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Use of water hyacinth (*Eichhornia crassipes*) in poor and remote regions – a case study from Lake Alaotra, Madagascar

vorgelegt von

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For my Dad

Ho an´i Dada

"You may never know what results come of your action, but if you do nothing there will be no result." *Mahatma Gandhi*

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Summary

The water hyacinth (*Eichhornia crassipes*) is one of the top ten most invasive aquatic plant species in the world. Due to its worldwide distribution, the plant has caused tremendous damage on ecosystems and human livelihoods alike. These negative impacts are especially problematic for developing countries such as Madagascar. Considering the weak economic situation of the country, using water hyacinth to generate economic profits remains the last option to manage the species. We investigated the use of water hyacinth at Lake Alaotra, the largest lake in the country. This lake and the surrounding area are of great ecological and economic relevance for Madagascar. However, the isolation of the region and poverty limit water hyacinth use only to alternatives suitable to the weak local infrastructure. The goal of this research is firstly to identify suitable water hyacinth use options according to the local conditions and to compare them with the locally used raw materials. The first part of this research identified drivers and barriers for using water hyacinth in the region according to the prevailing socioeconomic conditions. It identified especially the use of water hyacinth as raw material for fertilizers and handicrafts as suitable alternatives for Lake Alaotra. Within the second phase, water hyacinth handicrafts were produced and compared with the predominantly used traditional papyrus handicrafts regarding production path and related costs. It was found that assembling water hyacinth handicrafts was easier and faster and they could be sold at three times the sale prices of the traditional papyrus handicrafts. Within the last part, fertilizers based on water hyacinth (composts, green manure and ash) were locally produced and compared with the commonly used agricultural fertilizers NPK and cow dung. This was done by conducting a growth experiment with Chinese cabbage, a common fast-growing vegetable in the region. Additionally, the production and transportation costs of each type of fertilizer were also taken into account. The results showed high biomass gain of cabbage grown with water hyacinth composts which was also proved be cheaper than using NPK and cow dung. All in all, this research demonstrated the efficiency of water hyacinth use as compost and handicraft as a new source of income for the Alaotra region. However, the poverty and high vulnerability of the local population must be considered along the process for a successful implementation of water hyacinth use at Lake Alaotra. A participatory approach and by offering financial insurance to the farmers during the implementation phase could encourage them to test water hyacinth compost on their own fields. Due to the various external factors influencing the marketing of water hyacinth handicrafts, an intensive and sustained supervision should be provided to the craftswomen.

Zusammenfassung

Die Wasserhyazinthe (*Eichhornia crassipes*) gehört zu den zehn invasivsten Wasserpflanzenarten der Welt. Infolge ihrer weiten Verbreitung hat die Pflanze enorme ökologische, ökonomische und soziale Schäden verursacht. Diese negativen Auswirkungen sind besonders für Entwicklungsländer wie Madagaskar problematisch. In Anbetracht der schwachen wirtschaftlichen Situation des Landes stellt die Nutzung der Wasserhyazinthe zur Erzielung wirtschaftlicher Gewinne eine gute Alternative dar. In dieser Promotion wurde die Verwendung der Wasserhyazinthe als Rohstoff am Alaotra See, dem größten Süßwassersee Madagaskars, untersucht. Der See und das Umland sind für Madagaskar von großer ökologischer und ökonomischer Bedeutung. Die Isolation der Region und die vorherrschende Armut limitieren die Nutzung der Wasserhyazinthe jedoch nur auf solche Alternativen, die für die schwache lokale Infrastruktur geeignet sind. Ziel der Promotion war es zunächst geeignete Nutzungsmöglichkeiten für die Wasserhyazinthe entsprechend den lokalen Gegebenheiten zu identifizieren und diese mit den lokal verwendeten Rohstoffen zu vergleichen. Im ersten Teil der Studie wurden Treiber und Barrieren für die Verwendung entsprechend der, in der Region vorherrschenden sozioökonomischen Bedingungen identifiziert. Hierbei stellte sich insbesondere die Verwendung der Wasserhyazinthe als Rohstoff für Düngemittel und Flechtprodukte als geeignete Alternative heraus. In der zweiten Phase wurden Flechtprodukte aus der Wasserhyazinthe hergestellt und mit den traditionell hergestellten Flechtprodukten aus Papyrus hinsichtlich der Produktionswege und der damit verbundenen Kosten verglichen. Es zeigte sich, dass das Herstellen von Flechtprodukten aus der Wasserhyazinthe einfacher und schneller war und diese zum dreifachen Verkaufspreis (im Vergleich zu traditionellen Flechtprodukten) verkauft werden konnten. Im letzten Teil des Forschungsvorhabens wurden Düngemittel auf der Basis der Wasserhyazinthe vor Ort produziert und mit den gängigen Düngemitteln wie dem Mineraldünger NPK verglichen. Dazu wurde ein Wachstumsexperiment mit Chinakohl durchgeführt. Zusätzlich wurden die Produktions- und Transportkosten der hergestellten Düngemittel berücksichtigt. Die Verwendung von Wasserhyazinthenkompost stellte sich als effizienter und kostengünstiger heraus. Insgesamt zeigt die Promotion, dass die Nutzung der Wasserhyazinthe als Kompost und zur Herstellung von Flechtprodukten effizient und einfach ist und als neue Einkommensquelle für die Alaotra Region genutzt werden kann. Allerdings müssen für eine erfolgreiche Umsetzung der Wasserhyazinthennutzung die Armut und schwache Infrastruktur berücksichtigt werden. Ein partizipatorischer Ansatz und eine intensive Betreuung sind vor Ort zur Umsetzung der Nutzung der Wasserhyazinth notwendig.

Chapter 1

General introduction

1.1 Invasive species: definitions, ecological impacts and managements options

Invasive species are plant or animal species that have succeeded to reach a new habitat with or without human assistance and are able to adapt to the new conditions and spread quickly within the new area (Simberloff 2010). Particularly, invasive plants species have higher value in performance-related traits such as physiology, leaf area and shoot allocation, growth rate, size and fitness (van Kleunen et al. 2010). In the past and recently, the term 'invasive species' has widely been used by different authors referring to a range of common characteristics and thus was used synonymously for 'alien' and 'exotic species' (e.g. Heard and Sax 2013; Ordonez and Olff 2013; Capinha et al. 2015). Other terms, such as weeds and naturalized species, aiming to classify species related to their plant invasion ecology similarly often refer to a range of definitions which are overlapping in many cases (e.g. DiTomaso 2014; Abe et al. 2015; Arora et al. 2015). To date, there are no widely accepted conventional definitions of the different terms in use in the field. This study will therefore use the following terminology, introduced by Richardson et al. (2000): Alien species (exotic species, non-native species, non-indigenous species) is a general term to indicate plant taxa introduced intentionally or accidentally in a new area by humans. Casual alien species are alien species that can flourish and reproduce in a new area only under repeated introductions and not being able to form self-replacing population. Naturalized species are alien species that could sustain populations without any human assistance, keeping offspring next to adult forms and do not necessarily invade ecosystems. Invasive species are naturalized species that produce a large number of reproductive offspring located at a considerable distance from the parents making them able to spread over a considerable area.

Nowadays, invasive species represent one of the most important problems for biodiversity conservation and lead to species loss, especially on islands (Allen and Lee 2006). The impact of invasive species can be classified into ten types (Simberloff 2010): ecosystem modification, resource competition, aggression, predation, herbivory, pathogens and parasites, hybridization, chain reactions, invasional meltdown and multiple effects. One example of ecosystem modification was the introduction of the North American beavers (*Castor canadi*ensis) in Tierra del Fuego. The beaver has converted entire forest of southern beech (*Nothofagus* spp.) to meadows dominated by grass and sedge (Aralde et al. 2014). Another example is the spread of *Caulerpa taxifolia*, a tropical plant species from the southwest Pacific Ocean to the Mediterranean Sea. This species has replaced the seagrass meadows over thousands of hectares

(Meinesz 1999). Resource competition between the introduced North American grey squirrel (*Sciurus carolinensis*) and the native red squirrel (*Sciurus vulgaris*) in Piedmont in Italy will likely lead to the decline of latter species in Italy and probably later in Europe (Bertolino et al. 2008). The aggressive Argentine ant (*Linepithema humile*) decreased many North American ant species populations by attacking them (Holway and Suarez 2004). Regarding predation, the ship rat (*Rattus rattus*) has led to the extinction of at least 37 species and sub-species of birds on islands all over the world (Atkinson 1985). Through herbivory, the European rabbits (*Oryctolagus cuniculus*) had tremendous negative effects on plant populations on islands by killing shrubs, seedlings and sapling trees (Simberloff 2010). In Hawaii, several bird species were lost due to avian malaria caused by *Plasmodium relictum capristranoae* brought in by Asian birds and vectored by introduced mosquitoes (Woodworth et al. 2005). Hybridization of the introduced North American ruddy duck (*Oxyura jamaicensis*) with the European white-headed duck species (*O. leucocephala*) in Spain will probably lead to the genetic extinction of the latter species (Muñoz-Fuentes et al. 2007). An example of a chain reaction constitutes the devastation of the rabbit population in Great Britain by the New World myxoma virus. This led to the decrease in population of the native ant *Myrmica sabuleti* dependent on the grazing behavior of the rabbit. The decrease of the ant species led in turn to the disappearance in Great Britain of the native large blue butterfly (*Maculina arion*) whose caterpillars require the underground nest of the ant species (Ratcliffe 1979). The invasional meltdown consists of the positive interaction of two or more invasive species profiting at least to one of them (Simberloff and von Holle 1999). The introduction of the red-whiskered bulbul (*Pycnonotus jocosus*), an Asian bird species on the island of La Réunion is a perfect example of invasional meltdown. It has led to the dispersion of several invasive plants species whose seeds are dispersed by the introduced bird species (Baret et al. 2006). Regarding multiple effects, the introduced round goby (*Neogobius melanostomus*) feeds on native invertebrates, eggs and larvae of native fish species in North America (King et al. 2006).

Simberloff (2010) proposed a comprehensive methodology for managing invasive species. Applying regulations, risk analyses and border control are the first measures used to prevent invasive species reaching new habitats. In case invasive species have already established populations, monitoring studies must be quickly conducted. Depending on the level of invasion, the invasive species can be completely eradicated or at least maintained at a level with minimal effects on humans and the ecosystem. The management of invasive species can be achieved through mechanical control using human labor and machinery, chemicals such as pesticides or herbicides and biological control using natural predators or pathogens. Interestingly, in some regions invasive species have been 'accepted' by human populations as part of the landscape instead of being controlled or eradicated. They are used as sources of fodder and fuel wood (e.g. *Mikania micrantha* in Nepal), food and medicines (e.g. *Opuntia ficus* in South Africa) or income (e.g. *Lantana camara* in India) (Shackleton et al. 2007; Rai and Scarborough 2013).

1.2 The invasive water hyacinth: origin, distribution and characteristics

The water hyacinth (*Eichhornia crassipes*, Mart.) is a monocotyledon belonging to the family of Pontederiaceae (Solms) (Fig. 1.1). It is a perennial floating macrophyte with thick rounded green leaves, lavender blue flowers with a central yellow dot organized in spike inflorescence and dark purple to black roots with rhizomes and stolons (Gettys 2014). Water hyacinth is classified as one of the ten most invasive aquatic plant species in the world (Patel 2012).

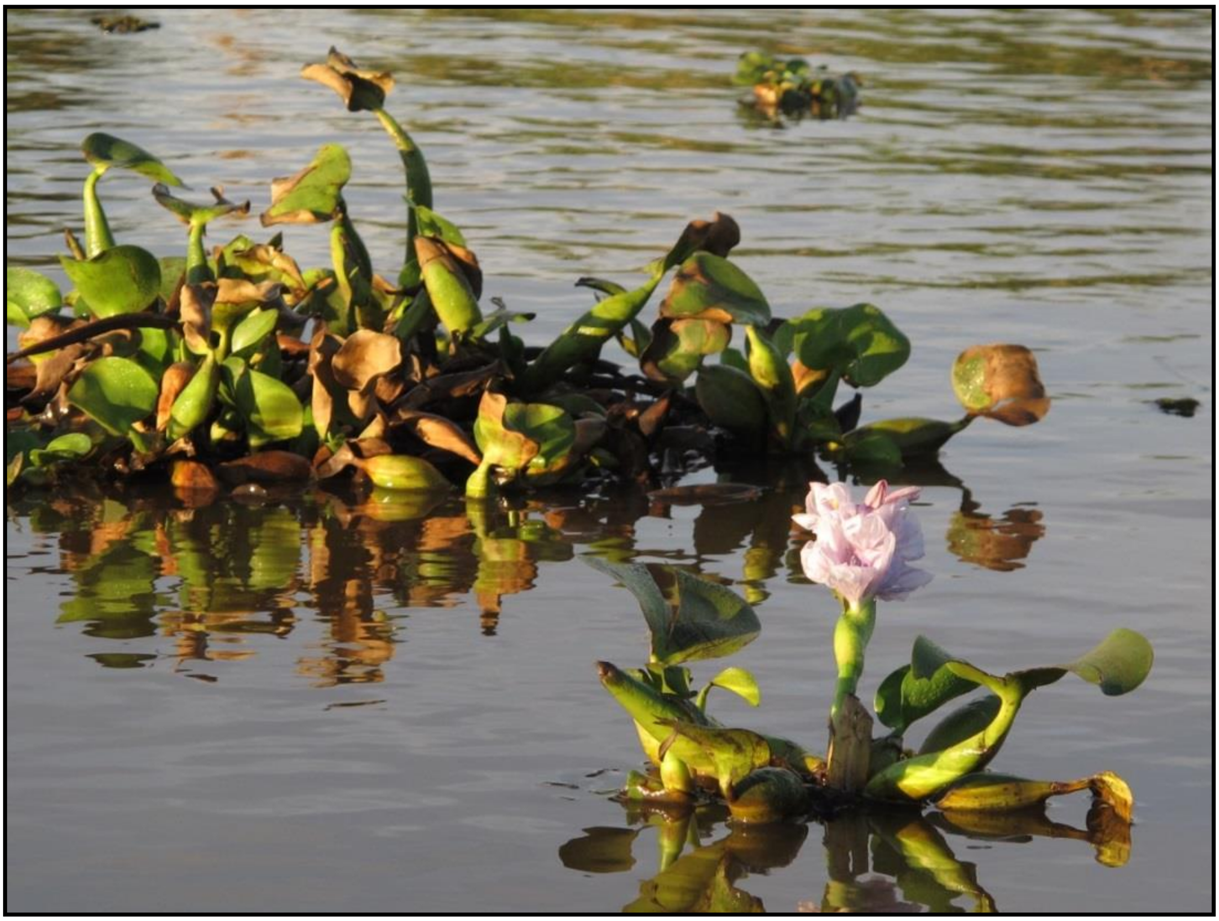

Figure 1.1: Free floating water hyacinth at Lake Alaotra in Madagascar.

Since the end of the 19th century, its usage as ornamental plants has tremendously increased its distribution area (originally from the Amazon Basin) nowadays to more than fifty tropical and sub-tropical countries over five continents (Barrett and Forno 1982; Toft et al. 2003) (Fig. 1.2). Water hyacinth first reached North America in the late 1800s, Africa in the early 1900s and Europe in the 1930s (Chabot 1959; Lindsey and Hirt 1999; Brundu et al. 2013). Nowadays, the plant is especially abundant in Southeast Asia, central and western Africa, southeastern United States and Central America (Bartodziej and Weymouth 1995; Brendonck et al. 2003; Lu et al. 2007; Martinez-Jimenez and Gomez-Balandra 2007). Particularly in nutrient-rich water bodies and areas with high isolation, water hyacinth is able to double its number vegetatively within one to three weeks (Gopal 1987; Ndimele et al. 2011). It is one of the most productive plant species in the world with a mean biomass production of 140 tons per hectare per year (Abdelhamid and Gabr 1991). Water hyacinth can regenerate rapidly even from stem fragments only. The seeds germinate after six months and can remain viable for more than 15 years in the soil (Ueki and Oky 1979; Gunnarsson and Petersen 2007; Malik 2007). It can persist from a temperature ranging between 1 to 40 °C with optimal growth at between 25 to 27.5 °C and a pH between 6 to 8 (Malik 2007). A salinity level of more than 0,6% is lethal for the plant (Mangas-Ramirez and Elias-Gutierrez 2004). Water hyacinth is rich in nitrogen (3.2% of dry material) with a C/N ratio of 15. However, due to its ability to uptake considerable amounts of nutrients and other chemicals, its chemical composition is highly variable depending on its environment (Gunnarsson and Petersen 2007).

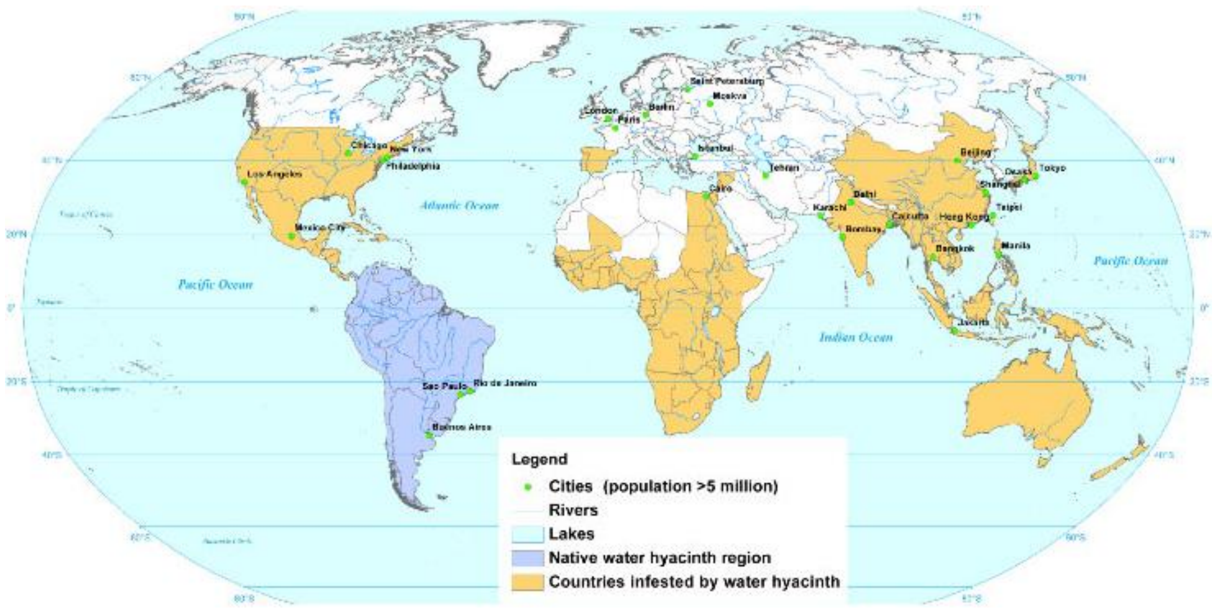

Figure 1.2: Global distribution of water hyacinth (retrieved from Téllez et al. 2008)

1.3 Ecological and socioeconomic impacts of water hyacinth

The invasion of water hyacinth leads to a multitude of ecological and socioeconomic problems (Fig. 1.3). By building up dense mats with up to two million plants per hectare, the water hyacinth alters water quality by reducing light penetration and dissolved oxygen due to the constant rotting of the mat base (Villamagna and Murphy 2010). Besides, its evapotranspiration rate can exceed ten times the water evaporation rate of open water bodies making it particularly dangerous for shallow lakes (Gopal 1987). These changes are altering aquatic ecosystem abiotic factors and negatively affect the aquatic fauna and flora communities. The low light penetration under water hyacinth mats decreases phytoplankton abundance which in turn leads to a reaction chain affecting aquatic invertebrate, fish and bird communities (Gratwicke and Marshall 2001; Toft et al. 2003; Midgley et al. 2006; Villamagna and Murphy 2010). However, the complex structure offered by the water hyacinth root system could also have positive effects on the abundance of zooplankton, macroinvertebrates and fish communities (Villamagna and Murphy 2010). Overall, the degree of food web disturbance by water hyacinth is decisive in comparison to these eventual positive impacts (Villamagna and Murphy 2010). Due to its quick spreading capacity, the water hyacinth can easily outcompete and displace submerged native species (Mitchell 1985).

Humans are also affected by water hyacinth. By blocking waterways, water hyacinth hinders transportation, irrigation schemes, fishing activities and intakes for hydropower leading to huge economic losses (Calvert 2002). In Lake Victoria, the spread of water hyacinth has caused annually 0.2 million US$ losses in local fishery and 1.5 million US$ in urban water supply due to clogging (Joffe and Coocke 1997). Finally, water hyacinth represents a microhabitat for disease vectors (*Anopheles* sp. for Malaria and *Biomphalaria* sp. for Bilharzia) therefore threatening human health (Plummer 2005). In certain areas covered with water hyacinth, precaution must be taken against snakes, hippos and crocodiles (Gunnarsson and Petersen 2007).

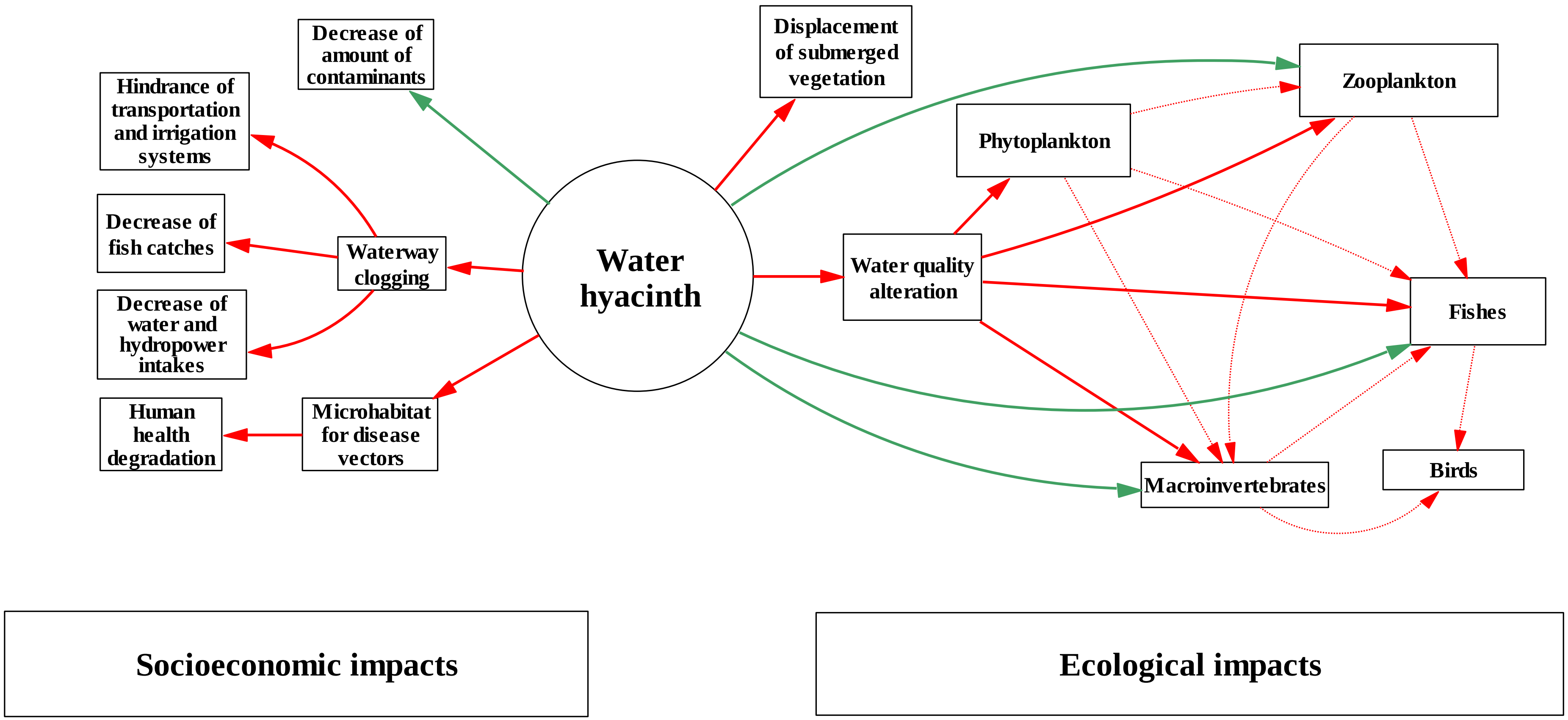

Figure 1.3: Impacts of water hyacinth on humans and the aquatic ecosystem: Red arrows represent negative effects. Disturbances affecting aquatic food web are represented by red dashed lines. Eventual positive effects of water hyacinth are illustrated with green arrows (modified from Villamagna and Murphy 2010).

1.4 Management of water hyacinth

Worldwide, several control methods have been adopted to manage the water hyacinth. The first, mechanical control consists of using machinery and human labor. This method is highly efficient but is very expensive especially for poor countries in the tropics. In Nigeria, removing water hyacinth comes at a cost of 9500 US$ per square kilometer (Alimi and Akinyemiju 1990). The chemical control uses 2-4D, Diquat or Glyphosate and is less expensive. In the USA, chemical control is estimated to 183 US$ per square hectare (Charudattan et al. 1996). However, applying chemicals into water faces public non-acceptance due to the risk engendered for the ecosystem and humans. Another alternative is the biological control using a natural predator (the weevil species *Neochetina eichhorniae, N. bruchi* or the moth species *Sameodes abligullatis*) or pathogen (the fungus *Alternaria eichhornia*) (Shabana et al. 1995; Coetzee et al. 2009). The biological method is risky because introduced species could attack non-target species (Simberloff 2010). In addition, the performance of biological control agents is often site-dependent. The application of the two weevil species used to reduce water hyacinth population was successful in New Guinea and Lake Victoria but failed in Florida (Schardt 1997).

Instead of controlling water hyacinth, many countries have exploited the plant to generate economic benefits. Worldwide, this plant is used to produce fertilizers, fodder, biogas, briquettes, furniture, handicrafts and to clean water waste through phytoremediation processes (Jafari 2010; Ndimele 2011; Patel 2012). However, several challenges were identified in developing countries where water hyacinth occurs most. The lack of technological skills and investments hinder the usage of water hyacinth as source of biogas and briquettes (Thomas and Eden 1990; Gunnarsson and Petersen 2007). Those alternatives require investments in machinery and technical abilities which are often missing in poor rural areas. Producing furniture and handicrafts out of water hyacinth is feasible but requires market outlets which are often inefficient in poor countries (Patel 2012). Due to the intensive labor required for transportation, making composts out of water hyacinth seems not realistic for large application (Gunnarsson and Petersen 2007). Using dried water hyacinth seems to be more adapted to developing countries. Due to its high crude protein content, water hyacinth was proved to be suitable as fodder (although as a part of the diet) for ruminants, pigs and ducks (Tag El-din 1992; Jafari 2010; Tham 2012). In conclusion, alternative usages without or requiring a minimal processing could only be applicable to developing countries.

1.5 Water hyacinth in Madagascar

Madagascar is one of the top biodiversity hotspots of the world where considerable concentration of biodiversity and endemism is facing tremendous human pressures and natural threats (Myers et al. 2000). The dependency of a majority rural poor population on natural resources represents the main factor of ecosystem degradation in Madagascar (Ganzhorn et al. 2001; Eubanks 2012; Rakotomanana et al. 2013; UNDP 2013). As a consequence, the island has already lost most of its natural forest cover (Ghulam 2014). The main threats to Madagascar biodiversity are the shifting cultivation, illegal logging, poaching and the spread of invasive species such as water hyacinth (Rakotomanana et al. 2013). In the beginning of the 20th century, water hyacinth was introduced as ornamental plants in Madagascar (Binggeli 2003). By the 1930s, the distribution of water hyacinth had increased all over the island leading Perrier de la Bathie (1928) to qualify the species as invasive. Nowadays, the plant occurs in the rivers and lake systems of Madagascar (e.g. Lake Ravelobe, Betsiboka Basin, Pangalane channel) (Fig. 1.4) and no concrete management program has been conducted to combat it (Binggeli 2003). This is the first comprehensive research attempting to implement water hyacinth use as raw material in Madagascar.

Figure 1.4: Water hyacinth covering entirely the Lake Ravelobe in Ankarafantsika National Park in Madagascar (photo: J. Mantilla-Contreras).

1.6 Water hyacinth at Lake Alaotra in Madagascar

Water hyacinth also occurs at Lake Alaotra, the biggest freshwater lake of Madagascar (20,000 ha) (Copsey et al. 2009). To date, the plant dominates the fringe vegetation at Lake Alaotra with a mean up to 53% coverage (Lammers et al. 2015) (Fig. 1.5). Home to 560,000 people centering their livelihoods on rice cultivation and fishing (INSTAT 2013), the Alaotra region faces continuous anthropogenic pressures. The population has increased fivefold during the last 50 years (INSTAT 2013). The quasi-dependency on natural resources by the fast growing and poor rural population at Lake Alaotra has submerged the whole system into a vicious cycle.

Figure 1.5: Water hyacinth in the fringe vegetation of Anororo at Lake Alaotra in Madagascar.

This has led to massive bushfire on the hillsides, soil erosion and degradation, field embankments, overgrazing and overfishing, overuse of pesticides and mineral fertilizers, lake siltation and acidification, marsh conversion into rice fields and spread of invasive species, one of the most problematic being water hyacinth (Bakoariniaina et al. 2006; Copsey et al. 2009; Lammers et al. 2015). In addition, the Alaotra region suffers from a general weak infrastructure displayed by the bad condition of roads connecting the area to other regions, the inexistence of permanent electricity and potable water. Furthermore, the poor diversification of local livelihoods increases the vulnerability of the local population to risks (e.g. production and price fluctuations), stress (e.g. shortened rainy season and decrease of fish catches) and shock (e.g. cyclones and floods). Moreover, a long history of several agricultural program failures (Penot et al. 2014) generates a prevalent skepticism amongst the local population toward innovations.

Our research revealed that around 98% of the interviewees earn less than 5 US$ a day (Rakotoarisoa et al. 2015). Due to the ever-present poverty at Lake Alaotra, to date water hyacinth is barely used or managed in the region (Rakotoarisoa et al. 2015). Worldwide, water hyacinth has already been successfully used in rural areas as fertilizers and raw material for handicrafts (Gunnarsson and Petersen 2007; Jafari 2010; Ndimele 2011; Patel 2012). Its application in the Alaotra region would alleviate its negative impacts on the lake ecosystem and diminish anthropogenic pressures on the marshland (conversion into rice fields, overexploitation of papyrus) by ameliorating local soil fertility and increasing household income.

1.7 Aims of the study

The major aims of the study were:

(i) to identify the drivers and barriers for using water hyacinth as a new resource appropriate for the socioeconomic and environmental conditions in the Alaotra region by selecting suitable usages. (Chapter 3).

(ii) to test if water hyacinth could substitute the commonly used papyrus (*Cyperus madagascariensis*) as raw material for handicrafts at Lake Alaotra (Chapter 4).

(iii) to investigate if water hyacinth fertilizers can be produced under the local circumstances and if they could replace the locally used NPK (mineral fertilizers) and cow dung for vegetable farming in the Alaotra region (Chapter 5).

Chapter 2

METHODS

2.1 Study area

Lake Alaotra is the biggest freshwater lake of Madagascar encompassing 20,000 ha of open water surrounded by 23,000 ha of marsh vegetation and 120,000 ha of rice fields (Copsey et al. 2009). With a mean depth of 1.5 m, the lake is classified as very shallow (Ferry et al. 2009). This region is of high ecological and economic significance. The marsh vegetation, dominated by papyrus (*Cyperus madagascariensis*) and common reed (*Phragmites australis*), shelters several endemic plant and animal species including the Alaotran gentle lemur (*Hapalemur alaotrensis*), the only permanent swamp living primate in the world (Andrianandrasana et al. 2005; Ralainasolo et al. 2006; Guillera-Arroita et al. 2010). On the economic front, the Alaotra region represents the first rice granary (300,000 tons per year) of the country and one of the largest producers of freshwater fish (Copsey et al. 2009; Wallace 2013). The regional climate is divided into two distinct seasons: the rainy season from December to April and the dry season from May to November. The annual precipitation ranges from 1092 to 1200 mm and the temperatures vary from 11 °C in July to 28.4 °C in January (Ferry et al. 2009).

For this study, three study sites were selected around Lake Alaotra according to the level of ecosystem degradation, the number of population and the abundance of water hyacinth (Fig. 2.1). From the least to the most degraded, the sites are: Vohimarina (302 ha of intact marshes) located in the northern side of the lake, Andreba Gara (235 ha of marshes) situated in the western side and Anororo (9,850 ha of marshes) in the eastern side. Vohimarina has a population of around 500 inhabitants followed by Andreba with 4,000 inhabitants and Anororo with 8,000 inhabitants (Andrianandrasana et al. 2005). Four groups of stakeholders were identified within those areas: rice cultivators, vegetable farmers, fishermen and breeders.

Figure 2.1: The three study sites where research on water hyacinth was conducted at Lake Alaotra in Madagascar. Upper row: from low level of marsh degradation to high level of degradation: Vohimarina (left), Andreba (middle) and Anororo (right). Lower row: the three villages Vohimarina (left), Andreba (middle) and Anororo (right).

2.2 Summary of used methods

For assessing the socioeconomic conditions in the region, group surveys (McNamara 2003) were conducted from November 2012 to April 2013 within the three study sites with a total of 120 stakeholders. In addition, semi-structured (Bernard 2005) interviews were performed with another 120 stakeholders to estimate the potential drivers and barriers of the use of water hyacinth in the region with a focus on personal perception toward the plant, attitudes using future resource use scenarios, current use and future potential use of water hyacinth at Lake Alaotra (Chapter 3).

In order to test if water hyacinth handicrafts could substitute the common papyrus handicrafts, six different handicraft products made from the two raw materials were produced from February 2014 to July 2014 with the help of two experienced craftswomen from Andreba Gara, a village next to Lake Alaotra. The two types of products were compared based on the production process (from raw material collection to end products) and income generated, taking into account the workload, additional materials, labor costs and sale prices. Feedback regarding product quality, design and marketing strategies were collected from customers (n=50) and retailers (n=50) in Antananarivo (capital of Madagascar) using structured interviews (Chapter 4).

To investigate if water hyacinth fertilizers can be produced under local conditions and if they could replace NPK and cow dung in the Alaotra region, water hyacinth fertilizers (composts, green manure and ash) were produced and compared with NPK and cow dung within a growth experiment using Chinese cabbage, a local common vegetable in Andreba Gara from March 2014 to April 2014. Nutrient contents, pH and heavy metal concentrations were determined for all used fertilizers and soil within the growth experiment. Furthermore, a general assessment of the nature and properties of soils in the Alaotra region was conducted by analyzing humidity rate, nutrient contents, pH, grain texture and cation exchange capacity of soil samples from the three study sites (Chapter 5).

Chapter 3

Water hyacinth (*Eichhornia crassipes*), any opportunities for the Alaotra wetlands and livelihoods?

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3.1 Abstract

Species invasions are one of the world's most severe conservation threats. The invasive water hyacinth (Eichhornia crassipes) is one of the most troublesome plants in the world. It appears in over 50 tropical and subtropical countries. This plant species causes several ecological and socioeconomic problems affecting ecosystems and local livelihoods. The water hyacinth occurs in the Alaotra wetlands encompassing the largest lake of Madagascar. The Alaotra region is renowned as Madagascar's bread basket as it is the biggest rice and inland fish producer. The current study collected socioeconomic data from the Alaotra wetland stakeholders within three locations around Lake Alaotra to contextualize local livelihoods and to identify the drivers and barriers for the utilization of this plant. Methods of control seem to be unrealistic due to institutional and financial limitations in Madagascar. Using the plant as fertilizer, animal fodder or for handicrafts seems to represent a feasible alternative to improve the livelihood of the local population. However, local concerns about livelihood security may hinder acceptance of such new alternatives. Providing information as well as financial and technical support to local stakeholders may help encourage the use of the water hyacinth in the Alaotra region.

***Key words**: Species invasion, Invasive species management, African wetlands, Madagascar*

3.2 Introduction

The water hyacinth (*Eichhornia crassipes*, Pontederiaceae) is an aquatic plant, originating from the Amazon Basin. It is listed by IUCN as one of the "100 most invasive species" in the world (Lowe et al. 2000) due to its high reproduction rate, the complex root structure and the formation of dense mats with up to two million plants per hectare (Gopal 1987, Villamagna and Murphy 2010). The water hyacinth is to date recognized as invasive in over 50 tropical and subtropical countries on five continents (Africa, Australia, Asia and America and for Europe in Portugal) (Gopal 1987; Villamagna and Murphy 2010). The spreading of the plant can lead to great ecological, social and economic problems (Kull et al. 2014). The plant can reduce light and oxygen leading to deteriorating water quality, increase water loss due to high evapotranspiration and thus negatively affect the flora and fauna. Moreover, it can hinder transportation, fishing and block intakes for hydropower and irrigation schemes affecting therefore the livelihood of local communities (Calvert 2002). Furthermore, the water hyacinth represents a microhabitat for disease vectors (*Biomphalaria* sp. for bilharzia or *Anopheles* sp.

for malaria) and therefore constitutes a threat to human health (Masifwa et al. 2001; Plummer 2005).

Globally, a number of methods are used to manage and control the water hyacinth: the manual and mechanical control requires high expenses. In China, removing water hyacinth comes at a cost of more than US$ 1 2 Million per year (Jianqing et al. 2001). Chemical control, using 2,4-D or glyphosate, is seemingly a more economically feasible option. In the USA, chemical control is estimated to cost US$ 183 per hectare (Charudattan et al. 1996). However, in many countries public opinion is strongly against the use of chemicals in water bodies, which are oftentimes used for drinking purposes (ibid). Biological control, though less widely applied, uses the weevil species *Neochetina eichhornia*, *N. bruchi* and the moth *Sameodes abligutallis* which adults feed on water hyacinth leaves and the larvae tunnel in petioles (Coetzee et al. 2009). Pathogens can also be used to control the water hyacinth. In Egypt, the fungus *Alternaria eichhornia* was condensed in cottonseed oil emulsion and spread on the water hyacinth killing 100% of the plants seven weeks after application (Shabana et al. 1995). Biocontrol is economically feasible and environmentally viable but requires several years of implementation (Charudattan et al. 1996). As an alternative to mechanical, chemical or biological controls, the economic utilization of this invasive plant has to be considered. Globally, the water hyacinth is used in China, Indonesia, India, Malaysia, Bangladesh, Sri Lanka, Thailand, Philippines and in some African countries such as Kenya and Nigeria for producing fertilizers, handicrafts, paper, biogas, fodder, briquettes, furniture and to clean industrial waste water by phytoremediation (Jafari 2010; Ndimele 2011; Patel 2012). However, in remote poor regions in developing countries the use of water hyacinth is hindered by absence of electricity, lack of technology and poor infrastructure (e.g. Gunnarsson and Petersen 2007).

The water hyacinth (vernacular name: *tsikafona* or *tsikafoka*) occurs in Madagascar's largest wetland, located in the Alaotra- Mangoro region encompassing about 23,000 ha of freshwater marshes. Lake Alaotra is the largest freshwater lake in Madagascar (20,000 hectares of open water); with an average depth of 1–1.5 m, it is a very shallow lake (Ferry et al. 2009). The natural freshwater marshes fringing the lake are dominated by common reed (vernacular name: *bararata*) (*Phragmites australis*) and cyperus (vernacular name: *zozoro*) (*Cyperus madagascariensis*). The marsh vegetation supports endemic species such as the Alaotran gentle lemur (vernacular name: *bandro*) (*Hapalemur alaotrensis*) which is the only permanent swamp living primate in the world (Andrianandrasana et al. 2005; Ralainasolo et al. 2006; Guillera-

Arroita et al. 2010; Waeber et al. In press). The water hyacinth occurs in both the open water where it is freely floating and moved by winds as well as in the marsh vegetation.

The water hyacinth has been introduced to Madagascar at the beginning of the twentieth century as ornamental plant (Binggeli 2003) and was identified later as serious threat by Perrier de la Bathie (1928). Goarin (1961) reported that the plant was already present in the Lake Alaotra during the period of French colonization.

Lake Alaotra is home to over 560,000 people who live along its shores (INSTAT 2013). Rice cultivation and fishing constitute the main income in the region, resulting in an increasing pressure on the marshlands (Ralainasolo et al. 2006; Copsey et al. 2009). To support a steadily growing human population in the region, many marshlands have been converted into rice fields during dry season when the water level is low (Ranarijaona 2007). The surrounding hills are dominated by open grasslands and subject to continuous erosion. This leads to the reduction of the lake water surface by sedimentation (Raharijaona-Raharison and Randrianarison 1999; Wright and Rakotoarisoa 2003; Bakoariniaina et al. 2006). In the last 30 years, Lake Alaotra has lost 5 km^2 in size (Bakoariniaina et al. 2006). Fish catches (4,000 tons in 1960 to 2,000 tons in 2004) are declining due to overfishing. Rice production decreased by approximately 40% in recent years due to deposits of sand and infertile laterite in poorly maintained irrigation systems and deterioration of fertile soils (Pidgeon 1996; Rakotonierana 2004; Razanadrakoto 2004; Bakoariniaina et al. 2006). Consequently, reduced incomes are further exacerbating the pressures on the remaining marshlands.

According to Lammers et al. (2015), the water hyacinth is found everywhere on Lake Alaotra, building occasionally thick and dense mats spanning hundreds of square meters. The plant, however, is barely used in the region; a few people occasionally use it to produce compost, to feed pigs and geese and for installing fish traps on the mats. It is currently unclear to what degree the water hyacinth in the Alaotra region is affecting local livelihoods (sensu Chambers and Conway 1991), or whether the plant could be used systematically and economically by a wider range of stakeholders. The objective of this study is to identify the potential drivers and barriers to the use of water hyacinth by depicting the socioeconomic conditions of the concerned local stakeholders. The basic assumption is that the plant has negative ecological and economic impacts. Using the plant as an additional source of income could potentially benefit a wider range of stakeholders; this could alleviate its possible impacts and diminish pressure on the marshland ecosystem. A typology of the main stakeholders of the Alaotra wetlands is provided to describe the qualitative and quantitative features of local livelihoods. An assessment of the local population's perception and knowledge of water hyacinth as well as current and potential usages are discussed.

3.3 Methodology

Field work was conducted from November 2012 to April 2013 in the Lake Alaotra region. Three study sites were chosen according to the level of marsh degradation (cf. Lammers et al. 2015): Vohimarina (E48° 32' 59.7", S1 7° 20' 02.4", 761 m), situated on the north shore of the lake, with about 500 inhabitants, entails 302 hectares of intact marsh vegetation. Anororo (E48° 26' 01 .4", S1 7° 30' 44.0", 724 m) on the western coast of the lake has over 8,000 inhabitants, and encompasses over 9,850 hectares of marshland vegetation. Andreba Gara (E48° 30' 08.0", S1 7° 37' 51 .7", 739 m), located in the eastern part with 4,000 inhabitants, contains 235 hectares of marshes (Andrianandrasana et al. 2005).

Qualitative and quantitative data focusing on socioeconomic conditions and the use of water hyacinth were collected using two methods: group surveys and semi-structured interviews. Oral information from the village heads (chef *fokontany*) was considered to identify and select the main local stakeholders (sensu Reed 2009) of the Alaotra wetland system. Group surveys (cf. McNamara 2003) were conducted to assess the socioeconomic conditions for each of the households of the four stakeholder groups (rice cultivators, fishers, vegetable farmers and cattle breeders). Twelve meetings representing each of the four resource user groups were organized in the three study sites with a total of 120 stakeholders. The survey covered livelihood characteristics such as the individual daily income, the description of targeted resources (e.g. fish or rice), the type and use of equipment and application of respective techniques as well as time allocation, associated investments, costs and benefits and the encountered daily livelihood challenges (cf. Appendix 1).

Semi-structured one-on-one interviews (Bernard 2005) were conducted to assess the potential drivers and barriers of the use of the water hyacinth. Again, a total of 120 stakeholders (others than the ones engaged in the survey) were interviewed (rice cultivators, fishermen, vegetable farmers and cattle breeders). The interview was subdivided into (i) personal perception of resources and value system; (ii) assessment of personal attitudes through the depicting of possible future resource use scenarios; (iii) awareness and potential use of the water hyacinth as an alternative source of income.

All data were analyzed using MAXQDA 2011, a qualitative data analysis software. This software is designed to facilitate qualitative data analysis by coding and categorizing the answers expressed by each interviewee.

3.4 Results

Stakeholder typology

The main stakeholders at Lake Alaotra were fishermen and rice cultivators. A majority, however, had several activities (e.g. vegetable farming and breeding) and depend on the marshes for arable land and for obtaining several plant species for their livelihoods. Cyperus (*Cyperus madagascariensis*) is the most widely used plant species in this region, and together with the common reed *(Phragmites australis*), are deeply rooted in *Sihanaka* tradition and used for constructing houses, fences, animal shelters, handicrafts, fish traps as well as during traditional ceremonies (Rendigs et al. 2015). Across the three study sites, 38% of the stakeholders interviewed (n=46) earn less than US$ 2.5 per day (exchange rate MGA/USD=2,884), 60% (n=72) earn US$ 2.5 to US$ 5 and 2% represented by retired officials (n=2) earn more than US$ 5. In contrast, 60% (n=72) of the stakeholders stated that they cannot make ends meet, 30% (n=37) could but only without mishaps, 8% (n=9) with difficulties and 2% represented by the same retired officials (n=2) do not have problems to ensure their livelihoods. Most individuals therefore are already under severe economic stress.

Fishermen: Only practiced as source of local subsistence a century ago, fishing in the Alaotra developed gradually with the introduction of fishnets and opportunities created by the railroad for selling fish outside the region (Moreau 1979). Several types of fishing tools exist at Lake Alaotra; their use depends on the targeted species and on the season. The fishing nets are generally used year-round and target various fish species according to the mesh size. The fishing rods (*fintana*), spears, sticks (*jorira*) and fish traps are mainly used during the rainy season as long as high water levels allow their usage. Fish traps and fishing nets are the most common tools. A single fish trap and one kilometer of fishing reel sell for US$ 0.75 and US$ 3.5, respectively. Depending on the size a canoe sells for US$ 35–100. Fish catch is now reserved mainly for cash income rather than subsistence. The fish price depends on the season (and peaks during the period of rice harvesting), the buyers (local or national collectors) and the targeted species (Copsey et al. 2009). The common carp (vernacular name: *besisika*) (*Ciprinus carpio*) is the most expensive fish followed by Tilapia spp. (vernacular name: *lapia*)

(Cichlidae) and the Asian snakehead (vernacular name: *fibata*) (*Channa maculata*). A full ten-liter bucket (ca. 16 kg) of common carp costs US$ 25, while tilapia or Asian snakehead brings US$ 18 and the Alaotra rainbow fish (vernacular name: *katrana*) (*Rheocles alaotrensis*) sells for US$ 10 on the local markets. Official fishing activity requires a license from the fisheries state department which can be obtained for an annual fee of US$ 5. Fishermen are organized in federations encompassing several associations. The federations control the mesh size diameter and fishing activities during the period of fishing closure (15 November to 15 January) during which only subsistence fishing is allowed. A majority of fishermen, however, do not have permits and many do not respect the fishing closure due to a lack of alternative income.

Rice cultivators: Rice represents the most important crop production in the Alaotra region and therefore constitutes the main subsistence and source of income of the farmers (Ducrot and Capillon 2004). In general, a rice field can be under traditional irrigation systems or modern systems of irrigation with dams and canals (*mailles*) allowing reliable water control and supply. Rice cultivation occurs mainly in lowland parcels (*rizières*) and occasionally in upland parcels (*tanety*) and forest plots during the rainy season (January-June, *vary taona*) and in former marshes converted into rice fields during the dry season (July–December, *vary jebo*); cf. Ducrot and Capillon (2004) for detailed farming typology. The first investments required for rice cultivation are the acquisition (or leasing) of land, seeds, pesticides and tools. Planting one hectare of rice requires 15 kg of seeds costing between US$ 3.5–5; currently, there are more than ten different types of rice in use (Ducrot and Capillon 2004). The most common tools used in rice cultivation are spades (*angady*, US$ 4), ploughs (US$ 150), small tractors (*kibôta*) (US$ 4,500), carts for transporting the harvest ($US 500), and weeders (US$ 10). Rice cultivation consists of various activities such as irrigating and ploughing the soil, direct seeding or transplanting the sprouts, irrigating the fields and discarding the weeds manually or with chemicals. The daily salary for workers in the rice fields ranges from US$ 1.5–3. The rent of land can either be paid in cash or in part of harvest: the landowner usually earns one ton of rice per hectare without working with the lender or 1.5 tons when working with the lender. The tenure contract also includes responsibilities for both lessee and lessor regarding input, labor and equipment (Jacoby and Minten 2007). One hectare of rice field produces about three tons of rice. The yield is attributed more for self-subsistence than for cash income. One kilogram of rice on local markets costs about US$ 0.4. Water supply and control represent the main issues of rice cultivation in the Alaotra (Ducrot and Capillon 2004).

Vegetable farmers: Though negligible compared to rice cultivation in terms of cultivated surface and production, vegetable farming produces enough vegetables for the Alaotra region and supplies for other regions of Madagascar (Monographie Régionale 2003). In contrast to rice, vegetables are produced mainly for cash income. Collectors from the cities buy and export vegetables to the islands around Madagascar. The main investments for planting vegetables are the seeds (3 sachets for US$ 1), tools (e.g. spade), cow dung (US$ 4.5 per one cart) and to have a well built for the water (US$ 60). Compost is rarely used compared to the cow dung because it needs extra preparation. However, cow dung is relatively rare and expensive (US$ 4.5 per cart). One hectare of field needs ten carts of cow dung. Therefore, it is combined with industrial fertilizers and pesticides. Vegetables are planted in the lake shore during the dry season (May to November). However, onions, beans and peanuts are still planted during the rainy season. As for the rice cultivation, the rent of land can be paid in cash or in part with the harvest.

Breeders: Breeding represents a food and income source as safety net against stress and shock for the Alaotra farmers. The majority of breeders have zebus, pigs and poultry (e.g. chicken, ducks and geese); only few are breeding sheep and goat. During day time, the animals (except pigs) are let free and kept inside shelters in the villages during night hours because of eventual thieves (*dahalo*). Zebu in the Alaotra region represents, as in other parts of Madagascar, a banking system (Kaufmann and Tsirahamba 2006); they are used for milk production and work (e.g. pulling a plough for rice production). A zebu is butchered or sold on the local market only in circumstances where money is needed, e.g. for cultural purposes such as marriage or funerary tradition *famadihana*. A male adult zebu costs between US$ 250–400, an adult pig costs about US$ 200. The lack of income decreases the investments into animal care such as vaccines and proper supply of animal food.

Drivers and barriers of water hyacinth utilization

In order to assess possible drivers and barriers for using water hyacinth in the Alaotra region, a survey with five questions was administered.

(i) What are the most invasive plant species in the Alaotra wetlands? This question intended to unveil the stakeholders' knowledge related to the marshland ecosystem. Due to the ambiguity of the term 'invasive' (Kull et al. 2014) it was presented as plant species that spread rapidly in the area and with potentially negative impacts on the livelihood of local stakeholders. Accordingly, water ferns (vernacular name: *ramilamina*) (*Salvinia* spp.) (40%) and the water hyacinth (36%) are considered as most abundant and harmful species for rice cultivation and fishing in the Alaotra wetlands (Tab. 3.1). A few participants (4%) affirm that there is no invasive plant species in the wetlands.

Table 3.1: Plant species in the marshes identified by respondents (n=120) as covering large areas and having negative impacts within the three study sites.

Harmful and widespread plant species at Lake Alaotra	English names	Malagasy names	Abundance (%)
Salvinia spp.	Water fern	Ramilamina	40
Echhornia crassipes	Water hyacinth	Tsikafona	36
Echinochloa pyramidalis	Antelope grass	Karangy	10
Phargmites australis	Common reed	Bararata	5
Leersia hexandra	Southern cutgrass	Vilona	3
Argyreia vahibora	Vine	Vahankelana	2

(ii) What are the current negative impacts caused by the water hyacinth in the Alaotra region? Nineteen percent of the stakeholders stated not to be affected by the water hyacinth. All impacts listed by the participants represented mainly visible clues such as waterway clogging (63%) and invasion of rice fields (14%). The rest of opinions (4%) were the bad smell generated by decaying water hyacinth, decrease of space for fishing occupied by the plant, reduction of fish catches due to waterway clogging and destruction of fish nets by the plant and water flows decrease due to thick mats of water hyacinth.

(iii) How do you use the water hyacinth in your daily life? This question intends to assess the awareness for this plant in the region. Most of the stakeholders have never used this plant (89%). This is accentuated in particular in Vohimarina, the least degraded site with lowest abundance of water hyacinth (Lammers et al. 2015), where more than 93% of the stakeholders have never used water hyacinth. The rest of the stakeholders occasionally used the plant for fish trapping, pig farming or compost production (Tab. 3.2).

Table 3.2: Current and Potential usage of water hyacinth expressed by stakeholders during interviews (n=120) within the 3 study sites (Vohimarina, Andreba and Anororo). Current use does not reflect the potential use.

Current use of *Eichhornia crassipes*	**Percentage of respondents**
No use	89
Support for fish trap	5
Fodder	4
Compost	2
Potential use of *Eichhornia crassipes*	**Percentage of respondents**
No possible usage	33
Compost	32
Fodder	23
Raw material for handicraft	10
Water purification/Shelter for fish and crab/keep humidity	2

(iv) How can the water hyacinth be used? This question assesses the stakeholders' knowledge on potential benefits deriving from this plant. 67% of the respondents would use water hyacinth either as a source for composting, mulch, fodder, handicraft and water purification (Tab. 3.2). Local composting consists of mixing fresh water hyacinth with cow dung. Mulching this plant consists in spreading chopped fresh water hyacinth before planting rice in the fields. Pigs and geese feed on this plant. Pigs eat the whole plant except the roots whereas geese feed only on the leaves. Handicrafts are made with dry water hyacinth stems. Thirty-three percent of the stakeholders do not see any possible use of this plant.

(v) What would you do if the entire lake would be covered with water hyacinth? This question intends to test the creativity and willingness of resource users to using the plant in an extreme scenario. Only 16% of the interviewees would use the water hyacinth as compost and handicrafts; in contrast, all other proposed activities are either laborious and/or financially costly and without any economic gain for the stakeholders (Tab. 3.3).

Table 3.3: Proposed management actions in case of total invasion of the Lake Alaotra by the water hyacinth (n=120) within the three study sites (Vohimarina, Andreba and Anororo). The majority of the actions do not generate economic benefits.

Proposed management actions	Percentage of respondents
Dry and kill *E. crassipes*	33
Kill *E. crassipes* using chemicals	18
No solution	17
Compost/handicraft	16
Alert the government	7
Ashes as fertilization/ Convincing people to get rid of it/ fence to contain the plant	6
Invest only in agriculture	3

3.5 Discussion

Potential threats

Extensive use of chemical fertilization for agricultural production around wetlands leading to an increase of nutrient concentrations of water bodies (eutrophication) and combined with high solar energy (Ndimele et al. 2011) represent favorable conditions for the spread of the water hyacinth (Charudattan et al. 1996). These conditions are found at Lake Alaotra (Pidgeon 1996). High water temperatures peaking more than 41 °C have been measured in the littoral zone of the lake (Lammers et al. 2015) and are further favoring the spread of water hyacinth and depleting dissolved oxygen (Gratwicke and Marshall 2001). The thick mats of water hyacinth lead to a decrease of phytoplankton (due to light deprivation), an increase in water turbidity (due to the constant rotting of the mat base) and a decrease of dissolved oxygen (due to the high oxygen consumption of rotting plant biomass) (Masifwa et al. 2001; Rommens et al. 2003; Mangas- Ramírez and Elías Gutiérrez 2004; Perna and Burrows 2005: Villamagna and Murphy 2010). Collectively these effects may negatively impact animal and plant species at Lake

Alaotra. The impacts of water hyacinth on invertebrate communities are variable: A greater number of invertebrates is observed in the transition zone from *E. crassipes* stands to open water due to increased structural diversity as compared to open water zones (Masifwa et al. 2001). However, the total amount of invertebrates decreases because of the overall reduced availability of phytoplankton (Toft et al. 2003; Midgley et al. 2006). The decrease of invertebrates reportedly leads to reduced fish diversity (Howard and Harley 1998; Gratwicke and Marshall 2001). As with the invertebrate communities, the impacts of the water hyacinth on waterbirds are ambivalent: The positive effects of the water hyacinth on the invertebrate communities could lead to higher diversity and density of waterbirds whereas dense mats of water hyacinth or the low dissolved oxygen under the mats could physically hinder waterbirds access to prey or impact negatively the abundance of the prey species (Villamagna and Murphy 2010). At Lake Alaotra, several bird species such as the white backed duck (*Thalassornis leuconotus insularis*) suffer from the spread of the water hyacinth (Nicoll and Langrand 1989). Due to its strong competitiveness regarding light and nutrient acquisition, the water hyacinth is able to out-compete and displace submerged vegetation (Mitchell 1985). The impact of the water hyacinth on the local lemur *Hapalemur alaotrensis* remains up to now understudied. However, since *H. alaotrensis* needs tall vegetation (papyrus) to cross water channels (Ralainasolo 2004), the potential isolation of tall vegetation patches due to further spread of large water hyacinth mats might hinder genetic exchange between the populations of *H. alaotrensis*. Interestingly, *H. alaotrensis* was reported to feed on the stems and flowers of the water hyacinth at Lake Alaotra (Birkinshaw and Colquhoun 2003). As discussed by Rendigs et al. (2015), the cumulative effects combined with the spreading of water hyacinth can lead to further loss in fish and increasing the vulnerability of fishermen in the Alaotra region. Regarding the impact of water hyacinth on the fishing activities at Lake Alaotra, 63% of the stakeholders considered waterway clogging as the main problem caused by the plant on their livelihood since it decreases fish catches and destroys fishing material such as fishnets. The floating thick mats of water hyacinth are moved around by winds. These can also invade rice fields; suppressing rice crop, inhibiting rice germination and interfering with rice harvest. These negative impacts have been shown to cause important losses of rice paddies in West Bengal (EEA 2012, Patel 2012). At Lake Alaotra, this phenomenon can be observed frequently due to inefficient water control. The risk of production loss due to the water hyacinth can become more prevalent in the near future; the water scarcity at the lake, combined with badly maintained irrigation systems are pushing the rice fields closer into the marshlands. Another factor adding to the water issue is the high evapotranspiration demand of this invader, which can exceed by ten times the one by open water bodies (Gopal 1987). Increased water loss by the water hyacinth leads especially in shallow lakes such as Lake Alaotra to a drop in water level. In turn this can add an additional stress to the hydrologic balance in the region (Ferry et al. 2009), which constitutes another factor further stressing the rice production in the wetlands. A reverse effect could happen during periods of heavy rain or cyclones. By clogging waterways, the water hyacinth can slow down the water flow up to 95% leading to severe flooding (Jones 2009). The management of the water hyacinth requires prior estimations of the current state of invasion to evaluate the costs. Shackleton et al. (2007) created models about invasive species characterized by the time since invasion, abundance and level of cost and benefits. The models can be used as a tool to guide interpretation and future management of invasive species and simultaneously assessing vulnerabilities of local populations toward the invasive species. According to classifications and procedures used in the model and combined with our findings from the Alaotra in this study, the water hyacinth can be defined as a "undesirable, strongly competitive species" Shackleton et al. (2007: p 124). Regarding time since invasion, the water hyacinth invasion in the Alaotra seems to be in 'phase 2': rapid spreading thanks to its competitive nature. Awareness of the water hyacinth increases as it becomes first a nuisance, and later on a significant hindrance to local livelihood activities and options (e.g. rice cultivation and fishing activity in the Alaotra). The future costs (ecological, aesthetic, harvesting, and control) are increasing rapidly thus reducing the productivity of other resources; hence, the vulnerability of the livelihood of local population is further increasing (Shackleton et al. 2007).

Potential opportunities

Some invasive plants have been in the landscapes for several generations, and instead of being controlled or eradicated, they became part of the livelihood and the well-being of human communities. In South Africa, for example, the prickly pear (*Opuntia ficus-indica*) is a source of food (jam and the fruit itself), used for beverages (beer and syrup) or for medicine and income for local traders (Beinart and Wotschela 2003; Shackleton et al. 2011). In Nepal the invasive climbing weed *Mikania micrantha* is used by the local population as fuel wood and fodder (Rai and Scarborough 2013). In India, due to the unsuccessful attempts to eradicate the tickberry (*Lantana camara*), the local communities addressed as adaptation strategy the use of this plant as source of income. In Madagascar, the use of the water hyacinth as a source of raw material for handicrafts was initiated through the collaboration between the Government of Madagascar and the Embassy of Indonesia (Rakotomalala 2014).

In the Alaotra wetlands, composting based on water hyacinth could represent a realistic possibility due to attributes such as its relative short period of maturation (about 30 days), its ability to retain nitrogen (N), phosphorus (P) and potassium (K) and thus to improve soil structure and nutrient contents (Polprasert et al. 1980). The plant should be chopped into 5 cm long pieces and put into piles with cow dung and other leaves before composting in order to enhance microbial access (Dalzell et al. 1979; Polprasert et al. 1980). Due to its high moisture content (90%), Elserafy (1980) stated that composting water hyacinth does need only little amount of water but should be covered or performed in pits to avoid excessive water loss in compost pile. Since composting requires time and workload investments, local stakeholders from the Alaotra region prefer to use directly cow dung instead. Despite the relative 'short' duration of maturation of water hyacinth compost, this is already perceived as a long-term investment for the interviewees and thus represents a potential barrier to its adoption. In comparison to developed countries where farmers often possess health and production insurance (cf. Fisher et al. 2002), the rural poor farmers of the Alaotra region are less resilient to eventual shocks such as drought, floods, landslides, crop pests, market collapse, health problems and accidents (affecting households and individuals). Especially the direct dependence on rice and fish production as main source of food or cash income leads to increased vulnerability due to the unpredictability of production and price fluctuations, with the latter depending oftentimes on outside drivers such as the national demands for the products or the season influencing the road conditions. As an adaptation to these high uncertainties, mutual aid groups give relative insurance and flexibility to the Alaotra farmers especially during hard times (Ducrot and Capillon 2004). However, the dissolution of mutual aid group can be traumatic for poor-equipped farmer (ibid). The high exposure to risks for the local farmers can reduce or inhibit investment in time demanding innovations and prevent long term perspectives. This is supported by our results; only 16% of the stakeholders showed an opportunistic attitude towards the water hyacinth. Another limitation for composting in developing countries is probably the intense workload for transporting large amounts of fresh water hyacinth (Gunnarsson and Petersen 2007). According to a vegetable farmer "(…) the only possibility to involve people [in the Alaotra region] to use the water hyacinth as compost is to process it via a small factory where people can work and compost can be sold".

An alternative to composting could be the use of green manure out of water hyacinth to reduce the labor requirements due to the usage of dried material (Gunnarsson and Petersen 2007). Green manuring consists of spreading plant material (with high nitrogen content) on the fields or working it into the soil (Stopes et al. 1995). The green manure could be the most feasible alternative for farmers in the Alaotra region. Due to its high ash content (40% of dry weight, Thomas and Eden 1990), the water hyacinth can also be burnt and used as mineral fertilizer. Ashes from water hyacinth could be applied in the fields to provide minerals, mainly phosphorus (P) and potassium (K). The ash spreading would require a relatively low labor input; however, the effects and application rate must be investigated (Gunnarsson and Petersen 2007).

Thanks to its high content in crude protein (20%) (Abdelhamid and Gabr 1991), the water hyacinth is excellent as fodder for ruminant animals (Tag El-Din 1992). However, the air-filled tissues of water hyacinth lead to high consumption of water by the animal, therefore decreasing the nutritional value of the diet. The calcium oxalate occurring in its tissues represents a potential harm for the animal digestive tract in case of low amount of digestive acid (Bolenz et al. 1990). The water hyacinth should be chopped into pieces to reduce air and negate water absorption. The material should be pressed, centrifuged and washed with acid to eliminate the calcium oxalate (Bolenz et al. 1990). Some Alaotra farmers are already feeding their pigs with this plant, but at current stage it is unclear to what degree it is used. However, including water hyacinth in the diet of pigs and geese could at least reduce the cost of animal food.

Water hyacinth can be used as part of fish diet (*Tilapia* spp., *Cyprinus carpio*) (Igbinosun et al. 1988; Mohapatra and Patra 2013); this however, showed limited application with low proportion of water hyacinth in the diet (15–23%). Sixty years ago, fish farming was introduced by the Department of Forests and Water in the Alaotra with 85,000 ponds (each pond about 235 m^2) covering an area of 2,000 ha and collapsed to 10,000 ponds in 1984 (Pidgeon 1996). In comparison during the same period integrated rice-fish culture within villages covered only some 400 ha (Kiener 1963). Nowadays for the Alaotra region, fish breading has lost its importance (Anonymous 2010). Currently, only one private company in Anosiboribory produces alevin of *Tilapia niloticus* and *Cyprinus carpio* to supply the very few pisciculturists around Lake Alaotra (Bary-Jean Rasolonjatovo, pers. comm.). The limiting factor for pisciculturists is the water supply in the Alaotra. The low proportion of water hyacinth in fish diet and the negligence of pisciculturists in the region limit the use of the plant as fish food. However, fish farming may gain momentum given the lake fish catches have dropped by about half (i.e., by about 2,000 t) within the last fifty years while human population has increased more than five times in the same period (Razanadrakoto 2004).

Water hyacinth can be used as raw material for making handicraft and furniture (Ndimele 2011). Long stems of water hyacinth (equal or more than 70 cm) are collected and sun-dried.

The stalks should be completely dry (Jafari 2010). However, the only use of the stem does not allow successful infestation reduction and the market for these products is far too small to have any impact on water hyacinth populations (UNEP 2013). Nonetheless, it could improve cash income at least for the handicraft makers of the Alaotra. The reduction of sedges and reeds utilization for handicraft can alleviate pressure on the critically endangered lemur *H. alaotrensis* feeding mainly on those plant species (Ratsimbazafy et al. 2013; Waeber et al. In press).

Due to its high moisture content (90%) and its high ash production (40% of dry weight) using water hyacinth as charcoal is unattractive because its incineration produces only 1.3 kJ/m^3 in comparison to 9.8 kJ/m^3 for firewood (Thomas and Eden 1990). However, briquettes out of this plant produce 8.6 kJ/m^3 which is comparable to charcoal (9.6 kJ/m^3) (ibid). In the Philippines, a company supplies local restaurants with briquettes (Laguador et al. 2013). The process of making briquettes is relatively simple but requires material (burning, briquetting and drying machines) (ibid). Meier (2008) concluded that using water hyacinth briquettes at Lake Alaotra is not efficient since it produces too much ash and smokes therefore reducing its calorific performance and representing a threat for human health. Also, it does not suit to the local used cooking oven and requires more preparation time and effort in comparison to the charcoal. Moreover, a mechanical press machine is needed to reduce those latter cited preparations but it would not be likely affordable for the local population (from US$ 2,000).

Water hyacinth can be used to produce ethanol, methane and sludge. The ethanol is produced by hydrolyze and fermentation of water hyacinth. However, pretreatment is necessary due to the lack of yeast fermentable sugar within the plant (Thomas and Eden 1990). In China, the plant is mixed with pig manure to produce biogas (Lu et al. 2010). Biogas is generated by the degradation of organic material through anaerobic biological process. Due to high content of lignin in water hyacinth tissues, thermochemical pretreatment such as addition of ions is needed (Gunnerson and Stuckey 1986; Patel et al. 1993). The remaining sludge can be used as fertilizers due to its high concentration of nutrients (Hons et al. 1993). The transportation of the sludge would represent important labor force requirements due to its high water content (Gunnarsson and Petersen 2007). Producing ethanol, biogas and sludge out of the water hyacinth in the Alaotra wetlands is limited by technical and financial requirements since they need important transfer of technology and infrastructure.

Madagascar belongs to the category of low human development countries with a HDI (Human Development Index) of 0.483, ranked as 36th poorest country in the world (UNDP 2013). In a system where input credit, crop production and health insurances are not sufficient or missing, stakeholders adopt their own strategies to manage covariant and idiosyncratic risks (e.g. weather uncertainty or illness, respectively) (Devereux 2001). Peasants in the Alaotra region depend mainly on fishing and rice cultivation; however, diversification of activities, land tenure flexibility and mutual aid are used to buffer uncertainties effects (cf. Ducrot and Capillon 2004). Governmental administrations in collaboration with NGOs should increase effort to help poor farmers to increase their capabilities to improve their assets and to cope with risks, stress and shocks affecting their livelihood. In the near future, fish and rice production will likely drop continuously with increasing anthropogenic pressures and degradation in the Lake Alaotra. Investing into new technologies or adoption of new resource use could represent additional buffers and increase resilience of farmers to an uncertain future. However, this would require increased and concerted educational efforts to raise the awareness for environment and its potentials such as the usage of water hyacinth (cf. Reibelt et al. 2014).

3.6 Conclusion

The livelihoods of local stakeholders can benefit from using water hyacinth but only to some degree. Based on limited access to cash and technology, the most feasible use are green manure, animal fodder, handicrafts, compost and ash as mineral fertilizer. Using water hyacinth as fertilizers could be implemented to promote conservation agriculture by improving and maintaining soil fertility and therefore reducing pressures on the marshlands. Water hyacinth could be combined with local craft materials improving cash income. However, access to information, financial and technical supports as well as markets for handicrafts constitute important but currently missing aspects. This is also the case in other wetland regions of Madagascar where the plant occurs (e.g. Lake Ravelobe within Ankarafantsika National Park, Betsiboka Basin, Imerina and Betsileo regions, northern rivers of Madagascar and Pangalanes Canal) (Binggeli 2003). Additional cost/benefit and risk analyses are needed to assess potential utilization of the water hyacinth. The most significant barrier to local adoption of new water hyacinth use seems to be uncertainty linked to long term investments and planning.

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Chapter 4

Turning a problem into profit: using water hyacinth (*Eichhornia crassipes*) for making handicrafts at Lake Alaotra, Madagascar.

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4.1 Abstract

In diverse ecosystems, invasive plant species represent a serious threat for nature conservation by leading to loss of native species as well as environmental degradation. The water hyacinth (*Eichhornia crassipes*) belongs to the top 10 worldwide most troublesome aquatic weeds. This study assesses the use of this invasive plant as a new source of raw material for handicrafts to substitute for the traditionally used papyrus (*Cyperus madagascariensis*) in the poor and remote region of Lake Alaotra in Madagascar. It has been recently observed that the current exploitation of papyrus in this region adds pressure on the receding Alaotra wetland and notably decreases habitat and food resources for the locally endemic and critically endangered lemur species *Hapalemur alaotrensis*. Within our research, water hyacinth handicrafts were produced by local artisans and compared with papyrus handicrafts regarding production path (collection, transportation and processing of raw material) with a focus on financial costs, workload and selling price. In addition, structured interviews were conducted with town-based handicraft retailers and potential customers to specify market expectations (quality, design and marketing strategies). Our study revealed that despite the requirement for a longer time regarding raw material selection and drying (seven days vs. three days) as well as additional financial costs (23% in addition) for ornaments, water hyacinth handicrafts displayed many advantages in comparison to papyrus handicrafts: (a) assembling water hyacinth handicrafts was easier and faster (33% less time investment), (b) led to robust products that were rated as being of acceptable to very good quality by 91% of the interviewees (c) and sold at three times (mean 2.25 US$) the sale prices of the traditional papyrus handicrafts (mean 0.75 US$). The use of water hyacinth has therefore the potential to increase local household incomes, open up new markets and attenuate the pressure on the Alaotra wetland biodiversity by reducing the use of papyrus. A SWOT (strengths, weaknesses, opportunities and threats) analysis combined with research findings on rural handicrafts was drafted to identify four main steps for promoting the market establishment of water hyacinth handicrafts at Lake Alaotra: creation of artisans' clusters and networks, improvement of managerial and marketing competence, access to finance and exploration of markets possibilities. This research can provide insights for other small rural handicraft enterprises in developing countries facing problem with water hyacinth throughout the world.

***Key words**: Wetland conservation, Invasive species, Alternative sources of income, Natural resource management, Markets, Ethnobotany, Rural development.*

4.2 Introduction

The water hyacinth (*Eichhornia crassipes* (Mart.) Solms, Pontederiaceae), one of the top ten troublesome weeds worldwide, is a floating aquatic macrophyte that originally occurred only in the Amazon Basin (Villamagna and Murphy 2010; Patel 2012). This invasive species is a perennial plant with thick rounded green leaves, lavender blue flowers with a central yellow dot organized in spike inflorescence and dark purple to black roots with rhizomes and stolons (Gettys 2014). Since the beginning of the 19th century its distribution has increased tremendously due to its use as an ornamental plant (Barrett and Forno 1982; Toft et al. 2003). Today, the water hyacinth can be found in over 50 tropical and sub-tropical countries on five continents (Villamagna and Murphy 2010). This plant species represents a serious threat for both the environment and humans due to its ability to form dense mats with up to two million plants per hectare (Gopal 1987; Villamagna and Murphy 2010). The high density is based on the plant's complex root structure while the enormous mat size is attributed to the species high rate of reproduction (doubling its numbers in one to three weeks) triggered by nutrient-rich conditions and high insolation (Gopal 1987; Ndimele et al. 2011).

The ecological and socioeconomic impacts of water hyacinth are diverse; large mats of water hyacinth reduce light penetration into underlying water layers, deplete dissolved oxygen, and increase water loss due to high evapotranspiration capacity (Lallana et al. 1987; Masifwa et al. 2001; Rommens et al. 2003; Mangas-Ramirez and Elias Gutierrez 2004; Perna and Burrow 2005; Villamagna and Murphy 2010). Water quality subsequently deteriorates and aquatic communities are altered (Gratwicke and Marshall 2001). The mats clog waterways, which hinder fishing activities as well as intakes for hydropower and irrigation schemes (Mailu 2001). Disease vectors use the water hyacinth as microhabitats and threaten human health (*Biomphalaria* sp. for bilharzia or *Anopheles* sp. for malaria) (Masifwa et al. 2001; Plummer 2005).

Globally, a number of methods (manual, mechanical, chemical, biological) are used to control the water hyacinth (FAO 1996; Shabana et al. 2006; Coetzee et al. 2009). However, controls would consume time and energy and are expensive and ecologically unfriendly (especially with chemical control). These methods can have considerable undesirable consequences for the environment and people as well (FAO 1996). An alternative method of control is thus represented by the economic use of the plant. Across the world, this plant is currently exploited for producing fertilizers, handicrafts, paper, biogas, fodder, briquettes, furniture and for cleaning industrial waste water by phytoremediation (Jafari 2010; Ndimele 2011; Patel 2012). Nevertheless, in poor and remote regions of developing countries the absence of electricity, technology and a generally poor infrastructure impedes the use of water hyacinth (Gunnarsson and Petersen 2007).

In Madagascar, one of the world's poorest countries, water hyacinth already infests lake and river ecosystems (Binggeli 2003). This includes Lake Alaotra, the country's largest freshwater lake (20,000 hectares of open water) where the plant has existed since the 20th century. Today it represents up to 53% of the marsh fringe vegetation (Lammers et al. 2015). The Alaotra region is economically important, given its status as the country's rice granary and its biggest freshwater fisheries (Wallace 2013). The wetland includes 23,000 hectares of freshwater marshes dominated by papyrus (*Cyperus madagascariensis* (Willd.) Roem. and Schult.) and common reed (*Phragmites australis* (Cav.) Trin. ex Steud.) and also supports several endemic plant and animal species (Andrianandrasana et al. 2005; Ralainasolo et al. 2006; Guillera-Arroita et al. 2010). However, crushing poverty and population growth in the region pose severe threats to the Alaotra wetland, one of the most devastating being marsh burning for additional rice fields and fishing areas (Andrianandrasana et al. 2005; Ralainasolo et al. 2006; Ranarijaona 2007; Copsey et al. 2009). The marsh degradation increases the spread of water hyacinth, locking the wetland system into a vicious circle (Lammers et al. 2015).

A recent study showed that more than three fourths of local stakeholders are already affected negatively by water hyacinth clogging waterways and invading rice fields (Rakotoarisoa et al. 2015). They also identified the drivers for and barriers to the use of water hyacinth as a local source of income at Lake Alaotra. It is to date still poorly used (fodder, compost and support for fish trap) and controlled in the Alaotra region (Goarin 1961; Rakotoarisoa et al. 2015). Three major opportunities were identified as most likely both profitable and suitable under local conditions—the production of fodder, fertilizers and handicrafts (Rakotoarisoa et al. 2015). The current study focuses on the assessment of water hyacinth handicrafts as an alternative source of income. At present, local artisans mainly use papyrus for handicrafts. This high demand for papyrus puts additional pressure on the marshes. It especially threatens the diet and habitat quality of the locally endemic and critically endangered lemur species, the Alaotra gentle lemur (*Hapalemur alaotrensis*), which feeds primarily on papyrus (Mutschler et al. 1998).

In this paper, we tested whether water hyacinth could substitute for papyrus as raw material for handicrafts and could thereby generate benefits for local artisans in the Alaotra region. The objectives of this study were: (a) to design and produce water hyacinth handicrafts with local artisans, (b) to compare the production process and sale prices against traditional papyrus handicrafts, and (c) to determine retailers and costumers' opinions and expectations of handicrafts quality, design and marketing strategies. Finally, recommendations for the successful establishment of water hyacinth handicraft markets are proposed for the Alaotra region.

Handicraft sector in Madagascar

In Madagascar, handicrafts are deeply rooted in the culture and tradition. A high diversity of raw materials, handicrafts and techniques exists throughout the island. In total, 2,000,000 artisans (about 10% of the population) are generating 15% of the country's GDP (Gross Domestic Product). This broad handicraft sector is administrated by one national and several regional centers (CENAM and CERAMs) by the Ministry of Culture and Handicraft (Ratovomahefa 2014). A few other organizations (e.g. IFC, BAMEX and ECATCH) provide financial and technical support to small and medium sized handicraft enterprises in Madagascar (e.g. FIVMPAMA, MMF and MNDC) (Ashamu et al. 2005). Malagasy handicraft products are exported to France by conventional entrepreneurs (e.g. Tongasoa Artisanal, Hautex Artisanat de Madagascar, Fleur des Tropiques, Madabascar), but fair-trade organizations (e.g. Artisan du monde, Tear Craft, Ravinala Italie) are poorly represented (CITE 2011). According to a study by CITE (2011), due to a lack of marketing knowledge only 36,000 Malagasy artisans (approx. 2% of all artisans in Madagascar) are able to export their products themselves. This missing marketing knowledge, communication barriers and an insufficient capacity for innovation and design are the principal weaknesses of the Malagasy handicraft sector (Ashamu et al. 2005; CITE 2011).

4.3 Material and methods

a. Papyrus (*Cyperus madagascariensis*)

Papyrus (*Cyperus madagascariensis*) is perennial sedge native from Madagascar. Belonging to the family of Cyperaceae, papyrus has tall green stout and triangular stems (2.13 m to 3.65 m) without leaves. The inflorescence is umbel-like with 4 to 8 basal bracts, 50 to 100 thin green branches with reduced leaves at their base and spikelets of flowers on the top. Papyrus has very firm roots and spread mainly by means of woody rhizome (Clarke 1906). With the common reeds (*Phragmites australis*) papyrus dominates the marsh vegetation at Lake Alaotra (Ferry et al. 2009). In addition, papyrus is the most widely used plant species in the Alaotra region being deeply rooted in Sihanaka (an ethnic group from Lake Alaotra) tradition for constructing houses, fences, animal shelters, handicrafts, fish traps and as items during traditional ceremonies (Rendigs et al. 2015). Lower part of stems and rhizome are eaten by fishermen because of it sweet taste (pers. obs.). Papyrus handicrafts are made and sold by women between June and August. However, no accurate data were found regarding percentage of household involved in making handicrafts and income generated from those handicrafts.

b. Study Area

This study was carried out from February 2014 to July 2014 in the village of Andreba Gara (E48° 30’ 08.0”, S1 7° 37’ 51 .7”, 739 m), located on the southeastern side of Lake Alaotra, Madagascar (Fig. 4.1). Andreba Gara was selected for its proximity to the lake allowing artisans to easily access water hyacinth raw materials. The regional climate is characterized by two distinct seasons: a rainy season from December to April and a dry season from May to November. Annual precipitation ranges from 1092 to 1200 mm, nearly all of which occurs within the span of 100 days. Mean monthly temperatures vary from 11 °C in July to 28.4 °C in January (Ferry et al. 2009). Despite its remoteness, the village has a reputation as a tourist site due to Park Bandro, a small protected area managed by the local community. This nature reserve supports the biggest sub-population of the locally endemic lemur species Hapalemur alaotrensis known as ‘Bandro’ (Ratsimbazafy et al. 2013). The village Andreba Gara has a population of approximately 4,830 inhabitants, 70% of whom are under 17 years old. Fishing and rice cultivation are the main sources of income (Head of Andreba Gara village, pers.comm.). Daily wages range from 2.5 US$ to 5 US$ (Rakotoarisoa et al. 2015) and are above the national average (80% of the population live with 1.25 US$ a day) (Rendigs et al. 2015). This leads to considerable flow of migrants into the Alaotra region. Besides the low standard of living, the infrastructure of the region is also weak: there is no permanent electricity and the roads connecting this area to the outside world are few and in bad condition (Pidgeon 1996). Subsequently, local products such as handicrafts are mainly sold in the nearby, bigger market town Ambatondrazaka located about 20 km from Andreba Gara (Fig. 4.1). This lack of mobility leads on the one hand to oversaturation of the handicraft market in the Alaotra region and on the other hand to very low selling prices of the products to handicrafts middlemen transporting and selling them in the capital Antananarivo (pers.obs.).

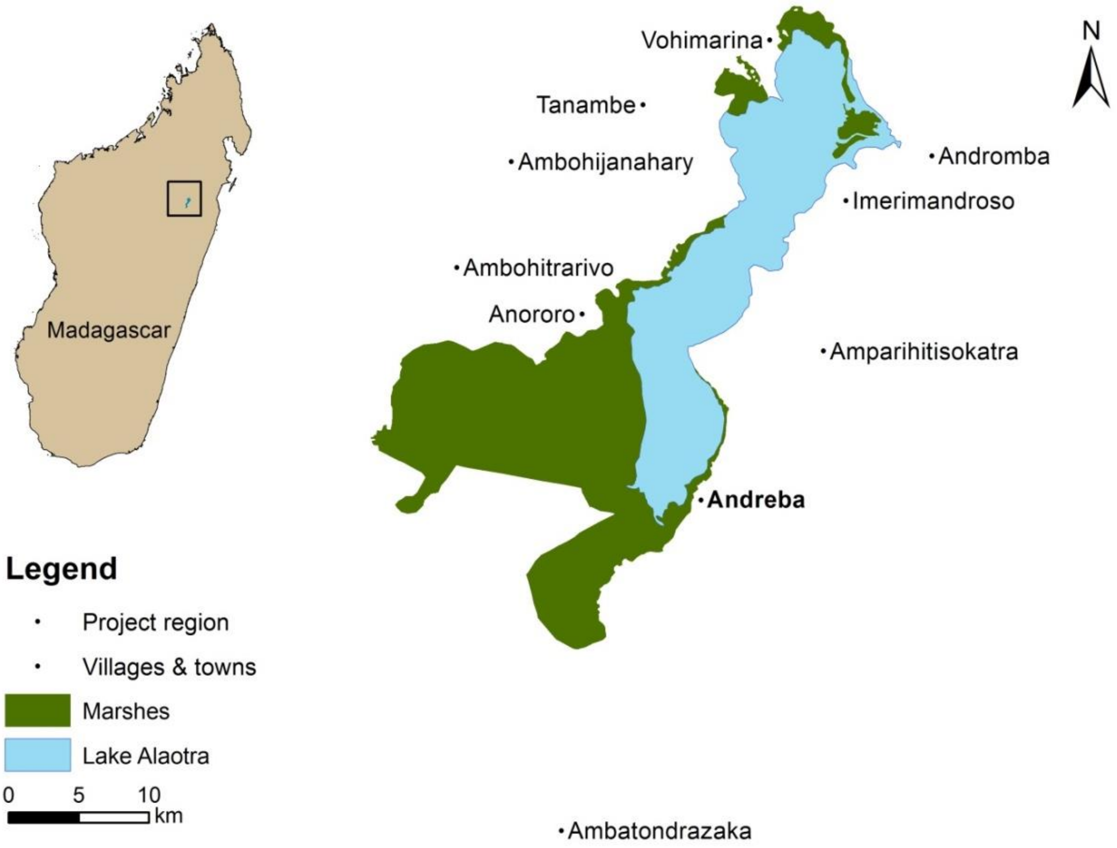

Figure 4.1: Map showing the village of Andreba Gara where the study was conducted and Ambatondrazaka town which is the nearest handicraft market in the Alaotra region, Madagascar.

c. Data collection and analysis

Six different handicraft products were produced from water hyacinth raw material instead of traditionally used papyrus with the assistance of two experienced artisans from Andreba Gara: large and small hats, shopping bags, handbags, sandals and mats (Fig. 4.2). These types of handicrafts are common in the region. At the beginning, pictures of water hyacinth handicrafts selling on international markets were shown to the artisans serving here as initial inputs for designing the products. In addition, the artisans were asked to include their own preferences and those of their customers into the new product design. However, no preliminary training was provided to introduce the use of the new water hyacinth raw material. To estimate the potential of water hyacinth as a substitute for papyrus, the whole production process, from raw material collection to end products, and income produced from the two source materials were compared. Workload, material and labor costs, and sale prices were analyzed. Actual selling prices of papyrus handicrafts were collected with local handicraft sellers (n=10) at the local market of Ambatondrazaka while the prices of water hyacinth handicrafts were expressed by retailers (n=50) and costumers (n=50) in the capital city of Antananarivo.

Figure 4.2: Sundried stems of water hyacinth collected during the rainy season (left) and local artisans making handicrafts from water hyacinth (right) in Andreba Gara at Lake Alaotra, Madagascar.

Product quality (5 categories: 1=very good, 2=good, 3=acceptable, 4=bad, 5=very bad) and product design (color, fiber size, combination with other materials) as well as further suggestions regarding marketing strategies were investigated using structured interviews with handicrafts retailers (n=50) and customers (n=50) in Antananarivo. Differences in product quality regarding gender and age classes of the retailers and customers were tested with the Mann-Whitney-U test. To detect differences related to consumer and retailer age, individuals were assigned to two age classes using the median as a cutoff (1= $<$ 44 years old, 2= $\geq$ 44 years old).

4.4 Results

a. Production path and sale prices

The production path of water hyacinth and papyrus handicrafts includes (1) raw material selection, (2) transportation, (3) the drying process, (4) ornament choice and (5) the construction of the item itself (Tab. 4.1). (1) Concerning the selection of raw material, the water hyacinth stems must have a length of $\geq$ 50 cm to be suitable for handicraft production (Fig. 4.2). No particular selection was necessary for papyrus raw material, due to the mature plants height of around 3 m. (2) Labor and financial costs associated with transportation were the same for both raw materials. (3) Once in the village, both plants were sundried and then stored in dry places. The stems of water hyacinth required one week to dry whereas three days were enough for the papyrus stems. (4) Regarding the products decoration, a greater variety of materials (varnish, leather and cardboard) were combined with the water hyacinth with the aim of drawing customers' attention. This led to an increase of production costs in comparison to papyrus handicrafts. (5) Processing water hyacinth handicrafts required one third less work in comparison to papyrus handicrafts. Due to their size and flexibility, the water hyacinth stems were easier to slit and weave. In contrast, papyrus stems are more rigid and thus break easily reducing therefore the load capacity. Remarkably, the sale prices of water hyacinth handicrafts reached three times the market prices of papyrus (Tab. 4.2, Fig. 4.3).

Figure 4.3: Water hyacinth handicrafts produced in this study (left) and papyrus handicrafts sold on the regional market of Ambatondrazaka (right).

Table 4.1: Production paths of papyrus and water hyacinth handicrafts in Andreba Gara at Lake Alaotra for the assemblage of six different handicraft items per raw material type. Workload indicates tasks being executed by the artisans themselves.

		Papyrus handicrafts			**Water hyacinth handicrafts**		
		Cost (US$)	**Duration (d)**	**Workload (d)**	**Cost (US$)**	**Duration (d)**	**Workload (d)**
External costs	Collection	0.99	1	0	0.99	1	0
	Transportation (Lake-inland)	0.49	1	0	0.49	1	0
Material costs	Varnish	-	-	-	0.82	-	-
	Dyes	0.99	-	-	0.99	-	-
	Raffia fiber	0.79	-	-	0.79	-	-
	Leather	-	-	-	0.99	-	-
	Cardboard	-	-	-	0.20	-	-
Production processes	Drying	-	3	0.5	-	7	1
	Slitting	-	3	3	-	1	1
	Coloring	-	1	1	-	1	1
	Weaving	-	3	3	-	2	2
Total		3.26	12	7.5	5.27	13	5

Table 4.2: Sale prices of papyrus (n=10) and water hyacinth (n=100) handicrafts. Mean and standard deviation (SD) are shown.

Products	**Papyrus handicrafts (US$)**		**Water hyacinth handicrafts (US$)**	
	Mean	SD	Mean	SD
Big hat	0.66	0.07	2.63	0.32
Small hat	0.49	0.05	2.30	0.14
Sandals	0.33	0.05	1.32	0.41
Shopping bag	1.32	0.13	3.95	0.76
Handbag	0.26	0.04	1.32	0.31
Mat	1.32	0.05	1.97	0.30

b. Quality assessment

Data regarding age and gender of retailers and customers are summarized in Tab. 4.3. The two groups were represented by 126 women and 74 men. The mean age was 40 for the women and 37 for the men.

Table 4.3: Gender and age of customers and retailers. Mean and standard deviation (SD) are shown.

Group	**Gender**	**Mean age**	**SD**	**Percentage of individuals**
Customers	Male	37	14.41	48
	Female	38	14.85	52
Retailers	Male	37	11.80	26
	Female	41	14.03	74

65% of customers and retailers assessed the water hyacinth handicrafts as of "good" quality and 22% rated the products' quality as "acceptable." The categories "bad" quality represented 9% of the respondents and the remaining 4% evaluated the quality as "very good". No statistical difference was detected in quality assessment of the water hyacinth handicrafts between men (2.44, SD=0.73) and women (2.27, SD=0.70) (Mann-Whitney U Test, p=0.25) (Fig. 4.4) or between younger (2.31, SD=0.70) and older interviewees (2.38, SD=0.71) (Mann-Whitney U Test, p=0.36) (Fig. 4.5).

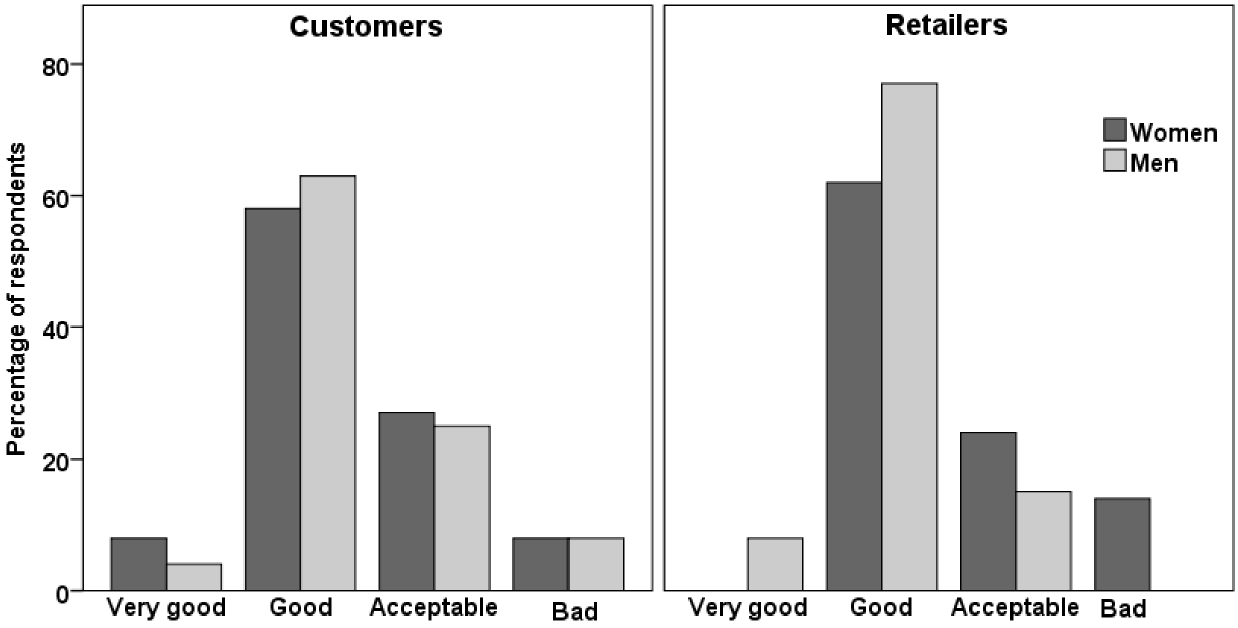

Figure 4.4: Quality assessment of water hyacinth handicrafts according to the gender of customers (n=50) and the retailers (n=50) in Antananarivo.

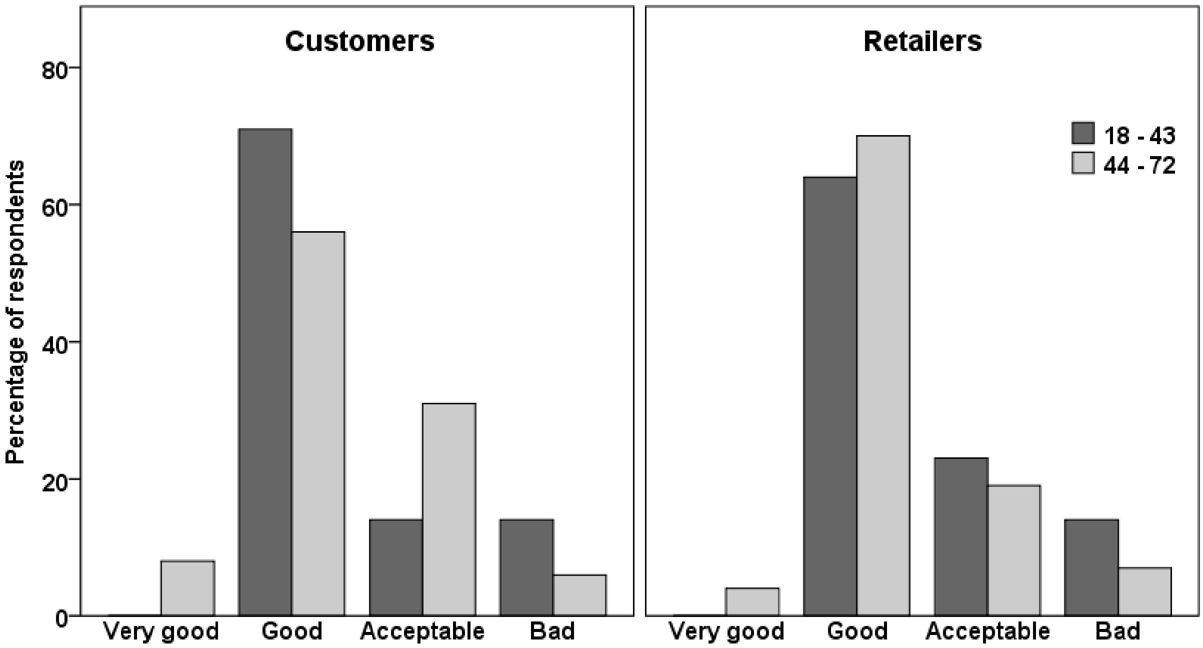

Figure 4.5: Quality assessment of water hyacinth handicrafts based on the age of customers (n=50) and the retailers (n=50) in Antananarivo.

c. Product design and marketing strategies

The product design results revealed a strong preference for natural (36%), green (19%) and varnish colors (15%). Half of the interviewees preferred thinner water hyacinth fiber for handicrafts. According to 67 % of the interviewees, the proportion of raffia fiber should be increased within the products. Other new possibilities for extra materials such as banana leaves, sisal fiber and rubber were suggested by 34 % of the respondents. Taking into account specific design and quality improvements of the different water hyacinth handicrafts products the following modifications were proposed by the interviewees:

- Hats: flatter, wider brims and improved seams
- Handbags: Incorporate ribbons, zips and frames
- Sandals: rougher and harder soles combined with raffia, sisal and rubber

Considering marketing strategies, the majority of the retailers insist on the implementation of an effective system of order and delivery (43%), the creation of magazines (12%) and special boutiques (5%). The customers recommended strategies such as participation in fairs and market exhibitions (57%) or the use of mass media (e.g.TV, radio) and the internet (37%) for advertisement and selling. The establishment of associations for producers and retailers was mentioned by both groups (6%) as an additional strategy to organize the trade of water hyacinth handicrafts (Tab. 4.4).

Table 4.4: Design and marketing strategies for the water hyacinth handicrafts suggested by the customers (n=50) and the retailers (n=50) in Antananarivo.

		Retailers (n=50)	Customers (=50)
Attributes	**Answers**	**Percentage of respondents**	
Colors	Natural color	34	38
	Green and varnish	33	35
	Others colors	33	27
Fiber size	Thinner	50	50
	Natural size	50	50
Extra materials	Raffia	59	75
	Banana leaves	29	13
	Sisal	7	12
	Rubber	5	-
Marketing strategies	Order and delivery	43	-
	Fair and markets	35	57
	Magazines	12	-
	Special boutique	5	-
	Associations	5	6
	Mass media and internet	-	37

4.5 Discussion

a. Key factors influencing market establishment of water hyacinth handicrafts

This study has shown that despite the longer time investment required for raw material selection and drying (seven days vs. three days) as well as additional financial costs (23% in addition) for ornaments, overall water hyacinth handicrafts displayed many advantages in comparison to papyrus handicrafts. Processing water hyacinth handicrafts (a) was easier and faster (one third less time investment) due to size and flexibility of the material, (b) led to robust products which were rated as being of acceptable to very good quality by 91% of the interviewees, and (c) sold at three times (mean 2.25 US$) the sale prices of the traditional papyrus handicrafts (mean 0.75 US$). These findings reinforce the idea that water hyacinth has a high potential as a substitute for papyrus as raw material for handicrafts at our study site. However, other factors must be considered to determine the best options for the production and marketing of water hyacinth handicrafts. A SWOT analysis (Leigh 2006) was carried out to identify internal (strengths and weaknesses) and external factors (opportunities and threats) which may influence the establishment of a market for water hyacinth handicrafts (Tab. 4.5).

Strengths

The high abundance of water hyacinth at Lake Alaotra (Lammers et al. 2015) insures a widely available source of raw materials for the production of handicrafts. Longer stems are usually collected and processed during the rainy season. However, additional raw material can also be stored for use in the dry season. Water hyacinth is known for its robustness. It combines toughness and flexibility (Keawmanee 2015) and thus offers the possibility for making a larger set of products in comparison to papyrus. From usual handicraft products to furniture (Jafari 2010), water hyacinth products can last up to five years of use (Keawmanee 2015). Additionally, risks during storage and transportation are reduced. The simplicity of the production path is likely the most convincing factor in favor of the production of water hyacinth handicrafts in poor and remote areas such as Andreba Gara (sensu Gunnarsson and Petersen 2007): no machinery or other new technological or chemical inputs were used in this study at any point, from collection of raw material to the final product. Additionally, the ability of artisans to reproduce weaving patterns from handicraft pictures is an advantage for future improvements to handicraft designs.

Weaknesses

The limited access to financial resources combined with the low number of artisans with experience with water hyacinth at Lake Alaotra restricts the production capacity required for larger market scales. However, the availability of financial resources alone does not guarantee the proper running of a business. In Kenya, the Orongo women's group (producer of water hyacinth handicrafts) succeeded to access donor organizations (USAID and Red-Cross) but still suffered from severe difficulties regarding handicrafts design and marketing (Subbo and Moindi 2008). In Brillo Nuevo (Peru), the commercialization of the palm species, Chambira (*Astrocaryum chambira*), as hammocks and bags resulted in very low incomes due to marketing deficiency (Vormisto 2002). According to Millard (1996), knowing how to market the products is far more important than producing them. The lack of managerial and marketing backgrounds in the artisan community in our study area is therefore a limiting factor for promoting water hyacinth handicrafts. Another concern is the lack of the organizational structure of amongst rural artisans. The absence of artisans' association in Andreba Gara hinders interventions and might generate additional initial costs.

Opportunities

The fact that water hyacinth handicrafts are not yet sold on a commercial market in Madagascar represents an enormous marketing opportunity. The uniqueness and high quality of water hyacinth handicrafts have the potential to generate new markets faced with little competition (sensu Millard 1996). The access to microcredit loans in the Alaotra region (e.g. CECAM, Microcred) can help to increase local initiative in producing and marketing water hyacinth handicrafts. Additionally, the economic and ecological advantages of water hyacinth handicrafts as a source of income for local artisans and at the same time a mean to reduce marsh vegetation degradation at Lake Alaotra provide further opportunities to broaden market scope. As a motive for customers to purchase water hyacinth products, an ecolabel can be designed. Apart from regular handicraft markets, a partnership with tourist enterprises (e.g. Maki Company) could be pursued to secure permanent outlets. In the long term, as artisans acquire sufficient knowledge and skills for dealing with export procedures, the products could be commercialized on an international level.

Threats

The poor condition and lack of roads connecting the Alaotra region to other areas in Madagascar is a significant threat for the marketing of water hyacinth handicrafts. Effectively, this situation leads to the oversaturation of the few existing regional handicraft markets and likely reinforces the detrimental influence of handicraft middlemen on prices. Millard (1996) argued that small locality markets become quickly saturated leading to a dramatic decrease of handicraft prices. This threat may be overcome if the area represents an important attraction for tourists, but this is not the case for the Alaotra region where tourists are scarce throughout the year (pers.obs.). However, due to the fact that this area (despite its remoteness) is the biggest rice producer in Madagascar and provides many regions throughout the country with rice (Andrianandrasana et al. 2005), it is feasible that water hyacinth handicrafts could also be exported to those regions. Additionally, the railway company Madarail connects the town of Ambatondrazaka to the Tamatave (the economic capital of Madagascar) twice a week. This option is cheaper and offers the possibility to transport large amounts of products. At the international level, market competition is hard regarding water hyacinth handicrafts.

Table 4.5: SWOT analysis for the establishment of market for water hyacinth handicraft from Lake Alaotra.

Internal factors (product and workforce)

Strengths	Weaknesses
– Raw material availability	– Long time for raw material selection and drying
– Tough and flexible raw material	– Additional costs due to ornaments
– Simple production path	– Limited access to financial resources
– Time efficient raw material processing	– Few experienced artisans
– Wide set of robust products	– Lack of managerial and marketing competences
– Reduced storage and transportation risks	– Limited production capacity
– Good quality rating	– Weak organization of artisans
– Higher sale prices	
– Quick adaption to work standards	

External factors (markets)

Opportunities	Threats
– New markets and segments	– Bad condition of road infrastructures
– New products	– Few regional markets
– Less competition	– Oversaturation of regional markets
– Access to local microcredits	– High bargaining power of middlemen
– Ecolabel	– Climate change
– Partnership opportunities	– International competition
– International markets	– Dilemma conservation vs. profits

This requires the constant creation of new designs, improvement of quality and selling products at competitive prices. Climate change represents another threat for water hyacinth handicraft production. Periods of droughts at Lake Alaotra could impact the growth of water hyacinth (cf. Wilson et al. 2001) and reduce the availability of adequate stems for handicraft production. On a long-term perspective, people at Lake Alaotra might want to maintain or spread water hyacinth stands if the handicrafts are getting higher market values. That will create a dilemma which will likely prioritize profits over conservation goals.

b. Strategic planning for establishing a market for water hyacinth handicrafts at Lake Alaotra

Since the 1980s, international development agencies have acknowledged the contribution of rural handicrafts to poverty alleviation in developing countries (Rogerson 2000). Rural handicrafts provide employment and income (especially for women and the landless), promote skill transfer and offer affordable basic products to the poor. However, artisans suffer from difficulties concerning access to marketing, finance and technology; raw material shortages; a lack of managerial competence and weak institutional support (Rogerson 2000). To tackle those issues, local economic development should focus on creating competitive local business environments, developing networks and partnerships between the public, and private sectors and the local community, facilitating knowledge transfer and education and encouraging investment into the region (Rücker and Trah 2007). Based on our SWOT analysis, a strategic plan entailing four interlinked main steps is proposed to promote the establishment of a water hyacinth handicraft market at Lake Alaotra:

<u>Step1: Creation of artisan associations, clusters and networking</u>

The weakness of Malagasy governmental institutions to efficiently support artisans and the general inexistence of structural organization within rural artisans make it difficult to conduct interventions. Rogerson (2000) argues that in developing countries assistance can usually only be efficient when applied to groups of artisans. Besides, Schmitz (1990) argues that the main problem of African small enterprises is not their size but their isolation. Therefore, the growth of each small enterprise depends on its ability to create clusters which gather several associations or cooperatives of rural artisans generally in close proximity (Dawson 1992; Van Dijk and Rabellotti 1997; Rabellotti 1998). Clusters facilitate information transfer, technology diffusion, learning and imitation effects among small enterprises (Van Dijk and Rabellotti 1997; Nadvi 1998; Rabellotti 1998). Further, they allow artisans to afford business development services, to increase their negotiation power and to reach more powerful market actors (Nadvi

1998; Miehlbradt and McVay 2004). In this way, the establishment of an artisan association in Andreba Gara is needed before building clusters from other villages. In addition to the clusters, networking with experienced artisan associations outside the area as well as supporting institutions and organization are valuable sources of information, finance, experiences and opportunities.

Step 2: Improvement of managerial and marketing competence of artisans

By using associations as a base, a series of workshops and trainings focused on basic management and marketing (product quality and design, adoption of new tools and techniques) can be addressed to improve the capabilities of artisans (sensu Chambers and Conway 1991). As defined by Millard (1996): "Marketing is the process of finding out what customers will buy and then producing, promoting and distributing it at a profit." This consists thus of producing what can be sold instead of trying to sell what has been produced. Besides, final products must be of acceptable design with reasonable quality and sold at competitive prices (Millard 1996). To put these background concepts into practice, drafting a marketing plan and profit-loss and cash flow statements are needed (Millard 1996).

Step 3: Stimulation of finance access

In developing countries, diverse financial structures are necessary to improve rural savings and increase competitiveness on the market (Rogerson 2000). The existence of microcredit loans within our study site was identified as an opportunity within the SWOT analysis. However, Penot et al. (2014) argue that the fear of credit failure hinders microlending in the Alaotra region. Thus, financial support should be provided in the form of donations at least in the beginning of the project. Financial problems experienced by rural artisans are often interlinked with institutional weakness and market instability (FAO 1987). Therefore, in our case building networks is crucial to access finance.

Step 4: Exploration of market possibilities

The geographical isolation of the Alaotra region combined with the low purchasing power of its rural population lead to the oversaturation of regional markets making it difficult to stimulate their economic growth. As a matter of priority, efforts should be directed to reach out to national markets located outside the area (especially in tourist regions) and creating production and storage centers that promote economy of scales at least on a national level. Although limited to a well-defined territory (Trah 2004; Helmsing and Egziabher 2005), local economic development initiatives can profit from globalization (ILO 2006). In that sense, export options must be considered. Exportations offer more benefits but request more effort in communication, planning and preparation (e.g. export permit, product packing and labeling, strict quality control) (Millard 1996). Partnership with fair trade organizations in Madagascar (e.g. Artisan du monde, Tear Craft, Ravinala Italie) can generate more profit compared to the conventional trading channels. In general, rural artisans at Lake Alaotra will need regular information about market expectations and conditions in order to adjust handicrafts design, quality and production to changing market requirements. Collaboration with development organizations working in Madagascar is recommended.

4.6 Conclusion

Although considered as a bane imperiling aquatic life, the environment and human wellbeing alike, water hyacinth offers several opportunities through utilization. The case study of Andreba Gara in Madagascar demonstrates the high potential of water hyacinth handicrafts to improve rural artisans' incomes and simultaneously reduce pressure on the threatened Alaotra wetland. In our study, the water hyacinth handicrafts were more highly rated, required one-third less production time and could be sold at three times the market price of the local papyrus handicrafts. A SWOT analysis identified the simple production process and new markets opportunities as the main factors enhancing the production and commercialization of water hyacinth handicrafts while the lack of marketing competences and weak organization of artisans are potential inhibitors. Knowing how to market handicrafts is far more relevant than the production phase. It is evident that promoting rural handicraft at Lake Alaotra will demand interventions that address cluster and network creation, marketing competences, financial access and market exploration. From this study, a number of recommendations are drawn for the development and success of rural handicrafts in Madagascar but which could be also applicable to other developing countries all over the world.

4.7 Acknowledgements

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4.9 Abbreviations

BAMEX:	Business and Market Expansion Program
CECAM:	Caisse d’Epargne et de Crédit Agricole Mutuels (Agricultural Credits and Savings)
CENAM:	Centre National de l’Artisanat Malgache (National center of Malagasy Handicrafts)
CERAM:	Centre Régional de l’Artisanat Malgache (Regional Center of Malagasy Handicrafts)
CITE:	Centre d'Information Technique et Économique (Economic and Technic Information Center)
ECATCH:	East and Central African Trade Competitiveness Hub
FAO:	Food and Agriculture Organization of the United Nations
FIVMPAMA:	Fivondronan’ny Mpandraharaha Malagasy (Association of Malagasy Entrepreneurs)
IFC:	International Finance Corporation
ILO:	International Labour Organization
MMF:	Madagascar Magic Fingers
MNDC:	Madagascar New Design Council
SWOT:	Strengths, Weaknesses, Opportunities and Threats
USAID:	United States Agency for International Development

Chapter 5

Water hyacinth (*Eichhornia crassipes*) fertilizers - An alternative for agriculture at Lake Alaotra, Madagascar?

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Journal of Rural and Community Development (submitted)

5.1 Abstract

In the context of a global increase of human population coupled with continuous environmental degradation, eco-friendly agricultural innovations are essential to reduce poverty and food insecurity in the world. This is particularly evident in developing countries where nature conservation and agricultural production remain in conflict. We investigated the effectiveness of using a locally free natural resource, the invasive plant species water hyacinth (*Eichhornia crassipes*), as a source for fertilizers (composts, green manure and ash) at Lake Alaotra, one of the most important agricultural areas of Madagascar. In this study, our objective was first to produce water hyacinth fertilizers according to the local conditions and secondly to test if they could substitute or supplement the mineral fertilizer NPK or cow dung locally used in vegetable farming by conducting a growth experiment with Chinese cabbage (*Brassica rapa*, ssp. *chinensis*), a common fast-growing vegetable in the Alaotra region, NE-Madagascar. Our results showed higher biomass gain of Chinese cabbage treated with water hyacinth composts compared with NPK (11%-22%-16%) and cow dung. Water hyacinth green manure and ash showed low performances. Besides, applying composts was cheaper than NPK and cow dung. The higher biomass gain was likely due to an improvement of soil structure after compost addition. Furthermore, recommendations are derived to prevent water hyacinth compost from becoming the next episode in a long history of failed agricultural innovations at Lake Alaotra. The success of such future implementation depends not only on knowledge transfer but must also consider the economic, social and institutional settings ruling the agricultural sector in the target area. This research can provide insights for rural farmers in developing countries facing problem with water hyacinth throughout the world.

***Key words**: Invasive species, Natural resource management, Soil fertility, Agrarian change, Rural development.*

5.2 Introduction

Biodiversity conservation and sustainable land use are a particular challenge in developing countries of the Tropics where most of the worlds' biodiversity is concentrated but undergoes detrimental anthropogenic pressures partly from a prevalent rural population mostly living from the agricultural exploitation of natural resources (Myers et al., 2000; Minten and Barrett, 2008). In Madagascar, a high rate of population growth coupled with a quasi-dependence on natural resources and land for agriculture represents a central problem for biodiversity conservation. Madagascar, one of the most important biodiversity hotspots and one of the poorest countries in the world (rated 155st amongst 185 regarding the Human Development Index and with 75% of the population living under the poverty line), obtains a quarter of its GDP ($5.18 billion) from agriculture that provides employment for 80% of its population (Ganzhorn et al., 2001; Eubanks, 2012; UNDP, 2013). The agriculture is based on shifting cultivation or slash and burn. This practice, when accompanied with the frequent use of fire and short fallow periods, leads to habitat and biodiversity losses coupled with soil degradation and erosion (Vågen et al., 2005; Styger et al., 2007; Thomaz, 2013). Rice is the main staple food and the most cultivated crop in the country (Minten and Barrett, 2008). The Alaotra region is one of the most important agricultural areas of the country and represents the rice granary of the island with 120,000 ha of rice fields (90,000 ha non-irrigated and 30,000 ha irrigated) producing approximately 300,000 tons per year (Copsey et al., 2009; Penot et al., 2014). Apart from rice cultivation, the Alaotra region is also important for other staple foods (cassava (*Manihot esculenta*), maize (*Zea mays*), sweet potatoes (*Ipomoea batatas*) and potatoes (*Solanum tuberosum*)), vegetable crops (tomatoes (*Solanum lycopersicum*), onions (*Allium cepa*), beans (*Phaseolus vulgaris*), cabbages (*Brassica* sp.) and cucurbits (*Cucurbita* sp.)), rent and industrial products (sugarcane (*Saccharum officinarum*), coffee (*Coffea* sp.)) and fruits (banana (*Musa* sp.)) (Penot, 2009). From an ecological standpoint, Lake Alaotra represents the biggest freshwater wetland of Madagascar with 20,000 ha of open water surrounded by 23,000 ha of marsh vegetation sheltering several endemic plants and animal species such as the Alaotran gentle lemur (*Hapalemur alaotrensis*), the only primate worldwide that lives in wetlands (Andrianandrasana et al., 2005; Ralainasolo et al., 2006; Guillera-Arroita et al., 2010). Due to the high demographic pressure and rural poverty coupled with extended soil degradation and high climatic variation (high fluctuation of rainfalls), the local population at Lake Alaotra depends highly on natural resources for securing their subsistence. This creates a chronic conflict between conservation and development goals leading to marsh conversion into rice fields and overexploitation of natural resources (overfishing, overgrazing, and overuse of marsh vegetation) (Bakoariniaina et al., 2006; Copsey et al., 2009).

To solve these complex problems, several agricultural innovations have been attempted in the Alaotra region which mainly focused on rice cultivations (SRI System of Rice Intensification, conservation agriculture, use of special rice varieties) (De Laulanié, 1993; Chabierski et al., 2005; Jenn-Treyer et al., 2007; Rasoamanana et al., 2011; Scopel et al., 2013). However, their successful diffusion failed due several reasons: technical limitations (water control), expensive labour force, costly seeds, requirement of considerable amounts of mineral fertilizers, general preference for rice varieties with long straw used for feeding livestock, long learning process, competition with fodder for livestock and only moderate increase of income and yield compared to conventional agriculture due to the doubling of local fertilizers prices in 2008 (Penot et al., 2012; Penot et al., 2014). In comparison to rice cultivation, vegetable farming has received less attention in the Alaotra region. In this research project, we propose the use of the water hyacinth (*Eichhornia crassipes*), one of the most problematic invasive aquatic plant species at Lake Alaotra (Lammers et al., 2015) as a new source for organic fertilizers, potentially increasing fertilizer use among farmers making their subsistence from vegetable farming. In Madagascar, to our knowledge no attempts have been made so far for using this plant as a source for fertilizers. Secondly, due to the higher amounts of fertilizers needed for the large rice fields in the Alaotra region, we decided to focus this explorative study on small scale agriculture based on vegetables. By converting *E. crassipes* into fertilizer, local farmers could concurrently improve soil quality and thus increase their vegetables yields while attenuating the negative impacts of water hyacinth on the lake and local livelihoods. Globally, belonging to the 10 most troublesome aquatic weeds, the water hyacinth has been already successfully used as compost and green manure in China, Indonesia, India, Malaysia, Bangladesh, Sri Lanka, Thailand, Philippines and in some African countries such as Kenya and Nigeria (Gunnarsson and Petersen, 2007; Jafari, 2010; Ndimele, 2011; Patel, 2012). It has been proved to improve soil structure and soil nutrient contents and the compost is quickly ready for use within one month (Polprasert et al., 1980; Gunnarsson and Petersen, 2007). Despite these advantages, the intensive workload (harvesting of plants, transportation and production of compost) required for its production is often a hindrance for the adoption of compost use (Gunnarsson and Petersen, 2007). Water hyacinth green manure and ashes represent other alternatives with less workload (Gunnarsson and Petersen, 2007).

The main goal of this study was first to test if water hyacinth fertilizers could be produced in the poor and remote Alaotra region; and if they can substitute or complement chemical fertilizers (NPK) and cow dung in vegetable farming according to the local conditions (i.e. raw materials, tools, labour force, financial costs and time consumption). NPK is known as one of the best agricultural intensification fertilizers in the region. Despite the doubling of prices in 2008 (Penot et al., 2012), we have recently observed in the field that NPK is still currently on sale in local farm supply stores and is used in vegetable farming although in reduced fashion in the Alaotra region. Within this research, we evaluated five different methods of producing organic fertilizers based on water hyacinth (aerobic, anaerobic and pit compost, ashes and green manure). In order to identify which water hyacinth fertilizer is best suited to replace or complement NPK and cow dung, a growth experiment was conducted using Chinese cabbage (*Brassica rapa*, ssp. *chinensis*), a fast growing and commonly used vegetable in the region.

5.3 Methods

a. Study site

The research was conducted in the Alaotra region at the end of the rainy season (March-April) 2014. The regional climate is characterized by two seasons: a rainy season from December to April and a dry season from May to November. Annual precipitation ranges from 1092 to 1200 mm. Mean monthly temperatures vary from 11.0 °C in July to 28.4 °C in January (Ferry et al., 2009). In the beginning of the field study, soil samples from three areas around Lake Alaotra were collected in regard to the different level of ecosystem degradation for evaluating the physico-chemical properties of the agricultural soils for vegetable farming: Vohimarina (low level of degradation, northern side of Lake Alaotra), Andreba Gara (intermediate level of degradation, eastern side of the lake) and Anororo (high level of degradation, western side of the lake; Fig 5.1). The criteria for the level of degradation are developed in Lammers et al. (2015) and used as reference for a larger project called AMBio (Alaotra Marshland Biodiversity) entailing the current research. For the production of water hyacinth fertilizers (composts, green manure and ashes) and growth experiments, the region of intermediate level of degradation, Andreba Gara was selected due to its proximity to the lakeshore covered at app. 24% by water hyacinth (Lammers et al., 2015; Fig. 1). Andreba Gara has a population of approximately 4830 inhabitants, 70% of whom are under 17 years old. Fishing and agriculture are the main sources of income (Head of Andreba Gara village, pers.comm.) and daily salaries range from 2.5 US$ to 5 US$ (Rakotoarisoa et al., 2015). Besides the low standards of living, the infrastructure of the region is also weak: there is no permanent electricity and the roads connecting this area to the outside world are few and in bad condition.

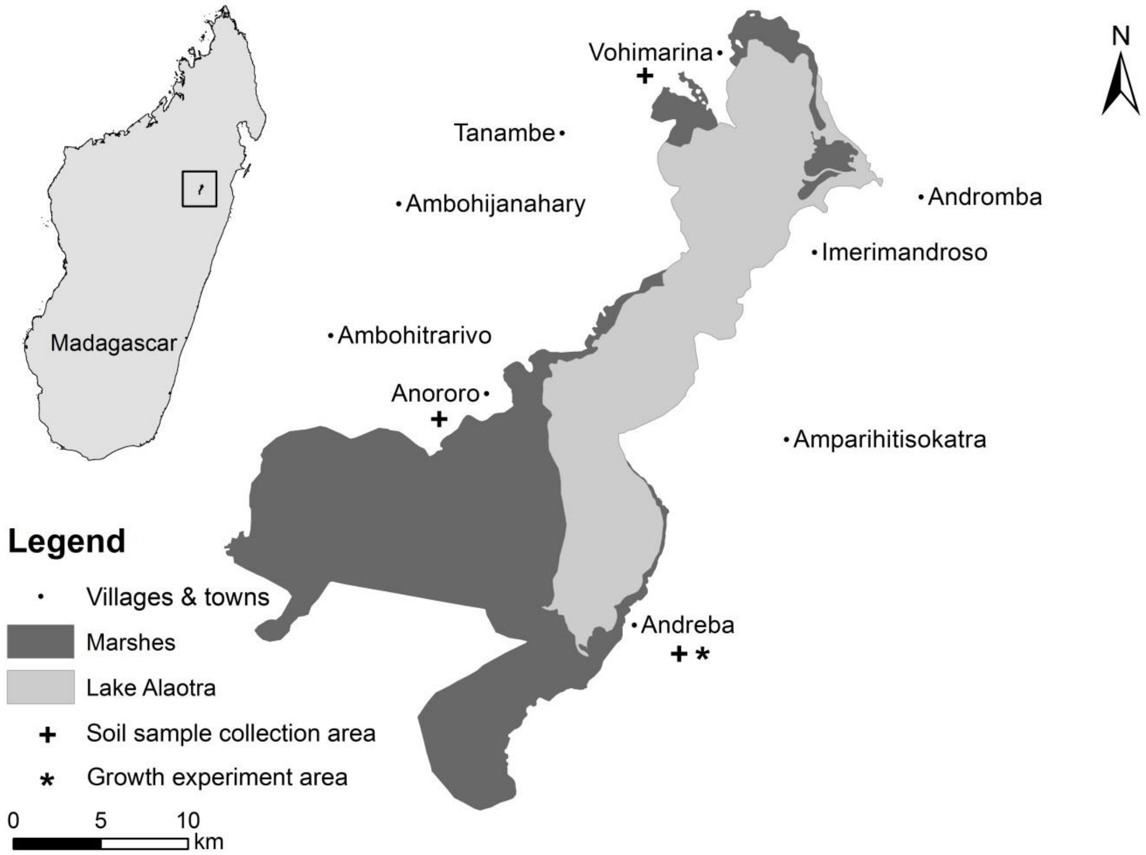

Figure 5.1: Map showing the Alaotra region, the three locations where soil samples were collected and the village of Andreba Gara where the growth experiment with Chinese cabbage was conducted in the end of the rain season (March-April 2014).

b. Degradation status of agricultural soils at Lake Alaotra

In order to assess the physico-chemical properties of the vegetables fields at Lake Alaotra, soil samples were collected from Andreba Gara (n=2) and two further localities: Anororo (western part of the lake, n=2) and Vohimarina (northern part of the lake, n=2). The samples were collected within vegetable fields located between the village and the lakeshore. The humidity (%), pH, macroelement contents (organic carbon (C, %), nitrogen (N, %), plant available phosphorus (P, ppm, Bray II), potassium (K, méq/100g), microelement contents (calcium (Ca), magnesium (Mg), natrium (Na) (még/100g)) and texture were measured. Besides, the soil fertility was assessed using CEC (Cation Exchange Capacity) by measuring the amount of colloids in the soil and the CEC of each of these colloids using buffered method using NH_4^+(at pH=7). All these soil analyses were performed by the Laboratory of Pedology (FOFIFA in Antananarivo, Madagascar).

c. Production of water hyacinth fertilizers

For evaluating which water hyacinth fertilizer can be processed under the local conditions present at Lake Alaotra (i.e. raw materials, tools, labour force and time consumption), we produced five different types of inputs: green manure, ashes and three different types of compost. For all fertilizers, fresh plants of water hyacinth were collected at the shore of Lake Alaotra and transported with zebu carts into Camp Bandro (a local ecotouristic camp offering a fenced off and undisturbed area for the experiments). Afterwards, the roots were removed since water hyacinth accumulates heavy metals (when present) mostly in these organs (Matindi et al., 2014). The preparation of all the fertilizers was based on the methods described by Lindsey and Hirt (1999). For green manure, shoots were chopped and sundried for one week prior to incorporation into the soil. For ash production, water hyacinth was sun-dried and burnt thereafter. For the composts, fresh water hyacinth was chopped into 2 cm pieces to speed up the decomposition process. The composts were produced under three different conditions: (i) aerobic conditions (after installing branches at the base of the pile), (ii) anaerobic conditions (using plastic sheets to cover the pile) and (iii) in a pit in the ground. For compost preparation a sequence of three layers was used: cow dung and soil to supply micro-organism for decomposition (5 cm), chopped water hyacinth (20 cm) and mango (*Mangifera indica* L.) leaves to increase N and the amount of compost in general (5 cm). The layered pile was then watered and layering repeated until the pile was up to 1.5 m. Subsequently, composts were watered every two days and turned onto new base every two weeks until composting had turned the substrates into a crumbly dark mass after one month (Polprasert et al., 1980).

d. Growth experiment with Chinese cabbage

In order to test which water hyacinth fertilizer was most efficient in enhancing plant growth at Lake Alaotra and to what degree water hyacinth substrates can potentially replace or supplement NPK and cow dung, we conducted a growth experiment using Chinese cabbage. Chinese cabbage is a common vegetable in the region and particularly suitable as a test crop given its fast growth. Cabbage plants were raised in a nursery for 18 days before transplantation into experimental pots. Local soil was used in order to simulate the soil conditions under which farmers cultivate crops in the region. Because the soil was very compact and dry, it was grounded and watered before planting the cabbage. The growth experiment consisted of eight treatments with 12 repetitions per treatment : (i) a control (4,5 kg of local soil per pot), (ii) aerobic compost of water hyacinth (3 kg soil + 1,5 kg compost), (iii) anaerobic compost of water hyacinth (3 kg soil + 1,5 kg compost), (iv) compost of water hyacinth in a pit (3 kg soil + 1,5 kg compost), (v) green manure of water hyacinth (4,5 kg soil + 76 g of fresh water hyacinth pieces), (vi) ash of water hyacinth (4,5 kg soil + 2,54 g ash), (vii) cow dung (3 kg soil + 1,5 kg cow dung) and (viii) NPK (4,5 kg soil + 2,25 g NPK) (Gajalakshmi and Abbasi, 2002). Plants were watered daily with 800 ml lake water (0.04 mg/L NO_2^-, 2.04 mg/L NO_3^-, 1.18mg/L $PO4_3^-$) (Lammers et al. 2015) as common in the region at 6 am to avoid quick evaporation. The pots were randomly arranged every three days to avoid effects of possible differences in exposure to sunlight. 30 days after cabbage transplanting, all plants were measured, harvested and separated into leaves, stems and roots. To calculate biomass production, all plant parts were first sun dried in the field and later in an oven at 40 °C for four days to constant weight. Images of fresh leaves were taken in the field before sun drying and leaf area (LA, cm^2) was measured by using image J (public domaine software, https://imagej.nih.gov/ij/download.html). Growth rate (cm/day) was obtained by dividing the difference of the plant final length (before the harvest) and the plant initial length (after transplantation) by the number of growth days. Root to shoot ratio (R/S) was calculated as was Specific Leaf Area (SLA, in cm^2/g, calculated by dividing the leaf area with the leaf biomass for all individuals). Leaf Weight Ratio (LWR) was obtained by dividing total leaf biomass by the total biomass. In addition, leaf total N content (LTN, mg/g) was measured for each Chinese cabbage individual (by mixing the dried leaves before taking a sample for the measurement) (n=96) from C/N elemental analysis using an automated C and N analyser (Heraeus Elementar Vario EL, Hanau, Germany).

e. Analysis of plant nutrients and heavy metals concentrations of soil and fertilizers used for the plant growth experiment

The soil used for the growth experiment was collected in Andreba Gara within the same zone (from vegetable fields between lakeshore and village) but not at the same location as the soil samples for laboratory analysis. Macronutrient contents (total N, total P and K) (n=16) were determined for all fertilizers and the soil using photometric methods (DIN EN 16169:2012-11, determination of Kjeldahl nitrogen for total N, DIN ISO 11263:1996-12, spectrometric determination of phosphorus soluble in sodium hydrogen carbonate solution for total P and JIS K 0809:2008-07-20, determination of total potassium). In addition, pH measurements (n=12) were performed for all treatments (1:2 with 25 ml 0.01 $CaCl_2$). Soil texture was determined to assess soil drainage (Sponagel et al., 2005). To avoid incidental heavy metal contamination of the soil and the vegetables by using water hyacinth, we analysed concentrations of the most common heavy metals (Pb, Cd, Zn, Cu, Cr and Ni) for the soil and water hyacinth samples (n=36) from different parts of the lake (Andreba Gara, Anororo and Vohimarina) by Atomic Absorption Spectroscopy (DIN EN ISO 11885, Calibration method DIN 32645, NLWKN Hildesheim, Germany).

f. Raw material and transportation costs for the different fertilizers

To compare the total use costs of the different type of fertilizers, the cost of raw materials, labor force and transportation were recorded. The comparison of raw material and transportation costs of the different fertilizers were based on their application rate per hectare found in the literature.

g. Data analysis

The Shapiro-Wilk test revealed non-normal distribution of our data. The Kruskal-Wallis test and Mann-Whitney U test (with Bonferroni correction) were used to determine statistical differences between the treatments.

5.4 Results

a. Soil physico-chemical properties in the Alaotra region

Three soil types were identified depending on the sampling location: loamy sand (Anororo), sandy loam (Vohimarina) and sandy clay loam (Andreba) (Sponagel et al., 2005, Table 5.1). Soil humidity varied from 7.9% to 36.9% and decreased with increasing sand content. Generally, soils were acidic (pH 3.4 to 5.4). Nutrient concentrations were low in Anororo compared with those of Andreba and Vohimarina. Except for C and N contents, soil samples from Andreba contained higher nutrient concentrations compared with samples from Vohimarina. In contrast, the CEC was highest for soil in Vohimarina compared with the soils from Andreba and Anororo.

Table 5.1: Physico-chemical properties of soils at three locations around Lake Alaotra, northeastern Madagascar. Data show means of two samples at each site.

	Clay (%)	**Silt (%)**	**Sand (%)**	**Type of soils**	**Humidity (%)**	**pH**	**C (%)**	**N (%)**	**P (ppm)**	**Ca**	**Mg**	**K (méq/ 100g)**	**Na**	**CEC**
Vohimarina	15	15	71	Sandy loam	21.9	5.45	8.79	0.63	10.9	6	3.5	0.24	0.87	80.7
Anororo	11	3	87	Loamy sand	7.9	3.45	0.42	0.04	3.3	2.2	1.5	0.05	0.65	15.1
Andreba	23	25	53	Sandy clay loam	36.9	4.82	2.29	0.21	26.9	12	9.6	2.18	3.39	34

Means of Clay (%, n=6), Silt (%, n=6) and Sand (%, n=6), humidity (%, n=6), pH (n=6), Carbon content (%, n=6), Nitrogen content (%, n=6), Phosphorus (ppm, n=6), Calcium, Magnesium, Potassium, Natrium and Cation Exchange Capacity (méq/100g) are shown for soil samples collected in Vohimarina, Anororo and Andreba.

b. Nutrient concentrations and parameters of soil and fertilizers used for the cabbage experiment

Macronutrient analyses revealed that the soil used for the experiment was very poor in nutrients (Table 5.2). Additionally, soil texture analyses showed a high clay content which classifies the soil as weakly sandy (45% <clay< 65%, 0% <silt< 15%, 0% <sand< 10%, Sponagel et al., 2005). Wilted leaves and very low water percolation were observed frequently and are seen as indicators for water stress. Symptoms of water stress were noticed for all treatments except for the pots treated with composts. The pH of the soil (control) and the composts were near neutral with a mean value of 6.57, whereas it was higher (slightly alkaline) for cow dung, green manure and ash (mean 7.8). NPK showed a strongly acidic pH (mean 4.8). Regarding the macronutrient contents, NPK had the highest concentration of total N and total P. K content was highest for the ash. Aerobic compost had higher macronutrient concentrations than pit and anaerobic composts. Green manure had lower macronutrient concentrations than composts but higher ones than cow dung.

Table 5.2: Comparison of macronutrient concentrations and pH of soil and different fertilizers used for a growth experiment with Chinese cabbage at Lake Alaotra, northeastern Madagascar. Data show means of two samples per treatment.

Treatments	N (%)	P (%)	K (%)	pH
Soil	0.00005	0.00005	0.0005	6.42
Cow dung	0.35	0.09	0.21	7.93
NPK	22	4.84	11.62	4.8
Ash	0.00005	0.00005	23.24	7.92
Green manure	1.29	1.78	1.85	7.8
Aerobic compost	1.99	2.95	2.51	6.26
Anaerobic compost	1.53	1.85	2.34	6.9
Compost in a pit	1.79	2.57	2.36	6.56

c. Application rate and costs of water hyacinth fertilizers, NPK and cow dung

The results show that independently from the crops a higher amount of compost and cow dung would be needed per hectare when compared with green manure, ash and NPK (Table 3). Based on the application rate for one hectare of field, cow dung was the most expensive fertilizer (100 US$ per hectare), followed by NPK (67 US$ per hectare) and compost (20 US$ per hectare) when regarding the raw materials only. Around 2 tons of cow dung is needed to produce 10 tons of compost while the mango leaves can be collected for free. Green manure and ash were made exclusively out of water hyacinth which reduces the costs to transportation only. Local farmers said they would collect the raw materials (mango leaves and water hyacinth) themselves without hiring labour force. However, in case they had to hire people, collecting 10 tons of water hyacinth needs in total 3 whole days and 3 men (1.5 US$ per person per day). Collecting mango leaves near the village would take only half a day and could be performed by family members. The transportation cost in the Alaotra region is estimated at app. 3.2 US$ per ton. The cost allocated to the transportation of each fertilizer type depends thus on their respective application rate per hectare. In general, total costs were higher for cow dung, similar for NPK and compost (if farmers had to hire labor force for collecting raw materials) and lower for green manure and ash (Table 5.3).

Table 5.3: Application rate and costs of the different fertilizers used for the growth experiment with Chinese cabbage at Lake Alaotra.

Type of fertilizer	Application per hectare* (tons)	Costs per hectare (US$)			
		Labor	Raw material	Transportation	Total
NPK	0.1	0	67	0.32	67.32
Cow dung	10	13.5	100	33	145.5
Green manure	3	4.5	0	10	14.5
Compost	10	13.5	20	33	65.5
Ash	2	4	0	7	11

* Retrieved from Lindsey and Hirt (1999); Gajalakshmi and Abbasi (2002); Gunnarsson and Petersen (2007).

d. Biomass production of Chinese cabbage

The results showed that the highest biomass production was achieved when the plants where grown with the water hyacinth composts (Fig. 5.2). No significant difference was recorded between the total dry weight productions of Chinese cabbage grown with the three compost types. Following the performance of the composts, the Chinese cabbage grown with NPK showed higher total dry weight although there were no statistically differences between the NPK and the remaining treatments. Plants that were fertilized with green manure, ash and cow dung showed a very limited growth and presented only very low biomass compared to the control and the other treatments.

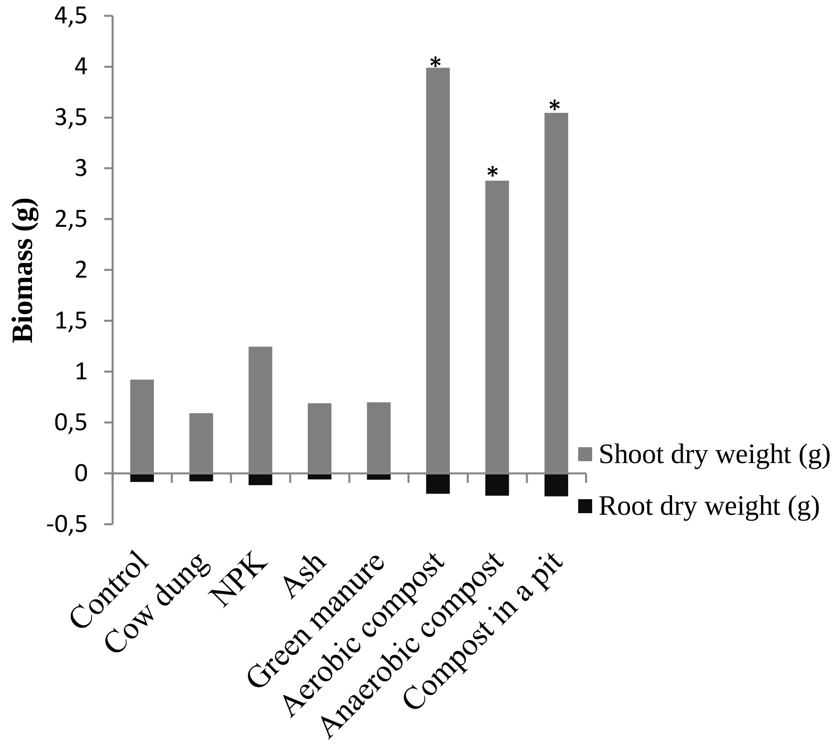

Figure 5.2: Means of shoot biomass and root biomass for Chinese cabbage grown with water hyacinth and locally used fertilizers. Asterisks show significant mean difference at $p < 0.05$ using the Kruskal-Wallis test.

e. Growth analysis of Chinese cabbage

Treatments mainly affected leaf growth of Chinese cabbage. Growth rate was significantly higher for plants that were grown in the compost in a pit and lowest for plants treated with cow dung. Plants grown within the other treatments showed no significant differences in growth rate (Table 5.4).

Similarly, to total biomass production, highest leaf area was observed in plants treated with the different water hyacinth composts. The increase in leaf area was due to enhanced number and surface of leaves. Plants grown with composts had more and larger leaves. In contrast, plants treated with cow dung, green manure, ash and NPK developed only few and small leaves which explain low leaf area and biomass production. Interestingly, total biomass and leaf area did not follow the trends of the growth rate.

SLA was significantly lower for the plants grown with aerobic compost and higher for the ones grown with the water hyacinth ash. Plants grown within the other treatments showed no significant differences in SLA. The low SLA for the plants grown with aerobic compost shows that those plants have thicker leaves. Combined with the high leaf area recorded for those plants, the low SLA explains the measured high total biomass. In contrast, the high SLA of plants treated with the ash reflected that they had thinner leaves.

Root to shoot ratio was significantly lower for plants treated with aerobic compost and higher for those treated with cow dung. Plants grown within the other treatments showed no significant differences in root to shoot ratio. The lower root to shoot ratio for the plant treated with aerobic compost may indicate a better access to water and nutrients which is confirmed by the better shoot development for those plants.

LWR was significantly higher for plants treated with aerobic compost whereas the lowest values were recorded for the ones grown with cow dung treatment. Plants grown with aerobic compost had thus heavier leaves than the one grown with cow dung. Plants grown with the other treatments showed no significant differences in LWR.

LTN content was relatively higher for the plants grown with the three composts but no evidence of statistical significant differences was detected amongst all the treatments.

In conclusion, plants grown with composts (especially with aerobic compost) exhibited better growth (thick, large, numerous and heavy leaves) whereas the remaining treatments (especially when grown with cow dung and ash) displayed poor growth (thin, small, few and light leaves).

Table 5.4: Comparisons of different plant traits for Chinese cabbage along different treatments at Lake Alaotra, northeastern Madagascar. Data show means and standard errors of twelve samples per treatment. Asterisks show significant mean difference at $p < 0.05$ using the Kruskal-Wallis test.

Treatments	GR (cm/day)	LA (cm^2)	SLA (cm^2/g)	R/S	LWR	LTN (mg/g)
Control	0.31 ± 0.02	358 ± 24.2	379 ± 43.8	0.086 ± 0.01	0.844 ± 0.07	25.4 ± 1,2
Cow dung	0.18* ± 0.02	233 ± 34.7	396 ± 38.8	0.13* ± 0.01	0.807* ± 0.07	28.4 ± 1,5
NPK	0.36 ± 0.03	553 ± 50	477 ± 28.8	0.095 ± 0.01	0.913 ± 0.01	26.5 ± 1,09
Ash	0.22 ± 0.03	347 ± 29	616* ± 12.4	0.088 ± 0.01	0.933 ± 0.01	27.7 ± 1,2
Green manure	0.19 ± 0.05	282 ± 36.8	411 ± 32.6	0.097 ± 0.01	0.912 ± 0.009	27.6 ± 1,4
Aerobic c.	0.33 ± 0.01	1376* ± 94.9	348* ± 13.9	0.047* ± 0.004	0.955* ± 0.004	28.4 ± 2,07
Anaerobic c.	0.34 ± 0.02	1129* ± 46.3	395 ± 14.5	0.076 ± 0.006	0.929 ± 0.005	31.5 ± 3.8
Pit c.	0,43* ± 0.02	1306* ± 96.3	383 ± 27.3	0.066 ± 0.007	0.938 ± 0.006	30.5 ± 1.9

f. Heavy metal concentrations in water hyacinth and local soil

Our results show that water hyacinth contained far less heavy metals than the maximum safe values (Amlinger, 2004) regarding compost quality standards (Table 5.5). As the heavy metal concentrations were very low, no further analysis was made with the fertilizers made from the plant material. Therefore, eventual higher heavy metal contents in water hyacinth compost would come from the local soil but not from the plant.

Table 5.5: Means of heavy metal concentrations in water hyacinth (n=23) and local soil (n=23) at Lake Alaotra.

Heavy metal (mg/Kg)	Water hyacinth	Local soil	Compost quality standards*
Cd	< 0.001	< 0.001	1
Ni	< 5	80	60
Cr	< 5	147	70
Pb	< 5	25.5	120
Cu	17	125	150
Zn	26	170	500

* Retrieved from Amlinger (2004)

5.5 Discussion

This study demonstrated that it is possible to produce different water hyacinth fertilizers under the local conditions (i.e. no electricity, no high technology machine and no infrastructure) encountered in the Alaotra region. Further, the results of the growth experiment with Chinese cabbage displayed higher biomass gain of treatments with water hyacinth composts compared to the other water hyacinth (green manure and ash) and locally used fertilizers (NPK and cow dung). Therefore, it can be concluded that water hyacinth composts are suitable for improving vegetable field soil structure and fertility and further have the potential to substitute or complement NPK and cow dung in the Alaotra region. The lack of facilities (laboratory, materials, electricity) did not allow us to conduct preliminary nutrient analyses of the different fertilizers when designing the growth experiment. This is a common problem in the Tropics where often mass balance is used for that reason instead of nutrient balance (e.g., Sarwar et al., 2007; Chukuwka and Omotayo 2009, Sanni and Adesina 2012). Similarly, to those studies, the current research focused mainly on biomass gains. However, it is important to mention that the usage of mass balance has limitations which need to be considered.

a. Agricultural soils in the Alaotra region: problems and alternatives

According to our results, agricultural soils in the Alaotra region show signs of degradation. Generally, the observed soil texture and acidity might affect the soil fertility and plant nutrients availability negatively: the high proportion of sand and the low pH of the soil in Anororo reduced the soil water holding capacity (soil humidity). Additionally, the low pH (3.45) could explain the low amount of soil nutrients fixed by humus and clay. Effectively, the low organic carbon content (0.42%) might reflect the low humus content and the low proportion of clay (11%) might be mainly formed with 1:1-type silicate clays (having less negative charges) common in weathered and acidic soil in the Tropics (Brady and Weil, 2008). Another sign of degradation is also the very low plant available phosphorus. In conclusion, the low humus and clay contents could explain the low CEC value and therefore the lower fertility of soil in Anororo.

The CEC (80.7) in Vohimarina is far higher than the total of nutrient contents measured (Ca, Mg, K and Na). Since buffered methods were used to determine CEC and that pH of native soil (5.45) is lower that buffer solution pH (7), the higher value of CEC in Vohimarina must mainly come from the higher amount of pH-dependent negative charges likely associated predominantly with humus, here reflected by the higher organic carbon content (Brady and Weil, 2008). In Andreba, the value of CEC is closer to the amount of total nutrient contents. This reflects a lower amount of pH-depending negative charges (compared to Vohimarina) which could be due to a lower humus content reflected by the lower organic carbon content.

Interestingly, while NPK and cow dung could supply nutrients (but not on a sufficient basis) to the poor soils in the Alaotra region, their use may contribute to accelerated soil acidification. Overall, a soil pH ranging from 5.5 to 7 should allow a satisfactory nutrient availability to plants (Brady and Weil, 2008). Repeated amendments providing carbonate, hydroxide or silicate or gypsum is thus needed to increase the acidic soil pH in the Alaotra region. More efficiently, the supply of organic matter such as water hyacinth composts can simultaneously increase the soil pH and nutrient contents while improving soil structure (Brady and Weil, 2008).

Management alternatives are suggested depending on the state of degradation of vegetable fields within the three villages (Table 5.6). Due to its high content in sand particles (87%), the soil in Anororo requires several treatments before being suitable for agriculture. Firstly, clay should be added to the soil to enhance its nutrient and water retention capacity (Noble et al., 2004). Afterwards, the nutrient cycle could be closed by applying water hyacinth compost and mineral fertilizers, reducing tillage, using leguminous plants for catching atmospheric N and retaining crop residues (Bell and Seng, 2004). For the soil in Andreba Gara, revegetation of the hillsides should become a priority to reduce soil erosion and embankment of fields downstream while mineral fertilizers and water hyacinth compost could supply nutrient and improve soil structure. Due to its relatively high content of sand (71%), clay application might be needed for the soil in Vohimarina. Depending on the case, water hyacinth compost could be applied there to improve soil structure and fertility.

Table 5.6: Nature of soil, ecosystem degradation and soil restoration alternatives for the three villages around Lake Alaotra.

Villages	Soil type	Ecosystem degradation	Restoration measures
Anororo	Loamy sand	High	Clay application Water hyacinth compost Mineral fertilizers Leguminous plants Reducing tillage Retaining crop residues
Andreba Gara	Sandy clay loam	Middle	Water hyacinth compost Mineral fertilizers
Vohimarina	Sandy loam	Low	Clay application Water hyacinth compost Retaining crop residues

The absence of irrigation schemes in upland and non-irrigated lowlands and the effects of climatic variation leading to an unpredictable succession of extreme inundation and drought, both harmful for crops, are threatening the agriculture outside the irrigated zones in the Alaotra region. Therefore, stabilizing the gullies on the hillsides of the Alaotra must be a priority to keep the non-irrigated agricultural fields and the lake safe from embankments.

In order to draft a wider and practical application of water hyacinth fertilizers for the whole Alaotra region, the different topographic sequences (Rahajaharitompo, 2004; Penot, 2009) were described regarding the soil physicochemical properties, their usages, potentialities and problems and finally the type of suitable fertilization (Table 5.7). The sequence starts form the hilltop to the marshes in the shore of Lake Alaotra. Due to their high degree of degradation, the acidic ferrallitic soils in the summit plateau, slope land and piedmont require the application of water hyacinth fertilizers combined with mineral fertilizers (Phosphate fertilizers, NPK, Urea) and calcium phosphate amendment to reduce the soil acidity and boost sustainably the productivity. Depending on the type of soils, these three zones could be only suitable for fodder production, tree plantation, or low nutrients adapted crops (cassava, corn). In contrast, the fertile alluvial soils (in particular the *baiboho*) in the Alaotra offer more agricultural alternatives by including fruit trees and market gardening. For these zones the usage of water hyacinth fertilizers might not always be indispensable. Similarly, to the ferrallitic soils, the drained rice fields in the Alaotra could be fertilized with a mixture of water hyacinth and mineral fertilizers due to their medium state of degradation. However, the high degree of degradation of the undrained rice fields would require exclusively organic fertilizers such as water hyacinth compost and long periods of fallow land for accumulating organic materials. Despites their low aeration, the organic and hydromorphic soils in the Alaotra marshes are generally adapted to rice cultivation. Rice has the ability to provide oxygen to the roots from leaves and stems (Kirk, 2003). However, the application of organic fertilizers such as water hyacinth compost might be necessary to reactivate the biological activity in these soils and might be combined with calcium phosphate amendment to reduce the soil acidity.

Table 5.7: Type and properties of soils and alternative measures for soils restoration using water hyacinth compost along the topographic sequence in the Alaotra region.

Topographic sequence	Soil	Soil pH	Fertility	Current usage	Current crops or vegetation	Potentiality	Problems	Compost application
Summit plateau	Ferrallitic soils	4 to 6	Poor to middle	Grazing	No crops, Grass species, Tree species (*Eucalyptus* sp.), Ferns	Rice, Corn Peanuts, Cassava	Sensitive soils, Low water retention	Mixture with mineral fertilizers (Phosphate fertilizers, NPK, Urea) and calcium phosphate amendment
Slope land	Ferrallitic soils	4 to 5	Poor	Not used	No crops, Grass species, Tree species (*Eucalyptus* sp.)	Fodder production, Tree plantation	Slope, Very eroded soil	Mixture with mineral fertilizers (Urea) and calcium phosphate amendment
Piedmont	Ferrallitic soils	4.5 to 5	Poor to middle	Agriculture	Corn, Cassava	Corn, Cassava	Very sensitive to erosion, Low water retention	Mixture with mineral fertilizers and cover plants
Village zone	Alluvial soils	n.a.	Good	Agriculture	Fruit trees (banana, mangoes and citrus fruit), Rare market gardening	Market gardening, Fruit trees, Rice, Corn	n.a.	Mixture with mineral fertilizers or no fertilization depending on the case
Alluvial zone	Alluvial soils	n.a.	Good to very good	Agriculture	Market gardening, Fruit trees	Market gardening Fruit trees Rice, Corn	n.a.	Mixture with mineral fertilizers or no fertilization depending on the case
Drained rice fields	Loamy sandy soils	n.a.	Middle to good	Agriculture	Rice	Rice Market Gardening	n.a.	Mixture with mineral fertilizer (NPK)

Topographic sequence	**Soil**	**Soil pH**	**Fertility**	**Current usage**	**Current crops or vegetation**	**Potentiality**	**Problems**	**Compost application**
Undrained rice fields	Sandy soil	n.a.	Poor	Agriculture	Rice	Rice	No clay-humic Complex	Water hyacinth fertilizer and fallow land
Marsh soil	Organic and Hydromorphic soils	Acidic	Poor	Agriculture	Rice	Rice	Low aeration, Low release of nutrients, Floods	Mixture with calcium phosphate amendment and soil aeration

Modified from Rahajaharitompo (2004) and Penot (2009).

b. Relevance of water hyacinth composts use at Lake Alaotra

Although green manure and ash seem generally more attractive considering their low degree of investment and complexity, they showed poor performances in Chinese cabbage yields compared to water hyacinth compost. Promoting water hyacinth compost is a practical and efficient method to improve soil structure and nutrient contents while reducing the harmful ecological and socioeconomic impacts of this invasive plant in the Alaotra region. In contrast to NPK, the compost can retain the nutrient in the soil avoiding therefore the eutrophication of the Lake Alaotra due to nutrients entry (Polprasert et al., 1980). Besides, it can increase the soil resistance to erosion, suppress plant diseases and improve the soil fertility and its water holding capacity (Eklund, 1996; Gunnarsson and Petersen, 2007). Further, the low concentration of heavy metals in water hyacinth supports its suitability as source for fertilizers in the region.

Taking into account the different barriers hindering agricultural innovations at Lake Alaotra, in general low cost, simple, low time consuming and cost-effective innovations seem to hold better chances to be accepted and adopted by the farmers (Penot et al., 2014). The water hyacinth compost fits to these criteria: At Lake Alaotra, the invasive water hyacinth is an abundant and free-floating plant that can be directly processed into compost next to the lakeshore. Gunnarsson and Petersen (2007) considered the use of water hyacinth as compost as the best way for reducing costs since it can be performed during the rainy season next to the area where the plant is harvested and thus reducing transportation efforts. Besides, the additional inputs (cow dung and mango leaves) needed for composting were locally available and the whole process did not require any sophisticated equipment or technology. Further, the results of this study displayed that applying compost was cheaper than using NPK (if farmers collects raw material themselves) and cow dung. The relatively short time required for the compost maturation (1 month) could be an important driver for its acceptance. The urgency of providing for the immediate needs of the families induces a general short-term time horizons within farmers in poor countries (Pannell et al., 2014). Finally, including water hyacinth composts in conservation agriculture at Lake Alaotra could relaunch its diffusion. The moderate increase of income and yield by conservation agriculture could be improved by a reasonable intensification consisting of combining water hyacinth compost with mineral fertilizers (Urea, NPK) leading to a significantly and sustainably improvement the productivity (Penot et al., 2014). Considering its simplicity, low costs and high production speed and productivity, water hyacinth compost would appear to be likely attractive for local farmers at Lake Alaotra.

c. Central factors influencing Chinese cabbage growth

Photosynthetic efficiency affects plant growth and is influenced by radiation use efficiency, water use efficiency and nitrogen use efficiency (Badger, 2013). In our case, the first two parameters (light and water supply) were controlled allowing over a first phase the use of N supply as central factors for explaining the results. Knops and Reinhart (2000) found out that the increase of N input implies an increase of plant biomass. This was not the case for this study. On the one hand, high N content of NPK (which is directly available for cabbage) did not lead to higher biomass gain. One the other hand, higher biomass gains were measured with plants treated with water hyacinth composts having lower N contents than NPK. These observations could allow deducing that the biomass production of Chinese cabbage might not have been influenced by the macronutrient contents of the different fertilizers. Instead, the improvement of soil structure by water hyacinth composts might offer a better explanation for high biomass gain of Chinese cabbage treated with them.

Clay rich soils have poor aeration and drainage retaining tightly water and hindering water supply for the plants (Leeper and Uren, 1993). In our study, positive influences of the water hyacinth composts on the structure of the local clay rich soil used for the growth experiment were shown by the better water percolation after watering the Chinese cabbage. This infers that the soil structure improvement by the composts might provide a better explanation for the increased biomass production than the macronutrient contents of the fertilizers. Effectively, composts could improve soil structure and nutrient availability (Carpenter-Boggs et al., 2000). Additionally, the significantly higher root biomass of Chinese cabbage treated with composts might be a sign of a better soil structure within these treatments which in turn fosters a better access to water and nutrients for the plants. Therefore, the unexpected low agronomic performances of the remaining tested fertilizers might be the result of an unreduced water stress experienced by Chinese cabbage due to the clay rich soil composition that might have reduced subsequently water percolation and plant nutrient uptake. The observed withered leaves of Chinese cabbage might have been a sign of water stress. The strong acidic pH of NPK (4.8) is undoubtedly harmful for the soil since it hinders soil microbial activities (Singh and Kalamdhad, 2013).

d. Strategies for implementing the use of water hyacinth fertilizers in the Alaotra region

The success of the diffusion of water hyacinth fertilizers will require efforts on capacity building, creation of demonstration plots and interested farmers groups to share, exchange and spread knowledge and information (Wall, 2007). On a large scale, the success of the implementation of agricultural innovations must include not only knowledge transfer but also taking into account the economic, social and institutional settings characterizing the targeted region (Klerkx et al., 2012). This is important for the Alaotra region where poor farmers constantly struggle with land availability and demographic pressures, market instabilities and environmental problems. Since the relatively short time (1 month) required for the compost maturation could be perceived as a long-term investment from poor farmers, assisting local farmers who are interested in the production and marketing of water hyacinth compost could present an additional option to decrease the negative effects of this invasive plant on the biodiversity and livelihoods at Lake Alaotra (Rouse et al., 2008). Thus, other farmers could directly purchase water hyacinth compost without spending time producing it. This would also offer new economic perspectives for people specializing in compost production.

Water hyacinth compost has been proven to produce significantly higher yields compared to mineral fertilizer for peanuts (*Arachis hypogaea*) and cassava (*Manihot esculenta*) (Oroka, 2012), two important crops grown in the Alaotra region. Most importantly, water hyacinth fertilizers showed great results in low-land rain-fed rice farming system in North-east India, rice being the main crop in the Alaotra region (Balasubramanian et al., 2013). In a short-term perspective, future research should first focus on implementing water hyacinth compost within groups of poor farmers (Types D, E and F according to Chabierski et al. (2009)) making subsistence agriculture on small vegetable fields at Lake Alaotra. These groups of farmers are more vulnerable compared to bigger rice cultivators. They produce mainly vegetables. In the long-term run, water hyacinth fertilizer could be applied to rice cultivation and compared with Urea, different types of manure (real wet manure and dry manure) or other types of compost in the Alaotra region.

5.6 Conclusion

Efforts concentrated on poverty and food insecurity alleviation for rural populations in developing countries is likely to be the best strategy to keep natural ecosystems safe. In poor countries, such as Madagascar, food production will always have the priority over nature conservation in a system where no alternatives are offered. In this study, we evaluated the efficiency of using the invasive water hyacinth as an alternative source of fertilizers for vegetables fields in the Alaotra region in Madagascar. The results of the growth experiment using Chinese cabbage showed higher biomass production by water hyacinth composts when compared to NPK and cow dung. Thus, water hyacinth composts are suitable and can substitute NPK and cow dung for vegetable farming in the Alaotra region. Besides, the overall production and transportation costs for compost were cheaper than NPK and cow dung. Further, no health risks were detected considering heavy metal concentrations within water hyacinth at Lake Alaotra. Future application of water hyacinth composts should first target poor farmers making subsistence agriculture on small fields. Over the long term, water hyacinth fertilizer could be applied for rice cultivation at Lake Alaotra. Most of all, the agricultural past of the Alaotra, especially the lessons learnt from several failures in disseminating agricultural innovations, should be considered in future implementation attempts. Finally, a holistic approach entailing technical, social, economic, environmental and institutional aspects is recommended to promote the use of water hyacinth compost at Lake Alaotra where food production and nature conservation are competing for the same land.

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5.9 Abbreviations

CEC: Cation Exchange Capacity)
GDP: Gross Domestic Product
GR: Growth Rate
LA: Leaf Area
LTN: Leaf Total Nitrogen
LWR: Leaf Weight Ratio
NPK: Nitrogen Phosphorus Kalium
R/S: Root to Shoot ratio
SLA: Specific Leaf Area
SRI: System of Rice Intensification
UNDP: United Nations Development Programme

Chapter 6

USER GUIDE

6.1 User guide for water hyacinth use as compost in the Alaotra region

Within this research, water hyacinth has been demonstrated to be efficient and suitable for making compost and handicrafts according to the socioeconomic conditions of the Alaotra region (Chapter 4 and 5). However, the adoption of water hyacinth use will depend on the efficiency of its implementation (see also Chapter 7). For the implementation of water hyacinth compost, a simple user guide was developed for the local farmers (Appendix 2). With short and comprehensible texts, information is provided to the farmer regarding the water hyacinth: its origins, distribution and invasiveness. In addition, it explains clearly how and when the plant should be collected at Lake Alaotra, how to produce the compost and for what the compost can be applied. With six self-explaining illustrations, the guide can be easily understood. The guide is written in Malagasy for the local population at Lake Alaotra.

In detail: the first illustration shows the water hyacinth forming a big mat next to a stand of papyrus plants. Growing next to the lakeshore, the water hyacinth is easily recognizable by its purple flowers with a yellow dot in the center. The next picture explains how water hyacinth can be collected: A man takes water hyacinth plants with the hand out of the lake water and gathers them on his canoe. Afterwards he transports the plants landward next to the lakeshore. The third illustration makes clear that the roots are not usable for the compost. This is due to the eventual high concentration of heavy metals inside. The next illustration shows how the compost is made. Branches are installed in the base of the pile to allow the compost to breath. The compost is made from a succession of three layers: chopped water hyacinth (20 cm high) followed by fresh broad leaves (5 cm high) and a mixture of soil and cow dung (5 cm high). The different ingredients are zoomed to make them recognizable. The water should be generously water after each three layers. The pile should be watered every two days and turn onto a new base every two weeks until one to one and half months. The compost maturation is reached when a crumbly dark mass is obtained. The fifth picture informs about the use possibility of the compost. Here it is shown that the compost can be used to cultivate rice and different vegetables. The last picture compares the efficiency of the compost to the chemical fertilizer NPK, mostly used in vegetable farming. Using compost saves money: the man has some cash in his left hand. In conclusion, the guide's instruction can be executed directly by farmers on the field and that without external assistance. The guide can be also used as a supporting material for workshops and demonstration plots installation aiming to implement the use of water hyacinth compost in Lake Alaotra, in other regions of Madagascar and in rural areas in developing countries having problems with water hyacinth (see also Chapter 7).

Chapter 7

SYNOPSIS

7.1 Difficulties and possibilities for water hyacinth use in the Alaotra region

The results of this thesis show that the invasive water hyacinth (*Eichhornia crassipes*), which is now widely distributed at Lake Alaotra, can be used by the local population even under the very basic and rural conditions of the study area (Chapter 4 and 5). In addition, people are generally open-minded to its use (Chapter 3). However, some limitations and difficulties occur and those must be taken into account when implementing the use of the plant.

The greatest advantage for using water hyacinth is its high abundance as free natural resource at Lake Alaotra. Lammers et al. (2015) found that up to 53% of the lake's fringe vegetation is currently covered by the plant. This implies that the abundance of water hyacinth is largely sufficient to supply raw material for the local population in a long term. Another advantage is the proximity of the plant to villages and agricultural fields. As such, water hyacinth can be harvested and processed directly next to the lakeshore thus reducing labor intensity. However, the high water content of water hyacinth (app. 90%) (Elserafy 1980) makes the collection and transportation laborious and thus is one of the most important barriers to its use, especially for a poor rural population having no sophisticated technology (Gunnarsson and Petersen 2007). The socioeconomic part of this thesis (Chapter 3) emphasized the absence of technological assets and the low investment power in the Alaotra region as important hindrances for the use of water hyacinth. This situation excludes several water hyacinth uses that are widely distributed in other countries (e.g. biogas, briquettes, methane, sludge, Thomas and Eden 1990; Patel et al. 1993; Lu et al. 2010) which require investment in machinery and pretreatment costs (Gunnarsson and Petersen 2007). As the infrastructure in the Alaotra region is very basic and most villages have neither electricity nor running water, the first part of my research aimed to identify the possible uses of water hyacinth according to the environmental and socioeconomic conditions of this region. By coupling a socioeconomic investigation with the perception of the local population toward water hyacinth (Chapter 3), I concluded that producing fertilizers, fodder and handicrafts from water hyacinth are the best options for this poor and remote region. The main choice criteria were the low processing complexity and low investment costs required for those options. Due to the lack of investment and technology in rural areas, using water hyacinth directly with a minimum of processing is the best alternative for small-scale use (c.f. Gunnarsson and Mattsson 1997). However, the socioeconomic investigation conducted in the beginning of my study revealed some barriers to the use of water hyacinth at Lake Alaotra (Chapter 3). The results show that water hyacinth and the water ferns *Salvinia* spp. are recognized by the local stakeholders as the most invasive plant species at Lake Alaotra (Chapter 3). Around 77% of the interviewees complained of being negatively affected by the plant (mostly by waterway clogging and rice field invasion). Although two thirds of the local stakeholders were aware of some potential usages for water hyacinth (compost, mulch, fodder, raw material for handicrafts and water purification), only 11% are using the plant as support for fish trap (5%), fodder (4%) and compost (2%). Moreover, even in case of a total invasion scenario of Lake Alaotra in the future, only 16% of the interviewees would use water hyacinth (as compost and handicrafts). Obviously, there is a gap between knowledge and readiness of the local stakeholders toward the use of water hyacinth. This situation can be explained by the cautious approach of the poor farmers toward innovations due to their already high exposure to risks (e.g. crop failure, price fluctuations) (Chapter 3). The livelihood insecurity and high vulnerability of the local population to economic and environmental risks lead to the general preference for the relative insurance offered by local mutual aid groups (Chapter 3) (c.f. Ducrot and Capillon 2004).

Although water hyacinth was observed to be occasionally used for feeding pigs and geese at Lake Alaotra (Chapter 3), I did not select this option as a suitable alternative due to the high calcium oxalate content of water hyacinth that could harm the animal digestive tract (Bolenz et al. 1990). In addition, the air-filled tissues of water hyacinth decreased feed intake thus reducing the nutritional values of the diet. In Vietnam, cattle fed with fresh water hyacinth exhibited abnormal distension of the rumen indicating a long period of adaptation and a rate of water hyacinth not exceeding 30% of the diet dry weight (Tham 2012). Further investigating the efficiency of water hyacinth as a source of fodder would not be possible due to the local conditions (financial and technical issues). Generally, feeding livestock directly with water hyacinth is not advisable without pretreatments like pressing, centrifuging and washing with acid (Bolenz et al. 1990). The latter would be too expensive for the poor local farmers at Lake Alaotra. In the following, I therefore focused my research on the use of water hyacinth as a source for fertilizer and raw material for handicrafts. For both, fertilizers and handicrafts, my study reveals several use options (Chapter 4 and 5). Globally, water hyacinth is successfully used for producing fertilizers and handicrafts in countries like China, Indonesia, Bangladesh, Sri Lanka, Thailand, Philippines and some African countries like Kenya and Nigeria (Jafari 2010; Ndimele 2011; Patel 2012). In this study, different types of fertilizers were produced from water hyacinth: composts (aerobic compost, anaerobic compost and pit compost), green manure and ash. The preparation of all the fertilizers was based on the methods described by Lindsey and Hirt (1999) (Chapter 5). The water hyacinth fertilizers were compared with the locally used mineral fertilizers in vegetable farming, NPK and cow dung, by conducting a growth experiment with Chinese cabbage (*Brassica rapa chinensis*). Due to the low nutrient content of the soil in the region, producing water hyacinth fertilizers has a great chance to be accepted by the local farmers. Promoting the use of water hyacinth fertilizers is also very relevant. It would attenuate the negative impacts of the plants on the environment and the local livelihoods while improving soil fertility and thus crop yields. Although limited to the group of artisans, producing and marketing handicrafts from water hyacinth has the potential to increase household income. In this research, water hyacinth handicrafts were produced with local artisans and compared with the common papyrus handicrafts regarding production path (collection, transportation, and processing of raw material) with a focus on financial costs, workload, and selling price (Chapter 3). Although water hyacinth handicrafts are not yet produced and commercialized in Madagascar, the long experience of many Asian countries in producing and marketing water hyacinth handicrafts (Jafari 2010; Ndimele 2011; Patel 2012) could facilitate its application at Lake Alaotra. Additionally, the use of water hyacinth as raw material for handicrafts could reduce the pressure on the commonly used papyrus (*Cyperus madagascariensi*s) (Chapter 4). This can contribute to the conservation of the marsh ecosystem and its biodiversity (e.g. the Alaotran gentle lemur *Hapalemur alaotrensis* which feeds mainly on papyrus and is critically endangered).

The results of my research on water hyacinth handicrafts (Chapter 4) show that despite the requirement for longer time periods regarding raw material selection and drying (seven days vs. three days) as well as additional financial costs (23% in addition) for ornaments, water hyacinth handicrafts displayed many advantages in comparison to papyrus handicrafts: assembling water hyacinth handicrafts was easier and faster (33% less time investment), led to robust products which were rated as being of acceptable to very good quality by 91% of the interviewees and potentially sold at three times (mean 2.25 US$) the sale prices of the traditional papyrus handicrafts (mean 0.75 US$). In addition, a SWOT (Strenghts, Weaknesses, Opportunities and Threats) (Leigh 2006) analysis was performed for promoting the establishment of water hyacinth handicrafts at Lake Alaotra (Tab. 4.5). Strengths such as the ability of local artisans to reproduce weaving pattern from handicraft pictures represent an advantage for future design adjustment. However, the investigation especially emphasized the lack of access to financial resources and markets for handicrafts as the limiting factors for successful diffusion of this alternative (Tab. 4.5). These limitations could explain the low percentage of stakeholders (2%) willing to use water hyacinth as raw material for handicraft even in case of a future total invasion of Lake Alaotra by this plant (Chapter 3). In rural areas, artisans suffer from difficulties concerning access to markets, finance, and technology; raw material shortages; a lack of managerial competence; and weak institutional support (Rogerson 2000). In Kenya, the Orongo women's group (producer of water hyacinth handicrafts) succeeded to access donor organizations (USAID and Red-Cross) but still suffered from severe difficulties regarding handicrafts design and marketing (Subbo and Moindi 2008). In Brillo Nuevo (Peru), the commercialization of the palm species, Chambira (*Astrocaryum chambira*), as hammocks and bags resulted in very low incomes due to marketing deficiency (Vormisto 2002). Due to the geographical isolation of the Alaotra region, the artisans will continuously require external inputs (e.g. for product quality and design, outlets) for being able to sell handicrafts on national or international markets. Schmitz (1990) argues that the main problem of African small enterprises is not their size but their isolation. This implies the necessity of assisting local artisans along the whole marketing chain (market expectations, production, transportation, promotion and selling). Otherwise, water hyacinth handicrafts will share the common fate of fish and crop productions in the Alaotra region: bought at very low prices and transported by middlemen to big cities (Copsey et al. 2009).

My study on water hyacinth use as a source of fertilizers (compost, green manure and ash) proved that it is possible to produce fertilizers from water hyacinth under the environmental and socioeconomic conditions of the Alaotra region. However, the growth experiment with Chinese cabbage revealed that only the three types of water hyacinth composts were efficient for improving the clay-rich soil structure and fertility. Clay rich soils have poor aeration and drainage retaining tightly water and hindering water supply for the plants (Leeper and Uren 1993). No significant difference was observed between the three compost types in term of biomass production in Chinese cabbage. Chinese cabbage grown with water hyacinth green manure and ash showed very low performances, even lower than the control. In contrast, Chinese cabbage treated with water hyacinth compost had large, thick, numerous and heavy leaves (Tab. 4.4). In addition, producing water hyacinth compost was more cost effective when compared with the commonly used NPK and cow dung in vegetable farming. Producing and transporting water hyacinth compost costs 53 US$ per hectare whereas it costs 67 US$ for NPK and 133 US$ for cow dung. Chukwuka and Omotayo (2008) reported that amendment of soil with water hyacinth compost (1:3 ratio) can enhance the nutritional status of poor quality soil and could substitute the costly mineral fertilizers in Nigeria. The simplicity of the compost preparation is another driving factor for its adoption. In comparison to water hyacinth handicrafts, the compost has a higher probability of being implemented since it offers a direct use namely to improve the soil structure and fertility, soil erosion and degradation being central problems in the region. Small scale composting is the main interest in developing countries due to the lack of capital and infrastructure (Gunnarsson and Petersen 2007). In contrast to water hyacinth compost, the success of marketing water hyacinth handicrafts depends on many external factors (e.g. presence of outlets, efficiency of promotion). As such, a user guide (Chapter 6) was exclusively designed for promoting the use water hyacinth compost as a first step. Encouraging artisans to produce water hyacinth handicraft does not make sense without previous market analysis. Knowing how to market water hyacinth handicraft is far more important than the production phase (c.f. Rogerson 2000). The limiting factors for the use of water hyacinth compost are the preparation time (one month) and its collection and transportation from the harbor to the fields. This reflects the recorded low willingness (14%) of local stakeholders in using water hyacinth as source of compost even in the extreme case of total invasion by the plant (Chapter 3). Additionally, due to the general livelihood insecurity and poverty in the Alaotra region, one month is perceived as a long-term investment by poor farmers (Chapter 3). The urgency of providing for the immediate needs of the families induces a general short-term time horizon within farmers in poor countries (Pannell et al. 2014).

While considering the local conditions of the Alaotra region, using water hyacinth as compost and handicraft has the potential to improve local livelihood and attenuate its impacts on the ecosystem. Compared to compost, using water hyacinth for handicrafts has no influence on water hyacinth stands since collecting water hyacinth stems does not reduce the overall abundance of the plant. This is due to the fact that water hyacinth uses primarily stolons to generate new daughter plants making the partial destruction of its aerial parts not problematic for its spread capacity (Gettys 2014). The loss of flowering plant parts is therefore no hindrance for a fast reproduction. However, in general eradicating water hyacinth is almost impossible: utilization alone is not enough for getting rid of water hyacinth and eradication successes using sophisticated methods of control are rare due to the very efficient spreading abilities of water hyacinth and the longevity of its seeds in the seed bank (Osmond and Petroeschevsky 2013). In addition, some successful eradication has even led to an opposite effect (eutrophication) (Bicudo et al. 2007). This fact is understandable since in the Alaotra region water levels are generally low and high amounts of waste water and fertilizers enter regularly into the lake (Ferry et al. 2009). Considering the economic situation of the Alaotra region and overall in Madagascar, expensive control methods (mechanical, chemical and biological) are unlikely to be applied in the Alaotra region (c.f. Charudattan et al. 1996). In conclusion, promoting the local utilization of water hyacinth represents the only feasible alternative to at least reduce its negative ecological and socioeconomic impacts at Lake Alaotra. However, detailed and locally adapted implementation strategies are necessary to introduce the use of the plant and to convince the local population.

7.2 Implementation strategies for water hyacinth use

A strategic plan based on different timescales is proposed for the implementation of water hyacinth use as compost and handicrafts for the Alaotra region and for Madagascar (Fig. 7.1). Especially for water hyacinth compost, the multiple past failures in the diffusion of different agricultural innovations makes it particularly difficult to implement new methods in the Alaotra region. The first agricultural innovation, the SRI (System of Rice Intensification), was introduced in 1998 in the Alaotra region. This technique consists of transplanting very young rice sprouts along a line and with low densities in systems of efficient water control allowing intermittent flooding and mechanical hoeing (Laulanié 1993). The SRI is proved to increase the yield up to six times (8 to 12 tons per hectare) and is very efficient for saving water (Serpantié et al. 2013). However, the complex technical requirement coupled with the high cost and labour intensity were the main barriers to its adoption. The second innovation in the region, conservation agriculture, combines soil tillage reduction, mulching, crop rotation and association (Scopel et al. 2013). Conservation agriculture allows a better water control, increases microorganism activities in the soil and reduces the emission of CO_2 and agrochemical leaching (Hobbs et al. 2008). Similarly, to the SRI, the diffusion of conservation agriculture failed due to the long learning process, the competition with fodder for livestock and the moderate increase of yield (Penot et al. 2014). The last innovation consisted of using new rice varieties adapted to extreme water fluctuation (Rasoamanana et al. 2012). It also failed due to the costly seeds, the high requirement in mineral fertilizers and the local preference for long straw rice varieties for feeding livestock (Penot et al. 2014). It can be deducted from these aforementioned barriers that only innovations with low cost, low complexity andlow time consumption hold better chances to be accepted and adopted by the farmers (c.f. Penot et al. 2014). I argue that water hyacinth compost fits to these criterions. In my research it was demonstrated that producing and applying water hyacinth compost is cheaper compared to NPK and cow dung. Additionally, the other compost components (cow dung and broad leaves) are locally available and the preparation is simple. Further, the compost is mature after only one month. Furthermore, considering all these advantages, the compost is cost effective because of the higher biomass production of Chinese cabbage grown with it (Chapter 5).

Implementation of water hyacinth compost

Although the Alaotra region is a poor and remote region, this area still is one of the most important fishery and agricultural area of Madagascar. Nowadays, the daily income at Lake Alaotra (2.5 to 5 US$ per day) (Chapter 3) is still above the national standard (1 US$ per day) (Eubanks 2012). This led to a high rate of migration into the region which, combined with high demographic growth rates, resulted in a population increase up to fivefold during the last fifty years (INSTAT 2013). Population growth will inevitably reduce the surface of available agricultural fields per individual. This increasing land pressure combined with a general lack of water supply during the dry season leads to the ongoing conversion of the marshes into rice fields in the region (Bakoariniaina et al. 2006; Copsey et al. 2009). Many agricultural fields stay non-cultivated during the dry season (Ranarijaona 2007). In addition, the advanced degree of soil degradation in the region (c.f. Rahajaharitompo 2004; Penot 2009) makes cultivation difficult without using fertilizers, NPK and cow dung being commonly used in the region in vegetable farming (Chapter 3). To reduce marsh degradation, efforts should be thus oriented in the promotion of a sustainable use of agricultural fields through the improvement of soil fertility leading to better yields and the possibility to plant different crops during the whole year. Due to the insufficient crop production for supporting households and the general lack of protein sources in the Alaotra region, farmers attempt to fill the gap by increasing fishing efforts (Wallace et al. 2016). Although fishing was only allocated for subsistence one century ago, the introduction of fishnets has increased fish catches. Afterward, the following overfishing led to a drastic decline of fish catches in the region (Moreau 1976). Additionally, the establishment of fishing closure by the fisheries department (from 15th of November to the 15th of January) for helping fish population to recover (Copsey et al. 2009), increases in contrast the fishing effort (Wallace et al. 2016) and in addition aggravates marshland conversion into rice field due to the lack of alternative sources of income (Chapter 3). Similarly, to the alleviation of marsh degradation, maintaining fish populations and catches can only be achieved by improving agricultural yields on land. For these purposes and based on the results of my research described in the previous part, I propose the use of water hyacinth compost as an alternative fertilizer to improve soil structure, water retention and soil fertility in the Alaotra region.

Particularly, due to the non-cultivation of soils during the dry season, applying water hyacinth with intercropping methods could represent an option. To valorize agricultural soils during the dry season, intercropping methods could be applied on soils previously fertilized with water hyacinth compost during the rainy season. According to Brooker et al. (2014): “intercropping systems involved two or more crop species or genotypes growing together and coexisting for a time". Legumes (e.g. cowpeas, beans, Bambara groundnut) are largely intercropped with cereals (e.g. maize), potatoes and cucurbits in developing countries (Francis 1986). These crops are cultivated in the Alaotra region. In addition, intercropping is particularly adequate in areas with mainly subsistence agriculture since it increases yield without increasing inputs or maintaining yield while decreasing inputs (Brooker et al. 2014). That would be a very important argument for convincing the local farmers. This method not only increases income but also protects farmers against crop failure and market fluctuations while diversifying food and improving soil quality (Rusinamhodzi et al. 2012).

For promoting the use of water hyacinth as a source of compost at Lake Alaotra, three main challenges must be addressed: transportation and production costs, relatively long production time and the local skepticism toward agricultural innovations (c.f. Gunnarsson and Petersen 2007; Penot et al. 2014). The first targeted group for the implementation of water hyacinth compost use should be the subsistence vegetable farmers because of their higher vulnerability to environmental and economic risks. The success of the implementation of agricultural innovations must include not only knowledge transfer but also taking into account the economic, social and institutional settings characterizing the target region (Klerkx et al. 2012). Through a genuine participatory approach (sensu Cohen and Uphoff 1980), local vegetable farmers should be included in the process of decision-making before and during the implementation phase. As such, they are given the chance to share their experiences, needs, priorities and challenges. (Wall 2007) Organizing regular workshops might be useful to promote knowledge exchanges, constructive debates and participative planning. In addition, workshops can provide additional information regarding the factors influencing farmer's participation. For this purpose, it is particularly important to collect data on who is participating, what kind of participations, how they are participating and why they are participating (Cohen and Uphoff 1980). Based on the analyses of those questions, a certain number of motivated farmers should be selected for the next step. These farmers should be encouraged to install some demonstration plots using water hyacinth compost on their fields. The compost should be produced and shared without cost and the farmers could select their own crops. An eventual crop failure should be financially reimbursed. This way, the farmers could have the possibility to test the compost with their normal crops without fearing the consequences of a crop failure. This might dispel doubts and encourage them to further use water hyacinth compost in the future. In addition, through this voluntary use, the farmers may play the role of change agents for future water hyacinth compost use in the local community (c.f. Weick and Quinn 1999).

When compost use is widely established among vegetable farmers, applying it to rice cultivation could be a next step. In comparison to other countries growing rice two times a year (Naylor et al. 2001), rice is generally grown only during the rainy season in Alaotra. However, due to the large surface allocated to rice cultivation in the Alaotra region, a higher amount of compost will be required. Producing an important amount of water hyacinth compost might represent a higher risk investment. As this study did not test the efficiency of compost for rice cultivation, further experiments are needed for evaluating the enhancement of rice productivity with water hyacinth compost. Only then, the implementation of compost for rice cultivation is an option. In highly degraded areas with nutrient poor soils (such as Anororo), a combination of the use of compost and Urea might be a possibility.

Within the socioeconomic investigation conducted in the beginning of this study (Chapter 3), a local farmer proposed the creation of a small factory for producing and selling water hyacinth compost in the village. According to him, the factory would create jobs for the local population while supplying water hyacinth compost to the rest of the community without spending time and energy producing it. In the event that the proposal for the use of water hyacinth compost in the society would fail due to labor costs and time issues, marketing water hyacinth compost could be an opportunity to reduce the abundance of water hyacinth at Lake Alaotra. The previously selected farmers can be financially supported to produce and market the compost to the rest of the community. Marketing water hyacinth will require a market assessment for quantifying the demand and adjusting the amount of production and pricing (Rouse et al. 2008).

To get a general overview of the soil characteristic in the Alaotra region, I collected soil samples in three different study sites selected along a level of marsh degradation (degradation levels are according to Lammers et al. 2015): Anororo (most degraded site), Andreba (intermediate degraded site) and Vohimarina (least degraded site). Different soil physico-chemical properties were identified within those three study sites (Tab. 5.1). Depending on the level of soil degradation, I propose different applications of water hyacinth compost depending on the soil conditions (Tab. 5.6): In Anororo, the sandy soil requires clay application in combination with water hyacinth compost application, mineral fertilizers, tillage reduction, crop residues retention and use of legumes to improve nutrient level and water retention capacity of the soil. Application of clay enhances soil nutrient and water retention capacity (Noble et al. 2004). Additionally, applying water hyacinth compost and mineral fertilizers, reducing tillage, using leguminous plants (for catching atmospheric nitrogen) and retaining crop residues could help to sustainably manage the nutrient cycle (Bell and Seng 2004). In Andreba, the application of water hyacinth compost with mineral fertilizers might be sufficient for the sandy clay loam, whereas the loamy sand soil in Vohimarina might only require (if needed) the use of water hyacinth compost (Chapter 5). Within the study, it was also observed that most degraded soils occur in areas with higher level of marsh degradation, population size and water hyacinth abundance. The implementation of water hyacinth compost use should thus prioritize high degraded sites. Anororo has a population of about 8,000 inhabitants practicing mainly rice cultivation and fishing (Andrianandrasana et al. 2005). Due to the high degradation of soil in Anororo, local farmers are not enthusiastic about planting vegetables making them dependent on the surrounding villages and leading to an increase in household expenses. Applying water hyacinth compost (combined with intercropping methods) on rice fields might encourage local farmers to plant vegetable in Anororo during the dry season. Marketing water hyacinth compost could represent one option there because of eventual higher demands (c.f. Rouse et al. 2008). In comparison to Anororo, Andreba is home to 4,000 inhabitants who center their livelihoods mainly on rice cultivation, vegetable farming and fishing (Andrianandrasana et al. 2005). The main issue in Andreba is linked to the continuous soil erosion on the hillsides causing a major sedimentation of agricultural fields with lateritic soils during the rainy season. Improving soil fertility in Andreba (using water hyacinth compost) should be coupled with the stabilization of gullies on the hills. Vohimarina has a population of around 500 inhabitants practicing the same activities as the farmers in Andreba (Andrianandrasana et al. 2005). The presence of trees on the hillsides reduces soil erosion in Vohimarina and allows local farmers to grow crops under good soil conditions. Applying water hyacinth compost in Vohimarina might be only necessary for some cases where higher yields are required.

On a regional level, I propose different applications of water hyacinth compost based on the topographic sequences (Rahajaharitompo 2004; Penot 2009) (Tab. 5.7). Low nutrient and acidic ferrallitic soils are very frequent in the Alaotra region and thus would require treatments combining calcium phosphate amendment, mineral fertilizers (e.g. NPK, Urea) and water hyacinth compost (Chapter 5). Additionally, stabilizing the deforested hillsides surrounding Lake Alaotra through reforestation is a prerequisite for reducing soil erosion and sedimentation in a sustainable way (Bakoariniaina et al. 2006; Ranarijaona 2007). However, due to the great extent of soil degradation, reforestation projects would be complex and very expensive to realize under the local conditions. Promoting agroforestry within the most affected areas could at least increase their resilience to soil erosion and sedimentation (c.f. Sepúlveda and Carrillo 2015). Water hyacinth compost can assist the realization of such projects by improving the soil structure and fertility.

In the long term, water hyacinth compost could be implemented in other regions facing problems with this plant in Madagascar (e.g. Lake Ravelobe in Ankarafantsika national park, Pangalanes channel on the eastern coast). Other alternatives such as biogas, ethanol, briquettes and sludge from water hyacinth could be realized in areas having more opportunity to access financial resources and technology (e.g. Antananarivo, the capital of Madagascar) (c.f. Gunnarsson and Petersen 2007).

Implementation of water hyacinth handicrafts

Due to the isolation of the Alaotra region, implementing the use of water hyacinth as raw material for handicrafts might be more challenging compared to water hyacinth compost. The oversaturation of handicraft markets in the region coupled with the low purchasing power of local customers requires selling water hyacinth handicrafts outside of the region (c.f. Millard 1996). Within my research, market exploration was identified as one of the most relevant strategies for promoting water hyacinth handicrafts from Lake Alaotra (Chapter 4). Since marketing is a dynamic and cyclic process (market results, product design, market identification, production, promotion, selling, market results) (Millard 1996), the isolation of local artisans implies a dependence on external assistance for the transfer of information flows. In Thailand, as one of the largest producers of water hyacinth handicrafts, fifty groups of artisans (20 to 600 members per group) are living solely from these products (Keawmanee 2015). One of them, the Ban-Aoy, an association of 300 water hyacinth artisans in Thailand, is able to export 80% of their production thanks to their 27 years of experiences in creating their own design using information from the national and international market expectations (Keawmanee 2015). Alone, local artisans at Lake Alaotra will unlikely be able to access market data on national and international markets (c.f. Schmitz 1990). As a solution, the creation of artisan association was identified as the first step of the implementation of water hyacinth handicrafts (Chapter 4). The association can facilitate interventions and gather interested artisans. Additionally, within the association, several workshops could be regularly conducted to improve artisan's competences in product design and quality, marketing strategies, finance access and market exploration (Chapter 4).

In my study, interviews with town-based customers and retailers allowed collecting information preference in color, fiber size and additional material (Tab. 4.4). For instance, the thickness of water hyacinth fiber was only appreciated by half of the interviewed costumers and retailers (Chapter 4). This calls for a better diversification of water hyacinth handicrafts in the future (e.g. coating for furniture, baskets, big mats) for generating new markets. However, due to the fact that water hyacinth handicrafts are not yet commercialized in Madagascar considering only the Malagasy expectations is not sufficient. The promotion of water hyacinth handicrafts should also refer to the data from international standard regarding water hyacinth handicrafts. Thus, new products with new designs should be presented and produced with local artisans in Andreba. Labeling water hyacinth handicrafts with an environmental awareness logo is an additional strategy to increase market values. Each product could be marketed with an etiquette explaining the meaning of purchasing water hyacinth handicrafts for the conservation of the Lake Alaotra biodiversity. Afterwards, these new products could be sold in regional markets (Ambatondrazaka, the largest town in the Alaotra region) and national markets (Antananarivo, the capital of Madagascar). Based on the selling outputs, the product design, quality, quantity and selling price can be adjusted to the customers' expectations. Generally, the fact that water hyacinth handicrafts are not yet commercialized also offers the possibility to develop a market with a minimum or without competition (Tab. 4.5). To gain the participation of local artisans, all costs (raw material collection and transportation, additional materials, accessories, transportation of the products to the markets, sellers) should be financed by the implementation project. In addition, the artisans should receive a monthly salary to allow them to work exclusively on the handicrafts.

At a regional level and in the middle term when marketing water hyacinth handicraft is successful within the association level, other artisan associations can be created in the Alaotra region and connected into clusters to facilitate learning and imitation effects (Van Dijk and Rabellotti 1997; Rabellotti 1998; Nadvi 1998). Clusters have higher negotiation power and can easily convince powerful market actors (Miehlbradt and McVay 2004).

At a national level, networking with other associations and supporting organizations outside the Alaotra region represents a source of valuable information and finance (Millard 1996). In addition, cooperating with tourist enterprises (e.g. Baobab Company) or international fair-trade companies (e.g. El Puente) can offer additional secure outlets for the products.

In the long term, when water hyacinth handicrafts are established on the national level, targeting international markets could represent the next step. Export marketing for handicrafts is more complex because it requires more effort in communication, preparation and planning: high production capacity, strict quality control, up to date design, commercial documents, precise labeling and packaging instructions, prompt delivery and specific method of payment (Millard 1996). Thus, the installation of storage centers in developed cities such as Tamatave (on the eastern cost of Madagascar) or Antananarivo will be necessary to gather, label and pack the products before shipping them.

In conclusion, although using water hyacinth as a raw material for handicrafts does not directly contribute to the reduction of the water hyacinth stands at Lake Alaotra (collecting the stems of water hyacinth does not limit its spread), the generation of additional streams of income from water hyacinth handicrafts can contribute to an increase in household quality of life in a poverty-stricken area and reduces the pressure on the commonly used papyrus plant. In addition, the association of artisans can increase the empowerment of women groups in the society of Lake Alaotra. The recommendations from this research could be applied to develop water hyacinth handicrafts in other rural regions in Madagascar too and in other developing countries facing problems with water hyacinth.

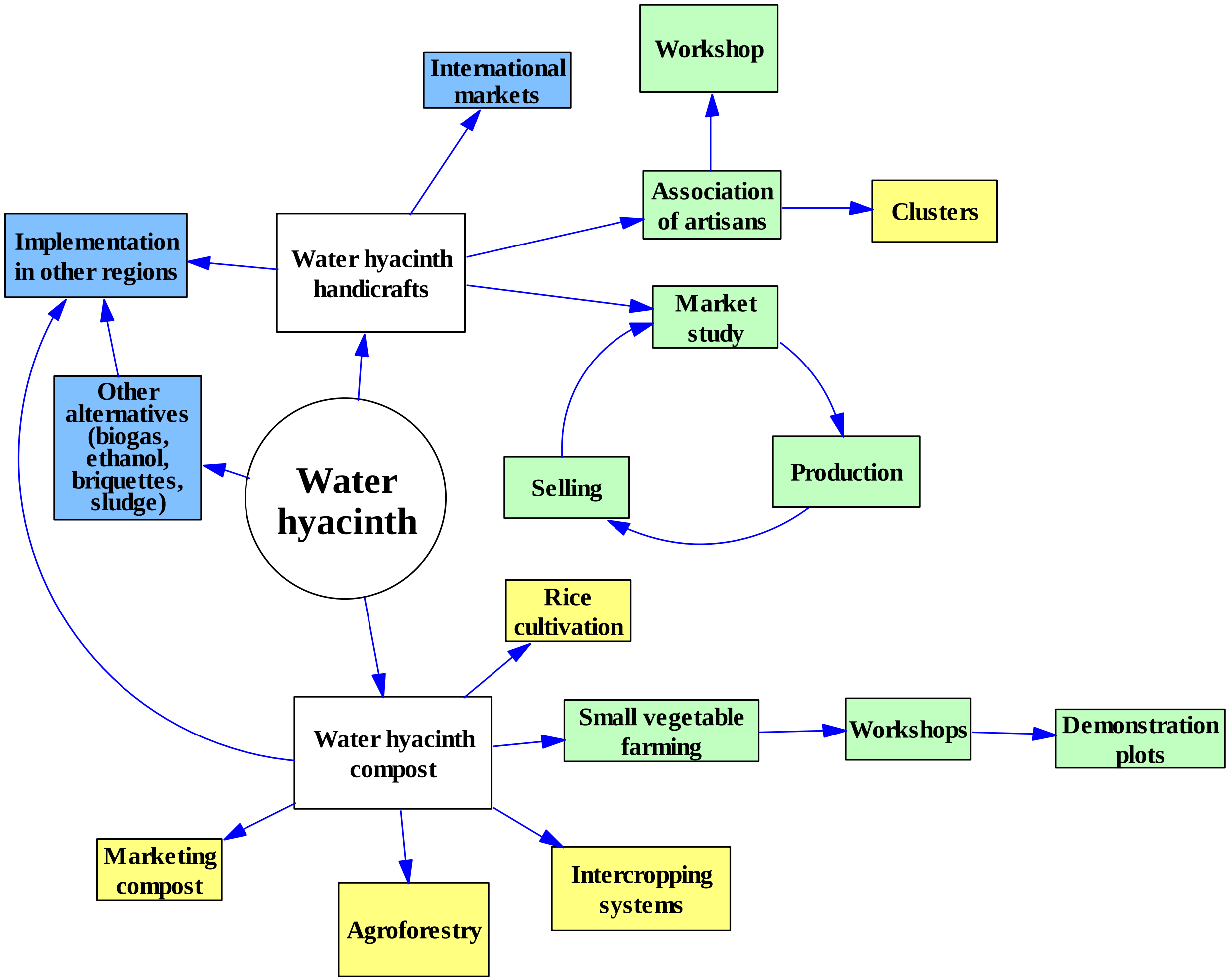

Figure 7.1: Strategic plan for the implementation of water hyacinth compost and handicrafts in the Alaotra and other regions in Madagascar. Green boxes represent short run activities, yellow boxes show middle term activities and blue boxes are for long term activities.

7.3 Conclusion

From this research, it was deduced that it is possible to valorize water hyacinth, an invasive aquatic plant species, according to the environmental and socioeconomic conditions of the poor and remote rural Alaotra region in Madagascar. In this study, producing compost and handicrafts out of water hyacinth were identified as the most suitable alternative use for this region. Using water hyacinth has a triple advantage: it alleviates the negative effects of the plant on the ecosystem and local livelihoods while providing profits for the local population and thus reducing the anthropogenic pressures on the Alaotra marshland ecosystem. Based on the findings of this thesis, some emerging points deserve to be emphasized for a successful implementation of water hyacinth use:

(1) ‘Preaching’ the positive results of this research to the local farmers and artisans is alone not sufficient to convince the local population to use water hyacinth.

(2) A participatory approach that includes local farmers from the decision-making process to the implementation phase is essential to increase the acceptance of water hyacinth use as a source of compost.

(3) Offering financial insurance to the farmers during the implementation phase will encourage them to test water hyacinth compost on their own fields and with crops corresponding to their demand.

(4) Due to the various external factors influencing the marketing of water hyacinth handicrafts, a lengthy and sustained supervision should be provided to the craftswomen.

The positive feedback effect of a successful implementation phase will help to increase farmers’ willingness and readiness to further use water hyacinth compost and thus promoting the diffusion effect in the society. Further, marketing success of water hyacinth handicraft will improve empowerment of women associations in the society at Lake Alaotra.

In the long-term perspective, the experience gained in the Alaotra region could be transferred to other regions in Madagascar and other developing countries facing similar challenges with water hyacinth.

7.4 References

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APPENDIX

Appendix 1: Questionnaire for stakeholders' typology at Lake Alaotra (Chapter 3)

Fishermen

1. What have you done when you started to work at the very first time?
2. How many times does it take to be a fisherman?
3. How long have you been a fisherman?
4. Why have you decided to be a fisherman?
5. Where do you usually fish?
6. Do you have your own area for fishing?
7. How far is it from the edge?
8. Who teach you how to fish?
9. What kinds of investments are required for fishing?
10. How many tools do you know for fishing?
11. What kind of tools do you need for fishing?
12. How do you get the tools that you need?
13. How many tools do you use?
14. How much does it cost?
15. What kind of material is needed to build it?
16. How can you get a canoe for fishing?
17. How many techniques do exist here?
18. What is your favorite one?
19. Why have you chosen that method?
20. At what time, when, how long and how often do you fish?
21. What species do exist here?
22. What kind of species do you fish?
23. What kind of fish do you prefer?
24. How much fish do you get during the dry/wet season? Where do you fish?
    Why do you fish there?
25. How big are the fish during the wet/dry season?
26. How do you use the fish? (Self sustain or cash income). Where to sell it?
    How much and how many do sell? Who makes the price? Has it changed?
27. How much money do you get from fishing? How much is the kilo for each species?
28. What do you do for your living during the fishing closure?
29. Do you breed fish? Which species? When? Why? How many?
    How much money do you get from breeding fish? How do you feed them?
    How much do you spend for breeding?
30. Do you have some taboo about fishing? Please explain the reason?
31. Is there any association of fishermen here?
32. How can one enter it?
33. What roles does that organization play?
34. What else do you do apart from fishing for your living?
35. Why have you chosen that/those other jobs?
36. How much money and time do you spend for that/those other jobs?
37. How do you use the yield of that/those other jobs?
38. How much money do you get from that/those other jobs?
39. As a fisherman, what are you struggling with? Why? When?
40. How do you tackle theses problems?

Rice cultivators

1. What have you done when you started to work at the first time?
2. How many times does it take to be a rice farmer?
3. How long have you been a rice farmer?
4. Why have you decided to be a rice farmer?
5. Where do you plant rice?
6. Why do you plant rice there?
7. Are you a land owner or a landless farmer?
8. What are the price for leasing or for farming on someone else’s land?
9. How and when in the year do the negotiations start?
10. Who teach you how to plant rice?
11. What kinds of investments are required for rice farming?
12. What kind of tools does exist here?
13. What kind of tools do you use?
14. How many? How much does it cost/ do they cost?
15. What kind of material do you need to build them?
16. What kind of agricultural input do you use to improve your yield? Why? When?
17. How can you get them? How much, how many?
18. How do you make them?
19. How many methods do exist here for planting rice?
20. How do plant rice?
21. What is your favorite method?
22. Why have you chosen that method?
23. When, how often do you plant rice?
24. How many rice species do exist here?
25. What species do you plant?
26. What species do you prefer?
27. How much rice do you harvest in the normal and in the *contre-season*?
28. How do you harvest rice here?
29. How do you use your rice production? (self sustain or cash income)
30. How much is the kilo for each rice species?
31. How much/how many do you sell it?
32. Who buy it? Who makes the price? Has it changed?
33. How much money do you get from your rice production?
34. What do you do when you don’t plant rice?
35. How do you do the monitoring of your rice exploitation?
36. Do you have some taboo or custom about rice production? Please explain the reasons?
37. Is there any association of rice cultivator here?
38. How can one enter it?
39. What roles does that organization play?
40. What else do you do apart from planting rice for your living?
41. Why have you chosen that/those jobs?
42. How much money and time do you spend for that/those jobs?
43. How do you use your rice production?
44. How much money do you get from them?
45. As a rice farmer what are you struggling with? Why and when?
46. How do you tackle theses problems?

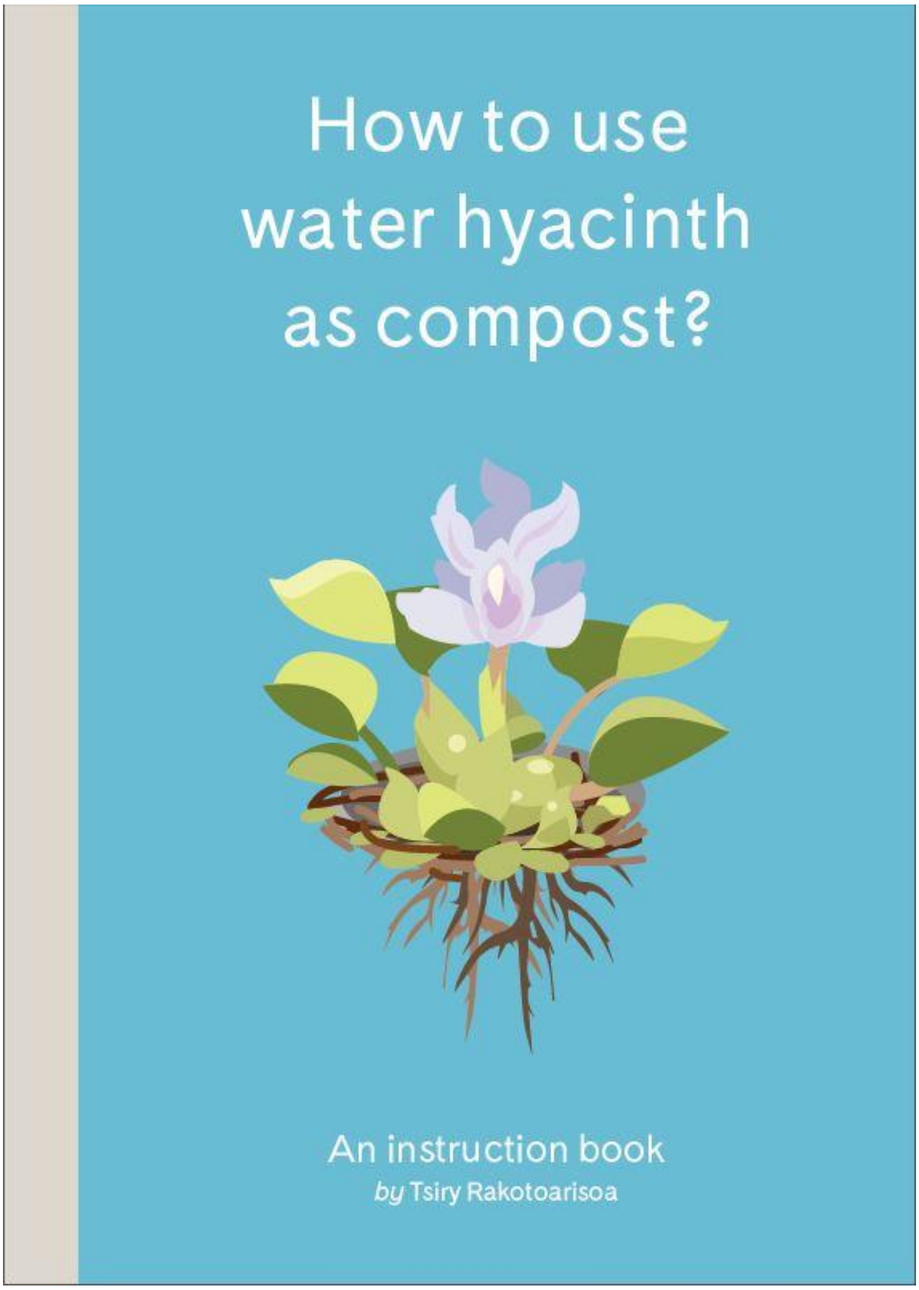
Vegetable farmers

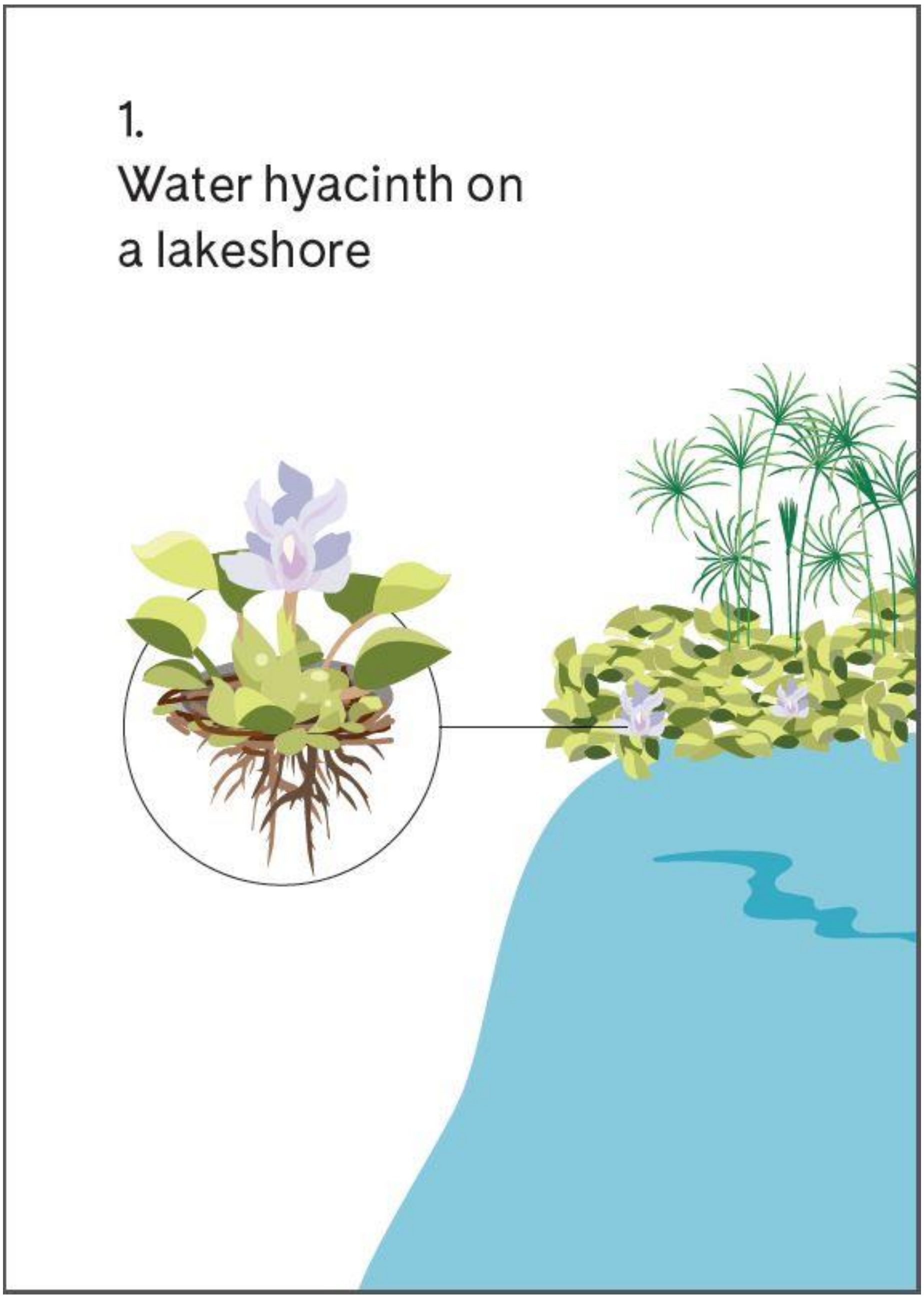
1. What have you done when you started to work at the very first time?
2. How many times does it take to be a vegetable farmer?
3. How long have you been a vegetable farmer?
4. Why have you decided to be one?
5. Where do you plant vegetable? Why?
6. Are you land owner or landless farmer?
7. What are the price of leasing or for farming on someone else’s land?
8. How and when in the year do the negotiations start?
9. Who teach you how to grow vegetable?
10. What kinds of investments are required for growing vegetable?
11. What kind of tools do you need for it?
12. How many tools do they exist here?
13. How many tools do you use?
14. How much do they cost?
15. What kind of material do you need to build them?
16. What kind of intrans do you use to grow vegetable? Why? When?
17. How do you make them?
18. How many industrial fertilizers do you use?
19. How much is it? How often do you use it?
20. How do you plant vegetable?
21. How many methods do exist here?
22. What is your favorite one? Why?
23. When and how often do you plant vegetable?
24. What sorts of vegetable do exist here?
25. What vegetable do you prefer?
26. How much vegetable do you harvest? And how often do you harvest?
27. How do you use your production?
28. How many/much do you sell it?
29. Who buy it? Who makes the price? Has it changed?
30. How much money do you get from your production?
31. What do you do when you don’t plant vegetable?
32. How do you do the monitoring of your exploitation?
33. Do you have some taboo or custom about vegetable production? Please explain the reasons.
34. Is there any association of vegetable cultivator here?
35. How can one enter it?
36. What roles does it play?
37. What else do you do apart growing vegetable?
38. Why have you chosen that/those jobs?
39. How much time and money do you spend for that/ those jobs?
40. How do you use their production?
41. As a vegetable farmer what are you struggling with? Why and when?
42. How do you tackle these problems?

Cattle breeders

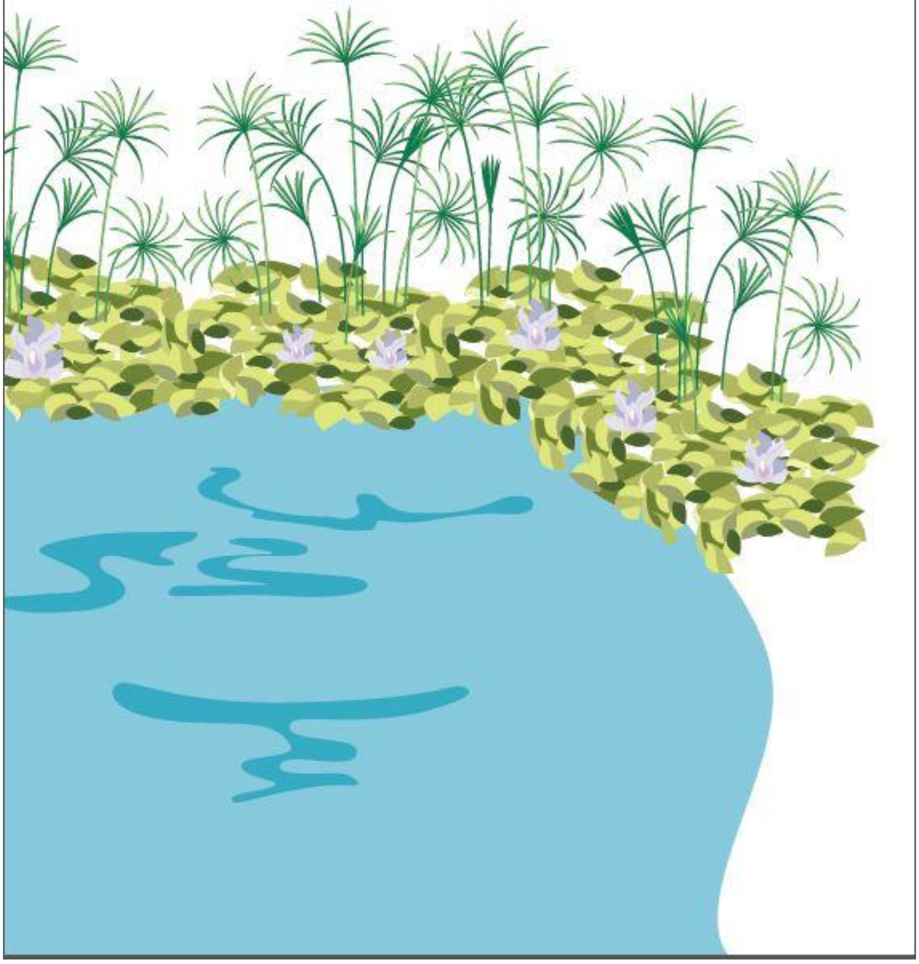
1. What have you done when you started to work at the very first time?
2. How many times does it take to be a breeder?
3. How long have you been a breeder?
4. Why have you decided to be a breeder?
5. What animals do you breed?
6. Who teach you how to breed domestic animal?
7. Where do you breed them?
8. How do you breed them?
9. What kinds of investments are required for breeding animals?
10. What kind of tool do you need for breeding each animal?
11. How many tools do exist?
12. How many tools do you use?
13. How can you get the tools?
14. What kind of material do you use to build them?
15. How much do they cost?
16. When and how often do you breed?
17. How do you use your production (livestock) self-sustain or cash income?
18. Where do you sell them?
19. How many do you sell them?
20. Who does make the price?
21. Has it changed?
22. How much money do you get from breeding?
23. Do you have some taboo or custom about breeding? Explain the reasons please.
24. Is there any association of breeders here?
25. How can one enter it?
26. What roles does it play?
27. What else do you do for your living apart from breeding?
28. Why have you chosen that/those other jobs?
29. How much time do you spend for that/those other jobs?
30. How do you use the yields of that/those jobs?
31. How much money do you get from them?
32. As a breeder, what are you struggling with? Why and when?
33. How do you tackle these problems?

Appendix 2: User guide for water hyacinth use as compost in the Alaotra region



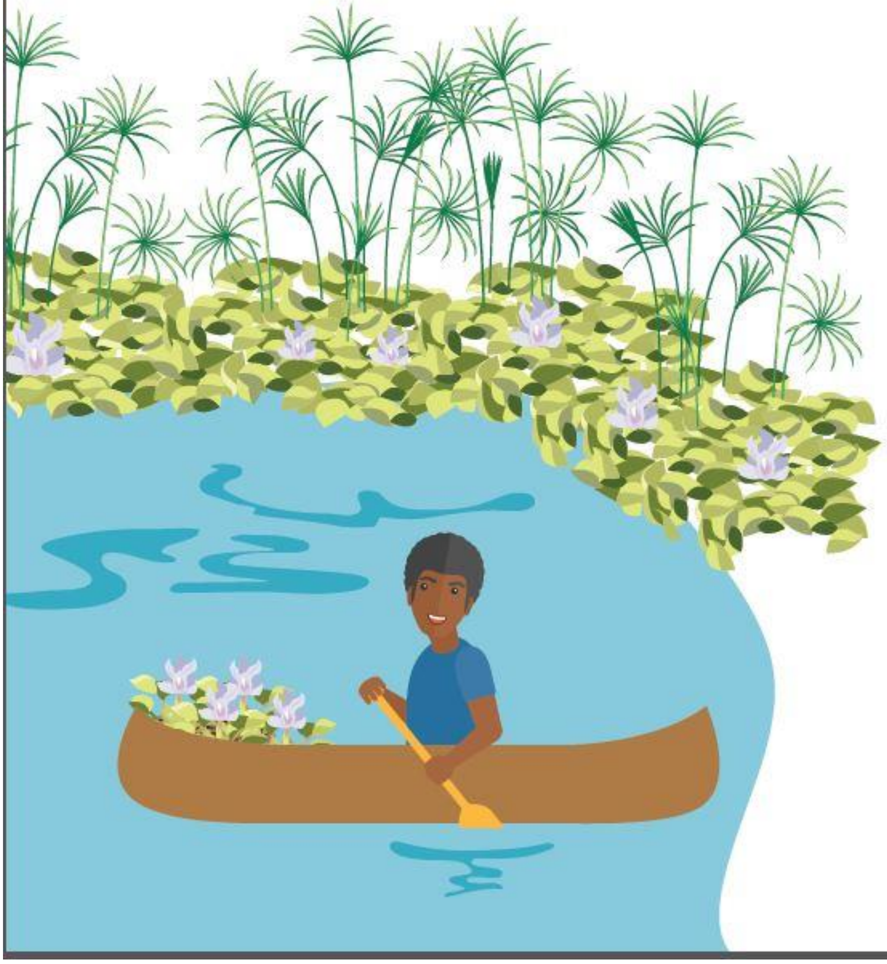

1.
Water hyacinth on
a lakeshore

The water hyacinth is an abundant plant that provides very good and cheap compost. Producing compost out of this plant helps to reduce its negative effects when it clogs waterways or invades rice fields.



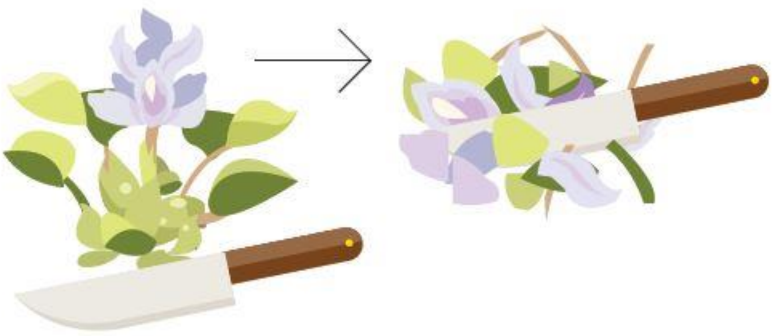
2. Collection and transportation of water hyacinth

The water hyacinth is abundant on the lakeshore and is manually collected and transported on a canoe landward.



3.

Cutting water hyacinth roots away and chopping the plant

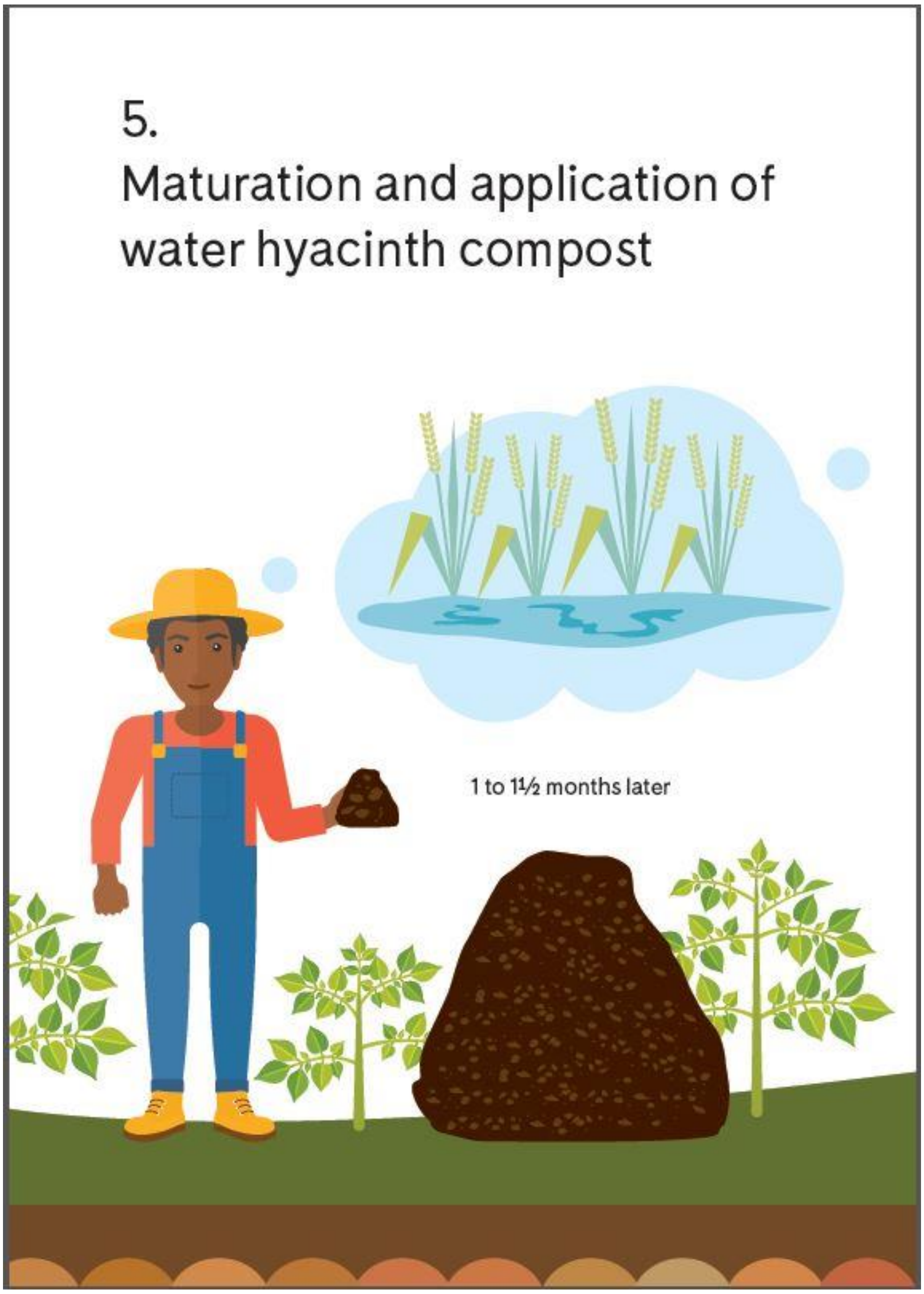


Once gathered on the lakeshore, remove the roots. Afterwards, chop the rest of the plants into to 2 cm pieces.

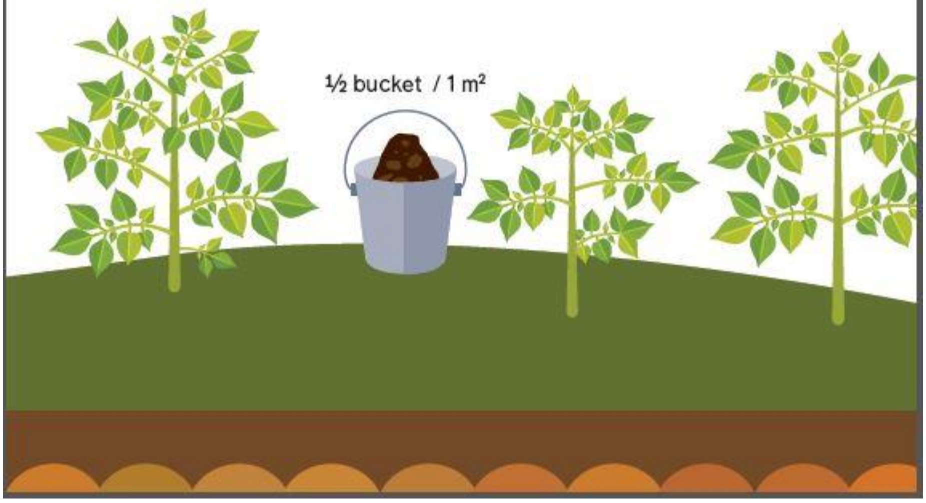
4.

Ingredients and preparation of water hyacinth compost

Put branches on the ground. Put chopped water hyacinth on the branches (as high as your underarm). Put Mango leaves on the chopped water hyacinth. Put cow dung mixed with earth on the Mango leaves. Both layers as high as your palm. Add water generously. Start again with water hyacinth. Stop when the pile is as high as your breast. Water the pile every 2 days and turn it onto a new base every 2 weeks.

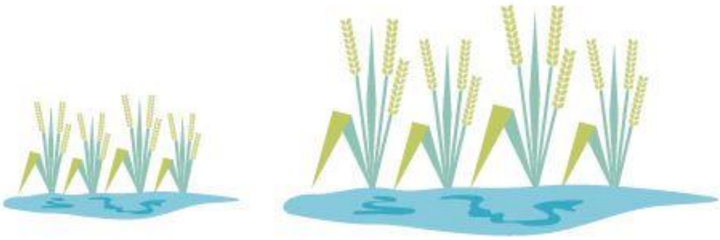

5.
Maturation and application of water hyacinth compost
1 to 1½ months later

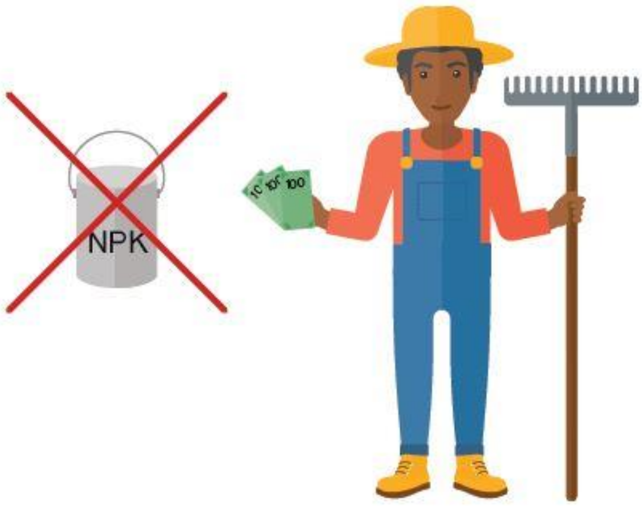
With a dosage of one kilo for 1 m² (10 ton per hectare), the compost can be directly spread and mixed with the soil on the field. It is ready for planting rice and different vegetables (e.g. potatoes, pumpkins, cucumbers, zucchinis, beans, ...).



6.
Advantages of using water hyacinth compost

The compost guarantees better crop yields and saves money for buying chemical fertilizers. Depending on the degree of soil degradation, water hyacinth compost can be applied once a year for 2 or 3 years.





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Using water hyacinth as source of compost alleviates its negative impacts on ecosystem (e.g. alteration of water quality affecting aquatic life) and local livelihoods (e.g. waterway clogging for fishing, invasion of rice fields) while supplying an excellent fertilizer to sustainably improve soil fertility.

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Eidesstattliche Versicherung

Ich, Tsiry Fanilonirina Rakotoarisoa, versichere, dass ich die Abhandlung selbständig und ohne unerlaubte Hilfe verfasst habe, die benutzten Hilfsmittel vollständig angegeben und die Zitate und Quellen wissenschaftlich korrekt ausgewiesen habe und, dass die Anforderungen an die Abhandlung nach der Zulassung zur Promotion erfüllt sind.

Hildesheim den 20.12.2016

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