest losses (-45%) during the past 40 years (Brinkmann et al., 2014). Addressing these concerns, the SuLaMa project conducted research activities on alternative land management techniques provide the scientific basis for more sustainable management of ecosystems, biodiversity and livelihoods of the local population in this region.

1.3. Reason for investigating wild yams and medicinal plants among the range of forests provisioning services?

Within the framework of the SuLaMa project, a preliminary study mainly based on survey and observations were carried out in the Mahafaly region, from August to September 2011. The baseline survey followed a Participatory Rural Appraisal (PRA) approach. The goal of this survey was to identify desires and problems of the local population, investigate existing infrastructure, develop communication, identify research sites and involve local stakeholders to act as a coherent group (SuLaMa, 2011). From this study, it has been reported that, a substantial part of the people collect wild fruits, root crops and medicinal plants to cope with the prevailing food insecurity and the lack of basic health services. Among the non-timber forests products, the collection of wild yam species (*Dioscorea* spp.) and medicinal plants was frequently mentioned by the local population, as they contribute to the well-being of rural households in terms of direct use, alternative sources of nutritional supplements and supplementary income generation. In addition to those reports, medicinal plants have often been used as an alternative to conventional medicine, especially in rural areas of developing countries (Shippmann et al., 2002). The existence of many cultural practices showing the high social cohesion among the population was also reported. For example, ‘Ombiasy’ or traditional healers are important in the collection of medicinal plants.

Madagascar has a rich diversity in yams. However, out of the 42 yam species inventoried in Madagascar, only three species are cultivated (only under extensive cultivation or cultivated in backyard or on fallows), and the rest grow wild and in forests areas. Wild yams are known as an important subsistence food throughout Madagascar (Perrier de la Bathie, 1925; Jeannoda et al., 2007). Yet, the baseline village survey (SuLaMa, 2011) reported that during the past years, the amount of harvested wild yam tubers has strongly increased given a rising insufficiency of crop production. Thus, within the overall objective of the SuLaMa project, we chose to investigate wild yams and medicinal plants as case studies for provisioning services from forests areas in the Mahafaly region. We argue that focusing on such frequently used and locally important resources may help to explain the interlinkage between the local communities and the forests provisioning services in the Mahafaly region.

1.4. Research objectives and research hypotheses

To broaden the scope of the SuLaMa project in the area of conservation and farmers’ livelihood with the sustainable use of plant diversity, the present study aims at assessing the diversity of plant resources utilized by the local population, understanding the socio-ecological conditions that drive their uses and availability, and the indentification of possible alternatives for their sustainable use in the Mahafaly region, using wild yams and medicinal plants as an example.

Therefore, the objectives of the following studies were:

- To assess and analyse the diversity and local use of wild yams and medicinal plants in the Mahafaly region, and to identify their role in the livelihoods of local people.
- To analyse the impact of environmental factors, human activities and their interactions on wild yam species distribution in the Mahafaly region, and to predict their abundance using species distribution models (SDM).
- To investigate the potential regeneration performance of wild yam species and a local variety of cultivated yam species (*D. alata* var. *bemako)* using field trials, and *in-situ* experiments.

In view of these aims and objectives, we hypothesize that:

- Local knowledge on the usage of wild yams and medicinal plants depends on the socioeconomic conditions and wealth status of households. Thereby, poorer households depend to a higher degree on forest resources and have a higher knowledge as to their uses than well-off farmers.
- Occurrence and abundance of wild yam species is largely determined by soil properties, vegetation structure and human interventions rather than topography.
- Domestication of wild species and promoting the cultivation of domesticated varieties are important elements in a comprehensive strategy to fulfil local subsistence needs while protecting wild germplasm of yam.

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2 Effect of socio-economic household characteristics on traditional knowledge and usage of wild yams and medicinal plants in the Mahafaly region of south-western Madagascar

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2.1. Abstract

Background: Rural households in the Mahafaly region of semi-arid SW-Madagascar strongly depend on the exploitation of natural resources for their basic needs and income regeneration. An overuse of such resources threatens the natural environment and people's livelihood. This study focuses on the diversity and use of wild yams and medicinal plants.

Methods: We hypothesize that knowledge on the use of these resources highly depends on farmers 'socio-economic household characteristics. To test this hypothesis, an ethnobotanical survey was conducted based on semi-structured interviews recording socio-economic base data and information on local knowledge of medicinal and wild yam species. This was followed by field inventories compiling plant material for botanical identification.

Results: Six species of wild yam and a total of 214 medicinal plants from 68 families and 163 genera were identified. Cluster and discriminant analysis yielded two groups of households with different wealth status characterized by differences in livestock numbers, off-farm activities, agricultural land and harvests. A generalized linear model highlighted that economic factors significantly affect the collection of wild yams, whereas the use of medicinal plants depends to a higher degree on socio-cultural factors.

Conclusions: Wild yams play an important role in local food security in the Mahafaly region, especially for poor farmers, and medicinal plants are a primary source of health care for the majority of local people. Our results indicate the influence of socio-economic household characteristics on the use of forest products and its intensity, which should be considered in future management plans for local and regional forest conservation.

Keywords: Discriminant analysis, Local knowledge, Medicinal plants, Socio-economic factors, Wild yams

2.2. Background

Madagascar constitutes one of the most important biodiversity hotspots worldwide with more than 90% of its plant and animal species being endemic, however, these resources are severely threatened by ecosystem degradation (Myers et al., 2000; UNFP, 2008). With a gross national income (GNI) per capita of $US 828 (UNDP, 2013), Madagascar ranks 151 out of 187 countries on the Human Development Index (HDI). Altogether, 74% of the population lives in rural areas of which 78% are considered poor (WRI, 2002) and mostly depend on the direct exploitation of natural resources (fields, water, forests) for their livelihoods.

The arid south-western region of Madagascar, commonly referred to as the Mahafaly region, is the country's economically and climatically most disadvantaged area. It is characterized by high biotic endemism, listed as one of the 200 most important ecological regions in the world (Olson and Dinnerstein, 2002). The subsistence production of the rural population comprises fishery, agriculture, livestock husbandry, and the collection of forest resources. Farmers' livelihoods and economic development is hampered by a low level of education, limited income alternatives and poor infrastructure. The productivity of the cropland is limited by highly unpredictable rainfall and soil fertility constraints very similar to those encountered in the West African Sahel (Batiano et al., 1998; Buerkert et al., 1998). Therefore, collection of forest products provides an important supplementary source of income (SuLaMa 2011), and an overuse of such resources threatens people's livelihood. Among these forest products, the collection of wild yam (*Dioscorea* spp.) species and medicinal plants were identified as important for the local population (SuLaMa 2011; The SuLaMa at http://www.sulama.de/index.php/en/), as they contribute to the well-being of rural households in terms of direct use, human nutrition and income generation. Medicinal plants constitute an important alternative to conventional medicine, especially for poor communities in rural areas without access to health services and they display a very large diversity in terms of species number (Shippmann et al., 2002). According to the World Health Organization, approximately 80% of the world's inhabitants rely predominantly on traditional medicine for their primary health care (Cao et al., 2009). Of approximately 13,000 species present in Madagascar, about 3,500 are reported to have medicinal properties (Rasoanaivo, 2006). Madagascar has also a rich diversity of yam with altogether 40 species of which 27 are endemic and most of the species have edible tubers (Burkill and Perrier de la Bathie, 1950), which are a staple food in many tropical countries. Wild yams have been reported to play an important role in rural household livelihood systems where they are traditionally eaten during periods of food insecurity (Jeannoda et al., 2007). The genus *Dioscorea* is distributed in various areas in Madagascar, but 24 species including 20 endemics were observed in the south western region (Tostain et al., 2010). These species are all edible, but the intensity of local usage depends on taste, local needs, market prices, location and harvested amounts. Other factors governing tuber use are differences in culture, gender, language, ethnicity, political belief system, personal preferences, appropriation skills and the availability of these resources in collection areas (Bardhan et al., 2000).

Detailed information on the importance of wild yams and medicinal plants for people's livelihood and the factors influencing the intensity of their use are urgently required for natural resource management policy and planning, and is lacking for south-western Madagascar. Therefore, the objective of this study is to analyze the diversity and use of wild yams and medicinal plants in the Mahafaly region, and to identify their role in the livelihoods of local people. We hypothesize that local knowledge on the usage of wild yams and medicinal plants depends on the socio-economic conditions and wealth status of households. Thereby, poorer households depend to a higher degree on forest resources and have a higher knowledge of their use than well-off farmers.

2.3. Materials and methods

2.3.1. Description of the study area

The study area is situated in the northern part of the Mahafaly region, in south-west Madagascar. The studied villages are located on the adjacent coast (Littoral) and on the west side (Plateau) of the Tsimanampetsotsa national park (24°03′ -24°12 ′ S, 43°46 ′ - 43°50 ′ E; Figure 2-1). The area is characterized by dry and spiny forest vegetation with the highest level of endemism in plant species registered in Madagascar (48% of genera and 95% of species; (Elmqvist et al., 2007). The natural vegetation consists of a deciduous forest characterized by drought tolerant woody species of Didieraceae and Euphorbiaceae, xerophytic bushland and savannah. In the Littoral zone dry forests on sandy soil dominate while on the Plateau, dry and spiny forests on tertiary limestone or ferruginous soil occur (Du Puy and Moat, 1998). The semi-arid climate is characterized by an annual mean temperature of 24°C and a highly variable annual rainfall ranging between 300 - 350 mm in the Littoral and 400-450 mm on the Plateau (UPDR, 2003). The dry season lasts nine to ten months and the rainy season usually starts from November to April. The unreliability and unpredictability of rainfall is one of the major factors limiting agricultural production by the predominantly small holder farmers and herders, who also rely on forest products to fulfil their daily needs throughout the year. During the past 40 years forest cover declined by 45% due to slash and burn agriculture and uncontrolled bushfires (Sussman et al., 2003; Brinkmann et al., 2014). In addition, the region has the lowest education rate of Madagascar and the majority of the households were classified as poor (INSTAT, 2013) in combination with a lack of basic health services and infrastructure. Altogether, 41% of the local population on the Mahafaly region is affected by food insecurity and famine (WFP, 2013). Rapid population growth and the recent expansion of the Tsimanampetsotsa national park (from 42,200 to 203,000 ha in 2007) have increased the pressure on the forests resources in and outside the park area (Brinkamann et al., 2014; Mamokatra, 1999; Ratovomanana et al., 2013).

Combined with the effects of climate change this leads to an increasing over-use of the natural resources in the Mahafaly region.

In the Mahafaly region wild yams are used to supplement cassava (*Manihot esculanta* Krantz) and maize (*Zea mays* L.), especially during hunger periods (‘Kere’). Local reports indicate that during the past years the amount of harvested wild yam tubers has strongly increased given a rising insufficiency of crop production.

2.3.2. Field survey

The field work was conducted from June to December 2012 in five villages that were part of a larger village and household survey (Brinkmann et al., 2013; Neudert et al., 2014): (1) Efoetse in the Littoral (S 24°4 ′ 42,41 ″ - E 43°41 ′ 54,78 ″), (2) Ampotake (S 23°52 ′ 27,78 ″ - E 43°58 ′ 36,55 ″), (3) Andremba (S 23°58 ′ 17,60 ″ - E44°12 ′ 17,05 ″), (4) Itomboina (S 23°51 ′ 59,15 ″ - E 44°5 ′ 10,9 ″) and (5) Miarintsoa (S 23°50 ′ 14,21 ″ - E 44°6 ′ 17,68″) on the Plateau. Village selection was based on (1) market accessibility, (2) distance to the national park, (3) intensity of forest product collection of village inhabitants and (4) diversity of household activities.

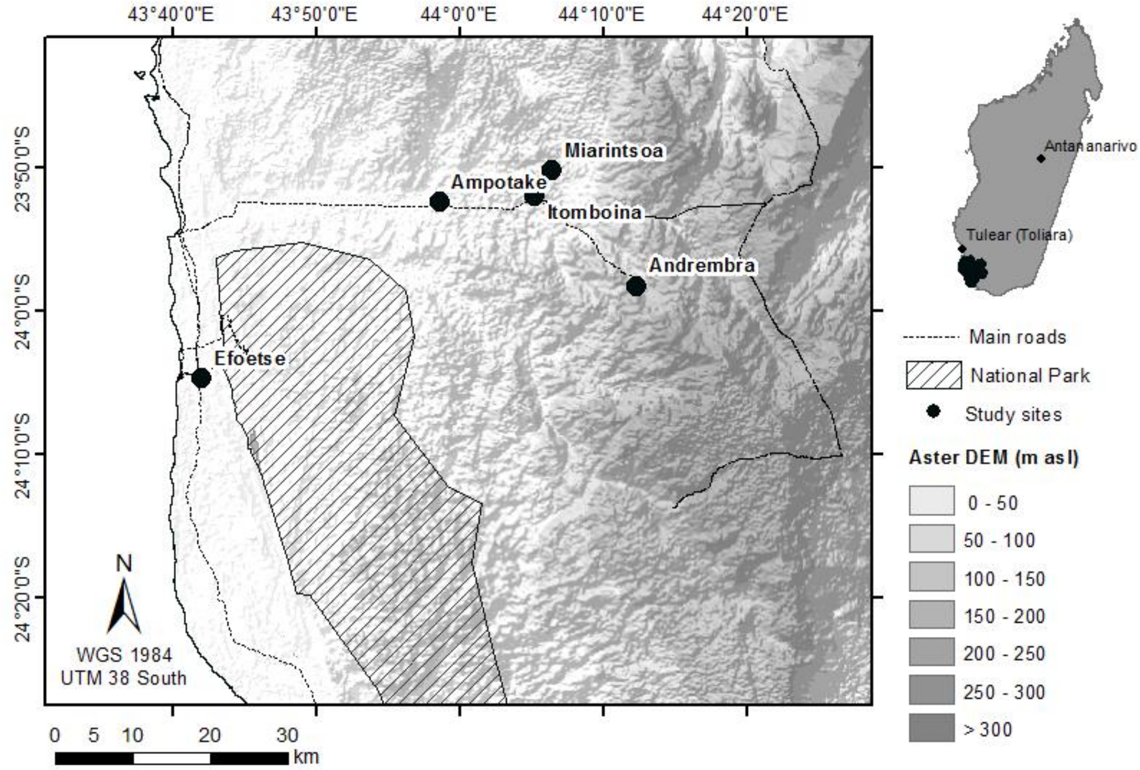

Figure 2-1 Location of the study area in the Mahafaly region of SW-Madagascar.

For each village, 50 households (HH) were randomly selected based on acomplete household list (total N = 250). Pre-testing interviews and field observations were performed with key informants selected by snowball sampling (Stepp, 2005). Semi-structured interviews (Berlin, 2005) were conducted with the household head after we received his consent. The Code of Ethics of the International Society of Ethnobiology was followed. If household head declined to take part in an interview, an alternative household was chosen based on an existing household list of the village. The questionaire was divided in three thematic sections:

1. Information on socio-cultural and economic characteristic (family size, source of income, agricultural harvest, origin of the head and spouse, land area available for cultivation, livestock owned, harvest satisfaction, education level, ethnic group, religion, gender affiliation and age of respondents);
2. Household consumption, collection and use of wild yam species;
3. Medicinal plants and the knowledge about their uses. Respondents were also asked about specific plant parts used and the habitat from which they collected the plant material.

All interviews were supplemented with field observations and forest walks. Since informants were only able to mention the local species name, plant specimen were collected in the field to establish a digitalherbarium of inventoried specimens for botanical identification (Martin, 1995) in the Herbarium of the Botanical and Zoological Parc of Tsimbazaza (PBZT) in Antananarivo (Madagascar), following the nomenclature of the Tropicos database of the Missouri Botanical Gardens (Tropicos.org; http://www.tropicos.org). In the absence of any formal ethics committee the concept, content and questions related to this study conducted within the participatory SuLaMa (Sustainable Land Management in South-Western Madagascar) project (http://www.sulama.de/index.php/en) were discussed and approved at the governmental and the village level in several meetings as were the outcomes of the interviews.

2.4. Data analysis

The consumption, collection intensity and usage of wild yams were analysed using the following interview data: number of species collected, frequency of collection per month, period of collection per year, average number of tubers collected per collection event (estimated by the number of harvest holes), number of collectors per households, type of consumption (staple or additional food) and sale of tubers. The types of medicinal usage were categorized in different medicinal categories according to Cook (1995). To estimate the informant knowledge on the use of medicinal plants, the diversity of medicinal plant uses (Simpson, 1949; Byg and Balslev, 2001) was calculated for each informant. The species (UVs) and the family use values (FUV) were computed (Table 2-1) (Phillips and Gentry, 1993; Albuquerque et al., 2007) to compare the importance of plant species and families.

All statistical analyses were carried out using SPSS 17.0. A two-step cluster analysis was used to identify household groups based on socio-economic characteristics and plant use patterns. The existence of collinearity was tested based on correlation coefficients and suspicious data was removed from the dataset resulting in the following parameters used for cluster analysis: Education level, agricultural harvest, household activities, family size, tropical livestock units, agricultural area, medicinal plants used, number of medicinal uses and diversity of medicinal plant use (D), wild yam species collected, amount of tubers harvested (number of holes harvested for each collection), frequency of collection, sale, collection period and use of wild yams. To evaluate the contribution of each variable in separating the resulting households groups, a Discriminant Analysis (DA) was conducted using the standardized canonical coefficients, canonical correlation coefficients, Eigen value and Wilk's Lambda. A structure coefficient matrix was established which allowed to assess the importance of each variable in relation to the discriminant function.

Table 2-1 Ethnobotanical indices used for measuring informant's medicinal plant knowledge in the Mahafaly region of SW-Madagascar

Indices	Calculation	Description
Diversity of medicinal plant use (D)	$D = 1/\sum Pi^2$, where Pi^2 is equal to the number of times a species was mentioned by informant 'i' divided by the total number of informant answer.	Simpson's Reciprocal Index (Simpson, 1949), adapted by Byg and Balslev (2001). Measures how many medicinal plant species an informant uses and how evenly his uses are distributed among the species.
Species use value (UVs)	$UVs = \sum UVis / ni$, where UVis is the sum of the total number of use citations by all informants for a given species and ni is the total number of informants.	Evaluates the relative importance of each plant species based on its relative use among informants (Phillips and Gentry, 1993), adapted by Albuquerque et al. (2007).
Family use value (FUV)	$FUV = \sum UVs / ns$, where $\sum UV_S$ is the sum of species use value (UVs) within a family and ns the number of species within a family.	Evaluates the use importance of a given plant family (Phillips and Gentry, 1993)

A One Way ANOVA (Analysis of variance) was performed to compare the differences of knowledge and use between communities in relation to their location (villages). Additionally, we used Jaccard's similarity index, which was based on species usage data to determine the similarity of species usage among villages (Mueller-Dombois and Ellenberg, 1974).

To determine which cultural and socio-economic variables influence the use intensity and knowledge on medicinal plants and wild yams (response variables), we used a Generalized Linear Model (GLM) based on a Poisson distribution. The GLM consisted of two models with eight response variables, which explain the relationship between predictors and the knowledge on medicinal plants (number of medicinal plants used) and the use of wild yams (frequency of yam collection per month). The performance and the fit of the models were assessed using the Akaike Information Criterion (AIC; Burnham and Andreson, 2002). In each model, we included main effects and choose the Type III analyses and Wald chi-square as statistical tests. The 0.05 significance level was used to assess if an in dependent variable related significantly to a dependent variable.

2.5. Results and discussions

Socio-economic characteristics of the interviewed households average household size varied between 6.3 persons in Itomboina and 7.2 persons in Miarintsoa (Table 2-2) whereby big households typically comprised a polygamous household head. Thus, each sub-family might live separately, but all family members eat together and share the same income. The education level of the households was highly variable across the villages, but in general, 30% of interviewed households did not receive formal education and only half visited at least the first year of primary school. The village with the highest rate of illiteracy, Ampotake, had no school. However, in Efoetse, where public and even private schools are available, literacy was high. The majority of the households comprise smallholder farmers, which conduct different off-farm activities for cash income generation, such as salaried work, artisanal activities, trading, fishing, charcoal production or the collection of wood and other forest resources. The average household's agricultural area was 2.2 ha of which some was partly left uncultivated due to heavy weed encroachment or a perceived decline in soil productivity. For the majority of households, periods of food insecurity due to unpredictable and insufficient rainfall are frequent and people heavily depend on supplementary off-farm income. Most of the household heads were born in the village where they live, only 26% are immigrants. The majority of households (60%) has traditional religious beliefs (ancestor reverence) and conduct ritual practices, while 30% are Christian (Catholic, Protestant or Anglicans).

2.5.1. Diversity and traditional use of plants

2.5.1.1. Wild yams

Altogether, six endemic species of wild yam were identified as potential food resource in the Mahafaly region: *Dioscorea ovinala* Baker (local name: 'Angily'), *Dioscorea alatipes* Burk. & H. Perr. ('Ovy'), *Dioscorea nako* H. Perr. ('Fandra'), *Dioscorea fandra* H. Perr. ('Andraha'), *Dioscorea bemandry* Jum. & H. Perr. ('Baboky') and *Dioscorea soso* Jum. & H. Perr. ('Sosa'). Two thirds of the interviewed households (70%) were collecting wild yams. Yam collection was only uncommon in Efoetse where yams could be purchased from nearby markets. This is mainly due to the limited access to forest and yam resources in the Littoral zone, where larger forest areas are lacking except of the Tsimanampetsotsa national park area. In addition, wild yam species are relatively rare on that adjacent side of the national park where only *D. nako* occurs. Wild yam tubers are used as a staple food by 42% of the households where they substitute cassava, maize or sweet potato (*Ipomoea batatas* L.), especially in villages situated near forest areas, where daily plant collection is possible. Respondents mentioned that they eat yams before the meal to reduce the quantity of staple food during the lean season. *D. alatipes* was most frequently collected (99% of yams collecting households), mainly because of its sweet taste and nutritional value. The so called water yam, *D. bemandry*, was also important and collected by 88% of households, because of its sweet taste and its big and long tubers (50 - 120 cm long). *D. soso* had the lowest collection rate (34% of households) given its scarce occurrence in the surrounding forests, although its taste is also appreciated by the local population.

Table 2-2 Socioeconomic characteristics of the interviewed households (HH) in the five villages of the Mahafaly region in SW-Madagascar

Characteristics		Ampotaka (n = 55)	Andremba (n = 50)	Itomboina (n = 50)	Miarintsoa (n = 50)	Efoetse (n = 50)	Total
Age of the respondents		41.7±17.3	44.2±15.5	46.7±18.3	40.4±17.6	42.6±19.9	43.1±17.8
Family size		6.8±3.9	6.4±3	6.3±3.3	7.2±3.7	6.7±2.3	6.7±3.3
TLU		1.6±3.1	5.1±9.2	4.8±7.5	6.9±10.9	9.2±12.8	5.5±9.5
Land owned (ha)		1.6±1.4	1.7±1.1	2.3±2.1	2.7±2.1	2.7±2.1	2.2±1.8
Agricultural harvest (%)	Low	44	36	62	32	14	38.0
	Medium	50	42	36	52	66	49.2
	High	6	20	2	16	20	12.8
HH activities (%)	Low	42	38	38	24	46	37.6
	Medium	36	46	44	46	40	42.4
	High	22	16	18	30	14	20.0
Education level	Low	52	22	32	16	24	29.2
	Visit primary school	34	56	50	54	54	49.6
	Finish primary school	14	22	18	30	22	21.2
Origin of the head of the HH (%)	Born in the village	28	10	40	38	18	26.8
	Not born in the village	72	90	60	62	82	73.2
Gender of the respondents (%)	Male	60	70	64	74	84	70.4
	Female	40	30	36	26	16	29.6
Religion (%)	No religion	14	8	4	6	17	9.7
	Traditional	60	62	64	58	55.3	59.9
	Christian	26	30	32	36	27.7	30.4

2.5.1.2. Medicinal plants

Altogether, 221 medicinal plants are used by the local people in the Mahafaly region (Appendix 1-1) of which 214 plant species were taxonomically identified and belong to 163 genera in 68 plant families. These plants are used to treat 46 diseases occurring in human and/or livestock. Most species belonged to the Fabaceae (34 species), followed by Apocynaceae (17 species), Euphorbiaceae (16 species) and Malvaceae (10 species; Figure 2-2). Some families, such as the Aizoaceae, Aristolochiaceae, Flacourtiaceae, Myrtaceae, Sapotaceae, and Moringaceae were represented by only one species. Plant families with the highest FUV are Rutaceae (1.53), Capparaceae (1.37), Hernandiaceae (1.27) and Asteraceae (1.24). Among the 46 uses reported, the most common are digestive disorders, muscular skeletal problems and cosmetic care for women.

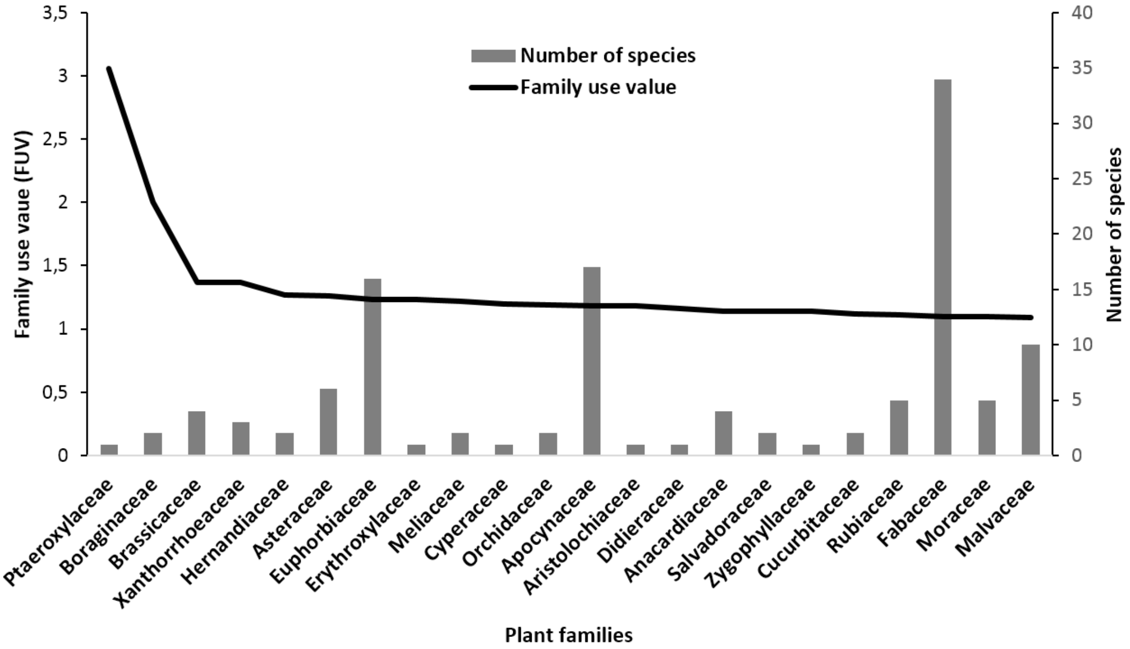

Figure 2-2 Most important plant families identified by family use value (FUV, description see Table 1) and number of medicinal plant species per family used in the Mahafaly region in SW-Madagascar.

The growth forms of the recorded plants species are shrubs (38%), trees (28%), herbs (20%), lianas (11%), vines (2%), and epiphytes (less than 1%; Figure 2-3A). Most medicinal plants (82%) are collected in forest areas, 14% are cultivated and the rest is typically found in fallow land or rangelands such as bushland and grassland. Although the majority of the used plants are endemic to Madagascar (68%), exotic plants or plants that have a large worldwide distribution are used as well. Altogether, 95% of the recorded medicinal plants can be found in the Mahafaly region, the remainder are species bought or imported from the nearest town or from neighbouring regions. The most frequently collected plant parts are the aboveground plant material, e.g., stems and leaves, (25%), leaves (23%) and subterranean parts (roots and tubers, 20%; Figure 2-3B). Single stems are generally not used for medicinal purposes (2%), whereas the roots of plants are often used, especially for post-delivery treatment, women genital and cosmetic care, such as *Ximenia perrieri* (‘Kotro’). Sometimes people use different parts of the same plant, especially if it has a high use value (e.g. used for different medicinal purposes), such as *Neobeguea mahafaliensis* (‘Handy’). The stem barks of the *Neobeguea mahafaliensis* species is used to treat muscular-skeletal problems and its below ground parts serve women during the post-delivery process. Regarding the use of species, Aloe divaricata (used by 100% of informants), *Cedrelopsis grevei* (100%) and *Neobeguea mahafaliensis* (91%) predominate. *Aloe divaricata* is a locally important species with 28 different uses. In total, 46 types of medicinal uses were reported (Cook, 1995; Table 2-3). Some species, such as Operculicarya decaryi, may also be used in multiple ways such as a body tonic, for women genital menstrual care and to alleviate nutritional disorders during famine periods. *Tamarindus indica* was used to treat eye problems, but it is similarly important to alleviate nutritional disorders. Apparently digestive system disorders (13%), wound and injury problems (12%) and post-delivery care for women (11%) represented the most prevalent health problems in the study area. The use of medicinal plants in cosmetic and genital care of women amounted to 8%, similar to plant use for 'body tonic' after hard physical work.

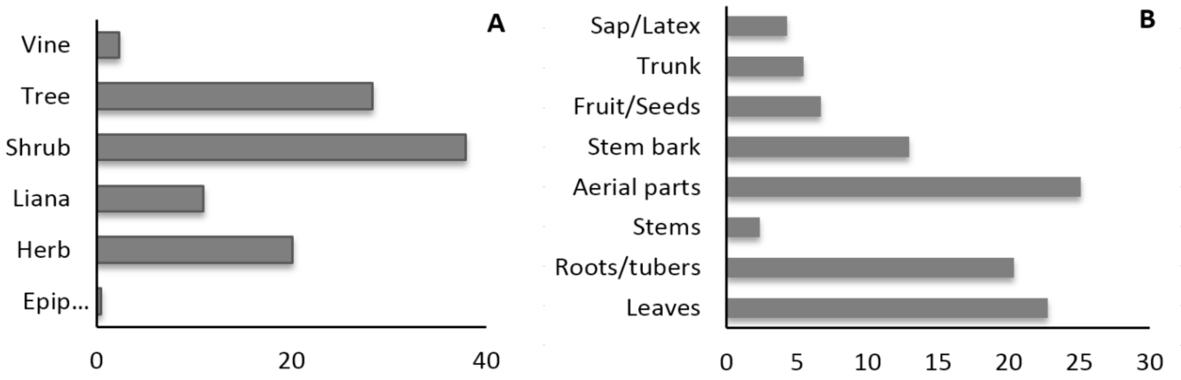

Figure 2-3 Proportion of life forms used as medicinal plants (A); Proportion of plant parts used for traditional healing (B) in the Mahafaly region of SW-Madagascar.

2.5.2. Plant uses and knowledge patterns among households

Based on their socio-economic characteristics and the use intensity of forest products, the cluster analysis revealed two groups of households (Table 2-4). The well-off farmers represent households with a high number of livestock, off-farm activities and a higher education level. They use yam as a supplementary food, practice a more sustainable harvest technique and collect less wild yam tubers compared with the poorer farmers. The latter are characterized by lower household assets and off-farm activities. Farmers of this group collect more yam species and use their tubers as staple food. Most of the socio-economic variables used for the cluster analysis were effective in discriminating the two defined household groups except for the education level and the diversity of medicinal plant use. Together the predictors accounted for 51% of the between-group variability. Based on the conclusions that structure coefficients ≥ 0.30 indicate a strong discriminating power (Ali, 1999), households cluster groups were determined by the amount of agricultural harvest, livestock owned by household, and the frequency of wild yams collection. In contrast, the number of medicinal plants used and the use intensity of medicinal plants differed only slightly among the two groups.

Table 2-3 Categories of diseases and their respective most cited plant species in the Mahafaly region of SW Madagascar

Diseases and use category	Most cited species
Digestive disorders	*Aloe divaricata* A.Berger, *Cedrelopsis grevei* Baillon
Muscular_Skeletal	*Neobeguea mahafaliensis* J.-F. Leroy, *Cedrelopsis grevei* Baillon
Eye problems	*Tamarindus indica L., Jatropha mahafalensis* Jum. & H.Perrier, *Fernandoa madagascariensis* (Baker) A.H. Gentry
Wound/Injury/Swelling	*Tridax procumbens* L., *Tabernaemontana* sp., *Croton geayi* Leandri
Ear infections	*Citrullus lanatus* (thumb.), *Cynanchum grandidieri* Liede & Meve
Flue/Fever	*Ocimum canum* Sims , *Croton geayi* Leandri
Skin disorders	*Lemuropisum edule* H. Perrier
Post delivery care	*Erythroxylum retusum* Baill. ex O.E. Schulz, *Salvadora angustifolia* Turill, *Loeseneriella rubiginosa* (H. Perrier) N. Hallé
Toothache	*Zanthoxylum tsihanimposa* H.Perrier, *Euphorbia tirucalli* L.
Venereal infections	*Cynodon dactylon* (L.) *Pers, Euphorbia tirucalli* L., *Blepharis calcitrapa* Benoist
Respiratory system disorders	*Cynanchum perrieri* Choux, *Indigofera compressa* Lam.
Malaria	*Cajanus cajan* (L.) *Millsp., Indigofera tinctoria* L.
Sprains	*Aloe divaricata* A.Berger, *Delonix floribunda* (Baill.) Capuron
New born care	*Coffea grevei* Drake ex A.Chev, *Pentatropis nivalis subsp. Madagascariensis* (Decne.) Liede & Meve
Circulatory system disorders	*Opuntia* sp. (Raketamena)
Woman genital hygiene	*Ximenia perrieri* Cavaco & Keraudren, *Operculicarya decaryi* H. Perrier, *Cedrelopsis grevei* Baillon
Cosmetic/Hair care	*Ficus trichopoda* Baker, *Cedrelopsis grevei* Baillon
Body tonic	*Erythroxylum retusum* Baill. ex O.E. Schulz, *Neobeguea mahafaliensis J.-F. Leroy, Operculicarya decaryi* H. Perrier
Nutritional disorders	*Tamarindus indica* L., *Adansonia za* Baill., *Operculicarya decaryi* H. Perrier
Livestock disease	*Vigna unguiculata* (L.) Walp.

2.5.3. Plant uses and knowledge patterns among villages

Collection and use of forest plants differed between the Littoral (Efoetse) and the Plateau (the other three villages) which may be mainly explained by the lack of forest resources and wild yams in the coastal area. The number of medicinal plants and wild yam species used were higher on the Plateau (Ampotake, Andremba, Itomboina, Miarintsoa), and the number of species collected was highest in Itomboina and Miarintsoa (Table 2-5). However, the collection frequency, period, and the amount of harvested wild yam were higher in Ampotake. This may be mainly due to the proximity of community based forests, where collection of forest products is not restricted. Itomboina and Miarintsoa are situated in the middle of the Plateau, where different soil types (ferralitic, red sandy and calcareous soils) and forest habitats prevail, which may explain the high diversity in species collection by the informants. Knowledge, traditional uses and the number of species used differ significantly ($P < 0.01$) among villages. Overall, the knowledge and the uses of plants are higher in

Ampotake than in the other villages. In Ampotake, Miarintsoa and Itomboina, similar medicinal plant species are used as indicated by the Jaccard similarity indices ranging between 0.68-0.7 (Table 2-6).

2.5.4. Effects of socio-economic characteristics on the use and knowledge of plants

The number of livestock owned (TLU), education level, family size and agricultural harvest were significant predictors for the number of medicinal plants used and the frequency of yam collection. The TLU and the age of respondents significantly affected the collection of wild yams (P < 0.001; Table 2-7). In the study region, a high number of livestock owned is a sign of wealth. Households with a low TLU are characterized by higher yam collection intensities. For the number of medicinal plants used, the only significant predictor variables were family size and healer consultancy. The latter indicates how often a household asked a traditional healer for advice on appropriate medicinal plants. The higher the diversity of different household activities (salaried work, trading, artisanal), the more cash income is produced. Consequently, the households have the possibility to buy food during difficult seasons, and depend less on wild food collection. In addition, female respondents use and know more plants than men. Age did not affect the use and knowledge on medicinal plants, which is maybe due to the direct knowledge transfer within one household. In this study, 79% of the households did not report to consult a traditional healer in case of illness.

Table 2-4 Results of two step cluster and discriminant analysis of 250 interviewed rural households in the Mahafaly Region of SW-Madagascar

Selected variables	Cluster group		Discriminant analysis		
	Well-off farmers Mean±SD	Less well-off farmers Mean± SD*	Wilks' Lambda	Sig	Structure coefficients
Education level	1.03±0,71	0.86±0.69	0.986	0.068	0.116
Agricultural harvest	1.23±0.42	0.52±0.63	0.747	0.000**	0.574
households activities	1.11±0.71	0.26±0.44	0.928	0.000**	0.274
Family size	7.35±3.55	6.4±3.20	0.982	0.037*	0.133
Total livestock unit [1)]	12.53±12.32	2.18±5.40	0.746	0.000**	0.577
Agricultural area	2.86±2.30	1.19±1.60	0.945	0.000**	0.239
Medicinal plants used	27.77±13.55	32.7±14.30	0.974	0.011*	-0.162
Number of medicinal uses	13.87±4.27	15.6±3.60	0.976	0.016*	-0.153
SDi [2)]	23.35±2.12	25.92±2.10	0.988	0.089	-0.108
Wild yam species collected	2.23±2.71	3.17±2.17	0.960	0.002**	-0.201
Yam tubers harvested (Holes/each collection)	6.72±6.74	13.02±10.33	0.908	0.000**	-0.314
Frequency of collection	2.35±2.71	5.83±5.23	0.886	0.000**	-0.354
Sale	3.95±11.09	17.03±24.12	0.920	0.000**	-0.291
Collection period	2.40±2.29	13.78±2.79	0.943	0.000**	-0.243
Use of wild yams	1.73±0.44	1.49±0.50	0.948	0.000**	0.231
Eigen Value = 1.026			Percentage variance = 50.41		

[1)] (FAO, 1986) [2)] Number of harvest holes per collection event * Significance level at p ≤ 0.01

Table 2-5 Descriptive statistics of variables (Mean ± SD) used in evaluating the knowledge and uses of wild yams and medicinal plants of the Mahafaly region in SW-Madagascar

Variables		Ampotake (n = 50)	Andremba (n = 50)	Itomboina (n = 50)	Miarintsoa (n = 50)	Efoetse (n = 50)
Collection of wild yam species (%)	*D.alatipes*	92.16	80.3	80	42	0
	D. bemandry	94.12	51.52	80	87.23	0
	D.fandra	54.9	60.61	60	59.57	0
	D.ovinala	76.47	62.12	64.44	46.81	0
	D. nako	43.14	21.21	66.67	48.94	0
	D.soso	7.84	39.39	46.67	21.28	0
Number of wild yams species collected		3.9 (± 1.1)	3.9 (± 1.3)	4.2 (± 1.4)	4.9 (± 1.9)	0
Frequency of wild yams collection[1)]		9.8 (± 5.7)	5.1 (± 2.5)	5.6 (± 2.9)	5.7 (± 3.9)	0
Period of collection (N. months/year)		5.7 (± 1.9)	4.1 (± 1.9)	4.2 (± 1.4)	4.9 (± 1.9)	0
Wild yams harvested[2)]		21 (± 9)	12.8 (± 5.8)	14.1 (± 5.6)	13.1 (± 7.6)	0
Unsustainable harvest technique		89.6	81.5	89.5	78.6	-
Sustainable harvest technique		10.4	18.5	10.5	21.4	-
Monthly income, wild yams (US$)[3)]		5.5 (± 7.4)	1.3 (± 3.5)	2.0 (± 3.0)	1.3 (± 2.5)	0
Number of medicinal species used		43.5 (± 12)	29.8 (± 11.8)	36.6 (± 10)	27.4 (± 12.4)	18.4 (± 9.7)
D (Diversity of medicinal plant use)		33.5(±10.3)	23.9±8.6	32.2(±7.7)	23.4(±10.2)	14.7(±7.7)
Use report/ medicinal plants		17.6 (± 3.1)	14.4 (± 3.2)	16.7 (± 1.9)	12.6 (± 3.3)	12.8 (± 4.6)

[1)] Times per month; [2)] Number of harvest holes per collection event; [3)] US$ = 2,422 Ariary, 9.07.2014.

2.6. Discussion

2.6.1. Characteristics of the interviewed households

The basic characteristics of the interviewed households correspond to the results of INSTAT (2013) for SW Madagascar even though our survey indicated a higher education level. In Ampotake, the majority of the household heads (52%) are illiterate, which reflects the percentage of the non-educated people in the rural area in this region. The average land size per household (2.2 ha) corresponds to the respective value in Mozambique (Jayne et al., 2003). In this study, we used off-farm activities to determine the different cash income sources and diversification level of households based on the assumption that higher diversification leads to higher income (Beyene, 2008; Bigsten and Tengstam, 2011).

Table 2-6 Similarity among medicinal plant species usage in the studied villages (Jaccard similarity indices, 1 = similar) in the Mahafaly region of SW Madagascar

	Ampotake	Andremba	Itomboina	Miarintsoa	Efoetse
Ampotake	1	0.59	0.7	0.68	0.54
Andremba	0.59	1	0.58	0.58	0.43
Itomboina	0.7	0.58	1	0.71	0.55
Miarintsoa	0.68	0.58	0.71	1	0.51
Efoetse	0.54	0.43	0.55	0.51	1

2.6.2. Traditional knowledge and usage of wild yams

Among the six species of wild yam recorded, only *D. alatipes* and *D. bemandry* were frequently harvested by local people to substitute for staple food. This is comparable to the collection of wild yam species in the dry forest of NW-Madagascar (Ackermann, 2004). Mavengahama et al. (2013) recorded a similar importance of wild yam collection for rural livelihoods in South Africa, where wild vegetables are of high importance in supplementing staple food diets based on maize, sorghum (*Sorghum bicolor* Moench.), and millet (*Pennisetum glaucum* L.). In our study, the collection intensity of wild yams depended not only on the availability of the species, but also on the taste of the yam tubers. For Malagasy yams, the preference in taste was analysed by Jeannoda et al. (2007) who observed a significant correlation ($P < 0.001$) between the preference and the sensitivity to saccharose. Polycarp et al. (2012) stated that the high level of carbohydrate and energy with appreciable levels of minerals makes yam a very nutritious source of food. Bhandari et al. (2003) found that the nutritional composition of selected wild yams in Nepal was similar to those reported for cultivated species of yam. When analyzing the nutritional value of Malagasy yam germplasm, including those of wild species, Jeannoda et al. (2007) determined high contents of calcium in *Dioscorea ovinala*, which makes some wild yams physiologically important. However, a decline in the availability of wild yams was already reported by the respondents of our study who are forced to increase the search radius for tuber harvests. One main reason for the decline in this essential resource securing local livelihood strategies against drought related hunger risks may be the exploitative harvesting methods used by the majority of the collectors in the Mahafaly region, which hampers the regeneration of the species. In contrast, Ackermann (2004), who conducted a study in the NW-Madagascar, reported that traditional people try to harvest the tubers carefully to guarantee the survival of the plant stand. In our study only 15% of the household took care of the regeneration of the lianas. While the sale of wild yam tubers provides valuable cash income for many households it may also be one of the causes for its overexploitation and increasingly threatened existence (Termote et al., 2010). About 20% of the harvested tubers per households are sold on local markets.

Table 2-7 Generalized linear Model (GLM) showing the effect of selected independent variables on the number of medicinal plants used and the collection frequency of wild yam (n=250) in rural villages of the Mahafaly region in SW-Madagascar

Independent variable	Number of medicinal plants used			Frequency of yam collection (Frequency month)		
	B*	P	R	B	P	R
Education level	-0.087	0.029	-0.083	-0.249	0.008	-0.118
Tropical livestock unit	-0.007	0.038	-0.192	-0.460	0.000	-0.263
Agricultural harvest	-0.127	0.002	-0.270	-0.251	0.012	-0.229
Age	0.002	0.217	0.119	-0.014	0.000	-0.209
Family size	0.027	0.001	0.119	0.056	0.003	0.092
Gender	0.125	0.029	0.128	0.153	0.232	0.124
Healer consultancy	-0.472	0.000	-0.380	-	-	-
Households activities	-	-	-	0.053	0.550	0.038

(*) Beta coefficient; (R) regression coefficient, (-) the variable was not included in the model

2.6.3. Traditional knowledge and usage of medicinal plants

The majority of the medicinal plants used by the local people belong to the Fabaceae, Apocynaceae and Euphorbiaceae. In contrast to yams, none of the interviewed households was selling medicinal plants. Local people complained that some species are nowadays hard to find, which was confirmed by our field observation. Hamilton (2004) stated that globally 4,160 to 10,000 medicinal plants are endangered by habitat losses or overexploitation in areas where rural families traditionally collected them. The present study shows that the most popular plants with high use values, such as Aloe divaricata, *Erythroxylum retusum*, *Cedrelopsis grevei*, *Neobeguea mahafaliensis*, *Salvadora angustifolia* and *Croton geayi* are native species collected from forest habitats. This shows that the wild habitats are important for local communities in terms of basic needs. Beltrán-Rodríguez et al. (2014) also pointed to the importance of wild habitats for peoples' livelihood in a rural community of Mexico and found a greater diversity of plant uses in wild habitats than in managed environments. Some plants are less frequently used, which does not decrease their importance since most of them are needed for very specific therapeutic purposes. The increasing scarcity of such plants may also enhance the loss of traditional knowledge about the medicinal uses (Benz et al., 1994; Chaudhary et al., 2006). On the other hand there are cultivated speciessuch as *Tamarindus indica* and *Sclerocarya birrea* subsp. caffra, *Citrullus lanatus* and *Ziziphus spinachristi*, which are nowadays used more intensively for medicinal purposes. Different parts of the same plant are used for different purposes or by different population groups. Sometimes, a specific plant part is used for children and another part of the same plant for adults to treat a disease such as in the case of Aloe divaricate. The use of plant roots as traditional remedies is often problematic as it prevents plant regeneration (Flatie et al., 2009). Muthu et al. (2006) reported that the choice of plant species most used by people depended largely on the type of diseases treated. In our study, digestive disorders, post-delivery care, body injuries and wounds were the most frequently mentioned diseases. This is comparable to similar studies conducted in Africa (Maroyi, 2013; Ribeiro, 2010), China (Ghorbani et al., 2011), and in Colombia (Cadena-Gonzàlez et al., 2013), where digestive disorders were most frequently treated by medicinal plants. Compared to other developing countries, where sexually transmitted infections are most commonly treated with herbal medicines (Van Vuuren and Naidoo, 2010) this category was rarely cited in our study. Except for venereal diseases which are treated using a combination of different species (Zonyane et al., 2012; Bussman and Sharon, 2006) the majority of plant species utilized had a single therapeutic use. Some of the recorded medicinal plants in Madagascar are already pharmaceutically analysed and the active ingredients confirm traditional therapeutic uses. For example, *Koehneria madagascariensis* has a large and strong antimicrobial activity (Rakotonirina et al., 2010). *Hernandia voyronii* (Ratsimamanga-Urverg et al., 1994) is known for its antimalarial active substances, *Neobeguea mahafaliensis* and *Cedrelopsis greveii* for effectiveness against cardiovascular diseases (Ralay Ranaivo et al., 2004). Although the World Health Organization (WHO) reported that 60-70% of Madagascar inhabitants have ready access to primary health care (WHO, 2008), accessibility of effective modern medicines is still a challenge for the local population in the Mahafaly region and they thus make use of native plants for alternative treatment.

2.6.4. Effects of socio-economic conditions on the use of wild yams and medicinal plants

Our study revealed that the collected quantities and qualities of plants vary greatly between households. Poor farmers consume and sell more yams and have higher knowledge of traditional uses of medicinal plants than well-off or 'rich' individuals. Households needing off-farm income collect and consume wild yams more frequently than households with regular off-farm income. In addition, the regression results revealed, that households with more cropland and higher crop harvest collect less forest products. This was also confirmed by Reddy and Chakravarty (1999) in India. Variables showing the collection and consumption of wild yams ($P < 0.01$) were important discriminators for household groups in contrast to the variables on the use of medicinal plants ($P < 0.05$). The use of forest products was significantly higher in villages near forests, where wild yams and medicinal plants are more readily available. This confirms findings of Banana and Turiho-Habwe (1997) in Uganda and Kerapeletswe and Lovett (2002) in Botswana, where the dependency on the forests for food supply decreased rapidly with an increasing distance of the respondent's home from the forests. Furthermore, poor market access may increase the importance of forest products to sustain people's livelihood (Gunatilake, 1998). The number of livestock owned by the household, education level, agricultural harvest and family size affected the collection of wild yams and the usage of medicinal plants. Livestock and off farm activities determine the wealth condition of the household in this region and were negatively correlated with the use of wild yams and medicinal plants. However, we cannot generalize these findings as with time and location the direction of the relationship may change (Mcelewe, 2008). Socio-cultural factors are of higher importance for the use of medicinal plants than for the collection of wild yams. In contrast to other findings (Beltrán-Rodríguez et al., 2014) female respondents use more plant species than males. The use of medicinal plants is the basic health care for the majority of the households and the knowledge about their use was possibly shared over generations, which might explain, that there is no significant influence of informant age on the collection intensity of medicinal plants. In the study of Kirstin (Kirstin, 1993) on the usage of Budongo's forest products, the use of wild food such as *Dioscorea* spp. increased with age, whereas young village people focused on the use of fruits and wild game because of their higher income potential. This might also be true for our study region, were younger farmers predominate in collecting wild yams for sale. Overall, this study indicates that a household's wealth status affects the traditional knowledge and use intensity of forest products, which confirms previous studies (Beltrán-Rodríguez et al., 2014; Khanal, 2001; Sapkota and Odén, 2008). The World Resources Institute (2002) reported that families facing poverty, sickness, drought, wars and economic crisis depend to a higher degree on the collection of wild resources. Although, our study focused only on medicinal plants and wild yams as forest products, the rate of change in social and economic attributes of rural households is likely proportional to the rate of change in resource use (Kant, 2000). Therefore, what ever the products extracted, a household's socio-economic dynamics ultimately drives its ability to use village forest resources.

2.7. Conclusions

Our results revealed that wild yams play an important role in local food security in the Mahafaly region, especially for poor farmers. Conversly, medicinal plants are a primary source of health care for the majority of local people in SW-Madagascar and the results of this study can help to identify the most useful plant species and their importance for the local people. In many rural areas of developing countries, common property resource management plans may allow to combine poverty reduction and biodiversity conservation. In our study region the forest patches around the Tsimanampetsotsa national park are managed by local communities. Our results indicate the influence of socioeconomic household characteristics on the use of forest products and its intensity, which should be considered in future management plans for local and regional forest conservation.

2.8. Acknowledgements

We would like to thank the local people of the Mahafaly region for their trust and hospitality during the field part of this study. We also acknowledge the SuLaMa project team, and especially, the group of interviewers supervised by Regina Neudert and Miandrazo Rakotoarisoa, for their support during data collection. We thankfully acknowledge the support of DAAD for the scholarship grant for this research and the German Federal Ministry of Education and Research for funding (BMBF, FKZ: 01LL0914C).

2.9. Appendix

Appendix 2-1 List of medicinal plants species used in the Mahafaly region, SW-Madagascar

Scientific name	Family	Local name	Use value	Citation (%) n=235	Habitat	Parts used	Voucher number*
Aloe divaricata A. Berger	Xanthorrhoeaceae	Vahondrandro	1.87	100	Forest	Lx	Reynold 7860
Cedrelopsis grevei Baillon	Rutaceae	Katrafay	3.06	99.6	Forest	Lv,Br,Tr	R. Rabevohitra 2390
Neobeguea mahafaliensis Leroy, Jean F. P.	Meliaceae	Handy	1.44	91.1	Forest	Sb,Tr	R. Decary 16206
Salvadora angustifolia Turill	Salvadoraceae	Sasavy	1.19	79.6	Forest	Lv,Sb	P. B. Phillipson 3711
Croton geayi Leandri	Euphorbiaceae	Pisopiso	1.36	72.3	Forest	Sb,Br	H. Humbert 2397
Erythroxylum retusum Baill. ex O.E. Schulz	Erythroxylaceae	Montso	1.23	71.9	Forest	Lv	P.B. Phillipson 2464
Cynanchum perrieri Choux	Apocynaceae	Ranga	1.13	66.8	Forest	St	Labat J-N 2414
Pentatropis nivalis subsp. Madagascariensis (Decne.) Liede & Meve	Apocynaceae	Tinaikibo	1.05	61.7	Forest	Ar	
Zanthoxylum tsihanimposa H.Perrier	Rutaceae	Manongo	1.01	60	Forest	Sb	P. Morat 4677
Tamarindus indica L.	Fabaceae	Kily	1.47	59.2	Forest, Fallow	Lv,Br,Fr	Thomas B. Croat 31108
Tridax procumbens L.	Asteraceae	Angamay	1.04	53.6	Crop field, Fallow	Lv	P.B. Phillipson 1791
Euphorbia tirucalli L.	Euphorbiaceae	Laro	1.29	53.6	Forest	Lv,St	P.B. Phillipson 2480
Operculicarya decaryi H. Perrier	Anacardiaceae	Jabihy	1.24	52.3	Forest	Br,Tr	P. Morat 696
Indigofera tinctoria L.	Fabaceae	Sarikapiky	1	49.4	Fallow, Savana	Ar	J.N. Labat 2104
Musa sp.	Musaceae	Kida	1.04	46.8	Crop field	Fr	
Fernandoa madagascariensis (Baker) A.H. Gentry	Bignoniaceae	Somontsoy	1.02	46.8	Forest	Lv,Br	L.J. Dorr 3960
Leptadenia madagascariensis Decne.	Apocynaceae	Taritarika/Mozy	1.21	46.4	Forest	Sb,Ar	B. Descoings 1243

Jatropha mahafalensis Jum. & H.Perrier	Euphorbiaceae	katratra	1.05	46.0	Forest	Lv,Lx	H. Humbert 2521
Aristolochia acuminata Lamk.	Aristolochiaceae	Totonga	1.18	41.3	Forest	Sb	P. Morat 3512
Tabernaemontana sp.	Apocynaceae	Feka	1.01	40.4	Forest	Sb	
Delonix floribunda (Baill.) Capuron	Fabaceae	Fengoky	1.03	40.0	Forest	Lx	J. Bosser 13584
Ficus trichopoda Baker	Moraceae	Fihamy	1	39.2	Forest	Tr	S.T. Malcomber 1116
Jatropha curcas L.	Euphorbiaceae	Savoa	1.03	39.2	Forest	Lv,Sb,Lx	P.B. Phillipson 1725
Tetrapterocarpon geayi Humbert	Fabaceae	Hazolava/Voaovy	1.24	38.7	Forest	Sb,Br	B. Descoings 1433
Sclerocarya birrea Subsp. caffra (Sond.) Kokwaro	Anacardiaceae	Sakoa /Sakoamanga	1.09	38.7	Savana	Lv,Br	D.J. Mabberley 732
Ocimum canum Sims	Lamiaceae	Romberombe	1.02	37.9	Forest	Ar	B. Croat 31282
Aloe vaombe Decorse & Poisson	Xanthorrhoeaceae	Vahombe	1.25	37.9	Forest	Lx	H. Humbert 5418
Indigofera compressa Lam.	Fabaceae	Hazomby	1.15	36.6	Forest	Ar	M.R. Decary 9147
Loeseneriella rubiginosa (H. Perrier) N. Hallé	Celastraceae	Timbatse	1.03	35.7	Forest	Lv	B. Du puy MB 570
Chloroxylon falcatum Capuron	Rutaceae	Mandakolahy	1.05	35.3	Forest	St	
Ziziphus spina-christi (L.) Willd.	Rhamnaceae	Tsinefo	1.13	34.5	Crop field, Fallow	Br	J. Bosser 416
Coffea grevei Drake ex A.Chev	Rubiaceae	Hazombalala	1.28	31.5	Forest	Sb,Ar	C.C.H. Jonngkind 3746
Radamaea montana Benth.	Orobanchaceae	Tamotamo	1	31.5	Forest	Sb	J. Bosser 6071
Euphorbia stenoclada Baillon	Euphorbiaceae	Samata	1.12	28.9	Forest	Lv,Sb	RN 4768
Ximenia perrieri Cavaco & Keraudren	Ximeniaceae	Kotro	1.08	26.8	Forest	Lv,Sb	Rauh 1221
Croton kimosorum Leandri	Euphorbiaceae	Zanompoly	1.24	26.8	Forest	Br	J. Bosser 10429
Grewia humblotii Baill.	Malvaceae	Sely	1.11	26.4	Forest	Sb,Br	
Solanum hippophaenoïdes Bitt.	Solanaceae	Hazonosy	1.15	25.5	Forest	Lv,Sb	
Cynanchum grandidieri Liede & Meve	Apocynaceae	Betondro	1.15	24.7	Forest	Sb	
Lasiocladus anthospermifolius Bojer ex Nees	Acanthaceae	Maintemaso	1.11	24.3	Forest	Lv,Sb	J.N. Labat 2696
Cynanchum nodosu (Jum. & H. Perrier) Desc.	Apocynaceae	Try	1.1	24.3	Forest	Sb	P.B. Phillipson 1671

Stereospermum nematocarpum DC.	Bignoniaceae	Mahafangalitse	1.13	23.4	Forest	Br	Herb. Inst. Sci. Mad. 4630
Androya decaryi H.Perrier	Scrophulariaceae	Manateza	1.02	23.0	Forest	Lv	Herbier du Laboratoire de Botanique 1777
Abutilon indicum (L.)Sweet	Malvaceae	Lahiriky	1.08	22.1	Forest, Fallow	Ar	L.J. Dorr 4056
Psiadia angustifolia (Humbert) Humbert	Asteraceae	Ringandringa	1.38	22.1	Forest	Lv	RN 3806
Hyphaene sp.	Arecaceae	Satra	1.06	22.1	Crop field	Lv,Sb	
Cassia siamea Lam.	Fabaceae	Farefare	1.16	21.3	Forest	Br	M. B. Dupuy M98
Capsicum sp.	Solanaceae	Sakay	1	21.3	Crop field	Fr	
Citrullus lanatus (Thunb.) Mansf.	Cucurbitaceae	Voamanga	1.24	20.9	Crop field	Ar	J. Bosser 13567
Streblus sp. Lour.	Moraceae	Hazondranaty	1.13	20.4	Forest	Sb.Tr	
Vigna unguiculata (L.) Walp.	Fabaceae	Loji	1	20.4	Crop field	Fr	Thomas B. Croat 32050
Agave sisalana Perrine	Agavaceae	Lalohasy	1.04	19.6	Forest	Lx	
Strychnos sp	Loganiaceae	Mangerivorika	1.04	19.6	Forest	Ar	
Blepharis calcitrapa Benoist	Acanthaceae	Sitsitse	1.13	19.6	Forest	Sb	H. Humbert 5136
Commiphora monstruosa (H. Perrier) Capuron	Burseraceae	Taraby	1.13	19.2	Forest	Ar,Tr	
Cynanchum mahafalense Jum. & H. Perrier	Apocynaceae	Vahimasy	1.25	19.2	Forest	Sb,St	B. Descoings 3251
Margaritaria anomala (Baill.) Fosberg	Phyllanthaceae	Tsivano	1	18.7	Forest	Sb	
Rhigozum madagascariense Drake	Bignoniaceae	Hazonta	1.12	17.9	Forest	Ar	J. Bosser 14420
Arachis hypogaea L.	Fabaceae	Kapiky	1	17.5	Crop field	Fr	
Cajanus cajan (L.) Millsp.	Fabaceae	Ambatry	1.1	15.3	Crop field	Ar	Thomas B. Croat 32106
Euphorbia arahaka Poisson	Euphorbiaceae	Samatafoty	1	14.9	Savanna, Forest, crop field	Lv	M.D. Decary 3008
Secamone tenuifolia Decne.	Apocynaceae	Langolora	1.09	14.5	Forest	Sb	J. Bosser 17209
Zingiber officinale Roscoe	Zingiberaceae	Sakaviro	1.06	14.5	Crop field	Sb	M.R. Decary 1440
Croton sp.	Euphorbiaceae	Zalazala	1.38	14.5	Forest	Br	
Acacia bellula Drake	Fabaceae	Rohy	1.3	14.0	Forest	Ar	R. Ranaivojaona 492
Colvillea racemosa Bojer	Fabaceae	Sarongaza	1	14.0	Forest	Br	P.B. Phillipson 2802
Terminalia ulexoides H. Perrier	Combretaceae	Fatra	1.03	13.6	Forest	Sb	L. J. Dorr 4057

Hypoestes phyllostachya Baker	Acanthaceae	Fotivovona	1.13	13.6	Forest	Ar	J. Bosser 43
Dalbergia sp.	Fabaceae	Manary	1.33	12.8	Forest	Br	
Didierea madagascariensis Baill.	Didieraceae	Sono	1.16	12.8	Forest	Tr	D. Lorence 1928
Bathiorhamnus cryptophorus Capuron	Rhamnaceae	Losy	1	11.5	Forest	Sb	
Rhopalopilia hallei Villiers	Opiliaceae	Malainevotsy	1	11.5	Forest	Ar	
Capurodendron androyense Aubrév.	Sapotaceae	Nato	1	11.5	Forest	Sb,Br	J. Bosser 10352
Paederia grandidieri Drake	Rubiaceae	Tamboro	1.19	11.1	Forest	Lv	P.B. Phillipson 2810
Hippocratea angustipetala H. Perrier	Celastraceae	Vahimpindy	1.04	11.1	Forest	Ar	
Lemuropisum edule H. Perrier	Fabaceae	Berotse	1.36	10.6	Forest	Sb	J. Bosser 1984
Securinega perrieri Leandri	Phyllanthaceae	Hazomena	1.16	10.6	Forest	Lv	Herb., Inst.Sci. Mad. 4497
Gyrocarpus americanus Jacq.	Hernandiaceae	Kapaipoty	1.24	10.6	Forest	Lv	P.B. Phillipson 2350
Commiphora simplicifolia H. Perrier	Burseraceae	Sengatse	1.04	10.6	Forest	Ar	Z.S. Rogers 870
Mollugo decandra Scott-Elliot	Molluginaceae	Andriamanindry	1.08	10.2	Forest	Ar	H. Humbert 5293
Pentarhopalopilia madagascariensis Cavaco & Keraudren	Opiliaceae	Fandriandambo	1.08	10.2	Forest	Ar	B. Descoings 1214
Henonia scoparia Moq.	Amaranthaceae	Fofotse	1.13	10.2	Forest	Lv	M.R. Decary 2531
Dicoma incana (Baker) O. Hoffm.	Asteraceae	Peha	1	10.2	Forest	Sb	P.B. Phillipson 2426
Uncarina stellulifera Humbert	Pedaliaceae	Farehitse	1.04	9.8	Forest	Lv	P.B.Phillipson 2723
Pentopetia androsaemifolia Decne.	Apocynaceae	Ntsompia	1.04	9.8	Crop field, Fallow	Lv	Arne Anderberg 123
Hydnora esculenta Jum. & H. Perrier	Hydnoraceae	Voantany	1.09	9.8	Forest	Sb	Herb., Inst.sci. Mad. 2
Lablab purpureus (L.) Sweet	Fabaceae	Antaky	1	9.4	Crop field	Fr	Michelle Sauther 27
Azima tetracantha Lam.	Salvadoraceae	Tsingilo	1.09	9.4	Forest	Lv	M.R Decary 3470
Ipomoea pes-caprae (L.) R. Br.	Convolvulaceae	Fobo	1.15	8.5	Seaside	Sb	Robert W. Books 19
Commiphora mahafaliensis Capuron	Burseraceae	Maroampotony	1.15	8.5	Forest	Ar	

Vanilla madagascariensis Rolfe	Orchidaceae	Amalo	1.19	8.1	Forest	St	
Manihot esculenta Crantz	Euphorbiaceae	Balahazo	1	8.1	Crop field	Lv,Sb	
Strychnos madagascariensis Poir.	Loganiaceae	Bakoa	1	7.7	Forest	Sb,Fr	J. Bosser 14492
Chamaesyce hirta (L.) Millsp.	Euphorbiaceae	Kimenamena	1	7.7	Crop field	Lv	Robert W. Brooks 8
Chadsia grevei Drake	Fabaceae	Sanganakoholahy	1	7.7	Forest	Ar	D.J. & B.P. Dupuy M38
Grewia leucophylla Capuron	Malvaceae	Fotilambo	1.12	7.2	Forest	Sb,Br	Michelle Sauther 23
Enterospermum pruinosum (Baill.) Dubard & Dop	Rubiaceae	Mantsake	1.06	7.2	Forest	Br	
Ruellia anaticollis Benoist	Acanthaceae	Reforefo	1.21	7.2	Forest	Ar	P.B.Phillipson 1795
Ficus lutea Vahl.	Moraceae	Amonta	1.38	6.8	Forest	Ar	G McPherson 14634
Sida rhombifolia L.	Malvaceae	Mandravasarotse	1.38	6.8	Fallow	Ar	Thomas B. Descoings 30725
Gonocrypta grevei (Baill.) Costantin & Gallaud	Apocynaceae	Piravola	1	6.8	Forest	Lx	P.B.Phillipson 1669
Azadirachta indica A. Juss.	Meliaceae	Nimo	1	6.4	Forest	Lv	Armand Rakotozafy 1798
Opuntia sp.	Cactaceae	Raketamena	1.13	6.4	Crop field, Fallow	Sb	
Mundulea sp.	Fabaceae	Sofasofa	1.2	6.4	Forest	Ar	
Alysicarpus vaginalis (L.) D.C.	Fabaceae	Tokampototse	1	6.4	Crop field, Fallow	Ar	Thomas B. Croat 31195
Zea mays L.	Poaceae	Tsako	1.13	6.4	Crop field	Fr	-
Ehretia decaryi J. S. Mill.	Boraginaceae	Lampana	1	6.0	Forest	Ar	J.Bosser 10116
Carica papaya L.	Caricaceae	Papaye	1	6.0	Crop field	Lv	Herbier du Jardin Botanique 324
Phyllanthus casticum Willemet	Phyllanthaceae	Sanira	1	6.0	Forest	Lv	P.B.Phillipson 2392
Aerva javanica (Burm. f.) Juss.	Amaranthaceae	Volofoty	1	6.0	Forest	Sb	M.R. Decary 18863
Phaseolus lunatus L.	Fabaceae	Kabaro	1	5.5	Crop field	Fr	J.Bosser 1011
Ricinus communis L.	Euphorbiaceae	Kinana	1	5.5	Crop field, Fallow	Lv	Thomas B. Croat 28615
Moringa drouhardii Jum.	Moringaceae	Maroserana	1.08	5.5	Forest	Ar	B. Descoings 2411
Pluchea grevei (Baill.) Humbert	Asteraceae	Samonty	1.91	5.5	Forest	Lv	J.Bosser 9917
Allium sativum L.	Amaryllidaceae	Tongologasy	1	5.5	Crop field	Sb	-
Tephrosia purpurea (L.) Pers.	Fabaceae	Engetsengetse	1	5.1	Forest	Lv	Jacqueline & M. Peltier 9936

Commiphora lamii H. Perrier	Burseraceae	Holidaro	1.17	5.1	Forest	Br	C.C.H. Jongkind 3681
Capuronianthus mahafalensis J.-F. Leroy	Meliaceae	Ringitse	1.08	5.1	Forest	Sb	_
Adenia olaboensis Claverie	Passifloraceae	Hola	1.09	4.7	Forest	Lx	Jacqueline & M. Peltier 1396
Cynodon dactylon (L.) Pers.	Poaceae	Kidresy	1	4.7	Forest	Ar	J. Bosser 10540
Secamone geayi Costantin & Gallaud	Apocynaceae	Kililo	1	4.7	Forest	Ar	J.Bosser 15917
Cryptostegia madagascariensis Bojer ex Decne	Apocynaceae	Lombiry	1	4.7	Forest	Lv,Sb	P.B.Phillipson 2622
Mangifera indica L.	Anacardiaceae	Mangavato	1.23	4.7	Crop field	Br	_
Ziziphus mucronata Willd.	Rhamnaceae	Tsinefonala	1	4.7	Forest	Br	Harb. Inst. Sci. Mad. 4517
Hernandia voyronii Jum.	Hernandiaceae	Hazomalany	1.3	4.3	Forest	Tr	J.Bosser 9178
Adansonia za Baill.	Malvaceae	Zan	1	4.3	Forest	Fr	P.B.Phillipson 2638
Avicennia marina (Forssk.) Vierh.	Acanthaceae	Afiafy	1.06	3.8	Forest	Br	James L.Zarucchi 7552
Ficus polita Vahl	Moraceae	Aviavy	1	3.8	Forest	Br	M.R. Decary 5031
Gossypium arboreum L.	Malvaceae	Hasy	1	3.8	Crop field, Fallow	Lv	H. Humbert 5166
Grewia microcyclea (Burret) Capuron & Mabb.	Malvaceae	Hazofoty	1	3.8	Forest	Br	Jacqueline & M. Peltier 1285
Flacourtia indica (Burm. f.) Merr.	Salicaceae	Lamonty	1	3.8	Forest	Sb,Fr	C.C.H. Jongkind 3720
Kalanchoe sp.	Crassulaceae	Relefo	1	3.4	Forest	Lv	
Indigofera mouroundavensis Baill.	Fabaceae	Sambobohitse	1.13	3.4	Forest	Sb	Jacqueline & M. Peltier 3171
Polycline proteiformis Humbert	Asteraceae	Zira	1.22	3.4	Forest	Sb,ar	J. Bosser 248
Croton sp.	Euphorbiaceae	Andriambolafotsy	1.14	3.0	Forest	Lv	
Zygophyllum depauperatum Drake	Zygophyllaceae	Filatatao	1.14	3.0	Forest	Lv	J. Bosser 10129
Acacia viguieri Villiers & Du Puy	Fabaceae	Roybenono	1	3.0	Forest	Ar	H.Humbert 2487
Mundulea sp.	Fabaceae	Taivosotse	1.14	3.0	Forest	Ar	
Marsdenia cordifolia Choux	Apocynaceae	Bokabe	1	2.6	Forest	Lx	P.B.Phillipson 2741
Adansonia rubrostipa Jum. & H.Perrier	Malvaceae	Fony	1	2.6	Forest	Fr	J. Bosser 15743

Erythrophysa aesculina Baill.	Sapindaceae	Handimbohitse	1	2.6	Forest	Ar	G.E.Schatz 1777
Kleinia madagascariensis (Humbert) P. Hallyday	Asteraceae	Malaohira	1	2.6	Forest	Ar	P.B.Phillipson 2475
Opuntia monacantha Haw.	Cactaceae	Notsoky	1	2.6	Fallow, Savanna	Fr	
Abrus precatorius L.	Fabaceae	Voamena	1	2.6	Forest	Ar	J.Bosser 19395
Dioscorea fandra H. Perrier	Dioscoreaceae	Andraha	1	2.1	Forest	Sb	Gordon McPherson 17451
Bulbostylis xerophila H. Cherm.	Cyperaceae	Foentany	1.2	2.1	Forest	Ar	M.R. Decary 8531
Albizia bernieri E. Fourn. ex Villiers	Fabaceae	Halimboro	1	2.1	Forest	Br	P.B.Phillipson 5285
Oeceoclades decaryana (H. Perrier) Garay & P. Taylor	Orchidaceae	Hatompototse	1.2	2.1	Forest	St	Gordon Mc Pherson 17376
Grewia sp.	Malvaceae	Malimatse	1.2	2.1	Forest	Br	
Helinus integrifolius (Lam.) Kuntze	Rhamnaceae	Masokarany	1	2.1	Forest	Ar	P.B.Phillipson 1737
Diospyros tropophylla (H. Perrier) G.E. Schatz & Lowry	Ebenaceae	Remeloky	1	2.1	Forest	Ar	P.Morat 565
Poupartia minor (Bojer) L. Marchand	Anacardiaceae	Sakoakomoky	1	2.1	Forest	Br	P.B.Phillipson 1813
Aloe antandroi (R.Decary) H. Perrier	Xanthorrhoeaceae	Sotry	1	2.1	Forest	Lv	M.R.Decary 9886
Cymbopogon excavatus (Hochst.) Stapf ex Burtt Davy	Poaceae	Ahibero	1.07	1.7	Forest	Lv	Bosser 5208
Koehneria madagascariensis (Baker) S.A. Graham, Tobe & Baas	Lythraceae	Fizolotsora	1	1.7	Forest	Ar	L.J. Dorr 4063
Acacia farnesiana (L.) Willd.	Fabaceae	Kasy	1	1.7	Savanna	Ar	D.J. & B.P. Dupuy M69
Dicraeopetalum mahafaliense (M.Pelt.) Yakovlev	Fabaceae	Lovainafy	1	1.7	Forest	Br	Thomas B.Croat 30969
Plumbago aphylla Bojer ex Boiss.	Plumbaginaceae	Motemote	1	1.7	Forest	Ar	H. Humbert 19960
Ficus sp.	Moraceae	Nonoka	1	1.7	Fallow, Forest	Br	
Mundulea stenophylla R. Vig.	Fabaceae	Rodrotse	1	1.7	Forest	Lv	M.R. Decary 2527
Ipomea sp.	Convolvulaceae	Sarivelahy	1	1.7	Forest, Savanna, Fallow	Lv	
Maerua nuda Scott-Elliot	Capparaceae	Somangilahy	1	1.7	Forest	Lv	J.Bosser 10507
Terminalia disjuncta H. Perrier	Combretaceae	Taly	1	1.7	Forest	Ar	B.Dupuy 629

Leucosalpa grandiflora Humbert	Orobanchaceae.	Tamborisahy	1	1.7	Forest	Sb	P. Morat 2978
Calopyxis grandidieri (Drake) Capuron ex Stace	Combretaceae	Tsambara	1	1.7	Forest	Fr	B Lewis 1294
Cordia caffra Sond.	Boraginaceae	Varo	1	1.7	Forest	Lv	Thomas B .Croat30787
Berchemia discolor (Klotzsch) Hemsl.	Rhamnaceae	Vorodoke	1	1.7	Forest	Ar	-
Anisotes madagascariensis Benoist	Acanthaceae	Hazontsoy	1	1.3	Forest	Ar	Rauh 1097
Gnidia linearis (Leandri) Z.S. Rogers	Thymeleaceae	Ronisa	1	1.3	Forest	Lv	Z.S. Rogers 930
Acacia sakalava Drake	Fabaceae	Roymena	1.33	1.3	Savanna, Forest	Ar	J.F. Villiers 4056
Maerua filiformis Drake	Capparaceae	Somangy	1	1.3	Forest	Lv,Ar	P.B. Phillipson 2417
Cyphostemma amplexicaule Desc.	Vitaceae	Tahezantrandrake	1	1.3	Forest	Lv	J. Bosser 19194
Xerosicyos danguyi Humbert	Cucurbitaceae	Tapisaky	1	1.3	Forest	Lv	Thomas B. Croat 30795
Ipomea sp.	Convolvulaceae	Velahy	1	1.3	Forest	Lx	
Dioscorea ovinala Baker	Dioscoreaceae	Behandaliny	1	0.9	Forest	Ar	J.N. Labat 2111
Karomia microphylla (Moldenke) R.B. Fern.	Lamiaceae	Forimbitika	1	0.9	Forest	Br	P.B. Phillipson 3438
Crotalaria androyensis R. Vig.	Fabaceae	Katsankantsa	1	0.9	Forest	Ar	M.R.Decary 9517
Roupellina boivinii (Baill.) Pichon	Apocynaceae	Lalondo	1	0.9	Forest	Lv	-
Croton catatii Baill.	Euphorbiaceae	Somorombohitse	1	0.9	Forest	Ar	M.R.Decary 10495
Grewia grevei Baillon	Malvaceae	Tombokampaha	1	0.9	Forest	Ar	J. Bosser 19338
Cadaba virgata Bojer	Capparaceae	Tsihariharinaliotse	1.5	0.9	Forest	Ar	Bewerley Lewis 534
Euclinia suavissima (Homolle ex Cavaco) J.-F. Leroy	Rubiaceae	Voafotaky	1	0.9	Forest	Fr	J.Bosser 13353
Crotalaria fiherenensis R.Vig.	Fabaceae	Voniloha	1	0.9	Savanna, Forest, Fallow	Ar	_
Persea americana Mill.	Lauraceae	Zavoka	1	0.9	Crop field	Fr	_
Panicum pseudowoeltzkowii A. Camus	Poaceae	Ahikitoto	1	0.4	Forest	Lv	J.Bosser 308
Acacia sp.	Fabaceae	Anadrohy	1	0.4	Forest	Br	
Commiphora humbertii H. Perrier	Burseraceae	Andrambely	1	0.4	Forest	Lv	S. Eboroke 870
Trema orientalis L. (Blume)	Cannabaceae	Andrarezona	1	0.4	Forest	Tr	B.Lewis 1292

Dioscorea bemandry Jum. & H. Perrier	Dioscoreaceae	Baboke	1	0.4	Forest	Sb	L.R. Caddick 339
Olax andronensis Baker	Olacaceae	Bareraky	1	0.4	Forest	Sb	L.J. Razafintsalama 785
Amaranthus viridis L.	Amaranthaceae	Beamena	1	0.4	Crop field, Fallow	Ar	-
Dioscorea nako H. Perrier	Dioscoreaceae	Fandra	1	0.4	Forest	Sb	L.R. Caddick 331
Asparagus calcicola H. Perrier	Asparagaceae	Fio	1	0.4	Forest, Fallow	Sb	J. Bosser 10599
Psidium sp.	Myrtaceae	Goavy	1	0.4	Crop field, Fallow	Lv	
Alantsilodendron alluaudianum (R.Vig.) Villiers	Fabaceae	Havoa	1	0.4	Forest	Ar	-
Ziziphus mauritiana Lam.	Rhamnaceae	Konazy	1	0.4	Savanna	Br	D. Seigler 12891
Boscia tenuifolia A. Chev.	Capparaceae	Lalangy	2	0.4	Forest	Ar	
Carissa spinarum L.	Apocynaceae	Lamontindahy	1	0.4	Forest	Ar	-
Panicum sp.	Poaceae	Mandavohita	1	0.4	Fallow, Forest, Savana	Ar	
Enterospermum madagascariense (Baill.) Homolle	Rubiaceae	Masonjoany	1	0.4	Forest	Tr	-
Albizia tulearensis R.Vig.	Fabaceae	Mendoravy	1	0.4	Forest	Br	D.J.&B.P.Dupuy M54
Kalanchoe beharensis Drake	Crassulaceae	Mongy	1	0.4	Forest	Lv	James L. Zarucchi 7471
Barleria brevituba Benoist	Acanthaceae	Patipatikantala	1	0.4	Savanna, Fallow	Ar	P. Morat 627
Pervillaea phillipsonii Klack.	Apocynaceae	Sangisangy	1	0.4	Forest	Ar	P.B.Phillipson 3472
Croton sp.	Euphorbiaceae	Tambio	3	0.4	Forest	Sb	
Crinum asiaticum L.	Amaryllidaceae	Tongolondolo	1	0.4	Forest	Sb	-
Cucurbita maxima Duch.	Cucurbitaceae	Trehaky	1	0.4	Crop field	Ar	J.Bosser 13577
Xerophyta tulearensis (H. Perrier) Phillipson & Lowry	Velloziaceae	Tsimatefaosa	1	0.4	Forest	Ar	P.B Phillipson 2459
Citrus medica L.	Rutaceae	Tsoha	1	0.4	Crop field	Sb	-
Cymbopogon citratus (DC.) Stapf	Poaceae	Veromanitse	1	0.4	Crop field	Ar	-
Commiphora marchandii Engl.	Burseraceae	Vingovingo	1	0.4	Forest	Ar	James S. Miller 6160
Cocos nucifera L.	Arecaceae	Voanio	1	0.4	Seaside	Fr	-
Typha angustifolia L.	Typhaceae	Vondro	1	0.4	Forest	Lv	M.R. Decary 14868

Pachypodium geayi Costantin & Bois	Apocynaceae	Vontake	1	0.4	Forest	Tr	P.B Phillipson 2610
-	Fabaceae	Antsambindolo	1.08	5.5	Crop field, Fallow	Lv	
-	-	Vahombata	1.02	21.7	-	Lx	
-	-	Tsifolahy	1.09	19.2	-	Tr	
-	-	Entenenty	1.04	9.8	-	Lv,Sb	
-	-	Tsagniria	1	6.0	-	Tr	
-	-	Trakitraky	1	3.8	-	Tr	
-	-	Tailandravy	1.3	8.5	-	Lv	

Lv = Leaves, Ar = Aerial parts, Sb = Subterranean parts, Fr = Fruits or seeds, Lx = Sap or latex, Tr= Trunk, St = Stems, Br =stem barks; (*) name of the diseases code and medicinal uses are listed in the annex.

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3. Modelling the distribution of four Dioscorea species on the Mahafaly Plateau of south-western Madagascar using biotic and abiotic variables

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3.1. Abstract

Wild yam species (*Dioscorea* spp.) provide important supplementary food and thus contribute directly to the livelihood and well-being of local people in SW-Madagascar. Given the ongoing exploitation of this resource, there is a necessity to identify and predict yam species distribution along environmental gradients to improve our understanding of sustainable management of this resource. Therefore, the aims of the current study were to identify predictors for the distribution of important wild yam species and to spatially predict their availability. To this end species abundance and environmental variables were collected in the field using a systematic sampling approach within a yams collection area of four villages (58 plots). A redundancy analysis (RDA) was conducted to investigate the relationship between wild yamnspecies and 12 environmental variables. Species distribution models and species response curves were established for the most abundant wild yam species using nonparametric multiplicative regression (NPMR). These models were subsequently used in conjunction with geospatial data for predictive mapping. RDA depicted a clear pattern of species habitats with D. alatipes occurring in dry spiny forests on calcareous soils at remote places, while *D. bemandry* and *D. fandra* were found in forest habitats on sandy soils with high harvest intensities. The NPMR models explained 88% (*D. alatipes*), 82% *(D. bemandry*) and 37% (*D. fandra)* of the variation in species abundance. Sensitivity analysis indicated the importance of vegetation structure, human interventions, and soil characteristics in determining wild yam distribution. Predicted distribution maps showed that the population of wild yam is scarce and mostly located in restricted areas of open spiny forests and dry spiny forest thickets, where harvest intensity is high. This study highlights the need for long-term assessment and public awareness actions on yam harvest practices as well as the importance of anthropogenic factors for the distribution of yam as a key forest resource in SW Madagascar.

Keywords: *Dioscorea spp*., Mahafaly Plateau, NPMR, RDA, species response curves

3.2. Introduction

Plant genetic resource managers need to know how species are distributed, how abundantly they occur, what site preferences they have and how resilient they are to human use or other environmental disturbance to effectively protect habitats or to forecast changes in species distribution in response to biotic or abiotic stresses (Bustamante and Seoane, 2004). Distribution, abundance, and diversity of plant species are controlled by number of factors, which are a major preoccupation of community ecologists. Climatic conditions have always played a major role in affecting species distribution and vegetation patterns (Gaston, 2003) but gradients of nutrients, water, and light may be similarly important (Austin, 2002; Guisan and Zimmermann, 2000). Several conceptual models showed that climate, topography, and geology are the primary environmental factors determining plant species distribution (Franklin, 1995) causing species-specific habitat niches. The species niche concept has been a central issue in ecology for decades and emphasized the existence of multiple causal factors for plant species distribution (Austin, 2002; Austin and Smith, 1990). In contrast to the fundamental niche, which is simply the response of species to environmental resources, the realized niche additionally includes the effect of biotic interactions such as predation, competition and dispersal limitation (Austin, 2002; Chase and Leibold, 2003). The Mahafaly Plateau in SW Madagascar is an example of an ecosystem that experienced a complex human-induced landscape transformation over the last centuries(Casse et al., 2004) resulting in major land cover changes (deforestation) and degradation of natural resources (Brinkmann et al., 2014). Simultaneously, this unique ecosystem provides a range of services to local inhabitants such as fuel wood and construction material, food, fodder and medicinal plants (Sulama, 2011). As one of the poorest regions in Madagascar, the local population depends to a high degree on the exploitation of natural forest resources, which include wild yam (Dioscorea spp., Dioscoreaceae) as an important supplementary food. The tubers of wild yam, in many parts of Madagascar called 'food for the poor', are mainly consumed during periods of seasonal food shortages and therefore represent a high traditional value in rural areas as they contribute directly to the livelihood and well-being of local communities (Perrier de la Bathie, 1925). Madagascar harbours at least 42 yam species and most of them are endemic (Wilkin et al., 2008, 2009). *Dioscorea* spp. are distributed in various areas of Madagascar, ranging from the humid lowlands and the mountain regions to the dry and semi-arid zones (Jeannoda et al., 2003). However, most of the species are found in the dry regions (west and south) and many of these species survive under harsh environmental conditions(Abraham et al., 1996). Despite the growing interest on the diversity and use of Malagasy yams, relatively little effort has been made to study in detail their ecological response to environmental gradients. One study on the distribution of wild yams in SW Madagascar has not adequately identified the main factors affecting species distribution and availability (Tostain et al., 2010). While land cover, climatic gradients, regional variability on the actual use and knowledge of wild yams seem to determine their availability in West Africa (Devineau et al., 2008; Yasuoka, 2013), human impacts, such as over-exploitation and land clearing are important determinants in Madagascar (Ackermann, 2004; Ramelison and

Rakotondratsimba, 2010) that reduce wild yam populations. To improve our ecological understanding on species distribution and to predict it across landscapes, species distribution models (SDMs) are often used (Franklin, 2010). Predictive maps are a possible outcome of SDMs to test hypotheses on habitat characteristics but also for resource management and conservation planning including biodiversity assessment (Gioia and Pigott, 2000; Kremen et al., 2008). In SDMs, climate, elevation, temperature, land surface and geology are important factors influencing species distributions at broader scales, while soil properties (Fu et al., 2004; Gerhardt and Foster, 2002) become increasingly important at smaller scales. The existing methods for SDM vary in terms of complexity, assumptions, data requirements and usability (Syphard and Franklin, 2009). Generalized Additive Models (GAMs; Yee and Mitchell, 1991) have been used in SDMs as an alternative to Generalized Linear Models (GLMs; Guisan et al., 1999). Other statistical methods, such as classification tree analysis, have been used to better capture the complex, non-linear relationships between response variables and multiple predictors (Brinkmann et al., 2011; Hastie et al., 2005). McCune (2006) recently demonstrated the power of Nonparametric Multiplicative Regression Analysis (NMPR) in analyzing species response surfaces in a multi-dimensional niche space, which has subsequently been successfully used in other studies (Jovan and McCune, 2006; Lintz et al., 2011).

In view of the above, the aim of this study was to analyse the effects of environmental factors and their interactions on wild yam distribution on the Mahafaly Plateau and to predict yam species abundance using SDMs to define pressure zones for effective resource management. We hypothesize that the occurrence and abundance of wild yam species is largely determined by soil properties, vegetation structure and human interventions rather than topography.

3.3. Materials and methods

3.3.1. Study area

The study area is located in the northern part of the Mahafaly Plateau in SW-Madagascar (23°46'-24°1'S, 43°54'-44°15'E) and comprises different forest habitats where people collect wild yam tuber (Figure 3-1). This region is characterized by a semi-arid climate with a dry season from April to November and an annual mean temperature of 24°C, classified as hot arid steppe climate. The rainfall is very irregular, and varies strongly from the coastal zone to the 10 km distant Plateau area, but the most reliable records indicate long term averages of < 500 mm throughout the region (Hanisch et al., 2015). The natural vegetation consists of deciduous savannah forests with xerophytic species of the Didieraceae and Euphorbiaceae families. From the coastal plain to the inland, the area is characterized by different ecological zones: dry forest on sandy or ferruginous soils and dry spiny forest on tertiary limestone (Du Puy and Moat, 1998). This ecosystem harbours the highest level of plant endemism at the generic (48%) and species (95%) level in Madagascar (Mamokatra, 1999).

The study region includes the recently extended Tsimanampetsotsa National Park, numerous 'sacred forests', and community forests where the collection of forests products is not legally restricted. The zone is inhabited by three main ethnic groups (Mahafaly, Vezo, and Tanalana), which comprise mainly small holder farmers and herders with little formal education. Agricultural production, based on the cultivation of cassava *(Manihot esculenta* Crantz), maize (*Zea mays* L.) and different varieties of beans, is hampered by unpredictable rainfall. Consequently people are often affected by food insecurity (WFP, 2013) and rely on the collection of forest products that provide food, medicinal plants fuel wood and construction material, to sustain their livelihoods. This has increased the pressure on forests resources outside the park area and led to forest degradation with high forest losses (45%) during the past 40 years (Brinkmann et al., 2014).

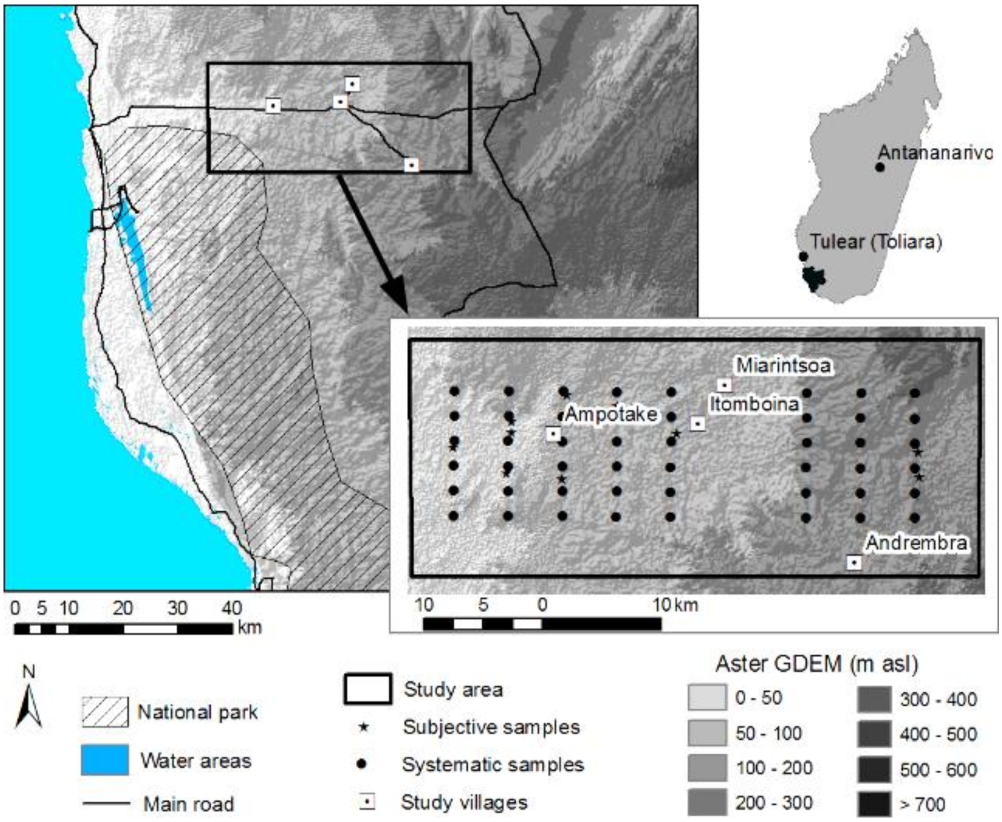

Figure 3-1 Location of the study area and distribution of sample plots on the Mahafaly Plateau region in SW Madagascar.

So far, a total of 24 yam species are known from SW-Madagascar (Tostain et al., 2010). Their local name '*oviala*' means 'tuber from the forest' are used as supplementary food during lean periods in rural areas (Jeannoda et al., 2003, 2007). The collection of wild yam tubers is a common practice for 90% of the households in the Mahafaly Plateau to supplement their diet (Andriamparany et al., 2014).

3.3.2. Field inventory and indigenous soil classification

Five important species of wild yams have been identified during recent field studies (*D. alatipes*, *D. bemandry*, *D. nako*, *D. fandra*, and *D. soso*) of which the first two are particularly important (Andriamparany et a., 2014). Since the aboveground lianas of Dioscorea spp. are only visible for a few months after the onset of rainfall, proper species identification was limited to a short time period, and a field inventory was therefore conducted from January to March 2013. Study site selection was based on existing data of an ethnobotanical survey (Andriamparany et al., 2014). In total, four villages (Ampotake, Miarintsoa, Itomboina and Andremba) were selected and the corresponding wild yam collection area of these villages delineated the study area (Figure 3-1; 350 km²) for field inventory and SDM.

Using a systematic sampling approach, 48 plots (size of plot = 400m²) placed every 2 km along eight transects were used for a yam species inventory. Because of environmental heterogeneity, ten additional plots were placed between the systematic ones. The geographical locations and altitude of each plot were recorded with a handheld GPS unit (GARMIN, eTrex, HCx, Ireland; accuracy ± 2 m). For each plot, yam species were identified and their abundance was recorded by counting the number of individuals per species. The harvest intensity of wild yams was estimated based on the number of harvest holes at each plot, which were typically left open after local people have collected tubers (Andriamparany et al., 2014). Five soil samples were taken at 0–20 cm depth from the centre and corners of each plot. Subsequently, these were mixed to obtain a homogenous Due to a lack of detailed soil maps for the study region and insufficient data on soil classifications, we used an indigenous soil classification approach to characterize the different soil types for subsequent yam species distribution modelling. Since our main objective was to differentiate the existing soil types in the study region, we used a simplified participatory method. During interviews with ten wild yam collectors per village ($N = 40$), general information on indigenous soil types (name, characteristics, site suitability for agriculture and wild yam species) were compiled. The most important local criteria for soil classification were the physical aspects such as soil colour and texture. After classifying the indigenous soil types, local people assisted during field survey to identify the local soil names for each plot.

3.3.3. Analysis of soil parameters

The composite soil samples of the plots were air dried, sieved and analysed in the laboratory. Standard analyses were conducted to determine plant-available phosphorus (P; P-Bray II method for soil with pH < 7 and P-Olsen for pH > 7), total nitrogen (N_{total}), pH (pH-water), calcium (Ca), organic carbon (C_{org}), potassium (K), and soil texture (percentage of clay, silt and sand). To determine how indigenous soil classes differed in terms of soil properties (P, N total, pH, Ca, K, C org, texture), a discriminant analysis was conducted using SPSS 20.0 (IBM Corp., Armonk, NY, USA). The results were evaluated using structure coefficient matrices, canonical correlation coefficients, eigenvalues and Wilk's Lambdas. For predictive mapping of yam species distribution, we created maps of each measured soil parameter (P, N, pH, Ca, K, C_{org}, texture) with Ordinary Kriging, using the spatial analysis tool in ArcGIS 10.0 (ESRI, Redlands, CA, USA).

3.3.4. Analysis of yam species distribution

Among the five sampled yam species in the study region, D. soso was excluded from the data analysis, because of its rare occurrence. To investigate the relationship between the abundance of the four remaining yam species and 12 environmental variables, a Redundancy Analysis (RDA) was used. A forward selection for explanatory variables was conducted manually using partial Monte Carlo permutation tests to check the significance of each variable and remove non significant variables from the model. The significance of the constrained axes were statistically tested by the Monte Carlo Permutation test (499 permutations) and the sum of all canonical eigenvalues was used to estimate the proportion of explained variation (Table 3-1), a constrained ordination method was conducted.

The model included the identified indigenous soil classes as environmental factors. Further environmental variables were extracted from existing geographical data. The topographic conditions (slope and elevation) were generated from a Digital Elevation Model (ASTER GDEM Version 2, date of acquisition 17.10.2011, a product of NASA/METI). To describe the vegetation structure, existing data on land cover and forest fragmentation for the Mahafaly Plateau, classified for the year of 2013 by Brinkmann et al. (2014) was used to identify areas with open vegetation (barren land, cropland, savannah, shrubland) and non-fragmented forest areas. Human interventions were estimated based on the harvest intensity measured during the field inventory (number of harvest holes) and the distance to the main road. The latter was calculated using the Euclidian distances between each plot and the main road within ArcGIS.

Prior to analysis, the nominal variables (soil classes, open vegetation, non-fragmented forests) were recoded using a set of dummy variables; species data were logarithmically transformed. Additionally, the species data set were tested for spatial autocorrelation, which is known to violate the assumption required to use statistical models and often results in biased parameter estimates (Dormann et al., 2007). Therefore, Moran's I indices were used and statistically tested for significance (499 randomized permutations) by applying the GeoDa software (https://geodacenter.asu.edu/software; Anselin et al., 2006). Results revealed no spatial autocorrelation ($p > 0.05$; Appendix 3-2).

To choose the appropriate ordination method for statistical analysis of yam species distribution in CANOCO (version 4.5, Microcomputer Power, Ithaca, NY, USA), the length of environmental gradient was determined using a Detrended Correspondence Analysis (DCA). Because of linear species response (gradient length: 3.043; Lepš and Šmilauer, 2003), a Redundancy Analysis (RDA) was used. A forward selection for explanatory variables was conducted manually using partial Monte Carlo permutation tests to check the significance of each variable and remove non significant variables from the model. The significance of the constrained axes were statistically tested by the Monte Carlo Permutation test (499 permutations) and the sum of all canonical eigenvalues was used to estimate the proportion of explained variation.

Table 3-1 Variables used for the analysis of yam species distribution on the Mahafaly Plateau in SW-Madagascar.

Groups of variables	Variable		Unit	Values/Frequency (n=58)*
	Code	Scientific names and descriptions		
Wild yam species	DIAL	*Dioscorea alatipes*	Number of individuals plot-¹	13.2±27.5
	DIBE	*Dioscorea bemandry*	Number of individuals plot-¹	3.5±16.2
	DIFA	*Dioscorea fandra*	Number of individuals plot-¹	3.9±11.2
	DINA	*Dioscorea nako*	Number of individuals plot-¹	0.1±0.8
Soil (Indigenous classes)	CAL_1	harambato	Presence/absence	25
	CAL_2	harantomboaka	Presence/absence	7
	CAL_3	havoa	Presence/absence	3
	FER_1	tany lahy	Presence/absence	12
	FER_2	tany lembe	Presence/absence	3
	SAN_0	tany fasika	Presence/absence	8
Topographic conditions	Elev	Elevation	Meters	178.1±68.8
	Slope	Slope	Degrees	2.6±2.6
Vegetation structure	Open_Veg	Open vegetation	Presence/absence	47
	NoFrag_F	Non-fragmented forests	Presence/absence	13
Human interventions	Harv_Int	Harvest intensity of wild yam tubers	Number of holes plot-¹	4.9±11.5
	Road_Dis	Road distance	Kilometer	2.9±1.9

(*) Mean± Standard deviation

3.3.5. Modelling of yam species distribution

To predict the distribution of wild yams species and to study their response along soil gradients, we used Nonparametric Multiplicative Regression Analysis (NPMR), which is a niche based habitat modelling approach developed by (McCune, 2006). The modelling was restricted to the three most abundant species, *D. alatipes*, *D. bemandry* and *D. fandra*, to avoid unreliable predictions of rare species.

In total, 15 environmental variables related to topographic conditions, vegetation structure, human interventions and soil parameters, were included in the NPMR models. NPMR models and Species response curves (SRC) were generated using Hyperniche V.2 software (McCune, 2011). NMPR started with a calibration, in which species abundance was used to build the model in order to estimate abundance more effectively based on the predictors. In the second step, the most powerful subsets of predictors were identified and smoothing parameters of the Gaussian weighting function for each predictor were determined. Our NPMR models were based on local mean with Gaussian weighting. With the stepwise free search function a range of models with different combination of predictors were calculated to choose the best model for each species (McCune, 2006). To choose the best predictors, the relative importance of particular predictors within the model was evaluated using the sensitivity analysis in Hyperniche. The sensitivity of the model to the chosen predictors was estimated by calculating the tolerance as a proportion of the variables range (e.g. the relative importance of an environmental variable in the model). Sensitivity values range from 0 to 1 and greater sensitivity indicates higher influence of that variable in the model (McCune, 2006). For model validation, the cross R-Squared (xR^2) was calculated based on the residual sum of squares (RSS) divided by the total sum of squares (TSS), which differs from the traditional R^2 (Antoine and McCune, 2004). Consequently, negative xR^2 are common for weak models if RSS > TSS. The resulting SDM were further evaluated with a Monte Carlo permutation test (1000 randomized runs). Based on the NPMR results, SRC were computed for each species using the correspondent identified best predictors (pH, C_{org}, K, N_{total}, silt and clay content) and produced as series of two dimensional response graphs. Finally, in the application phase, predictive maps were generated for the selected models using the GIS function in Hyperniche. Prior prediction, ESRI grids (in ASCII format) were prepared for all predictors selected to build the best models (road distance, open vegetation structure, non-fragmented forests, harvest intensity, pH, K, N_{total}, C_{org}, silt and sand). Predicted relative abundances of wild yams were plotted against the observed ones, with a fitted line with 95% confidence intervals, and Pearson's correlation coefficient were calculated to evaluate the accuracy of the modelled abundance maps.

3.4. Results

3.4.1. Indigenous soil classification

Altogether, six indigenous soil classes (Table 3-2), which are used to describe the soil types in the natural environment, were identified by the local population. Classification occurred according to physical parameters (texture, stoniness, hardness, colour, water content, topographic position, land cover and site suitability aspects. For example '*harambato*' refers to 'rocky soils on a hillside' and '*tany lahy*' to 'male soil' similar to 'hard soil'. Although, the Mahafaly Plateau is mainly known for its calcareous soils derived from tertiary limestone, soil texture and stone content is highly variable and an important criterion for soil differentiation by the local people. Similarly divers was the perception of colour tones. Especially for red soils, respondents used very detailed descriptions (light red, dark red, bright red) to differentiate the unconsolidated sands and ferruginous soils. Other soil properties such as hardness, moisture content and thickness of litter were also used for soil description, but to a much lesser extent, whereas land cover or vegetation type and the topographic position were used very frequently. Similarly frequent was the use of site suitability aspects for crop cultivation ('good for maize cultivation' or 'dead soil').

Table 3-2 Properties of the indigenous soil classes in the study area according to the local people on the Mahafaly Plateau in SW-Madagascar.

Indigenous soil classes			Nomenclature
Name	Soil properties	Perceptual aspects	Soil map classification[1]
Harambato (CAL_1)	Dark soil, large and bare rocks, loamy, high litterfall, dry spiny forest thicket, hilly landscape	Suitable for *D. alatipes*$^{+++}$, fertile, maize cultivation	Tertiary limestone
Harantombake (CAL_2)	Dark soil, loamy, rocks are not large and not bare, upper soil visible on the surface of rocks, high litterfall, dry spiny forest thicket, hilly landscape	Suitable for *D. alatipes*$^{++}$, less fertile; suitable for maize ultivation	Tertiary limestone
Havoa (CAL_3)	Light yellow soil, sandy loam, light, hard, and dry soil with small stones, dry spiny forests thicket, hilly landscape	Bad soils, Suitable for *D. alatipes*$^{++}$	Tertiary limestone
Tany lahy (FER_1)	Light red soil, dry, loamy, very hard soil, wooded savannahand open spiny forests, lowland	Unfertile soil 'dead soils', not suitable for cultivation, suitable for *D. fandra*$^{+}$	Unconsolidated sands
Tany lembe (FER_2)	Dark red soil, soft and wet, loamy sand, dense spiny forests, lowland	Fertile soil; suitable for *D. nako*$^{++}$, *D. fandra*$^{+++}$, beans cultivation; rich wood resource area	Unconsolidated sands
Tany fasika (SAN_0)	Red soil, sandy, open spiny forests, lowland	Suitable for *D. bemandry*$^{+++}$, *D. nako*$^{+}$	Unconsolidated sands

([1]) Soil type based on Du Puy & Moat (Moat & DuPuy 1997); plus signs represent the indigenous perception of wild yam species availability ($^{+++}$ very abundant, $^{++}$ abundant, $^{+}$ occasional).

Discriminant analysis revealed that soil physical and chemical properties differed significantly between soil classes except for plant-available phosphorus (Table 3-3). The first canonical discriminant function explained already 80.5% of the variance (Wilks's Lambda = 0.82; $P < 0.001$). Using the structure matrix, we identified that the first discriminant function was associated with six variables (Corg, Ca, Ntotal, pH, sand, silt). Here, the most important discriminating factors were Corg, Ntotal, and Ca.

Table 3-3 Physical and chemical soil properties of the indigenous soil classes on the Mahafaly Plateau in SW-Madagascar and results of the discriminant analysis.

Measured soil properties	Indigenous soil classes						Discriminant analysis[1]		
	CAL_1	CAL_2	CAL_3	FER_1	FER_2	SAN_0	Wilks' Lambda[2]	Sig.	Structure matrix
pH	7.5±0.1	7.6±0.1	7.5±0.4	6.9±0.7	7.6±0.3	6.8±0.7	0.608	***	0.351
Corg (%)	4.6±1.4	3.5±1.1	1.8±1.2	1.4±0.9	1.2±0.4	0.9±0.7	0.306	***	0.720a
Ntotal (%)	0.38±0.1	0.31±0.1	0.15±0.1	0.1±0.05	0.11±0.04	0.06±0.03	0.324	***	0.695a
P (ppm)	5.9±3.6	5.2±4.7	1.8±0.2	9.8±8.6	1.8±1.8	7.1±3.6	0.832	ns	-0.095
Ca (meq/100g)	13.6±5.1	11.5±3.8	6.4±5.9	4.0±3.8	7.5±3.3	2.2±3.3	0.448	***	0.537a
K (meq/100g)	0.9±0.3	1.1±0.3	0.8±0.8	0.6±0.4	1.6±1.04	0.4±0.4	0.677	***	0.203
Clay (%)	4.7±1.7	7.7±3.1	8.6±5.1	8.8±3.9	8±3.0	5.8±4.8	0.746	***	-0.199
Silt (%)	20.7±4.3	21.7±1.4	14.3±9.1	9.2±6.1	21.0±7.8	5.8±6.0	0.383	***	0.569
Sand (%)	74.6±4.8	70.6±2.4	77±14.2	82±7.7	71.0±10.4	88.5±10.6	0.585	***	-0.325
Eigenvalue = 4.232									
Percentage variance = 80.5									

([1]) All values depict the first canonical discriminant function; (a) Largest absolute correlation with discriminant functions; ([2]) the smaller the Wilks's lambda, the more important is the independent variable for discriminant function; (ns) non-significant; (**) significant at 5% and (***) at 1%

3.4.2. Yam species distribution along environmental gradients

Using multivariate analysis, a clear relationship between the four wild yam species and the selected environmental variables was detected. Altogether, eight significant explanatory variables were included in the RDA analysis (four indigenous soil types, harvest intensity, road distance, open vegetation and non-fragmented forests; Appendix 3-1). The combined effect of explanatory factors explained 50.9% of the total variability of *Dioscorea* spp. distribution, from which 96.1% are explained by the first two axes (Figure 3-2, Table 3-4). A Monte Carlo permutation test revealed a significance level of P = 0.002.

Axis 1 explained 34.3% of the total variability in the species data and was positively correlated with the distance to road and calcareous soil types (CAL_1, CAL_2), which were characterized by a high content of Ca, N_{total}, C_{org} and silt. This axis represents a soil gradient from the closed forests at calcareous rocks, which are mostly situated far away from the road, to the ferralitic soils at lower altitudes. Occurrence of *D. alatipes* was positively correlated with the first axis and situated in the first quadrant, whereas *D. nako* occurred in the third quadrant of axis 1, where the environmental factors `ferralitic soils´ (FER_1 and FER_2, characterized by a high P and clay content) and 'open vegetation' prevailed.

The second axis explained 14.6% of the variance in the species data. This axis represented a gradient from the ferralitic soils with higher silt and clay content to the red sandy soils, where *D. fandra* and *D. bemandry* occurred. The yams harvest intensity and non-fragmented forests were positively correlated with the second axis. *D. bemandry* and *D. fandra* were abundant on sandy soils, in non-fragmented forests, affected by highest harvest intensity.

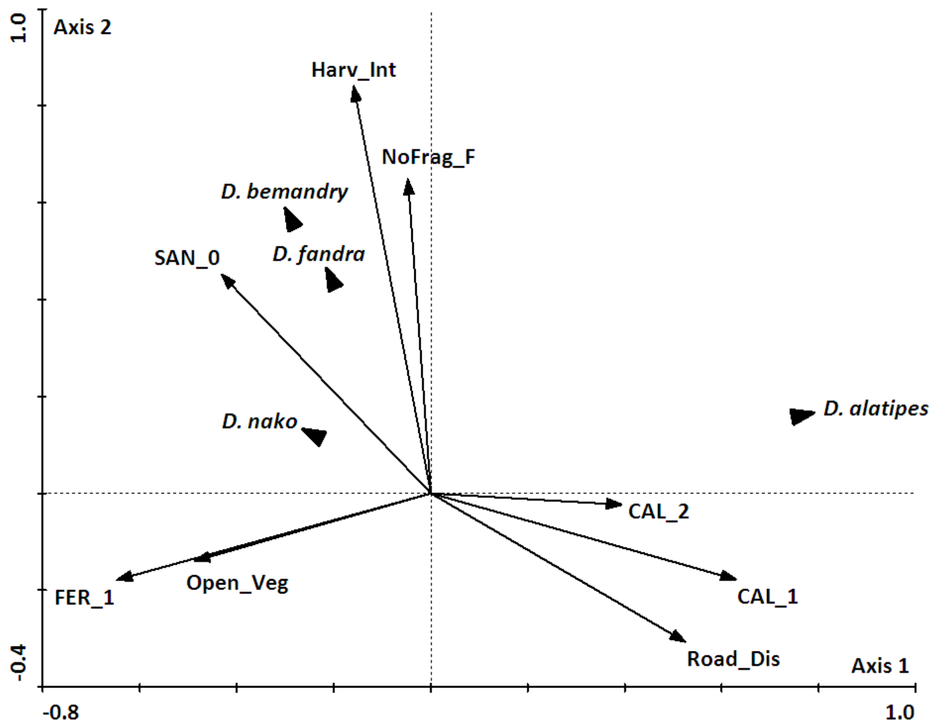

Figure 3-2 Ordination diagram of RDA showing the first and second ordination axes to display the relation of wild yam species (arrows with empty lines) and explanatory, environmental factors (arrow with solid lines) on the Mahafaly Plateau in SW-Madagascar.

Table 3-4 Correlation matrix of the two first ordination axis of an RDA of wild yams (*Dioscorea* spp.) occurrence on the Mahafaly Plateau in SW-Madagascar.

Explanatory factors		Axis 1	Axis 2
Main associated species on the axis		*D. alatipes, D. nako*	*D. bemandry, D. fandra*
Vegetation structure	Open vegetation	-0.386	-0.106
	Non-fragmented forests	-0.037	0.490
Human interventions	Distance to the road	0.417	-0.232
	Harvest intensity	-0.126	0.635
Soil	FER_1	-0.513	-0.135
	CAL_1	0.499	-0.135
	CAL_2	0.312	-0.018
	SAN_0	-0.343	0.342
Species-environment correlations		0.79	0.76
Eigenvalues		0.34	0.15
Cumulative variance (%)		67.4	96.1

3.4.3. Species distribution models (SDM) and species response curves (SRCs)

Species distribution models were best for *D. alatipes* (xR^2= 0.88), followed by *D. bemandry* (=0.82) and *D. fandra* (xR^2= 0.37). Every added predictor improved the fitness of each model by 5%, which might explain the high xR^2 for the *D. alatipes* model with six predictors (Table 3-5). In contrast, NPMR models of *D. bemandry* and *D. fandra* were only based on five predictors. Monte Carlo permutation tests revealed that two models were statistically significant. Out of the nine soil parameters included in the analysis, pH, C, K, N, silt and clay were identified as the best soil predictors for wild yam distribution.

SRC represented three step function curves, two sigmoid and a skewed hump-shaped. The remaining two SRCs, for *D. fandra* along a K-gradient and *D. fandra* along a gradient of Clay content showed no specific curve shape. Although skewed, only *D. alatipes* showed the classical shape of a unimodal response curve along an environmental gradient with an optimum at pH 7.2-7.5 and a rapid decline above or below this range.

For C and K, *D. alatipes* showed a sigmoid relationship, indicating that this species is widely abundant under high K and C contents in the soil (Figure 3-3 B, C). *D. bemandry* and *D. fandra* presented similar SRC step function shapes along N, Silt and C, where species abundance declines after a certain threshold (around 1% for C_{org}, 5% for silt and 0.1% for N_{total}). Highest species abundances were reached with low C_{org}, N_{total} and silt content in the soil.

Table 3-5 Summary of NPMR models for the three selected wild yam species on the Mahafaly Plateau of SW-Madagascar.

SDM	*D. alatipes* Predictor	Sensitivity	*D. bemandry* Predictor	Sensitivity	*D. fandra* Predictor	Sensitivity
1st	Road_dis	0.136	Road_dis	0.230	Harv_Int	0.099
2nd	Open_Veg	0.000	Harv_Int	0.028	NoFrag_F	0.027
3rd	NoFrag_F	0.154	NoFrag_F	0.016	N_{total}	0.231
4th	pH	0.167	C_{org}	0.017	K	0.005
5th	C_{org}	0.008	Silt	0.004	Clay	0.032
6th	K	0.004	-	-	-	-
xR^2)	(0.88)		(0.82)		(0.37)	
P value	0.04		0.04		0.09	

(-) not selected in the model

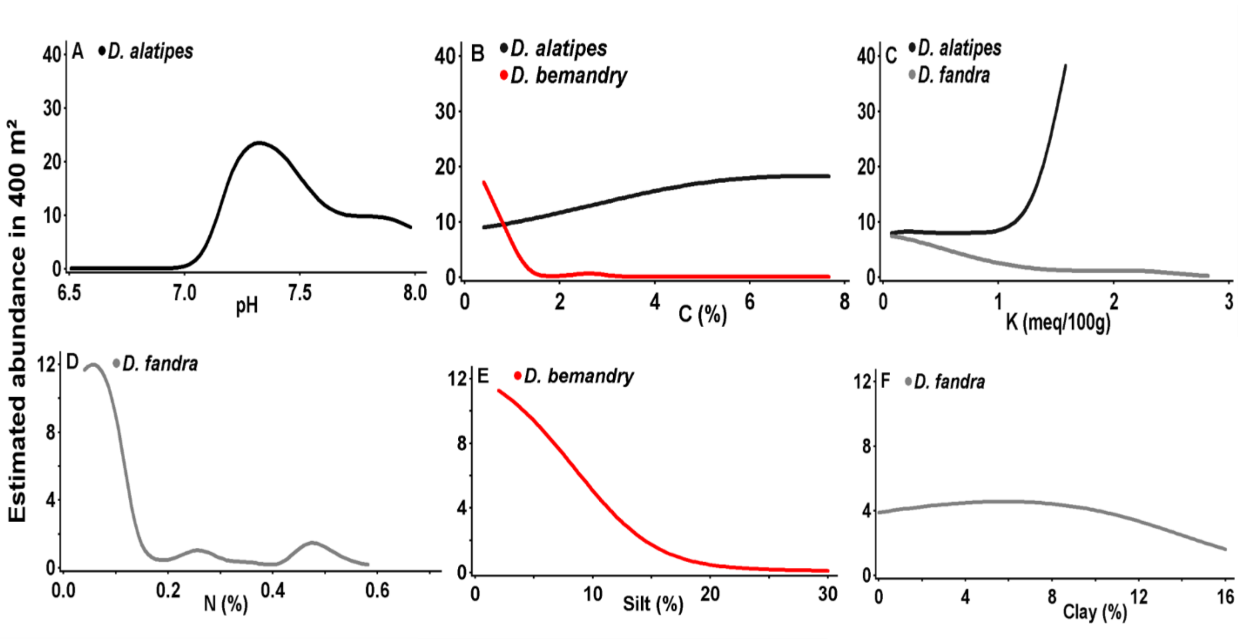

Figure 3-3 Nonparametric multiplicative regression (NPMR) response curve for selected wild yam species along edaphic gradients

3.4.4. Predictive mapping of yam species

Predictive maps of three wild yam species were generated using the NPMR models Figure 3-4for one of the most important collection area of wild yams near the villages (Figure 3-4). Highest species abundance (> 15 individuals in 400 m²) was predicted for only 8.7% of the total area for *D. alatipes*, 2.1% for *D. bemandry* and 1.1% for *D. fandra*. Lowest abundance (< 5) dominated, especially for D. *bemandry* and *D. fandra*, which were characterized by a patchy distribution with highest abundances in the northern part of the zone between the villages Miarintsoa and Ampotake. *D. alatipes* showed a different and more evenly distribution with highest abundances far away from the villages.

The observed species abundances were significantly correlated with the predicted abundance for all species, with high Pearson correlation coefficients ranging from 0.89 to 0.98 (Figure 3-5). Correlation coefficients were highest for more abundant species (*D. bemandry* and *D. alatipes).* The visual assessment of plots suggested that there are few plots, with very high predicted abundance, especially for *D. alatipes* and *D. bemandry*.

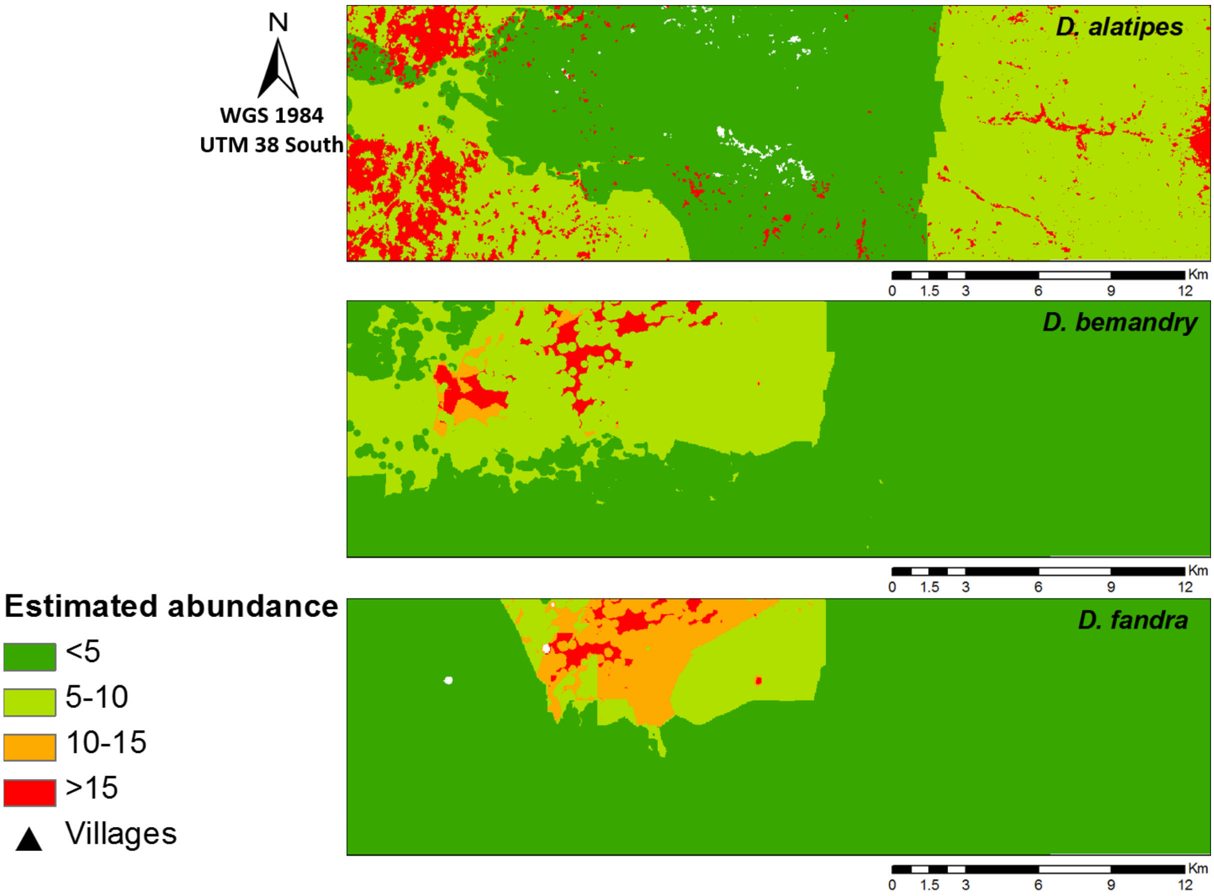

Figure 3-4 Predictive maps for three wild yam species on the Mahafaly Plateau of SW-Madagascar using the corresponding Nonparametric Multiplicative Regression (NPMR) models. Abundance classes represent predicted number of number of individuals of yams within 400 m². Areas where prediction was impossible are highlighted in white colour.

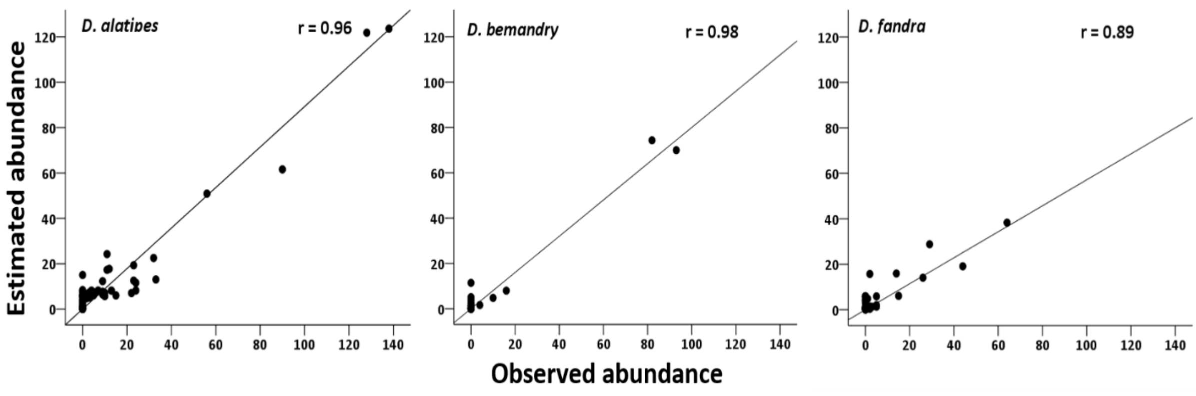

Figure 3-5 Accuracy assessment for the predicted yam species distribution on the Mahafaly Plateau estimated form NPMR models. Each data point represents a single sample (plot of 400 m²) and goodness of fit indicated with a trendline and Pearson's correlation coefficient r.

3.5. Discussion

3.5.1. Indigenous soil classification

Local knowledge on soil, land, plants and environment are a valuable resource for scientists (Barrera-Bassols et al., 2006a; Lo Nethononda and Odhiambo, 2011). Similar to other ethnopedological studies (Barrera-Bassols and Zinck, 2003), local population on the Mahafaly Plateau used typical soil characteristics for soil classification. The high discriminating power of discriminant analysis for most chemical and physical soils properties confirms that indigenous people are aware of soil differences, which often enables them to easily recognize soil fertility and site suitability for agriculture (Shah, 1995). There is a need to develop a more integrated methodological approach for ethnopedology and one of the main issues mentioned in several ethnopedological reports is the inconsistency of ISC at larger scale (Niemeijer, 1995; Sillitoe, 1998). The main objective of our ethnopedological survey was to differentiate the soil types and provide more practical results in studying local resource availability and land use practices of the current livelihood system. Thus, the identified local soil names in our study region cannot be extrapolated to other regions with different ethnics, livelihood types and habitats.

3.5.2. Yam species distribution along environmental gradients

The results confirmed our hypothesis and indicated that edaphic factors, vegetation structure and human interventions have a stronger influence on the occurrence of wild yam in the Mahafaly Plateau than topographic conditions. This might be due to the small topographic gradient in our study region ranging from 55 m to 200 m above sea level. The relative importance of topographic factors at local scale may be variable (Moeslund et al., 2013), but climatic and geological features are affecting species distribution at larger scales (Gerhardt and Foster, 2002). Other studies found that human interventions strongly affect wild yams availability at local scales (Devineau et al., 2008; Sato, 2001; Yasuoka, 2013).

A clear gradient has been delimitated for two major species (*D. alatipes* and *D. bemandry*) which is in line with studies conducted on wild yam species distribution in the same region (Tostain et al., 2010). The most prevailing gradient in the RDA ordination represented the differences in the soil substrate from calcareous rocks to unconsolidated, ferallitic sands. Only *D. alatipes* occurred on calcareous soils in dry spiny forest thickets with a closed canopy, which constitutes a restricted distribution zone for locally endemic species (Olson and Dinerstein, 2002) and a remarkable botanical richness (Du Puy and Moat, 1998). *D. alatipes* might be one of the ‘specialists’ species, adapted to extreme environmental conditions on poor limestone soils (Alcantara, 2007). In some limestone soils, high concentration of $CaCO_3$ can lead to very hard layers resulting in impermeability to water (Leytem and Mikkelsen, 2005) and almost no exchangeable H^+ (Misra and Tyler, 1999) that may cause nutrient deficiencies and nutrient imbalances (Kishchuk et al., 1999). Availability of phosphorus is often the most limiting factor for plant growth in calcareous soils due to the high amount of carbonate minerals (Carreira et al., 2006; Leytem and Mikkelsen, 2005).

In contrast to the report of Tostain et al. (2010), who observed the occurrence of *D. nako* on calcareous soils in the south-western region of Madagascar, we found *D. nako* on ferralitic soils. *D. fandra* and *D. bemandry* were related to sandy soils with low nutrient contents, high harvest intensity and non-fragmented forests at lower altitudes. This was also confirmed by Tostain et al. (2010)f or *D. bemandry*. According to Andriamparany et al. (2014), *D. bemandry* is highly appreciated by local people in this region and thus harvested intensively. The negative effects of unsustainable wild yam harvest techniques on yam regeneration and soil structure (Ackermann, 2004; Andriamparany et al., 2014) and the alarming degradation processes reported by Brinkmann et al. (2014) raise concern about the future viability of wild yams populations.

3.5.3. Yam species distribution models and response curves

The modelling was restricted to the three most abundant species to avoid unreliable predictions of rare species because regular sampling would not be representative (Eberhardt and Thomas, 1991). The average neighborhood size of all SRC models was higher than their respective minimum average neighborhood size needed for estimation, indicating that the model has enough data points for successful prediction of the species response for the given environmental variables (Beyene et al., 2014). Moreover, our total number of samples was higher than the recommended minimum value of 50 samples for an acceptable ecological response curve (Coudun and Gégout, 2006). More intensive sampling does not always significantly increase the accuracy in determining the curve characteristics (Stockwell and Peterson, 2002; Virtanen et al., 1998) because the shape of SRC is particularly determined by species and gradient properties.

Compared to linear (Carl and Kühn, 2008) or logistic (Pearce and Ferrier, 2000) regressions, GLMs (Guisan et al., 1999) and GAM (Guisan et al., 2002; Yee and Mitchell, 1991), NPMR models show non-linear species abundance relationships and account for interactions among predictors (McCune, 2006). Although the combination of predictors was slightly different for each model, ten variables were identified as important predictors for the three SDM: Road distance, open vegetation, non-fragmented forests, harvest intensity, pH, C_{org}, N_{total}, K, silt and clay content. This was also confirmed by other studies, where land use, vegetation types, anthropogenic pressure and soil characteristics were the most important factors influencing the density and spatial availability of wild yams (Dansi et al., 2013; Devineau et al., 2008; Rakotondratsimba, 2008).

In our modelling approach, the choice of predictors during the calibration phase of the analysis strongly influenced model quality and was based on the concept of multiple causal factors (Hutchinson et al., 1987) rather than selecting only significant predictor as we did in ordination methods. In SDM the inclusion of environmental predictors from more than one hierarchical scale tended to yield more accurate predictions (Meyer and Thuiller, 2006). The use of factor gradients with a direct physiological effect (pH, temperature) or resource gradients (water, light, nutrient) that are consumed are also suggested (Austin and Smith, 1990; Iverson and Prasad, 1998). We used soil chemical and physical parameters instead of indigenous soil classes for SDM. Since wild yam has always been used as supplementary food by the local people in SW-Madagascar (Perrier de la Bathie, 1934), we included not only environmental predictors but also variables, that describe human interventions. The performance of NPMR varied among species and explained 88% (*D. alatipes*), 82% (*D. bemandry*) and 37% (*D. fandra*) of the variation in the relative abundance. Except for *D. fandra*, the fitness of the models proved the power of NPMR in modelling plant species distribution similar to other studies (Fenton and Bergeron, 2008; Rood et al., 2011; Yost, 2008). One reason for the weak model of *D. fandra* could be the lack of suitable environmental predictors such as water availability for SDM.

The SRCs improved our understanding on yam species-environment relationships. The most important soil parameters for the distribution of three selected wild yam species were selected based on the sensitivity analysis of the SDM. The Hyperniche software allowed several ways to represent SRC, but we chose the two dimensional response graphs, because the interpretation of single gradients is relatively straightforward and easy to conduct (Jovan, 2003). The ecological niche of a species is optimally described by a bell-shaped symmetric unimodal curve (Austin, 2002), which has been widely used in ecological studies (Potapova et al., 2004; ter Braak al., 2004). However, we found more frequently step and sigmoid SRC shapes and only *D. alatipes* showed a hump-shaped response for the pH-gradient. Intra and inter-specific interactions, competition and environmental stress factors can cause linear, skewed and multimodal responses (Oksanen and Minchin, 2002; McCune, 2011) and real world datasets are rarely representative for all species responses (Lawesson and Oksanen, 2002), which was confirmed by our analysis. Skewness is common (Franklin, 2010) and its causes can be diverse (Austin and Smith, 1990), but it might be the direct effect of harvest intensity in our study. Environmental changes (Haire et al., 2000), human activities (Le Lay, 2002) and mortality-causing disturbances (Huston, 2002) can create complex response shapes to species environmental gradients. The species abundance of a sigmoid function increased slowly at the beginning with a rapid decrease after reaching an optimum level of gradient and this was found for *D. alatipes* along a potassium gradient. Such sigmoid curves possibly depict a part of an unimodal distribution over a long environmental gradient (McCune, 2011) and this might be true for *D. alatipes*, which mainly occurs on calcareous soils under extreme habitat conditions such as hot, dry, rocky limestone. A step-function was determined for *D. bemandry* and *D. fandra* along gradients of C_{org}, Nt_{otal}, silt and clay contents. This shape showed a sudden decrease of abundance at specific thresholds and may occur from an immediate establishment of a new vegetative population after a disturbance (McCune, 2011).

Altogether, *D. alatipes* was abundant under slightly alkaline soils with high soil C_{org} and Nt_{otal}. *D. bemandry* and *D. fandra* seems to perform better under low soil nutrient levels (C_{org}, N_{total} and K) and low silt content. However, we cannot give a clear statement on the 'specialist versus generalist' approach (Peers et al., 2012) because we did not build SRC models along the same gradient for all species. In contrast to *D. alatipes*, however, *D. fandra* might be a typical example of a generalist, since it occurs over a large range of soil gradients.

3.5.4. Predictive mapping of yam species

The predicted yam species maps confirmed our own field observations, expect for *D. fandra* where the weakness of the NPMR model resulted in unreliable predictions. *D. bemandry*, which was the most frequent collected species in Ampotaka (Andriamparany et al., 2014), mainly occurred within a limited area near the village, whereas *D. alatipes* was more evenly distributed with a high abundance. However, the predicted clumped occurrence of *D. bemandry* does not reflect its reported frequent distribution in SW-Madagascar (Tostain et al., 2010). It is likely, that the optimum microhabitat of *D. bemandry* on sandy soils (Tostain et al., 2010) was underrepresented within our studied area. In fact, sandy soils were not very frequent in our sampled zone (Du Puy and Moat, 1998). A reduced regeneration might be another reason for its low occurrence, probably because of high harvest intensities and the resulting overexploitation, which threatens the natural regeneration of wild yam throughout Madagascar (Ramelison and Rakotondratsimba, 2010).

The estimated abundances of yam species were slightly lower than the observed values especially for high abundances. Highest abundance for *D. alatipes* was found in non-fragmented forests at remote places, whereas *D. bemandry* and *D. fandra* occurred mainly in open forest habitats near roads, where harvest intensity was very high. If we compare the total density for all wild yam species, our results were similar to those of Sato (Sato, 2001), but different from those of Yasuoka (2013) in Cameroun, where dispersal of annual yams by hunter-gatherers inside their campsites increased the density.

To better detect habitat differences or dispersal barriers at smaller scales, the inclusion of further environmental factors such as water availability, which was not investigated in the current study, could increase model accuracy. The selection of explanatory variables as well as the prediction accuracy of the model generally depends on the sampling strategy of each dependent variables (Edwards Jr. et al., 2006) and prediction was limited to the spatial boundaries of the predictors (McCune, 2011). Nevertheless, the general underlying yam species-environment relationships and patterns may be extrapolated to similar regions in SW-Madagascar if predictor variables are available.

The current harvest practice by small holder farmers lead to overharvesting and forest degradation (Harvey et al., 2014) and to conflicts with conservation goals. The predicted maps for yam species may help to define hot spot areas and pressure zones and serve as a basis for conservation and management planning of forests resources. Due to overharvesting of tubers combined with unsustainable harvest methods (Ackermann, 2004), there may be already a population decrease. However, an impact of harvest intensity can only be investigated over much longer observation periods (Hall and Bawa, 1993) and we were unable to detect a clear negative correlation between harvest intensity and species abundance. Nevertheless, our data indicated a decrease in the number of saplings.

Similar to sustainable management approaches for other native species (e.g. for wild flowers in South Africa; Privett et al., 2014), certain harvest practices can maintain or increase yam population by replanting plant parts, a technique which was successfully used for wild yams in Cameroun (Yasuoka, 2013). Conservation projects such as Crop Wild Relatives (FAO) are already working on the valorisation and the in situ conservation of wild yams in Madagascar in the view of their vital importance for food security, especially in rural areas.

3.6. Conclusions

Wild yams are important for people’s livelihood on the Mahafaly Plateau and harvesting wild yam tubers is an important strategy to alleviate the effects of food insecurity in that region. In the view of the current over-exploitation, detailed information on wild yam distribution along environmental gradients is urgently needed for more efficient resource management. Our results show that soil properties, vegetation structure and human interventions directly affect the distribution of wild yam species. Combining biotic and abiotic factors improved the fitness of our species distribution models and allowed to predict the abundance of three wild yam species on the Mahafaly Plateau. Human intervention and interactions among predictors lead to relatively complex species response curves along environmental gradients. The species distribution models provide information on the actual availability of wild yam resources to improve the monitoring on the Mahafaly Plateau, where the Tsimanampetsotsa National Park is one of the main zones for biodiversity conservation while dealing with forest exploitation by the local communities. The observed niche characteristics of yam species should be interpreted with caution and an extrapolation of the current results is limited to the Mahafaly Plateau. For larger scale prediction, long term observations would be needed for different habitats in SW-Madagascar. This should include experiments on the cause-effects relationships between soil properties and occurence of wild yam that have been identified as apparently important in our study. For future research on the management of forest resources, we recommend to combine environmental factors with socio-economic variables, particulary human interventions, especially when dealing with intensively used resources that provide multiple services for local communities.

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3.8. Appendix

Appendix 3-1 Single effect of each explanatory factor on wild yam species distribution (Monte Carlo permutation test on the Mahafaly Plateau, SW-Madagascar

Explanatory variables	P-value
FER1 (tany lahy)	0.002**
CAL1 (harambato)	0.002**
Harv_int (harvest intensity of wild yam tubers)	0.004**
Road_dist (km)	0.002**
SAN0 (tany fasika)	0.002**
Open_Veg (open vegetation)	0.006**
NoFrag_Fr (non-fragmented forests)	0.022*
CAL2 (harantombake)	0.038*
Ele (elevation)	0.060ns
FER2 (tany lahy)	0.380ns
CAL3 (Havoa)	0.590ns
Slope	0.720ns

(*, **) Significance of each variable to species distribution model; (ns) not significant

Appendix 3-2 Morans I values of species data and significance test of spatial autocorrelation for yam (*Dioscorea*) species on the Mahafaly Plateau, SW-Madagascar

Species	Moran`s I	Randomization test (P_value)
Dioscorea alatipes	0.037	0.08
Dioscorea bemandry	0.009	0.11
Dioscorea fandra	-0.039	0.26
Dioscorea nako	0.063	0.16

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4. Promoting yams cultivation in the Mahafaly region of SW-Madagascar

By

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4.1. Abstract

Wild yams are an important food supplement for the local people of the Mahafaly Plateau in SW-Madagascar. Domestication of wild germplasm and in situ conservation of wild populations may contribute to counteract the devastating effects of high harvesting intensity on the existing wild yam populations in this region. This study investigated the relative regeneration abilities of six wild yam species (*D. alatipes*, *D. bemandry*, *D. fandra*, *D. soso*, *D. ovinala* and *D. nako*) as well as the agronomic performance of the wild yam species D. alatipes and a local variety of D. alata. The data were collected in seed pre-germination, pot and in situ vegetative regeneration experiments. Also tested were the effects of different levels of manure application (0, 10, 20, and 40 t ha^{-1}) on yam growth in field experiments. The effect of pre-germination treatments ($P < 0.05$) and the plant species used ($P < 0.01$) on the germination of seeds of the four wild yam species revealed to be significant. Two weeks of pre-chilling and imbibition in running water before sowing seems to be effective in breaking seed dormancy and promoting seeds germination of the investigated species, especially for *D. fandra* ($P < 0.05$) and *D. bemandry* ($P < 0.05$). Vegetative regeneration of the upper part of the tubers (corms) tended to yield higher sprouting percentage (SP) than of the minisetts of wild yam tubers, but these differences were not statistically different. Sprouting started 6 weeks after sowing (WAS) for the minisetts of tubers and 8 WAS for the corms. Both soil types ($P < 0.05$) and species ($P < 0.001$) significantly affected the regeneration performance of corms of the six wild yam species in their natural habitats. While *D. fandra* and *D. soso* grew on different soil types (calcareous, ferralitic, and sandy soils), the other species preferred only one soil type, whether on ferralitic or sandy soil. In the field experiments, the different rates of manure application did not significantly affect neither yield nor tuber characteristics. Nevertheless, manure application of 20 t ha^{-1} to *D. alata* and 10 t ha^{-1} to *D. alatipes* increased tuber yield by about 40% compared with the unamended control. Varietal choices in yam cultivation within the Mahafaly Plateau region are further complicated by labour requirement for minisett production and difficulties in finding appropriate yam seeds.

Key words: *Dioscorea*, Mahafaly Plateau, seed germination, vegetative regeneration, yield

4.2. Introduction

The genus *Dioscorea* spp. (Dioscoreaceae) comprises over 600 species of tuberous herbaceous lianas which are native throughout the tropical and warm temperate regions worldwide (Burkill, 1960). They are climbing, twining and perennial monocots (Coursey, 1967). Several species are important agricultural crops, particularly in parts of West Africa, whereby 95% of the world annual production is achieved along the yam growing belt of West Africa. In many countries tubers of wild yam species are also widely collected (Ackermann, 2004; Devineau et al., 2008; Sato, 2001; Yasuoka, 2013). There are several hundred cultivars of yams with widely differing chemical tuber composition (Coursey, 1967; Anosike and Ayaebene, 1981) and nutritional value (Agbor-Egbe and Trèche, 1995), but only a few species are of commercial importance including *Dioscorea rotundata*, *D. alata*, *D. opposite*, *D. esculenta* and *D. dumenterum*. The nutritional composition of wild yams were found to be similar to those reported for most cultivated yams in several parts of the world (Bhandari et al., 2003). Given their high nutritional value, wild yams can make a significant contribution to people's diets, particularly in rural areas. Besides their use as food, yams have been symbolically associated with culture and ritualism. In addition, certain wild yam species are used for their medicinal properties, particularly as an alternative to hormonal therapies because of their high content in steroidal saponins, primarily diosgenin (Bhandari and Kawabata, 2004; Komesaroff et al., 2001).

Altogether 42 yam species occur in Madagascar, of which some new species were recently described (Wilkin et al., 2008, 2009). They are used as food substitute, for cultural beliefs as well as medicinal purposes (Jeannoda et al., 2007). Of these, 37 species are native and 36 species are endemic to Madagascar. The endemic Malagasy species form a separate clade within the phylogeny of the genus, except for one species (Wilkin et al., 2005). One of their main characteristics is that most species are edible either raw or following simple cooking. It has been reported that the cultivated species (Jumelle, 1922; Rajaonah et al., 2010) found in Madagascar (*D. alata* and *D. esculenta*, and *D. bulbifera*) have been introduced with the first immigrant to the island (Raison, 1992).

For many years yam cultivation has been neglected in Madagascar likely as a consequence of discovering wild yams and intensive cultivation of rice and other root crops (Manihot esculenta, Colocasia esculenta, and Ipomoea batatas). It is now largely limited to extensive modes of cultivation in homegardens, backyards or on fallow land (Penche, 2008). Besides, wild yams are widely collected for home consumption and local sale. So far, 12 species of the Malagasy yams have been assessed as 'threatened with extinction' according to the IUCN criteria, largely as a consequence of over-exploitation and deforestation (Haigh et al., 2005; Ramelison and Rakotondratsimba, 2010; Randriamboavonjy et al., 2013a; Wilkin et al., 2008; Wilkin et al., 2009). Thus conservation plans are urgently needed to protect this potentially valuable germplasm (Ramelison and Rakotondratsimba, 2010; Randriamboavonjy et al., 2013b).

The Mahafaly Plateau, situated in the south-western tip of the island is one of the most disadvantaged areas of Madagascar where > 88% of the rural households are classified as poor (Neudert et al., 2014). People´s livelihoods suffer from poor infrastructure, lack of basic health services and education facilities. The semi-arid climate with low and highly unpredictable annual rainfall varying from 400-600 mm severely restricts agricultural production, leading to widespread food insecurity. In a recent study on yam use by locals, Andriamparany et al. (2014) concluded that high harvesting intensity for home consumption and an increase of local trade may be a major cause for the low abundance of wild yams species in the Mahafaly region. Knowing the high nutritional value of the Malagasy yams compared to other root crops (Jeannoda et al., 2007; Randriamboavonjy et al., 2013b), their conservation is of great importance as a food supplement for the rural poor, particularly during the ‘hungry period’.

This study was therefore undertaken to investigate the relative regeneration performance of wild yam species and a local variety of *D. alata* under pot, in situ and field experimental conditions, using different treatments and multiplication methods. We assumed that domestication of wild species and promoting the cultivation of domesticated varieties are important elements in a comprehensive strategy to fulfil local subsistence needs while protecting wild germplasm of yam.

4.3. Materials and methods

4.3.1. Pot experiments

All plant materials and substrates for pot experiments were collected from typical forest areas used for wild yam collection in the Mahafaly region (23°49’-23°57’ S, 43°54’-44°15’E). Pot experiments were conducted in the nursery of the Antsokay Arboretum (23°24’50.56’ S, 43°45’18.88’ E) in Tulear, the capital city of the ‘Atsimo-Andrefana’ region of SW-Madagascar.

4.3.1.1. Seed pre-germination tests

This experiment aimed at identifying appropriate methods to enhance seed germination of wild yam species from the Mahafaly Plateau. As dormancy is reportedly a major problem in seed germination of yams (Sadik, 1976), our experiments were based on the successful seed dormancy-breaking treatments used for *Dioscorea* spp by Ellis et al. (1985).

Fruits of four wild yam species (*D. fandra*, *D. bemandry*, *D. nako* and *D. alatipes*) were collected in August 2013 during the dry season. The climate from which these seeds were collected is characterized by a semi-arid climate, with a very irregular rainfall averaging 451 mm per year, registered between 2012-2013 (Hanisch, 2015; www.sulama.de). Seeds were released from the fruits’ wings, air dried and transported in brown paper bags to the nursery. Before sowing, seeds received different pre-germination treatments as follows:

1) Pre-chilling: moist seeds were placed in refrigerator set at 5°C for two weeks (PC2W) and four weeks (PC4W).
2) Chemical treatment using sulphuric acid (H_2SO_4): seeds were put in H_2SO_4 diluted with distilled water (50% v/v) for 2mn followed by thorough rinsing.
3) Soaking in running water (RW): seed were immersed in five times volume water for one hour.
4) Soaking in hot water: seed were imbibed in boiling water and removed after 5 min (HW). Seed were then allowed to cool in tap water.
5) Untreated or control (CT): no pre-germination treatment was used before sowing.

This experiment started in September 2013 with five repetitions leading to a total of 75 seeds per species, and pots that were placed into the nursery using a completely randomized design. Subsequently seedlings were carefully transferred into perforated plastic bags. Plants were watered twice a week until the end of the experimenta, for a period of eight weeks. The soils used for this experiment were taken from the harvesting sites of seeds (native soils of accessions). As a monocotyledon, yam hypogeal and germination was scored as the appearance of the seedling's epicotyl on the top of the substrate. Germinated seeds were counted every two weeks and well developed seedlings were removed from the pot to simplify counting and to prevent them from affecting the development of other seedlings.

4.3.1.2. Sprouting test of corms and minisetts of wild yam tubers

This experiment aimed at testing the sprouting ability of two types of plant materials (corms or minisetts of tubers) used for vegetative regeneration. To this end tubers of six species of wild yam (*D. fandra*, *D. bemandry*, *D. nako*, *D. alatipes*, *D. ovinala and D. soso*) and samples of their original soils were collected in September 2013. For each type of plant material, pots containing four plant materials each (corms and minisetts of tubers) were randomly placed in the nursery using four replications. Before the onset of the experiment, all collected tubers were measured and weighted. 'Corms' were obtained by cutting the upper part of each tuber and 'minisetts' by cutting tubers in small sets of 80-100g each. Pots were watered once a week until the end of the experimental period. Sprouted corms or minisetts were counted every two weeks until no more new sprouting were registered after 24 weeks.

4.3.2. In situ field experiments

Four corms of six species of wild yams (*D. fandra*, *D. bemandry*, *D. nako*, *D. alatipes*, *D. ovinala* and *D. soso*) were planted in the forests, in six types of soil using three repetitions. The soils represented the six main indigenous soil types found within a typical area for wild yams collection in the Mahafaly region, where CAL_1, CAL_2 and CAL_3 correspond to calcareous soils, FER_1 and FER_2 represent ferralitic soils, and SAND_0, a sandy soil (Andriamparany et al., 2015).

Experimental sites were fenced to protect the seedlings from grazing animals. Planted corms were exposed to similar conditions as in the undisturbed environment (no watering or particular treatments were applied). Sprouted corms were counted every two weeks until the end of the experimental period at 24 weeks.

4.3.3. Ex situ field experiments

This experiment aimed at testing manure effects on agronomic performance and yield of a local variety of *D. alata* and of *D. alatipes*, a highly consumed wild yam species in the Mahafaly region (Andriamparany et al., 2014). *D. alata* is one of the three cultivated yam species inventoried in Madagascar and the variety used in our experiments was 'Ovibe' (or 'Bemako' in the Mahafaly region) characterized by long and big tubers with brown skin and yellowish flesh (Jeannoda et al., 2007).

Tubers of *D. alatipes* were collected from the forest in September 2013 and from a local home garden in Andremba (a village situated in the Mahafaly region) for *D. alata*. Before the onset of the experiment, the dimensions and fresh weight of all collected tubers were measured. Tubers were cut into pieces of 80-100g following the guidelines of the International Institute of Tropical Agriculture (Aighewi et al., 2014). Each piece of minisett must possess a reasonable amount of peel (periderm) from which sprouting can occur. Minisetts were then treated with wood ash to protect them from pest attacks and then spread on suitable seed bed for pre-sprouting. No treatments were used during the pre-sprouting processes but the seed bed was watered once a week and untreated sprouted minisets were later on transplanted in the field. The pre-sprouting period lasted for three months (12 weeks) for *D. alata* and four months (24 weeks) for *D. alatipes*. Transplantation took part at the onset of rainy season for *D. alata* (November) and one month later for *D. alatipes* (December).

The experiment was conducted in a homegarden of Andremba, characterized by a ferruginous soil, where no amendments had been previously used for cropping. Prior to planting the field was cleared, divided into two plots (one for *D. alata* and one for *D. alatipes*) and holes dug of 15-20 cm depth placed every 1 m were prepared for transplanting of seedlings. Manure (0, 10, 20, and 40 t ha^{-1}) was incorporated in the soil before the transplantation and one sprouted minisett was placed in each hole.

The manure (Table 4-1) was taken from a local corral. Given the limited availability of seeds and sprouted minisetts, each treatment was repeated six times for *D. alata* and four times for *D. alatipes* and arranged in a completely randomized experimental design as no fertility gradients were apparent a priori. Weeds were manually removed one month after the planting, followed by a subsequent monthly weeding until the end of the experiment. The number of sprouted minisetts was recorded every two weeks. Field experiments started in November for *D. alata* and in December for *D. alatipes*. Tubers were harvested at the end the growing cycle, when the vines turned yellow and leaves were falling (July 2014) followed by the determination of tuber length, weight and yield (fresh matter).

Table 4-1 Average nutrient and organic carbon (C) concentration of the applied manure

Mean, n=3 KCL				(%)				
pH	C	N	N	P	K	Ca	Mg	Na
7.46±0.08	27.77	1.82	15.31	0.27	1.73	2.59	1.31	1.57

(Hanisch, 2015)

4.3.4. Labour costs

Yam production involves five types of activities: seed bed installation, land preparation, planting, crop maintenance and harvesting. We compared the three yam cropping systems *(D. alata* under minisett system 'MS', *D. alatipes* minisett under minisett system, and *D. alata* under traditional system 'TS'). Labour costs of yam production were assessed by comparing the number of working hours needed for each cropping system (traditional and minisett). For the minisett system, the number of working hours was estimated from our field trial. To compare these results with the labour input of the 'traditional' yam cultivation techniques, which consists of replanting the upper part of the yam tubers after each harvest, labour costs were estimated for a home garden, where yam cultivation was practiced.

4.3.5. Data analysis

Germination percentage (GP) and sprouting percentage (SP) were calculated as the number of germinated plant material (seeds, minisetts of tubers, and corms) divided by the number of sampled seeds and multiplied by 100. Data from all experiments were analysed using SPSS 20.0 (IBM Corp., Armonk, NY, USA). One way ANOVA was used to test for significance of treatment effects at $P < 0.05$ among manure treatments, seed germination treatments and soil types. Non-parametric tests (Mann-Whitney U and Kruskal Wallis tests) were used whenever residuals of data were not-normally distributed data.

4.4. Results

4.4.1. Effect of pre-germination treatments on seed germination of wild yam species

Pre-germination treatment effects were significant ($H = 14$, $P <0 .05$), but varied greatly among the four species ($H = 17$, $P< 0.01$; Table 2), but germination was highest for *D. fandra* with two weeks of pre-chilling (PC2W), and *D. nako* with soaking in running water (RW;Figure 4-1). Seeds of *D. fandra* failed to germinate with the acid treatment (H_2S_{O4}) and soaking in hot water (HW), and of *D. bemandry* with hot water. Without any treatments (CL), *D. nako* and *D. alatipes* performed better with an average GP of 38. 7 and 33.3 respectively (Table 4-2).

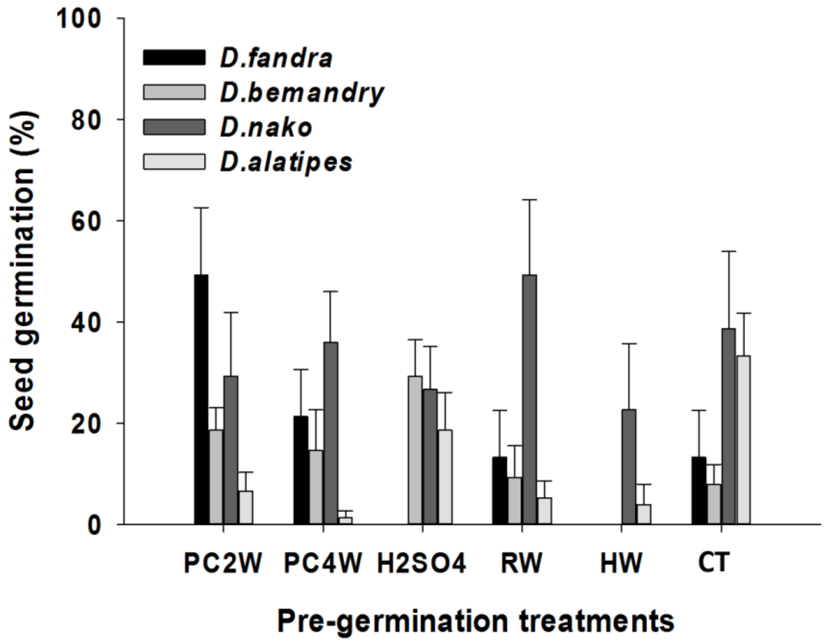

Figure 4-1 Effect of six pre-germination treatments on seed germination of four wild yam species from SW-Madagascar. Vertical bars indicate one standard error of the mean. Treatments: PC2W and PC4W = pre-chilling in refrigerator set 5°C for two and four weeks; H2S

Germination was highest for *D. fandra* with PC2W, for *D. bemandry* with H_SSO_4, for *D. nako* with RW and for *D.* alatipes without any treatment (CT). Post hoc tests (Mann-Whitney) showed significant differences in GP for *D. fandra* ($U = 3$, $P < 0.05$) and for *D. bemandry* ($U = 2.5$, $P < 0.05$), but not for *D. nako* ($U = 10$, $P = 0.59$). Although for *D. alatipes* germination was highest without treatment, it did not significantly differ from germination with H_2SO_4.

Table 4-2 Effects of different pre-germination treatments on seed germination rate of four wild yam species in SW-Madagascar.

Pre-germination treatments	Germination percentage (Mean, n = 5)			
	D. fandra	*D. bemandry*	*D. nako*	*D. alatipes*
PC2W	49.33a	18.67	29.33	6.67
PC4W	21.33	14.67	36.00	1.33
H2SO4	0	29.33b	26.67	18.67
RW	13.33	9.33	49.33	5.33
HW	0	0	22.67	4.00
CT	13.33a	8b	38.67	33.33
Kruskal Wallis test (P-value)	0.014*	0.017*	0.692ns	0.009**

Highest mean germination value from pre-germination treatments for each species were compared to the control and mean values with the same letter are significant at 5% level of significance; (*) Significant at (5%) and (**) at 1%; (ns) not significant. Treatments: PC2W and PC4W = pre-chilling in refrigerator set 5°C for two and four weeks; H2SO4 = chemical treatment with sulphuric acid; RW = soaking in running water; HW = soaking in hot water; CT = untreated.

Most seeds started to germinate after two weeks (Figure 4-2). However, with H_2SO_4 *D. bemandry* and *D. nako* already germinated at 2 weks afer sowing. The number of germinated seeds with pre-germination treatments exceeds the untreated seeds (CT), except for *D. alatipes*, but the optimum pre-germination treatment was different for each species.

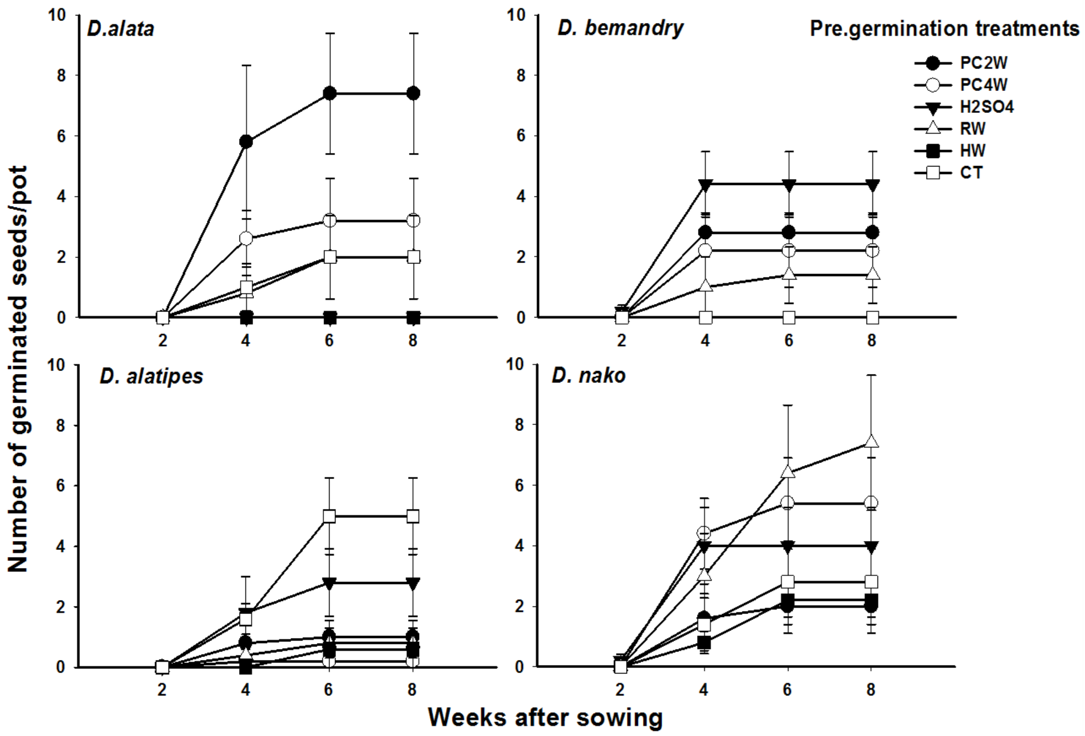

Figure 4-2 Effects of six pre-germination treatments on seed germination of four wild yam species of SW-Madagascar at 2, 4, 6 and 8 weeks after sowing. Vertical bars indicate ± one standard error of the mean. Treatments: PC2W and PC4W = pre-chilling in refrigerator set 5°C for two and four weeks; H2SO4 = chemical treatment with sulphuric acid; RW = soaking in running water; HW = soaking in hot water; CT = untreated.

4.4.2. Sprouting performance of corms and minisetts of wild yams under pot conditions

Sprouting started at 6 WAS for minisetts and at 8 WAS for corms (Figure 4-3). Sprouting tended to increase with time until 18 WAS for corms and until 22 WAS for minisetts. Sprouting abilities differed among species, whereby *D. fandra*, *D. soso* and *D. alatipes* appeared to perform better for both corms and minisetts. In contrast, *D. ovinala* sprouted poorly from minisetts and failed to sprout from corms and *D. bemandry* showed high sprouting from corms but very little from minisetts. It was evident that sprouting behavior depended on the species. *D. fandra* sprouted first from corms (after 8 WAS) and *D. alatipes* from minisetts (after 6 WAS). *D. nako* and *D. ovinala* with overall low sprouting had a longer delay than the others from both corms and minisetts.

Across species sprouting was similar for corms and minisetts (U = 225, P = 0.185), but species differences were significant (Chi-square = 28.99, P < 0.001).

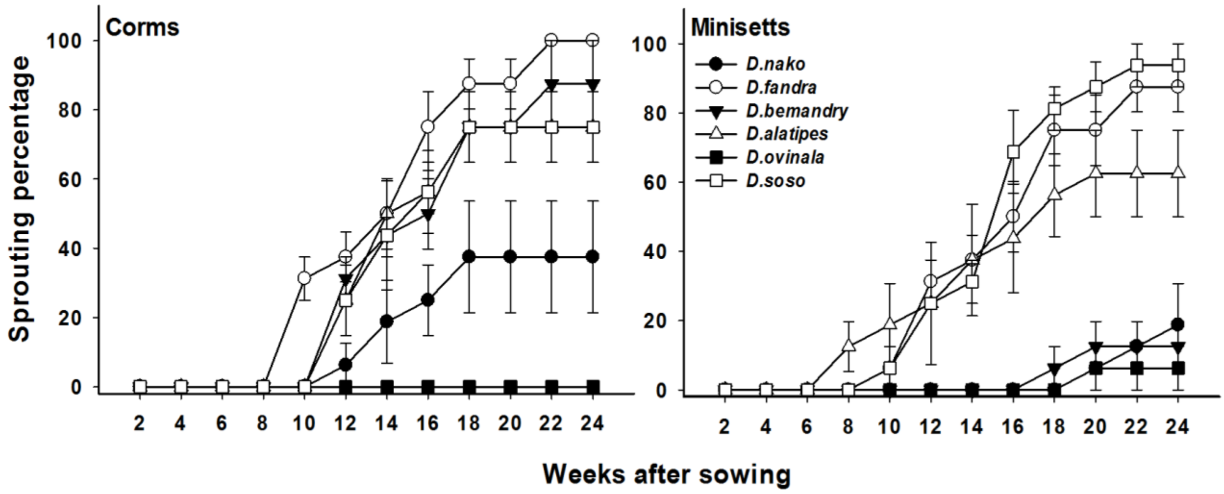

Figure 4-3 Sprouting behaviour from corms and minisetts of six wild yam tubers from SW-Madagascar at 2-24 weeks after sowing. Vertical bars indicate ± one standard error of the mean.

4.4.3. Regeneration performance of wild yams in their natural habitats

Both, soil types (Chi-square=15.1, P = 0.010) and species (Chi-square = 37.2, P < 0.001) affected the overall sprouting of the replanted upper tuber parts (corms) in their natural habitats. This effect was not significant for *D. fandra* and *D. soso*, but across soils, sprouting of both species exceeded 50% (Table 4-3). Sprouting of *D. alatipes* and *D. ovinala* was high, but highly variable across all investigated soil types (P < 0.009 and 0.022, respectively). Our results show that *D. nako* sprouted well on ferralitic soils 'FER_1' (average = 58%), and *D. bemandry* on ferralitic 'FER_1' (average = 100%) and sandy soil (average SP = 67) soils.

Table 4-3 Effect of soil types on the *in situ* regeneration of wild yam species in SW-Madagascar.

	Sprouting percentage (Mean, n = 3)					
Soil types	*D. bemandry*	*D. alatipes*	*D. fandra*	*D. ovinala*	*D. soso*	*D. nako*
CAL_1	41.67	8.33	66.67	41.67	91.67	8.33
CAL_2	16.67	100	91.67	100	100	0
CAL_3	0	91.67	100	91.67	83.33	0
FER_1	100	8.33	58.33	91.67	75	58.33
FER_2	0	0	58.33	58.33	66.67	0
SAND	66.67	100	83.33	100	75	0
Kruskall Wallis test (P)	0.010*	0.009**	0.055	0.022*	0.379	0.016*

(*) Significant at (5%) and (**) at 1%; The acronyms represent the six main indigenous soil types found within a typical area of wild yams collection in the Mahafaly region, where CAL_1, CAL_2 and CAL_3 are calcareous soils, FER_1 and FER_2 are types of ferralitic soils, and SAND_0 is a sandy soil.

4.4.4. Effect of manure application on tuber yield of *D. alata* and *D. alatipes*

Manure application did not significantly affect tuber yields (Table 4-4). Nevertheless, for *D. alata* manure application of 20 t ha^{-1} led to a higher yield compared with the other rates. For *D. alatipes,* manure application of 10 t ha^{-1} led to highest yield and highest number of tubers. For both species, the number of tuber and tuber yield was lowest at 40 t ha^{-1}.

Table 4-4 Effects of manure application on tuber yields of *D. alata* and *D. alatipes* in SW-Madagascar

Manure application rate (t ha^{-1})	*D. alata (n = 5)*		*D. alatipes (n = 4)*	
	Yield (t ha-^{1})	Tuber number plant-^{1}	Yield (ha)	Tuber number plant-^{1}
0	9.34	1.50	0.46	1.25
10	8.12	1.50	0.74	1.50
20	11.43	1.33	0.63	1.25
40	6.99	1.16	0.41	1.00
P-value (%)	0.387	0.492	0.07	0.475

Manure application did not significantly affect mean weight, length and diameter of tubers (Table 4-5). For *D. alata*, tuber weight was highest with 20 t manure ha^{-1} (1731.8 g) and lowest under 40 t ha^{-1} (72 g). For *D. alatipes* tuber weight was highest at 10 t manure ha^{-1} (84.3g) and lowest at 40 t ha^{-1} (22g). The same pattern was also noted for tuber length and diameter where manure application under 20t ha^{-1} (for *D. alata*) and 10 t ha^{-1} yielded highest.

Table 4-5 Effects of manure application at 0, 10, 20 and 40 t ha-^{1} on tuber characteristics of *D. alata* and *D. alatipes* in SW-Madagascar.

Manure application (t ha^{-1})	*D. alata*			*D. alatipes*		
	Weight (g)	Length (cm)	Diameter (cm)	Weight (g)	Length (cm)	Diameter (cm)
0	622.8	26.9	19.8	37.1	19.4	2.8
10	541.5	25.3	18.7	49.4	21.5	2.7
20	857.3	32.5	21.0	50.8	22.6	2.7
40	599.5	24.9	19.0	41.4	19.3	2.6
P-value (%)	0.529ns	0.493ns	0.848ns	0.736ns	0.677ns	0.967ns

(ns) not statistically significant.

4.4.5. Labor costs

Total labor requirements depend on the cropping system (Table 4-6), and yam production under the minisett system is more labour intensive than the other systems. Labour requirements were particularly high for the cultivation of the wild yam species *D. alatipes* using the minisett technique, where 124 working hours during the whole cropping cycle were required given more types of activities. Yam cultivation under the traditional system was much more labor efficient as it requires only re-planting of the upper part of each tuber after harvesting. Apart from weeding, no maintenance work was performed in the traditional system.

Table 4-6 Labor requirements of different yam cultivation systems in SW-Madagascar.

Cropping activities		Cropping system (hours/cropping cycle) Traditional	Minisett	
		D. alata	*D. alata*	*D. alatipes*
Bed sett installation	Tuber collection in the forests	0	0	10
	Bed sett preparation	0	6	6
	Bed sett installation	0	3	3
	Bed sett watering	0	18	24
Land preparation	Land clearing	12	12	12
	Amendments	0	10	10
Planting	Transplantation from bed sett	0	6	6
	Sowing	4	5	5
Crop maintenance	Staking	0	10	10
	Weeding	24	18	18
Harvesting	Harvest	6	5	5
Total		51	105	124

4.5. Discussion

4.5.1. Regeneration of wild yams through seed germination

We found that the pre-chilling treatments for two weeks and the imbibition of seeds in running water for one hour prior sowing yielded significantly higher germination percentage than the other treatments involved. The success of the pre-chilling treatments was somehow expected in our experiments as it has been shown to induce full seed germination in *Dioscorea* spp., especially for warm-climate species (Okagami and Kawai, 1982). The imbibition of seeds in tap water seems also to be an effective way of promoting the seed germination of the investigated species. It might be that the imbibition soften the seeds and/or the tap water had lower temperature and induced the germination, as seed germination *Dioscorea* spp. is sensitive to low temperature (Okagami, 1986). Nevertheless, it was observed that the highest germination percentage, implying the appropriate pre-germination treatment, was different for each species. Although pre-chilling is particularly effective in removing dormancy in *Dioscorea* spp., it has been stated that optimum pre-chilling treatment, however, vary between species and possibly even between seed lots of the same species (Okagami and Kawai, 1982). On the other hand, pre-treatment with acid and hot water prior sowing was not found to be efficient in germinating seed of wild yam species form the Mahafaly region. We assume that hot water may damage the seeds as two species failed to germinate with this treatment. Following this assumption, authors assumed that high temperature treatments can induce natural seed dormancy called ‘secondary dormancy’ in *Dioscorea* spp., but does not however cause mortal damage (Okagami, 1986; Okagami and Kawai, 1983). We have to consider that seed dormancy is one major problem in *Dioscorea* spp. regeneration (Okagami and Kawai, 1983; Zhong et al., 2002). Some species showed their highest germination percentage when seed were untreated prior to sowing, which is the case of *D. alatipes.* The reason of this high percentage is still unknown and further investigation with more repetition of experiments is needed. Although we performed the experiment in the same region as the natural habitat of the investigated species, seed germination involves highly integrated physiological processes and our experimental conditions are slightly different (CREAM, 2013) from natural habitats where adaptation of the species might play a role in the success of the experiment. Nevertheless, we can say that although not for all species, pre-germination treatments enhanced the germination rate of the investigated wild yams species.

4.5.2. Vegetative regeneration of wild yams species

We chose two approaches to test the regeneration performance of the six wild yams species inventoried in the Mahafaly region by Andriamparany et al. (2014). The first approach was to test the sprouting abilities of different subterranean organs (corms/setts of tubers) under pot experiment by keeping the original soils of accessions as substrates. When using the original soils of the accessions as substrates (no amendment was used), we wanted to minimize the factors that could influence the results, such as unexplained physiological adaptation due to new edaphic conditions. The second in situ approach reproduces the natural conditions in the experiment. Here, we assumed that in situ regeneration of wild yams in the Mahafaly region is a possible alternative solution to fulfill the demand of high harvesting intensity of wild yams in this region. Recent studies reported that wild yam species were found in different ecological zones and under varying edaphic conditions, which play a significant role in their availability (Andriamparany et al., 2015).

Sprouting performance of yam differed significantly between species, but not for the type of subterranean organs used. This finding is in line with results of Behera et al. (2009) who investigated 11 species of wild yams in Orissa (India) and found that each species had its own agronomic performance. They found a significance difference in tuber initiation (6-11 weeks), which was also highly variable across species in our case (7-18 weeks). Compared to other studies in Madagascar, our results are similar to the work of Damson et al. (2010) who tested the regeneration performance of wild yams species on alluvial and clay soils in the Bas Mangoky (SW-Madagascar) and found that 68% of the setts of tubers of *D. alatipes* sprouted. However, the same study showed a sprouting percentage of *D. ovinala* (28%) which was quite different from that in our work (6.2% for minisetts and no sprouting for corms).

Okugami (1986) stated that tubers of wild yam from warm and tropical climate sprouted without dormancy at ambient temperatures (15-25 °C) but that sprouting slowed down at higher temperature (30°C). For *Dioscorea* spp., the inability to sprout at higher temperature is considered to be an adaptation to unfavorable conditions (Okugami, 1986). Subterranean organs (tubers) of *Dioscorea* spp. were found to be less dormant because they contain more water that may lead to higher resistance compared to the bulbils and seeds which are dormant for longer periods (Okugami, 1986).

In general the sprouting performance of the investigated species was higher in their natural habitat than under pot conditions. *D. fandra* and *D. soso* performed in almost all investigated soils, implying the success of their in situ regeneration on the range of soil types found in the Mahafaly region (Andriamparany et al., 2015). Although the other species also sprouted in many soil types, they performed well only on specific soils such as calcareous ones for *D. alatipes* and surprisingly under sandy conditions.

We are unaware of any systematic domestication efforts of wild yams made by farmers in Madagascar, but some harvesters claimed to leave a part of tubers after harvest (usually the upper part; Ackermann et al. 2008, Andriamparany e al. 2014) in the soil and cover it. The effectiveness of such traditional practices was investigated by Yasuoka et al. (2013) in Cameroun for *Dioscorea* spp. In West Africa, mainly in Benin, farmers were reported to bring wild yam tubers under intensive vegetative multiplication called 'ennoblement' (Mignouna and Dansi, 2003). Under such practices, many of the yam species collected by farmers were shown to be of wild and hybrid genotypes (Scarcelli et al., 2006), with substantial changes in morphological and biochemical plant characteristics (Mignouna and Dansi, 2003)

4.5.3. Promoting 'yam minisett production' in the Mahafaly region

The pre-sprouting lasted for about three months (12 weeks) for D.alata and four for *D. alatipes*. It is known that freshly harvested yam tubers cannot sprout immediately (Onwueme et al., 1978) because they go through a period of dormancy (Campbell et al., 1962; Coursey, 1967). This may explain the late sprouting of *D. alatipes*. One major change during our experiment was the reduced tuber size across all experimental treatments (average tuber weight the field experiments = 44.6±6.5 g, n = 16) compared to the wild forms in the forests (391.4 ±176.2 g, n = 13). Such a change in tuber size with cultivation was also observed by (Chikwendu et al., 1989) in their preliminary results on the domestication of wild yams.

The different rates of manure application did not significantly affect tuber yield of the two investigated species. Nevertheless, our results showed that 20 t manure ha^{-1} led to 40% yield increases for *D. alata* and 10 t ha^{-1} for *D. alatipes* compared with the control. This strong yield effect likely reflects the low soil fertility of the experimental site where no amendments have ever been used before. It has been previously reported from southern Nigeria that poultry and goat manure applied at 20 t ha^{-1} led to higher yields (26.15 t ha^{-1}) and tuber numbers (3.43 $plant^{-1}$) than inorganic fertilizer in *D. alata* (Ikeh et al., 2013). For the first year of their experiment, neither yield nor number of tubers are, however, comparable to our results with *D. alata*, as they were much lower (respectively 11.43 t ha^{-1} and 1.5 $plant^{-1}$).

Promotion of the cultivation of *D. alata* in other parts of Madagascar showed promising yields (0.5-10 kg of tubers per plant) with yields being highest on alluvial lowland soils known as ‘Baiboho’ (Gahamanyi et al., 2010). In our experiment we observed only two minor pest attacks which may be due to the application of ashes before sowing. Ikeh et al. (2013) reported in their work on *D. alata* that no pest attack was recorded in treatments that had received oil palm bunch ash.

For the wild yam *D. alatipes* we did not observe a significant effect of manure application on tuber characteristics or yield. Behera et al. (2009) reported that many wild yams, especially those belonging to the clade of Enantiophyllum, would hardly merit domestication given their low yields. On the other hand, many left twinning species (one of the characteristics of all endemic yams in Madagascar) with satisfactory yields may not merit domestication because of their poor tuber quality (Behera et al., 2009). In their work with 11 wild yam species the same authors also found that tuber length (8.8- 60.4 cm) and yield per plant (0.61-648kg) varied widely across species.

While our results may be promising in principle, domestication and cultivation of wild yam will require substantial labor input throughout the years. In other studies labor has been found to account for up to 40% of total production costs (Ezeh, 1994; Nkewe et al., 1991). FAO (1998) reported that labor requirements in yam may exceed 400 person-days per hectare per annum under most systems which is nearly twice that of cassava and more than six times that of maize. We found that the adoption of the ‘yam minisett system’, especially with wild yam species involved higher number of activities as tubers are transported from the forest. In the Mahafaly region, labor requirements for the cultivation of wild yam may exceed the available family labour, especially in smaller households. Moreover, yams are planted using either tuber pieces or small tubers (minisetts) which reduces the amount of tubers available to eat (Aidoo et al., 2011). In our study, the so called ‘traditional yam system’ did not involve a lot of activities or time, but it was ineffective in increasing the yam seed available to farmers. In addition, this cultivation system gave lower yield (696 g plant^{-1}) compared to our best yield (1143 g plant^{-1}).

In Madagascar, most farmers do not grow yams in the field, but in their backyards or along their fences (Gahamanyi et al., 2010) which may also be a good starting point for innovative yam farmers in the Mahafaly region. Introducing other varieties of *D. alata* (‘Ovy soroka’, ‘Revoroke’, and ‘Ovy toko’) investigated in the same region of SW-Madagascar may also be a solution to provide yam seeds to the farmers in this area (Damson et al., 2010; Rajaonah et al., 2010). Cultivating yam in a mixed-cropping system, such as *D. alata* with cowpea (*Vigna unguiculata* Walp.) was also s for dry regions of Madagascar, as cowpeas were assumed to maintain soil humidity and to increase soil fertility by nitrogen fixation (Gahamanyi et al., 2010)

4.6. Conclusions

The collection of wild yams contributes significantly to the diet of local people living in the Mahafaly region of SW Madagascar, but an intensive collection threatens the remaining wild populations. Our results suggest that regeneration of those species is possible under pot, *in situ* or field conditions. The specific requirement for successful cultivation depends on the target species, whereby pre-chilling and imbibition in running water seem particularly effective in enhancing seed germination. For field cultivation of yam we recommend a manure application rate of 20 t ha^{-1} for the local 'Bemako' variety of *D. alata*. Regeneration of local wild yams was better using the upper part of the tuber but some species may require specific soil types to do well in the local forests areas. More replicated experiments are necessary to investigate the agronomic performance of *D. alata* and wild yams. Introduction of other varieties of *D. alata* found in SW-Madagascar would be an additional option to provide yam seeds to strengthen the livelihoods of resource poor farmers in the Mahafaly region.

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5. General conclusions

5.1. Introduction

Chapters 2 and 3 demonstrated how the diversity of medicinal plants and wild yams are used individually and within households to fulfill the basic health and food requirement in the livelihood systems of local people in the Mahafaly region. The study of their local use and current availability allowed us to identify the main threats to their sustainable utilization and to conclude that new strategies and actions (see chapter 4) are needed. In the final conclusion, I will return to the original research questions and reflect on the scientific and local implications of the research findings within a concept of biodiversity conservation and livelihoods of rural communities. I will also reflect on the study approach used in the present study. Following this, research findings will be discussed with regard to their scientific credibility within the concept of ecosystem services, and their implications at the local level as part of a participatory research project.

5.2. Reflections on the approach of study 1 and assessment of research findings

The main objective of chapter 2 was to assess and characterize the diversity and use of forests resources (wild yams and medicinal plants) utilized by the local population in the Mahafaly region. As discussed in Chapter 2, it is often assumed that the dependence on the use of forests resources is influenced by the socioeconomic status of households and usually higher for poorer households. To test whether this is the case on the Mahafaly Plateau, ethnobotanical and household surveys were carried out. We further assumed in our analysis that at the local level, the importance of socioe-conomic factors and the nature of their relationship can vary between villages, product types or group of users. We expected that contextual factors might also be important in the analysis (Yemiru et al., 2010). Those additional factors were assessed during a pre-study to characterize the study region (SuLaMa, 2011).

We considered the traditional knowledge of users as dependent variables. In this context, traditional knowledge was defined as the ‘knowledge, innovations, practices of indigenous and local communities, and the results of experiences gained over centuries, adapted to the local culture and environment, and transmitted from generation to generation’ (CBD, 2006). Our study approach has profited from the use of a number of different research methods (PRA, quantitative ethnobotanical, in-depth individual, socio-economic household and participatory surveys) which complemented one another. To select the villages for the surveys, we followed the approach used by the SuLaMa project using typcical villages and to represent the economic, social and cultural characteristics of many other villages in the locality. For example the data collected through the household survey was also used in the baseline survey to characterize the households on the entire Mahafaly Plateau (Neudert et al., 2014).

The results from socioeconomic survey conducted in the present study allowed us to statistically determine how household factors such as wealth status, gender or education may influence the use of forests resources in the Mahafaly region. Some general results on the access to forests resources from the baseline survey (Neudert et al., 2014; SuLaMa, 2011) were also confirmed by our case study (chapter 1). Our findings showed that not only potential household factors significantly determine the resource use in the area, but there are also additional factors related to the type of resources used, particularly cultural factors. However, the survey we conducted did not provide necessary insight into the precise nature of the cultural value and the significance attached to natural resources as this was out of the range of this study, but in the framework of another work package of SuLaMa project (http://www.sulama.de/index.php/en/). The use of participatory research approaches such as forest walks allowed us to increase the scientific credibility of the results (e.g. determination of botanical names of plants compared to local names of plants). Additional information was recorded by GPS devices during the forests walking allowing further studies (see chapter 3). However, it is important to point out the difficulties we experienced in implementing the large ethnobotanical surveys in rural areas as people were aware that their traditional knowledge was recorded. In this context, I conclude that it was beneficial for the study to target a large sample but it may have been more appropriate to use a lower sample size comprising more villages instead. Time spent on conducting survey size could have been more effectively spent on collecting better quality ethnobotanical data. Quantification of indigenous knowledge on plant use proved problematic given the diverse plants used by the local people in this area. The questionnaire provided by the ethnobotanical survey, excluding the socio-economic survey, lasted up to 1.5 hour with a highly knowledgeable interviewee, as we had to record the diversity and use of each cited plant. Therefore, we elaborated categories for the use of medicinal plants and asked at the end of the interview for additional cases of use. Also, by adapting Simpson diversity indices to the use of plants, we could assess at the same time the diversity of plants utilized and the knowledge about their use. Despite the difficulties faced during the data collection, it is felt that data allowed us to test our hypothesis and to attain the objectives of the present study.

Our findings from study 1 (i.e. chapter 2) largely confirmed our hypothesis that socio-economic factors (number of livestock, education level, family size and agricultural harvest) significantly affected the number of medicinal plants collected and the frequency of wild yam collection by individual household in the Mahafaly region.

Our results showed that the group of wealthier households in this region (especially those with high numbers of livestock and off-farm income) depended less on the collection and use of forests products and therefore have lower knowledge of their use than the poorer households. The potential importance of distance of the households to forests areas was also highlighted in this study, although not statistically confirmed. Medicinal plants are important for all households because of the lack of basics health services in the area. Conversly, the collection of wild yams was practiced by specific types of household where the household's wealth status is more important than the socio-cultural context. The findings from chapter 2 indicated that poor people are highly dependant on forests products, whereby only 14.4% of the households on the Mahafaly Plateau are considered as rich (Neudert et al., 2014). We cannot, however, generalize these findings as this study showed that the dependency on forests depends on the type of products.

The medicinal plants assessed in the present study comprise 15.7% of all documented plants in the south-western region of Madagascar (Lebigre, 2010). The ethnobotanical study of medicinal plants allowed us to assess if the collected part might present a threat to the survival of the species itself. Long-term monitoring is needed to confirm our findings that the collection of the subterranean part of the plants threatens species existence. A high proportion of households in the Mahafaly region use wild yams as staple food, especially in the villages near forest areas. In addition, this study emphasized that although all inventoried species were edible, which is one the main characteristic of Malagasy yams, only two were frequently collected. This was likely due to the taste of the tubers, the scarcity of plant stands in the area, and the harsh access of the harvesting sites.

5.3. Reflection on the approach of study 2 and assessment of research findings

In Chapter 3, we characterized and estimated the current distribution of wild yams on the Mahafaly Plateau based on the environmental conditions, the habitats characteristics combined with human intervention factors. To our knowledge the distribution and the species-environmental relationships of wild yam as a very important wild food species in the south-western rural areas of Madagascar, have not yet been studied in detail. Conversly, previous studies on Malagasy wild yams addressed the threats to their availability, mainly as a result of overharvesting of tubers and other disturbances in their natural habitats (see chapter 3 and 4). We thus expect that if we want to conserve these resources, a deeper understanding of their availability would be necessary before any effective conservation efforts could be started.

We based our approach on the classic ecological understanding of species distribution, mainly the species niches concepts that are relevant to species distribution (Austin, 2002). We considered the scenario of species niche which is the 'hypervolume defined by the environmental dimensions within which that species can survive and reproduce' (Hutchinson, 1987). One of the first steps in building predictive distribution models is to understand a conceptual model of the expected species-environment relationships. For Hutchinsonian niches, Ackerly (2003) asserted that a niche concept is all combinations of the relevant causal factors existed in the landscape. We thus selected our explanatory variables on the concept of fundamental (or potential) and the realized (or actual) niche (see chapter 3), which suggests multiple causal factors (biotic and abiotic factors). The choice of the appropriate niche based modelling approach has been justified in Chapter 3. We further built our hypothesis on the ecological factors that may be important at the local scale and that are being modelled in SDM. There are some generalizations of selection of explanatory variables in the literature that can guide empirical SDM, but we based our hypothesis on the hierarchical spatial scales (Holling, 1992; Pearson and Dawson, 2003), where distribution of primary environmental resources or factors acting at finer scale (land cover) are more powerful on local scale and factors that vary over larger extents (such as topographical variables in the present study) are more important at the macro-scale. Here we assumed that a niche is not the only ecological concept relating to species environment that has been used to frame SDM studies but that it can be relative to the targeted species. Thus, by considering the wild yams as highly used forest resources in the Mahafaly region, we understand human activities, vegetation structure and soil properties to be important factors.

Our findings suggest that wild yam species distribution in the Mahafaly region is mainly determined by edaphic factors, vegetation structures and human interventions (land use change and harvesting intensity), which confirm our initial hypothesis. The species-environmental model yielded well fitted NPMR models, for at least two out of the three investigated species. The identification of those influencing factors allowed us to spatially estimate the current availability of wild yam species in the Mahafaly region. Most studies identified the outcome of SDM as the description of a realized niche of the targeted species (Austin, 2002; Guisan and Thuiller, 2005; Thuiller et al., 2004), as actual species data are used and so the model extrapolates in geographical space the conditions associated with species abundance in the environmental 'hypervolume'. Further findings described in detail the relationship of wild yam species abundance to the availability of soil nutrients in the studied area. This increased our ecological understanding of species niches where an optimal bell-shaped and equally spaced curve is not common in real world datasets. They are rather skewed and more complex such as sigmoid or step functions as in the present study. On the other hand, no strong statement on the status of the investigated species ('generalist' or 'specialist') could be made based on our findings. As already discussed in Chapter 3, many studies argue that disturbances may create complex responses of species to environmental gradients and the numbers of alternative forms have been addressed in the literature. For wild yams, our study of species response curve allowed us to argue that human activities (forests fragmentation and harvesting intensity of wild yams tubers) are mainly responsible for this complex functions along environmental gradients. General models of the factors affecting species distributions are useful as a starting point in any SDM study, but the present study is a practical example of real data sets on species abundance-environmental relationship. It shows a species-environmental relationship at the local scale where human interventions were reported to be important. The explanatory variables which gave quite good results in relation to SDM can be used for other case studies of forests resources on the Mahafaly Plateau.The findings of the present study can be used for ecological modelling as more detailed conceptual models are developed that link species data with environmental drivers on a case-by-case basis. In our approach, data such climate data rainfall in each site or soil humidity may explain more variation in the datasets. Such uncertainty could be reduced by better preparation and literature review before data collection. Finally, mapping of the realized niche depicts the potential distribution or the habitat range selection of wild yams in the Mahafaly region.

5.4. Research implications

5.4.1. Suitability of wild yams and medicinal plants as model species of provisioning services

In rural areas such as the Mahafaly region, ecosystem services are almost entirely derived from the locally available natural resources, particularly the goods (agricultural products, fodder, fuel wood, construction wood, food, medicinal plants, and water) or even services such as water purification or soil protection. In the present study, we focused on forests provisioning services as they are the direct material benefits from the forests, closely linked to the everyday life of the local communities of the Mahafaly region. Studies on important provisioning services of forests often focused on non-timber forests products (NTFPs; Shackleton et al., 2008). The term NTFPs can indeed take a wide variety of forms (bush meat, medicinal plants, wild fruits, etc.). Nevertheless, their use allows local populations to meet their basic needs and support their livelihoods. Across the region people are seeking alternatives to meet their basic needs which comprise heath and food. The choice of the target plants has been justified in chapter 1. At this point, we argue for the suitability of the chosen plants as model plants representing the forests resources in the Mahafaly region.

Results from the ethnobotanical and households surveys showed the diverse benefits that people derive from the collection of wild yams and medicinal plants in the region. The choice of medicinal plants in the present work justifies the term ‘forests provisioning services’ as they are collected and used in the daily life of 100% of the interviewed households from five villages which are typical for the Mahafaly region. In addition, the study on the plant uses explained the direct link between ecosystem services and human well-being as they are the primary source of health care for the local communities in that area. By analyzing the use of medicinal plants, we were able to demonstrate the complex relationship between ecosystem services and livelihoods of local communities which are determined by households characteristics, wealth status, social factors (i.e. education level), and sociocultural factors. The plants are not yet traded and the indigenous knowledge of their use is locally perceived as a heritage that each interviewed household shares and continues to transmit to the young generation. On the other hand, these resources also serve for ‘subsistence and safety in the livelihood systems of local communities’ as response alternative to the local food insecurity (Shackeleton, 2011). Another example of distinct use patterns with other forests products in the Mahafaly region is charcoal production in which 8.5% of the households are involved (Neudert et al., 2014).

The use of medicinal plants clearly demonstrates the diverse use of biodiversity in this area where the 214 identified plant species serve the basic health care of the local people. The choice of medicinal plants and wild yams allowed us to better understand the link of forests provisioning services to the wellbeing of the population in the Mahafaly region.

5.4.2. Practical implications at the local level

The findings of the present study will be delivered to the SuLaMa project as 'products' and undergo an 'implementation phase'. In this phase, the relevant ecosystem services and functions will be evaluated with regards to biodiversity conservation, and land use scenarios will be presented. In this context, the overall outcome of the present study is that people in the Mahafaly region are highly dependent on forests resources in terms of health care and food security during difficult periods.

The results also indicate that local people are the most important stakeholders in the management of forests resources as they are the ones who decide 'why, how, and when' to use them. There are is evidence of large heterogeneity among the members of forest users and this diversity has to be taken into account in future conservation or forests management efforts. We can expect that dependency on the collection of wild yam tubers will continue as long as poor households face food insecurity, even as these resources become increasingly over-exploited. Given the lack of maternity services in the surrounding area, local people are using many plant species to treat women and new born children. Therefore, building maternity services accessible to the people in the region may decrease the quantity of collected plants. Our results showed that some of the plants are collected from homegardens where they were planted as medicinal plants so that one does not have to walk a long distance to collect them from wild habitats. This result provides evidence that cultivation of wild medicinal plants is possible.

In the present study, households living next to forests areas (e.g. in the village of Ampotaka) can earn up to 384,000 Ariary per year only from the sale of 50-75 of collected wild yam tubers (where 80% of the households in this area live below US$ 200 or 468,000 Ariary per year). These values are somewhat excessice as they were calculated from the frequency, the estimated number of tubers collected per household and the current sales price of wild yam tubers on the main local markets. The data indicate that any restriction in the supply of these resources will lead to an increase of vulnerability and poverty of the local population.

The fact that medicinal plants that are not yet traded in the Mahafaly region is largely the result of the poor infrastructure, the lack of market demand (local, regional or international) and the availability of alternative well established food and health products elsewhere in that region. The high similarity among medicinal plants utilized in some villages (Ampotaka, Miarintsoa and Itomboina) should be taken into account in future resource management plans as villages inhabited by the same ethnic group are likely to use similar plants.

Selective collection of favored species (i.e *D. bemandry* and *D. alatipes*) can have an impact on their regeneration, their availability and their habitats which are frequently disturbed. A better ecological understanding of the habitats and their plant species distribution allows us to predict where specific pecies may occur in the region and to define where current or future threats to their availability. More sustainable harvest and management strategies should be implemented to prevent overexploitation even if our data could not show that there is a significant impact of harvesting rate on the regeneration of wild yams (see chapter 4).

We conclude that initiatives and participatory actions (domestication of wild species and on-field cultivation of local yams variety) are needed for the sustainability of these resources to sustain local people. The present study showed that local communities know how to cope and adapt to difficult period, using their traditional knowledge in order to meet their basic needs despite low capital assets. Thus, conservation of biodiversity should focus on the provision of goods for local communities and not preclude potential food resources from human use. The multiple uses of forests resources by local communities in the Mahafaly region also have ecological importance for the nearby National Park even if collection areas are largely in non-protected buffer areas.

5.4.3. General importance of the present study

The present study provides information on the factors that determine the local use of wild non-timber forests species which are useful for their management. This study also provides evidence of the importance of culture in perceiving, preserving, and using nature and biodiversity for the Malagasy population (Brown et al., 2013). This study also provides reason for the selective use of of forest provisioning services in the Mahafaly region which is important for conservationists. We agree with Wunder et al. (2014) when they claime that 'it would be hard to blame the poorest households for deforestation and forests degradation', as their basic needs for wellbeing are directly linked to those resources. Instead, strategies to boost off-farm income, allowing people to diversify from their low-remunerative environmentally degrading activities will remain a policy need (Shively, 2004). Also, our efforts on developing suitable methods for the regeneration (pot, on-field, in-situ) of wild yams may be useful for the further work on the domestication or cultivation of Malagasy wild yams as most of the published research on this topic focuses on enhancing the yield of already cultivated species of yam (Gahamanyi, 2010).

5.5. Concluding statements and recommendations

Evaluation of the interlinkage between human and ecosystem services is the starting point of a long term conservation of natural resources. Local communities need to be considered as stakeholders in all decision on forests management as they are their main users and related knowledge holders.

From our findings, we suggest that:

- Lower sample size with more replicates (e.g. many villages) would improve the quality of ethnobotanical surveys within the framework of participatory research;
- The combination of different methods (qualitative and quantitative approach) and disciplines (ethnobotany, socioeconomy, ecology) may increase the quality of results when assessing ecosystem provisioning services as they are complex concepts;
- Rapid vulnerability assessments are needed for frequently used medicinal plants in the Mahafaly region;
- Long term monitoring would be necessary to evaluate the impact of harvesting on the population structure of wild yams;
- Considering the indigenous knowledge of local people on the use and availability of plant resources may make asessements more ecologically and socially relevant;
- Integrating human activities can improve the quality of species distribution models of forest resources;
- Local awareness of appropriate harvesting methods of wild yam tubers would be an initial but important step on the management of these highly used resources;
- Promotion of *in-situ* regeneration of wild yams species and cultivation of local varieties of cultivated species (e.g. *D. alata*) would enhance yam use in the Mahafaly region. Such effort would likely be more effective if conducted in a participatory manner;
- Future research is necessary on the regeneration, domestication and possible cultivation of wild yams under the particular socio-ecological conditions of SW-Madagascar.

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Published	Andriamparany, J.N., Brinkmann, B., Wiehle, W., Jeannoda, V. & Buerkert, A., 2015. Modelling the distribution of wild yam species in south-western Madagascar using biotic and abiotic factors. Agriculture, Ecosystems & Environment (212) 38-48
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Poster (TROPENTAG 2013)	The Potential of Wild Yams to improve Food Security on the Mahafaly Plateau in south-western Madagascar (by Andriamparany, J.N., Brinkmann, K., Jeannoda, V. & Buerkert, A.)
Poster (AETFAT 2010)	Inventaire et caractérisation des plantes susceptibles d'être utilisées commeplantes de couverture dans la région Sud Est de Madagascar (by Andriamparany, J.N., Jeannoda, V.)

Published Report

2014	Report on Household Baseline Survey Data conducted in the Mahafaly Plateau, south-western Madagascar (by Neudert, R., Andriamparany, N.J., Rakotoarisoa, M. & Götter, J.)

Scholarships	**Organizations**
PhD work (3 years and 9 months)	DAAD (Deutscher Akademischer Austauschdienst *or* German Academic Exchange Service)
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Affidavit

‘‘I herewith give assurance that I completed this dissertation independently and without prohibited assistance of third parties or aids other than those indentifed in this dissertation. All passages that are drawn from published or unpublished writings, either words-for-word or paraphrase have been clearly indentified as sush. Third parties where not involved in the drafting of the materials contents, of this dissertation; most specifically I did not employ the assistance of dissertation advisor. No part of this thesis has been used in another doctoral or tenure process”

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