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

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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.

RÉSUMÉ

Les espèces envahissantes ont été récemment identifiées comme l'une des principales menaces pour la protection de la biodiversité. La jacinthe d'eau (*Eichhornia crassipes*) est l'une des plantes envahissantes les plus problématiques au monde. Elle est connue dans plus de 50 pays tropicaux et subtropicaux. Cette plante est la source de nombreux problèmes écologiques et économiques et affecte par conséquent les écosystèmes ainsi que les moyens de subsistance des populations humaines des régions concernées. Elle est rencontrée au niveau des zones humides de l'Alaotra englobant le plus grand lac de Madagascar, le premier grenier à riz de l'île et qui tient une place importance pour la pêche. Les méthodes pour contrôler la prolifération des jacinthes d'eau semblent ne pas pouvoir être appliquées à cause des limitations institutionnelles et financières de Madagascar. L'utilisation de la jacinthe d'eau, comme fertilisants, fourrage ou dans la production artisanale, pourrait représenter une alternative pour améliorer les moyens de subsistance de la population locale. Au cours de cette étude, des données socioéconomiques touchant les parties prenantes des zones humides de l'Alaotra ont été collectées dans trois localités qui se différencient au niveau de la dégradation de l'habitat naturel (Anororo, Andreba et Vohimarina). Les objectifs de cette recherche consistent d'une part à décrire des différents moyens de subsistance locale et d'autre part à identifier les moteurs et barrières de l'utilisation de la jacinthe d'eau. Le contexte général affectant la sécurité des moyens de subsistance pourrait bloquer l'acceptation de l'utilisation de cette plante. Cependant l'information ainsi que des supports financiers et techniques pour les parties prenantes locales sont des moteurs importants pour encourager l'usage de la jacinthe d'eau au niveau du lac Alaotra.

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 sub-tropical 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 (snails for bilharzia or *Anopheles* sp. for malaria) and therefore constitutes a threat to

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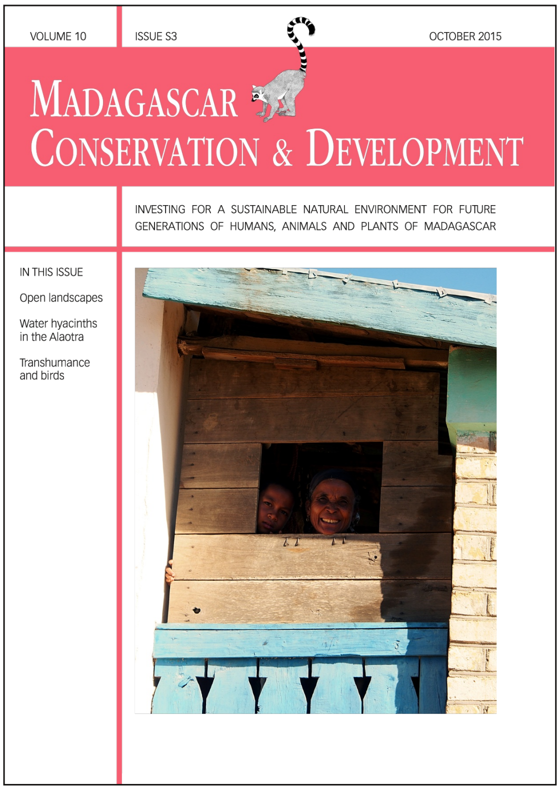

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human health (Masifwa et al. 2001, Plummer 2005).

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$ 12 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.

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", S17° 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", S17° 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 Gare (E48° 30' 08.0", S17° 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. Supplementary Material).

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 (cf. Supplementary Material).

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.

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 (Table 1). A few participants (4%) affirm that there is no invasive plant species in the wetlands.

(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 (Table 2).

Table 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 plants species at Lake Alaotra	English names	Malagasy names	Percentage of respondents
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

(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 (Table 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 hyacinths? 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 (Table 3).

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

Table 2. Current and Potential usage of water hyacinth expressed by stakeholders during interviews (n=120) within the three study sites (Vohimarina, Andreba and Anororo). Current uses do not reflect the potential uses.

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

Table 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 *Eichhornia 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 / Build fence to contain the plant	6
Invest only in agriculture	3

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 waterbird 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 (cyperus) 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 m2) 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 (≥ 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/m3 in comparison to 9.8 kJ/m3 for firewood (Thomas and Eden 1990). However, briquettes out of this plant produce 8.6 kJ/m3 which is comparable to charcoal (9.6 kJ/m3) (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).

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 uses 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 uses seems to be uncertainty linked to long term investments and planning.

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SUPPLEMENTARY MATERIAL.

AVAILABLE ONLINE ONLY.

S1. Questionnaire for stakeholders' typology in the Alaotra.

S2. Questionnaire regarding the identification of the drivers and barriers of using the water hyacinth at Lake Alaotra.