VOLUME 15 ISSUE 1 DECEMBER 2020

MADAGASCAR CONSERVATION & DEVELOPMENT

INVESTING FOR A SUSTAINABLE NATURAL ENVIRONMENT FOR FUTURE GENERATIONS OF HUMANS, ANIMALS AND PLANTS OF MADAGASCAR

IN THIS ISSUE

Covid-19

System Rice Intensification

Pet parrots

Madagascar Conservation & Development is the journal of Indian Ocean e-Ink. It is produced under the responsibility of this institution. The views expressed in contributions to MCD are solely those of the authors and not those of the journal editors or the publisher.

All the Issues and articles are freely available at http://www.journalmcd.com

Contact Journal MCD
info@journalmcd.net for general inquiries regarding MCD
funding@journalmcd.net to support the journal

Madagascar Conservation & Development
Institute and Museum of Anthropology
University of Zurich
Winterthurerstrasse 190
CH-8057 Zurich
Switzerland

io@i

Indian Ocean e-Ink
Promoting African Publishing and Education
www.ioeink.com

MISSOURI BOTANICAL GARDEN

Missouri Botanical Garden (MBG)
Madagascar Research and Conservation Program
BP 3391
Antananarivo, 101, Madagascar

TABLE OF CONTENTS

EDITORIAL

3 The perfect storm. *Waeber, P. O., Wilmé, L*

40 Impressum

ARTICLES

5 The use of System of Rice Intensification (SRI) near Maromizaha Protected Area, Madagascar. *Whitman, K. L., Ratsimbazafy, J. H., Stevens, N. J.*

13 Motivations of pet parrot ownership and captive conditions of the pets in Madagascar. *Rodríguez, L., Reuter, K. E., Schaefer, M. S. 2020.*

19 Vegetation thresholds for the occurrence of millipedes (Diplopoda) in different tropical forest types in Andasibe, Madagascar. *Spelzhausen, L. R., Wesener, T., Schütte, K. 2020.*

27 An alternative for agriculture at Lake Alaotra, Madagascar: organic fertilizer and soil amendment from the invasive wateR hyacinth (*Eichhornia crassipes*). *Rakotoarisoa, T., Richter, T., Schmidt, N., Mantilla Contreras, J.*

SHORT NOTE

35 Linking biodiversity conservation and education: perspectives from education programmes in Madagascar. *Brias-Guinart, A., Pyhälä, A., Cabeza, M. 2020.*

EDITORIAL http://dx.doi.org/10.4314/mcd.v15i1.6

The perfect storm

This has been an unusually tough year. The SARS-CoV-2, severe acute respiratory syndrome coronavirus 2, emerged in January 2020. The World Health Organization announced "covid-19" as the name of this new disease on 11 February 2020 while the world kept looking to China. Within weeks, the virus managed to circumvent the globe and engulfed the world into a pandemic unlike any seen for generations (Platto et al. 2020). To date, more than 73 million people have been infected and some 1.6 million people have died according to the World Health Organization (WHO 2020).

Science has been issuing warnings of looming pandemics for decades. "The single biggest threat to man's continued dominance on the planet is the virus." A punching quote from the Nobel laureate Joshua Lederberg in the 1990s. Previous epidemics and outbreaks like SARS in 2003, bird flu H5N1 in 2005, and Ebola (2014–2016), were alarm bells (Servigne et al. 2020). Yet, we went about our business ignoring those early warning signs. It seems that our immediate priorities are more pressing, our collective memory short and the Spanish flu—the last global pandemic caused by the HiN1 influenza that killed more than 50 million people or more than 2.5% of the World population, within the span of 2 years—too distant in time to create concern.

The global society came to a quasi-standstill. Travelling dropped to almost zero during the first wave experienced in March and April this year. The skies were almost free of airplanes. Oceans free of boats. Streets almost empty. Many national borders closed. People forced to stay in their houses. Only Nature took a moment to breathe (Corlette et al. 2020). This situation of reduced human activities, coined "anthropause" by some scientists (Rutz et al. 2020, Stockstad 2020), led to dramatic drops in air pollution, and for example whales being seen in waters that usually are noisy and full of boats.

Impacts of this ongoing pandemic are devastating on several levels. The tragic loss of so many human lives due to this new disease risks leading us forgetting about HIV, Malaria, Tuberculosis, and other diseases, causing annually millions of casualties. The Pandemic has battered the economy, disrupted supply chains and slowed international trade. It has disrupted the livelihoods of most of humanity. Many governments are struggling with the devastating economic costs. Already unlikely to be reached by 2030 before the pandemic, the Sustainable Development Goals now need to be carefully reassessed, as the pandemic's impacts likely further threaten many of the 169 SDGs targets (Naidoo and Fisher 2020).

So far, Africa remains one of the least affected regions worldwide by the virus despite an announced disaster (Nordling 2020). In Madagascar, a scientific study carried out over nine months by the Institute Pasteur and the Ministry of Health suggests a covid-19 prevalence level of close to 40% (Tétaud and Spiegel 2020). This means considerable spreading of the virus within the population, which is trending towards a level experts would label as herd immunity (but see Fontanet and Cauchemez 2020). Madagascar has officially accounted for less than 300 deaths. Taking this number with a grain of salt, the reason may be found in its demographic profile: some 60% of 27 million inhabitants are of age 25 or younger, while the higher covid-19 risk groups (>55 years) comprise less than 10% of the population. Science still needs to find the answer to this question and many more (e.g., Nordling 2020, Zeberg and Pääbo 2020).

A rare positive note emerging from this pandemic: Science emerges as a winner. Never in human history was the development of vaccines—a global race leading to some +150 candidates, some with >90% effectiveness—so fast and efficient. It took science less than 11 months from the discovery of this new virus to the distribution of the vaccines. This is truly remarkable and a result of international collaborations. Now that first candidates are already on the market, it remains to be seen how distribution of these vaccines will play out. How collaborative will human society actually be? Who will get a shot first? Who will have to pay for it and how much? More importantly, who will likely never get a chance to be vaccinated against covid-19? We refrain from conspiracies, but politics has shown in this spectral year of 2020, that, if anything, it can be extremely disruptive and divisive—take the USA as a sully example. To date, 7.48 billion vaccine doses have been pre-purchased. Some 40% may go to middle- and low-income countries that account for some 85% of the world population (So and Woo 2020). Nine out of 10 people from 67 low- and middle-income countries are set to miss out on the covid-19 vaccination in 2021. Madagascar is one of those (Oxfam 2020). Sadly, maybe herd immunity—through exposure to the virus, not vaccination—might be a more realistic strategy after all for some countries.

A number of factors can come into play and potentially pave the way for the emergence of infectious diseases like covid-19. (1) The globe has become a village. Increased mobility allowed more than 4.5 billion passengers to fly in 2019. Within a day, one can hop around half the globe, and so can a virus. (2) Over half of the human population lives in urban areas. Increasingly high-density cities are an ideal habitat for a virus to jump from host to host. (3) Climate defines the biophysical boundaries that allow species or populations to thrive. Climate change—leading to increased temperatures, changing rainfall patterns, increased frequency of extreme weather events—are shifting these boundaries (Ceballos et al. 2020, Watsa et al. 2020) and laying grounds for vectors—insects, bats, people—and their diseases to spread and establish. (4) Digging deeper into natural habitats by ways of agricultural expansion, infrastructure, and wood extraction—to mention the most salient direct drivers of deforestation—are increasingly exposing humans to zoonotic diseases. Wildlife trade is yet another means to bring humans directly in contact with animals—while calls for bans only risk undermining their purpose (Roe et al. 2020)—potentially further opening the doors to viruses spreading (McCleery et al. 2020).

A tough year to say the least. The years to come, however, will only become more challenging. While we will eventually overcome this pandemic, the virus will likely remain amongst us, similarly to the flu viruses. A global economic depression is looming and recovering from this will be a gargantuan task, while the pandemic may have revealed that our economic system is sick and not adapted to the survival of our species. The biggest threat to all life on Earth is already underway and will only grow in severity—the climate crisis. All in all, the perfect storm.

Citation Waeber, P. O., Wilmé, L. 2020. The perfect storm. Madagascar Conservation & Development 15, 1: 3–4. http://dx.doi.org/10.4314/mcd.v15i1.6

Patrick O. Waeber
Forest Management and Development
Swiss Federal Institute of Technology (ETH) Zurich, Switzerland
powaeber@gmail.com; patrick.waeber@usys.ethz.ch

Lucienne Wilmé
Missouri Botanical Garden
Madagascar Research & Conservation Program, BP 3391,
Antananarivo 101
&
World Resources Institute
Madagascar Program, BP 3884
Antananarivo 101
lucienne.wilme@mobot-mg.org; lucienne.wilme@wri.org

REFERENCES

Ceballos, G., Ehrlich, P. R. and Raven, P. H. 2020. Vertebrates on the brink as indicators of biological annihilation and the sixth mass extinction. Proceedings of the National Academy of Sciences of the United States of America 117(24): 13596–13602. <https://doi.org/10.1073/pnas.1922686117>

Corlett, R. T., Primack, R. B., Devictor, V., Maas, B., Goswami, V. R., et al. 2020. Impacts of the coronavirus pandemic on biodiversity conservation. Biological Conservation 246: #108571. <https://doi.org/10.1016/j.biocon.2020.108571>

Fontanet, A. and Cauchemez, S. 2020. COVID-19 herd immunity: where are we? Nature Reviews Immunology 20, 10: 583–584. <https://doi.org/10.1038/s41577-020-00451-5>

McCleery, R. A., Fletcher Jr., R. J., Kruger, L. M., Govender, D. and Ferreira, S. M. 2020. Conservation needs a COVID-19 bailout. Science 369: 515–516. <https://doi.org/10.1126/science.abd2854>

Naidoo, R. and Fisher, B. 2020. Reset sustainable development goals for a pandemic world. Nature 583: 198–201. https://doi.org/10.1038/d41586-020-01999-x

Nordling, L. 2020. Africa's pandemic puzzle: why so few cases and deaths? Science 369: 756–757. <https://doi.org/10.1126/science.369.6505.756>

Oxfam. 2020. Campaigners warn that 9 out of 10 people in poor countries are set to miss out on COVID-19 vaccine next year. Press release published 9 December 2020. Available online <shorturl.at/jsEIP>

Platto, S., Xue, T. and Carafoli, E. 2000. COVID19: an announced pandemic. Cell Death & Disease 11(9): #799. <https://doi.org/10.1038/s41419-020-02995-9>

Roe, D., Dickman, A., Kock, R., Milner-Gulland, E. J., Rihoy, E. and 't Sas-Rolfes, M. 2020. Beyond banning wildlife trade: COVID-19, conservation and development. World Development 136: #105121. <https://doi.org/10.1016/j.worlddev.2020.105121>

Rutz, C., Loretto, M.-C., Bates, A. E., Davidson, S. C., Duarte, C. M., et al. 2020. COVID-19 lockdown allows researchers to quantify the effects of human activity on wildlife. Nature Ecology & Evolution 4: 1156–1159. <https://doi.org/10.1038/s41559-020-1237-z>

Servigne, P., Stevens, R. and Chapelle, G. 2020. Another End of the World is Possible: Living the collapse (and not merely surviving it). John Wiley & Sons.

So, A. D. and Woo, J. 2020. Reserving coronavirus disease 2019 vaccines for global access: cross sectional analysis. BMJ 371: m4750. <https://doi.org/10.1136/bmj.m4750>

Stockstad, E. 2020. Pandemic lockdown stirs up ecological research. Science 369: 893. <https://doi.org/10.1126/science.369.6506.893>

Tétaud, S. and Spiegel, A. 2020. Près de 40% des Malgaches auraient été infectés par le Covid-19. RFI Interview. Available online <shorturl.at/lxNR2>

Watsa, M. and Wildlife Disease Surveillance Focus Group. 2020. Rigorous wildlife disease surveillance. Science 369: 145–147. <https://doi.org/10.1126/science.abc0017>

WHO 2020. Coronavirus disease (COVID-19) dashboard. <https://covid19.who.int/>

Zeberg, H. and Pääbo, S. 2020. The major genetic risk factor for severe COVID-19 is inherited from Neanderthals. Nature 587: 610–612. <https://doi.org/10.1038/s41586-020-2818-3>

ARTICLE http://dx.doi.org/10.4314/mcd.v15i1.1

The use of System of Rice Intensification (SRI) near Maromizaha Protected Area, Madagascar

Karie L. Whitman[I], Jonah H. Ratsimbazafy[II], Nancy J. Stevens[I]

Correspondence:
Nancy J. Stevens
Ohio University, Athens, OH 45701, United States
Email: stevensn@ohio.edu

ABSTRACT
Rice agriculture is key to food security in Madagascar, yet land conversion for traditional rice growing, or *tavy*, exerts significant deforestation pressures. A method known as System of Rice Intensification (SRI), has been promoted by development and conservation groups near Maromizaha Protected Area in Madagascar on the premise that it is more sustainable than traditional rice-growing practices. Although the aim of promoting SRI in the region has been to reduce deforestation pressures, preliminary observations suggest that SRI has not been widely adopted. Household surveys and observations were conducted in the communities surrounding Maromizaha Forest to assess the use of SRI, and to inform future decisions on SRI training and other approaches. Results reveal that SRI has not been widely adopted despite familiarity and generally positive perceptions of the method's usefulness. Various issues with SRI adoption near Maromizaha include disparities in access to training, the number of people per household available to participate in farming tasks, and the amount of land appropriate for implementation of SRI. We highlight questions surrounding SRI's perceived impacts upon rice yield and to explore locally-informed sustainable agricultural alternatives to both traditional rice growing practices and SRI to reduce deforestation pressures in the Maromizaha area.

RÉSUMÉ
L'agriculture rizicole est la clé de la sécurité alimentaire à Madagascar en même temps que la conversion de terres pour l'agriculture traditionnelle sous la forme de *tavy* est une source de déforestation. Des méthodes d'intensification agricole ont été proposées par des groupes de développement et de conservation. Une de ces méthodes, le Système de Riziculture Intensive (SRI), a été encouragée dans le site d'étude de l'Aire protégée de Maromizaha sur le principe d'une plus grande viabilité par rapport aux pratiques traditionnelles de la riziculture. Si la promotion de l'SRI dans la région était motivée par une réduction des pressions de déforestation, des indications préliminaires suggèrent que le SRI n'a pas été largement adopté. Des enquêtes auprès des ménages et des observations ont été menées auprès des communautés riveraines de la forêt de Maromizaha afin de comprendre les choix des intéressés afin de mieux orienter les futures décisions sur la formation à dispenser pour l'SRI et d'autres approches. Les résultats révèlent que le SRI n'a pas été largement adopté malgré la familiarité et des perceptions généralement positives de l'utilité de la méthode. Divers obstacles à l'adoption du SRI autour de Maromizaha comprennent les disparités dans l'accès à la formation, le nombre de personnes par ménage disponibles pour participer aux tâches agricoles et la quantité de terres appropriées pour la mise en œuvre du SRI. Les questions relatives aux impacts perçus du SRI sur la production de riz sont exposées et mises en contexte avec des alternatives agricoles durables aux pratiques traditionnelles de la culture du riz connues localement et au SRI afin de réduire les pressions de la déforestation dans la région de Maromizaha.

INTRODUCTION
Madagascar is an economically developing nation that ranks fifth among the 25 poorest nations of the world, with at least 71.5% of the population living in poverty (Jahan et al. 2016, World Food Programme 2016, Raveloharison 2017). It ranks 4th highest of 119 countries scored for hunger risk, with 42.3% of the population undernourished (von Grebmer et al. 2017). Among the 10 countries most vulnerable to food security impacts from natural disasters, local conditions are exacerbated by both local and global climate change (World Food Programme 2016). This vulnerability is exemplified by combined effects of a prolonged drought in 2015 into 2016 (Ibrahima and Rakotonirainy 2016, World Food Programme 2016), followed by Cyclone Enawo in February 2017, resulting in increased food prices, and intense erosion in areas lacking ground cover. Much of the island's population depends on smallholder subsistence agriculture, with rice constituting a culturally significant and vital food staple for much of Madagascar's population. As such, food security in Madagascar depends largely on effective and sustainable rice farming (Minten and Barrett 2008, Rist et al. 2014).

Notably, Madagascar also exhibits remarkable levels of biodiversity, with about 85% of species endemic to the island (Goodman and Benstead 2005). This has served as a driver of revenue for Madagascar's economy; indeed, 16.2% of Madagascar's GDP derives from tourism (total contribution – World Travel and Tourism

I Ohio University, Athens, OH 45701, United States
II Groupe d'Étude et de Recherche sur les Primates de Madagascar (GERP), Antananarivo 101

Citation Whitman, K. L., Ratsimbazafy, J. H., Stevens, N. J. 2020. The use of System of Rice Intensification (SRI) near Maromizaha Protected Area, Madagascar. Madagascar Conservation & Development 15, 1: 5–12. http://dx.doi.org/10.4314/mcd.v15i1.1

Council 2018). Since most of Madagascar's unique and charismatic species depend on forested habitats, effective forest management is key for biodiversity conservation (Goodman and Benstead 2005, Schwitzer et al. 2013, Waeber et al. 2015). Forest management also positively impacts human livelihoods due to the ecosystem services that forests provide, for example, in slowing soil erosion, cycling nutrients, influencing local climate conditions such as rainfall, and providing habitat for pollinators and/or pest predators (Costanza et al. 1997, Thrupp 2000, Toledo and Burlingame 2006, Karp et al. 2013, Mahmood et al. 2014). As such, habitat degradation threatens not only biodiversity, but also the future of agricultural productivity.

TRADITIONAL *TAVY* RICE AGRICULTURE. A slash-and-burn agricultural practice known in Malagasy as *tavy* (see Box 1) has been blamed for accelerated deforestation throughout Madagascar along with similar slash-and-burn practices in other tropical forest zones of the world (Geist and Lambin 2002, McConnell et al. 2004, Schwitzer et al. 2013, Brimont et al. 2015). Yet *tavy* holds great cultural and historical significance in Madagascar, as well as it being labor-efficient, requiring few inputs, and being potentially less prone to cyclone damage—all important considerations for resource-poor farmers (Raik 2007, Pollini 2010, Froger and Méral 2012, Desbureaux and Brimont 2015). The narrative of *tavy* as the primary driver of Madagascar's deforestation is debated, particularly in comparison to large-scale extractive industries now and during colonial times (Jarosz 1996, Kull 2000, Pollini 2010, Scales 2012). However, at present, factors such as movement toward permanent infrastructure, land-use restrictions, and increasing population densities have caused an increase in pressure on available land (Pollini 2010, Brimont et al. 2015). This makes slash-and-burn agriculture a proximate cause of deforestation, though it is important to remember that the ultimate causes are complex, global in scale, and largely beyond the control of individual smallholder farmers (Jarosz 1996, Pollini 2010). Nevertheless, tensions exist regarding agricultural practices in and around remaining forest resources (Ratsimbazafy et al. 2014, Brimont et al. 2015). One place where such tensions are particularly felt is in the communities surrounding Maromizaha Protected Area in eastern Madagascar, serving to focus the geographic scope of this study.

SYSTEM OF RICE INTENSIFICATION (SRI). In efforts to ensure reliable access to food in harmony with biodiversity conservation in places like Maromizaha, various agricultural techniques have been introduced with the aim of minimizing deforestation pressures (Moser and Barrett 2003, Serpantié and Rakotondramanana 2014, Brimont et al. 2015). In particular, a method called System of Rice Intensification —SRI (Uphoff 2007) has been promoted as a sustainable alternative to *tavy* to increase rice yield and relieve deforestation pressures (Stoop et al. 2002, Moser and Barrett 2003, Brimont et al. 2015). Yet the SRI technique is meant to be used as an improvement to rice paddy agriculture that typically occurs in the lowlands and is quite different from *tavy* which is usually practiced on hillsides (Box 1). As such, a false dichotomy exists

Comparing Rice Agriculture Techniques

Rice agriculture in Madagascar can either be rain-fed or irrigated. Rain-fed rice agriculture typically occurs on hillsides utilizing a rotating plot system, whereas irrigated forms of rice agriculture occur in flat or terraced areas of land that are consistently farmed each year.

Tavy

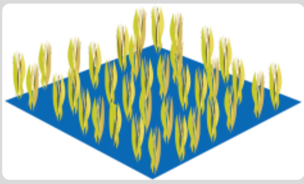
Tavy is a traditional method of rain-fed, hillside rice agriculture that involves cutting and burning vegetation prior to sowing rice seeds. *Tavy* plots are typically used for one or two years and then left to lie fallow for a time, as new areas are burned and added to the rotation (McConnell et al. 2004, Styger et al. 2009). Traditionally, these new areas would be forested. However, *tavy* encroachment upon protected forest areas is now banned in Madagascar (National Assembly of the Republic of Madagascar 2015). Though use of fire is discouraged, farmers are permitted to continue *tavy* in designated areas of previously cultivated fallow land known as *savoka*. Many farmers do not have sufficient plots to allow for adequately long (8-15 years or more) fallow periods between rotations, hence soil quality and agricultural productivity in many locales is decreasing (McConnell et al. 2004, Styger et al. 2009, Brimont et al. 2015, Desbureaux and Brimont 2015).

Conventional Paddy

Conventional paddy rice agriculture occurs in permanent lowland or terraced fields. The soil is tilled each year before planting. It is typically flooded throughout the course of the rice growing season, so it requires some level of water management and irrigation. The continuous flooding is said to aid in weed management. Seeds are sprouted in a small corner of a rice field and allowed to grow for 20-60 days before being transplanted. Farmers using this method typically plant two or three seedlings (*ketsa*) together in a bunch, estimating the space between bunches with their eyes or hands. The seedlings in this type of agriculture are not planted in a line, but are rather scattered throughout the field (*saritaka*) wherever there is space (Glover 2011, Berkhout et al. 2015).

SRA

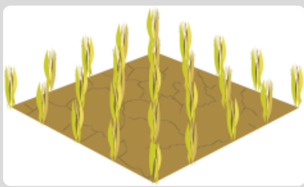
Improved Rice System or Système de Riziculture Améliorée (SRA) is an improvement upon conventional paddy agriculture that encourages uni-directional rows (as opposed to a grid) and external inputs such as fertilizer (either organic or inorganic). SRA may also include use of mechanical weeding tools and improved rice varieties (Glover 2011, Serpantié and Rakondramanana 2014).



SRI

System of Rice Intensification (SRI) is an irrigated, lowland, permanent method of rice agriculture developed in the Madagascar highlands in the 1970s and 80s (Stoop et al. 2002, Glover 2011). SRI comprises a set of practices related to the timing and placement of rice seedlings to increase yield productivity. Practices include carefully raising seedlings in a nursery, transplanting seedlings at 8-15 days, transplanting single seedlings in a 25cm grid pattern, and alternating dry periods in order to better aerate the soil. Farmers sometimes use a mechanical rotary weeder and apply organic fertilizer when possible (Uphoff 2007, Glover 2011).

Proponents of SRI see it as a sustainable alternative to conventional methods of rice agriculture, given that increases in productivity require low external inputs (Stoop et al. 2002, Uphoff 2008). Since SRI aims to intensify yields on existing plots (in contrast with the plot rotations typically associated with *tavy*), SRI is viewed as a sustainable strategy to reduce deforestation and habitat degradation pressures (Moser and Barrett 2003). However, more research is needed in different types of habitats to test the assumption that this method of rice intensification can be sustainable in the long term, in the context of broader debates related to the long-term implications of land-sparing versus land-sharing (Perfecto and Vandermeer 2010, Phalan et al. 2011).



in much of the literature regarding the promotion of SRI, where it is purported as an alternative to *tavy*. An initial hypothesis in the promotion of SRI was that intensifying lowland production would reduce clearing on upland slopes (Brimont et al. 2015). However, the promotion of an intensified lowland technique to farmers who are doing upland slash-and-burn agriculture rests on many assumptions and skips quite a few steps. In order to successfully adopt SRI, it is reasonable to assume that a farmer would first need a lowland rice field, and second, time and labor resources necessary to carry out the core practices that SRI encompasses, since SRI requires different labor inputs than does *tavy* (Stoop et al. 2002, Moser and Barrett 2003, Box 1). Despite targeted SRI training efforts over the past decade in and around Maromizaha, no study to date has documented empirical evidence on the productivity of SRI nor its adoption in the region (Glover 2011, Berkhout et al. 2015). Studies in the area have focused on fallow succession in *tavy* systems (Styger et al. 2007, Styger et al. 2009), and a study on SRI adoption was conducted in two other regions of Madagascar in 2003 (Moser and Barrett 2003). Those authors found high rates of disadoption of SRI in the areas they studied, and noted that poor farmers were less likely to adopt the technique. Moreover, Moser and Barrett noted that the promotion of SRI in rural Madagascar may contribute to income inequality. Over a decade has passed since that study, and SRI is still being widely promoted in the region of interest. As such, additional research is needed on whether farmers find SRI to be a worthwhile and practical endeavor at present, and the circumstances that influence this assessment, such as differential access to training in the method.

For at least a decade, discussion of "evidence-based conservation" has emphasized the importance of considering data in conservation decision-making practices (Sutherland and Wordley 2017, Petrovan et al. 2018). Presently, the lack of evidence on environmental and social contexts of SRI adoption makes it difficult to determine whether it is wise for development organizations to continue promoting SRI to optimize food security and biodiversity conservation at Maromizaha. This study explores SRI training, adoption, and perceptions of efficacy in and around Maromizaha Protected Area – a step toward better informing food security and conservation efforts.

METHODS

STUDY AREA. One of Madagascar's largest remaining contiguous humid forests, the Ankeniheny-Zahamena Corridor (CAZ), is located in the mountainous region of eastern Madagascar. The CAZ provides habitats for a myriad of plant and animal species, and because forest fragmentation threatens biodiversity, maintaining the contiguity of the CAZ is imperative to conservation goals (Turner and Corlett 1996, Schwitzer et al. 2013). Located at the southernmost tip of the CAZ is Maromizaha Protected Area (Figure 1), a 1880 hectare protected area ranging in elevation between 794m and 1224m (Ramanahadray 2009). Maromizaha provides habitat for at least 13 species of endangered lemurs alongside hundreds of other unique species of animals and plants, and is among the few places where two of the highest conservation-priority lemur species, *Indri indri* and *Propithecus diadema*, live in sympatry (Table 1, Portela et al. 2012, Schwitzer et al. 2013, GERP 2015b). Maromizaha Protected Area is presently managed by Groupe d'Étude et de Recherche sur les Primates de Madagascar (GERP), a non-profit primate research organization. In 2015, a total of 1257 people were reported to live in the villages surrounding

Table 1. Summary of recorded biodiversity in Maromizaha Forest (numbers are minimum number of species based on Schwitzer et al. 2013, GERP 2015b, GERP 2016).

Maromizaha forest biodiversity	
Vascular plants	433 species
Moths and butterflies	800 species
Beetles	400 species
Birds	77 species
Amphibians	60 species
Reptiles	20 species
Non-primate mammals	30 species
Lemurs	13 species

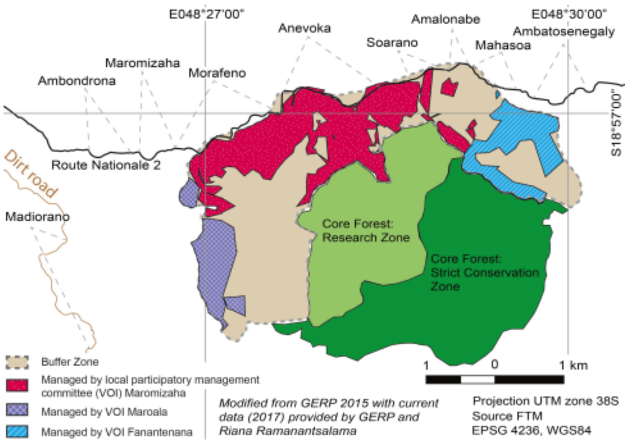


Figure 1. Map of Maromizaha Forest showing various zones of use. (Modified from GERP 2015b)

Maromizaha Forest (Figure 1), many of whom are farmers (Randrianarison et al. 2015, Surrans 2015). In this area, *tavy* has been cited as a primary driver of deforestation, and is forbidden in the forest and protected area but still occurs in fallow lands and non-protected forested areas. Notably, fallow periods in the area have decreased in the recent past due to human expansion pressures and land availability (Pollini 2010, Styger et al. 2009, Ratsimbazafy et al. 2014, GERP 2015a,b, Brimont et al. 2015).

Over the last decade, SRI has been promoted around Maromizaha by a number of development organizations, including the Peace Corps (Uphoff 2008, GERP 2015a). Promotional efforts include training sessions and the development of a Peace Corps SRI demonstration field in the village of Anevoka. Preliminary observations in 2015 suggested uneven adoption of SRI by community members, with the demonstration field underutilized by 2016. For these reasons, Maromizaha Protected Area can serve as a pilot location to explore knowledge and perceptions about SRI.

STUDY DESIGN. We anticipated that uneven adoption of SRI in the Maromizaha region may reflect either that not all people were familiar with SRI, or that not everyone familiar with SRI adopted its methods. To test among these possibilities, we used surveys to evaluate awareness about SRI in the Maromizaha community, together with the extent to which SRI techniques have been tried and adopted, tried and abandoned, or not tried at all. To provide more context surrounding familiarity, we also assessed the level of SRI training received and recorded the village of residence as it pertains to proximity to training resources. We predicted higher SRI use among farmers who had received formal training and who reside in close proximity to training and resources.

A decision not to use SRI may reflect that SRI is not considered an effective means of increasing rice yields. To test this hypothesis, we asked farmers whether they perceived an overall yield increase in fields where SRI was used. We asked farmers not using SRI a series of questions about their rice farming techniques, including whether they continued to use *tavy*. Because SRI is thought to be more labor-intensive than *tavy* (Moser and Barrett 2003), we asked how many people helped with farming in each household to provide insight into labor availability in relation to SRI adoption. We predicted that families with fewer labor resources would be less likely to have adopted SRI.

SURVEY METHODS. Household survey questionnaires were conducted between June and August of 2016, recruiting one adult (18 years of age or older) representative to survey from as many households as possible in all nine villages. Participants were engaged opportunistically in village settings, and via purposive snowball sampling in areas that were more difficult to access. All data collection described herein was reviewed and approved by the Institutional Review Board at Ohio University (IRB 16-X-58), with permissions in Madagascar obtained through the official offices GERP and MICET. Approved consent forms were used in the recruitment of participants, participation was voluntary, and no material compensations were offered in exchange for participation. Participants remained anonymous and were assigned survey numbers. To ensure understanding of the instrument items, all surveys were conducted face-to-face in Malagasy with an experienced translator-guide from the Maromizaha area. To address the possibility that respondents sometimes anticipate tangible benefits deriving from research participation, consent forms read to each respondent explained in Malagasy that they would receive no benefits other than knowing that they had contributed to the research project.

LIMITATIONS OF THE STUDY DESIGN. At the time the survey instrument was designed, our knowledge of the rice agriculture dynamics in the area were limited to what we gleaned from the literature and what we discussed with those who worked in the area. A false dichotomy between *tavy* and SRI was represented in the literature, but we found that some farmers had multiple fields (both upland and lowland) and used multiple rice agriculture techniques. The survey instrument yields insights about the techniques that SRI farmers and non-SRI farmers employed in their rice fields (e.g. spacing between seedlings, age at planting of seedlings, etc.). However, we cannot assess in detail other agricultural methods in the study area apart from SRI and *tavy*. The survey instrument is included in the supplementary materials. Results of only a small subset of questions are detailed in this paper.

RESULTS

SAMPLE OVERVIEW. A total of 174 household questionnaire surveys were completed in the villages surrounding Maromizaha Forest, with only 17 households of those asked declining to participate in the research. In total, surveys included approximately two-thirds (66%) of the 262 total households recorded by Surrans (2015). Although the number of households in the area has increased since 2015, we sampled all available households that were willing to participate, assembling a robust sample of farmer perspectives for the study. Respondents were engaged across the nine villages (Figure 2). Of the 174 respondents, 164 farmed rice and only 10 did not. Respondents were 52.3% male, 47.7% female and ranged in age from 18 to 80 with a median age of 40. Although many respondents identified with more than one ancestral group, the majority of respondents identified themselves as Betsimisaraka (68%), followed by Bezanozano (9.7%), Merina (8%), Betsileo (2.3%), Sihanaka (2.3%), Antaimoro (1.1%) and Antandroy (1.1%).

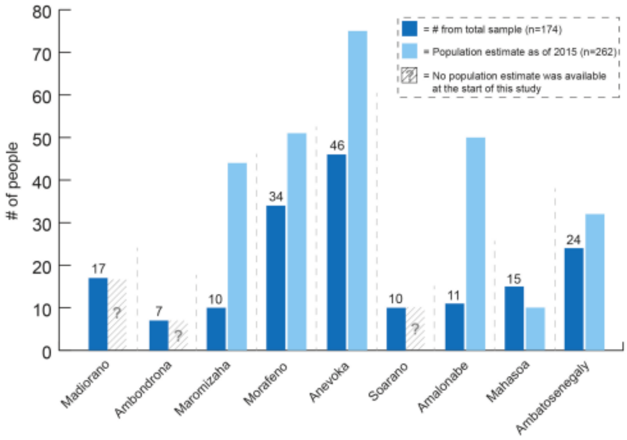


Figure 2. Sample size by village. (Sample size compared with total population estimates used in Surrans [2015]. Where bars are absent, population estimates were unavailable at the start time of the study)

SRI FAMILIARITY AND USE. The 164 rice-farming respondents were asked about their degree of familiarity and use of the SRI method. Just 12 (7.3%) reported that they employed SRI in their rice fields, all of them having participated in training on SRI techniques. A further seven respondents (4.3%) attempted SRI but subsequently disadopted it, four having received training. In addition, 14 respondents (8.5%) had heard of SRI and had trained in it but had never attempted it, and 75 respondents (45.7%) had heard of SRI but had no other experience with it. A total of 56 respondents (34.1%) had not heard of SRI at all at the time of the study. In summary, 65.9% of all respondents had heard of SRI, and 18.3% were formally trained in SRI methods; only 7.3% were using SRI at the time of the study (Figure 3).

Of the 12 respondents who were still practicing SRI, 7 respondents (58.3%) were from Anevoka, the central-most village where GERP and Peace Corps agricultural training efforts are centered. Outside of Anevoka, SRI was practiced by one respondent (8.3%) from each of the villages of Morafeno, Mahasoa, Maromizaha, Ambatosenegaly, and Madiorano (Figure 4), demonstrating a pattern of SRI adoption around Maromizaha Protected Area that varies by location and more specifically, by proximity to training resources.

PERCEPTIONS OF SRI YIELD. Ideally, we would hope to calculate gains from SRI use compared with other rice agriculture methods used around Maromizaha Protected Area, comparing es-

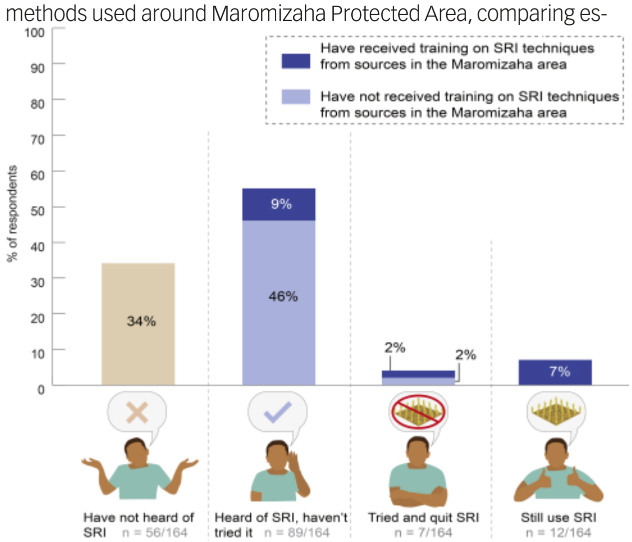


Figure 3. SRI knowledge and adoption. (Numbers are rounded to the nearest whole number for clarity)

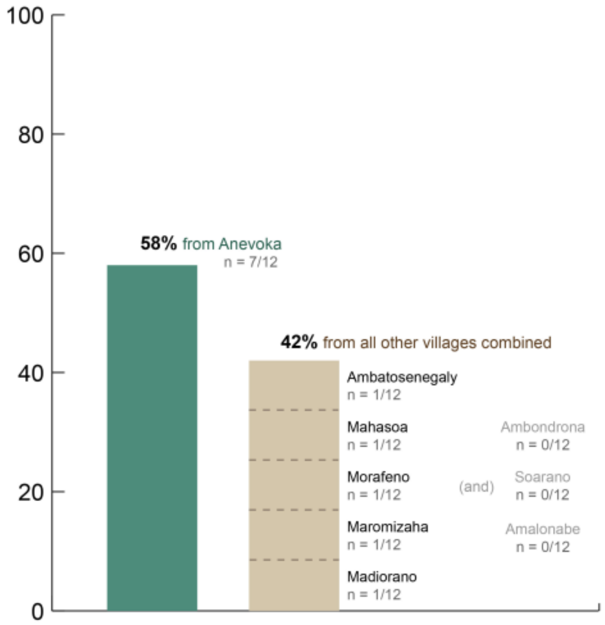


Figure 4. Village of residence: SRI respondents. (Numbers here are rounded to the nearest whole number for clarity)

timates of their yields together with the cost of inputs for each method. Few farmers were able to provide such estimates, so we instead evaluated farmers' perceptions about rice yields. SRI respondents were asked whether they would use SRI again next year, and whether they thought utilizing SRI techniques had increased their yield from what was obtained using a previous rice growing method. Notably, 100% of those who had ever attempted SRI, even those who quit, responded that they perceived an increase in yield with SRI. In addition, 100% of respondents who were using SRI at the time of the survey reported that they would use it again the following year. To reduce the chance that responses might be influenced by participant perception that researchers and NGOs view SRI positively, we made a clear effort to demonstrate a neutral research perspective in our informed consent process, noting that we were neither for nor against the use of SRI.

USE OF *TAVY*. As few farmers near Maromizaha were using SRI, we explored how many were using *tavy*. When asked about this, 139 of 164 (84.8%) respondents reported their current farming method to be *tavy*, with notable variations in the definition of the term *tavy*, and many farmers noting that they used multiple plots with different rice agriculture methods on each plot. Many people use the term "*tavy*" to refer to any hillside rice, regardless of use of fire. Importantly, 41.7% of farmers who use SRI also utilize *tavy* in other plots.

FACTORS THAT INFLUENCE SRI ADOPTION. With regard to the relationship between SRI adoption and labor resources, the median number of family members who help with farming was 2.5 among the 12 respondents who continue to practice SRI, compared with a lower median of just two helpers for the entire study sample (Figure 5).

Finally, to inform future studies, we noted any reasons that farmers expressed about deciding to disadopt SRI. One respondent reported that he disadopted SRI after the training program ended, a second quit because it was too difficult to do both SRI and *tavy*, a third quit because he perceived an increase in crop vulnerability to

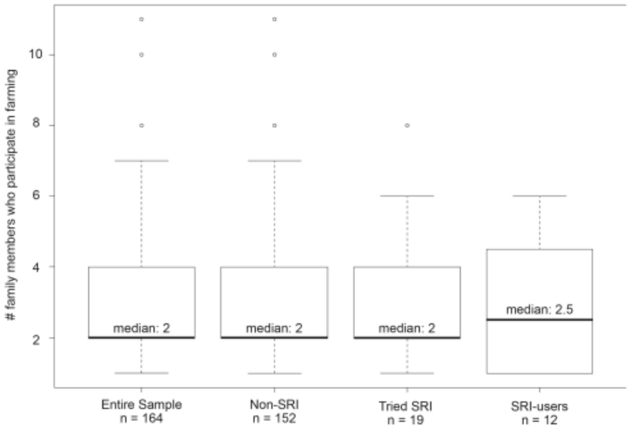


Figure 5. Number of family members who help with farming.

rats in SRI fields, and a fourth did not specify a reason for disadoption. The three remaining respondents reported having utilized SRI in their former residences (Antananarivo, Antsirabe and Beforona) commenting that they were unable to continue it upon relocating to the Maromizaha area, suggesting issues with suitable land availability. Although anecdotal, discontinued use of SRI among these farmers can provide insights into the challenges facing future implementation efforts of SRI around Maromizaha and elsewhere.

DISCUSSION

This study revealed that although most rice farmers around Maromizaha have heard of SRI, few have tried and continued practicing it. This is interesting in light of the reported positive perception of the method's ability to increase rice yields. Relatively few farmers have been trained in SRI techniques, and the fact that most SRI-users are from the village where training organizations are based suggests that broadened access to education and training may increase implementation of the method, particularly in isolated areas.

The compound aim of SRI is to increase rice yields, dissuading farmers from clearing upland slopes for *tavy* farming and indirectly decreasing deforestation pressure, which rests on several assumptions (Byerlee et al. 2014). All of the rice farmers who practiced SRI in the area perceived yields with SRI to be higher and would use the method again. However, a majority of farmers in the Maromizaha area reported use of *tavy*. Indeed, most farmers practicing SRI in some of their fields also continue to practice *tavy* in other fields. Efforts to introduce sustainable agricultural practices must further assess and take into account the reasons why *tavy* is still so widely used by Malagasy smallholder farmers. For example, SRI requires a different type of rice than is grown using *tavy*, and many farmers anecdotally report that the rice grown using *tavy* tastes better and is more filling. Future research exploring farmer preferences towards *tavy* and different varieties of rice will be important.

Of course, adoption of SRI may be easier in cases where more labor resources are available to contribute to farming efforts (Moser and Barrett 2003, Brimont et al. 2015). Informal observations suggest that those who currently have the ability to practice lowland, irrigated rice agriculture already have access to more labor resources, increasing their ability to adopt a method like SRI. Indeed, some farmers mentioned that they would be willing to try SRI if they had more help with the labor. Future studies might explore feasibility of farmer cooperatives to share both labor and harvests, facilitating labor-intensive SRI techniques at scale.

In a hilly area such as Maromizaha, many *tavy* farmers do not have the type of land necessary for SRI, and would first have to clear an adequate lowland field for farming. A significant amount of lowland area would need to be converted to fields in order for most people in Maromizaha to practice SRI. To this end, it may be useful to use existing GIS and satellite image data to create a feasibility map for lowland rice farm construction around Maromizaha, together with an environmental impact assessment. Development initiatives in many regions in Madagascar have provided support for the construction of small-scale dams that aid in the irrigation of lowland fields, a task that can be difficult for farmers. One such dam exists near Maromizaha (Brimont 2015). However, such a project on a large scale would be expensive, with other complications in terms of sustainability and equitable distribution of benefits. Given these considerations, it may prove more practical to target SRI training efforts and labor support at farmers already using lowland rice fields who may be more prepared to adopt and succeed with SRI. For farmers who are not equipped to practice SRI, however, targeted support for other rice agriculture methods could be useful.

In 2003, Moser and Barrett published a five-village study on the adoption of SRI, noting high rates of disadoption and a critical mismatch that demands SRI labor at a time when liquidity is low and labor effort is already high (Moser and Barrett 2003). Several studies have questioned the efficacy of SRI as a farming strategy in upland settings, and the sustainability of intensification more generally at large scales (Dobermann 2004, Sheehy et al. 2004, Perfecto and Vandermeer 2010, Byerlee et al. 2014, Brimont et al. 2015, Gossner et al. 2016). Brimont et al. (2015) examined complexities of poverty and climate vulnerability in northeastern Madagascar, noting that lowland fields are more prone to cyclone damage, and that those with minimal resources tend to rely on upland *tavy* as a risk management strategy. Given these findings, together with the low adoption rates of SRI in Maromizaha found here, the fact that SRI is still being promoted broadly without better understanding of how it performs in relation to elevation, soil characteristics, or farmer resources is concerning. We encourage that best practices be developed in consultation with stakeholders with farming experience *in situ*. It is clear that improvements in food security and conservation outcomes require improved communication, improved accessibility to information at all levels to various stakeholders in all relevant languages, with a reaffirmed dedication to consulting empirical evidence (e.g., the PRISM toolkit available through the Conservation Evidence project by Petrovan et al. 2018).

Lastly, it is not uncommon to hear the opinion that farmers who do not use SRI are 'lazy' and unwilling to adopt new techniques, or that low adoption is to be expected in behavior change initiatives. To quote Moser and Barrett (2003), "failure to take disadoption seriously signals an implicit assumption that new technologies are unambiguously superior to older ones" ignoring past and present local agricultural knowledge. Moving forward, conservation and development efforts can improve through better consulting and representing marginalized groups such as resource-poor smallholder farmers.

CONCLUSIONS

Madagascar has received targeted biodiversity conservation attention for decades. As pointed out by Pollini (2010), conservation efforts have largely failed in decreasing deforestation rates and have at times occurred at the cost of local livelihoods, creating a critical gap between the realities that Malagasy farmers experience and the representation of those realities by conservation and development actors. This gap is still apparent today in what Sutherland and Wordley (2017) would call a culture of "evidence complacency" that pervades many areas of science and policy, including present discussions of SRI promotion. Rice remains of critical importance to the culture and food security of communities living near Maromizaha Forest, hence agricultural solutions that improve soil quality and crop yields while minimizing land degradation are imperative. This paper offers a deeper understanding of the dynamics of agricultural decisions made in proximity to Maromizaha Protected Area. We encourage enhanced dialogue among local community members and protected area management organizations to help inform decision-making strategies, with the goal of improved sustainable food security and biodiversity conservation outcomes across a complex assemblage of stakeholders.

ACKNOWLEDGEMENTS

We express deep gratitude to all community member participants, without whom our study would not have been possible. GERP and MICET provided field season logistical support and facilitated research permissions. We sincerely appreciate the Maromizaha region's traditional local authorities for their cooperation, and extend special recognition to Christian Evariste Naina for serving as research guide and in-field translator, and especially our host family Zafison, Hanta and their relatives for in-field support. Thanks also to Riana Ramanantsalama (of GERP) for access to Maromizaha GIS data, and to William Dreyer, Holi Rabemananjara, Angela Raharinirina, and Domoina Rakotoson for assisting with translations, providing helpful insights on the project design, and offering critical background knowledge and critical logistical support. Special thanks to Romain Surrans and Soloson Ramanahadray for sharing their unpublished DESS research with the scientific community. We thank Geoffrey Dabelko, Director of Ohio University's Environmental Studies Program, for unwavering support and encouragement of international engagement. Risa Whitson and Thomas Smucker of Ohio University provided thoughtful input on survey questionnaire design, and Patrick O'Connor contributed to logistical support. Funding for aspects of this study were provided by the Ohio University Graduate Student Senate (GSS), the Environmental Studies Program, fellowship funds from the Ohio Center for Ecology and Evolutionary Studies, and support from Ohio University's Heritage College of Osteopathic Medicine and the Voinovich School of Leadership and Public Affairs.

REFERENCES

Assemblée Nationale de la République de Madagascar. Loi n° 2015-005 portant refonte du Code de Gestion des Aires Protégées 2015. Republic of Madagascar. Available online <http://extwprlegs1.fao.org/docs/pdf/mad146122.pdf>

Berkhout, E., Glover, D. and Kuyvenhoven, A. 2015. On-farm impact of the System of Rice Intensification (SRI): Evidence and knowledge gaps. Agricultural Systems 132: 157–166. <https://doi.org/10.1016/j.agsy.2014.10.001>

Brimont, L., Ezzine-de-Blas, D., Karsenty, A. and Toulon, A. 2015. Achieving conservation and equity amidst extreme poverty and climate risk: The Makira REDD+ project in Madagascar. Forests 6, 3: 748–768. <https://doi.org/10.3390/f6030748>

Byerlee, D., Stevenson, J., Villoria, N. 2014. Does intensification slow crop land expansion or encourage deforestation? Global Food Security 3, 2: 92–98. <http://doi.org/10.1016/j.gfs.2014.04.001>

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., et al. 1997. The value of the world's ecosystem services and natural capital. Nature 387: 253–260. <https://doi.org/10.1038/387253a0>

Desbureaux, S. and Brimont, L. 2015. Between economic loss and social identity: The multi-dimensional cost of avoiding deforestation in Eastern Madagascar. Ecological Economics 118: 10–20. <https://doi.org/10.1016/j.ecolecon.2015.07.002>

Dobermann, A. 2004. A critical assessment of the system of rice intensification (SRI). Agricultural Systems 79, 3: 261–281. <https://doi.org/10.1016/S0308-521X(03)00087-8>

Froger, G. and Méral, P. 2012. Towards an institutional and historical analysis of environmental policy in Madagascar. Environmental Policy and Governance 22, 5: 369–380. <https://doi.org/10.1002/eet.1595>

Geist, H. J. and Lambin, E. F. 2002. Proximate causes and underlying driving forces of tropical deforestation. BioScience 52, 2: 143–150. <https://doi.org/10.1641/0006-3568(2002)052[0143:PCAUDF]2.0.CO;2>

GERP a. 2015. Étude d'Impact et Environnementale de Maromizaha. Antananarivo, Madagascar.

GERP b. 2015. Plan d'aménagement et de gestion de la nouvelle aire protégée de Maromizaha. Antananarivo, Madagascar.

GERP. 2016. GERP: Maromizaha Project. Available online <http://gerp.squarespace.com/maromizaha/>

Glover, D. 2011. A system designed for rice? Materiality and the invention/discovery of the System of Rice Intensification. East Asian Science, Technology and Society 5, 2: 217–237. <https://doi.org/10.1215/18752160-1273080>

Goodman, S. M. and Benstead, J. P. 2005. Updated estimates of biotic diversity and endemism for Madagascar. Oryx 39, 1: 73–77. <https://doi.org/10.1017/S0030605305000128>

Gossner, M. M., Lewinsohn, T. M., Kahl, T., Grassein, F., Boch, S., et al. 2016. Land-use intensification causes multitrophic homogenization of grassland communities. Nature 540: 266–269. <https://doi.org/10.1038/nature20575>

Ibrahima, H. and Rakotonirainy, M. 2016. FAO/WFP Crop and Food Security Assessment Mission to Madagascar. Available online <http://www.fao.org/3/a-i6335e.pdf>

Jahan, S., Jespersen, E., Mukherjee, S., Kovaceric, M., Abdreyeva, B., et al. 2016. Human Development Report 2016. United Nations Development Programme. <http://shorturl.at/tBQW1>

Jarosz, L. 1996. Defining deforestation in Madagascar. In Liberation Ecologies: Environment, Development, Social Movements. R. Peet and M. Watts (eds), pp 148–164. Routledge, London.

Karp, D. S., Mendenhall, C. D., Sandí, R. F., Chaumont, N., Ehrlich, P. R., et al. 2013. Forest bolsters bird abundance, pest control and coffee yield. Ecology Letters 16, 11: 1339–1347. <https://doi.org/10.1111/ele.12173>

Kull, C. A. 2000. Deforestation, erosion, and fire: Degradation myths in the environmental history of Madagascar. Environment and History 6, 4: 423–450. <https://doi.org/10.3197/096734000129342361>

Mahmood, R., Pielke Sr., R. A., Hubbard, K. G., Niyogi, D., Dirmeyer, P. A., et al. 2014. Land cover changes and their biogeophysical effects on climate. International Journal of Climatology 34, 4: 929–953. <https://doi.org/10.1002/joc.3736>

McConnell, W. J., Sweeney, S. P. and Mulley, B. 2004. Physical and social access to land: spatio-temporal patterns of agricultural expansion in Madagascar. Agriculture, Ecosystems & Environment 101, 2–3: 171–184. <https://doi.org/10.1016/j.agee.2003.09.012>

Minten, B. and Barrett, C. B. 2008. Agricultural technology, productivity, and poverty in Madagascar. World Development 36, 5: 797–822. <https://doi.org/10.1016/j.worlddev.2007.05.004>

Moser, C. M. and Barrett, C. B. 2003. The disappointing adoption dynamics of a yield-increasing, low external-input technology: The case of SRI in Madagascar. Agricultural Systems 76, 3: 1085–1100. <https://doi.org/10.1016/S0308-521X(02)00041-0>

Perfecto, I. and Vandermeer, J. 2010. The agroecological matrix as alternative to the land-sparing/agriculture intensification model. Proceedings of the National Academy of Sciences of the United States of America 107, 13: 5786–5791. <https://doi.org/10.1073/pnas.0905455107>

Petrovan, S. O., Junker, J., Wordley, C. F. R., Kühl, H. S., Orth, L., et al. 2018. Evidence-based synopsis of interventions, a new tool in primate conservation and research. International Journal of Primatology 39, 1: 1–4. <https://doi.org/10.1007/s10764-018-0017-y>

Phalan, B., Onial, M., Balmford, A. and Green, R. E. 2011. Reconciling food production and biodiversity conservation: land sharing and land sparing compared. Science 333: 1289–1291. <https://doi.org/10.1126/science.1208742>

Pollini, J. 2010. Slash-and-Burn Cultivation and Deforestation in Madagascar: Representations and Realities. Lambert Academic Publishing, Saarbrücken, Germany.

Portela, R., Nunes, P. A. L. D., Onofri, L., Villa, F., Shepard, A. and Lange, G.-M. 2012. Assessing and valuing ecosystem services in the Ankeniheny-Zahamena Corridor (CAZ), Madagascar: A demonstration case study for the Wealth Accounting and the Valuation of Ecosystem Services (WAVES) Global Partnership. Wealth Accounting and the Valuation of Ecosystem Services (WAVES) Global Partnership. Available online <https://bit.ly/2OYiZMd>

Raik, D. 2007. Forest management in Madagascar: An historical overview. Madagascar Conservation & Development 2, 1: 5–10. <https://doi.org/10.4314/mcd.v2i1.44123>

Ramanahadray, S. J. 2009. Étude Écologique de Différents Types de Formations Végétales de Maromizaha (Corridor Biologique Ankeniheny-Zahamena): Schéma d'Aménagement et Plan de Gestion. Unpub. DESS de Sciences et Environnement : Biologie de Conservation. Faculté des Sciences, Université d'Antananarivo.

Randrianarison, R. M. S., Rajaonson, A., Ralison, J. M., Rabemanajara, Z., Andrianantenaina, T. D., et al. 2015. Local socio-economic effects of protected area conservation: The case of Maromizaha forest, Madagascar. Madagascar Conservation & Development 10, 2: 93–97. <https://doi.org/10.4314/mcd.v10i2.9>

Ratsimbazafy, J., Ralison, J., Dreyer, W., Rajaonson, A., Andrianantenaina, T., et al. 2014. Maromizaha Rainforest Project: Houston Zoo Annual Report 2014. Available online <http://shorturl.at/gxH01>

Raveloharison, H. 2017. 2017–2019 Economic Development Paper. Country report No. 17/225. International Monetary Fund, Washington, DC. Available online <http://www.samifin.gov.mg/sites/default/files/fichier_pdf/cr17225.pdf>

Rist, C., Headrick, E., Zohdy, S., Wright, P. and Gillespie, T. 2014. Interdisciplinary approaches to global health: A cross-sectional cluster sample survey examining health risks at the human-animal interface in Madagascar. Annals of Global Health 80, 3: 238–239. <https://doi.org/10.1016/j.aogh.2014.08.202>

Scales, I. R. 2012. Lost in translation: conflicting views of deforestation, land use and identity in western Madagascar. The Geographical Journal 178, 1: 67–79. <https://doi.org/10.1111/j.1475-4959.2011.00432.x>

Schwitzer, C., Mittermeier, R. A., Davies, N., Johnson, S., Ratsimbazafy, J., et al. 2013. Lemurs of Madagascar: A Strategy for Their Conservation 2013–2016. IUCN 2013. Available online <https://portals.iucn.org/library/node/10414>

Serpantié, G., and Rakotondramanana, M. 2014. From standards to practices: The intensive and improved rice systems (SRI and SRA) in the Madagascar highlands. In B. Vanlauwe, P. Van Asten, and G. Blomme (eds.), Challenges and Opportunities for Agricultural Intensification of the Humid Highland systems of Sub-Saharan Africa, pp 149–163. Springer. <https://doi.org/10.1007/978-3-319-07662-1_13>

Sheehy, J. E., Peng, S., Dobermann, A., Mitchell, P. L., Ferrer, A., et al. 2004. Fantastic yields in the system of rice intensification: fact or fallacy? Field Crops Research 88, 1: 1–8. <https://doi.org/10.1016/j.fcr.2003.12.006>

Stoop, W. A., Uphoff, N. and Kassam, A. 2002. A review of agricultural research issues raised by the system of rice intensification (SRI) from Madagascar: opportunities for improving farming systems for resource-poor farmers. Agricultural Systems 71, 3: 249–274. <https://doi.org/10.1016/S0308-521X(01)00070-1>

Styger, E., Rakotondramasy, H. M., Pfeffer, M. J., Fernandes, E. C. M., and Bates, D. M. (2007). Influence of slash-and-burn farming practices on fallow succession and land degradation in the rainforest region of Madagascar. Agriculture, Ecosystems and Environment 119, 3–4: 257–269. <https://doi.org/10.1016/j.agee.2006.07.012>

Styger, E., Fernandes, E. C. M., Rakotondramasy, H. M. and Rajaobelinirina, E. 2009. Degrading uplands in the rainforest region of Madagascar: Fallow biomass, nutrient stocks, and soil nutrient availability. Agroforestry Systems 77, 2: 107–122. <https://doi.org/10.1007/s10457-009-9225-y>

Surrans, R. 2015. Contribution to the revision of the social backup plan of the new protected area in Maromizaha for the preparation of annual work plan 2016. Unpub. Master's Thesis. The University of Antananarivo and the University of Bordeaux.

Sutherland, W. J. and Wordley, C. F. R. 2017. Evidence complacency hampers conservation. Nature Ecology & Evolution 1, 9: 1215–1216. <https://doi.org/10.1038/s41559-017-0244-1>

Thrupp, L. A. 2000. Linking agricultural biodiversity and food security: the valuable role of sustainable agriculture. International Affairs 76, 2: 265–281. <https://doi.org/10.1111/1468-2346.00133>

Toledo, Á. and Burlingame, B. 2006. Biodiversity and nutrition: A common path toward global food security and sustainable development. Journal of Food Composition and Analysis 19, 6–7: 477–483. <https://doi.org/10.1016/j.jfca.2006.05.001>

Turner, I. M. and Corlett, R. T. 1996. The conservation value of small, isolated fragments of lowland tropical rain forest. Trends in Ecology & Evolution 11, 8: 330–333. <https://doi.org/10.1016/0169-5347(96)10046-X>

Uphoff, N. 2007. Reducing the vulnerability of rural households through agroecological practice: considering the System of Rice Intensification (SRI). Mondes en Développement 4, 140: 85–100. <https://doi.org/10.3917/med.140.0085>

Uphoff, N. 2008. The System of Rice Intensification (SRI) as a System of Agricultural Innovation. Cornell International Institute for Food, Agriculture and Development (CIIFAD) 10,1: 27–40. Available online <http://soil.ipb.ac.id/jtl/images/art/ART_JTL_10_1_5.pdf>

von Grebmer, K., Bernstein, J., Hossain, N., Brown, T., Prasai, N., et al. 2017. 2017 Global Hunger Index: the inequalities of hunger. International Food Policy Research Institute (IFPRI), Washington, DC, Welthungerhilfe, Bonn, Germany and Concern Worldwide, Dublin, Ireland. Available online <http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/131420>

Waeber, P.O., Wilmé, L., Ramamonjisoa, B., Garcia, C., Rakotomalala, D., et al. 2015. Dry forests in Madagascar, neglected and under pressure. International Forestry Review 17, S2: 127–148. <https://doi.org/10.1505/146554815815834822>

World Food Programme and Office National de Nutrition. 2016. Fill the Nutrient Gap Madagascar: Full Report. Available online <http://shorturl.at/knF15>

World Travel and Tourism Council. 2018. Travel & Tourism Economic Impact 2018, Madagascar. Available online <http://shorturl.at/gmpER>

SUPPLEMENTARY MATERIAL

S1. Survey instrument used in this study.

S2. Étude d’Impact et Environnemental de Maromizaha. 2015. GERP, Antananarivo.

S3. Plan d’Aménagement et de Gestion (PAg) de la Nouvelle Aire Protégée de Maromizaha. 2015. _GERP, Antananarivo.

S4. Élaboration du Plan d'Aménagement et de Gestion (PAG) de la Nouvelle Aire Protégée de la Forêt Humide de Maromizaha. Période 2015–2019. 2015. GERP, Antananarivo.

S5. Ramanahadray, S. J. de D. 2009. Étude Écologique des Différents Types de Formations Végétales de Maromizaha (Corridor biologique Ankaniheny – Zahamena) : schéma d’aménagement et plan de gestion.

Mémoire de fin d’étude pour l’obtention de Diplôme d’Études Supérieures Spécialisées (D.E.S.S) en Sciences de l’Environnement Option : Biologie de Conservation. Université d’Antananarivo, Faculté des Sciences. Antananarivo.

S6. Surrans, R. 2015 Contribution à la Révision du Plan de Sauvegarde Sociale de la Nouvelle Aire Protégée Maromizaha en vue de l’Élaboration du Plan de Travail Annuel 2016. Mémoire de master Option Études d’Impacts Environnementaux. École Supérieure Polytechnique d’Antananarivo, UFR Sciences Économiques et de Gestion de Bordeaux.

ARTICLE http://dx.doi.org/10.4314/mcd.v15i1.2

Motivations of pet parrot ownership and captive conditions of the pets in Madagascar

Lucía Rodríguez[I], Kim E. Reuter[II], Melissa Schaefer Seabocy[III, IV]

Correspondence:
Lucía Rodríguez
Cambridge, United Kingdom
Email: lrodriguez.v6@gmail.com

ABSTRACT
In Madagascar, parrots (*Coracopsis nigra*, *C. vasa*) are often kept as pets, with 8% of urban households surveyed having owned a *Coracopsis* spp. However, the motivations for pet parrot ownership and the captive conditions of these animals remain unexamined. In this study, we present qualitative information on the motivations and captive conditions of pet parrots in Madagascar based on 440 urban household surveys and 64 hotel surveys in central, southern, and eastern Madagascar. We present evidence that the primary motivation for owning pet parrots in Madagascar is for companionship, with no evidence that money-making is a primary motivation for ownership by households or hotels. Of the 11 *Coracopsis* spp. individuals that we saw in private homes during our data collection efforts, most were kept in sub-standard captive conditions (average cage size of ~0.06 ± 0.03 m^3). Less than half had access to food and/or water when we observed them and some showed evidence of stereotypical behavior and feather chewing. Because many of the pet parrots were taken from the wild, motivations for owning a pet parrot and their captive conditions can impact their conservation.

RÉSUMÉ
À Madagascar, les perroquets (*Coracopsis nigra*, *C. vasa*) sont souvent gardés comme animaux de compagnie, avec 8 % des ménages urbains interrogés ayant été propriétaires d'un *Coracopsis* spp. Cependant, les motivations poussant les gens a garder des perroquets comme animaux de compagnie et les conditions en captivité de ces animaux restent non examinées à Madagascar. Dans cette étude, nous présentons des informations qualitatives sur les motivations et les conditions de captivité des perroquets de compagnie à Madagascar, basées sur 440 enquêtes auprès des ménages et 64 enquêtes dans des hôtels dans le centre, le sud et l'est de Madagascar. Des preuves montrent la principale motivation comme étant tout simplement la compagnie ; par contre, aucune preuve supporte l'idée que gagner de l'argent est une raison principale motivant les ménages ou les hôtels à garder ces animaux. Parmi les 11 *Coracopsis* spp. que nous avons vus dans des maisons privées au cours de nos efforts de collecte de données, la plupart ont été maintenus dans des conditions de captivité inférieures aux normes (taille moyenne de la cage d'environ 0,06 ± 0,03 m^3). Moins de la moitié d'entre eux avaient accès à de la nourriture ou à de l'eau lorsque nous les avons observés, et certains ont montré des signes de comportement stéréotypé et de mastication de plumes. Parce que beaucoup de perroquets de compagnie ont été pris dans la nature, les motivations pour posséder un perroquet de compagnie et leurs conditions de captivité peuvent avoir un impact sur leur conservation.

INTRODUCTION
Around the world, parrots have been owned as pets for thousands of years. Alexander the Great, Marie Antoinette, and Theodore Roosevelt each had pet parrots (Weston and Memon 2009). Christopher Columbus returned to Spain with Cuban Amazons (*Amazona leucocephala*) as gifts for the royals, some petroglyphs evidence *Pssittacina* spp. trade among Central American cultures, and there are Scarlet macaw (*Ara macao*) skeletons in burial sites of the Mogollon people in Arizona (Weston and Memon 2009). Even with this long history of pet parrot ownership and trade, studies on the motivations and captive conditions for pet parrot ownership in their range countries are often limited. The motivations for owning a pet bird likely varies by species. Globally, the Psittacines, have proven to be the most popular group for companionship and entertainment (Weston and Memon 2009). Their colorful plumage and their mimicry make them especially attractive for the pet trade (Engebretson 2006). Studies on the captive conditions of pet parrots usually find serious animal welfare problems (Engrebetson 2006). This means that, though many of the pet parrots' owners describe their affection for their pets, they usually cannot fulfill the parrot's physical and mental needs, resulting in difficulties in maintaining their pets' health and wellbeing.

In Madagascar, three species of parrots (*Coracopsis nigra*, *C. vasa*, *Agapornis canus*) are subjected to the pet trade (Reuter et al. 2017a,b). Historical accounts (e.g. Shaw 1885) indicate that Malagasy people have owned pet parrots for generations and that they liked teaching captive *Coracopsis* spp. words to mimic them. Despite evidence that thousands of parrots are currently kept as pets

I University of Cambridge, United Kingdom
II University of San Diego, San Diego, California, USA
III University of Utah, Salt Lake City, Utah, USA
IV Salt Lake City Community College, Salt Lake City, Utah, USA

Citation Rodríguez, L., Reuter, K. E., Schaefer, M. S. 2020. Motivations of pet parrot ownership and captive conditions of the pets in Madagascar. Madagascar Conservation & Development 15, 1: 13–18. http://dx.doi.org/10.4314/mcd.v15i1.2

in urban areas throughout Madagascar every year (Reuter et al. 2017a,b), there are still gaps in the understanding of this trade. Specifically, the motivations for the ownership of parrots by private individuals in Madagascar and the conditions of their captivity have not been studied.

Though the live capture of parrots as pets in Madagascar has received scant attention (Martin et al. 2014), recent studies indicate that almost 8% (n = 38/440 respondents) of urban households surveyed have owned a *Coracopsis* spp. (Reuter et al. 2017b). More than half of pet parrots on the island are purchased (59 %, n=29/49 respondents) and many are captured directly by their owners from the wild (22 %, n=11/49 respondents) (Reuter et al. 2017a). McBride (1996) indicated that after capture in the north-east of the country, *C. vasa* and *C. nigra* wing feathers were clipped and that parrots are often kept in small cages that limited movement. Captive *C. vasa* and *C. nigra* were reportedly often fed bananas and rarely provided with drinking water (McBride 1996). Studies have found that *Coracopsis* spp. are often only kept in captivity for an average of 3.17 ± 2.51 years, with ownership ending most often with the death of the bird (Reuter et al. 2017b). Given that the three species can live elsewhere in captivity for 16-38 years (Young et al. 2012) and the length of ownership is comparatively short in Madagascar, it may be that the captive conditions of parrots in private ownership are sub-standard.

Likely similar to the ownership of other wild animals on the island (e.g. lemurs; Reuter and Schaefer 2017), one can hypothesize that parrots would be kept as pets both for personal/companionship reasons and for money-making from the tourism industry. Regarding money-making, *Coracopsis* spp. have been seen by the authors on the grounds of hotels catering to tourists around a national park in northern Madagascar as well as in the capital city (KER, pers. obs.). Still, it is not clear whether hotels regularly keep parrots on the grounds as a tourist attraction or whether this is a rare phenomenon. In this study, we provide qualitative information from pet parrot owners. Given the limited information in published reports on this topic, the information presented here tries to provide some insights into both the motivations of ownership as well as typical captive conditions of parrots kept as pets.

METHODS

STUDY SPECIES. Our study investigated two species of parrots: the greater vasa parrot (*Coracopsis vasa*) and the lesser vasa parrot (*Coracopsis nigra*). These species are considered to be common in many areas of Madagascar (del Hoyo et al. 1997) and are listed as Least Concern (BirdLife International 2016, 2018). There are no published population estimates for the species, but they are thought to have at least 10,000 mature individuals in the wild with the population of *C. nigra* being stable and the population of *C. vasa* decreasing. (BirdLife International 2016 2018). Both species have plant-based diets (Hino 2002, Bollen and Elsacker 2004). *Coracopsis vasa* and *C. nigra* are frugivores/granivores and *C. nigra* feeding extensively on ripe and unripe seed (Bollen and Elsacker 2004, Czaja et al. 2015).

ETHICAL RESEARCH STATEMENT. International standards for research ethics were followed and research was approved by an ethics oversight committee (Institutional Review Board, University of Utah). This research followed all national and local laws pertaining to the survey of adults in Madagascar. It was authorized by locally elected officials in every town and commune in which research took place. This research required no government research permits.

DATA COLLECTION. During July and August 2016, we surveyed 440 households across nine urban towns (Figure 1) and visited 64 hotels in towns in central, southern, and eastern Madagascar. Eight percent of these households surveyed have owned a *Coracopsis* spp. and 11 are current owners (Reuter et al. 2017b). We focused the interviews about the motivations for owning a pet parrot and the conditions of the pets on these previous and current owners. Verbal informed consent was received, and interviews were conducted by a two-person team comprised of one international project leader (KER, LR, MSS) and one trained Malagasy translator (note that different individuals did the translation in different towns to ensure fluency in the local Malagasy dialect, see Acknowledgments). Respondents were not compensated for their participation.

Interviewees were asked about their motivations for owning a pet parrot and how they cared for their pet parrot. If the individual currently owned the bird, we also asked to see the bird and take photos of the bird's captive conditions. All photos were taken with the owner's consent.

We did not provide interviewees with a definition of a pet bird but noted when they reported to us on birds that were both caged

Figure 1. Map of towns where surveys were undertaken during this study.

and not caged. Pet birds typically included birds that had a clear human owner (regardless of whether they were caged or not), though we excluded birds seen in zoos or reserves. Interviewees rarely identified the species of a pet bird and we did not show them images of birds to facilitate species identification. Occasionally, species identification was possible based on direct observation of the pet bird or through the use of local or scientific names. For this reason, we differentiate in this paper only by genus (i.e. *Coracopsis* spp.).

We also visited 64 hotels in four towns (Table 1) to understand whether for-profit entities targeting tourists might be using captive parrots as on-site attractions (similar to what has been reported for captive lemurs in Madagascar, Reuter and Schaefer 2016). When visiting hotels, we recorded the presence/absence of a caged bird on the premises and collected information regarding the size of the hotel (number of beds) and hotel price points (standard nightly room rates).

RESULTS

MOTIVATIONS FOR HOUSEHOLD OWNERSHIP. Three of the eleven current owners indicated that they liked having parrots as pets because they provided company, were funny (in their imitation of humans), or provided entertainment. One individual indicated that the parrot would warn her of intruders. Three respondents reported selling their parrot, two of them selling multiple parrots. One respondent reported eating the parrot and two indicated the parrot was *fady* (taboo) and was killed.

Table 1. The nine towns in Madagascar (Figure 1) where interviews were conducted, with population, number of household interviews conducted, number of hotels visited, and number of hotels had pet birds on their premises. Population estimates for cities were obtained from the Ilo Project (2003) or from local officials.

Town	Population	No. of households interviewed	No. of hotels interviewed	No. of hotels with a pet bird (%)
Ambositra	32,818	*62*	14	0
Andasibe	12	*53*	0	0
Antananarivo	1,054,649	*53*		
Antsirabea	186,253	*25*	28	0
Beforona	13	*55*		
Fianarantsoa	126	*32*	14	0
Tôlanaro (Fort Dauphin)	46,298	*50*	8	0
Moramanga	40,050	*60*	-	-
Toamasina (Tamatave)	201,729	*50*	-	-
Total	-	*440*	64	0

Several of our respondents (22 %) reported they captured their parrots from the wild. Additionally, three respondents who had purchased the parrot or received it as a gift noted that the parrots were taken from the wild. Two sellers of parrots reported that they stopped selling parrots because they were becoming difficult to find in the wild.

CAPTIVE CONDITIONS. Some respondents mentioned aspects of *Coracopsis* spp. captive care in passing. Parrots were kept in cages (n = 2 respondents), sometimes with their wings clipped (n = 1 respondent). Most of the parrots we observed were kept in cages, with one being kept in an open cage (where the parrot could move in and out at will), one was kept in a room by itself (a nonfunctioning bathroom; it had clipped wings), and four were kept loose (three had clipped wings) (Figures 2, 3). Several of the parrots were in cages that overlooked the street and were, thus, exposed to the elements. Only one parrot was kept alongside a pigeon (Figure 3).

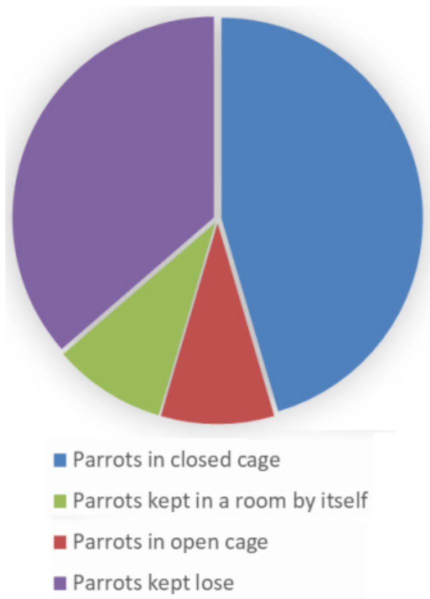


Figure 2. The captive environments of the pet parrots identified in this study.

Figure 3. Caging conditions of captive *Coracopsis* spp.
((a) A parrot was provided with an open cage environment in which it could climb into and out of the cage at will; the cage overlooked a street and the parrot was provided with food and water. (b) A parrot was seen in a cage (for several days in a row) which was affixed to a second-story balcony over a busy street. The parrot did not have much space to move around and was exposed, at least during the days observed, to all outdoor weather. (c) A parrot was kept in a cage in the back corner of a dark, upstairs room; this parrot was reportedly handled by its owners frequently and food and water were present in the cage. (d) A parrot was kept in a small cage overlooking a street; this parrot showed evidence of abnormal behaviors including pacing, repetitive movements, and biting on its own feathers. (e) This parrot frequently stayed close to humans and was seen multiple times at the same location, although it did not have a clear owner. (f) A parrot is seen sitting on a perch spanning a balcony in a residential neighborhood. We did not interview the owner of this parrot but saw several other, similar situations in which the parrot appeared to be habituated and/or to have had its wings clipped (and to be otherwise unrestrained). (g) A parrot was kept in a nonfunctioning bathroom (it was hiding under the bathtub) where it had access to natural light from a window and corn on the ground. This bird had clipped wings and was not able to fly. Photos were taken by KER, LR, and MSS)

Ten of the eleven parrots we observed had a clear owner; the eleventh was a loose parrot that apparently liked to be near people (and those people described it as a pet parrot), but we could not determine if it had an owner. At least three of the parrots were handled by their owners (Figure 4). The average cage size appeared to be ~0.06 ± 0.03 m3. Five parrots had access to food and/or water when we observed them. We observed them being fed seeds, corn kernels, and bananas [three individuals that had owned parrots in the past stated that their pet *Coracopsis* spp. ate "everything" (n = 2) or ate "peanuts, corn, tomatoes, water, and fruits" (n = 1)]. Two respondents who had seen a pet parrot noted that a parrot was in bad health ("near-death"; "eating himself"). One parrot we observed showed what appeared to be stereotypical behavior (pacing, weaving). No pet parrots were observed in any of the 64 hotels (Table 1).

On occasion, we happened to see birds being sold by vendors on the side of the road (once in the middle of a major city and the second time along a well-traveled road between two large cities). In one instance, we observed a street-side location selling three *Coracopsis* spp. (two kept in a ~0.06 m^3 cage; one kept in a ~0.06 m^3 cage). The cages were in full sunlight, none had water, and only one cage appeared to have some dried corn and rice available as food.

DISCUSSION

MOTIVATIONS. Though our sample size is small, it appears that the primary motivation for keeping parrots as pets is for companionship. Money-making was not mentioned by any respondents as a reason for owning a pet parrot (though three respondents had sold parrots), nor were they kept by any of the hotels that we visited. However, these hotel establishments did admit to having captive lemurs, tortoises, snakes, and chameleons on their properties (and we sometimes saw these wild animals as pets) for money-making (i.e. as an added-value attraction from tourists, Reuter and Schaefer 2016). Surprisingly, pet parrots were not evident at hotels as a similar value-added attraction.

In accordance with our results, there are numerous examples from around the world where parrots are in demand for varying reasons, with companionship being a common reason. For example, in Costa Rica, a study in 2002 revealed that 24% of the households kept one or more parrot(s) as a pet (Drews 2002), people would usually keep them for companionship and entertainment (Morales 2005). In Costa Rica, it used to be common for the elderly to have parrots as pets, where they would be trained to sing, dance, and talk (LR, pers. obs.). In addition, during Holy Week, a religious festivity in the country, the demand for parrots would increase, since the parrots were of value for these festivities (Morales 2005). In some cases, parrots have been described as being able to fill the social, emotional, and cognitive needs of their caretakers (Engebretson 2006). For many of their owners, they are viewed as an addition to the family for their human-like characteristics (Grant et al. 2017). In Peru, there are tens of thousands of birds kept because of their ability to mimic the human language (Pires et al. 2016). Of course, pet parrot owners might own a parrot for multiple reasons, and not simply just for companionship.

Figure 4. Contact of *Coacopsis* spp. with other animals.
((a) Human contact with a Malagasy male in his 20's. (b) and a parrot co-housed with a pigeon. Photos were taken by KER)

CAPTIVE CONDITIONS. We observed *Coracopsis* spp. in a wide range of captive conditions, most of which indicated poor bird welfare, despite the affection with which some owners discussed their pets. This can be measured by the animal welfare tool which articulates the "five freedoms", (Farm Animal Welfare Council 1992, cited by Engebretson (2006)) which should be accorded to captive animals. These freedoms are (1) freedom from hunger, thirst and malnutrition, (2) freedom from disease and injury, (3) freedom from physical and thermal discomfort, (4) freedom from fear, distress and negative psychological states and lastly, (5) freedom to carry out normal forms of behavior. None of the captive parrots that we studied in this paper (nor two other pet parrots that the authors opportunistically saw in Madagascar, not reported here), were provided the "five freedoms".

The parrots we observed did not have freedom from hunger, thirst, and malnutrition (Freedom 1) as more than half of the pet parrots we saw did not have access to food and/or water. Many parrots were being fed inadequate diets. For example, 68 % of the diet of wild *C. nigra* is made up of seeds (Bollen and van Elsacker 2004), but seeds were not commonly fed to pet *C. nigra* that we observed. Some parrots were fed with bananas, other fruits, and even meat, which are not part of their natural diets. Pet parrots did not experience the freedom from disease and injury (Freedom 2) either. As with the handling of any wild animal, there is a danger of disease transmission. Our study found that pet parrot owners commonly had direct contact with their pet parrots so disease transmission was possible. Parrots can become infected by their owners, with viral, bacterial, fungal and other diseases (e.g. avian polyomavirus, proventricular dilatation disease (PDD), psittacine beak and feather disease (PBFD), and Pacheco's disease (Ritchie et al. 2000), which can cause the death of the pet parrots. Further evidence for this is found in Reuter et al. (2017a), where it was noted that some parrots died from an illness or a cold (in 6 % of cases where it was known how pet parrot ownership ended). Additionally, birds can have several diseases/injuries associated with being caged, including burns from hot foods and fungal dermatitis (Paterson 2008).

Regarding the final three freedoms, pet parrots were often kept in cages that were too small for physical comfort (Freedom 3) and they were isolated from conspecifics; both of these captive conditions preclude normal behavior (Freedom 5). It is recommended that cages should be big enough for the parrot (minimum 24 x 24 x 36 inches) (RSPCA 2019) to be able to exercise, play and accommodate toys, perches and water (Bradshaw et al. 2009) and these conditions were largely absent for the pet parrots we saw. Stereotypical behaviors (pacing, self-mutilation, feather-picking) that could indicate that the pet parrots were not provided the freedom of negative psychological states (Freedom 4) was also evident. This type of behavior is usually manifested when the captive conditions are harsh or limit the parrots' biological needs (Paterson 2008). Even though only one out of the eleven pet parrots we saw, displayed some of these patterns of behavior, three former pet owners said that their pets were in very bad health, "with no feathers", "crazy", or "almost dying".

Even though we did not ask pet parrot owners in Madagascar whether they had difficulties keeping their pet parrots in better conditions, owners in other areas of the world do have a lack of knowledge, resources, and motivation to improve the welfare or life quality of exotic pets (Engebretson 2006). The sub-optimal captive conditions we observed may explain why pet parrots in Madagascar are kept alive in captivity for such short periods. Reuter et al. (2017) reported an average lifespan for pet parrots of 3.17 ± 2.51 years. Lifespans are considerably longer in other captive environments. For example, the maximum lifespans for *C. nigra* and *C. vasa* are 38 years and 29 years respectively (Young et al. 2012). Psittacines, in general, are among the longest-lived birds so the short lifespan in captivity in Madagascar is surprising.

CONSERVATION OF PARROTS. When it comes to birds, 2,600 of the more than 9,600 species are registered as being subject to trade (FAO 2011). As such, the trade of live birds sourced from the wild is causing increasing concern, with parrots (Psittacidae) among the most threatened group of bird species in the world (28 % of species threatened on the IUCN Red List, Olah et al. 2016). Taking *Psittacus erithacus* as an example: these species have been greatly affected by the global pet trade with over 3.5 million individuals traded since the 1970s (Martin et al. 2014). There are countries such as Ghana, where 90-99 % of the bird population has been lost due to trade since the 1990s (Annorbah et al. 2015).

Even though the two parrot species subjected to the pet trade in Madagascar are not currently endangered, Reuter et al. (2017 a, b) estimated that there were 38,000 parrots kept as pets in Madagascar in 2015-2016. Additionally, three respondents who had purchased the parrot or received it as a gift noted that the parrots were taken from the wild. Two sellers of parrots reported that they stopped selling parrots because they were becoming difficult to find in the wild. These results indicate that the trade in pet parrots may not be sustainable. As noted by Clarke et al. (2019), every wild animal kept as a pet is either directly or indirectly driving the capture of the animals in the wild to be used or sold as a pet and is, therefore, impacting their conservation. Because of this, it is impossible to completely separate the motivations for owning pet parrots and the conditions in which they are kept in captivity, from their conservation. The pet parrot trade is not only a welfare issue but also a conservation issue. Pet parrots' ownership in Madagascar is an important factor to include in policies and regulations to improve the captivity conditions of these individuals and their health. Therefore, we conclude that parrots are unsuitable as human companions and its trade should be prohibited or regulated with education for owners regarding proper care.

ACKNOWLEDGMENTS

Many thanks to GERP (Groupe d'étude et de recherche sur les primates de Madagascar), Association Mitsinjo, the Sainte Luce Reserve, and to Conservation International for facilitating research in some of the towns visited. Thanks to Toby Schaeffer for making the map for this paper. Many thanks to Irène Ramanantenasoa, Tiana Ratolojanahary, Housseini Maihidini, Tokihenintsoa Andrianjohaninarivo, and Tolotra Fanambinantsoa for serving as translators during part of the data collection. We thank host communities for their hospitality.

REFERENCES

Annorbah, N., Collar, N. and Marsden, S. 2015. Trade and habitat change virtually eliminate the Grey Parrot *Psittacus erithacus* from Ghana. Ibis158, 1: 82–91. <https://doi.org/10.1111/ibi.12332>

BirdLife International. 2016. *Coracopsis nigra*. The IUCN Red List of threatened species 2016. Accessed 3 November 2018. <https://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22727885A94964612.en>

BirdLife International. 2018. *Coracopsis vasa*. The IUCN Red List of threatened species 2016. Accessed 3 November 2018. <https://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T22685261A131279943.en>

Bollen, A. and van Elsacker, L. 2004. The feeding ecology of the Lesser Vasa Parrot, *Coracopsis nigra*, in south-eastern Madagascar. Ostrich 75, 3: 141 –146. <https://doi.org/10.2989/00306520409485425>

Bradshaw, G. A., Yenkosky, J. P. and McCarthy, E. 2009. Avian affective dysregulation: Psychiatric models and treatment for parrots in captivity. Proceedings of the 30th Annual Association of Avian Veterinarians Conference, Minnesota. Available online. <https://bit.ly/354Klqd>

Clarke, T. A., Reuter, K. E., LaFleur, M. and Schaefer, M. S. 2019. A viral video and pet lemurs on Twitter. PLoS ONE 14, 1: e02085747. <https://doi.org/10.1371/journal.pone.0208577>

Czaja, R., Wills, A., Hanitriniaina, S., Reuter, K.E., and Sewall, B.J. 2015. Consumption of domestic cat in Madagascar: Frequency, purpose, and health implications. Anthrozoös 28, 3: 469–482. <https://doi.org/10.1080/08927936.2015.1052280>

del Hoyo, J., Elliott, A. and Sargatal, J. (1997). Handbook of the Birds of the World, Vol. 1: Ostrich to Ducks. Lynx Edicions, Barcelona.

Drews, C. 2002. Attitudes, knowledge and wild animals as pets in Costa Rica. Anthrozoös 15, 2: 119–138. <https://doi.org/10.2752/089279302786992630>

Engebretson, M. 2006. The welfare and suitability of parrots as companion animals: a review. Animal 15: 263–276. Available online. <http://shorturl.at/lUY48>

FAO. 2011. International Trade in Wild Birds and Related Bird Movements, in Latin America and the Caribbean. Animal Production and Health Paper No. 166. FAO, Rome. Available online. <http://www.fao.org/docrep/01 3/i0708e/i0708e00.pdf>

Grant, R. A., Montrose, V. T. and Wills, A. P. 2017. ExNOTic: should we be keeping exotic pets? Animals 7, 6: #47. <https://doi.org/10.3390/ani7060047>

Hino, T. 2002. Breeding bird community and mixed-species flocking in a deciduous broad-leaved forest in western Madagascar. Ornithological Science 1, 2: 111–116. <https://doi.org/10.2326/osj.1.111>

Martin, R. O., Perrin, M. R., Boyes, R. S., Abebe, Y. D., Annorbah, N. D., et al. 2014. Research and conservation of the larger parrots of Africa and Madagascar: a review of knowledge gaps and opportunities. Ostrich 85, 3: 205–233. <https://doi.org/10.2989/00306525.2014.948943>

McBride, P. 1996. Concern for the Greater Vasa Parrot. PsittaScene 8, 2: 10. Available online. <https://www.parrots.org/files/psitta/435/ps_8_2_may_96.pdf>

Morales, H. A. 2005. Fauna silvestre en condiciones de cautividad doméstica en Costa Rica: problemática y soluciones. Revista Biocenosis 19, 2: 31–37. Available online <https://revistas.uned.ac.cr/index.php/biocenosis/article/view/1324/1399>

Olah, G., Butchart, S. H. M., Symes, A., Guzman, I. M., Cunningham, R., et al. 2016. Ecological and socio-economic factors affecting extinction risk in parrots. Biodiversity and Conservation 25: 205–223. <https://doi.org/10.1007/s10531-015-1036-z>

Paterson, S. 2008. Skin Diseases of Exotic Pets. Wiley- Blackwell, Hobokrn, NJ.

Pires, S., Schneider, J. and Herrera, M. 2016. Organized crime or crime that is organized? The parrot trade in the neotropics. Trends in Organized Crime 19: 4–20. <https://doi.org/10.1007/s12117-015-9259-7>

Reuter, K. E. and Schaefer, M. S. 2016. Captive conditions of pet lemurs in Madagascar. Folia Primatologica 87: 48–63. <https://doi.org/10.1159/000444582>

Reuter, K. E. and Schaefer, M. S. 2017. Motivations for the ownership of captive lemurs in Madagascar. Anthrozoös 30, 1: 33–46. <https://doi.org/10.1080/08927936.2017.1270589>

Reuter, K. E., Clarke, T. A., LaFleur, M., Rodriguez, L., Hanitriniaina, S. and Schaefer, M. S. 2017a. Trade of parrots in urban areas of Madagascar. Madagascar Conservation & Development 12, 1: 41–48. <https://doi.org/10.4314/mcd.v12i1.5>

Reuter, K. E., Rodriguez, L., Hanitriniaina, S. and Schaefer, M. S. 2017b. Ownership of parrots in Madagascar: Extent and conservation implications. Oryx 53, 33: 582–588. <https://doi.org/10.1017/S003060531700093X>

Ritchie, B. W., Gregory, C. R., Latimer, K. S., Pesti, D., Campagnoli, R. and Lukert, P. D. 2000. A review of the most common viruses affecting Psittaciformes. International Zoo Yearbook 37, 1: 257–273. <https://doi.org/10.1111/j.1748-1090.2000.tb00731.x>

RSPCA (Royal Society for the Prevention of Cruelty to Animals). 2019. What size enclosure does my pet bird need? Available online. <http://shorturl.at/EOUZ5/>

Shaw, G. A. 1885. Madagascar and France: With Some Account of the Island, Its People, Its Resources and Development. American Tract Society, New York.

Weston, M. K. and Memon, M. A. 2009. The illegal parrot trade in Latin America and its consequences to parrot nutrition, health, and conservation. Bird Populations 9: 76–83. Available online. <http://birdpop.net/pubs/files/weston/2009/552_Weston2009.pdf>

Young, A. M., Hobson, E. A., Lackey, L. B. and Wright, T. F. 2012. Survival on the ark: life- history trends in captive parrots. Animal Conservation 15, 1: 28–43. <https://doi.org/10.1111/j.1469-1795.2011.00477.x>

ARTICLE http://dx.doi.org/10.4314/mcd.v15i1.3

Vegetation thresholds for the occurrence of millipedes (Diplopoda) in different tropical forest types in Andasibe, Madagascar

Lea R. Spelzhausen[I], Thomas Wesener[II], Kai Schütte[III]

Correspondence:
Lea R. Spelzhausen
University of Bremen
Center for Environmental Research and Sustainable Technology
Department of General and Theoretical Ecology
Leobener Strasse 6
28359 Bremen, Germany
Email: lea@spelzhausen.de

ABSTRACT

Forest clearance, especially in the tropics, leads to habitat loss for many organisms including litter-dwelling arthropods. Among other invertebrates, millipedes (Diplopoda) provide important ecosystem services like decomposition and nutrient cycling in forest ecosystems. Despite their importance, little is known about litter invertebrates' response to tropical forest degradation and their role in reforestation. The present article should rather be regarded as a review of millipedes' occurrence in tropical forests with a pilot study from Madagascar, because the sample size is small and results need to be confirmed. This pilot study investigated the relationship between millipedes and vegetation characteristics in the eastern rainforests of Madagascar, in the region of Andasibe, parts of which are undergoing reforestation. Vegetation characteristics were measured in ten different forests encompassing different types: remnant rainforest, secondary forest, old *Eucalyptus* plantations, recently enriched with indigenous tree species, and degraded sites. Millipede species were searched by hand, identified and their occurrence in relation to the environmental characteristics was described.

Vegetation characteristics differed between forest types. Old *Eucalyptus* plantations, secondary forest, and primary rainforest were associated with higher litter depth and more native millipede species than degraded sites and forests afforested with native tree species since 2007. Non-native millipedes occurred in all vegetation formations except the primary rainforest site and did not show any relationship with vegetation characteristics. In contrast, native millipedes' occurrence was related to conditions associated with mature forest, such as high litter depth and high foliage cover. Logistic regression revealed a threshold of litter depth above which native millipedes are likely to occur. The results indicate that native millipedes are affected by forest degradation and are incompletely restored even when the afforested forest might approach the original state. Special care should be taken during reforestation efforts, as non-native soil arthropods can be introduced, completely replacing the indigenous biota.

RÉSUMÉ

Les conséquences de la déforestation globale sont multiples. Pour la plupart des organismes, la déforestation est la cause principale de la destruction des habitats. Les arthropodes qui vivent sur le sol forestier ou dans le feuillage sont ainsi menacés, surtout dans les forêts tropicales. Ces organismes sont pourtant indispensables au maintien de la résilience de la forêt. Dans l'écosystème forestier, les millepattes et autres arthropodes sont très importants pour la mise à disposition de différents services écosystémiques, par exemple pour leur rôle dans le cycle des éléments nutritifs, la formation des sols et la décomposition. Malgré leur importance, peu d'informations sont disponibles sur la réaction des invertébrés suite à la dégradation des forêts et leur rôle dans la reforestation.

Cette étude tient surtout lieu de révision de l'occurrence des millepattes dans les forêts tropicales avec une étude pilote menée à Madagascar, dans la mesure où l'échantillonnage est réduit et que les résultats restent partiels. Cette étude pilote analyse les relations entre les millepattes et les caractéristiques végétales dans les forêts de l'Est de Madagascar, dans la région d'Andasibe. Ces forêts sont très diverses et dix types de forêt ont été considérés, à savoir une forêt récemment dégradée et une forêt dégradée, une forêt dégradée et reboisée avec des espèces arborées indigènes en 2007, 2012 ou 2015, des plantations d'Eucalyptus abandonnées depuis 1930 ou 1909, deux forêts secondaires, une forêt primaire. Dans ces différents types de forêt, les caractéristiques de la végétation ont été enregistrées et des millepattes ont été récoltés à la main. Les espèces de millepattes ont été identifiées et leur occur-

I University of Bremen, Center for Environmental Research and Sustainable Technology, Department of General and Theoretical Ecology, Leobener Strasse 6, 28359 Bremen, Germany
II Zoological Research Museum A. Koenig, Leibniz Institute for Animal Biodiversity, Bonn, Germany
III University of Hamburg, Zoological Institute, Department of Animal Ecology and Conservation, Martin-Luther-King-Platz 3, 20146 Hamburg, Germany

Citation Spelzhausen, L. R., Wesener, T., Schütte, K. 2020. Vegetation thresholds for the occurrence of millipedes (Diplopoda) in different tropical forest types in Andasibe, Madagascar. Madagascar Conservation & Development 15, 1: 19–26. http://dx.doi.org/10.4314/mcd.v15i1.3

rence ont été analysées par rapport aux caractéristiques de la végétation. Les vieilles plantations d'*Eucalyptus* et les forêts secondaire et primaire étaient caractérisées par une couche plus épaisse de feuilles et davantage d'espèces de millepattes indigènes par rapport aux forêts dégradée et replantée. Les espèces allogènes étaient présentes dans tous les types de forêt à l'exception de la forêt primaire. La présence de ces espèces n'était pas liée aux caractéristiques de la végétation. En revanche, l'occurrence des espèces indigènes était associée à des conditions qui sont caractéristiques des forêts matures, par exemple une couche de feuilles épaisse et une couverture foliaire dense. L'analyse de régression logistique a révélé une valeur seuil pour la hauteur de la couche de feuilles mortes. Au-delà de ce seuil, il est probable que les millepattes indigènes soient présents. L'étude a montré que les millepattes indigènes sont impactés par la déforestation et qu'ils ne sont pas facilement restaurés même si la restauration semble permettre à la forêt de se rapprocher de son état initial.

INTRODUCTION

Deforestation is a major problem worldwide. Although the rate of deforestation rate has decreased over the last few decades, forest gain is mainly restricted to temperate forests, while forest loss continues in the tropics (Keenan et al. 2015, Sloan and Sayer 2015). In Madagascar, after 1990 the deforestation rate was declining to 42,000 ha y-1 in 2000–2005 but increased again since 2005 to 99,000 ha y-1 for the years 2010–2014 (Vieilledent et al. 2018). The ongoing forest loss is detrimental to Madagascar's flora and fauna, given that forests are home to the majority of its biodiversity (Goodman and Benstead 2005). Approximately 80% of the biodiversity depends on forests (Waeber et al. 2020). Especially Madagascar is considered as a biodiversity hotspot with high percentages of endemism being seriously endangered (Myers et al. 2000, Ganzhorn et al. 2001). In a publication of 2003, this island is estimated to host 5,800 macroinvertebrate species of which 86% are endemic (Goodman and Benstead 2005), thereunder 268 different diplopod species of which 86% are endemic (Enghoff 2003, Wesener 2009, Wesener et al. 2009). In addition to forests, forest soil and litter are also essential for a great portion of described species worldwide. Some 25% of the global biodiversity is dependent on it (Decaëns et al. 2006). The clearance of forest (and thus of its soil and litter) poses a major threat to soil biodiversity (Mathieu et al. 2005).

Soil animals (including all organisms living in habitats related to soil, e.g., litter, dead wood or rocks) are divided into microfauna (< 0.1 mm), mesofauna (0.1–2 mm), macrofauna (2–20 mm), and megafauna (> 20 mm). In addition to arachnids and insects, which account for a large part of soil animals (Decaëns et al. 2006), slugs, snails, woodlice, earthworms, centipedes and millipedes also belong to the macrofauna (Zanella et al. 2018). Millipedes are typical forest-dwelling organisms and need sufficient humidity, being meso- to hygrophile (Golovatch and Kime 2009). They are largely restricted to the leaf litter, the soil-litter interface, the uppermost layer of soil, and dead wood of principally deciduous temperate, subtropical, and humid tropical forests, where they can feed and stay concealed in a humid shelter (Alegasan 2016). In temperate and tropical environments, they represent one of the major groups of soil and litter fauna (Alegasan 2016).

Invertebrates provide several ecosystem services, such as nutrient cycling, soil formation, and micro-climate regulation (Lavelle et al. 2006). Nutrient cycling is initiated by the ecosystem process decomposition, which in turn is accelerated by the comminution of dead organic material of soil invertebrates, by increasing the surface of detritus, which can be further decomposed by microbial organisms (Coleman and Wall 2015). Soil fauna has a positive impact on decomposition (García-Palacios et al. 2013).

Considering the ongoing deforestation worldwide, but especially in the tropics, we need to know under which habitat conditions the soil fauna is maintained and their associated important ecosystem functions remain undisturbed. Powers et al. (2009) quotes a reduction of the decomposition rate by 50% after the artificial removal of the mesofauna. Another study states also the importance of a more numerous soil fauna, indicating that the decomposition process in a humid tropical environment is accelerated when millipedes and earthworms are present in the litter layer (Tian et al. 1995). In general, there is a need of more specific knowledge of soil fauna diversity and abundance and their contribution to decomposition in tropical forests (Powers et al. 2009). Regarding the habitat requirements in tropical and subtropical forests for the soil fauna community, the literature states mostly litter quality and quantity: Burghouts et al. (1992), for example, found a positive effect of litter quantity on litter invertebrate abundance in tropical rainforests in Malaysia. Another study showed also significant effects of litter quantity and quality on litter invertebrate abundances at a local scale but argues that at a regional scale precipitation and temperature explain mostly the variance in tropical forests in China (Lu et al. 2016). Yang et al. (2007) investigated tropical forests in Puerto Rico and demonstrated that higher litter quantity results in an increase of litter arthropods abundance. They could, however, not prove that litter quality affects arthropod density. Sayer et al. (2010) investigated the effect of nutrients and litter mass in a lowland tropical forest in Panama and concluded that at a local scale, arthropod abundance is related to habitat space in terms of litter quantity, while arthropod diversity is associated to the habitat quality. For New Zealand, Wardle et al. (2006) argues that the resource quality in terms of the litter species has an effect on soil faunal diversity. For millipedes in specific, there is also an effect of litter quantity and quality documented. Litter depth is a driver for millipede's morphotaxa richness in Australian tropical rainforests and for millipede abundance in New Zealand (Nakamura et al. 2003, Tomlinson 2014). Millipede biomass is highly correlated with N concentration and C/N ratio in a tropical forest in Puerto Rico (Warren and Zou 2002). Furthermore, millipede abundance and species richness tend to be higher in leave litter with higher N content in Guadeloupe (Loranger-Merciris et al. 2008).

In order to preserve these crucial animals and the provision of associated ecosystem services (e.g., soil fertility and climate regulation), we have to restore their habitats but especially need to know their habitat requirements. However, the effects of restoration on ecosystem structures and native biodiversity are little studied, as are the factors controlling the recovery of litter arthropods in successional environments (Cole et al. 2016) and the response of soil macrofauna after forest clearance in the tropics (Mathieu et al. 2005). For Madagascar, the ecology of invertebrates received less attention in general and the application of vegetation thresholds remains limited.

In this context, the present pilot study investigates (i) the relationship between millipedes' occurrence and several vegetation variables, and (ii) the difference between native and introduced millipedes in their response to environmental conditions in different forest types. This pilot study complements the current literature on the links between millipede occurrence and habitat characteristics.

METHODS

STUDY AREA. The study area is located in the region of the Ankeniheny-Zahamena Corridor (CAZ), which is a 381,000 ha belt of rainforest east of the capital Antananarivo. The climate of the CAZ region is characterized as hot, humid and tropical, with an average annual rainfall of 2,500 mm and an average annual temperature of 18–24°C (Dolch 2003, Andriamananjara et al. 2016). The Andasibe region is situated at about 900 m above sea level (Vallan 2002), has a humid climate with 1–2 dry months and its soil type is mainly Ferralsols, according to FAO classification (Andriamananjara et al. 2016). The study was conducted in the Analamazaotra forest of Andasibe (Figure 1), which is managed by Madagascar National Parks. The sampling was undertaken at the Analamazaotra Forest Station situated outside the National Park; this is managed by the local Association Mitsinjo. The Analamazaotra Forest Station encompasses 700 ha of rainforest and abandoned *Eucalyptus* plantations, which are currently being restored with native tree species. In addition to the Analamazaotra forest, we investigated two types of forests which are located approximately 30 km north of Andasibe (Figure 1, with native trees in different years (R07, R12, R15), reforestation with *Eucalyptus* around 1930 (E30), reforestation with *Eucalyptus* around 1909 (E09), two secondary forests (S1, S2), and an undisturbed and accordingly primary forest (P). Until 1817, the rainforests around Andasibe were pristine (Vallan 2002). Though large deforestation started under French colonialism in the early 1900s, Analamazaotra forest was able to recover when the management was overtaken by the Ministry of Water and Forests (Ministère des Eaux et Forêts) around 1970. In 2003, the Association Mitsinjo took over the management of a portion of the secondary forest (S1). One type of reforestation forest is the monoculture of *Eucalyptus*. The fragments with monoculture of *Eucalyptus* are remains from the French colonialists, who experimented with fast growing trees for timber production. Reforestations with *Eucalyptus* took place around 1909 (E09) and 1930 (E30). Today, the old *Eucalyptus* plantations are not being exploited anymore. In contrast, the reforestation project that started in 2007 includes native tree species. We selected sites where reforestation took place in 2007 or 2008 (R07), in 2012 (R12), and in 2015 (R15). About 50 different native tree species were planted in the restoration efforts, among which are species of the genera of *Symphonia*, *Macaranga*, *Eugenia*, and *Cryptocaria*. These reforested sites have experienced different land-use management before being abandoned. Some were burned for charcoal in 1988, others experienced rice farming, manioc cultivation or tree logging (according to G. Rakotonirina, pers. comm., April 2017). Degraded sites are characterized as land laid fallow after farming, deforestation, or burning, and which has an open canopy with many gaps. After abandoning rice cultivation, herbaceous vegetation and bush fallows did establish (Vallan 2002). The older degraded (D) sites have been laid fallow since approximately 1988 and the younger sites (DY) since approximately 2008 (according to G. Rakotonirina, pers. comm., April 2017). In addition to the Analamazaotra forest, two types of forests were investigated in a different region which is located approximately 30 km north of Andasibe, and belongs to the Ankeniheny-Zahamena Corridor. These sites were selected in order to compare afforested and degraded sites with a primary forest fragment (P) and another secondary forest (S2). The primary forest sites are remnant rainforest patches.

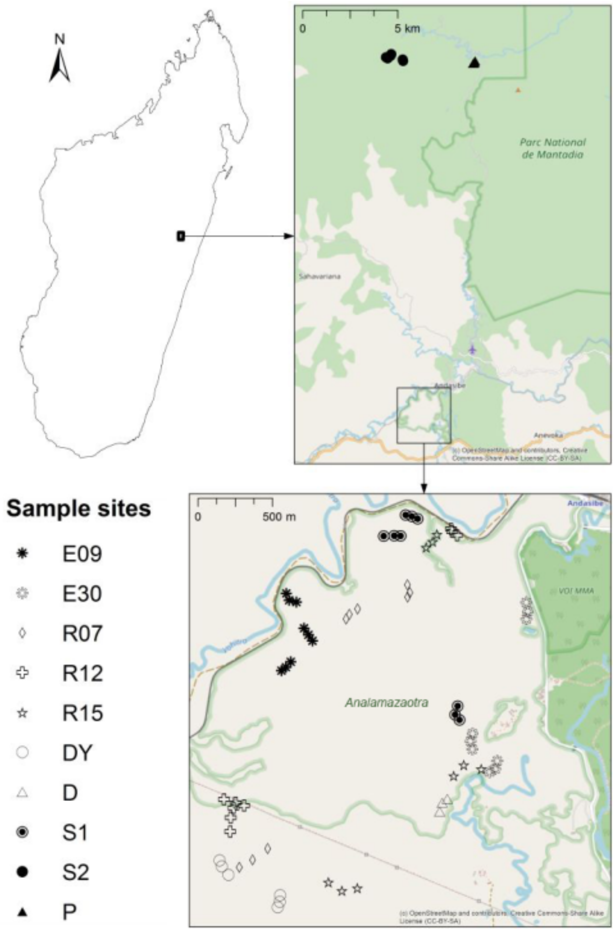


Figure 1. Sample sites. (E09: reforestation with *Eucalyptus* around 1909, E30: reforestation with *Eucalyptus* around 1930, R07: reforestation with native trees in 2007, R12: reforestation with native trees in 2012, R15: reforestation with native trees in 2015, DY: freshly degraded forest, D: degraded forest, S1: secondary forest, S2: secondary forest, P: primary forest).

COLLECTION OF ECOLOGICAL PARAMETERS. Sampling was conducted in April 2017. The sampling design was adapted to Bogyó et al. (2015) and Nakamura et al. (2003). For this, three 100 m transects (= 3 replicates) were established per site with three 2 m x 2 m plots per transect spaced 50 m apart (10 habitat types x 3 transects x 3 plots). Eight vegetation variables were measured to test their relation to millipede occurrence. After having installed the 2 m x 2 m quadrate, the four variables that needed to be recorded before the plot was disturbed, in order to collect the millipedes, were documented: (1) litter depth (cm; mean of nine measurements/plot), (2) shrub cover (%), (3) bare soil (%), and (4) absence or presence of coarse woody debris scored at four different diameters (on a scale from 0 to 3 based on maximum diameter of debris, whereby 0 = debris with a diameter of < 1 cm, 1 = 1–10 cm, 2 = 11–20 cm, 3 ≥ 21 cm).

Additional four environmental variables were recorded after the collection of the millipedes: (5) canopy height (in meters; if no canopy was present, a measurement of 0 was recorded), (6) foliage cover (%; mean of 9 measurements/plot, taken through a vertical sighting tube), (7) tree spacing measure (m; average distance from center of plot to three nearest trees), and (8) DBH (in centimeters; diameter of the tree nearest to center of plot with a minimum DBH of 10 cm).

MILLIPEDE COLLECTION AND IDENTIFICATION. Two people systematically investigated the litter for millipedes for 10 to 13 minutes, depending on the thickness of the litter layer. Litter was carefully removed and all millipedes on top of the soil or in the litter were collected by hand. The collected millipedes were stored in 70% ethanol. The hand collection method was chosen because it represents an efficient method for collecting millipedes (Snyder et al. 2006). The comparison of the methods 'pitfall trapping', 'Berlese extraction', and 'hand collection' proved that the latter yielded the greatest diversity and second highest abundance (Snyder et al. 2006).

For the identification of millipedes, we used Wesener (2009), Wesener et al. (2009), Jeekel (1999), de Saussure and Zehntner (1897, 1901, 1902), and Attems (1910, 1914, 1951). Male specimens that could not be identified with the existing literature were grouped into morphospecies, which were characterized by their differences in gonopod structure. For the order Spirobolida, Thomas Wesener also identified juvenile and female specimens. For the order of Spirostreptida, juveniles and females could not be grouped with absolute certainty to the morphospecies *Iulomorpha* sp. 1 due to the lack of reliable morphological structures. Therefore, two subgroups, *Iulomorpha* sp. 1a and *Iulomorpha* sp. 1b, are here included to highlight this uncertainty (Table 1). For the statistical analysis, the two *Iulomorpha* sp. 1 were treated as one morphospecies.

DATA ANALYSIS. Analyses were based on the means of the vegetation characteristics per transect. For testing whether there is a threshold value that describes millipedes' occurrence, we performed logistic regression between all vegetation variables, native millipede occurrence as well as non-native millipede occurrence separately. Due to the replicated design, mixed models were conducted by including replicates as a random effect to account for the lack of independence. To assess the quality and the fit of the model a pseudo *R2* test statistic (Nagelkerke) was calculated. We plotted the presence/absence of millipedes against the mean litter depth of each replicate. In addition, to investigate differences between native and non-native millipedes in relation to litter depth, we conducted a t-test, as both homogeneity and normality were confirmed. Normality was tested with a Shapiro-Wilk test, and Levene's test was conducted for the equality of variances. Analyses were run with R (version 3.4.2).

RESULTS

In total, 113 Diplopoda specimens from five orders (Sphaerotherida, Siphonophorida, Polydesmida, Spirobolida, and Spirostreptida) and 12 species were recorded (Table 1). Out of the 113 individuals, 85% belonged to non-native species. The non-native species were either *Oxidus gracilis* (86 individuals) or belonged to the genus *Iulomorpha* (11 individuals). The remaining 16 individuals were species endemic to Madagascar.

The general trend for the environmental factors is the difference between the degraded (DY, D) and reforested sites with native tree species (R15, R12, R07) compared to the older sites reforested with *Eucalyptus* (E30, E09), secondary forests (S1, S2), and primary forest (P) (Table 2). The lowest amount of litter was found at the sites reforested with native tree species (R15, R12, R07) as well as at the two degraded sites (DY, D). Litter depth was highest in both secondary forests (S1, S2) as well as in the primary forest (P). Native millipede species were found in all forest types, except for the forests reforested with native trees (R15, R12, R07). Non-native millipedes (*Oxidus gracilis* and *Iulomorpha* sp.) were present in all forest types, except for the primary forest (P). The highest abundance for *Oxidus gracilis* was in R07.

Since we did not expect to find as many non-native millipedes as we did, and because single species abundances were too low for statistical analyses, with the exception of *Oxidus gracilis*, we conducted a binary categorization (native and non-native). Mixed logistic regression models did not reveal any relationship between vegetation characteristics and the occurrence of non-native species occurrence (Table 3, Figure 2). In contrast, native species were related to litter depth, foliage cover, and shrub cover (Table 3). The pseudo *R2* value indicated the best fit of the mixed model with litter depth as the predictor variable. The threshold value for a 50%

Table 1. Millipede species with their taxonomic classification, their abundance, and their origin.

Order	Family	Genus	Species	Nbr.	Origin
Sphaerotheriida	Arthrosphaeridae	*Zoosphaerium*	*platylabum*	3	native
	Arthrosphaeridae	*Zoosphaerium*	*neptunus*	2	native
Siphonophorida	Siphonorhinidae	*Siphonorhinus*	sp.	1	native
Polydesmida	Dalodesmidae	G.	sp.	1	native
	Paradoxosomatidae	*Oxidus*	*gracilis*	86	non-native
	F.	G.	sp.	1	native
Spirobolida	Pachybolidae	G.	sp.	1	native
	Pachybolidae	*Flagellobolus*	*pauliani*	5	native
Spirostreptida	Spirostreptidae	*Charactopygus*	sp.	1	native
	Spirostreptidae	G.	sp.	1	native
	Cambalidae	*Iulomorpha*	sp. 1	6	non-native
	Cambalidae	*Iulomorpha*	sp. 1a	2	non-native
	Cambalidae	*Iulomorpha*	sp. 1b	2	non-native
	Cambalidae	*Iulomorpha*	sp. 2	1	non-native

Table 2. Average values of the environmental factors in the forest types studied and abundance of millipede species per forest type. (DY = recently degraded forest; D = degraded forest, R15 = reforested with native tree species in 2015; R12 = reforested with native tree species in 2012; R07 = reforested with native tree species in 2007 or 2008; E30 = abandoned Eucalyptus plantation from 1930; E09 = abandoned Eucalyptus plantation from 1909; S1 = secondary forest in Andasibe; S2 = secondary forest of Sahanody; P = primary forest)

	Forest type	DY	D	R15	R12	R07	E30	E09	S1	S2	P
Vegetation characterisitcs	Replicates (n)	2	3	3	3	3	3	3	3	3	2
	Litter depth (cm)	2.75	3.43	2.85	1.94	2.93	4.99	5.32	5.6	5.52	5.74
	Woody debris (0–3)	2	2.78	1.56	1.22	1.78	2.44	1.33	1.89	2.22	2.17
	Canopy height (m)	7.46	7.55	8.43	6.84	12.43	24.42	26.45	25.64	20.72	19.13
	Foliage cover (%)	35.07	37.72	31.46	18.5	44.81	42.78	31.42	69.93	67.1	64.54
	DBH (cm)	20.48	26.27	21.21	12.61	21.33	26.82	44.87	23.23	27.24	25.6
	Shrub cover (%)	18.83	37.78	39.44	52.78	34.44	23.89	27.11	3.89	11.44	20.83
	Uncovered soil (%)	7.67	6	9.78	15.56	3.5	0.33	2.89	0	0	0
	Tree spacing measure (m)	1.27	2.1	2.58	2.34	1.67	1.74	1.57	1.02	0.91	0.92
Abundance of diplopod species	*Z. platylabum*	1	0	0	0	0	0	0	0	0	2
	Z. neptunus	0	0	0	0	0	0	0	0	0	2
	Siphonorhinus sp.	0	0	0	0	0	0	0	1	0	0
	Dalodesmidae sp.	0	0	0	0	0	0	1	0	0	0
	Oxidus gracilis	3	11	16	2	32	11	8	3	0	0
	Polydesmida sp.	0	0	0	0	0	1	0	0	0	0
	Pachybolidae sp.	0	0	0	0	0	0	0	0	1	0
	Flagellobolus pauliani	0	0	0	0	0	0	2	3	0	0
	Charactopygus sp.	0	1	0	0	0	0	0	0	0	0
	Spirostreptidae sp.	0	0	0	0	0	0	0	0	0	1
	Iulomorpha sp. 1	0	1	0	0	0	2	0	4	3	0
	Iulomorpha sp. 2	0	0	1	0	0	0	0	0	0	0

probability of occurrence of native millipede species is above a litter depth of 4.83 cm (Figure 3). Litter depth does predict native millipede presence or absence. The probability of presence exhibited a significant non-linear response to different depths of litter (Table 3, Figure 3), which indicates that native millipedes may occur above a critical minimal amount of litter.

The boxplots in Figure 4 show that native millipedes are restricted to a higher litter depth. The t-test accounts for a significant difference in litter depth between the means of the two groups ($t = 2.361$, $df = 28$, $p = 0.025$).

DISCUSSION

The first question of this study deals with the relation of vegetation variables with the occurrence of millipedes, the second question pertains to whether native and introduced millipedes differ in their response to environmental conditions. The majority of the collected millipede species were native species. However, non-native species occurred in much higher abundances. The most abundant species in this study, *Oxidus gracilis*, is not native to Madagascar. It occurred mainly at the reforested sites with native tree species, which is evidence of the relatively disturbed conditions in this habitat type. Other than *Oxidus gracilis*, the non-native *Iulomorpha* sp. 2 is the only other millipede species found in reforested forests, with just one specimen. The congregating behavior of *Oxidus gracilis*, inhabiting formerly unoccupied niches in high abundances, may outcompete native species (Bulpitt 2016) who could potentially return. However, Tomlinson (2014) found little evidence of non-native millipedes (including *Oxidus gracilis*) displacing native millipede fauna in small forest fragments in New Zealand. Millipedes in New Zealand might not be impacted by competition with *Oxidus gracilis*, but this says nothing about the Malagasy millipedes which are all endemic. In contrast to the reforested sites, the primary forest is associated with three native millipede species.

Regarding environmental characteristics, the *Eucalyptus* plantations, the secondary, and primary forests are similar, but different millipede species were recorded. This leads to the assumption that even though environmental variables are similar, species composition is not. Höfer et al. (2001), who investigated decomposer groups in the Amazon, as well as Mathieu et al. (2005) also found that species richness is highest in the primary forest. David and Handa (2010) question whether tropical secondary forests can provide an appropriate habitat for species that depend on old-growth forests. Although sites might meet the required habitat conditions, time is required for recolonization of arthropods (Nakamura et al. 2003). Millipedes have particularly poor dispersal abilities (Alegasan 2016). Therefore a low degree of forest patch isolation and vegetation corridors should be considered for conservation purposes, especially for invertebrates like millipedes depending on forests for dispersal (Galanes and Tomlinson 2011). An alternative explanation may be that the sampling design did not include enough sampling units to meet a species accumulation curve. For example, there is evidence of occurrence of *Zoosphaerium neptunus* in the secondary forest of Andasibe (Wesener and Schütte 2010). *Zoosphaerium neptunus* is not regarded as threatened despite the eastern rainforest's rapid declining due to fragmentation and deforestation (Vieilledent et al. 2018). It is listed as "least concern" in the IUCN RedList (Rudolf and Wesener 2017a), occurring in several protected areas and being widely distributed (Wesener and Wägele 2008).

Table 3. Results of logistic regression analysis predicting the occurrence of native and non-native millipedes.

		Estimate	Standard error	z-value	p-value	Pseudo R2 Nagelkerke
Native	Litter depth	1.23	0.626	1,960	0.05	0.466
	Woody debris	0.036	0.154	0.232	0.817	0.042
	Canopy height	0.096	0.058	1,646	0.1	0.221
	Foliage cover	0.064	0.026	2,412	0.016	0.373
	DBH	0.076	0.057	1,336	0.181	0.15
	Shrub cover	-0.065	0.032	-2,012	0.044	0.252
	Uncovered soil	-0.36	0.177	-2,038	0.042	0.328
	Tree spacing measure	-1,338	0.816	-1,639	0.101	0.195
Non-native	Litter depth	-0.14	0.301	-0.466	0.642	0.012
	Woody debris	-0.246	0.2	-1,257	0.209	0.123
	Canopy height	-0.029	0.041	-0.716	0.474	0.029
	Foliage cover	0.02	0.028	0.736	0.462	0.042
	DBH	0.076	0.057	1,336	0.181	0.044
	Shrub cover	-0.0256	0.025	-1,024	0.306	0.061
	Uncovered soil	0.01	0.066	0.137	0.891	0.002
	Tree spacing measure	-0.488	0.5	-0.987	0.324	0.053

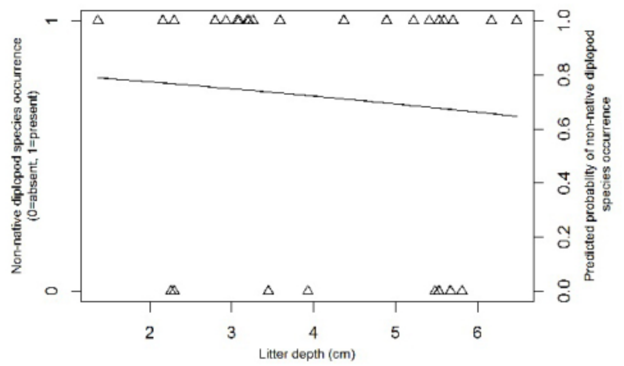


Figure 2. Occurrence of non-native diplopod species in different forests types with different litter depths (cm) and with a regression line representing the probability of occurrence based on the mixed logistic regression model in Table 3.

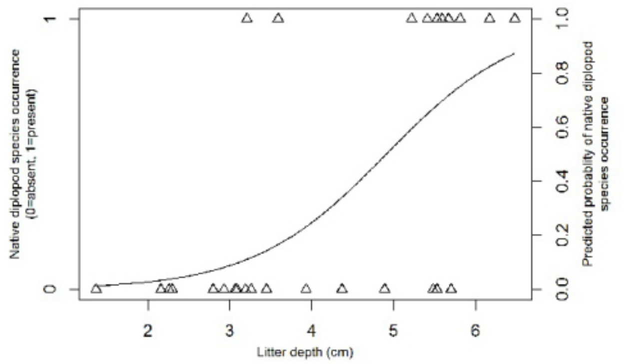


Figure 3. Occurrence of native diplopod species in different forests types with different litter depths (cm) and with a regression line representing the probability of occurrence based on the mixed logistic regression model in Table 3.

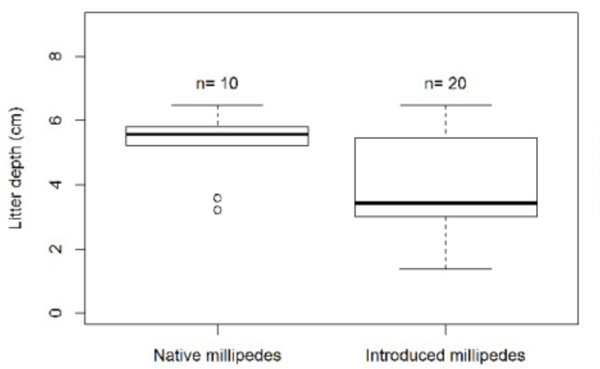


Figure 4. Comparison of the means of replicates, where native or non-native species occurred, for litter depth. (The number of samples n refers to the number of replicates where native millipedes and non-native millipedes were present, respectively)

One explanation why native millipede species were not present at the *Eucalyptus* sites may be the fact that tree species have an impact on millipede assemblages because they influence the microclimate as well as the quantity and quality of leaf litter (Stoev et al. 2010, Stašiov et al. 2012). The litter quality influences arthropod species diversity and assemblages in general (Wardle et al. 2006, Sayer et al. 2010, Lu et al. 2016), as well as millipede species richness and assemblages (Warren and Zou 2002, Loranger-Merciris et al. 2008). A possible explanation why similar native species do not inhabit the *Eucalyptus* sites could be poorer litter quality containing mainly *Eucalyptus* leaves. Furthermore, *Eucalyptus* litter has relatively low N concentrations, which is related to lower millipede biomass (Warren and Zou 2002). In addition, because tropical *Eucalyptus* plantations do not restore the original forest, in terms of diversity of tree leaf litter, macroarthropod abundance may be similar but species richness may be lower (David and Handa 2010). Concluding, saprophagous (feeding on dead/decaying organic matter) macroarthropod compositions changes according to the vegetation structure (David et al. 1999), which also influences litter quantity and quality, the main food and habitat of millipedes.

Several studies confirm the positive effect of litter quantity on litter invertebrate abundance in tropical and subtropical forests (Burghouts et al. 1992, Yang et al. 2007, Sayer et al. 2010, Lu et al. 2016). Another study (Nakamura et al. 2003) identifies litter depth as a factor predicting millipede's morphotaxa richness. Suitable habitats for millipedes are characterized by a high amount of leaf litter, dead wood, closed canopy cover and a humid microclimate (Bogyó et al. 2015). Consequently, it is very likely that the more habitat space in terms of litter depth exists, the more millipede species will be present. In addition, a higher amount of litter facilitates structural habitat complexity, thus supporting more invertebrates (Lu et al. 2016). Therefore available habitat space, in this case litter depth, may be a very significant predictor of arthropod abundance (Sayer et al. 2010). Tomlinson (2014) also indicates that litter quantity is a significant variable for explaining the abundance of most native species in New Zealand, while the abundance of *Oxidus gracilis* increased significantly with decreasing fragment size and lower canopy density. For non-native millipedes, mixed logistic regression models relating the occurrence of non-native millipedes and vegetation characteristics were not significant. Accordingly, non-native millipedes occurred on plots with highly diverse vegetation characteristics.

Oxidus gracilis represents 87% of the collected specimens of non-native millipedes. The species are found in plots with a relatively high variation of litter depth, whereas, in this study, native diplopods only occur at sites with a minimum depth of 4.83 cm. There is evidence that *Oxidus gracilis* deals with a large range of habitat conditions. Its distribution is not related to specific environmental factors (Bulpitt 2016), which is probably why it occurs on each continent in greenhouses as well as in natural ecosystems, e.g., in countries like USA, Australia, China, India, Finland, Italy, Morocco, South Africa, and Madagascar (Stoev et al. 2010). How *Oxidus gracilis* was introduced remains largely unknown. The introduction of *Oxidus gracilis* in Europe, for example, is likely due to the trading of tropical plants (Stoev et al. 2010).

Native millipede species appear to be restricted to habitats with specific characteristics. Although there are no studies for millipedes, there is some indication that habitat specialists are more affected by habitat loss than habitat generalists (David and Handa 2010). In general, deforestation in the tropics could outweigh any other influence for habitat specialists (David 2009), which could pose an especially severe threat to microendemics of the genus *Zoosphaerium* in Madagascar's rainforests (Wesener 2009). However, the two pill-millipedes from this study, *Zoosphaerium neptunus* and *Zoosphaerium platylabum*, are not classified as microendemic, though they are restricted to the rainforest (Wesener 2009). Both pill-millipede species are IUCN RedListed as "least concern" (Rudolf and Wesener 2017a, 2017b). However, some studies showed the negative effects of invasive species on soil invertebrates, e.g., the abundance of many native endemic arthropod species in Hawaii decreased locally because of an invasive ant species from Argentina (*Iridomyrmex humilis*) (Cole et al. 1992) and the abundance and species richness of millipedes were impacted by non-native earthworm species *Amynthas agrestis* in the Great Smoky Mountains in the US (Snyder et al. 2011), because they compete probably for the same food resources (Snyder et al. 2013). Alien species were identified as the main drivers of millipede extinctions, particularly on the Seychelles Islands (Blackburn et al. 2019).

This pilot study identified a threshold value of around 5 cm for litter depth, indicating appropriate habitat conditions for native millipedes. Deriving conservation guidelines from habitat thresholds and predicting species responses to habitat restoration sounds promising, especially because recent empirical evidence has delivered much support and some indication for the existence and usefulness of ecological thresholds (Johnson 2013). However, conservation purposes must consider limitations of ecological thresholds and should not overestimate their relevance for management decisions (Johnson 2013). Van der Hoek et al. (2015) and Müller and Bütler (2010) even advise against applying threshold values to answer questions like "How much is enough?" and against oversimplification. While it is evident that thresholds should not be defined in absolute terms, the study illustrates that ecosystem processes are disrupted by forest degradation and are not restored easily even though the restored forest might approach the original state.

CONCLUSION

The old *Eucalyptus* sites and the primary and secondary forests are associated with more native species than the degraded sites recently reforested with native tree species. Although the reforested sites with *Eucalyptus* exhibit a similar amount of litter as the secondary and primary forests, they clearly do not provide the same litter quality characteristics. Furthermore, the study indicates that litter depth is very likely the most significant variable in explaining native millipede occurrence. It is expected that the threshold value of litter depth indicates suitable habitat conditions, because litter-dwelling millipedes are dependent on the litter layer. However, the results presented here should be interpreted with caution due to the small sample size. In future studies, changes in sample size, as well as in the sampling method should be taken into account to fully understand differences between native and non-native millipedes and to elaborate the threshold approach for millipedes in the forests of Andasibe. Of special concern is the presence of numerous introduced millipedes at sites replanted with native vegetation, in combination with the complete absence of any indigenous millipedes at these sites. As millipedes are poor dispersers, the non-native millipede species were most-likely introduced by the reforesting efforts and might outcompete the native species. It would be useful to investigate, whether the provision of ecosystem functions like decomposition of introduced millipedes is redundant to that of endemic millipedes. Great care should thus be taken to avoid permanent damage of native forests through potential introduction of non-native soil arthropods via reforestation.

ACKNOWLEDGEMENTS

For helpful comments, we thank Karina Montero and Susanne Kobbe and for his general contribution, we thank Jörg Ganzhorn, without whom this study would not have been possible. Many thanks go to Jacques Rakotondranary and Toloana Rakotondranary-Andrianasolo for their hospitality and their help with both research and export permission, as well as organization in general. Many thanks also to the members of Association Mitsinjo for their help with organizational tasks, and especially to Gervais Rakotonirina, for his help in conducting fieldwork. The study was carried out under the collaboration between Madagascar National Parks (MNP), the Departments of Animal Biology, Department of Plant Biology and Ecology (Antananarivo University, Madagascar) and the Department of Animal Ecology and Conservation (Hamburg University, Germany). We thank the Malagasy authorities for issuing the research permit. Fieldwork was authorized by the Ministère de L'Environnement, de l'Écologie, de la Mer et des Forêts. The study was supported by the University of Hamburg.

REFERENCES

Alegasan, P. 2016. Millipedes: Diversity, distribution and ecology. In: Arthropod Diversity and Conservation in the Tropics and the Sub-tropics. A. K. Chakravarthy and S. Sridhara (eds.), pp 119–137. Springer, Singapore.

Andriamananjara, A., Hewson, J., Razakamanarivo, H., Andrisoa, R. H., Ranaivoson, N., et al. 2016. Land cover impacts on aboveground and soil carbon stocks in Malagasy rainforest. Agriculture, Ecosystems & Environment 233, 3: 1–15. <https://doi.org/10.1016/j.agee.2016.08.030>

Attems, C. 1910. Myriopoden von Madagaskar, den Komoren und den Inseln Ostafrikas. In: Reise in Ostafrika in den Jahren 1903–1905. A. Voeltzkow (ed.), pp 73–115. Schweizerbartsche Verlagsbuchhandlung, Stuttgart.

Attems, C. 1914. Die indo-australischen Myriopoden. Archiv für Naturgeschichte 80A, 4: 1–398.

Attems, C. 1951. Myriapodes d'Afrique, de Madagascar et de la Réunion récoltés par le Pr. Paul Remy. Mémoires de l'Institut Scientifique de Madagascar, Série A, 5: 173–186.

Blackburn, T. M., Bellard, C. and Ricciardi, A. 2019. Alien versus native species as drivers of recent extinctions. Frontiers in Ecology and the Environment 17: 203–207. <https://doi.org/10.1002/fee.2020>

Bogyó, D., Magura, T., Nagy, D. D. and Tothmeresz, B. 2015. Distribution of millipedes (Myriapoda, Diplopoda) along a forest interior, forest edge, grassland habitat complex. ZooKeys 510: 181–195. <https://doi.org/10.3897/zookeys.510.8657>

Bulpitt, G. 2016. Congregating behavior and response to resource distribution of the Green House Millipede, *Oxidus gracilis*. PeerJ PrePrints 4: e2642v1. <https://doi.org/10.7287/peerj.preprints.2642v1>

Burghouts, T., Ernsting, G., Korthals, G. and De Vries, T. 1992. Litterfall, leaf litter decomposition and litter invertebrates in primary and selectively logged Dipterocarp forest in Sabah, Malaysia. Philosophical Transactions of the Royal Society B: Biological Sciences 335, 1275: 407–416. <https://doi.org/10.1098/rstb.1992.0032>

Cole, F. R., Medeiros, A. C., Loope, L. L. and Zuehlke, W. W. 1992. Effects of the Argentine Ant on arthropod fauna of Hawaiian high-elevation shrubland. Ecology 73, 4: 1313–1322. <https://doi.org/10.2307/1940678>

Cole, R. J., Holl, K. D., Zahawi, R. A., Wickey, P. and Townsend, A. R. 2016. Leaf litter arthropod responses to tropical forest restoration. Ecology and Evolution 6, 15: 5158–5168. <https://doi.org/10.1002/ece3.2220>

Coleman, D. C. and Wall, D. H. 2015. Soil fauna: Occurrence, biodiversity, and roles in ecosystem function. In: Soil Microbiology, Ecology and Biochemistry. E. A. Paul (ed.), pp 111–149. Elsevier.

David, J.-F., Devernay, S., Loucougaray, G. and Le Floc'h, E. 1999. Belowground biodiversity in a Mediterranean landscape: relationships between saprophagous macroarthropod communities and vegetation structure. Biodiversity & Conservation 8: 753–767. <https://doi.org/10.1023/A:1008842313832>

David, J.-F. 2009. Ecology of millipedes (Diplopoda) in the context of global change. Soil Organisms 81, 3: 719–733.

David, J.-F. and Handa, I. T. 2010. The ecology of saprophagous macroarthropods (millipedes, woodlice) in the context of global change. Biological Reviews 85, 4: 881–895. <https://doi.org/10.1111/j.1469-185X.2010.00138.x>

Decaëns, T., Jiménez, J. J., Gioia, C., Measey, G. J. and Lavelle, P. 2006. The values of soil animals for conservation biology. European Journal of Soil Biology 42, S1: 23–38. <https://doi.org/10.1016/j.ejsobi.2006.07.001>

Dolch, R. 2003. Andasibe (Périnet): are current efforts sufficient to protect Madagascar's biodiversity hotspot? In: The Natural History of Madagascar. S. M. Goodman and J. P. Benstead (eds.), pp 1480–1485. The University of Chicago Press, Chicago.

Enghoff, H. 2003. Diplopoda, Millipedes. In: The Natural History of Madagascar. S. M. Goodman and J. P. Benstead (eds.), pp 617–627. The University of Chicago Press, Chicago.

Galanes, I. T. and Thomlinson, J. R. 2011. Soil millipede diversity in tropical forest patches and its relation to landscape structure in northeastern Puerto Rico. Biodiversity & Conservation 20, 13: 2967–2980. <https://doi.org/10.1007/s10531-011-0128-7>

Ganzhorn, J. U., Lowry, P. P., Schatz, G. E. and Sommer, S. 2001. The biodiversity of Madagascar: one of the world's hottest hotspots on its way out. Oryx 35, 4: 346–348. <https://doi.org/10.1046/j.1365-3008.2001.00201.x>

García-Palacios, P., Maestre, F. T., Kattge, J. and Wall, D. H. 2013. Climate and litter quality differently modulate the effects of soil fauna on litter decomposition across biomes. Ecology Letters 16, 8: 1045–1053. <https://doi.org/10.1111/ele.12137>

Golovatch, S. I. and Kime, R. D. 2009. Millipede (Diplopoda) distributions: A review. Soil Organisms 81, 3: 565–597. Available online <http://shorturl.at/oO247>

Goodman, S. M. and Benstead, J. P. 2005. Updated estimates of biotic diversity and endemism for Madagascar. Oryx 39, 1: 73–77. <https://doi.org/10.1017/S0030605305000128>

Höfer, H., Hanagarth, W., Garcia, M., Martius, C., Franklin, E., et al. 2001. Structure and function of soil fauna communities in Amazonian anthropogenic and natural ecosystems. European Journal of Soil Biology 37, 4: 229–235. <https://doi.org/10.1016/S1164-5563(01)01089-5>

Jeekel, C. A. W. 1999. A new *Sechelleptus* from Madagascar, with a key to the species of the genus (Diplopoda-Spriostreptida). Myriapod Memoranda 1: 45–57.

Johnson, C. J. 2013. Identifying ecological thresholds for regulating human activity: Effective conservation or wishful thinking? Biological Conservation 168: 57–65. <https://doi.org/10.1016/j.biocon.2013.09.012>

Keenan, R. J., Reams, G. A., Achard, F., de Freitas, J. V., Grainger, A., et al. 2015. Dynamics of global forest area: Results from the FAO Global Forest Resources Assessment 2015. Forest Ecology and Management 352: 9–20. <https://doi.org/10.1016/j.foreco.2015.06.014>

Lavelle, P., Decaëns, T., Aubert, M., Barot, S., Blouin, et al. 2006. Soil invertebrates and ecosystem services. European Journal of Soil Biology 42: S3–S15. <https://doi.org/10.1016/j.ejsobi.2006.10.002>

Loranger-Merciris, G., Imbert, D., Bernhard-Reversat, F., Lavelle, P. and Ponge, J.-F. 2008. Litter N-content influences soil millipede abundance, species richness and feeding preferences in a semi-evergreen dry forest of Guadeloupe (Lesser Antilles). Biology and Fertility of Soils 45, 1: 93–98. <https://doi.org/10.1007/s00374-008-0321-3>

Lu, J., Turkington, R. and Zhou, Z.-k. 2016. The effects of litter quantity and quality on soil nutrients and litter invertebrates in the understory of two forests in southern China. Plant Ecology 217, 11: 1415–1428. <https://doi.org/10.1007/s11258-016-0600-2>

Mathieu, J., Rossi, J.-P., Mora, P., Lavelle, P., Martins, P. F. S., et al. 2005. Recovery of soil macrofauna communities after forest clearance in Eastern Amazonia, Brazil. Conservation Biology 19, 5: 1598–1605. <https://doi.org/10.1111/j.1523-1739.2005.00200.x>

Müller, J. and Bütler, R. 2010. A review of habitat thresholds for dead wood: A baseline for management recommendations in European forests. European Journal of Forest Research 129, 6: 981–992. <https://doi.org/doi: 10.1007/s10342-010-0400-5>

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. and Kent, J. 2000. Biodiversity hotspots for conservation priorities. Nature 403, 6772: 853–858. <https://doi.org/10.1038/35002501>

Nakamura, A., Proctor, H. and Catterall, C. P. 2003. Using soil and litter arthropods to assess the state of rainforest restoration. Ecological Management & Restoration 4, S1: 20–28. <https://doi.org/10.1046/j.1442-8903.4.s.3.x>

Powers, J. S., Montgomery, R. A., Adair, E. C., Brearley, F. Q., DeWalt, S. J., et al. 2009. Decomposition in tropical forests: a pan-tropical study of the effects of litter type, litter placement and mesofaunal exclusion across a precipitation gradient. Journal of Ecology 97, 4: 801–811. <https://doi.org/10.1111/j.1365-2745.2009.01515.x>

Rudolf, E. and Wesener, T. 2017a. IUCN Red List of Threatened Species: *Zoosphaerium neptunus*. The IUCN Red List of Threatened Species 2017: e.T65524274A65527955. <https://dx.doi.org/10.2305/IUCN.UK.2017-1.RLTS.T65524274A65527955.en>

Rudolf, E. and Wesener, T. 2017b. IUCN Red List of Threatened Species: *Zoosphaerium platylabum*. The IUCN Red List of Threatened Species 2017: e.T65525169A65527965. <https://dx.doi.org/10.2305/IUCN.UK.2017-1.RLTS.T65525169A65527965.en>

de Saussure, H. and Zehntner, L. 1897. Atlas de l'histoire naturelle des Myriapodes. In: Histoire Physique, Naturelle et Politique de Madagascar. A. Grandidier (ed.), pp. 1–12. Imprimerie Nationale, Paris.

de Saussure, H. and Zehntner, L. 1901. Myriapoden aus Madagaskar und Zansibar, gesammelt von Dr. A. Voeltzkow. Abhandlungen der Senckenburgischen naturforschenden Gesellschaft 26: 429–460.

de Saussure, H. and Zehntner, L. 1902. Myriapodes de Madagascar. In: Histoire Physique, Naturelle et Politique de Madagascar. A. Grandidier (ed.), pp. 13–15. Imprimerie Nationale, Paris.

Sayer, E. J., Sutcliffe, L. M. E., Ross, R. I. C. and Tanner, E. V. J. 2010. Arthropod abundance and diversity in a lowland tropical forest floor in Panama: The role of habitat space vs. nutrient concentrations. Biotropica 42, 2: 194–200. <https://doi.org/10.1111/j.1744-7429.2009.00576.x>

Sloan, S. and Sayer, J. A. 2015. Forest Resources Assessment of 2015 shows positive global trends but forest loss and degradation persist in poor tropical countries. Forest Ecology and Management 352: 134–145. <https://doi.org/10.1016/j.foreco.2015.06.013>

Snyder, B. A., Callaham, M. A. Jr. and Hendrix, P. F. 2011. Spatial variability of an invasive earthworm (*Amynthas agrestis*) population and potential impacts on soil characteristics and millipedes in the Great Smoky Mountains National Park, USA. Biological Invasions 13, 2: 349–358. <https://doi.org/10.1007/s10530-010-9826-4>

Snyder, B. A., Callaham, M. A. Jr., Lowe, C. N. and Hendrix, P. F. 2013. Earthworm invasion in North America: Food resource competition affects native millipede survival and invasive earthworm reproduction. Soil Biology and Biochemistry 57: 212–216. <https://doi.org/10.1016/j.soilbio.2012.08.022>

Snyder, B. A., Draney, M. L. and Sierwald, P. 2006. Development of an optimal sampling protocol for millipedes (Diplopoda). Journal of Insect Conservation 10, 3: 277–288. <https://doi.org/10.1007/s10841-006-6699-z>

Stašiov, S., Stašiová, A., Svitok, M., Michalková, E., Slobodník, B., et al.. 2012. Millipede (Diplopoda) communities in an arboretum: Influence of tree species and soil properties. Biologia 67, 5: 945–952. <https://doi.org/10.2478/s11756-012-0097-7>

Stoev, P., Zapparoli, M., Golovatch, S., Enghoff, H., Akkari, N. and Barber, A. 2010. Myriapods (Myriapoda). Chapter 7.2. BioRisk 4, 1: 97–130. <https://doi.org/10.3897/biorisk.4.51>

Tian, G., Brussard, L. and Kang, B. T. 1995. Breakdown of plant residues with contrasting chemical composition under humid tropical conditions: Effects of earthworms and millipedes. Soil Biology and Biochemistry 27, 3: 277–280. <https://doi.org/10.1016/0038-0717(94)00182-Z>

Tomlinson, A. 2014. Interactions between native and exotic detritivores and impacts on ecosystem processes. Doctoral dissertation. University of Auckland. Available at <http://hdl.handle.net/2292/21610>

Vallan, D. 2002. Effects of anthropogenic environmental changes on amphibian diversity in the rain forests of eastern Madagascar. Journal of Tropical Ecology 18, 5: 725–742. <https://doi.org/10.1017/S026646740200247X>

van der Hoek, Y., Zuckerberg, B. and Manne, L. L. 2015. Application of habitat thresholds in conservation: Considerations, limitations, and future directions. Global Ecology and Conservation 3: 736–743. <https://doi.org/10.1016/j.gecco.2015.03.010>

Vieilledent, G., Grinand, C., Rakotomalala, F. A., Ranaivosoa, R., Rakotoarijaona, J. R., et al. 2018. Combining global tree cover loss data with historical national forest-cover maps to look at six decades of deforestation and forest fragmentation in Madagascar. Biological Conservation 222: 189–197. <https://doi.org/10.1016/j.biocon.2018.04.008>

Waeber, P. O., Rafanoharana, S., Rasamuel, H. A. and Wilmé, L. 2020. Parks and reserves in Madagascar: Managing biodiversity for a sustainable future. In: Protected Areas, National Parks and Sustainable Future. A. N. Bakar and M. N. Suratman (eds.), pp 89–108. IntechOpen, London. <https://doi.org/10.5772/intechopen.85348>

Wardle, D. A., Yeates, G. W., Barker, G. M. and Bonner, K. I. 2006. The influence of plant litter diversity on decomposer abundance and diversity. Soil Biology and Biochemistry 38, 5: 1052–1062. <https://doi.org/10.1016/j.soilbio.2005.09.003>

Warren, M. W. and Zou, X. 2002. Soil macrofauna and litter nutrients in three tropical tree plantations on a disturbed site in Puerto Rico. Forest Ecology and Management 170, 1–3: 161–171. <https://doi.org/10.1016/S0378-1127(01)00770-8>

Wesener, T. 2009. Unexplored richness: discovery of 31 new species of Giant Pill-Millipedes endemic to Madagascar, with a special emphasis on microendemism (Diplopoda, Sphaerotheriida). Zootaxa 2097: 1–134. < http://dx.doi.org/10.11646/zootaxa.2097.1>

Wesener, T. and Schütte, K. 2010. Swarming behaviour and mass occurrence in the world's largest giant pill-millipede species, Zoosphaerium neptunus, on Madagascar and its implication for conservation efforts (Diplopoda: Sphaerotheriida). Madagascar Conservation & Development 5, 2: 89–94. <https://doi.org/10.4314/mcd.v5i2.63137>

Wesener, T. and Wägele, J.-W. 2008. The giant pill-millipedes of Madagascar: Revision of the genus *Zoosphaerium* (Myriapoda, Diplopoda, Sphaerotheriida). Zoosystema 30, 1: 5–85. Available online <http://sciencepress.mnhn.fr/sites/default/files/articles/pdf/z2008n1a1.pdf>

Wesener, T., Enghoff, H. and Sierwald, P. 2009. Review of the Spirobolida on Madagascar, with descriptions of twelve new genera, including three genera of 'fire millipedes' (Diplopoda). ZooKeys 19: 1–128. <https://doi.org/10.3897/zookeys.19.221>

Yang, X., Warren, M. and Zou, X. 2007. Fertilization responses of soil litter fauna and litter quantity, quality, and turnover in low and high elevation forests of Puerto Rico. Applied Soil Ecology 37, 1–2: 63–71. <https://doi.org/10.1016/j.apsoil.2007.03.012>

Zanella, A., Ponge, J.-F. and Briones, M. J. I. 2018. Humusica 1, article 8: Terrestrial humus systems and forms—Biological activity and soil aggregates, space-time dynamics. Applied Soil Ecology 122: 103–137. <https://doi.org/10.1016/j.apsoil.2017.07.020>

ARTICLE http://dx.doi.org/10.4314/mcd.v15i1.5

An alternative for agriculture at Lake Alaotra, Madagascar: organic fertilizer and soil amendment from the invasive water hyacinth (*Eichhornia crassipes*)

Rakotoarisoa, T.[I], Richter, T.[I], Schmidt, N.[I], Mantilla Contreras, J.[I]

Correspondence:
Jasmin Mantilla Contreras
Institute of Biology and Chemistry, University of Hildesheim, Hildesheim, Germany
Email: mantilla@uni-hildesheim.de

ABSTRACT

In the context of a globally increasing 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 organic fertilizer and soil amendment (composts, green manure and ash) at Lake Alaotra, one of the most important agricultural areas of Madagascar. Five different products were produced under the local conditions of Lake Alaotra. In addition, we conducted a growth experiment with Chinese cabbage (*Brassica rapa* ssp. *chinensis*) to evaluate the effectiveness of the water hyacinth products in comparison to the mineral fertilizer NPK—nitrogen, phosphorous, potassium—and to cow dung. The results of our study show that it was easily possible to produce water hyacinth fertilizer/soil amendment under the remote conditions of Lake Alaotra. In addition, our results show that a higher biomass gain of Chinese cabbage treated with water hyacinth composts was achieved compared to NPK and cow dung. A higher biomass gain was mainly obtained due to an improvement of soil structure after compost addition. Water hyacinth green manure and ash showed low performance. Besides, applying composts was cheaper than buying NPK or cow dung. Our results show that water hyacinth can serve as a fertilizer and soil amendment and could help to improve agriculture at Lake Alaotra.

RÉSUMÉ

Dans un contexte d'accroissement mondial de la population humaine couplé d'une dégradation continue de l'environnement, les innovations agriculturales respectueuses de l'environnement sont essentielles pour réduire la pauvreté et l'insécurité alimentaire mondiale. Cette situation est particulièrement évidente au niveau des pays en voie de développement où la conservation de la nature et la production agricole sont en constant conflit. Nous avons étudié l'efficacité de l'usage d'une ressource naturelle locale, la plante envahissante jacinthe d'eau (*Eichhornia crassipes*) comme source de fertilisant organique (composts, engrais vert et cendre) au niveau du Lac Alaotra, une des plus importantes zones agricoles de Madagascar. Cinq types de fertilisants ont été produits à partir de la jacinthe d'eau selon les conditions locales du Lac Alaotra. De plus, nous avons conduit une expérience avec le chou de chine (*Brassica rapa*, ssp. *chinensis*) pour évaluer les performances des fertilisants de la jacinthe d'eau en comparaison avec les fertilisants locaux NPK (11% d'azote, 22% de phosphore et 16% de potassium) et le fumier de bétail. Nos résultats montrent que la production de fertilisants à partir de la jacinthe d'eau et son usage pour l'amendement du sol sont possibles et faciles à réaliser dans les conditions locales. De plus, un gain de biomasse important a été observé avec les choux traités avec les composts de jacinthe d'eau en comparaison avec le NPK et le fumier de bétail. L'important gain de biomasse est certainement dû à l'amélioration de la structure du sol après l'application du compost. L'engrais vert et les cendres de jacinthe d'eau ont montré cependant de maigres performances. De plus, l'utilisation du compost est moins chère par rapport à celle du NPK et du fumier de bétail. Nos résultats montrent que la jacinthe d'eau peut être appliquée en tant que fertilisant et pour l'amendement du sol, et par conséquent peut contribuer à l'amélioration de l'agriculture au niveau du Lac Alaotra.

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 and increasing anthropogenic pressures partly from a rural population mostly living from the agricultural exploitation of natural resources (Myers et al. 2000, Urech et al. 2015, Zähringer et al. 2016, Jones et

I University of Hildesheim, Hildesheim, Germany
Citation Rakotoarisoa, T., Richter, T., Schmidt, N., Mantilla Contreras, J. 2020. An alternative for agriculture at Lake Alaotra, Madagascar: organic fertilizer and soil amendment from the invasive water hyacinth (Eichhornia crassipes). Madagascar Conservation & Development 15, 1: 27–34. http://dx.doi.org/10.4314/mcd.v15i1.5

al. 2019). In Madagascar, a high rate of population growth coupled with a 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 (ranked 162 amongst 189 regarding the Human Development Index and with 70,7% of the population living under the poverty line), obtains a quarter of its GDP from agriculture that provides employment for 80% of its population (Eubanks 2012, UNDP 2019).

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 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, vegetable crops, rent and industrial products and fruit production (Penot 2009). From an ecological point of view, 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 (Guillera-Arroita et al. 2010). Due to the high demographic pressure and rural poverty coupled with 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. The main problem for the local biodiversity is the use of shifting cultivation. On a global level, this land use pattern is declining but it is still widespread throughout Madagascar (Curtis et al. 2018, UNDP 2019). This creates a chronic conflict between conservation and development goals leading to marsh conversion into rice fields and overexploitation of natural resources (Copsey et al. 2009, Waeber et al. 2018).

To solve this complex problem, 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. 2006, Jenn-Treyer et al. 2007, Rasoamanana et al. 2011, Scopel et al. 2013). However, their diffusion failed due to several reasons: technical limitations (water control), expensive labour force, costly seeds, requirement of considerable amounts of mineral fertilizer, general preference for rice varieties with long straw used for feeding livestock, long learning process, and competition with fodder for livestock. The doubling of local fertilizer prices in 2008 due to the credit policy failures has aggravated the general skeptical opinions of local farmers toward agricultural innovations. A significant yield difference to the conventional agriculture cannot be reached without an optimal application of NPK (Penot et al. 2012, 2014). Since 2015, the price of fertilizers dropped again to its pre-2008 value, thereby relaunching their usage in the Alaotra region (pers. comm.).

In comparison to rice cultivation, the improvement of vegetable farming has received less attention in the Alaotra region. One main problem for crop planting in the region are the relatively nutrient poor soils. Farmers regularly use fertilizers which are on the one hand expensive and on the other hand harmful for the environment. Within this study, we propose the use of the water hyacinth (*Eichhornia crassipes*) as a source for organic fertilizer and soil amendment. It is one of the most problematic invasive aquatic plant species covering 53% of the marsh belt fringe, altering water parameters and plant communities at Lake Alaotra (Lammers et al. 2015). In addition, we found out that the livelihood of 81% of the local stakeholders at Lake Alaotra (mainly rice farmers and fishers) are affected by water hyacinth, as the plant clogs waterways, reduces fishing areas and thus fish catches, and invades rice fields during the rainy season (Rakotoarisoa et al. 2015). Globally, belonging to the 10 most troublesome aquatic weeds, the water hyacinth has already been 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, 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 water hyacinth compost (Gunnarsson and Petersen 2007). Water hyacinth green manure and ashes represent other alternatives with less workload (Gunnarsson and Petersen 2007).

In Madagascar, to our knowledge no attempts have been made so far at using this plant as a source for organic fertilizer and soil amendment. A recent study of Rakotoarivelo (in press) showed that only 30% of the people living in the Alaotra region are using the plant, and those who do use it nearly only as fodder for pigs. We therefore tested if water hyacinth organic fertilizer and soil amendments could be produced in the poor and remote Alaotra region, and if they can substitute or complement the commonly used fertilizers. As a first attempt we decided to focus our study on small scale agriculture and vegetable farming and not on rice production. In the region, three fertilizers are commonly used: the complex mineral fertilizer NPK (Nitrogen-Phosphorus-Potassium), cow dung and urea. Urea is mostly used in rice fields. NPK and cow dung are more commonly used in vegetable farming. 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 observed that NPK is still widely used for vegetable farming. Cow dung is also widely used, although it is very expensive as only few cattle are present in the region. Within this research, we evaluated five different methods of producing organic fertilizer and soil amendment based on water hyacinth (aerobic, anaerobic and pit compost, ash and green manure). In order to identify which water hyacinth product is best suited to replace or complement commonly used fertilizers, we conducted a growth experiment with Chinese cabbage (*Brassica rapa* ssp. *chinensis*), a fast growing and commonly used vegetable in the region.

MATERIALS AND METHODS

STUDY AREA. 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). The production of water hyacinth organic fertilizer and soil amendment (composts, green manure and ashes) took place in the village of Andreba Gara. The village 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.

SOIL CONDITIONS OF VEGETABLE FIELDS. In order to assess the physico-chemical properties of the soil used for vegetable farming at Lake Alaotra, soil samples were collected from Andreba Gara (n=2) and two further locations: 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. Soil moisture (%), 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. Soil type identification followed Sponagel et al. 2005. The soil fertility was assessed using Cation Exchange Capacity (CEC) by measuring the amount of colloids in the soil and the CEC of each of these colloids using buffered method with NH_4^+ (at pH=7). All soil analyses were performed at the Laboratory of Pedology (FOFIFA) in Antananarivo, Madagascar.

PRODUCTION OF WATER HYACINTH ORGANIC FERTILIZER AND SOIL AMENDMENT. For all water hyacinth products, fresh plants were collected at the shore of Lake Alaotra and transported with zebu carts into a Camp ("Camp Bandro", a local ecotouristic camp offering a fenced off and undisturbed area). Afterwards, the roots were removed since water hyacinth accumulates heavy metals and pollutants mostly in these organs (Matindi et al. 2014). The preparation of all water hyacinth products 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 nitrogen 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 bases every two weeks until composting had turned the substrates into a crumbly dark mass after one month (Polprasert et al. 1980).

GROWTH EXPERIMENTS WITH CHINESE CABBAGE. In order to test which water hyacinth product was most efficient in enhancing plant growth and to what degree water hyacinth substrates can potentially replace or supplement commonly used fertilizer, we conducted a growth experiment with Chinese cabbage (*Brassica rapa* ssp. *chinensis*). Chinese cabbage is a common vegetable in the region and particularly suitable as a test crop given its fast growth. Cabbage plants were raised from seeds 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 (Figure 1).

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). The amount of fertilizer was based on the mass balance method and followed suggestions by 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^-, 1.18 mg/L PO_4^{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.

Figure 1. Location of the Alaotra region, the three localities where soil samples were collected and the village of Andreba Gara where the growth experiment with Chinese cabbage was conducted at the end of the rainy season (March–April 2014).

LABORATORY ANALYSIS. Macronutrient contents (total N, total P and K) 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, for total potassium). In addition, pH measurements 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). Even though to our knowledge no heavy metal contamination exists at Lake Alaotra, we could also not exclude its presence. As the water hyacinth can store a large amount of heavy metals in its plant compartments and we wanted to avoid any risk, 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).

ECONOMIC ASPECTS. To compare the total use costs of the different fertilizer, the costs of raw materials, labour force and transportation using Zebu carts were investigated by questioning local farmers on real local pricing. We rewarded all services related to the experiment according to the local cost standards. The comparison of raw material and transportation costs of the different fertilizer was based on their common application rate per hectare (Lindsey and Hirt 2000, Gajalakshmi and Abbasi 2002, Gunnarsson and Petersen 2007).

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

RESULTS

SOIL CONDITIONS OF VEGETABLE FIELDS. Three soil types were identified depending on the sampling location: loamy sand in Anororo, sandy loam in Vohimarina and sandy clay loam in Andreba (Table 1). Soil moisture 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.

PRODUCTION AND PERFORMANCE OF WATER HYACINTH PRODUCTS. All water hyacinth products could be easily produced under the local conditions at Lake Alaotra. Water hyacinth compost was ready after 30 days. Our results also demonstrate that especially water hyacinth compost was more beneficial for plant growth than commonly used fertilisers as we recorded the highest biomass production of Chinese cabbage in treatments with compost (Figure 2). However, no significant difference occurred between the three compost types. Second highest biomass production was reached in treatments with NPK. Plants that were fertilized with green manure, ash and cow dung showed a very low biomass production. 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). Plants in the control treatment (plain soil) showed strong signs of water stress, e.g. wilted leaves.

NUTRIENT CONCENTRATIONS AND PARAMETERS OF SOIL AND FERTILIZER USED FOR THE GROWTH EXPERIMENT. Macronutrient analyses revealed that the soil used for the experiment was very poor in nutrients (Table 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%). 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.

ECONOMICAL ASPECTS. 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 are 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 costs only. Local farmers said they would collect the raw materials (mango leaves and water hyacinth) themselves without hiring labour force. However, in case they have 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. Transportation cost in the Alaotra region is estimated at approximately 3.2 US$ per ton. The cost allocated to the transportation of each fertilizer type de-

Table 1. Physico-chemical properties of soils at three locations around Lake Alaotra, north-eastern Madagascar. (Data show means of two samples at each site)

	Vohimarina	Anororo	Andreba
Clay (%)	15.0	11.0	23.0
Silt (%)	15.0	3.0	25.0
Sand (%)	71.0	87.0	53.0
Type of soils	Sandy loam	Loamy sand	Sandy clay loam
Humidity (%)	21.9	7.9	36.9
pH	5.45	3.45	4.82
C (%)	8.79	0.42	2.29
N (%)	0.63	0.04	0.21
P (ppm)	10.9	3.3	26.9
Ca (meq/100g)	6.0	2.2	12.0
Mg	3.50	1.50	9.60
K	0.24	0.05	2.18
Na	0.87	0.65	3.39
CEC	80.7	15.1	34.0

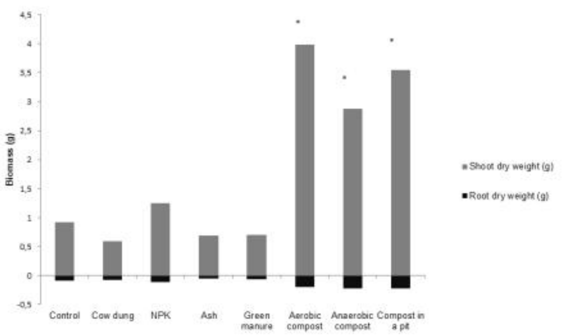


Figure 2. Means of shoot biomass and root biomass for Chinese cabbage grown with water hyacinth and locally used fertilizer. (Asterisks show significant mean difference at $p < 0.05$ using the Kruskal-Wallis test)

Table 2. Comparison of macronutrient concentrations and pH of the different fertilizer used for the growth experiment with Chinese cabbage at Lake Alaotra, north-eastern Madagascar. (Data show means of two samples per treatment. For soil values see Table 1)

Treatments	N (%)	P (%)	K (%)	pH
Cow dung	0.35	0.09	0.21	7.93
NPK	22.00	4.84	11.62	4.80
Ash	0.00	0.00	23.24	7.92
Green manure	1.29	1.78	1.85	7.80
Aerobic compost	1.99	2.95	2.51	6.26
Anaerobic compost	1.53	1.85	2.34	6.90
Compost in a pit	1.79	2.57	2.36	6.56

Table 3. Application rate and costs of the different fertilizers used for the growth experiment with Chinese cabbage at Lake Alaotra. (*Retrieved from Lindsey and Hirt 2000, Gajalakshmi and Abbasi 2002, Gunnarsson and Petersen 2007)

		Costs per hectare (US$)			
Type of fertilizer	Application per hectare* (tons)	Raw material	Labor	Transportation	Total
NPK	0.1	67.0	0.0	0.3	67.3
Cow dung	10.0	100.0	13.5	32.0	145.5
Green manure	3.0	0.0	4.5	10.0	14.5
Compost	10.0	20.0	13.5	32.0	65.5
Ash	2.0	0.0	4.0	7.0	11.0

pends 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 3).

HEAVY METAL CONCENTRATIONS. Our results show that water hyacinth contained far less heavy metals than the maximum safe values (Amlinger 2004) regarding compost quality standards (Table 4). As the heavy metal concentrations were very low, no further analysis was made with the fertilizer 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.

DISCUSSION

This study demonstrated that it is possible to produce different water hyacinth fertilizer under the local conditions encountered in the Alaotra region (i.e. no electricity, no high technology machine and no infrastructure). Further, the results of the growth experiment with Chinese cabbage displayed higher biomass gain of treatments with water hyacinth compost compared to the other water hyacinth products (green manure and ash) and locally used fertilizer (NPK and cow dung). Therefore, it can be concluded that water hyacinth compost is suitable for improving vegetable field soil structure and fertility and further has the potential to substitute or complement NPK and cow dung in the Alaotra region.

VEGETABLE FIELDS IN THE ALAOTRA REGION: PROBLEMS AND CONTRIBUTION OF WATER HYACINTH FERTILIZER. According to our results, vegetable 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 amount of plant available phosphorus within soils. 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 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 than 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.

Table 4. Means of heavy metal concentrations in water hyacinth (n=23) and local soil (n=23) at Lake Alaotra. (*Retrieved from Amlinger (2004))

Heavy metal (mg/Kg)	Water hyacinth	Local soil	Compost quality standards*
Cd	< 0,001	< 0,001	1.0
Ni	< 5	80.0	60.0
Cr	< 5	147.0	70.0
Pb	< 5	25.5	120.0
Cu	17.0	125.0	150.0
Zn	26.0	170.0	500.0

Management alternatives are suggested depending on the state of degradation of vegetable fields within the three villages (Table 5). Due to its high content in sand particles (87%), the soil in Anororo requires several treatments before being suitable for agriculture. First, 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 chemical fertilizer, reducing tillage, using leguminous plants for catching atmospheric N and retaining crop residues (Bell and Seng 2007). For the soil in Andreba Gara, revegetation of the hillsides should become a priority to reduce soil erosion and embankment of fields downstream while the joint use of chemical fertilizer and water hyacinth compost could supply nutrients 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.

RELEVANCE AND IMPLEMENTATION OF WATER HYACINTH COMPOST USE AT LAKE ALAOTRA. Although green manure and ash generally seem 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 at once reducing the harmful ecological and socioeconomic impacts of this invasive plant in the Alaotra region. In contrast to NPK, compost can retain nutrients in the soil, avoiding therefore the further eutrophication of Lake Alaotra due to nutrients entry by runoff (Polprasert et al. 1980; Lammers et al. 2015). Besides, it can increase soil resistance to erosion, suppress plant diseases and improve 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 of fertilizer 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 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 the labor can be undertaken during the rainy season next to the area where plants are harvested,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 much time or any sophisticated equipment

Table 5. Nature of soil, ecosystem degradation and soil restoration alternatives for the three villages around Lake Alaotra.

	Anororo	Andreba Gara	Vohimarina
Soil type	Loamy sand	Sandy clay loam	Sandy loam
Ecosystem degradation	High	Middle	Low
Restoration measures	Clay application; Water hyacinth compost; chemical fertilizer; leguminous plants; reducing tillage; retaining crop residues	Water hyacinth compost; chemical fertilizer	Clay application; Water hyacinth compost; retaining crop residues

or technology. Further, the results of this study displayed that applying compost was cheaper than using NPK (if farmers collect raw materials themselves) and cow dung. However, using NPK shows practical advantages since it requires no production costs and can be applied immediately without any treatment. The relatively short time required for the compost maturation (1 month vs up to 3 to 6 months for other compost types) could be an important driver for its local acceptance. The urgency of providing for the immediate needs of families induces general short-term time horizons within farmers in poor countries (Pannell et al. 2014). However, since even the relatively short time required for the compost maturation could be perceived as a long term investment for poor farmers, assisting local farmers who are interested in the production and marketing of water hyacinth compost on a larger scale 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. 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 chemical fertilizer (Urea, NPK) leading to a significant and sustainable improvement in productivity (Penot et al. 2014). Considering its simplicity, low costs, high production speed and productivity, water hyacinth compost would likely be attractive to local farmers at Lake Alaotra.

So far it is difficult to assess how successful water hyacinth use as source of fertilizer has been on a global scale since the studies are based on results of experiments and recommendations. Practically no data about real diffusion are available. This might be linked to the intensive labor required for transportation, making a large scale application of water hyacinth compost very difficult (Gunnarsson and Petersen 2007).

The success of the diffusion of water hyacinth fertilizer will require efforts of capacity building, creation of demonstration plots and interested farmer groups to share, exchange and spread knowledge and information (Wall 2007). On a large scale, the success of the implementation of agricultural innovations such as water hyacinth compost 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 implies especially maintained financial support of local farmers. This is important for the Alaotra region where poor farmers constantly struggle with land availability and demographic pressures, market instabilities and environmental problems.

CENTRAL FACTORS INFLUENCING CHINESE CABBAGE GROWTH WITHIN THE GROWTH EXPERIMENT. 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 that the increase of N input generally 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. On 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 fertilizer. 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 subsequently reduced 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).

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 present. In this study, we evaluated the efficiency of using the invasive water hyacinth as an alternative source of fertilizer for vegetable 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. Demonstration plots are here needed to check and confirm the results under real farming life conditions before upscaling, especially for estimating the real duration of required workload, which might be the main barrier for the adoption of water hyacinth as source of organic fertilizer. Over the long term, water hyacinth fertilizer could be applied to 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.

ACKNOWLEDGEMENTS

We would like to acknowledge the DREF (National Department of Water and Forests) Antananarivo and CIREF (Regional Department of Water and Forests) Ambatondrazaka for the research and export permits. We are also grateful to the Durrell Wildlife Conservation Trust for field assistance. We are indebted to Tanja Fischer (Institute of Biology and Chemistry, University of Hildesheim) and Robin Stadtmann (Institute of Geography, University of Hildesheim) for their assistance in soil determination and chemical analyses procedures. Finally, we are thankful to the Bauer-Foundation (Stifterverband für die Deutsche Wissenschaft) for the financial supports.

REFERENCES

Amlinger, F., Favoino, E., Pollak, M., Peyr, S., Centemero, M. and Caima, V. 2004. Heavy metals and organic compounds from wastes used as organic fertilisers. Final Report N. TEND/AML/2001/07/20. Study on behalf of the European Commission, Directorate-General Environment, ENV. A, 2. Available online <https://ec.europa.eu/environment/waste/compost/pdf/hm_finalreport.pdf>

Badger, M. R. 2013. Role of plant leaf development in optimizing photosynthetic efficiency, capacity, growth and yield. In: Applying Photosynthesis Research to Improvement of Food Crops. J. E. Gready, S. A. Dwyer and J. R. Evans (eds.), pp20–26. Australian Center for International Agricultural Research Proceedings 140. Canberra, Australia,. Available online <https://aciar.gov.au/sites/default/files/legacy/pr140_web.pdf>

Bell, R. W. and Seng, V. 2007. The management of agroecosystems associated with sandy soils. In: Management of Tropical Sandy Soils for Sustainable Agriculture. Symposium on the Management of Tropical Sandy Soils, 27th November – 2nd December 2005, Khon Kaen, Thailand, pp 298–304. Available online <http://www.fao.org/3/AG125E23.htm>

Brady, N. C. and Weil, R. R. 2008. The Nature and Properties of Soil, 14th ed. Prentice Hall, New Jersey.

Carpenter-Boggs, L., Kennedy, A. C. and Reganold, J. P. 2000. Organic and biodynamic management effects on soil biology. Soil Science Society of America Journal 64, 5: 1651–1659. <https://doi.org/10.2136/sssaj2000.6451651x>

Chabierski, S., Dabat, M. H., Grandjean, P., Ravalitera, A. and Andriamalala, H. 2006. Une approche socio-éco-territoriale en appui à la diffusion des techniques agro-écologiques au Lac Alaotra, Madagascar. In: Third World Congress on Conservation Agriculture: Linking Production, Livelihoods and Conservation, Nairobi, Kenya, 3–7 October 2005. Available online <http://agritrop.cirad.fr/529152/>

Copsey, J. A., Rajaonarison, L. H., Randriamihamina, R. and Rakotoniaina, L. J. 2009. Voices from the marsh: Livelihood concerns of fishers and rice cultivators in the Alaotra wetland. Madagascar Conservation & Development 4, 1: 25–30. <http://www.dx.doi.org/10.4314/mcd.v4i1.44008>

Curtis, P. G., Slay, C. M., Harris, N. L., Tyukavina, A. and Hansen, M. C. 2018. Classifying drivers of global forest loss. Science 361: 1108–1111. <https://doi.org/10.1126/science.aau3445>

de Laulanié, H. 1993. Le système de riziculture intensive malgache. Tropicultura 11, 3: 110–114. Available online <http://www.tropicultura.org/text/v11n3/110.pdf>

Eklund, A. 1996. Composting opportunities in Kondoa Eroded Area, Tanzania. Working Paper 319. International Rural Development Centre, SUAS, Uppsala, Sweden.

Eubanks, T. 2012. The impoverished island: Development intervention in Madagascar. The Catalyst 2, 1: 33–45. <https://doi.org/10.18785/cat.0201.07>

Ferry, L., Mietton, M., Robison, L. and Erismann, J. 2009. Le lac Alaotra à Madagascar-Passé, Présent et Futur. Zeitschrift für Geomorphologie 53, 3: 299–318. <https://doi.org/10.1127/0372-8854/2009/0053-0299>

Gajalakshmi, S. and Abbasi, S. A. 2002. Effect of the application of water hyacinth compost/vermicompost on the growth and flowering of *Crossandra undulaefolia*, and on several vegetables. Bioresource Technology 85, 2: 197–199. <https://doi.org/10.1016/S0960-8524(02)00096-2>

Guillera-Arroita, G., Lahoz-Monfort, J. J., Milner-Gulland, E. J., Young, R. P. and Nicholson, E. 2010. Using occupancy as a state variable for monitoring the Critically Endangered Alaotran gentle lemur *Hapalemur alaotrensis*. Endangered Species Research 11: 157–166. <https://doi.org/10.3354/esr00274>

Gunnarsson, C. C. and Petersen, C. N. 2007. Water hyacinths as a resource in agriculture and energy production: A literature review. Waste Management 27, 1: 117–129. <https://doi.org/10.1016/j.wasman.2005.12.011>

Jenn-Treyer, O., Dabat, M. H. and Grandjean, P. 2007. Une deuxième chance pour le système de riziculture intensive à Madagascar ? La recherche d'un compromis entre gain de productivité et investissement en facteur de production. In: Actes du Colloque International, La Pauvreté Rurale à Madagascar : Caractéristiques, Dynamiques et Politiques Publiques, 15–17 Novembre, 2007, Antananarivo, Madagascar. Available online <https://agritrop.cirad.fr/539341/>

Jones, J. P. G., Ratsimbazafy, J., Ratsifandrihamanana, A. N., Watson, J. E. M., Andrianandrasana, H. T., et al. 2019. Last chance for Madagascar's biodiversity. Nature Sustainability 2: 350–352. <https://doi.org/10.1038/s41893-019-0288-0>

Klerkx, L., Schut, M., Leeuwis, C. and Kilelu, C. 2012. Advances in knowledge brokering in the agricultural sector: towards innovation system facilitation. Institute of Development Studies Bulletin. 43, 5: 53–60. <https://doi.org/10.1111/j.1759-5436.2012.00363.x>

Knops, J. M. and Reinhart, K. 2000. Specific leaf area along a nitrogen fertilization gradient. The American Midland Naturalist 144, 2: 265–272. <https://doi.org/10.1674/0003-0031(2000)144[0265:SLAAAN]2.0.CO;2>

Lammers, P. L., Richter, T., Waeber, P. O. and Mantilla-Contreras J. 2015. Lake Alaotra wetlands: how long can Madagascar's most important rice and fish production region withstand the anthropogenic pressure? Madagascar Conservation and Development 10, 3S: 116–127. <http://dx.doi.org/10.4314/mcd.v10i3.4>

Leeper, G. W. and Uren, N. C. 1993. Soil Science: An Introduction. Melbourne University Press, Australia.

Lindsey, K. and Hirt, H.-M. 1999. Use Water Hyacinth! A Practical Handbook of Uses for the Water Hyacinth from Across the World. Anamed, Winnenden, Germany.

Matindi, C. N., Njogu, P. M., Kinyua, R. and Nemoto, Y. 2014. Analysis of heavy metal content in water hyacinth (*Eichhornia crassipes*) from Lake Victoria, Kenya. Proceedings of Sustainable Research and Innovation Conference 5: 196–199. Available online <http://erepository.uonbi.ac.ke/handle/11295/97132>

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B. and Kent, J. 2000. Biodiversity hotspots for conservation priorities. Nature 403: 853–858. <https://doi.org/10.1038/35002501>

Ndimele, P. E., Kumolo-Johnson, C. A. and Anetekhai, M. A. 2011. The invasive aquatic macrophyte, water hyacinth (*Eichornia crassipes* (Mart.) Solm-Laubach: Pontedericeae): Problems and prospects. Research Journal of Environmental Sciences 5: 509–520. <https://doi.org/10.3923/rjes.2011.509.520>

Noble, A. D., Ruaysoongnern, S., Penning de Vries, F. W. T., Hartmann, C. and Webb, M. J. 2004. Enhancing the agronomic productivity of degraded soils in Northeast Thailand through clay-based interventions. In: Water in Agriculture. V. Seng, E. Craswell, S. Fukai and K. Fisher (eds.), pp 147–160. Australian Center for International Agricultural Research Proceedings 116, Canberra, Australia,. Available online <http://hdl.handle.net/102.100.100/188005?index=1>

Pannell, D. J., Llewellyn, R. S. and Corbeels, M. 2014. The farm-level economics of conservation agriculture for resource-poor farmers. Agriculture, Ecosystem and Environment 187: 52–64. <https://doi.org/10.1016/j.agee.2013.10.014>

Patel, V. 2012. Threats, management and envisaged utilization of aqutic weed *Eichornia crassipes*: an overview. Review of Environmental Sciences and Bio/Technology 11: 249–259. <https://doi.org/10.1007/s11157-012-9289-4>

Penot, E. 2009. Des savoirs aux savoir faire : l'innovation alimente un front pionnier : le lac Alaotra de 1897 à nos jours : Projet de mise en valeur et de protection des bassins versants au lac Alaotra (BV Alaotra). Document de travail BV lac n°27, Paris. Available online <http://agritrop.cirad.fr/550622/>

Penot, E., Domas, R., Raharisoa, B., Rakotondravelo, J.C. and Andriamalala, H. 2012. Évolution des itinéraires techniques à base de riz pluvial et adoption paysanne des techniques de l'agriculture de conservation depuis 2003 au lac Alaotra (Madagascar). . Available online <http://hal.cirad.fr/cirad-00766338>

Penot, E., Benz, H. and Bar, M. 2014. Utilisation d'indicateurs économiques pertinents pour l'évaluation des systèmes de production agricoles en termes de résilience, vulnérabilité et durabilité : le cas de la région du lac Alaotra à Madagascar. Ethics and Economics 11, 1: 44–61. <http://hdl.handle.net/1866/10261>

Polprasert, C., Wangsuphachart, S. and Muttamara, S. 1980. Composting nightsoil and water hyacinth in the tropics. Compost Science and Land utilization 21, 2: 25–27.

Rakotoarivelo, N. H., Manjato, N. V., Andriamiarisoa, L. R., Bernard, R. and Andriambololonera, S. (2019In Press). Useful plants in the Park Bandro and its surroundings, Lake Alaotra, Madagascar. Madagascar Conservation & Development. <http://dx.doi.org/10.4314/mcd.wetlands.4>

Rakotoarisoa, T. F., Waeber P. O., Richter, T. and Mantilla Contreras, J. 2015. Water hyacinth (*Eichhornia crassipes*), any opportunities for the Alaotra wetlands and livelihoods. Madagascar Conservation & Development 10, 3: 128–136. <http://dx.doi.org/10.4314/mcd.v10i3.5>

Rasoamanana, V. P., Penot, E., Rakotondravelo, J. C. and Domas, R. 2011. Diffusion latérale des techniques en RMME : itinéraires techniques développés par les paysans et variétés utilisées. Document de travail BV lac n. 63, AFD. Available online <http://agritrop.cirad.fr/562857/1/document_562857.pdf>

Rouse, J., Rothenberger, S. and Zurbrügg, C. 2008. Marketing compost. A Guide for Compost Producers in Low-and Middle-Income Countries. Eawag, Dübendorf, Switzerland. Available online <http://nccr-north-south.ch/Upload/Marketing_compost_eawag.pdf>

Scopel, E., Triomphe, B., Affholder, F., Da Silva, F. A. M., Corbeels M., et al. 2013. Conservation agriculture cropping systems in temperate and tropical conditions, performances and impacts. A review Agronomy for Sustainable Development 33, 1: 113–130. <https://doi.org/10.1007/s13593-012-0106-9>

Singh, J. and Kalamdhad, A. S. 2013. Effects of lime on bioavailability and leachability of heavy metals during agitated pile composting of water hyacinth. Bioresource Technology 138: 148–155. <https://doi.org/ 10.1016/j.biortech.2013.03.151>

Sponagel, H., Grottenthaler, W., Hartmann, K. J., Hartwich R., Janetzko, P., et al. 2005. Bodenkundliche Kartieranleitung, 5. Verbesserte und erweiterte Auflage. Bundesanstalt für Geowissenschaften und Rohstoffe, Schweizerbart Hannover.

UNDP 2019. Human Development Report. 2019. The Rise of the South: Human Progress in a Diverse World, United Nations Development Program. Available online <http://hdr.undp.org/sites/default/files/hdr2019.pdf>

Urech, Z. L., Zähringer, J. G., Rickenbach, O., Sorg, J. P. and Felber, H. R. 2015. Understanding deforestation and forest fragmentation from a livelihood perspective. Madagascar Conservation & Development 10, 2: 67–76. <http://dx.doi.org/10.4314/mcd.v10i2.5>

Waeber, P. O., Reibelt, L. M., Randrimalala, I. H., Moser, G., Raveloarimalala, L. M., et al. 2018. Local awareness and perceptions: consequences for conservation of marsh habitat at Lake Alaotra for one of the rarest lemurs. Oryx 52, 4: 677–686. <https://doi.org/10.1017/S0030605316001198>

Wall, P. C. 2007. Tailoring conservation agriculture to the needs of small farmers in developing countries: an analysis of issues. Journal of Crop Improvement. 19, 1–2: 137–155. <https://doi.org/10.1300/J411v19n01_07>

Zähringer, J. G., Hett, C., Ramamonjiosa, B. and Messerli, P. 2016. Beyond deforestation monitoring in conservation hotspots. Analysing landscape mosaic dynamics in north-eastern Madagascar. Applied Geography 68: 9–19. <https://doi.org/10.1016/j.apgeog.2015.12.009>

SHORT NOTE http://dx.doi.org/10.4314/mcd.v15i1.4

Linking biodiversity conservation and education: perspectives from education programmes in Madagascar

Aina Brias-Guinart[I,II,III], Aili Pyhälä[II,III], Mar Cabeza[I,III]

Correspondence:
Aina Brias-Guinart
Global Change and Conservation Lab, Organismal and Evolutionary Biology Research Program, Faculty of Biological and Environmental Sciences, University of Helsinki, Finland
Email: aina.briasguinart@helsinki.fi

ABSTRACT

Education is used to foster supportive behaviour for conservation. This paper examines how environmental education is implemented in Madagascar, and its potential for conservation. These reflections are based on literature insights and in-depth experiences from the field. We found that environmental education is only marginally integrated in the national curriculum and NGOs are the primary promoters. Evaluation methods focus on quantifying short-term changes in knowledge and attitudes, and interventions fail to integrate local knowledge, values and needs. We call for researchers to examine the long-term impacts, on governmental commitment and support, and for future interventions to be inclusive and locally meaningful.

RÉSUMÉ

L'éducation est un moyen utilisé pour encourager les comportements favorables à la conservation, en particulier dans les communautés locales vivant autour des aires protégées. À partir de la littérature et d'expériences sur le terrain, cette contribution examine les manières dont l'éducation environnementale est mise en œuvre à Madagascar, et son potentiel dans la conservation. Il a été constaté que, dans le cadre des écoles primaires, l'éducation environnementale n'est intégrée que de façon marginale dans le curriculum, et les ONG sont les principaux acteurs qui promeuvent l'éducation environnementale. Le principal cible les élèves pour conduire des activités dans le cadre strictement scolaire avec peu de visites dans les aires protégées. Les méthodes d'évaluation se concentrent sur la quantification des changements à court terme dans les connaissances et les attitudes, et non dans les comportements. Les interventions ne parviennent pas à intégrer les connaissances, les valeurs et les besoins locaux. L'influence de l'éducation sur le succès de la conservation reste floue, de sorte qu'il est proposé que la recherche examine également les impacts qualitatifs et comportementaux à long terme des interventions éducatives, l'engagement et le soutien du gouvernement national, et que les futures interventions soient inclusives et significatives au niveau local.

INTRODUCTION

The IPBES Global Assessment on Biodiversity (2019) identifies education as a key point of intervention to enable transformative change towards sustainability. Education can strengthen conservation efforts by increasing knowledge, contributing to improved awareness and encouraging positive attitudes towards conservation (Jacobson et al. 2006, Heimlich 2010, Reibelt et al. 2014). For this reason, education programmes for communities living in or near protected areas are a common support strategy for conservation management (Heimlich 2010, Breuer et al. 2017, Superina et al. 2019)

Madagascar's unique biodiversity has attracted hundreds of international research, conservation and development institutions, which have advised relevant political bodies, including the Ministry of Environment and the Ministry of Education (MENETP 2016, WWF 2016), strongly influencing the national environmental and educational agenda (Waeber et al. 2016). Additionally, concerns about biodiversity loss have motivated non-governmental organisations (NGOs) to include environmental education in their work to promote conservation (Reibelt et al. 2014). Shared narratives among practitioners hold that education benefits conservation. However, studies investigating the long-term impacts of education programmes—both ecological and socio-cultural— are still scarce (e.g., Rakotomamonjy et al. 2015, Richter et al. 2015, Balestri et al. 2017).

The international conference held by the Association for Tropical Biology and Conservation in Antananarivo in 2019 drew attention to the urgent need for the national government to address the decline of biodiversity in Madagascar (Ivato Petition 2019 based on Jones et al. 2019). During the conference, environmental education

I Global Change and Conservation Lab, Organismal and Evolutionary Biology Research Program, Faculty of Biological and Environmental Sciences, University of Helsinki, Finland
II Development Studies, Faculty of Social Sciences, University of Helsinki, Finland
III Helsinki Institute of Sustainability Science, University of Helsinki, Finland

Citation Brias-Guinart, A., Pyhälä, A., Cabeza, M. 2020. Linking biodiversity conservation and education: perspectives from education programmes in Madagascar. Madagascar Conservation & Development 15, 1: 35–39. http://dx.doi.org/10.4314/mcd.v15i1.4

was presented as a timely tool to help achieve long-term success in conservation while considering human well-being. This paper reflects on the different ways in which environmental education is implemented in Madagascar and its potential to address the urgent challenges currently facing conservation initiatives.

The reflections we provide in this perspective piece are derived from extensive literature insights, and months of fieldwork in Madagascar including, but not limited to, a range of key informant interviews with relevant stakeholders related to environmental education in Madagascar (conducted in November and December 2018). These are used to elicit a variety of perspectives, including from: (i) representatives from civil society organisations, (ii) authorities from the Ministry of Education, Ministry of Environment and Madagascar National Parks, (iii) directors and practitioners from conservation NGOs, (iv) researchers, (v) primary school directors and teachers, (vi) local community customary leaders, touristic guides, villagers and (vii) participants from the education programmes themselves. By weaving together these different strands of data, we provide a general overview of the status quo of environmental education in general, with a particular focus on long-running education programmes situated near protected areas. Moreover, we scope needs and opportunities for change across the broader context and suggest new directions for future research in the field of environmental education in Madagascar.

ENVIRONMENTAL EDUCATION IN MADAGASCAR: SCHOOLING AND THE ROLE OF NGOS

Strategies of environmental education within the current Malagasy school system remain weak (Reibelt et al. 2014, Schüßler et al. 2019). Representatives from NGOs and primary schools equally agree that environmental education is largely lacking in practice in primary education and when it is present, with a curriculum designed at the national level, it lacks site-specific content. "The curriculum is very fixed and teachers do not have the time, the skills or the motivation to adapt it to include environmental education topics" [Primary school Director]. Moreover, the Malagasy educational system presents a series of dysfunctions and equity issues. Primary school exclusion is one of the biggest challenges: a large majority of children are deprived of a complete cycle of quality primary education, including over one million children who are not attending school, for a number of reasons (d'Aiglepierre 2012). Additionally, the percentage of students continuing from primary to secondary school is relatively low (65.4% national average in 2014-2015) (PSE 2017), with strong inequalities among regions (from 17 to 87%) (ibid). Therefore, primary schools remain the sole formal education for a majority of children, particularly in rural areas (Reibelt et al. 2014), and thus are the target of most of the NGOs that we interviewed. Worryingly, there is also a lack of professionally trained teachers in rural areas due to national budget restrictions, leading instead to a reliance on community recruited youth to step in as teachers (67% of all teachers in 2014–2015) (PSE 2017).

In the past decades NGOs have been filling gaps in the formal school system by providing education material (Dolins et al. 2010) and promoting new approaches to move from teacher-centred learning towards non-traditional participatory methods (Reibelt et al. 2014). Researchers have also begun to engage more in environmental education with local schools and communities (Rakotomamonjy et al. 2015), lobbying for the integration of environmental education in the official school curriculum (Jolly 2012). NGO education interventions are usually not undertaken in isolation, but integrated within broader sustainable livelihoods programmes such as reforestation, trainings on agriculture and renewable energy, ecotourism, health, and alternative livelihoods.

Protected areas have been the principal conservation strategy in Madagascar (Gardner et al. 2018). Thus, environmental education interventions have been mostly conducted around protected areas by international, national and local NGOs, targeting primary school children (Schüßler et al. 2019). Similarly, the conservation NGOs we interviewed work around protected areas (see Table 1 as an example), and mostly target primary school children, while the educational activities are varied and range from lecture-based activities to school gardens, hands-on experiments, radio programmes, creation of educational material, and environmental clubs. The frequency of the activities can vary from a single day intervention—all of the interviewed NGOs celebrate, for instance, the World Lemur Day—to an entire academic course with regular weekly sessions.

LINKING EDUCATION WITH BIODIVERSITY CONSERVATION: OUTCOMES AND IMPACTS

A common assumption amongst NGOs and protected area managers is that improved conservation outcomes can be reached through educational interventions (Richter et al. 2015). However, it is still unclear to what extent education programmes are having an impact on conservation and which might be the pathways for such impacts. Practitioners interviewed recognise that despite having

Table 1. Similarities and differences amongst conservation education programmes (EP) conducted near protected areas (PAs). These particular NGOs were visited in-situ and illustrate some of the longest-running programmes in Madagascar.

Variables comparing the diversity within the education programmes that NGOs are conducting:
i. Target: Participants of the education programmes. The vast majority target primary school children;
ii. Educators: Most NGOs use their own employees to implement the education programmes (external), while others train the teachers from primary schools (trained teachers);
iii. Setting: Education activities often take place within the school settings (school). In some cases, the participants go to the NGO's facilities (MFG and MWC);
iv. Frequency: Number of sessions that each participant attends. This varies from a single time (MFG), to several sessions over the course of one year (Mitsinjo and MFG), to every day during the school term (CVB);
v. Starting date: Year when the specific education programme started;
vi. Topics: Content of the education programme;
vii. PA visit: Number of visits inside the nearby protected area by the same participant;
viii. Evaluation: Type of evaluation conducted to assess the impact of the education programme; *Others includes external evaluation, project presentation evaluation and participant evaluation.

Note: The interviews were done in French whenever possible, and when necessary supported with Malagasy simultaneous translation by Malagasy research assistants. We obtained free, prior, informed consent from each participant, guaranteeing to each interviewer anonymity and confidentiality. The mentioned organisations (Centre Valbio, Mitsinjo, MFG and MWC) have agreed on the content and publication of this table)

	Valbio - Ranomafana	Mitsinjo - Andasibe	MFG - Ivoloina	MWC – Alaotra
Main EP	My Rainforest, my World	Environmental Education	Saturday School	WEdu
Target	children	children	children	adults
Educators	external	external	trained teachers and external	external
Setting	school	school	Ivoloina & school	NGO camp
Frequency	every day during 1 year	4 times/month during 1 year	~ 30 sessions during 1 year	one-off
Starting date	2015	2013	1996	2018
Topics	conservation	environment	environment, French & maths	environment
PA visit	once a year	once a year	once a year	-
Evaluation	pre/post questionnaire and others*	pre/post questionnaire	pre/post questionnaire	-

long conducted environmental education, the threats to biodiversity —mainly deforestation— remain unresolved. They question whether this is due to internal factors - such as their approach to environmental education - or external ones - such as poverty and lack of livelihood alternatives. "Despite all the efforts in environmental education, there have been no outcomes, because of poverty, or insecurity. How can environmental education be effective?" [Madagascar National Parks regional representative]. However, some recognise that educational programmes may have further impacts beyond conservation, such as their contribution to well-being and positive youth development. Similarly, as argued by an environmental NGO representative working close to a large scale mining operation: "Education can make people less vulnerable to external factors such as abuses by mining companies".

All interviewees agreed that there is a need for the scientific community to understand the role of education at all levels. As exemplified in Table 1, most of the programmes we studied evaluate their outcomes by quantifying short-term changes in knowledge and attitudes using pre- and post- intervention questionnaires, as has been done elsewhere (e.g., Breuer et al. 2017, Freund et al. 2019). Other studies that have evaluated longer-term impacts (one year after the intervention), have solely focused on changes in knowledge and attitudes (Rakotomamonjy et al. 2015, Richter et al. 2015, Balestri et al. 2017). Indeed, many educational strategies still focus on the provision of knowledge. Yet, the discourses of some of the education practitioners interviewed seem to be questioning the overly simplified assumption that knowledge directly affects people's attitudes, which in turn motivates them to change their behaviour (Heimlich 2010).

While knowledge is a key factor in moving people towards action, it is rarely enough to motivate long-term changes in behaviour, especially when basic needs and value orientations are mismatched (Manfredo 2008). Therefore, it is essential to identify and recognise other key factors influencing behaviour. As an example, efficacy, having a sense of place, and social capital have been identified as key elements to consider in future education programmes (Krasny 2020). It therefore remains imperative to measure the impact of environmental education initiatives in order to evaluate their effectiveness in achieving conservation goals (Freund et al. 2019), yet conducting more comprehensive evaluations that go beyond simply measuring knowledge or attitudes towards charismatic species.

PARTICIPATION AND INCLUSIVITY IN EDUCATION PROGRAMMES

The conservation agenda has lacked an inclusive approach both in terms of the types of knowledge incorporated and representation of worldviews, interests and values (Pascual et al. 2017). Moreover, the voices, needs, and knowledge systems of local communities have rarely been heard in these processes (Corson 2017). Likewise, this study highlights the same caveats both in the designing of the national curriculum and in the planning and implementation of NGOs interventions (Reibelt et al. 2014, Schüßler et al. 2019). Amongst the NGOs interviewed, there are differences in the extent of participation of local communities, local authorities and local teachers in the design and implementation of the education programmes, potentially compromising programme success. For some NGOs (Table 1), primary school teachers are involved in designing and executing the programmes, and they have a strong collaboration with some regional public institutions (e.g., Circonscriptions Scolaires or CiSco, or school districts). For others, the education programmes are designed by the NGO and delivered by external educators instead of training local teachers. This can create conflicts between local and external teachers, and diminish the opportunities for future involvement on the project by local teachers. Finally, in line with others (Bekalo and Bangay 2002, Reyes-García et al. 2010), we argue that educational programmes should place a much stronger emphasis on the inclusion of local knowledge. NGOs, as opposed to the formal school system, have the flexibility to adapt the content and teaching methods—i.e., via field trips or informal instruction—to ensure that their education programmes are locally meaningful and recognise the richness of local wisdom.

Most environmental education programmes in Madagascar target children (Schüßler et al. 2019). However, many practitioners stated that it is unclear how knowledge is further transmitted. "There are around 40 NGOs working in conservation in Madagascar, and we usually ask ourselves the same: when should we educate? And whom? If we educate children, we will see the impacts in 20 years" [International NGO representative]. A common justification is that those children will not only grow up into adults with responsible behaviour, but that they can also in fact educate their parents. However, there is a lack of agreement amongst practitioners as to whether children can or do educate their parents. Previous studies have demonstrated a transfer of environmental knowledge from child to parent (Vaughan et al. 2003, Damerell et al. 2013), although it has been difficult to infer the mechanisms by which knowledge is transferred (Rakotomamonjy et al. 2015). The education programme from the Alaotra region by Madagascar Wildlife Conservation (Table 1) represents an exception, being one of the few cases where the targets are adults as active natural resource users, and provides also an example on how to address the challenge to integrate local knowledge, perceptions and values into conservation education (Reibelt et al. 2018).

Further reflection needs to be given to the role of NGOs in education in Madagascar, and in environmental education in particular. Their role can be seen as contributing towards the achievement of internationally set goals, such as the Sustainable Development Goal 4 on quality education, which otherwise might not be met. Accordingly, NGOs can play a pivotal role in the provision of education (e.g. numeracy and literacy), addressing the challenge of access to school (Rose 2009), focusing their efforts on children and/or in strengthening the capacity of teachers that could act as promoters of education. Providing access to basic education in communities around protected areas could be a long-term investment to provide alternative livelihoods, and reduce the pressure on natural resources. Additionally, NGOs can have a role in advocacy by involving higher levels of the school system (Reibelt et al. 2014) and even adults, including policy makers, putting pressure to implement new policy plans. Despite all these potential roles, it should not be forgotten that most of the education programmes conducted by NGOs are highly (if not entirely) dependent on external funding sources and it is beyond their scope and capacities to support all schools and sectors with environmental education (Reibelt 2017). Therefore, the long-term feasibility of NGOs' interventions also depends on the support of governmental organizations and the state, as NGOs are bounded both financially and legally, and should not substitute the education responsibility of the state (Schüßler et al. 2019).

Nonetheless, there are a number of policy plans to incorporate environmental education and education for sustainable development into the national curriculum, considering the education system as a catalyst to reach national and international sustainable development objectives (Ministère de l'Environnement et des Forêts 2013, PSE 2017).The aim of those plans is to promote education that prepares future generations to be responsible, supportive and committed citizens who participate in the country's socio-economic, cultural and environmental sustainability. What this means in terms of implementation remains open, and strong governance is needed to ensure that these education policies actually contribute to an improvement also in the quality of the education system. Political instability and lack of collaboration between Ministries may instead slow down the implementation of these plans.

FURTHER STEPS

These reflections are relevant beyond the Malagasy context, and raise intriguing questions regarding the influence of education in a context of high priority for conservation, but also where poverty and natural resource dependency represents an acute challenge. It thus emerges from several studies and our own experiences that environmental education strategies in Madagascar depend – almost exclusively –on the role of NGOs. Yet it remains unclear what the impacts of the present education programmes are. We see the potential for improvements in conservation outcomes both in terms of quality and in terms of quantity. First and foremost we call for research to understand the narratives behind those education programmes and, at the same time, to conduct impact evaluation to measure long-term changes, focusing not only on knowledge and attitudes, but also on other possible outcomes, such as behaviour, in order to better understand why or how certain programmes work or not. Meanwhile, it is important to recognise that not all the possible outcomes from environmental education can be measured, nor should its importance be diminished as a result.

While the role of NGOs has been – and is likely to remain – crucial (Schüßler et al. 2019), their bounded resources as well as constraints brought by the geographies of their programmes limit the scalability of their interventions, and thus will not be enough to tackle the ongoing biodiversity threats. While researchers around the world have highlighted the urgent need for governmental commitment to directly address the decline of biodiversity in Madagascar, we take this a step further to call for government commitment in education at large, and to better integrate environmental education across the national programme, as a tool to support biodiversity conservation whilst improving the well-being of local communities.

It has been widely suggested that the future of protected areas depend on the support from their immediate neighbours (Brockington 2002). Education programmes should not exclusively answer the needs of the conservation agenda, as a tool for disseminating benefits of the protected areas and encouraging local support for them. Instead, it is key that governmental and non-governmental practitioners consider local community needs, concerns, values and knowledge systems to ensure that future education programmes are inclusive, culturally rooted and locally meaningful.

ACKNOWLEDGEMENTS

This research was funded by the Global Change and Conservation Lab and the Doctoral Program of Interdisciplinary Environmental Sciences from Helsinki University. We would like to give special thanks to Eric Marcel Temba and to Santatra Andriamitandrina for their advice and logistical support. Also, we would like to thank Dr. Lena Reibelt for insightful discussions before and after the trip to Madagascar. We also thank all the people interviewed, particularly the NGOs that kindly invited us to visit their projects. Finally, endless thanks to Marketta Vuola, for so many shared moments, reflexions and laughs.

REFERENCES

Balestri, M., Campera, M., Nekaris, K. A. I. and Donati, G. 2017. Assessment of long-term retention of environmental education lessons given to teachers in rural areas of Madagascar. Applied Environmental Education and Communication 16, 4: 298–311. <https://doi.org/10.1080/1533015X.2017.1348275>

Bekalo, S. and Bangay, C. 2002. Towards effective environmental education in Ethiopia: Problems and prospects in responding to the environment-poverty challenge. International Journal of Educational Development 22, 1: 35–46. <https://doi.org/10.1016/S0738-0593(00)00076-6>

Breuer, T., Mavinga, F. B., Evans, R. and Lukas, K. E. 2017. Using video and theater to increase knowledge and change attitudes—Why are gorillas important to the world and to Congo? American Journal of Primatology 79: e22692. <https://doi.org/10.1002/ajp.22692>

Brockington, D. 2002. Fortress Conservation. The Preservation of the Mkomazi Game Reserve, Tanzania. Indiana University Press, Bloomington.

Corson, C. 2017. A history of conservation politics in Madagascar. Madagascar Conservation & Development 12, 1: 49–60. <https://dx.doi.org/10.4314/mcd.v12i1.4>

d'Aiglepierre, R. 2012. Primary School Exclusion and Ways to Improve Inclusion in Madagascar. UNICEF, New York. Available online <https://www.researchgate.net/profile/Daiglepierre_Rohen/publications>

Damerell, P., Howe, C. and Milner-Gulland, E. J. 2013. Child-orientated environmental education influences adult knowledge and household behaviour. Environmental Research Letters 8, 1: #015016. <https://doi.org/10.1088/1748-9326/8/1/015016>

Dolins, F. L., Jolly, A., Rasamimanana, H., Ratsimbazafy, J., Feistner, A. T. C. and Ravoavy, F. 2010. Conservation education in Madagascar: Three case studies in the biologically diverse island-continent. American Journal of Primatology 72, 5: 391–406. <https://doi.org/10.1002/ajp.20779>

Freund, C. A., Achmad, M., Kanisius, P., Naruri, R., Tang, E. and Knott, C. D. 2019. Conserving orangutans one classroom at a time: evaluating the effectiveness of a wildlife education program for school-aged children in Indonesia. Animal Conservation 23, 1: 18–27. <https://doi.org/10.1111/acv.12513>

Gardner, C. J., Nicoll, M. E., Birkinshaw, C., Harris, A., Lewis, R. E., et al. 2018. The rapid expansion of Madagascar's protected area system. Biological Conservation 220: 29–36. <https://doi.org/10.1016/j.biocon.2018.02.011>

Heimlich, J. E. 2010. Environmental education evaluation: reinterpreting education as a strategy for meeting mission. Evaluation and Program Planning 33, 2: 180–185. <https://doi.org/10.1016/j.evalprogplan.2009.07.009>

IPBES, Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. 2019. Global Assessment Report on Biodiversity and Ecosystem Services. Bonn, Germany. Available online <https://ipbes.net/global-assessment>

Jacobson, S. K., McDuff, M. D. and Monroe, M. C. 2006. Conservation Education and Outreach Techniques. Oxford University Press, Oxford.

Jolly, A. 2012. Challenges of Environmental Education in Madagascar. In: Proceedings of the Conference Environmental Education in Madagascar, pp 27–28. University of Sussex, Brighton.

Jones, J. P. G., Ratsimbazafy, J., Ratsifandrihamanana, A. N., Watson, J. E. M., Andrianandrasana, H. T. et al. 2019. Last chance for Madagascar's biodiversity. Nature Sustainability 2: 350-352. <https://doi.org/10.1038/s41893-019-0288-0>

Krasny, M. E. 2020. Advancing Environmental Education Practice. Cornell University Press, Ithaca

Manfredo, M. J. 2008. Who cares about wildlife? Springer, New York.

MENETP, Ministère de l'Éducation Nationale et de l'Enseignement Technique et Professionnel. 2016. Mahazoarivo: le Gouvernement a approuvé le Plan Sectoriel de l'Éducation et les Partenaires Techniques et Financiers ont remis leur lettre d'endossement. Accessed 21 January 2020 <http://shorturl.at/oHIJ9>

Ministère de l'Environnement et des Forêts. 2013. Décret N° 2013-880 fixant la Politique Nationale de l'Éducation relative à l'Environnement pour le Développement Durable (PErEDD). Available online <https://www.environnement.mg/wp-content/uploads/2018/10/PErEDD.pdf>

Pascual, U., Balvanera, P., Díaz, S., Pataki, G., Roth, E. et al. 2017. Valuing nature's contributions to people: the IPBES approach. Current Opinion in Environmental Sustainability 26–27: 7–16. <https://doi.org/10.1016/j.cosust.2016.12.006>

PSE, Plan Sectoriel de l'Éducation 2018–2022. 2017. Ministère de l'Éducation, Antananarivo. Available online <https://planipolis.iiep.unesco.org/fr/node/6526>

Rakotomamonjy, S. N., Jones, J. P. G., Razafimanahaka, J. H., Ramamonjisoa, B. and Williams, S. J. 2015. The effects of environmental education on children's and parents' knowledge and attitudes towards lemurs in rural Madagascar. Animal Conservation 18, 2: 157–166. <https://doi.org/10.1111/acv.12153>

Reibelt, L. 2017. Communities, Teachers, Conservationists – Deconstruction and Reconstruction of Environmental Education in Madagascar. Unpubl. Ph.D. thesis, University Hildesheim, Hildesheim. <https://doi.org/10.18442/764>

Reibelt, L. M., Richter, T., Waeber, P. O., Rakotoarimanana, S. and Mantilla-Contreras, J. 2014. Environmental education in its infancy at Lake Alaotra, Madagascar. Madagascar Conservation & Development 9, 2: 71–82. <https://dx.doi.org/10.4314/mcd.v9i2.3>

Reibelt, L. M., Stoudmann, N. and Waeber, P. O. 2018. A role-playing game to learn and exchange about real-life issues. In Learn2Change—Transforming the World through Education. R. Hembrom, T. Holthoff, G. Janecki, S. Laustroer, M. Rolle and L. Zulu (eds.) pp 163–171. VNB e.V., Hannover.

Reyes-García, V., Kightley, E., Ruiz-Mallén, I., Fuentes-Peláez, N., Demps, K., et al. 2010. Schooling and local environmental knowledge: Do they complement or substitute each other? International Journal of Educational Development 30, 3: 305–313. <https://doi.org/10.1016/j.ijedudev.2009.11.007>

Richter, T., Rendigs, A. and Maminirina, C. P. 2015. Conservation messages in speech bubbles-evaluation of an environmental education comic distributed in elementary schools in Madagascar. Sustainability 7, 7: 8856–8880. <https://doi.org/10.3390/su7078855>

Rose, P. 2009. NGO provision of basic education: alternative or complementary service delivery to support access to the excluded? Compare: A Journal of Comparative and International Education 39, 2: 219–233. <https://doi.org/10.1080/03057920902750475>

Schüßler, D., Richter, T. and Mantilla-Contreras, J. 2019. Educational approaches to encourage pro-environmental behaviors in sustainability educational approaches to encourage pro-environmental behaviors in Madagascar. Sustainability 11, 11: #3148. <https://doi.org/10.3390/su11113148>

Superina, M., Cortés Duarte, A. and Trujillo, F. 2019. Connecting research, management, education and policy for the conservation of armadillos in the Orinoco Llanos of Colombia. Oryx 53, 1: 17–26. <https://doi.org/10.1017/S0030605318000790>

Vaughan, C., Gack, J., Solorazano, H. and Ray, R. 2003. The effect of environmental education on schoolchildren, their parents, and community members: a study of intergenerational and intercommunity learning. The Journal of Environmental Education 34, 3: 12–21. <https://doi.org/10.1080/00958960309603489>

Waeber, P. O., Wilmé, L., Mercier, J.-R., Camara, C. and Lowry II, P. P. 2016. How effective have thirty years of internationally driven conservation and development efforts been in Madagascar? PLoS ONE 11, 8: e0161115 <https://doi.org/10.1371/journal.pone.0161115>

WWF. 2016. Le concept de l'Éducation pour le Développement Durable est Intégré dans le Système Éducatif Malgache. Accessed 21 January 2020 <http://shorturl.at/kLV45>

IMPRESSUM

Madagascar Conservation and Development is the journal of Indian Ocean e-Ink. It is owned by this institution and its production is its own responsibility.

COVER PICTURE
"Entre père et fille"
crédit : © Henitsoa Rafalia

LAYOUT EDITOR
Arnaud De Grave [EcoPalimpsesto(Photo)Graphies, France]

PRODUCTION SOFTWARE
MCD has been layouted and produced using the open-source Scribus DTP (desktop publishing application) – http://scribus.net

FOUNDER EDITORS
Patrick O. Waeber [Madagascar Wildlife Conservation, Switzerland]
Daniel C. Hänni [Jane Goodall Institute Switzerland]

JOURNAL INFORMATION
All journal related information for authors, reviewers, readers and sponsors is available online at http://www.journalmcd.com
ISSN 1662-2510
Madag. conserv. dev.