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MADAGASCAR CONSERVATION & DEVELOPMENT

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

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Plight of the unsung ecosystems

Although science aims to eliminate bias, it can never be fully objective. Wildlife and conservation research are far from being exempt from this tendency. For example, flagship species often take precedence over species that may be in more dire need of assistance. Factors such as species' role within ecosystems, their habitat range, degree of endangerment and taxonomic uniqueness do not stand much chance when competing against "charismatic" species receiving adulation from the public and funding agencies (Troudet et al. 2017, Tensen 2018). This is not to say that these emblematic species should not be recipients of conservation attention. However, considering the all-too limited funding pot available to conservation projects, taking a system perspective rather than a species perspective, by considering flagship species as part of a larger whole —i.e., at the ecosystem scale—is crucial, although unfortunately not often achieved (Ripple et al. 2016, Donaldson et al. 2017).

Currently, and in part due to this taxonomic bias, entire ecosystems are subject to wide discrepancies in research and funding attention, unrelated to their biodiversity richness or the ecosystem services they provide (Di Marco et al. 2017). Wetlands are a case in point. Covering an estimated 6% of terrestrial surface and occurring around the globe, these ecosystems are home to high concentrations of biodiversity and play a vital role for communities and society as a whole (Reis et al. 2017). Wetlands provide a wide variety of ecosystem services, falling under the umbrellas of regulating services (air and water quality, erosion, natural hazard mitigation), provisioning services (fish, crops, biomass), cultural services (recreation, tourism), and supporting services (formation of soils) (Ramsar Convention on Wetlands 2018). However, a large proportion of these ecosystems are under threat due to anthropogenic activities (Dohong et al. 2017, Ricaurte et al. 2017, Sievers et al. 2018). The Ramsar Convention's Global Wetland Outlook (2018) report found that natural coastal and inland wetlands were declining at three times the rate of forests globally, with 35% having been lost since 1970.

In Madagascar, wetlands provide vital nutritional resources to its inhabitants, being the cultivation ground for rice, and supplying fish, raw materials such as reeds used for housing, crafts and tools, and medicinal plants to a large proportion of the population (Neugarten et al. 2016, Rakotoarivelo et al. 2020). This intense use has however put these ecosystems under enormous pressure, and has led to their widespread degradation. Pollution, over-extraction, and the introduction of alien species are just a few of the drivers behind their deterioration (Jones et al. 2016, Máiz-Tomé et al. 2018, Scales and Friess 2019).

Despite their growing vulnerability and biological and societal importance, wetlands have received little attention from research compared to other ecosystems. Looking at freshwater systems across Africa (Madagascar was not included), Darwall et al. (2011) found that a strong discrepancy between conservation attention and the threat and richness of species, as well as freshwater systems being underrepresented within protected area networks. In Madagascar, most conservation work over the past decades has focused on forest protection, with far less resources having gone towards wetlands (Bamford et al. 2017). The country's wetlands have been rapidly shrinking, for example in the highlands that have seen the disappearance of 60% of wetlands compared to 20% of forests since 1960 (Kull 2012, Bamford et al. 2017). In a study looking at the dynamics of Madagascar's mangroves, Jones et al. (2016) found an overall net loss of 21% between 1990 and 2010. Searching Web of Science illustrates this research imbalance: while the keywords (Forest AND Madagascar) returns 2228 hits, searching for ((Wetland OR Lagoon OR Coral reef OR Delta OR Marsh* OR Mangrove OR Swamp OR Bog) AND Madagascar) returns a meagre 438 results (25 October 2019). One explanation for this large discrepancy could be the taxonomic bias discussed above. Arguably, Madagascar's most well-known flagship species are lemurs (Thalmann 2006), which almost exclusively inhabit forests, and have helped attract conservation resources and the establishment of protected areas (Scales 2014, Waeber et al. 2016). An exception is the Alaotra gentle lemur (*Hapalemur alaotrensis*), the only lemur living exclusively in marshes and endemic to the disappearing wetlands of Lake Alaotra (Rendigs et al. 2015). This species has helped attract much research and conservation attention for the socio-ecological system of the Alaotra region as a whole (Naudin et al. 2015, Wallace et al. 2016, Waeber et al. 2019). Despite these efforts, the future of the species and the ecosystem they are part of looks bleak (Reibelt et al. 2019). Yet, these wetlands are in actual fact the lucky ones, having been able to attract funding and research interest. The difficulties in curbing the degradation trend they are facing only makes the safeguard of wetlands not home to such flagship species seem more daunting.

Yet, considering the high stakes of wetland conservation and the fast pace of change they are experiencing, research surrounding these ecosystems is ever more crucial. The articles in this special issue show us that many researchers are undertaking this challenging task. The studies cover a wide variety of Madagascar's wetlands, and take both ecological and social approaches, illustrating their diversity and significance for the country as a whole. I hope that this special issue will help shine a brighter light on these vital ecosystems, and contribute to their further understanding and protection.

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"Fishermen of the Alaotra lake" © 2016, Arnaud De Grave / Agence Le Pictorium

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

Circuit court du marché des produits agricoles : pour une gestion efficace du paysage ouvert, cas du bassin-versant de Maningory, Madagascar

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RÉSUMÉ
Séparés par le rideau forestier du Parc National Zahamena, les paysans du côté Ouest du bassin versant du Maningory vivent en grande partie de la riziculture irriguée, alors que sur le versant Est, la culture itinérante sur brûlis ou *tavy* caractérise les pratiques agricoles des paysans. Ils sont connus pour les cultures pluviales de riz, d'arachide, de haricot et les cultures de rente de girofle, de café, et de letchi. Le bassin versant est constitué de la forêt naturelle de l'Aire Protégée, de la forêt de reboisement d'eucalyptus et des zones marécageuses autour du Lac Alaotra. Cet ensemble forme une mosaïque de paysage ouvert—défini dans cet article comme l'ensemble des zones herbeuses et arbustives, des zones de culture sur formations dégradées, ainsi que des espaces cultivables en bas-fond et en bas de pente. Le constat est que les surfaces des rizières cultivables deviennent de plus en plus res-treintes, incitant les paysans à coloniser les *tanety* ou le paysage ouvert pour les pratiques agricoles. Cet article tente de comprendre le rôle du circuit court de commercialisation des produits agricoles dans le changement d'occupation de ce paysage. Deux approches ont été utilisées à cette fin : la modélisation d'accompagnement à travers un jeu de rôle, et des entretiens individuels. Les résultats démontrent que l'économie paysanne est surtout basée sur une économie de subsistance. La plupart de la pro- duction agricole est destinée à l'autosubsistance, incitant ainsi une faible résilience du paysage et suggère une forte vulnérabilité face à l'économie de marché. Le rôle du marché dans les stratégies d'occupation du sol reste encore allusif mais intrinsèquement lié aux prix des produits agricoles et à l'accessibilité des sites.

ABSTRACT
Separated by the Zahamena National park, smallholder farmers in the western part of the Maningory watershed largely rely on irrigated rice cropping, whereas those on the eastern front mainly rely on cash crops cultivated using slash and burn practices known as *tavy* in addition to rice cultivation. The watershed is made up of a mosaic of open landscapes, defined in this article as all grasslands, degraded cropland, and agricultural land. This mosaic is interspersed with the forests of the Zahamena National Park as well as those of eucalyptus reforestation, and Lake Alaotra's marshlands. As cultivable rice parcels become increasingly scarce, farmers are pushed to extend their farming into the *tanety* and open landscape. This study aims to gain a better understanding of the role of local agricultural product markets commercialization in landscape changes. Two approaches were implemented to this end, namely companion modelling using role-playing games and personal interviews. Results show that small farming economy is largely based on local subsistence. Most of the agricultural production is used for personal consumption, leading to a weak resilience of the landscape and suggesting high vulnerability towards the market. The role of the market on land use strategies remains allusive and intrinsically linked to the product prices, as well as to the ease of access to locations.

INTRODUCTION
Mondialement, deux personnes sur sept dépendent de l'agriculture pour leurs besoins de subsistance (IFAD 2011). Sous les tropiques, l'agriculture est principalement de type familial (Bowman et Haberle 2010). Les paysans sont considérés, à toute échelle, comme des producteurs. Ils dépendent étroitement d'une chaîne de valeur de commercialisation et de consommation. A l'instar des pays sous-développés, les pratiques agricoles à Madagascar dépendent des besoins des paysans (Kull 2000), mais également d'une rationalité locale qui les pousse à agir (Darré et al. 2004). Dans un contexte plus large, le secteur politique constitue un facteur transversal dans leurs prises de décision (Vågen 2006). L'agriculture est souvent pratiquée dans un paysage hétérogène et dynamique (Burel et Baudry 1999). Il se traduit par un changement de l'environnement en fonction des objectifs individuels des paysans ainsi que des processus sociaux-économiques qui les entourent (Caillault et Marie 2009, Sayer et al. 2013). L'activité agricole,

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pratiquée dans un système socio-écologique complexe, considère la terre comme une unité paysagère. Il est alors primordial de comprendre la perception de la réalité par les paysans et d'identifier les facteurs qui peuvent influencer de manière directe ou indirecte leurs stratégies d'occupation du sol (Godelier 1984, Deffontaines et Petit 1985).

La forte croissance démographique à Madagascar, avec un taux d'accroissement annuel de 2.8% (Unfpa 2016), entraîne une insuffisance notable en terres cultivables. Les surfaces rizicoles sont souvent limitées aux vallées alluvionnaires, et les forêts sont soumises à des initiatives de conservation à l'encontre de la déforestation, laissant l'alternative de mise en valeur du paysage ouvert comme prometteuse. Entre les trois types d'écosystèmes globaux formés par les forêts, *tanety*, et zones humides ou marais qui coexistent dans le bassin-versant de Maningory, cet article traitera uniquement de l'utilisation des *tanety*. En s'inspirant de la classification de Moat et Smith (2007), le paysage ouvert, défini dans cet article sous le terme de *tanety*, est composé d'une mosaïque de zones herbeuses et arbustives, d'une forêt dégradée issue de la pratique agricole sur brûlis ou *tavy*, ainsi que d'une zone de culture en bas-fond et en bas de pente. Cet article essayera de mettre en valeur la potentialité de ces espaces ouverts, sachant qu'ils constituent près de 80% de la superficie totale de la zone d'étude. A l'échelle du bassin-versant, les produits agricoles sont limités aux produits de riz, de quelques cultures pluviales annuelles et de cultures de rente. Ces produits sont faiblement mis sur le marché, et souvent sur un circuit court de commercialisation (Bernard et al. 2007, Randrianarison et al. 2009).

L'hypothèse avancée par cet article est que les pratiques agricoles individuelles des paysans influencent la configuration du paysage sur le long terme. La principale question est de comprendre comment ce circuit de commercialisation des produits agricoles influence les stratégies d'occupation du paysage ouvert. Appréhender une meilleure gestion de cette ressource insinue une compréhension de sa structure et de son fonctionnement. Deux approches ont été couplées pour la collecte des données: la modélisation d'accompagnement à travers un jeu de rôle (Etienne 2014), et la méthode d'entretien individuel selon un questionnaire directif utilisé dans la science sociale.

MATÉRIELS ET MÉTHODES

PRÉSENTATION DE LA ZONE D'ÉTUDE. Le bassin versant de Maningory se situe sur la partie Est de Madagascar, à cheval entre les régions Alaotra-Mangoro et Analanjirofo (Wilmé et al. 2012). Il est constitué d'une grande mosaïque de paysages à forêts denses humides (13,46%), d'une formation secondarisée de forêts dégradées (34,28%), de paysages herbeux (36,58%), de zones de cultures (9,32%) et de zones marécageuses (4,20%), d'après une analyse de l'occupation du sol en 2014 (Randriamalala 2015). Le paysage ouvert concerne toutes les zones herbeuses et arbustives, cultivées ou non, les zones de culture sur les versants des collines et les formations de *savoka*—une jachère arborée et arbustive issue de la pratique de la culture sur brûlis. Quatre communes ou sites, représentants différentes variantes de paysages ouverts, ont été choisis d'amont en aval: Ambohijanahary, Vohimenakely, Antanandava et Vavate- nina (Figure 1).

COLLECTES DES DONNÉES. Sur la partie occidentale du bassin versant, le mot *tanety* décrit la pente d'une colline et la crête des montagnes, souvent colonisées par des herbacées telles

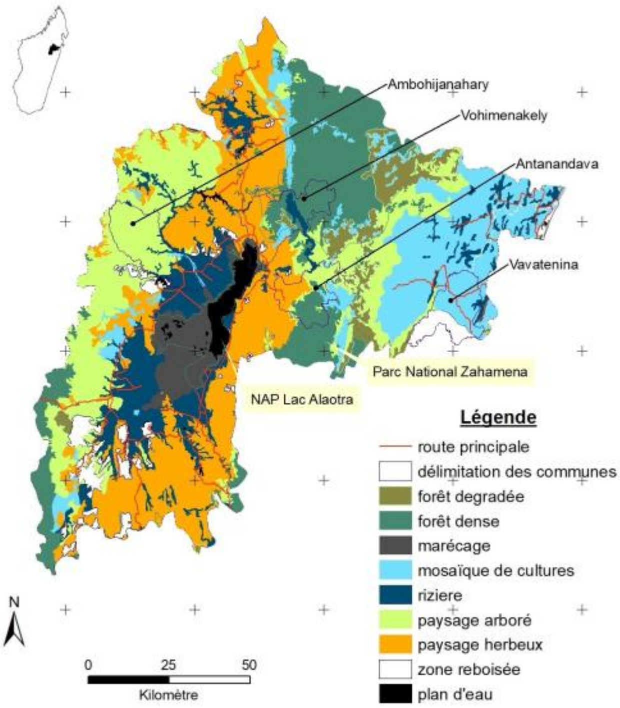

Figure 1. Localisation de la zone d'étude. Les quatre communes choisies pour la collecte des données formant un transect d'Ouest en Est du bassin-versant de Maningory.

que *Aristida multicaulis* et *Imperata cylindrica*. Le sol y est alors souvent lessivé et peu fertile. Il est destiné aux pâturages, aux activités de reforestation et à la culture annuelle de quelques variétés pluviales d'arachide, de pois de terre ou de manioc. Quant à l'Est, il est composé par les versants de collines et de montagnes, souvent autour d'un lambeau de forêt naturelle. Dans son ensemble, le bassin versant de Maningory est majoritairement composé d'un paysage herbeux et arbustif avec quelques vestiges de forêts primaires. Par souci de concertation sur le terme utilisé, dans cet article *tanety* est défini comme un composant global du paysage du bassin-versant désignant les espaces ouverts, à l'exception des espaces boisés et des marais.

La structure et le fonctionnement du paysage est un système complexe formé de plusieurs composantes et d'acteurs locaux. Cet article se focalise sur l'identification des facteurs pertinents pouvant influencer ce système et par conséquent l'occupation du sol, à travers les activités agricoles des paysans. Les entretiens semi-directifs effectués contribuent à comprendre la structure de ce système socio-écologique, avec une orientation sur l'accessi-bilité des sites par rapport aux routes, les superficies des espaces cultivés en riz irrigué, en d'autres cultures vivrières pluviales et en cultures de rente ; la production totale par individu enquêté et la répartition des récoltes pour l'autoconsommation des ménages et la vente. Outre les questions relatives aux pratiques agricoles et à leur écoulement sur un système d'autoconsommation ou de marché, les retombées des facteurs sociaux tels que la position familiale et l'origine sociale ont aussi été évoquées dans le questionnaire de collecte de données. Un entretien directif auprès de 326 individus répartis entre les quatre sites a alors été effectué afin de comprendre la structure de ce paysage (Table S1). L'objectif a été de définir si le circuit de commercialisation des produits conduit à un changement de pratiques agricoles et subséquemment à l'agencement du paysage global.

Cette organisation des différentes composantes du paysage implique le besoin d'appréhender son fonctionnement. La modélisation d'accompagnement comprend des outils pour anticiper d'une manière participative cette tendance d'évolution du paysage. Parmi ces outils, les ateliers « AR(D)I » (Etienne et al. 2011) entrepris dans les sites montrent une description des acteurs concernés ainsi que leurs interactions avec les ressources attribuées dans l'utilisation du paysage ouvert (Figure 2). Un « jeu de rôle » sur le paysage ouvert a été conçu par la suite, afin de représenter de manière simple, implicite et ludique ledit paysage. Cette approche de modélisation d'accompagnement et de jeu de rôle présente la même structure de base que celle réalisée dans les marais autour du Lac Alaotra (cf. Reibelt et al. 2017). La dynamique de changement de couverture du sol ainsi que les modes agricoles d'utilisation des terres ont été décrits schématiquement à cet effet (Figure 3). Le jeu a été développé de manière participative grâce à la méthode de modélisation d'accompagnement (Barreteau et al. 2003). Vingt et une sessions ont été réalisées avec des paysans des quatre communes et de quelques représentants d'autorités locales. Une partie des résultats est utilisée dans cet article afin de comprendre le fonctionnement du paysage suivant la perception des joueurs. La table de jeu est une maquette de mosaïque de paysage composée de 18 parcelles. Les joueurs ont à leur disposition toutes les ressources reflétant les conditions réelles, nécessaires pour travailler individuellement leurs lopins de terre et subvenir à leurs besoins. Les facteurs pouvant modifier la trajectoire du paysage ont été traduits comme scénarios dans les tours de jeu. Le point commun des trois scénarios est l'intégration du rôle du marché et de la tenure foncière. Le premier scenario est considéré comme référence, suivi par l'introduction du facteur migration dans le deuxième scenario, et la tendance de la dégradation des forêts dans le troisième scenario. Dans chaque tour, les joueurs émettent leurs propres stratégies d'utilisation du sol pour subvenir à leurs besoins (Figure 4 et Figure 5). L'objectif est de comprendre, à travers leurs actions individuelles, la trajectoire du changement d'occupation du sol à l'échelle du paysage.

A l'instar des travaux de recherche publiés dans les journaux scientifiques à Madagascar et de par le monde, la réalisation de cet article a respecté les codes de conduite sur l'éthique (Wilmé et al. 2016). Les entretiens et les sessions de jeu ont été effectués de façon anonyme et confidentielle, priorisant ainsi le consentement de chaque individu.

RÉSULTATS

LA RIZICULTURE IRRIGUÉE : UNE TRADITION PLUTÔT QU'UNE ACTIVITÉ AGRICOLE. Le riz, une monoculture courante dans le bassin-versant de Maningory comme dans toutes les régions de Madagascar, accapare la plupart des terres arables, surtout les espaces irrigués. Le système agraire des paysans dépend, entre autres, de leur commune d'origine, de leur appartenance ethnique et de leur superficie agricole. Ces facteurs jouent un rôle prépondérant dans l'explication de la répartition des produits agricoles à l'autoconsommation des ménages et à la vente, mais également à la relation entre ces facteurs et l'accessibilité des gens aux infrastructures routières.

Les cultures sur *tanety* et sur bas-fond semblent toujours être interconnectées dans la stratégie des paysans (Table S2). La récolte des cultures vivrières pluviales offre un complément de source de revenu, alors que le riz est départagé entre l'autoconsommation et la vente sur le marché régional et national. Les deux sous-bassins versants de Sahamaloto et d'Anony, dans la commune d'Ambohijanahary au nord du Lac Alaotra, alimentent quelques grandes exploitations familiales réparties sur 8 000 ha de périmètre irrigué. Cette zone est composée d'une population de l'ethnie Sihanaka, des paysans habitant autour du lac et approvisionnant le « grenier à riz » de Madagascar. En 1946, lors du temps de la colonisation française, une politique publique de l'État a contribué à façonner cette localité avec une stratégie appelée « opération Lac Alaotra ». Depuis cette époque, la riziculture irriguée s'est améliorée grâce à la gestion de la fertilisation et à la maîtrise de l'eau à l'instar des aménagements hydro-agricoles. Elle s'est peu à peu développée grâce à une agriculture méca- nisée, permettant de multiplier les rendements agricoles et passer de la subsistance à la commercialisation. Malgré que la zone soit considérée comme grande productrice de riz, les paysans attribuent une bonne part de leurs récoltes à l'autoconsommation des ménages. D'autant plus que l'étendue des superficies culti- vables se trouve être de plus en plus restreintes à cause de la pression foncière, la croissance démographique et d'autres facteurs socio-économiques (Fujiki et al. 2015). L'agriculture reste alors, pour la plupart, de type familial et la production restante est subdivisée entre la semence pour la prochaine saison culturale et la vente à petite échelle. Cette politique de renforcement de la politique agricole s'est prolongée durant toute la première Répu- blique à Madagascar (1960–1972) (Alain et al. 2007). A travers l'idéologie socialiste imposée par l'Etat à cette époque, toutes les initiatives agricoles se sont concentrées sur la production de riz même au dépit des communautés paysannes à cause d'une hausse considérable de l'importation. La mise en valeur des *tanety* a été laissée pour compte par manque de technicité et d'une assise stratégique stable.

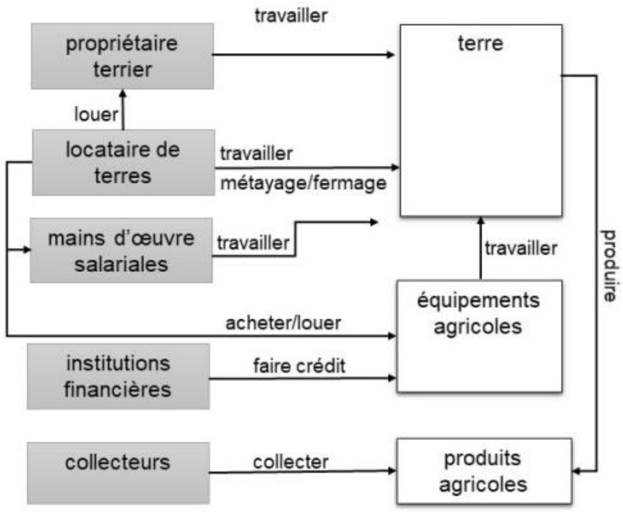

Figure 2. Modèle conceptuel montrant l'interaction entre les acteurs et les ressources, basé sur la méthode AR(D)I ou Acteurs, Ressources, Dynamiques et Interaction (Etienne et al. 2011).

Au Sud du Lac, dans les communes de Vohimenakely et d'Antanandava, les superficies rizicoles sont plus restreintes, de 1020 à 3000 ha. Partagés entre les ethnies Sihanaka et Betsimisaraka, les paysans se ruent de plus en plus vers les cultures sur *tanety*. Ce type de culture est vivement monté en puissance, particulièrement depuis 1945 (Penot et al. 2014), autour des forêts naturelles. Le seul vestige de forêt important existant dans le bassin versant est le Parc National de Zahamena, vivement menacé par la pratique de la culture itinérante sur brûlis ou *tavy*. Les paysans étendent petit à petit leurs surfaces agricoles, situées autour de la forêt, pour subvenir à leurs besoins. Au cœur du bassin, les surfaces rizicoles disponibles sont plus limitées. Successive-

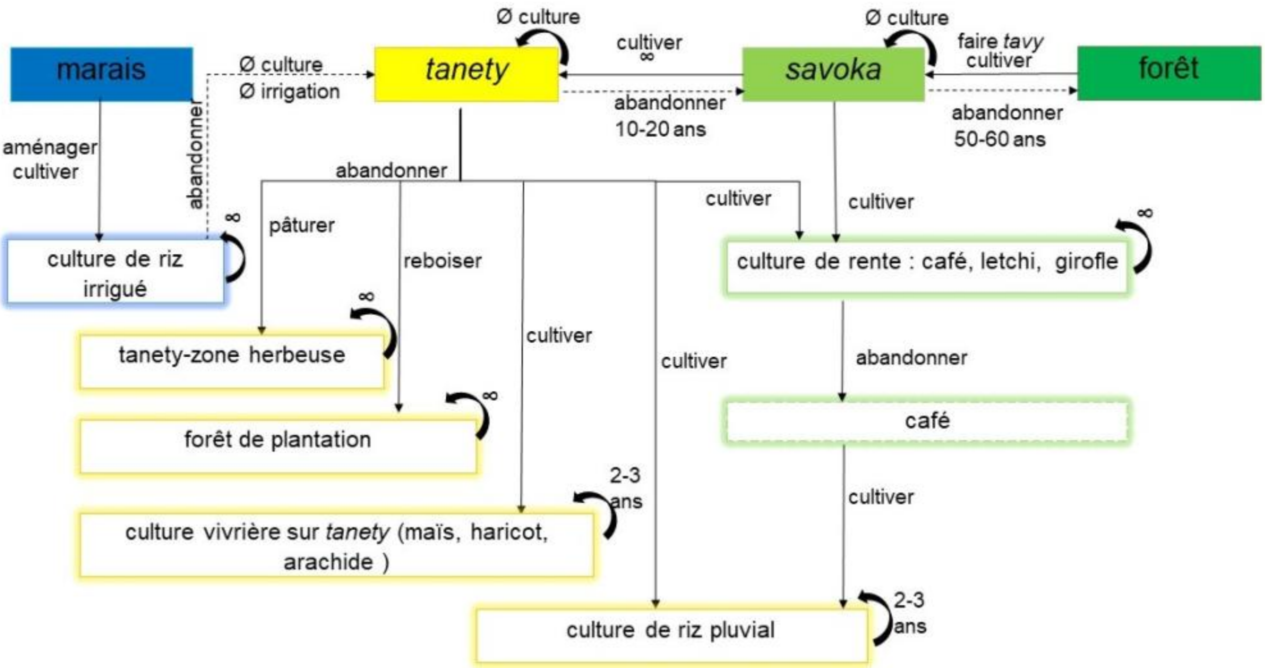

Figure 3. Diagramme de changement d'occupation et de couverture du sol à l'échelle du paysage. Les flèches en arc représentent une utilisation du sol sur des années consécutives, soit pour une durée de 2 à 3 ans, soit indéfiniment. Pour les périodes de reconstitution des *tanety* en *savoka* et des *savoka* en forêt, se conférer à Styger et al. 2006.

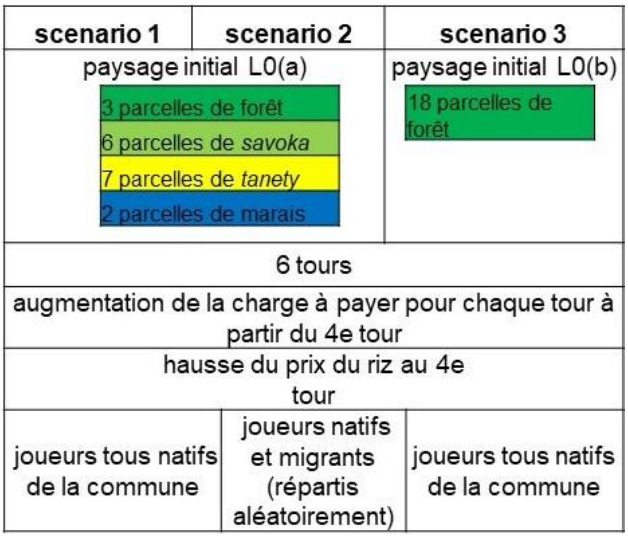

Figure 4. Description des scénarios d'une session de jeu de rôle. En total, il y a trois scénarios, chacun composé de six tours, joués suivant les mêmes règles à l'exception du paysage de départ et des caractéristiques de joueurs. La table de jeu est composée de 18 parcelles réparties de façon similaire L0(a) pour les deux premiers scénarios et en L0(b) pour le 3e scénario.

ment, seuls 25 à 50% et 10 à 25% des ménages dans les communes de Vohimena et d'Antanandava pratiquent la rizi-culture sur zones irriguées. La production est donc principalement consacrée à l'autoconsommation.

La commune de Vavatenina, en aval du bassin-versant (Figure 1), est habitée par une population Betsimisaraka. Elle est connue pour une forte pratique du *tavy*, notamment pour le riz pluvial et les produits d'exportation tels que le girofle, le café et le letchi. La culture de rente, contrairement aux cultures annuelles pluviales du front Ouest, constitue la principale source de revenu pour les paysans. La riziculture irriguée est réalisée de manière secondaire dans cette région, avec seulement 25 à 50% de la population la pratiquant. Les paysans préfèrent vendre leur produit de riz, chaque kilo rapportant autour de 200 à 500 Ariary en 2015, et acheter du riz importé pour leur propre consommation. Les revenus issus du riz sont importants pour les paysans. Ils leurs permettent de subvenir à leurs besoins quotidiens de premières nécessités tels que l'achat de sucre, de gros sel, d'huile de cuisson et de pétrole pour les lampes d'éclairage. Accessoirement, le surplus est rajouté au budget pour payer les salaires des mains d'œuvre travaillant et cultivant les terres au début de la saison, coïncidant avec la période de soudure. Pendant cette pé-riode, les paysans combinent les pratiques agricoles à d'autres sources de revenus

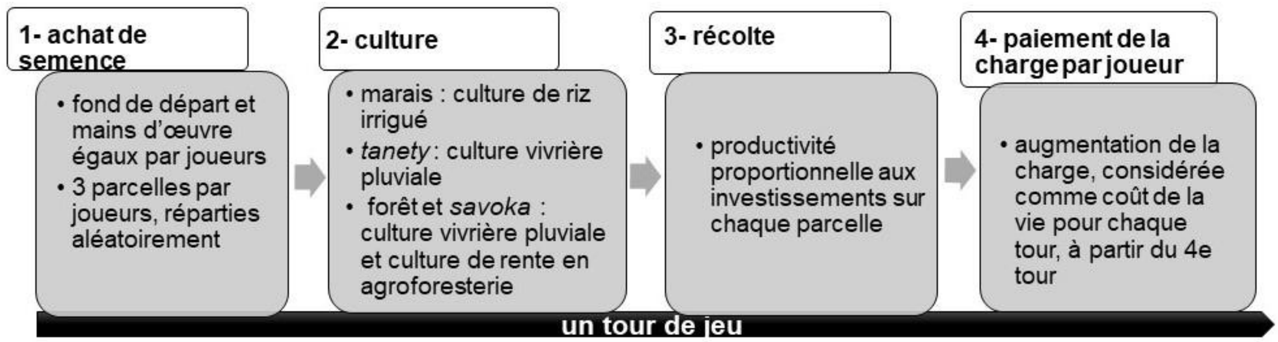

Figure 5. Description d'un tour de jeu de rôle.

telles que la fabrication d'huile essentielle de girofle et les activités minières grâce à une migration temporaire.

Une analyse de régression multiple, au seuil de significativité de 5%, montre que ni le prix du kilo du riz (valeur p = 0.445) ni la distance du marché (valeur p = 0.655) n'ont une incidence statistiquement significative sur la quantité de riz mise sur le marché par chaque ménage, et de ce fait sur la superficie cultivée. La riziculture est plutôt considérée comme partie intégrante de la coutume malgache et se perpétue de génération en génération. Malgré la faible plus-value octroyée par la culture de riz, les paysans lui accordent une attention particulière. Elle détient une place importante dans les habitudes alimentaires et même dans la tradition familiale. Dans le bassin-versant de Maningory, surtout en amont où les paysans disposent de grandes superficies rizicultivées, pouvoir subvenir aux besoins du ménage jusqu'à la prochaine récolte et avoir une possibilité d'alimenter directement les marchés régionaux et nationaux en riz constituent un indi- cateur de richesse. Malgré le fait qu'il n'existe pas de marché réellement formel, le prix du riz fluctue rarement, vendu entre 1200 et 1500 Ariary le kg selon les données d'enquête en 2015. Pour les communes au nord du Lac Alaotra et certaines communes productrices de riz à l'extrême Est du bassin versant, une partie des produits est accumulée par les collecteurs locaux. Ils les acheminent directement vers les grandes villes par leurs propres moyens. La part restante est recueillie par les collecteurs externes, qui viennent jusqu'aux chefs lieu des communes après la saison de récolte.

COLONISATION DES *TANETY* : VERS UNE MEILLEURE OCCUPATION DU PAYSAGE OUVERT. Les espaces ouverts sont très peu mis en valeur dans la zone d'étude. Alors que les superficies rizi-cultivées sont devenues plus restreintes à cause de la croissance démographique, les paysans se ruent peu à peu vers les cultures sur *tanety*. Globalement dans la zone d'étude, les cultures les plus pratiquées sont les cultures annuelles pluviales d'arachide et de haricot, ainsi que les cultures pérennes de produits de rente tels que le girofle et le letchi (Figure 6). L'espace ouvert décrit dans cet article couvre 80% de la superficie totale du bassin. Chaque ménage détient en moyenne 0.2 ha d'espace ouvert cultivé.

Uniquement 5% des paysans de la commune Ambohijanahary s'adonnent à la culture sur *tanety*. Sa valorisation est considérée comme un investissement non rentable, à cause de la faible fertilité du sol et d'une forte exposition à l'érosion. Au cœur de la zone d'étude, 10 à 50% des paysans des communes de Vohimena et d'Antanandava pratiquent la culture sur *tanety*. Ces espaces ont une faible accessibilité routière, une sécurité vulné- rable rendant difficile et couteuse l'utilisation des équipements agricoles ainsi que le transport des récoltes. Dans la commune de Vavatenina, plus de 80% de la population pratique le *tavy*. Cette habitude culturale est considérée comme une des causes di- rectes de la dégradation des forêts sur le front oriental malgache et contribue à l'extension de la superficie des espaces ouverts.

Une analyse de régression linéaire multiple a permis de comprendre que la quantité de produits sur *tanety* augmente en fonction du prix sur le marché (valeur p<0.001), et entraîne une augmentation de la superficie cultivée. Les résultats des entretiens auprès des paysans montrent qu'une grande partie de la production est écoulée sur le marché local. Toutefois, certains types de produits, tel que le haricot et l'arachide arrivent à approvisionner les marchés des grandes villes de Toamasina et même de la capitale Antananarivo. En effet, ces villes sont reliées par les principales routes nationales existantes dans le bassin-versant. Elles sont constituées par la Route Nationale 22 de Vavatenina jusqu'à la bifurcation, qui la relie à la Route Nationale 5 condui- sant à Toamasina où se situe le premier port de Madagascar, puis donnant vers le Sud sur la Route Nationale 2 menant à Antananarivo. La Route Nationale 44 est additionnée à cette liste, quoique plus ou moins délaissée compte tenu de son mauvais état, surtout durant la saison de pluie. Elle sert ainsi au transport des produits sur tanety à l'échelle régionale et de riz irrigué sur le marché national.

La commercialisation des produits de rente est considérée comme une source de revenu d'appoint pour les paysans. Une fois

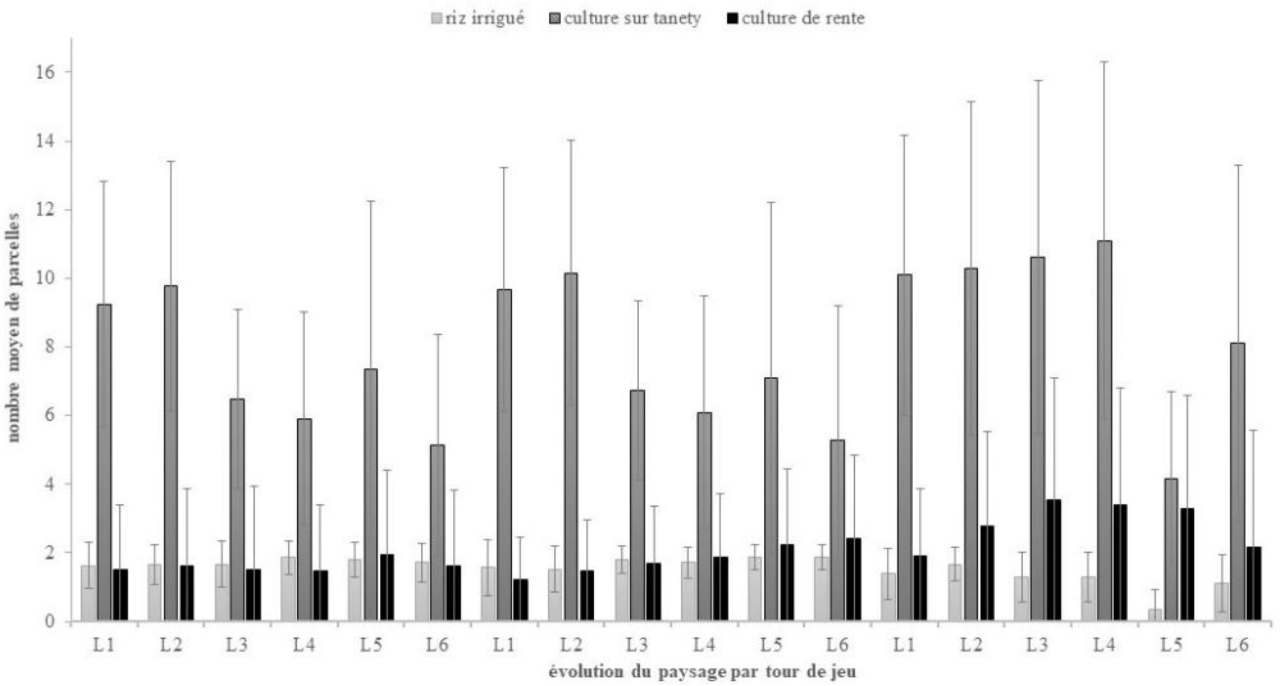

Figure 6. Répartition des modes d'utilisation du sol sur 21 sessions de jeu ; les barres d'erreur représentent les écart-types.

que les plantes pérennes ont fructifiées, elles produisent d'une manière conséquente chaque année, à l'exception du girofle. La récolte de clous de girofle reste aléatoire jusqu'à l'ouverture de la campagne de collecte et offre un revenu sporadique, alors que les feuilles sont utilisables toute l'année pour produire de l'essence. Sur le marché, au niveau des collecteurs locaux, l'essence de girofle est vendue à 30 000 Ariary par litre. Les paysans produisent alors de l'essence presque toute l'année afin de répondre à leurs besoins financiers. Les années où les récoltes de clous sont bonnes, des gens jouant à la fois le rôle de collecteur et de docker auprès des paysans collectent les clous de girofle préparés, à raison de 18 000 Ariary le kg, les transportant sur leur dos à l'aide de deux sacs fixés de part et d'autre d'une tige d'arbre ou de bambou. Ils les vendent par la suite aux collecteurs locaux se situant dans les chefs-lieux de la commune à raison de 22 000 Ariary le kg. Ces derniers revendent les produits aux grandes sociétés d'exportation à Toamasina et à Antananarivo.

Contrairement à la récolte de clou de girofle, les fruits du letchi sont plus stables et bénéficient d'un autre circuit de commercialisation. Ils représentent ainsi une source de revenu plus ponctuelle pour les paysans. Au moment de l'ouverture de la campagne de récolte, les collecteurs externes viennent avec des camions et des fourgonnettes pour collecter les paniers de letchis de 20 à 25 kg, déjà préparés par les salariés des propriétaires des pieds de letchis. Ces produits sont déposés tout au long de la Route Nationale n° 22 et sont vendus pour 600 à 750 Ariary le kg.

Enfin, la culture de la vanille a été abandonnée par les paysans de cette commune depuis une dizaine d'année à cause d'une baisse de prix et d'une insécurité accablante. Les paysans qui ont travaillé dans la production de vanille ont alors migré vers d'autres communes au Nord de la région Analanjirofo. La pro- duction de café a subi le même sort. La chute du prix depuis une dizaine d'années a poussé les paysans à convertir leurs champs de caféiers en cultures de riz pluvial. Le reliquat de production de café n'est mis sur le marché que si le cours est attractif ou en cas de besoin d'argent pressant, ce qui n'est que dérisoire.

ACCESSIBILITÉ, MIGRATION ET TENURE FONCIÈRE.

L'accessibilité aux routes facilite le transport des produits. Les paysans des communes disposant d'une bonne accessibilité ont une plus grande superficie cultivée et une plus grande quan- tité de production pour la vente. En comparant les données de simulation de l'évolution des parcelles occupées par la riziculture pour l'ensemble des sessions de jeu de rôle, on observe une augmentation de 33.5% entre le scenario 1 et le scenario 2 avec les facteurs « marché » et « migration ». Cette proportion est de 94.2% entre le scenario 1 et 3 en ajoutant les facteurs « dégradation du sol » et « tenure foncière ». A l'instar de la réalité, les rizières irriguées sont limitées par les bas-fonds et les vallées alluvionnaires dont les superficies restent immuables. Ainsi, les paysans ayant une faible accessibilité aux routes ont aussi un accès limité au marché. Ils attribuent alors une grande part de leur production en riz à la consommation de leur ménage.

Une migration de courte distance est souvent observée sur le front Ouest du bassin où les jeunes natifs ayant travaillé en tant que salarié dans d'autres communes reviennent dans leur commune natale pour hériter des terres de leurs parents ou pour acheter d'autres terres agricoles. Les propriétaires terriens sont des natifs de la localité, surtout concernant les rizières irriguées. Par contre, les migrants de longue distance, issus des ethnies Merina et Betsileo, travaillant en tant que main d'œuvre salariale, se sont peu à peu installés dans la commune. A l'ouest du bassin versant, les migrants occupent les *tanety* pour les cultures annuelles pluviales. Alors que sur le côté Est, où les *tanety* résultent souvent de la pratique de *tavy* sur les *savoka*, ils appartiennent aux gens natifs de la région qui ont pratiqué les cultures sur brûlis successives sur la forêt ou ont hérité de leurs parents pour faire place, dans le long terme, aux cultures de rente de girofle, de letchi et de café.

Ce résultat est renforcé par l'analyse de régression qui a démontré une corrélation significative entre l'origine des paysans en tant que migrant ou natif et la quantité de produits de rente qu'ils mettent sur le marché (Table S2). Le fait d'être natif de la commune augmente sensiblement l'accessibilité au marché, et donc également la quantité mise en vente. Quoi qu'il en soit, la migration ouvrière de longue distance sur le versant Est n'est que temporaire. Les gens sont attirés par le marché d'emploi, créé par la collecte et le conditionnement des produits de rente, les services de location de voiture pour le transport des produits ou la pratique de la bijouterie artisanale grâce à l'épanouissement de l'orpaillage aux alentours du Parc National pour les hommes et le commerce de vêtements ou d'autres produits artisanaux pour les femmes. L'accessibilité aux routes nationales accentue ce phénomène de migration. Une corrélation évidente entre la quantité agricole produite et l'accessibilité aux routes a été définie (Table S2). L'existence de ce courant migratoire renforce la conjoncture économique des produits agricoles et incite à une augmentation de la quantité de produits mise en vente par les paysans. Toutefois, les paysans font face à d'autres problèmes économiques, comme l'irrégularité des prix des produits sur le marché. Ils sont souvent fixés par les collecteurs et entraînent un impact sur l'écoulement des produits et sur les superficies cultivées.

DISCUSSION

La pratique de la riziculture irriguée tend plus vers une économie de subsistance qu'à une économie de marché, à l'exception de quelques grandes exploitations dans les périmètres irriguées du Lac Alaotra et certaines communes disposant de plaines irrigables sur la côte Est du bassin-versant. Ce type de culture est plutôt considérée comme une coutume avant d'être une activité agricole, le savoir-faire agricole est transmis de génération en génération (Cholez et al. 2010). Les paysans autochtones ont, pour la plupart, hérités des terres de leurs parents (ibid). Les rizières irriguées cultivables sont souvent limitées aux vallées alluvionnaires. Par conséquent, l'augmentation de la population a favorisé l'exploitation des tanety à des fins agricoles. Un paysan sans terre migre physiquement et économiquement pour survivre, en poursuivant des activités agricoles. Sur le versant Ouest du bassin-versant, les migrants occupent plus les *tanety* que les autochtones. Toutefois, une étude effectuée par Bertrand et Lemalade en 2003 dans la commune de Didy a démontré qu'ils viennent à se concurrencer avec les natifs faute de marais amé- nageable en rizière irriguée.

L'utilisation des *tanety* a pris plus d'envergure depuis une trentaine d'années (Durand et Nave 2008) surtout pour la recherche de cultures de rente prometteuses. Cette vision d'introduire l'économie de marché dans les sciences sociales ou « ethnographie économique » est apparue entre les années 1970 et 1990 (Dufy et Weber 2007). Il s'agit de décrire une assise naturelle au mécanisme de marché et à l'économie de subsistance par une « théorie néoclassique » complexe dite de « Polanyi » (ibid).

Les paysans du front Ouest utilisent les *tanety* pour les cultures annuelles pluviales. Sur l'Est, ces espaces sont issus de la pratique de *tavy* sur des formations secondarisées, pour faire place successivement à une culture de riz pluvial, puis à d'autres cultures vivrières pour se terminer avec des cultures pérennes, de rente, jouant souvent un rôle important en tant que marqueur foncier (Rabemananjara 2014). Dans cet article, les cultures de rente sont souvent des cultures pérennes. Une précision entre ces deux types de cultures a déjà été évoquée en insistant sur le fait que la culture de rente est liée à une question d'accessibilité alors que les cultures pérennes sont guidées par une stratégie d'occupation foncière par les paysans (Bertrand et Le Roy 1991, Bertrand et Lemalade 2003). D'ailleurs, cette question foncière demeure encore un sujet de confusion à Madagascar (Bellemare 2009, Penot 2010).

La population rurale envisage toujours des revenus monétaires même dans les zones à fort enclavement (Bertrand et Lemalade 2003). Le terme de circuit de commercialisation évoqué dans cet article mentionne un parcours habituel entrepris par les paysans. Il est relié à la vente de produits agricoles sur le marché. Le marché affecte également la migration, qui est considérée à la fois comme une stratégie économique et sociale par les paysans (Deschamps et al. 1959, Andriamanalina et al. 2014). Le phénomène de migration agricole d'Ouest en Est du bassin-versant de Maningory est particulièrement accentué par la commercialisation de produits de rente. En effet, la quantité produite augmente avec la hausse du prix sur le marché national. Cette situation entraîne implicitement une augmentation de la surface cultivée, induisant non seulement une extension des espaces ouverts et une augmentation du flux de migrants, mais aussi une dégradation de la couverture forestière (Rabemananjara 2014). L'espace ouvert occupe une grande proportion du paysage. Cette situation devrait être utilisée à priori, pour une amélioration de l'économie de subsistance vers une économie de marché.

L'approche, en termes de gestion des bassins versant, est encore un concept récent. Malgré que la question de migration interne ou externe ait été évoquée vers les années 1960 (Durand et Nave 2008), elle reste peu documentée et encore non articulée dans la politique de l'Etat. Les prochaines actions devront alors être axées sur l'articulation *tanety* / forêts / zones humides à travers une régularisation des marchés agricoles surtout pour la stabilisation des prix des produits à l'exportation. Malgré les savoir-faire acquis pour la mise en valeur des tanety depuis les années 1980 (Penot 2010), la récolte des cultures annuelles pluviales reste encore dérisoire pour un circuit de commercialisation à grande échelle. Un appui pour l'adoption des systèmes d'inno- vation tels que l'agriculture de conservation (Penot 2010, Andriarimalala et al. 2013) mérite encore la préoccupation des acteurs de développement. La valorisation des *tanety* implique une prise de risque par les paysans, basée sur une stratégie pour une amélioration de leur condition de vie (Brown et Everard 2015) et inconsciemment pour une gestion du paysage global.

Le jeu de rôle, dans cette étude, a été utilisé comme outil de modélisation d'accompagnement (Etienne 2014, voir également Waeber et al. 2017 pour le cas de l'Alaotra), et a permis de comprendre les facteurs pertinents qui ont pu influencer l'occupation du sol dans une mosaïque de paysage. Il a facilité l'analyse de l'interaction entre les paysans et le système socio-écologique complexe qui les entoure en contribuant au développement du circuit de commercialisation des produits agricoles à une échelle locale. Cholez et al. (2010) décrivent ces paysans de Base of the Pyramid ou BoP, visant à instaurer un système de marché qui favorise les plus pauvres, tel le cas des paysans du bassin-versant. Le paysage ouvert gagnera indéniablement en étendue au détriment des zones boisées. À l'issu des jeux de rôle, les cultures pratiquées sur le paysage ouvert, qu'elles soient vivrières ou de rente, gagneront largement de l'ampleur au cours du temps, compte tenu des facteurs économiques et sociaux qui les conditionnent.

CONCLUSION

La colonisation des tanety dépend de plusieurs facteurs tels que les superficies de rizières cultivables disponibles, la fertilité du sol et le marché des produits agricoles. Toutefois, elle nécessite encore un développement agro-écologique et d'une assise politique conséquents, quant à son application. Les perceptions et les actions des paysans sont étroitement liées au contexte de commercialisation. Elles dépendent principalement d'une analyse de la résilience du marché de produits agricoles, en tenant compte de la dynamique sociale existante et de la diversité du paysage. L'uti-lisation conjuguée de l'approche de modélisation d'accompagnement et de la méthode d'entretien individuel en science sociale permet d'émettre une suggestion sur la gestion du paysage ouvert en se concertant sur les prochaines décisions. À travers un système paysans-exploitation-paysage, réside une dimension de perception sociale étroitement liée au contexte de production. Quoi que basée sur une économie de subsistance, l'économie paysanne cherche à faire jouer ensemble le concept de réciprocité et la force des stratégies individuelles au niveau des mé- nages. Toutefois, le rôle du marché reste encore allusif quant aux stratégies d'occupation du sol dans le paysage ouvert, par contre il est intrinsèquement lié à d'autres facteurs sociaux tels que l'accessibilité aux routes, la migration et le foncier. D'autres études, telles que la construction des modèles de changement d'occupation du sol, l'analyse des politiques publiques sur les questions foncières et de migration, permettront d'anticiper, de manière participative et concertée, les enjeux de la valorisation du paysage ouvert et contribuer à la mise en place d'une stratégie de gestion effective dans le long terme.

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* Please contact the authors for the unpublished documents.

SUPPLEMENTARY MATERIAL.

Available online only.

Tableau S1 : Liste thématique des variables utilisées dans le questionnaire de collecte de données.

Tableau S2 : Les variables retenues et leurs valeurs p.

ARTICLE

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Tool development to understand rural resource users' land use and impacts on land type changes in Madagascar

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ABSTRACT

A majority of Madagascar's rural people depend on the primary sector. The country's agricultural hub, the Alaotra-Mangoro region, is mainly tied to fisheries and rice production. Increasing human population and decreasing output from fisheries and agriculture are pushing the rural resource users further into the protected marshlands. Understanding rural farmers' decisions can help developing improved management plans to support long-term functioning of (socio-) ecological systems. We present here an example of inter- and transdisciplinary research which uses a participatory modelling approach to develop a shared vision of the Alaotra socio-ecological system. The purpose of this study is to introduce the used gaming approach in detail by documenting the process of co-construction of the Alaotra wetlands' conceptual model. We then describe how the model is transcribed into a table-top role-playing game that will help researchers and stakeholders alike explore and understand decisions and management strategies. We finally report on first outcomes of the game including land use decisions, reaction to market fluctuation and landscape change.

RÉSUMÉ

La majorité des populations rurales de Madagascar dépendent du secteur primaire. Le centre agricole du pays, la région d'Alaotra-Mangoro, est principalement lié à la pêche et à la production de riz. L'accroissement de la population humaine et la baisse de la production agricole et de la pêche poussent les utilisateurs des ressources rurales vers les marais protégés. Comprendre les décisions des agriculteurs peut aider à développer de meilleurs plans de gestion pour soutenir le fonctionnement à long terme des systèmes (socio-) écologiques. Nous présentons ici un exemple de recherche interdisciplinaire et transdisciplinaire qui uti- lise une approche de modélisation participative pour développer une vision partagée du système socio-écologique d'Alaotra. Le but de cette étude est de présenter en détail l'approche des jeux utilisée, en documentant le processus de co-construction du modèle conceptuel pour les zones humides d'Alaotra. Nous décrivons ensuite comment le modèle est transcrit dans un jeu de rôle sur plateau qui aidera les chercheurs et les parties prenantes à explorer et à comprendre les décisions et les stratégies de gestion. Nous présentons enfin les premiers résultats du jeu, y compris les décisions d'utilisation des terres, la réponse aux fluctuations du marché et aux changements des paysages.

INTRODUCTION

A majority of Madagascar's rural people depend on the primary sector. One of the most important agricultural production areas in Madagascar is the Alaotra-Mangoro region (Figure 1). The primary economic driver in the region is tied to fisheries and rice production, providing one third of the country's rice output (Andrianandrasana et al. 2005, Ferry et al. 2009). The human population of the two lake districts of the Alaotra-Mangoro region has increased from 110,000 people in the 1960s to over 710,000 in the 2000s (Monographie Régionale Alaotra-Mangoro 2012), with increasing land area being titled or occupied (Jacoby and Minten 2007); consequently, land is becoming scarce, forcing many people into the marshes to establish rice fields (Ratsimbazafy et al. 2013, Waeber et al. 2017).

A majority of the marshland fringing the lake has already been converted to rice production (Ranarijaona 2007, Ratsimbazafy et al. 2013), with 100,000 ha outputting ca. 300,000 t per year. A particular problem in the whole of Madagascar is deforestation and land clearing (mostly through slash and burn swidden agriculture, called *tavy*). The marshlands, Alaotra's 'forests', are also in continuous decline (Ratsimbazafy et al. 2013). Studies and observations using remotely sensed imagery have further shown that Lake Alaotra had shrunk to 20% of its former size in 2000; in addition,

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Figure 1. The geographic boundaries of the Alaotra socio-ecological system considered in this study.

crop productivity in the basin is reputed to have dropped to about 40% of its former level as a consequence of river and irrigation canal silting, yet clear-cutting and *tavy* continue in the Alaotra-Mangoro region (Wright and Rakotoarisoa 2003, Bakoariniaina et al. 2006). It is broadly recognized that due to low yields, clear cutting and land clearing are used to expand areas under cultivation as well as for livestock, creating a self-reinforcing cycle between declining yields and continued deforestation and land transformation.

Understanding rural farmers' decisions can help develop improved management plans to support long-term functioning of (socio-) ecological systems. We present here an example of inter- and transdisciplinary research which uses a participatory modelling approach to develop a shared vision of the Alaotra socio-ecological system (SES, henceforth real SES). In this context, the creation of mechanistic models and boundary objects (e.g., games; White et al. 2010, Akkerman and Bakker 2011) are used in conjunction to help stakeholders navigate the complexities of a landscape in transition, and explore the multiple (social, ecological and economical) dimensions of the outcomes their individual decisions will generate. To help stakeholders and decision makers become aware of the complex interactions and feedback loops as well as allowing them to explore the current, expected, and potentially surprising behaviours of the territory they are managing, we developed a transdisciplinary landscape approach based on the Companion Modelling ComMod (Etienne 2014). The ComMod approach merges modelling, the development of boundary objects (toy models such as role-playing games) and stakeholder engagement processes.

The purpose of this study is to describe this gaming approach in detail: (i) we first document the process of co-constructing the conceptual model of the Alaotra wetlands environment in an interactive, iterative, and incremental manner. We then (ii) describe how the conceptual model is transcribed into a table-top role-playing game that will serve as boundary object, allowing stakeholders to play with it and helping researchers and stakeholders alike explore and understand decisions and management strategies. We (iii) report on first outcomes of the game; what are players' land use decisions? How is the landscape changing? In addition, how are participants reacting to changing market conditions?

CO-CONSTRUCTION OF A CONCEPTUAL MODEL

Our methodology to collectively construct the conceptual model of the Alaotra wetlands region builds upon a dedicated participatory modelling method developed by Etienne et al. (2011). This method, called ARDI, constitutes a framework to help identify the main components and drivers of change in a given natural resources management setting. It encourages different stakeholders to elicit their mental models of the system, and allows for co-constructing a common representation of the issues at hand, after agreeing on those most striking in a given context. Unfolding the method, the research team can identify together with the stakeholders the main Actors, Resources, Dynamics and Interaction (hence the acronym ARDI) that are relevant to the system under analysis and the agreed-upon issue(s).

In the Alaotra context we ran four full-day ARDI workshops in an iterative and incremental way (cf. Souchère et al. 2010) over a period of 10 months (April 2013 to February 2014). A total of 35 fishers and farmers from the Alaotra participated in these workshops; participants were approached randomly by our local research assistants at respective village markets and invited to join the research sessions. The first step in ARDI was to collectively formulate and agree on the 'burning' issues at stake in the marshland system. As a starting point, we offered the phrase "the marshes are changing" to present a neutral formulation and to avoid judgments or imposing constraints to further discussions. The derived research question was "What is driving the changes observed in the Alaotra marshes?". In the next steps, the participants of the ARDI workshops collectively identified and ranked (cf. Bernard 2006) actors that are important in driving change in the marshland system. The four main types of actors in the real SES identified during the workshops are fishers, farmers, migrants, and collectors (Figure 2). The term 'collector' is a broad description for the people in the supply chain that are placed between producers and markets. Information on the main wetland resource users' characteristics was validated through the stakeholder typology study by Rakotoarisoa et al. (2015). The same ranking exercise as for the main actors was applied to identify the main resources which are used, modified or traded by the actors in the real SES. Important resources identified relating to marshland change were money, fish, food, rice and cattle. In a final step, the participants agreed on the interactions between the actors and resources, while describing the temporal and spatial dynamics of these linkages. The most important interactions were farming (rice and vegetables), fishing, and buying or selling products at the market.

After each ARDI workshop, a summary was prepared by the research team, which was then presented to the next ARDI workshop participants, new to the process. This allowed incremental modification and verification of each previous conceptual mind map. After the fourth workshop, the ARDI results were complemented and triangulated with five focus groups (professional fishers, men only; onion farmers, women only; villagers who also practice fishing, mixed group; reed cutters, women only; and medicinal plants collectors, mixed group) that were held in the same period with a total of 30 resource users (same selection approach as for the ARDIs). Additional insights from the focus groups together with archival research from the Ministries of Fisheries, Agriculture, and Environment, allowed the verification and clarification of open questions that had emerged during the ARDI workshops. The final result was the conceptual model shown in Figure 2.

GAMIFICATION

'TRANSLATING' THE CONCEPTUAL MODEL TO A RPG. Role Playing Games (RPGs) in Companion Modeling can be fully computerized RPGs (agent based models), computer supported RPGs, or table-top RPGs, depending on the research context. As the game workshops were to take place in a rural setting around Lake Alaotra, with oftentimes no access to electricity, we opted for a computer-supported table-top role-playing game (henceforth RPG), as opposed to a computer-based game. The combination of participatory workshops with focus groups allowed the development of a shared vision of the socio-ecological system in the Alaotra, i.e., the main actors, resources, dynamics, and interactions that play a role in 'marshland changes' (Figure 2). These components and relationships, i.e., the conceptual model, served as the backbone to construct the RPG. Actors and resources identified in the conceptual stage were converted into players' profiles (Farmers; note that game components henceforth will be indicated by capitalisation) or institutions (Market with Collector, Bank) while resources were materialized through tokens or activity cards (Farming: Onion, Rice, Vegetable; Fishing; Hunting; Logging; Mining). The interactions and associated verbs from the conceptual model prompted the sequence of actions in the game, while processes and dynamics such as land-type changes were translated into rules and course of the game (details in the 'How to play the game' section).

For the gaming process (Figure 3), the research team decided to track both individual and summarized activities. We introduced a Personal Game Sheet where each player can keep track of personal decisions (activities) and cash income. Additionally, cumulative impacts of individual decisions and changes are monitored on a game board at the end of each round, where landscape cover types change depending on individual agricultural activities (e.g., Marshes turn into Agriculture land-type). This allows players to track their individual decisions and see whether there are knock-on effects, but also to experience the summarized results and consequences of their individual decisions on the game board. The game board shows the Landscape, which is a simplified and archetypal representation of the various land cover types to be found in the Alaotra region (Figure 1). From the basin to higher altitude these are the Lake, Marshes, Agriculture zone (*baiboho* in Malagasy, called *mailles* by Ducrot and Capillon 2004), Open landscape (representing the *tanety*, which is Malagasy for hilly slopes, dominated by grass species, cf. Kull 2012, Kull et al. 2013), and Forests (Figure 1, Figure 3). The landscape stratification representing all these zones was adapted from Husson et al. (2012).

Productivity in the real SES is highest in the agriculture zone, followed by marshes and open landscape; productivity in the game has accordingly been parameterized and calibrated proportionally based on statistics available from the Regional office, and is a proxy for soil fertility and water availability. The resource users (fishers, farmers) in the real SES are pursuing more than just one livelihood supporting activity (Rakotoarisoa et al. 2015). As the players in the game are the main actors found in the real SES, they can do as many activities as they can afford in each zone (at least four land-type-based activities per round are mandatory to ensure that the game process will last over six rounds). In the Agriculture zone however, where all land is already occupied, a maximum of one activity per game round and player is allowed; this is a proxy for increasing (over-) population. Apart from land-based activities, players can also invest into Compost, a proxy for technology, into Quality of Life (QoL), i.e., parameters such as Electricity, Education, Health and Protein, as well as the possibility to invest into improved Housing (from bronze to silver or gold standard; this decision cannot be undone in later game rounds). These parameters (Figure 3) are ways to track players' values and preferences.

During the course of the game, all players make decisions on how to pursue their livelihoods, and then cash the output at the

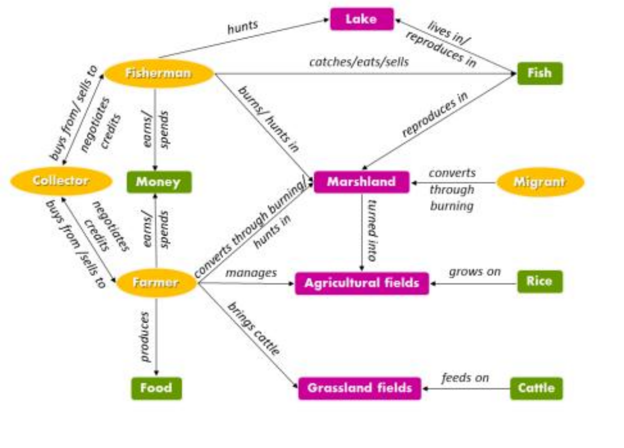

Figure 2. Conceptual model stemming from four ARDI workshops (Etienne et al. 2011) that encapsulates the elements that were common across the four locations, except for the onions as explained above (hence the use of the term 'farmer', which can represent either rice or onion farmer, or both). In green are the resources, in pink the zones, and in yellow the actors.

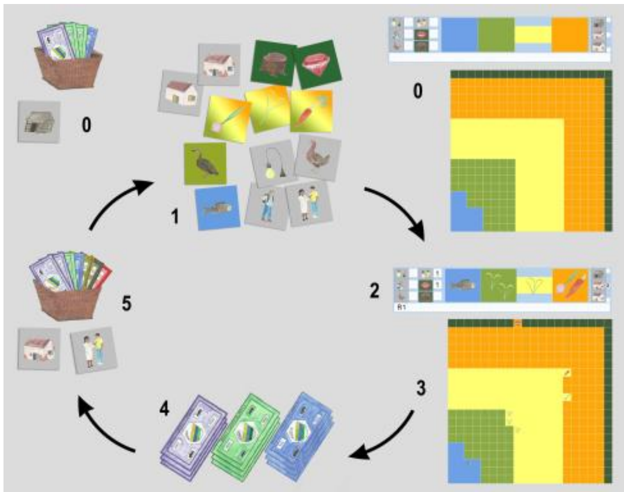

Figure 3. Table top model (role-playing game RPG). (0) Starting conditions, with Personal Cash Box and a Bronze House (lowest housing level); Personal Game Sheet; and Landscape where all changes will be shown. The game order is to (1) invest your money at the Market in: land-based action tokens (Fishing in the Lake, Hunting in the Marshes (light green), Onion/ Rice/ Vegetable Farming in either Marshes/ Agriculture zone (yellow)/ Open landscape (orange), or Rosewood logging or Sapphire mining in the Forest (dark green); players can also invest into Quality of Life: Electricity, Education, Protein, Health, or improve their House (silver or gold level); (2) track your spatial decisions on your Personal Game Sheet: where do you do what and how many of the purchased activities?; (3) place your land-based tokens on the Landscape to follow changes; (4) get your output calculated at the Bank; and (5) receive your earned money. R1= round one; in total there are six game rounds.

Bank. A member of the research team represents the Bank and uses a computer to collect all the decisions tracked on each player's Personal Game Sheet in an Excel working sheet. The Bank thus is a central place where all individual decisions are entered in a data sheet (Supplementary Material S1), and the production returns are calculated and cashed. Returns depend on the type, and frequency of the chosen activities and the zone. Returns can also be modified by the arrival of a Collector to the Market, or a Gendarme. Gendarmes are represented by the research team and stand for law enforcement in the real SES; in the game they represent the risk of illegal activities (Hunting in the Marshes, or Mining and Logging in the Forest). These so-called 'opportunity activities' come with a risk and opportunity cost: the Gendarmes might 'catch' the players and issue them fines (represented as a random process calculated in Excel). While the potential arrival of a Gendarme or the risk of a fine is not communicated, the players know that in the real SES these three activities are illegal, and participants assumed that these were also illegal activities in the game. All three illegal activities occur in the real SES: bushmeat hunting in the marshes, e.g. *Hapalemur alaotrensis*, a nationally and internationally protected lemur species (cf. Rakotoarivelo et al. 2011) and rosewood logging or sapphire mining in the humid forests of Madagascar (Randriamalala and Liu 2010, Innes 2010, Allnutt et al. 2013, Stoudmann et al. 2017). At the Bank, production return for Fishing stands as proxy for fish stock which varies with the number of actors fishing and number of actors farming in the Marshes, i.e., converting Marshes into the Agriculture zone land type, as these are crucial for fish reproduction (Wallace et al. 2015, 2016). In the game, the Bank also functions as a credit institution for actors needing cash for investing into future activities (this mechanism was introduced to avoid non-participation in game rounds and as a means to borrow money without further affecting the interactions between players).

Translating the conceptual model and scientific evidence into game components and rules resulted in a game (Figure 3), which represents an implicit reality. It is important to note that the game does not 'rebuild' reality, but is a model, and as such a simplification of reality allowing to explore and analyse livelihood strategies. Being a simplification of the actors, resources and space relevant to the Alaotra stakeholders, the players recognize their reality in the game.

GAME CRASH TESTS. After actors, resources, and interrelations had been 'translated' into a draft game, further gamification was undertaken as an iterative development process based on 10 crash-test workshops until we reached saturation, i.e., no new items were suggested to be added or removed from the game. One session was with game specialists and researchers in Montpellier (France), two sessions with conservationists in Antananarivo and Ambatondrazaka (Madagascar), one session with primary school teachers, and six sessions with resource users around Lake Alaotra (Madagascar). In total, over 60 people participated in this game testing and verification phase. The main changes compared to the conceptual mind map (Figure 2) were (i) the exclusion of 'zebu cattle', not deemed relevant in the game context by local stakeholders (it had been included in the conceptual model due to its importance as a working tool and status symbol, but players did not make use of it as it was irrelevant for the game setting), (ii) the inclusion of Forest to complement the landscape, since some of the Alaotra stakeholders also used to frequent forests for livelihood purposes. It was further agreed that 'population growth' (or overpopulation) will be implicitly included in the game by adding a restriction to the most fertile zone of the landscape (the so-called Agricultural zone); also, for simplicity, and to allow participants to play themselves (as farmers/ fishers, regardless of whether their status was local resident or migrant), it was decided to leave out 'migrants' as additional actors in the game.

HOW TO PLAY THE GAME. There are six rounds (R) to a game; a round can represent a year or a season, however this is not pre-defined and the players can decide what works best for them. The game was calibrated for five players, it was run and facilitated by 3–4 Malagasy research team members from the Alaotra region, including helping illiterate players, while the calculations at the 'Bank' were done by the senior author. A typical game round has the following structure: (1) players go to the Market to invest into activities and Quality of Life (QoL) tokens; (2) track their decisions on the Personal Game Sheet; (3) put their tokens on the Landscape; and (4) go to the Bank where their production output is calculated; and (5) cashed (Figure 3, Figure 4).

In the following, each step is explained in more detail. (0) At the outset of the game, each player receives a start capital of 4,500 $A (game money) and basic housing; to track decisions, each person has a Personal Game Sheet and the joint Landscape. (1) At the Market, the players have different options about how to invest their money; the respective prices are displayed at the Market. The activities include (i) land-type based activities such as Fishing (500 $A as one-time investment for a boat), Farming of Rice, Onion, or Vegetable (500 $A each); (ii) opportunity activities such as Hunting, Mining, and Logging (150 $A, respectively); (iii) Compost to increase productivity and thus return from Farming (200); (iv) QoL such as Health, Education, Proteins, or Electricity (300 $A, respectively), and (v) three levels of Housing (500, 700, or 1000 $A to be paid at the end of each round as a proxy for living costs). Players purchase the game tokens that represent the activities they decide to do. (2) On their Personal Game Sheet players track their decisions, i.e., which activity they do in which zone. This is done with stickers or written abbreviations in the respective cells of the Personal Game Sheet. (3) As a next step, players go to the collective game board, the Landscape, where they put their purchased tokens and can see how individual decisions scale up to a collective impact, i.e., how aggregated individual decisions can induce system change. The unit of a land-based activity is the cell (represented as squares; Figure 3). The original land-types can change when activities are done on them; for example Marshes (light green) or Open landscape (orange) gets transformed into Agriculture zone (yellow) when Farming is undertaken in these land-types (Farming in the Agriculture zone itself will not change the land-type). A Forest cell (dark green) will turn into Open landscape (orange) when Mining or Logging takes place. Fishing is only done in the Lake and does not invoke a land-type change, while Hunting in the game is restricted to the Marshes. The research team and players together change the land-types manually according to each player's Personal Game Sheet decisions. Additionally, there is a Table of Change (ToC) monitoring agricultural activity in the Marsh, Open landscape and Forest; for each activity in the Marshes, a token on the Table of Change is flipped, showing different symbols of biodiversity such as the Alaotran gentle lemur (*Hapalemur alaotrensis*), the White-faced Whistling Duck (*Dendrocygna viduata*), and the marsh plant *Cyperus sp*. The Table of Change is used to track land-type change and to serve

Figure 4. Pictures of the gaming session course as described in Figure 3. (0) Explaining the game to players; (1) players investing into activities at the Market; (2) Tracking decisions on the Personal Game Sheet; (3) Implementing decisions on the Landscape; (4/5) Bank calculating output which is then cashed.

for discussions during the debriefings after the game sessions. (4) At the end of each round, players go to the Bank where their activities are entered into an excel sheet to calculate the revenue of their activities. (5) Players receive their cash from the Bank. Then the next game round begins.

SCENARIOS. Participants in the game play the role of resource users who have to secure their livelihood and well-being, i.e., maintain or increase their Personal Cashbox and QoL. We did not predefine what a livelihood strategy could be or what well-being and QoL means for the players, since we hoped to gain insights concerning these through the gaming behavior of the participants (viz. physical model representing the real SES).

We played two scenarios. In scenario 1, the game approach was 'business as usual', i.e., players could decide which activities to pursue. In the second half of scenario 1 (rounds 4–6), a Collector appeared on the Market (represented by a member of the research team) to promote either Onions or Vegetables. The Collector on the Market was a representation of externally induced change and fluctuation of prices (i.e., of production returns). The Collector brought new money into the virtual SES, shifted demand and made the production return of specific products (Onion or Vegetables, i.e., the one that had been planted less before) substantially more attractive than in the first half of the game.

A second scenario of "disturbances" had the exact same rules as scenario 1, except that at the end of each round, there was an event card drawn by a player representing a disturbance. In total, there were 10 cards with five different disturbances; two climatic events (cyclone, drought); fire; and two disease events (onion, rice). These events affect the landscape in different zones, and have different severities, but all modulate the total production outcome. In contrast to scenario 1, there was no market change taking place in order to better track the possible impacts of the disturbances on game outcomes and players' strategies.

SERIOUS GAMING RESULTS

PARTICIPANTS. We held a total of 15 RPG workshops, with five local actors per workshop from around Lake Alaotra. The participants of the RPG workshops were randomly selected, while meeting the following criteria: (i) typical resource user with livelihood activities within the wetlands of the Alaotra, (ii) living close to Lake Alaotra; (iii) aged between 20–70 years old to ensure that all participants were still working for their livelihoods, and (iv) a gender balanced participation. The sample was comprised of 33 women and 42 men, with an average age of 44 years (range 23–67); they represented average households of five members. Main real-life livelihood activities were farming (83%) and fishing (19%). Mean years of schooling were 8.7 (range 0-15). In addition, we played three RPG sessions with a total of 15 decision makers, representing the Ministries of Agriculture, Fisheries, Water and Forest, Topography, and Livestock.

LAND-BASED ACTIVITIES AND LANDSCAPE CHANGES. We used exploratory data analysis to gain an overview of the 30 variables derived from the gaming. After collecting summary statistics, we used either the t-test or the Wilcoxon Rank Sum test to make comparisons between different groups of participants. The Mann-Whitney U test was used when dealing with non-normally distributed variables. All analysis was done in R, with versions ranging from 3.0.3 to 3.2.1. The significance level used for all hypothesis testing was $\alpha = 0.05$ unless stated otherwise.

The majority of activities in scenario 1 was farming (41% rice vs. 25% onion vs. 23% vegetable farming; Figure 5). After the first half of the game, a change of investment behavior occurred, i.e., 43% of participants changed their primary crop from rice to onion or vegetables, or some combination of the three. This coincided with the arrival of a Collector on the Market. Significantly less farming activities were done in the first half of the game (R1–3) vs. the second half (R4–6), also when comparing the separate farming activities (for example rice vs. rice, or onion vs. onion; all pairs with $p<0.0001$, Wilcoxon Rank Sum test) which also coincided with the market change (the arrival of a Collector). The various zones were targeted differently, with most activities undertaken in the Open landscape (Figure 6), despite its lower fertility. Significantly more farming activities were undertaken on the Open landscape compared to the Marshes ($p<0.0001$, Wilcoxon Rank Sum test). Considering the non-land-based activities, the investment in technology also increased during the course of the game (being strongly correlated with monetary variables, i.e., player's gain, investment, and total ownership). In contrast, the investment in Quality of Life parameters declined until R4, before rising again. Housing improved during the game, being associated with gain (all investments are detailed in Figure 5).

In the RPG, a majority of land-based activities were performed in the Marshes and the Open landscape since the Agriculture zone was already occupied (only allowing for a single activity per player and game round). In this context, landscape change was the sum of agricultural activities in the Marshes and Open landscape (Figure 7). During the first three rounds, the pace of landscape change was slower than during the last three rounds (cf. steeper slopes, mainly for the Open landscape), which implies the Landscape as a whole experienced an increasing speed of transformation, and hence that land conversion into Agriculture zone was increasing.

Globally, those who had more money (a threshold above the median = 5525 $A [game money] in the Personal Cashbox) invested in more than double the amount of total activities (approximately 12) than those who had less money (less than or equal to the median) (approximately 5)—Wilcoxon rank sum test, $p<0.0001$. We found that the cumulative land-type change for R1–3 was significantly lower than for R4–6 for all activities (t-test, all p-values less than 0.002).

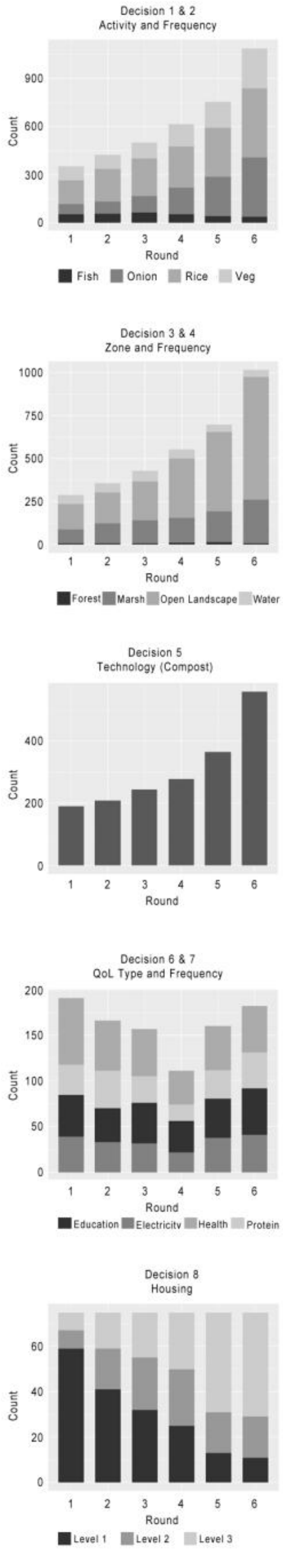

Figure 5. Decision tree. Chain of decisions that a player has to make during a game round. Graph 1: land-based activities such as fishing or onion or vegetable farming; Graph 2: zoning, where in the landscape have been done the land-based activities; Graph 3: How much compost (a proxy for technology) has been used; Graph 4: Quality of life investments, Graph 5: Housing types as proxy for living costs (from 1=basic to 3=high quality).

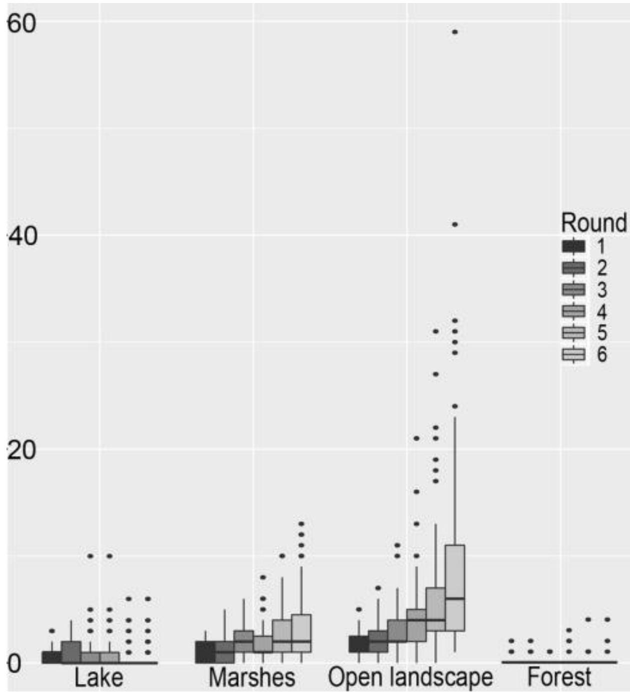

Figure 6. Spatial zoning (x-axis) and frequency of livelihood activities (y-axis). Box and whisker plots for total activities per zone. Testing for differences in median values between rounds using the Wilcoxon Rank sum test (n=75). Agricultural zone is not shown since there was a structural restriction in the game (one activity per player and round) to mimic land titling and occupancy. Significantly more farming activities were performed compared to opportunities (p <0.0001, Wilcoxon Rank Sum test—farming median 6, opportunities median 0), which included Hunting, Mining and Logging (all opportunities in this model are illegal activities).

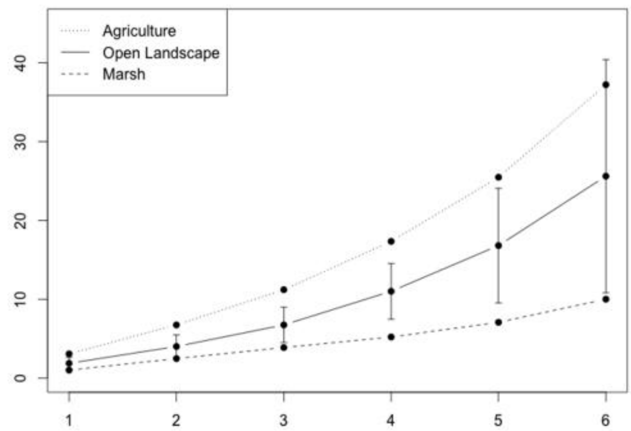

Figure 7. Landscape changes. Slopes of changing land types (Marshes vs Open landscape) and converted land into Agriculture zone (the cumulative curve of Marshes + Open landscape units). We calculated the median for each round (x-axis) of each activity for each RPG game workshop (GW1–7, GW9–16; n=75). Then we calculated cumulative change for each of the 15 games and the slope between each set of rounds for those cumulative change graphs. The slope in this graph was calculated as (y2 - y1)/(x2 - x1), where each set of coordinates comes from the cumulative change plot at each different round. Finally, the mean (and standard deviation for Open landscape) of the slopes over all games was calculated and plotted. We used a t-test for testing between rounds (1–2 vs 2–3, 2–3 vs 3–4, etc.) and found that there is a significant difference in slope: for Agriculture between rounds (1 vs 2) and (2 vs 3) (p-val = 0.04699) and for Open landscape between (2 vs 3) and (3 vs 4) (p-val = 0.01017). The x-axis denotes the rounds; the y-axis shows frequency of activities.

BRIDGING VIRTUAL AND REAL SES. When using RPGs for research, the most important phase of the research starts once the game sessions are accomplished. Debriefings help to bridge game behavior and real life decisions, to identify and discuss similarities and differences and to explain decisions. The importance of this research phase is reflected in the saying that 'the learning starts when the game stops' (Crookall 2010, Garcia et al. 2016). Thus, three questionnaires (one before the gaming session, one right afterwards, and one after two weeks) were administered, covering topics such as gaming behaviour and real-world livelihood strategies, the meaning of markets, and landscape change (Table 1).

After the workshop, the players could take home their Personal Game Sheets with their tracked decisions (while the researchers had tracked all decisions through the Bank, i.e., Microsoft Excel 2010 calculations). We assumed that people continued to think about the game after the workshops. Two weeks later, we conducted detailed face-to-face interviews with all participants in order to further bridge the virtual and real world, i.e., comparing players' decision made in the game with their real-world background.

All phases of our research, from the development of the conceptual model, to the gamification process, and the actual RPG sessions followed the recommendations of ethical code of conduct provided by Wilmé et al. (2016). This also includes obtaining prior informed consent from each participant, and assuring anonymity and confidentiality. A general feedback from our research participants of the game workshops (including the game development workshops) was that they appreciated a platform where they were able to discuss their real life issues revolving around agricultural development, livelihood concerns, and conservation and environmental values, without having to fear consequences from the authorities.

DISCUSSION

This study describes the tool development process of a serious role-playing game (RPG), which served to explore rural resource users' land use decisions and related impacts on land type changes in the Alaotra region in Madagascar. The research is placed in a common pool resource context (sensu Ostrom 2009) where a continuously growing human population in a finite landscape strives for increased food security, and a minimum level of well-being and quality of life (Rendigs et al. 2015). In such a world, the interactions within the social system and the ecological systems become increasingly complex. The RPG model represents and combines the most important components of the social system (Farmers/Fishers, Market, Collector, Bank) and the ecological system (spatial zones such as Lake, Marshes, Open Landscape, Forest; but also the Fish stock) in order to explore resource users' livelihood decisions. The majority of stakeholders involved in the wetland RPG workshops are the regular resource users that directly depend on the land by pursuing activities in agriculture, fisheries, cattle farming and forests. In the real Alaotra SES they are the 'actors of change'. Change at the landscape level is induced by the cumulative decisions of rural resource users. Even if making a chain of spatially and temporally smaller decisions, they transpose and manifest in the form of bigger changes at the landscapes or watershed level. Change here is more than simply the sum of all decisions, since there are linkages and feedback loops in both the ecological and social systems (Le et al. 2012). The gaming approach

Table 1. Exemplary participants' statements collected during the game debriefing sessions on questions concerning land use decisions, reaction to market fluctuations and landscape change. *Baiboho* means 'agriculture zone'; *zetra* means 'marshlands'; *tanety* stands for 'open landscape'. The questions are as follows: Q1: What are your strategies? Did you change them and why? Q2: Did you change your activity after the promotion [market change]? Q3: In the game, what changes do you see on the landscape, looking at all zones? Q4: In reality, what are the changes that you can observe in each zone? Q5: In real life, do you or would you use the zetra if the revenues were high?

Questions	Exemplary answers	
Q1	RPG2, P4.	In reality, I diversify my activities and also use more compost to increase my revenues. I have applied this strategy also here in the game.
	RPG3, P5.	I have increased my activities since the revenues were good and I had cash to invest.
	RPG6, P5.	Though I do not have much education, I use my knowledge on how to fish or plan my activities. Even if the fishing output is getting less and less, I continue to do fishing since I do it in my real life too.
Q2	RPG1, P1:	I have changed to vegetables due to the promotion. But to make sure to survive I have continued investing into other activities as well.
	RPG2, P2.	I have changed my activities, since everybody else in the game did. Also, the promotion made me invest more into vegetables.
	RPG2, P1.	I do always rice; just a little bit of vegetables. The promotion does not always bring good things, so I better stuck to rice, and increase rice activities, and I was right; I had more revenues.
	RPG5, P5.	In real life, I do everything, even if I do not know how to do, but I do an effort, and if I see that it brings good revenues then I continue.
Q3	RPG1, P2.	The majority of people practice the counter season rice [in the marshes], since it brings more cash in comparison to the other zones, and since in the *baiboho* there is not enough space for more than one activity, and the *tanety* is not as productive.
	RPG1, P2.	In the game, because we all did fishing, the lake is full of fish tokens, and the revenue is little; but we all need to survive.
Q4	RPG3, P5.	The *tanety* is affected by fires, and baiboho is becoming sandier due to erosion, which also progresses the destruction of the zetra. The fish stock is decreasing due to increased numbers of fishers and illicit fishing.
	RPG4, P1.	Cultivation on *tanety* is decreasing due to infertility of the soils and because it is still difficult to use *kibota* [tractor] on *tanety*. Hence, people push into *zetra* for cultivation; also it is still very humid and good growing conditions. We do use *zetra* to feed our families.
	RPG7, P3.	The total destruction of the environment due to human overexploitation; also climate change is affecting the water balance.
	RPG11, P3.	The human population is increasing continuously. People need more land, hence the *zetra* is disappearing. People are not aware or do not think of consequences and do not protect the *zetra*.
Q5	RPG1, P4.	In reality, I don't do activities in the *zetra* because if there is rain it floods my fields, and I would lose everything.
	RPG3, P4.	We would like to use the *zetra*, but I won't do it because it requires quite some effort and material; also, it means destroying the *zetra* and our lives are then endangered. Also, I still have enough land for agricultural production, and I prefer to improve the per unit output there.
	RPG6, P4.	It is our goal to become rich; hence I continue to increase my activities, even in the *zetra* if needed.
	RPG7, P2.	This depends on the law. If it was not illegal, then I'd do it.

allows players to experience these individual and up-scaled changes by tracking them on their Personal Game Sheets and the common game board, i.e., the Landscape.

It is important to note that the wetland RPG and the players' decisions do not necessarily mirror reality, but allow the researchers to observe the participants' decision making during the games and to use it as an entry point for discussion and reflection. The debriefing sessions after the gaming are hence the crucial part, as they allow to make comparisons between game behaviour and real life, and to reveal motivations or values that determine decisions in everyday life. Our results show that the majority of participants have played the game as they act in real life. Still, some mentioned that they fished or cultivated vegetables even though they do not do so in real life; congruency of game behaviour and real life ranged between 50 and 100%. Interestingly, while some players kept doing the same activities during the whole game session, others tried different strategies and reacted to market change or neighbours' successful strategies. Independent from external circumstances, a majority would always continue to cultivate rice (or others fishing) because it is central to both their culture and livelihood. Players reacted differently to this whole system perspective; for example, once players realized that the fish stocks were collapsing, some started shifting their activities towards more agriculture, while others went on as before. The latter did so because for them "fishing is part of our culture"; or, because "fishing is a quality of life". A majority of players invested into rice activities, because "it is the staple food of the Malagasy", or because "it is our habit", reflecting the central aspect of the real SES. Players noted that both in the game as well as in reality, fisheries output decrease due to increasing numbers of fishermen and resulting overexploitation. They also acknowledged the increasing occupation of the grasslands and marshes for agricultural activities (see also Ratsimbazafy et al. 2013). They referred to increasing population numbers and decreasing output per unit as being the reasons for the ongoing agricultural extensification.

The exemplary debriefing statements reveal different strategies of the players. In the game, as well as in reality, some stick to the activities they have been doing for years. They thus do not react to change or externalities, and continue with their traditional land uses, regardless of the external conditions. In opposition, some players/ resource users tried out different options and continued with the most successful or promising ones; similarly, in real life, they adapt quickly to change and know to use and potentially benefit from opportunities, sometimes by taking risks; they are responsive to market change and adapt their activities quickly and accordingly. Some players observe others' strategies and implement them once they see their success. Study participants acknowledged the changes occurring in the Alaotra landscape. With increasing population pressures (both population growth and migration) and decreasing outputs in agriculture and fisheries, people are in search for (easily accessible) alternatives. While some acknowledged the ecological importance of the marshes for ecosystem functioning, or would not touch the marshes because they are legally protected, others do already use them to increase their income. It is suggested that with increasing pressures on peoples' livelihoods, more and more individuals will decide to transform marshland to expand their fields for better agricultural output.

The game behaviour and corresponding debriefing answers also showed that the more cash was available in the SES, the more investment into farming activities were undertaken. In contrast, Quality of Life parameters did not follow this pattern. Further analysis is needed to clarify whether this indicates a prioritization of physical and financial capital above human and social capital, or whether this behaviour resulted from game design (e.g., in contrast to Housing, there were no different levels achievable for the QoL parameters). Players scarcely used opportunity activities since the risk of paying a fine was judged as being too high. In addition, players generally performed few activities solely in the forests as these, in reality, are too far away from their daily working space. Vicinity to, or contact to, resources matters, as shown in two studies in the region where attitudes and perceptions of resource users towards lemurs and the special conservation zone Park Bandro changed with distance (Reibelt et al. 2017, Waeber et al. 2017). These patterns were also confirmed during the debriefing discussions. An interesting finding is that the more money there is in the virtual SES, the faster the landscape is transformed (in the game, this was through increased investments into agricultural activities). During the debriefings, players also stated that if they had more money in real life they would have many more fields of onion or rice for productions, herewith referring to extensification of farming. However, in the game participants would also invest into better technology to increase their production output, which refers to agricultural intensification. In the real SES, however, both options are hampered: the best arable land is already occupied and space within a legal context is already scarce, while farmers barely have the means to invest into better agricultural technologies. What participants also wish for is more governmental support to inform them about new technologies.

After the third gaming round, with the arrival of the Collector (i.e., market change through the promotion of vegetables or onions), a significant shift in agricultural activities appeared. Many participants stated that they used Round 1 of the game as a learning process, and then started to strategize their activities, which again were mainly prompted by real-life experiences and backgrounds. Participants stated that they followed the Collector because they were either curious, or they needed to change their activities to earn more income, thus taking a risk; while others changed because they observed and followed other players' success. Such debriefing statements allow the identification of stakeholders' management strategies, which have the potential to inform policy decisions for an increased resilience of the agricultural sector.

Such information is urgently needed, since increased drought periods and decreasing output further put pressure on farmers and the rural population alike, who directly depend on rice. In addition, the political instability at the national level has caused an increase in market prices for the staple food rice (Randrianja 2012). The holistic approach pursued in the RPG and the results obtained allow the support of cross-sectorial and trans-boundary decision support and policy making. The regional governing institutions (e.g., Ministry of Environment, Ecology and Forest, Ministry of Agriculture, Ministry of Fisheries) can take the main actors' behavioural response into consideration but also farmers' different levels of vulnerability to changes for future management plans and thus increase the resilience of the socio-ecological system of the Alaotra region. As stated in the modified Environmental Charter (Loi n°2015-003), one of the objectives, inter alia, is to "(…) reconcile the people with their natural environment…for a sustainable development…through a green economy". Hence, policies need to take into consideration which types of activities are performed within which type of ecosystem. Changes potentially bear transition costs (North and Wallis 1994); in the Alaotra context, change or outside forces are also steering the farmers to change their livelihood strategies (Copsey et al. 2009a, b, but see also Waeber and Wilmé 2013). This often comes at the cost of biodiversity. In order to make the SES more resilient, policy making needs to create a framework that allows the buffering of market changes, which oftentimes are instilled by political changes at the uber-regional level. In the Alaotra, current trends, also shown in the RPG, indicate a clear 'bias' towards rice. System resilience in this context means allowing the future of the Alaotra SES to change trajectory and shift towards a scenario of more 'ecological agriculture', which should favour the introduction of agricultural intensification over current extensification trends, allowing space for biodiversity.

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SUPPLEMENTARY MATERIAL

Available online only.

- S0. General explanations on how to use the provided extra material to play the Alaotra Wetland Game.
- S1. Input parameters and calculation worksheets for running scenario 1 of the Alaotra Wetland Game.
- S2. Landscape.
- S3. Personal Game Sheet.
- S4. Market items: Farming (Rice, Onion, Vegetable).
- S5. Market items: Fishing and Housing.
- S6. Market items: Opportunities (Mining, Logging, Hunting).
- S7. Market items: Quality of Life (Education, Health, Proteins, Electricity).
- S8. Money.

ARTICLE

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Useful plants in the Park Bandro and its surroundings, Lake Alaotra, Madagascar

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ABSTRACT

Traditional use of plants constitutes an important activity in Malagasy life, especially in the countryside. The Sihanaka group is found in the east of Lake Alaotra and is the dominant cultural group in the lake region, including in the Fokontany of Andreba Gara, near Park Bandro, in the east of Lake Alaotra, in Ambatondrazaka district where the study was conducted. The Sihanaka holds traditional knowledge on plant uses and makes use of this knowledge in their daily lives. The objective of this study was to describe the use of aquatic plants in the region to better understand the importance of the Alaotra wetlands in the lives of local people. Surveys conducted among the people of Andreba, including one traditional chief (the Tangalamena) and one healer, revealed 55 useful species of aquatic plants, grouped into 41 genera and 23 families. Most species were used for their medicinal and veterinary virtues (32 species), for animal food (17 species), as utensils and tools (16 species), for cultural uses (10 species), and for human food (9 species). Leaves (76%) are the most exploited plant parts. The species with the most uses were *Cyperus papyrus* subsp. *madagascariensis* (Willd.) Kük. with 26 types of use recorded, then *Phragmites australis* (Cav.) Trin. ex Steud. (19 types of use), *Aeschynomene elaphroxylon* (Guill. & Perr.) Taub. and *Eichhornia crassipes* (Mart.) Solms (12 types of use each). *Nymphaea nouchali*, *Cyperus papyrus* subsp. *madagascariensis* and *Phragmites australis* were the species most frequently cited by informants, indicating that they are important for the local population. The most frequently cited types of use included *joro*, namely ancestor's invocation, food, materials for house walls construction, herbal teas to treat ailments, and fencing or demarcation of land boundaries. This study highlighted the importance of the Alaotra wetlands as a source of useful plants for the local population. Sustainable management of Lake Alaotra is therefore not just necessary for biodiversity conservation, but also for maintaining local livelihoods.

RÉSUMÉ

L'utilisation traditionnelle des plantes constitue une activité importante dans la vie des Malgaches, plus particulièrement dans les campagnes. Le groupe Sihanaka est rencontré à l'est du lac Alaotra et constitue le groupe culturel dominant dans la région du lac, y compris dans le Fokontany d'Andreba Gara, près du Parc Bandro, à l'Est du Lac Alaotra, dans le district d'Ambatondrazaka où l'étude a été menée. Les Sihanaka détiennent des connaissances traditionnelles sur l'utilisation des plantes et utilisent ces connaissances dans leur vie quotidienne. L'objectif de cette étude était de décrire l'utilisation des plantes aquatiques dans la région afin de mieux comprendre l'importance des zones humides de l'Alaotra dans la vie des populations locales. Des enquêtes menées auprès de la population d'Andreba, y compris auprès d'un chef traditionnel (le *Tangalamena*) et d'un guérisseur, ont révélé 55 espèces utiles de plantes aquatiques, regroupées dans 41 genres et 23 familles. La plupart des espèces étaient utilisées pour leurs vertus médicinales et vétérinaires (32 espèces), pour l'alimentation des animaux (17 espèces), en tant qu'ustensiles et outils (16 espèces), pour des usages culturels (10 espèces) et pour l'alimentation humaine (9 espèces). Les feuilles (76%) sont les parties de plante les plus exploitées. Les espèces ayant le plus d'utilisations étaient *Cyperus papyrus* subsp. *madagascariensis* (Willd.) Kük. avec 26 types d'utilisation recensés, puis *Phragmites australis* (Cav.) Trin. ex Steud. (19 types d'utilisation), *Aeschynomene elaphroxylon* (Guill. & Perr.) Taub. et *Eichhornia crassipes* (Mart.) Solms (12 types d'utilisation chacune). *Nymphaea nouchali*, *Cyperus papyrus* subsp. *madagascariensis* et *Phragmites australis* étaient les espèces les plus fréquemment citées par les informateurs, ce qui indique qu'elles sont importantes pour la population locale. Les types d'utilisation les plus fréquemment cités comprenaient le *joro* à savoir l'invocation des ancêtres, l'alimentation, les matériaux pour la construction des murs, les tisanes pour traiter les maladies et la construction de clôtures ou démarcation des limites de terrains. Cette étude a souligné l'importance des zones humides de l'Alaotra en tant que source de plantes utiles pour la population locale. La gestion durable du lac Alaotra n'est donc pas seulement nécessaire à la conservation de la biodiversité mais également au maintien des moyens de subsistance locaux.

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INTRODUCTION

Madagascar's freshwater wetlands include more than 3000 km of rivers and streams, and about 2000 km² of lakes (Chaperon et al. 1993). Currently, 20 wetlands of international importance are designated as Ramsar sites, including Lake Alaotra which is the largest freshwater lake in Madagascar. Established in 2003, and with a surface area of about 722,500 ha, the Alaotra wetlands are Madagascar's third Ramsar site after the Complexe des lacs de Manambolomaty and Tsimanampetsotse National Park that were both established in 1998 (Ramsar 2018). Lake Alaotra was officially recognized as a temporary New Protected Area in 2007. In June 2015, the area was designated a new protected area (IUCN Category V) (Waeber et al. 2017) by the Government of Madagascar.

Wetlands are critical for the livelihoods of those living in their vicinity, supporting provisioning services such as domestic water supply, fisheries, livestock grazing, cultivation, construction materials, and wild plants for food and medicinal use (Schuyt and Brander 2004, McCartney et al. 2010, Darwall et al. 2011). Moreover, wetlands support a highly diverse flora and fauna (Darwall et al. 2011). Lake Alaotra has a particularly high socio-economic importance because the surrounding landscape constitutes the largest rice granary in Madagascar, and the lake is well known for fish production (Pidgeon 1996, Andrianandrasana et al. 2005, Ranarijaona 2007, Copsey et al. 2009). In addition, the marshes are traditionally used by the resident population as a source of raw materials for construction, handicrafts, furniture manufacturing, and as hunting and fishing areas (Ramsar 2003, Rendigs et al. 2015). Unfortunately, the burning of marshes, the conversion of marshes to rice fields, and siltation reduced the area of both the marshes and the lake. The lake is very vulnerable to siltation because it is shallow with a maximum depth of just 4 m during the rainy season (Pidgeon 1996). Marshland and its biodiversity is disappearing "in a puff of smoke" with an average of 3000 ha burnt annually between the years 2000 and 2009 (Ratsimbazafy et al. 2013, Rendigs et al. 2015). An extreme year for fires was observed in 2012 with over 159 single fires recorded during the peak drought period, within less than three months (Ratsimbazafy et al. 2013). Further problems include the invasion of non-native plant species, such as the water hyacinth, *Eichhornia crassipes*, and the water ferns *Salvinia molesta* and *Azolla* spp. (Andrianandrasana et al. 2005, Lammers et al. 2015). While changes in plant community composition and structure have been noticed, the knowledge about the lake's flora is incomplete and outdated (Lammers et al. 2015), and biodiversity loss could lead to traditional knowledge loss on plant uses. Documentation on traditional knowledge of aquatic plant uses is as well scarce, even for Madagascar. In addition, as traditional knowledge is transmitted orally from generation to generation, its loss begins to be felt worldwide (Reyes-García et al. 2013). In the light of the prevalent loss and threatened future of this knowledge and cultures, it is currently a common practice for communities to document their knowledge (Maina 2012). This study is as such important because it reports and documents on the traditional knowledge of aquatic plant uses in the Alaotra communities, which largely contributes to prevent the loss of knowledge in this area due to ongoing anthropogenic pressures on the lake and the marshes.

While floristic studies were conducted at Lake Alaotra by Ranarijaona (1999) as part of her study to conceive a typology of Malagasy lentic waters, most of the biological research conducted in the area have been focused on population biology, distribution and behavior of vertebrate species, especially on *Hapalemur alaotrensis* (the Critically Endangered Alaotran gentle lemur), as well as on bird and fish species (Wilmé 1994, Waeber and Hemelrijk 2003, Ralainasolo 2004, Ralainasolo et al. 2006, René de Roland et al. 2009, Guillera-Arroita et al. 2010). Furthermore, almost nothing has been published on the use of marsh and lake plants by the Sihanaka ethnic group, the dominant ethnic group around the Lake, despite their continuing adherence to traditional practices. Past studies only contained sporadic reports of plant uses (Ranarijaona 2007, Lammers et al. 2015, Rakotoarisoa et al. 2015, Rendigs et al. 2015, Rakotoarisoa et al. 2016). While Pidgeon provided a plant inventory already in 1996, the present study is the first with a structured approach for an exhaustive assessment of local plants as well as their respective uses in the Lake Alaotra region.

In Madagascar, the Missouri Botanical Garden (MBG) is an organization working on research and conservation of the Malagasy flora, action that initially focused on terrestrial ecosystems. Since 2010, MBG has given a special interest to wetlands ecosystems and has started inventorying plant species of Malagasy wetland habitats including those from rivers, lakes and marshes. However, there are still many geographical gaps in this inventory. To address the issue, a collaboration with Madagascar Wildlife Conservation (MWC), under the Alaotra Resilience Landscape (AlaReLa) project, was then established to complete information on freshwater plant uses in Lake Alaotra area. This study undertaken following this collaboration has the objectives to (i) inventory plant species occurring in the lake and the marshes, especially in the Park Bandro and its surroundings, and (ii) record ethnobotanical information on the uses of these wetland plants.

METHODS

STUDY SITE. The Alaotra wetlands are located in the Alaotra-Mangoro Region, within Ambatondrazaka and Amparafaravola districts, and about 250 km northeast of Antananarivo. It is a complex ecosystem with a variety of habitats that includes open water, marsh, reed beds (dominated by papyrus, *Cyperus papyrus* subsp. *madagascariensis*, and common reed, *Phragmites australis*), and rice fields (Wallace 2012). The lake itself covers a surface area of some 20,000 ha and it is surrounded by 20,000 ha of marshland and 120,000 ha of rice fields (Mutschler 2003, Reibelt et al. 2017a).

Historically, the first observations on Lake Alaotra at the beginning of the 20th century showed that it had an area of 200,000 ha of which 25,000 ha was lake and the rest marshes (Moreau 1980). The first data on the hydrological regime of the lake and the first accurate bathymetric information were published by Longuefosse (1923). A recent study deduced that the lake once occupied more than 100,000 ha, thus with a present area of just 20,000 ha, the lake is now only 20–30% of its former size (Bakoariniaina et al. 2006). Different studies carried out after Madagascar's independence indicated that the marshes covered an area of 55,000 ha in 1961 (Thérézien 1963), 35,000 ha in 1974 (Moreau 1977), 30,000 ha in 1976 (Moreau 1987), and about 20,000 ha in 1994 (Mutschler and Feistner 1995, Mutschler et al. 1995, Mutschler 2003). Large areas of marshland have also disappeared and the remaining surface area is now considered less than 25% of the original area (Guillera-Arroita et al. 2010). Because of such observations, Moreau (1977) concluded that Lake Alaotra, in its present state, is a mere vestige of a much larger lake which, on the scale of geological time, is about to disappear. However, a more recent study by Mietton et al. (2018: 22) gives conflicting information: "Lake Alaotra has been in existence for at least 30,000 years, with evidence of climatically-driven fluctuations but no evidence of the lake ever being much larger or having occupied the entire floor of the topographic basin". Besides, "(…) the lake was not, unlike some claims to the contrary, threatened by imminent decline" (Ferry et al. 2013, Mietton et al. 2018: 37).

Located at the southeastern shore of the lake (Figure 1), in Ambatondrazaka district, the 85 ha Park Bandro was established as a special conservation zone in 2004 and is now nested within the newly-designated and much larger Lake Alaotra Protected Area (Reibelt et al. 2017a). Recently, the remaining area of marsh within this Park Bandro was estimated as 43 ha (Raveloarimalala and Reibelt 2017). The park was created by the local VOI (*vondron' olona ifotony*, a local community association for natural resource management) from the nearby village of Andreba with support from the conservation organizations Durrell Wildlife Conservation Trust and Madagascar Wildlife Conservation (Reibelt et al. 2017a). The park is of high conservation importance, as it hosts the biggest known subpopulation of *Hapalemur alaotrensis* or bandro (local name), a lemur species that is found only in the Alaotra marshes (IUCN 2014, Reibelt et al. 2017b). The population in Park Bandro was estimated as more than 170 individuals in 2013 but only 40–80 in 2017 (Ratsimbazafy et al. 2013, Raveloarimalala and Reibelt 2017). The park, with the marshes and the rice fields in its surroundings, was chosen to conduct the fieldwork. The study was focused on this small area as it is less affected by fire and human impact, thus a place where natural vegetation community likely continue to exist.

We decided to conduct ethnobotanical surveys on plant use by local people in Andreba (S17° 38' 05.1", E048° 30' 25.3", 765 m)

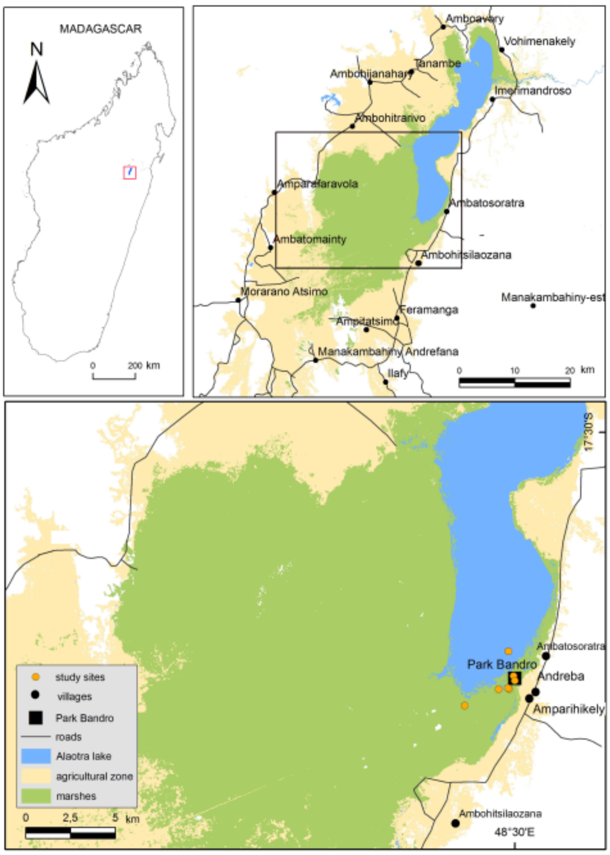

Figure 1. Location of the Park Bandro and the study sites.

because this is the closest village to Park Bandro, and its population depends on the lake and its marshes for their livelihoods. Like all the villages surrounding Lake Alaotra, the ca. 5000 inhabitants of Andreba rely primarily on rice cultivation and fishing as a source of income (Rakotoarisoa et al. 2015). They also use plant species in the marsh and its surroundings to get raw materials, for example, for construction, handicrafts and even to treat diseases (Rendigs et al 2015).

ETHNOBOTANICAL SURVEYS. Fieldwork was conducted in December 2016 and January 2017, a period when most flowering plants are fertile. Surveys were conducted with 30 informants from Andreba village including key informants (someone who has a profound knowledge on plant uses) such as one *tangalamena*, the traditional chief of the village, and one traditional healer called *reninjaza*. Two members of the local VOI served us as guides during the surveys and helped us to identify the participants who were likely knowledgeable about plants and their uses.

Free listing and semi-structured interviews (Martin 1995, Alexiades 1996, Gerique 2006) were carried out with informants to record information on useful plants, such as vernacular names, plant uses and plant part used, and in-depth interviews were held with the two key informants for more information. The free listing method consists on asking informants to list useful plants they know with their uses. Semi-structured interviews consist of a series of general questions that are used as a guide for the interview topics; it is more flexible than structured interviews, as it allows other questions than the pre-defined ones to be raised and answered. Most important questions ask which plants the informant takes from Lake Alaotra and its surroundings and for what purpose, what plants are collected for cultural uses, and which ones are used for healing? As techniques of inquiry, individual and group interviews, artifact interview, plant interview and field interview were performed (Alexiades 1996, Gerique 2006). In addition to individual interviews, group interviews were conducted based on the assumption that some people will be more willing to share their knowledge in a group environment (Gerique 2006). Artifact interview consists on asking informants about the plants, which were employed in the manufacture or preparation of particular items like baskets or tools. Plant interview consists on collecting plants in the field, bringing them back to the village and present them to informants. Field interview consists on walking in the Park Bandro and its surroundings with the two local guides and asking them about plants and their uses while collecting them.

For ethical consideration, prior informed consent was asked for from all participants before each interview in the respect of the Nagoya Protocol on access to genetic resources and fair and equitable sharing of benefits arising from their use (Secretariat of the Convention on Biological Diversity 2011). The proposal for ethical research conduct in Madagascar was also followed during the study (Wilmé et al. 2016).

Types of plant use were categorized using the classification established by Cámara-Leret et al. (2012). It is a standard protocol used for gathering ethnobotanical data on palms, but was used in this study as it describes more details on different types of plant use within ten use-categories which are 'animal food', 'construction', 'cultural uses', 'environmental uses', 'fuel', 'human food', 'medicinal and veterinary', 'toxic', 'utensils and tools', and 'other uses' not covered by the previous categories. Vouchers herbarium specimens of each of the plant species cited by informants were collected to enable scientific identification. Plant identification consists on using dichotomous keys for many diagnostic features and on comparing the voucher specimens with properly identified herbarium specimens. General botanical inventory was also conducted using this method. All vouchers were collected in replicate and specimens deposited at the national herbarium (known by the acronym TAN) and the two international herbaria with large botanical collections from Madagascar at Missouri Botanical Garden (MO) and the Muséum national d'Histoire naturelle (P). Digital images of plant species were also taken during the fieldwork. Those species for which voucher herbarium specimens could not be made during our fieldwork were identified using images provided by the staff of the Madagascar Wildlife Conservation. Coordinates of the collection locations were taken and are shown on the map in Figure 1.

Data analysis was performed by using Anthropac® 1.0 (Borgatti 1996), a qualitative data analysis software to evaluate the degree of knowledge of a domain by the informant. The results were expressed as frequency of citation (%) and salience (a value that lies between 0 and 1) (Borgatti 1999, Quinlan 2005). Frequency is considered as the repetition of citations during the surveys, in which one specific use of one plant part of one species by one informant is counted as one citation. Salience is a statistic accounting for rank and frequency of species citation in which one species is considered more salient when it appears more often and earlier in freelists. In this study, the most frequent and most salient species were considered most important for the local population. Statistical analysis using Mann-Whitney U test at alpha 0.05 was used to assess the difference of knowledge between men and women.

RESULTS

INFORMANTS' KNOWLEDGE. In total, 30 informants were interviewed. Of these, 15 were women and 15 were men, ageing from 22 to 84 years old. They are all farmers, especially rice cultivators, but some (7%) also practice fisheries and weaving. In general, informants were assumed to get knowledge on plant uses because they were used to life in the lake and marshes, but they may also inherit it from their parents or relatives.

A total of 84 aquatic plant species were recorded during the study. They are grouped into 60 genera and 29 plant families. Sixty-eight of them, belonging to 47 genera and 23 families, were collected in the field with vouchers. For the remaining, 14 were identified using images except for two species of *Ipomoea* L. that we did not find during the floristic inventory of Park Bandro and its surroundings.

A total of 55 species, belonging to 23 families and 41 genera, were cited as useful by the local population. Most of them (87%) are herbs, with the remaining species including five liana species, one shrub and one tree. Two species (*Emilia citrina* DC. and *Zehneria rutenbergiana* (Cogn.) Keraudren) were endemics, 36 native and 17 naturalized. The most represented plant families were Poaceae with 11 useful species, Cyperaceae (7), and Asteraceae and Fabaceae (five species each). The most representative genus was *Cyperus* L. with five species. The men knew 91% of the 55 useful plants recorded while the women knew 58% (Table 1). On average, men cited 9 species (± 1.4 standard error SE) and 13 types of uses (± 2.6 SE) per informant while women cited respectively 7 (± 1.2 SE) and 10 (± 1.8 SE). There was no significant difference of knowledge between the two genders for both the number of plant species cited as being useful and the plant uses recorded with $p>0.05$ each.

Within the age categories, informants in the age class 51 to 60 years cited on average 12 species (± 2.9 SE) and 19 types of uses (± 4.2 SE) per informant more than the others.

PLANT USES. For the 55 useful plant species, about 115 types of uses were recorded within eight major use-categories as defined by Cámara-Leret et al. (2012). Most species were recorded in the category 'medicinal and veterinary' (32 species), followed by 'animal food' (17), 'utensils and tools' (16), 'cultural uses' (10), 'human food' (9), 'construction' (6), 'fuel' (4) and 'environmental uses' (3) (Supplementary Material). An analysis of the data obtained from free listing highlighted 13 species of greatest importance for the local population with a frequency of citation (FC) higher than 25%, with number of uses varying from 5 to 26 (Table 2). The most important were *Nymphaea nouchali* Burm. f., *Cyperus papyrus* subsp. *madagascariensis* (Willd.) Kük., *Phragmites australis* (Cav.) Trin. ex Steud. and *Ethulia conyzoides* L. f. with FC > 50%. *Nymphaea nouchali* was the most frequent as well as the most salient species cited because it is mostly used by the local population. Leaves (76%) were the most important plant part used.

Regarding the types of use, the most frequently cited were *joro* or ancestors' invocation (FC = 63%), food (FC = 57%), house walls, herbal teas and fences or demarcation of land boundaries (FC = 50% each). The use of aquatic plants to produce mats had an FC of 40%. Six species were used as part of various ceremonies to invoke ancestors (e.g., circumcision, house building, marriage), of which *Cyperus papyrus* subsp. *madagascariensis* (FC = 90%) and *Nymphaea nouchali* (FC = 84%) were the most important.

Among the six species having at least 10 different uses (Table 2), *Cyperus papyrus* subsp. *madagascariensis* and *Phragmites australis* (the most used species) were among those used in the top ten uses (Table 3). They were both mainly cited for construction

Table 1. Informants' knowledge in Andreba village according to gender and age categories.

		Total number of people interviewed	Total of species recorded	Average number of species cited per informant (min-max)	Total of plant uses recorded	Average number of plant uses cited per informant (min-max)
Gender	Men	15	50	9 (3-19)	90	13 (2-37)
	Women	15	32	7 (1-19)	69	10 (1-24)
Age categories	[20-30]	4	14	4 (2-8)	11	4 (2-8)
	[31-40]	4	29	9 (1-19)	36	10 (1-20)
	[41-50]	7	15	6 (2-8)	38	9 (6-13)
	[51-60]	5	31	12 (6-19)	55	19 (8-31)
	[61-70]	5	26	9 (3-14)	44	13 (5-23)
	[71 +]	5	20	8 (5-16)	49	14 (2-37)

Table 2. Species mostly used by the local population of Andreba.

Family	Scientific name	Vernacular names	Frequency (%)	Salience	Number of uses
Nymphaeaceae	*Nymphaea nouchali* Burm. f.	Betsimihilana, tatamo, voahirana	70	0.33	6
Cyperaceae	*Cyperus papyrus* subsp. *madagascariensis* (Willd.) Kük.	Zozoro	67	0.22	26
Poaceae	*Phragmites australis* (Cav.) Trin. ex Steud.	Bararata	60	0.32	19
Asteraceae	*Ethulia conyzoides* L. f.	Revaka, Revaka mena	57	0.31	8
Convolvulaceae	*Cuscuta campestris* Yunck.	Tsihitafototra	47	0.19	10
Lamiaceae	*Pycnostachys coerulea* Hook.	Mihorondoa, Revaka fotsy	40	0.27	5
Onagraceae	*Ludwigia adscendens* subsp. *diffusa* (Forssk.) P.H. Raven	Bonaka	33	0.17	8
Cyperaceae	*Cyperus latifolius* Poir.	Vendrana	33	0.13	10
Molluginaceae	*Glinus oppositifolius* (L.) Aug. DC.	Anamafaitra	30	0.12	6
Fabaceae	*Aeschynomene elaphroxylon* (Guill. & Perr.) Taub.	Dofonga	30	0.10	12
Pontederiaceae	*Eichhornia crassipes* (Mart.) Solms	Tsikafona	30	0.10	12
Onagraceae	*Ludwigia octovalvis* (Jacq.) P.H. Raven	Felangoaka, hazomena	30	0.09	9
Araceae	*Typhonodorum lindleyanum* Schott	Viha	27	0.08	6

(FC = 75% each). A comparison of the uses of the two species showed that both species were used to invoke ancestors, for fence construction and for house walls whereas *Cyperus papyrus* subsp. *madagascariensis* alone was used for food and mat and basket weaving, and *Phragmites australis* alone was used for roof supports. *Cyperus papyrus* subsp. *madagascariensis* was one of the three most cited species (with *Cyperus latifolius* Poir. and *Eichhornia crassipes* (Mart.) Solms) used in basketry. For the other species, *Cyperus latifolius* is used to make roofs. *Aeschynomene elaphroxylon* (Guill. & Perr.) Taub. was not used for any of the top 10 uses as it was mainly used to make artisanal chairs and some toys for children.

In terms of medicinal plants, 32 species recorded were used for human medicine providing 44 different treatments. Only one species, *Gomphocarpus fruticosus* (L.) W.T. Aiton, was used both for human and animal medicine. Frequently cited medicinal plants included *Ethulia conyzoides* (FC = 61%), *Cuscuta campestris* Yunck. (FC = 46%) and *Pycnostachys coerulea* Hook. (FC = 43%). They were mainly administered as herbal teas, and used to treat colic and stomach ache.

For the other uses, *Eichhornia crassipes* (FC = 42%) was mostly cited being useful as fodder, especially for pigs. *Nymphaea nouchali* (FC = 63%), *Glinus oppositifolius* (L.) Aug. DC. (FC = 47%) and *Typhonodorum lindleyanum* Schott (FC = 42%) were mainly cited as human food, of which tubers, leaves and seeds respectively were the part consumed. *Aeschynomene elaphroxylon*, *Cyperus papyrus* subsp. *madagascariensis* and *Phragmites australis* can serve as fuel, and *Eichhornia crassipes* was sometimes used to make charcoal. The three species known to be invasive in wetland ecosystems, *Azolla pinnata* R. Br., *Eichhornia crassipes*, *Salvinia molesta* D.S. Mitch., were all used to make compost.

DISCUSSION

In terms of plant inventory, the number of plant species recorded for Lake Alaotra varies from 22 to 84 depending on the type of study and methods applied. Pidgeon (1996) first recorded 23 species. Three years later, Ranarijaona (1999) inventoried 42 species, and about eight years later, recorded only 35 out of the 42 that the author assumed to be present in the area (Ranarijaona 2007). Recently, only 22 species were recorded by Lammers et al. in 2015 and 33 two years later (Lammers et al. 2017). But no plant lists were provided by Pidgeon (1996), Ranarijaona (2007) and Lammers et al. (2015).

In comparison to Ranarijaona's (1999) and Lammers et al.'s (2017) plant lists, our results presented a high number of plant species recorded (84) for the lake and the wetlands in its surroundings (marshes and rice fields). The comparison of the

Table 3. Species recorded for the top ten uses cited by the informants.

Plant uses	Frequency (%)	Salience	Species used
Joro or ancestors' invocation	63	0.30	*Azolla pinnata* R. Br., *Commelina madagascarica* C.B. Clarke, *Cyperus papyrus* subsp. *madagascariensis* (Willd.) Kük., *Hydrocotyle bonariensis* Lam., *Nymphaea nouchali* Burm. f., *Phragmites australis* (Cav.) Trin. ex Steud. *Alternanthera sessilis* (L.) *R. Br. ex* DC., *Cyperus latifolius* Poir., *Cyperus papyrus* subsp. *madagascariensis* (Willd.)
Food	57	0.20	Kük., *Glinus oppositifolius* (L.) Aug. DC., *Grangea lyrata* (DC.) Fayed, *Ipomoea aquatica* Forssk., *Ipomoea* sp.1 L., *Nymphaea nouchali* Burm. f., *Typhonodorum lindleyanum* Schott *Cyperus papyrus* subsp. *madagascariensis* (Willd.) Kük., *Phragmites australis* (Cav.) Trin. ex Steud.
House walls	50	0.38	*Cuscuta campestris* Yunck., *Ethulia conyzoides* L. f., *Glinus oppositifolius* (L.) Aug. DC., *Pycnostachys coerulea*
Herbal teas	50	0.34	Hook. *Cyperus papyrus* subsp. *madagascariensis* (Willd.) Kük., *Phragmites australis* (Cav.) Trin. ex Steud.
Fences or land boundaries	50	0.32	*Cyperus latifolius* Poir., *Cyperus papyrus* subsp. *madagascariensis* (Willd.) Kük., *Eichhornia crassipes* (Mart.)
Mats	40	0.29	Solms *Ethulia conyzoides* L. f., *Ludwigia octovalvis* (Jacq.) P.H. Raven, *Parthenium hysterophorus* L., *Pycnostachys*
Colic	37	0.16	*coerulea* Hook. *Eichhornia crassipes* (Mart.) Solms, *Ludwigia adscendens* subsp. *diffusa* (Forssk.) P.H. Raven, *Nymphaea*
Fodder for pigs	33	0.09	*nouchali* Burm. f., *Typhonodorum lindleyanum* Schott *Phragmites australis* (Cav.) Trin. ex Steud.
Roof supports	30	0.23	*Cyperus latifolius* Poir., *Cyperus papyrus* subsp. *madagascariensis* (Willd.) Kük., *Eichhornia crassipes* (Mart.)
Baskets	27	0.13	Solms

three lists showed that 22 species (about half of that of Ranarijaona (1999)) were shared with Ranarijaona's (1999) list and 20 with Lammers et al.'s (2015). This means that in comparison to the two studies we recorded 53 species from this site for the first time. This difference may be due to the methods used by each author. For example, transects were used by Ranarijaona (1999) for vegetation typology and plant inventories while Lammers et al. (2015) employed plots of 100 m2 to evaluate the habitat quality inside and outside of the Park Bandro. For our study, we aimed to inventory all useful plants in the lake and its wetlands, but in addition we endeavored to identify all flowering and/or fruiting plants encountered at the study site, whether or not they were cited as useful by the informants. Local guides helped us to conduct the inventory allowing us to maximize the number of plants encountered. However, we did not find some of the species that Ranarijaona (1999) and Lammers et al. (2017) had recorded during their inventories, which totals 31 species. Some of those species might not have been fertile during our field period, but others could only be missed in the collection locations where we did the inventories. The combination of our plant list with Ranarijaona's (1999) and Lammers et al.'s (2017) lists would give a total number of 115 plant species for Lake Alaotra and its wetlands, i.e., near 34% of the 338 aquatic and semi-aquatic plant species known for Madagascar based on the bibliographical study made by Ranarijaona (1999) and 24% of the 489 species recently assessed by the Missouri Botanical Garden. Thus, Lake Alaotra retains a diverse flora that deserves conservation not only because of its importance to local people but also as a resource for scientific research, for example, for ethnobotanical studies. Compared with other wetlands in Madagascar, Lake Alaotra always has the highest plant biodiversity richness with 42 plant species recorded in 1999 (Ranarijaona 1999: 110) and 115 species estimated in this study. The loss of such diversity may lead to the loss of traditional knowledge on plant uses, a phenomenon that has already been observed worldwide (Reyes-García et al. 2013). Furthermore, the loss of Lake Alaotra plant diversity could indeed lead to the loss of its unique lemur's habitats and thus the loss of Madagascar's biodiversity patrimony, which makes it one of the most important Ramsar sites.

Several other authors have commented on the use of Lake Alaotra's plants by the local community. According to this study, *Cyperus papyrus* subsp. *madagascariensis* and *Phragmites australis* were the most used plants because in addition to being dominant species in the marshland, they were used for constructing houses, fences, animal shelters, handicrafts, fish traps as well as during traditional ceremonies. Ranarijaona (2007) noted the importance of *Cyperus papyrus* subsp. *madagascariensis* and *Cyperus latifolius* as raw materials for mat and basket weaving, while Rendigs et al. (2015) reported their uses for construction purposes and handicrafts. However, it has been recently observed that the current exploitation of *Cyperus papyrus* subsp. *madagascariensis* in the region contributes to pressures causing a reduction in Lake Alaotra's wetlands and notably decreases habitat and food resources for the Alaotran gentle lemur. Rakotoarisoa et al. (2016) evaluated the use of *Eichhornia crassipes*, one of the "100 worst invasive alien species" (Lowe et al. 2000) and among the 10 most troublesome floating weeds of the world (Lancar and Krake 2002), as an alternative source of raw materials for handicrafts. Rendigs et al. (2015) also reported the use of *Nymphaea nouchali* in traditional ceremonies and *Ethulia conyzoides* and *Cuscuta campestris* as medicine. Ranarijaona (2007) reported the importance of aquatic plants for medicine.

Apart from the utility of the plants growing in Alaotra's wetlands, Rendigs et al. (2015) and Waeber et al. (2017) noted the importance of Alaotra marshland in providing a range of important ecosystem services to the communities of adjacent villages. Unfortunately, continuous anthropogenic pressures on Alaotra wetlands are altering both the water body and the associated vegetation, leading to the formation of new plant communities in the fringe area of the marsh belt characterized by fast growing species like *Ludwigia adscendens* subsp. *diffusa* (Forssk.) P.H. Raven and *Echinochloa pyramidalis* (Lam.) Hitchc. & Chase (Lammers et al. 2015). Such changes will lead for some plant species, including some useful plants becoming increasingly rare or maybe even locally extinct. For example, *Cyperus latifolius* was not found during our exploration in the marsh, and now occurs only rarely outside the study site. Furthermore, the spread of invasive and disturbance-tolerant alien species (e.g., *Azolla pinnata*, *Eichhornia crassipes*, *Salvinia molesta*) represents a major threat to native freshwater plants, ecosystems and local livelihoods (Rakotoarisoa et al. 2015, Rendigs et al. 2015). In addition, relationship between biodiversity, traditional practices and traditional knowledge is also evident, which should be considered in any future management plans in order to preserve its biodiversity and cultural values.

CONCLUSION

Alaotra marshlands are important for supporting local livelihoods and providing crucial ecosystem services for the local population, thus also contributing to the area's cultural heritage. Our study emphasizes the important relationship between Alaotra's plants and local people. Plant species used by the riparian population are mainly collected in the lake and its surroundings, and are used in a variety of ways including traditional ceremonies, medicine, construction, weaving, and even for livestock. Fifty-five plant species out of the 84 recorded during the study were revealed to be useful. Unfortunately, continuous human pressures are impacting the area's flora and are leading to the increasing rarity of some important useful species. While the current benefits of aquatic plants are significant and far-reaching, new uses may be discovered in the future. As some species become rare, it is likely that traditional knowledge of their plant use will also be eroded and perhaps lost. Such loss of traditional knowledge on plant uses has been observed in many regions in the world. Accordingly, strategies for long term sustainable management of freshwater wetlands are required taking into account to their ecological functions and the goods and services they provide, and further documentation of traditional knowledge concerning aquatic plant uses is necessary to ensure that it is captured before it is lost.

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SUPPLEMENTARY MATERIAL

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Analysis of wetland uses by Common mynas (*Acridotheres tristis*) in the urban environment of Antananarivo, Madagascar

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ABSTRACT
The importance of wetlands as habitat and breeding grounds for waterfowls is recognized and has been extensively studied, but their role in regulating and maintaining ecosystems is less well documented. The use of wetlands by invasive species such as Common myna (*Acridotheres tristis*), considered as one of the 100 worst invasive species in the world, is largely unknown. Therefore, the Common mynas could have an influence on the occupation of native water bird species. The objectives of this study were to assess Common myna's (1) population size, (2) spatial occupation and (3) characteristics of foraging and roosting sites. Three urban wetlands in Antananarivo were studied: the Tsarasaotra Park, a private site classified as a Ramsar site, the Tsimbazaza Zoological and Botanical Park in the city center, and an area near the Ikopa River, close to the SOCOBIS biscuit factory. In total, 6196 Common mynas were counted with an estimated 7.9 individuals per hectare around the roosting sites. Vigilance and foraging behaviors were less observed when individuals were at a higher stratum, with communication and resting being the most observed behaviors at this level. Only 5.6% of wetlands are used during the day as foraging areas and 1.4% as roosting sites at night, where Common mynas cohabitate with herons and egrets. Finally, the environmental variables collected revealed that Common mynas favor wetlands with tall, wide trees, located far from human disturbance.

RÉSUMÉ
L'importance des zones humides en tant qu'habitat et site de reproduction pour les oiseaux d'eau est reconnue et a été abondamment étudiée. Cependant, le rôle des oiseaux d'eau dans la régulation et le maintien d'écosystème est moins bien documenté. Particulièrement l'utilisation des zones humides par des espèces envahissantes telles que le Martin triste (*Acridotheres tristis*), une des 100 pires espèces envahissantes dans le monde, reste peu étudiée. Le Martin triste pourrait avoir une influence et un impact par son occupation et son comportement envahissant sur les oiseaux d'eau autochtones. Afin d'évaluer la taille de la population du Martin triste, son utilisation et occupation spatiale, ainsi que les caractéristiques écologiques de ses zones d'alimentation et de dortoir, trois zones humides du milieu urbain d'Antananarivo ont été étudiées. Il s'agit du Parc de Tsarasaotra, un site privé classé RAMSAR, le Parc Zoologique et Botanique de Tsimbazaza dans le centre-ville, et une zone située à proximité de la rivière Ikopa, près de l'usine de fabrication de biscuits SOCOBIS. Un nombre de 6196 observations de Martins tristes ont été réa- lisées et l'abondance des populations a été estimée à 7.9 individus par hectare autour des dortoirs. Les observations ont aussi révélé que le Martin triste réduit certains comportements tels que la vigilance et l'alimentation lorsqu'il est à une hauteur plus élevée et privilégie alors des comportements de communication et de repos. Il utilise 5,6% des zones humides pendant la journée en tant que site de nourrissage et 1,4% pendant la nuit comme dortoir, où il cohabite avec des hérons et des aigrettes. Les varia-bles environnementales récoltées sur les sites ont révélé que le Martin triste privilégie les zones humides situées loin des perturbations humaines et présentant de grands arbres à diamètre important.

INTRODUCTION
Globally, wetlands play an important role in supporting biodiversity (Nummi et al. 2013) and harboring large populations of birds (Mitchell 1992, Dugan 1993, Razafimanjato et al. 2015). Unfortunately, wetlands remain among the most threatened ecosystems in the world (Secrétariat de la Convention de Ramsar 2013) and their destruction is likely to continue (Chari et al. 2003, Fraser and Keddy 2005). Drainage, dewatering, pollution and overexploitation of resources are the most common threats (Sécretariat de la Convention de Ramsar 2013) and cause degradation of wetlands that could also affect waterfowl species (Rajpar and Zakaria 2011).

The introduction of alien invasive species could pose a threat to native species and global ecosystems (Sala et al. 2000), including wetlands. According to the International Union for Conservation of Nature, invasive species are "animals, plants or other organisms introduced by man into places out of their natural range of distribution, where they become established and disperse, generating a negative impact on the local ecosystem and native species" (Global

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Invasive Species Database 2018). The Common myna *Acridotheres tristis* is native to Asia and has an extremely large range; its conservation status is Least Concern within its native range. The Common myna is considered an alien invasive species in several places where it has been introduced such as in Hawaii, the Middle East, South Africa, Israel, North America, Europe, New Zealand and various oceanic islands such as the Seychelles and Madagascar (Martin 1996).

The Common myna, originating from Southeast Asia (Feare and Craig 1998), is known as one of the 100 worst invasive species in the world (Lowe et al. 2000). On Fregate Island in the Seychelles, it has been shown that it is a serious threat to endemic bird species, including to the endangered *Zosterops modestus* (Henriette and Rocamora 2011) and *Copsychus sechellarum* (Canning 2011). The Common myna has also been shown to be a predator of the eggs and chicks of *Terpsiphone corvina* on Denis Island in the Seychelles (Feare 2010).

The Common myna was introduced to eastern Madagascar from Reunion Island in 1875 (Decary 1962) to eliminate locusts that attack crops (Vinson 1867, Milon 1951, Ali 2002). Since the beginning of the millennium, the species has been encountered throughout Madagascar, particularly in urban, rural and open areas, including the city of Antananarivo (Hawkins and Goodman 2003). Goodman and Hawkins (2008) suggested that a proliferation of this species could represent an important competitor for native bird species. However, this has never been extensively studied in Madagascar, despite its potential to cause an ecological catastrophe (Raherilalao and Goodman 2011).

Madagascar has a unique avian composition (Raherilalao and Goodman 2011). Efforts to conserve this avifauna are often focused on bird species found in pristine forests (Haslem and Bennett 2008) and waterfowl in wetlands (e.g., Rabearivony et al. 2008, Barratt et al. 2009, Roux and Bejoma 2009, Pruvot et al. 2018). The wetlands of the island host a great population of waterfowl, many of which are endangered or heavily threatened (Rabarisoa 2001). Eighteen species of birds are found in lakes, marshes, rivers and mangroves; amongst them, four species of ducks (Anatidae) highly dependent on these areas (Langrand and Wilmé 1993, Rene de Roland et al. 2009). The most studied wetlands in Madagascar are Lake Alaotra on the eastern slope of the island, Lake Itasy to the West, Lake Kinkony in the Northwest, Lake Ihotry and Lake Tsimanampetsotsa in the Southwest (e.g., Zicoma 1999, Andriamasimanana et al. 2013, Randriamiharisoa et al. 2015, Bamford et al. 2017). In Antananarivo, several types of wetlands are encountered, including swamps, extensive lakes (Mandroseza, Anosy, Masay, Tsimbazaza, Tsarasaotra, etc.), as well as rivers such as the Ikopa; they constitute the wetlands of the capital city and its immediate surroundings (Milon 1949, Malzy 1967, Bamford et al. 2017).

Over the years, several studies have been conducted on the wetlands in Antananarivo and its surroundings (Milon 1949, Malzy 1967, Wilmé and Jacquet 2002, Razafimanjato et al. 2007, Raherilalao and Goodman 2011), but few studies have focused on the uses of these wetlands by invasive alien bird species such as the Common mynas. The objective of this study is to assess the current situation of this species and to estimate its impact or influence on the indigenous waterfowl. To better understand how the Common myna is using the wetlands, this study has estimated: (i) the Common myna population size, (ii) the spatial occupation of bird species using the wetlands, and (iii) the characteristics of foraging and roosting sites.

METHODS

STUDY SITE. This study was mainly conducted in Antananarivo, the economic and political capital of Madagascar, in the Analamanga Region (E047° 31', S18° 55'). Three wetlands were selected where the Common myna has established roosting sites (Figure 1).

The first site (Site 1), Tsarasaotra (S18° 52', E047° 32'), is located in the north-eastern part of Antananarivo. It is also known as Alarobia, which is the name of the neighborhood (Malzy 1967). Tsarasaotra was the first private site classified in the Ramsar Convention on Wetlands on 9 May 2005. The site gives protection to several populations of breeding waterfowl (Wilmé and Jacquet 2002, Dodman and Diagane 2003). The park covers 27 hectares and is surrounded by a *tamboho* (old traditional wall), and further includes two shallow lakes, one with a central island. This central island has become a refuge for several species of Malagasy waterfowl. The vegetation of Tsarasaotra is composed of trees, shrubs, grasslands and aquatic vegetation. The dominant tree species near and at the roost site are *Pinus* sp., *Cryptocarya* sp., *Syzygium cuminii* and *Melia azedarach*. Bamboos, *Cyperus* spp. and *Juncus* sp. cover the edges of the two lakes and the central islet. Over the last 30 years, breeding herons' droppings have killed the trees on the central islet (Ranoelison 2009); two standing dead trees are still visible. The remaining of the roost site consists of cultivation areas and buildings.

Site 2 is located in the center of the city, at the Parc Botanique et Zoologique de Tsimbazaza, the zoological garden of Antananarivo (E047° 32', S18° 56 '). It covers seven hectares of forest, lakes, grasslands, rock garden and build-up. The park protects several breeding colonies of waterfowl including on the bamboos fringing the biggest lake, on the trees of the small lake, and on the larger *Eucalyptus* sp. trees on the eastern site of the park. The Common myna's roost is located in the trees of the small lake. The trees belong to *Ficus* sp., *Cryptocarya* sp. and *Melia azedarach*.

Site 3 is located in the south of Antananarivo, in the rural commune of Tanjombato, Tananarivokely (E047° 32', S18° 57'). The Common mynas' roost is located on the property of the SOCOBIS (Société de Confiserie et Biscuiterie) factory. It is located along the Ikopa River. The property of the SOCOBIS factory is characterized mostly by built-up areas with a few wooded areas along the riverbank. Trees found there are *Pinus* sp., *Cryptocarya* sp., *Spatodea* sp., *Jacaranda* sp., *Melia azedarach*, and *Casuarina* sp. Finally, on the other side of river are small cultivation areas.

BIRD SURVEY. Five transects of 2 km long were established on the periphery of each site to estimate the abundance of Common mynas (Bibby et al. 2000). The transects were walked on foot at a constant speed of ca. 2 km/h, during which all the Common mynas present at a distance of 5 m were counted. Each transect was walked two or three times between 0700h and 1200h. To evaluate the number of Common mynas, direct counting was performed in the roosting sites in Tsarasaotra, Tsimbazaza and the Socobis site. The counting was carried out five times from 1700h to 1800h during the month of April 2016, when the Common mynas returns to the roosts. The setting up took place at 16:30 when the roost was empty and when the Common mynas began to approach the roosting site. In Tsarasaotra, four people posted on the cardinal points of the roosts' periphery counted all the birds over a radius of 45° on both sides. Because the roosts at Tsimbazaza and Socobis were smaller, only two people counted the Common my-

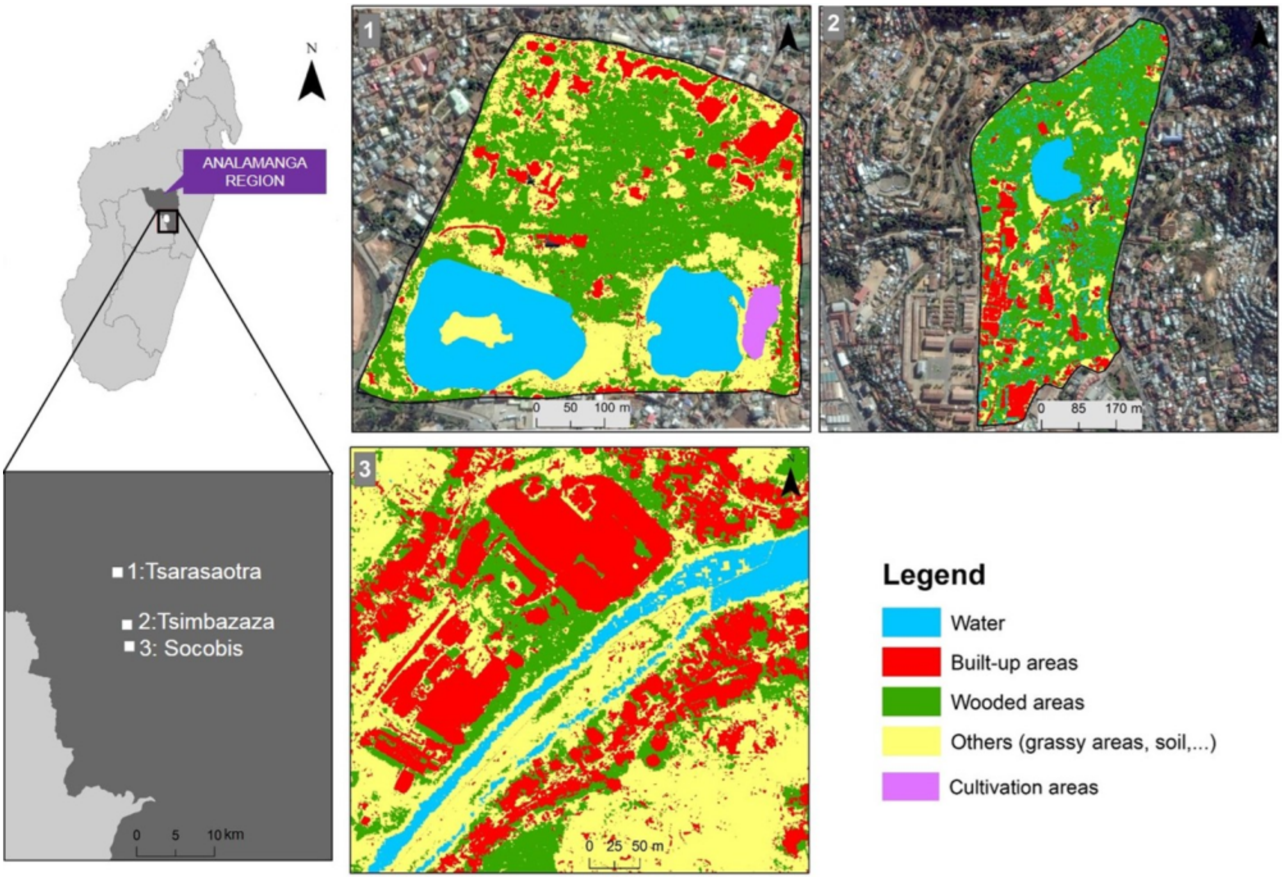

Figure 1. Location and description of study sites in the urban environment of Antananarivo, Madagascar, and occupation areas of Common mynas in the three wetlands.

nas on two opposite cardinal points of the periphery of the roosts. All individuals entering and leaving were counted to avoid duplicates.

The occupation of the wetlands and their use by the Common mynas were described by direct observation with binoculars and a telescope. The distinction was made between horizontal occupation to apprehend the use of different habitats and vertical occupation to consider the height preferred by the birds in the trees. Points were taken with a GPS on the ground to distinguish the different areas according to bird activity, from feeding sites during the day to the roost during the night. The areas were subsequently delineated with a GIS. The vertical stratum was divided into four: (i) ground level with crop fields and grasslands; (ii) ground to 8m high, mainly composed of bushes, shrubs and the surrounding wall; (iii) from 8 to 15 m with roofs of houses, poles and wires, and tree tops including in fruit trees; and (iv) strata from 15 to 20m with buildings including the factory and apartments. Direct observation of the behavior of the Common myna took place from 0900 to 1200h and from 1400 to 1600h. An individual was observed for five minutes, during which time each behavior was recorded and time was estimated for each activity. Five categories of behavior were defined: (i) communication with calls, song, head movements or play; (ii) feeding when birds were gleaning, jumping, actively seeking food, pecking or foraging in trees; (iii) grooming when removing parasites or preening feathers; (iv) resting when sleeping or sitting in the sun; and (v) vigilance when on the lookout or scrutinizing the surroundings. Observations could last less than five minutes if the birds left prematurely, or could occur on several strata if used within the five minutes.

ENVIRONMENT VARIABLES OF ROOSTS. Environmental variables were collected to identify the parameters inherent in the installation of the Common mynas' roost in a wetland. Several measurements of the trees in the roost were taken, including height, dbh (diameter at breast height) and crown cover of trees measured with decameters and clinometers. The woody cover is the surface of the crown of the tree projected vertically to the ground. It was measured with a decameter by considering the north-south and east-west axes of the projection. The distances between the roosts and surrounding features were measured, and the features were classified into two categories: (i) anthropogenic, such as road, factory, market, bus station, school, or parking lot; (ii) resources, such as water or food.

DATA ANALYSIS. The data were analyzed with the statistical functions provided in Excel. The density of the Common myna population was calculated from the data collected on the transects and formulated in terms of number of individuals per ha. The number of individuals in each roost are the maximum numbers obtained from the iterative counts at the roosts. To characterize the behavior of the Common myna in the vertical strata, the durations of the various activities in each stratum were converted to percentages. To analyze the occupation of the Common myna in the horizontal zones, Google Earth pro images with a resolution of 5m dated 12 July 2016 were used to estimate the surface of the feeding sites and the roosting sites. The images were cropped to extract the three study sites, Tsarasaotra, Tsimbazaza and Socobis. The study areas were classified according to different types of land use. The classification was subsequently launched on the maximum likelihood log on the Envi 4.5 software. Finally, the calculation of the Kappa coefficient was used to validate the classification, vectorization mapping and classification results. These manipulations allowed the conversion of raster images into polygons in a vectorial mode to facilitate the information management in ArcGIS (10.3). The environmental variables were processed with the statistical software SPSS 19.0. Crown cover was calculated from Ngom et al. (2013) to estimate tree density at the roost sites using the formula <eqn1>:

$$C = \frac{\sum \pi \left(\frac{d_{mh}}{2}\right)^2}{S_E} x100$$

C= ligneous coverage in percentage; d_{mh} = average diameter of crown in meter, S_E= sampling areas in ha

RESULTS

POPULATION SIZE. During the study period, 224 Common mynas individuals were counted along the 15 transects in the three study sites, including 119 at Tsarasaotra, 55 at Tsimbazaza and 50 at Socobis, representing an average of 7.9 individuals/ha. A total of 6196 individuals were counted in the three roosts, including 4411 at Tsarasaotra, 90 at Tsimbazaza and 1695 at Socobis. The Common mynas usually arrived at the roosts by pairs, sometimes forming groups of eight to ten individuals. Once at the roosts, they made a lot of noise until nightfall, at which time their singing and calling stopped.

WETLAND OCCUPATION AND USE. The observations of 144 Common mynas individuals showed that the four vertical strata were used by the species (Table 1). The strata of 8 to 15 meters (31%) and those at ground level (54%) are mostly used during the day (Figure 2).

At ground level, foraging was the most commonly observer behavior, accounting for 45.3% of time spent on the ground (Table 1). The Common mynas ate arthropods, larvae and plant debris present in the soil. They would move and jump to disturb prey on the ground. This activity was alternated with vigilance behavior for 8.7% of time spent on the ground. Vigilance behavior includes lateral displacement to avoid potential predators (e.g., dogs). The stratum between 8 and 15 m was mainly used for communication (64.3%), as well as for foraging (14.3%) on fruit trees such as *Morus* sp., *Ficus* sp., *Cryptocarya* sp. and *Melia azedarach*, grooming (9.8%), resting (5.7%), and vigilance (5.7%). Individuals frequently communicated during the day. To this end, one individual emitted a call or sang, and to answer, another individual either sang, moved or flew towards the first individual. It is also in this stratum that the nests were most often observed. The horizontal occupation is expressed by the area within which the Common mynas was observed for the study. Horizontal spatial analysis showed that wetlands are used both as foraging and roosting sites (Figure 3).

Table 1: Percentage of time spent by the Common myna in each layer per activity

Behavior	strata height			
	0m	0-8m	8-15m	15-20m
Communication	34.9%	38.3%	64.3%	50.0%
Foraging	45.3%	21.5%	14.3%	0.0%
Grooming	7.6%	23.4%	9.8%	8.3%
Resting	3.5%	5.6%	5.7%	41.7%
Vigilance	8.7%	11.2%	5.7%	0.0%

The three sites were used as roosts at night and as foraging sites during the day and at dusk. The roost of Tsarasaotra occupied an area of 0.27 ha, or 1.35% of the wooded area of site 1. The roost of site 2 covered an area of 0.07 ha, or 1.40% of the wooded area of Tsimbazaza Park. In the Socobis site, the roost covered 0.08 ha. Trees in the study sites were also used as day roosts for about 15 Common mynas. Other species of birds such as Cattle egrets (*Bulbucus ibis*) and Dimorphic egrets (*Egretta dimorpha*) were also present in these roosts, and used them to perch temporarily, rest, or nest. The Common myna and the two species of egrets shared the space in the trees according to the height available above the branches serving as perch or as a support for the nests. The Dimorphic egrets is the larger of the three species, with a length of ca. 60 cm, compared to ca. 50 cm for the Cattle egret and ca. 23 cm for the Common myna. The Dimorphic egret occupied the branches where few or no birds were already present, the Cattle egret perched on branches with a little less vertical space as compared to the branches where the Dimorphic egret perched, and the Common mynas were usually encountered in the most cluttered areas of the trees where the space between branches was limited. The

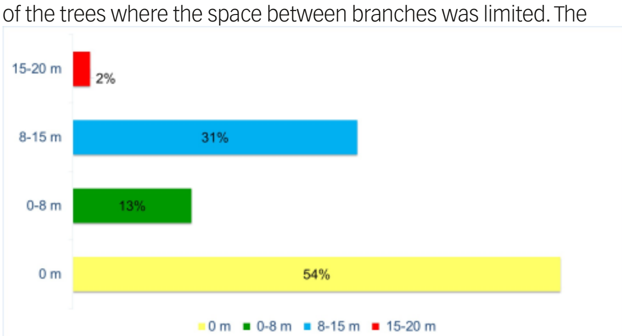

Figure 2. Use of the vertical layer by Common myna expressed by percentage of time spent in each layer.

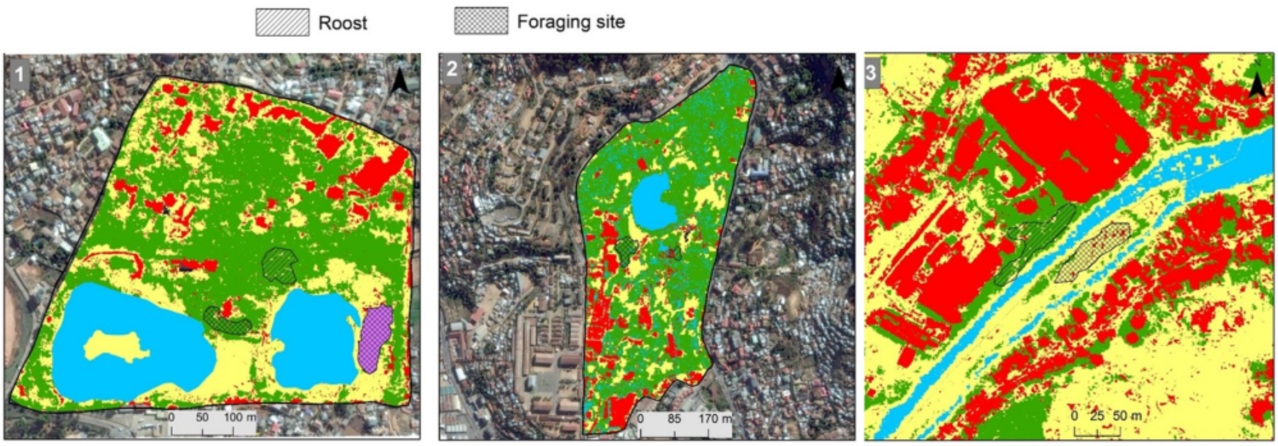

Figure 3. Roosting and foraging sites.

Common mynas formed a dense roost in each tree with four to six individuals on each smaller branch, below the larger branches occupied by the egrets.

For feeding, the Common mynas occupied about 0.58 ha of a watercress field and 0.22 ha of an orchard in Tsarasaotra. In the watercress field, Common mynas fed on larvae and insects, and in the orchard, they fed on fruits of *Syzygium cuminii* and *Melia azedarach*. In Tsimbazaza, the foraging site was estimated at 0.28 ha, about 5.6% of the orchard surface. The Common mynas fed on fruits and seeds of *Syzygium cuminii* and *Melia azedarach*. These trees were also used as day roost. The foraging areas at Socobis had an area of 0.21 ha of cultivated fields in which Common mynas fed on insects and larvae. In the three sites, the Common mynas were encountered in groups of two to eight individuals when feeding, and were randomly distributed in the horizontal and vertical strata.

ENVIRONMENTAL VARIABLES. The inventory of nests around wetlands showed that out of the 15 nests identified in the three sites, 13 nests (86.7%) had been built under the rooves of houses, one nest at Tsarasaotra had been constructed in a gutter and the last nest was in a cavity of a tree trunk in Tsimbazaza. Of the 13 nests built under rooves, nine were under a sheet roof (69.2%) and four under tile rooves (30.8%). The average height of the nests was 8.9 ± 3.4 m.

The diversity of the flora varied at each roost. It was limited to one species of Ficus sp. at the Tsimbazaza roost, versus a dozen species for the Tsarasaotra and Socobis roosts, with *Pinus* sp., *Cryptocarya* sp. and *Syzygium cuminii* common to both sites. The trees supporting the roosts had a high diameter, usually higher than 40 cm and up to more than 65 cm, and a height of at least 12 m and up to 20 m, with the exception of the small Ficus tree at Tsimbazaza, but having the densest crown cover (Table 2).

The roosts had different positions in the environment in the three studied sites, with varying distances to resources and anthropogenic disturbances (Table 3). Tsarasaotra sheltered the roost furthest from human disturbances with the greatest distance to the foraging site. The Tsimbazaza and Socobis roosts were close to foraging sites but Tsimbazaza was closer to anthropic disturbances (Table 3).

DISCUSSION

The inventory showed that the Common mynas are often encountered in pairs during the day and that they can go at least 2 km around their roosts. This could mean that the Common myna live in pairs during the day as a strategy to avoid competition for access to resources. The results also show that the abundance of the species at site 1 is greater than at the other two sites, both around the roosting sites and at the roosts themselves. Tsarasaotra is a

Table 3. Human disturbance parameters of each roost expressed as distance from roost to features (m).

Features	Distances to roosts (m)		
	Tsarasaotra	Tsimbazaza	Socobis
Food resources	200	30	30
Water (lake or river)	10	3	6
Roads	400	150	250
Bus station	400	150	600
Car parking	250	140	600
Market or shopping center	400	155	250
School	250		
Factory or industrial building			80

large private park with few people and few disturbances as compared to the other two sites in the city center, with a relatively large park attracting many visitors at site 2, and a small area with industrial activities at site 3.

The areas around sites 2 and 3 are less urbanized than the area around site 1. The distribution of Common myna depends on its preference for urban habitats or habitation areas where food, shelter and nesting are more easily accessible (Old et al. 2014). This finding was confirmed by other authors, such as Van Rensburg et al. (2009), Lowe et al. (2011) and Sol et al. (2012) and provides additional evidence that Common myna mainly live in urban areas with a high human population. As for the roosts, site 2 is less abundant than the other two sites. This is probably due to the presence of other bird species. Competition between Common Mynas, herons and egrets for branches to perch on might explain the low abundance of Common myna in site 2. However, the population of the capital city could increase over time. In this study, the Common myna occupied only 1.1 to 5.6% of the area of the feeding sites and 1.4% of the wooded area for the roosts. Elsewhere in the world, the species is known to nest one to three times a year (Markula et al. 2016), but we only observed it twice during this study. Human disturbances, either direct in the case of visitors at a site, or indirect such as industrial activities far from the sites, seem to limit the extension of the Common myna population. The Common myna seems to favor the wetlands of the city and the quiet spaces with large trees to accommodate the roosts. Given its recent arrival in the capital city, it is still difficult to estimate whether the population has reached its maximum number or whether it is still increasing in an ecological niche not yet saturated.

The results also show that the Common myna spends a lot of time on the ground to feed. Elsewhere, it is known to feed on the ground (Griffin et al. 2013), mainly on arthropods and annelids (Jalil 1985, Kang 1989, Yap et al. 2002, Markula et al. 2016). Certain behaviors such as vigilance and feeding decrease when the species is at a higher height, particularly in the 8 to 15 m stratum that is preferred for nest construction. Vigilance behavior in lower strata could be explained by the threat of potential predators such as dogs, cats, Madagascar kestrel *Falco newtoni*, or people, even if the species has a certain tolerance to human presence (McGiffin et al.

Table 2. Ecological parameters of the roosts at the three study sites. (DBH = diameter of trunk or branches at an height of 1.5 m above ground, H max = maximum height of tree, C = crown cover; repartition = number of trees of the species divided by the total number of trees in the roost, ± = standard deviation, n = sample size)

site	Family	Composition	Repartition	DBH (m)	H max (m)	C
Tsarasaotra	LAURACEAE	*Cryptocarya sp.*	19%	52,6 ± 15,7 n=16	18,4±2,7 n=16	50%
	MYRTACEAE	*Syzygium cuminii*	50%			
	PINACEAE	*Pinus sp.*	31%			
Tsimbazaza	MORACEAE	*Ficus sp.*	100%	25,6±7,5 n=12	8 n=1	96%
Socobis	BIGNONIACEAE	*Jacaranda acutifolia*	7%	41,7±23,4 n=14	12,3±2,3 n=14	83%
	BIGNONIACEAE	*Spatodea sp.*	43%			
	CASUARINACEAE	*Casuarina sp.*	7%			
	CUPRESSACEAE	*Cupressus sp.*	14%			
	LAURACEAE	*Cryptocarya sp.*	14%			
	MELIACEAE	*Melia azedarach*	7%			
	PINACEAE	*Pinus sp.*	8%			

2013). The communication behavior is more important in higher strata. This could be explained by the fact that the Common myna is more vigilant in the lower strata and therefore more discreet.

During this study, it should be noted that the Common myna cohabited in the three sites with other birds such as the Cattle egret and the Dimorphic egret. This cohabitation was only effective during the night and at the roost, and is therefore likely beneficial for the three species concerned. The Common myna would add density to the colony in each tree of the roost by occupying the spaces that the egrets cannot occupy. This increase in density could benefit the three species by them gaining in protection from wind and rain, for example. On the other hand, the Common myna could also threaten egrets by eating eggs or chicks, by transmitting parasites and diseases such as avian malaria (Caughley and Sinclair 1997, Lever 2005, Peacock et al. 2007), or attacking them, as the Common myna is known to be an aggressive bird (Holzapfel et al. 2006, Griffin 2008, Haythorpe et al. 2012). Also, the Common mynas seems to be present in more abundant numbers than egrets and herons during this study. However, this competition was not observed during this study.

The Common myna usually nests in tree cavities (Lowe et al. 2011), but in this study only one such nest was found, while the majority of nests were built under rooves. It is probable that the trees in the city have no suitable cavities to host a nest or that the rooves of houses are more favorable.

Floristic diversity does not appear to play a decisive role in the establishment of roosts of Common myna in Antananarivo, as in the case of Tsimbazaza there is only one species of *Ficus*. This result is consistent with what has been observed elsewhere (Tracey et al. 2007). Three other environmental variables for the location and density of roosts emerged from our three study sites: (i) tree height and diameter, (ii) proximity to a wetland, and (ii) human disturbance. According to a study by Yap et al. (2002), the location of a Common myna roost depends on crown cover and proximity to feeding sites. Variables such as distance from human disturbances and distance to a wetland are also mentioned (Nee and Yeo 1993, Yap et al. 2002). The crown cover is low in site 1 but important in the other two sites, while the biggest colony of Common myna is in site 1. Therefore, the degree of disturbance seems to be the main factor limiting the size of the roosts; it is low in site 1, housing the largest roost.

CONCLUSION

Each type of habitat has specific environmental variables; habitat is defined by compromises between food, roost and protection against predators (Raherilalao and Goodman 2011). The three sites in this study provide not only suitable habitat for waterfowl but recently also for the Common myna. The Common myna uses the vertical and horizontal strata of wetlands as they offer roosts and feeding sites with crop fields and fruit trees. The Common myna would have adopted a specific strategy in Antananarivo by occupying the wetlands surrounded by trees, crops and houses, thus finding feeding places close to water, nesting sites in height, and roosts with little nocturnal disturbances. These results provide qualitative and quantitative information on the current situation of the Common mynas in Antananarivo city. Although they only represent a sample of the species' population, these will serve as a reference for future studies.

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SHORT NOTE

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Play, learn, explore: grasping complexity through gaming and photography

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> "Science and art are only too often a superior kind of dope, possessing this advantage over booze and morphia: that they can be indulged in with a good conscience and with the conviction that, in the process of indulging, one is leading the 'higher life'."
>
> --Aldous (Leonard) Huxley, Ends and Means (1937), 320. In Collected Essays (1959), 369--

ABSTRACT

Increased demand for agricultural products, the aspirations of rural communities and a growing recognition of planetary boundaries outline the complex trade-offs resource users are facing on a daily basis. Management problems typically involve multiple stakeholders with diverse and often conflicting worldviews, needs and agendas, in an environment with growing uncertainty. How to improve the flow of information between decision makers? What future landscapes will best resolve the apparently conflicting demands? To address these questions, our methodology has been based on participatory modeling and 'ethnophotography in environmental science', a term we have coined to describe our use of photography to explore the perceptions of landscape by resource users. We apply these coupled methods in the social-ecological landscape of the Alaotra, Madagascar. Within the realms of the AlaReLa (Alaotra Resilience Landscape) project, we have developed conceptual models that link actors, resources, norms and institutions, ecological processes and social dynamics through participatory modeling workshops. These involved farmers, academics, conservationists and decision makers. Recognizing and understanding the multiple linkages and feedback loops between all of these components and processes is a crucial first step in the design of socially acceptable strategies. In this paper we highlight the interaction of participatory research and photography, to show how they exchange and nurture each other, and how this approach allows the evolution of a common understanding of a social-ecological system.

RÉSUMÉ

L'augmentation de la demande de produits agricoles, les aspirations des communautés rurales et la reconnaissance croissante d'une planète aux frontières limités mettent en exergue les compromis complexes auxquels les utilisateurs des ressources sont confrontés de manière quotidienne. Ces problèmes de gestion impliquent généralement de multiples parties prenantes ayant des visions du monde et des besoins variés et souvent conflictuels, dans un environnement où l'incertitude augmente. Comment peut-on améliorer le flux d'information entre les preneurs de décision ? Quels futures utilisations du territoire résoudront au mieux des demandes apparemment contradictoires ? Pour répondre à ces questions, notre méthodologie a été basée sur la modélisation participative et l'« ethnophotographie en sciences de l'environnement », terme que nous avons créé pour décrire notre utilisation de la photographie afin d'explorer les perceptions de leur environnement par les utilisateurs de ressources. Nous appliquons ces méthodes couplées dans le paysage socio-écologique de l'Alaotra, à Madagascar. Dans le cadre du projet AlaReLa (Alaotra Resilience Landscape), nous avons développé des modèles conceptuels qui relient les acteurs, les ressources, les normes et institutions, les processus écologiques et la dynamique sociale à travers des ateliers de modélisation participative. Les participants en étaient des agriculteurs, des universitaires, des conservationistes et des décideurs. Mettre en évidence et comprendre les liens multiples et les boucles de renforcement entre tous les composants et processus est une cruciale première étape dans la conception de stratégies

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socialement acceptables. Dans cet article, nous soulignons l'interaction entre la recherche participative et la photographie, afin de montrer comment elles échangent et se nourrissent l'une de l'autre, et comment cette approche permet une évolution vers une compréhension commune d'un système socio-écologique.

STAGING PARTICIPATORY RESEARCH

Protected areas globally cover 15.4% of the 13 billion hectares that form Earth's land mass (Deguignet et al. 2014). It does not seem enough to curb the loss of biodiversity and the decline of wild populations documented world over (Worm et al. 2006, Butchart et al. 2010, Cardinale et al. 2012). Yet, it is almost the same amount that is devoted to crop production—arable land and permanent crops cover some 1.6 billion hectares according to Guillou and Matheron (2014). It seems unlikely that we will be able to establish new parks to reduce the environmental damage man is causing to the biosphere. In this context, a crucial question is also related to how to deal with human dominated landscapes. Pett et al. (2016:2) note that "[policy- and decision makers] have to deliver and trade-off between multiple biodiversity, individual, and societal benefits (…), environmental interventions that deliver mutually reinforcing outcomes for both biodiversity conservation and people are highly desirable." We are confronted with fundamental questions: How do people cope with conflicting agendas, power imbalances, uncertainty and the unknown when managing natural resources? How do they resolve the trade-offs between satisfying their needs and maintaining the ecosystems they live in and depend on? Orstom (2009) speaks of increased complexity of a social-ecological system (SES) when its subsystems such as Resource System (e.g., wetlands, forests), the Resource Units (e.g., fish stock, marshes, protected area) or its Resource Users (e.g., fishers, park rangers) and respective Governance Systems (e.g., Ministry of Agriculture, or Ministry of Fisheries) are interacting with each other and feeding back at either the SES or lower subsystemic levels. The emergence of transdisciplinarity approaches in environmental and sustainability sciences represent ideal platforms to accommodate the interactions and exchanges between and amongst different types of actors to address aforementioned questions (Max-Neef 2005, Lang et al. 2012); Kates et al. (2001:641) suggests that "participatory procedures involving scientists, stakeholders, advocates, active citizens, and users of knowledge are critically needed" when dealing within complex and complicated realms such as natural resources management systems.

In this article we provide insights on how a participatory modeling approach based on the ComMod methodology (Etienne et al. 2014) and art, in particular photography, are complementing and nurturing each other to gain increased understanding of a complex landscape as that of the Alaotra, where agricultural needs and conservation biodiversity interests compete over space (e.g., Waeber et al. 2017a). This contribution is placed in the AlaReLa project, which is a "r4d" research for development project supported by the Swiss Programme for Research on Global Issues for Development.

PRESENTING ACTORS AND PLAYERS

Madagascar, a global biodiversity hotspot (Ganzhorn et al. 2001), hosts a vast variety of ecosystems from very dry to very wet forests and open landscapes (Waeber et al. 2015); this has created a unique assemblage of flora and fauna, with some of the species being found only in certain areas of this big island (Wilmé et al. 2006, 2012), and many being threatened or on the brink of extinction. In the north-eastern part of the island, Lake Alaotra was once the biggest inland fish supplier. It is referred to as the leading rice granary of Madagascar. Its marshes also provide habitat to the Alaotra Gentle Lemur (*Hapalemur alaotrensis*), the only lemur species to live constantly on water (Waeber et al. 2017b). In 2003, Lake Alaotra was the third wetland in Madagascar to be designated as a Ramsar site; in 2007, the Malagasy government added the Alaotra as a new protected area in the context of the Durban vision; in June 2015, the Alaotra has been inscribed as a permanent Protected Area (Waeber et al. 2017a). Despite these formal labels, marshes are burnt to expand rice fields and to ease access to fish ponds (Ralainasolo et al. 2006, Copsey et al. 2009a, b, Ratsimbazafy et al. 2013), thereby reducing the size of lemur habitat.

While bushmeat hunting was in decline in the early 2000s (Ralainasolo 2004), it recently sprang back, probably due to the political instability and the lack of governance and law enforcement during the High Authority of Transition (HAT) period (2009–2013) (Randrianja 2012). Reduced livelihood options forced many residents into the marshes in search of alternative sources of proteins, mainly birds and mammals. During our focus group meetings and participatory game workshops (cf. Reibelt et al. 2017), fishers were also raising the concern that more and more people are entering marshes in desperate search for fish, and they catch them by any means possible. As a result, the once thriving fisheries of Lake Alaotra are now imperiled. Overfishing, like bushmeat hunting or logging, are classic examples of a conservation crisis during times of political turmoil (e.g., Golden 2009, Innes 2010, Randriamalala and Liu 2010, Jenkins et al. 2011). Desperate people take whatever action is needed to make ends meet. Many environmental challenges, however, are "remotely controlled" (cf. Waeber and Wilmé 2013).

The Alaotra has many different actors (Figure 1) posing increased challenges to the ones responsible for the management of the wetlands. The biggest group of actors are the farmers and fishers. Their actions change the landscape; they directly depend on its natural resources to satisfy their needs. But they are not alone. In the supporting role, middlemen and consumers are linked to the direct actors by a web of exchanges and reciprocities, making the decisions of the latter the logical choice. And then there is the second type of actors: the policy makers, regulators, responsible for the norms and policies that shape and enable decision making by the main actors. These are often people that do not derive their subsistence from the land and its resources. The large number of poor people are prone to take chances in the form of illegal land conversions, hunting, mining, and logging. This brings into play a third type of actors: those who have the power to abuse the situation of the main actors and know how to manipulate and interfere with the supporting roles and the regulators. They are powerful and 'above the law'. No strategy for conservation that does not take them into consideration will work. Two changes can reduce the likelihood of these actors' interference and limit their power: the first, a reduced exposure of the direct actors (farmers, fishers), achieved by improving their economic situation and thus reducing their vulnerability to change. The second, better governance through increased accountability of the regulators. Creating conditions that can increase transparency in natural resources management is a crucial step towards any tangible solution (Grindle 2004, but see also Kolstad and Wiig 2009).

Through our serious games (haptic models), people can explore the complexity of the issues at stake, shatter their illusion of

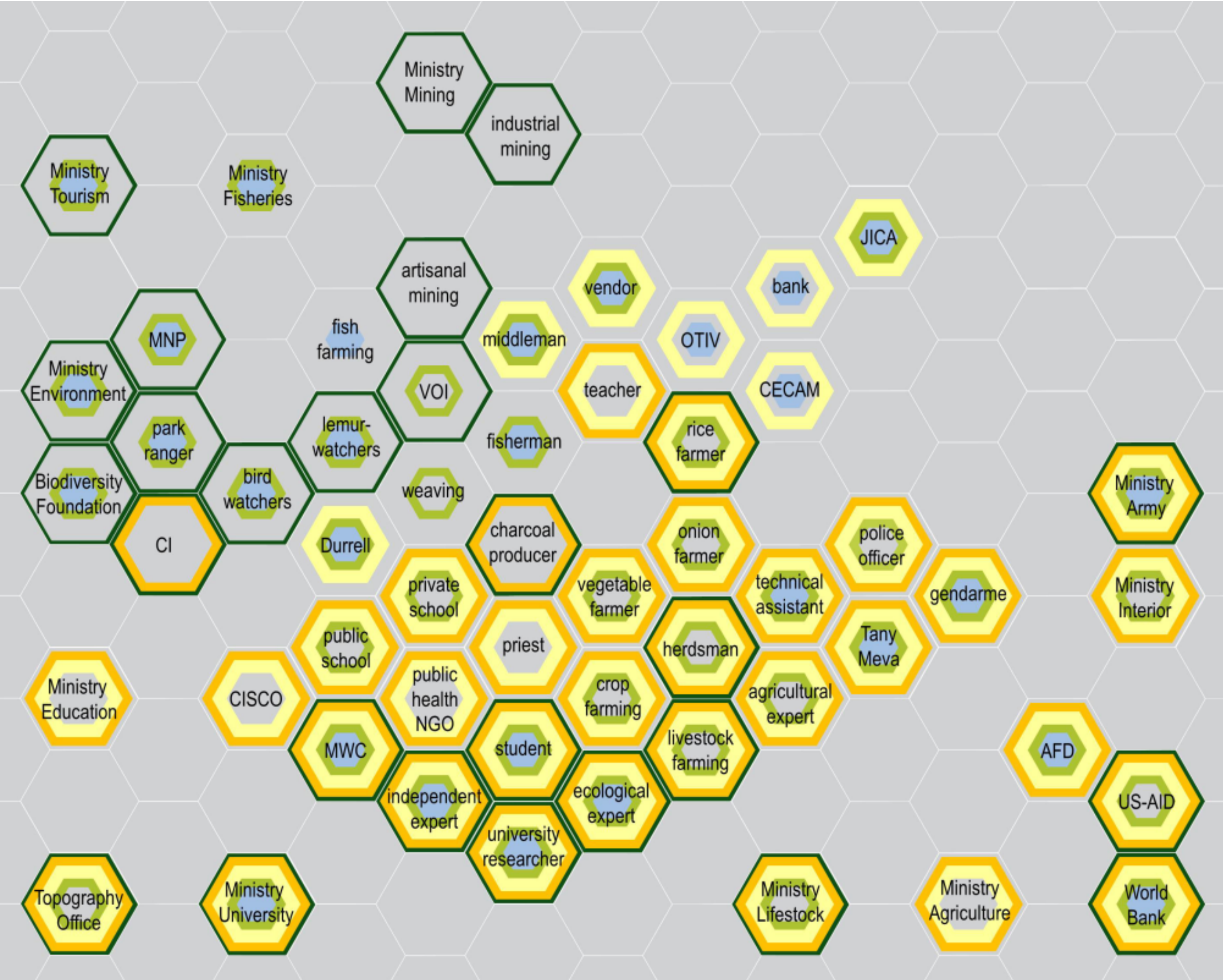

Figure 1. Stakeholder map developed in the course of the AlaReLa project, illustrating the social-ecological networks of the Alaotra landscape. An actor is represented by a hexagon, and is active in one to five zones of the landscape; lake (blue), wetlands (light green), agricultural zone (yellow), grasslands (orange), and forests (dark green). The position of an actor shows its connections with others as well as the spatial scale of activity; the closer an actor is to the center, the smaller the spatial range and bigger the dependency on local resources (village level). AFD = French Development Agency; CECAM = microcredit institution; CI = Conservation International; CISCO = regional school authorities; JICA = Japan International Cooperation Agency; MNP = Madagascar National Parks; MWC = Madagascar Wildlife Conservation; OTIV = microcredit institution; VOI = local association responsible for management of natural resources at community level.

understanding, and create space for communication and negotiation (e.g., García-Barrios et al. 2015, Le Page et al. 2016, Garcia et al. 2016). The models are first developed through workshops where local empirical knowledge meets scientific knowledge on an equal basis. Here, farmers and fishers explained to the research team what matters to them when deciding to manage resources (Reibelt et al.2017; Figure 2). We then translate these early mind-maps (Figure 2) into board games, where actors become players, resources are tokens, norms and processes define the rules, and the landscape is the board. These games can be played by the main actors, by regulators, or by other actors. Throughout the learning process, we can refine our understanding, when the players propose fixes to the game, and we can use the game board to explore potential policy—or scenarios—and see how players devise new strategies to cope with them. Finally, the game session and the board can be used as metaphors to discuss about the real world (Figure 2).

WHEN ORAL NARRATIVE MEETS VISUAL INTERPRETATION

In Madagascar, social or collective memory (sensu Coser 1992) and oral tradition is still ubiquitous; this is evident also during scientific meetings, where every workshop starts with a kabary (lengthy discourse) in local dialect, and also closes with a traditional narrative given by a more elder and respected member of the community (Cole 1997). Thus, game playing allows the local actors, in our case fishers and farmers, to express themselves orally and thus contributing to a broader and deeper insight of the social-ecological system. A professional photographer (ADG) joined the research team, and like the researchers, spent extended periods of time in the Alaotra. Embedding what we dubbed 'ethno-photography in environmental sciences' (Box 1) in the research project, we seek to develop synergies between this artistic approach and the participatory action research described earlier. Researchers thereafter use the photography as a support to engage local stakeholders, discover new elements of the system, and bring research outcomes beyond the walls of academia (cf. Figure 2 for the interlinking of photography, mental models, and role playing games). The photographer used the participatory research project to develop narratives about timelines, roles and actors.

The modus operandi for the photography project has well identified steps matching the development of the participatory modeling process. In the diagnostic phase, the photographer joined researchers in their initial field work and brought a first harvest of pictures. We obtained three different batches of pictures: (i) a set of black and white analog pictures ('analogies') showing the life of villagers as seen through the photographer's eyes; (ii) a set of color

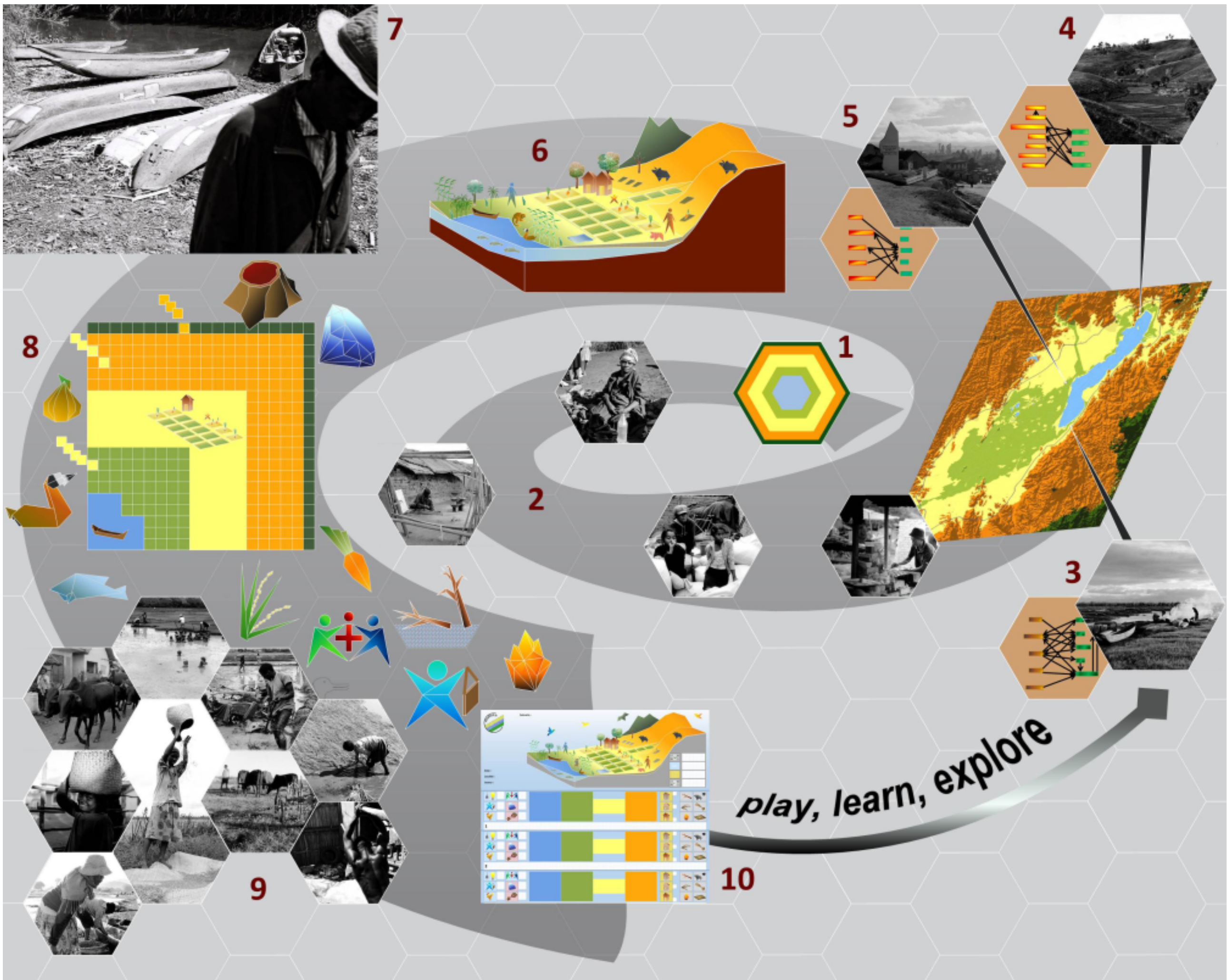

Figure 2. Transformative learning, i.e., the acquisition of knowledge and understanding through critical thinking (Mezirov 1997), with coupled approaches in an iterative process. [1] stakeholder mapping (cf. Figure 1); [2] black and white analog pictures describing the villagers' daily life; [3, 4, 5] social-ecological networks and mental models, as well as typical landscapes of three study sites mapped on a figure illustrating relief and land cover types, respectively in the Andreba region [3] along the lake border, the hilly north near Vohimarina [4], and the western plains near Anororo [5]; [6] stylized landscape with the lake (blue) and wetlands (light green) home to the narrow ranged endemic biodiversity, the agriculture zone (yellow), the hilly grasslands (orange) and remote rainforest (dark green); [7] a respected old man coming from the canoe port at dusk after a fishing journey; [8] board game representing the landscape, tokens and cards for the role-playing game where actors become players; [9] result of the iteration process in ethnophotography illustrating the farmers and fishermen working techniques; [10] game sheet filled by each participant during a game session and to be taken home to stimulate discussions in a household on the understanding of the Alaotra as an integrated landscape.

digital pictures overlapping the first set but with less of an aesthetic parti-pris and documenting the work of the researchers; and (iii) a set of instant photographs using a Fuji Instax camera that were given directly to the people as the first step in sharing the project outcomes, in this case, their image, with them (Figure 3). Through photography we followed the different types of actors we had identified in the system, in their daily lives, and see if and how they interconnect, documenting their social-ecological networks (see also Figure 1) that are at the basis of knowledge production and collective actions in a landscape to document the different roles a person takes in the system and in the transdisciplinary research process (Opdam et al. 2013). We wanted to have portraits of them 'acting', e.g., 'a day in the life of a fisherman' for example, and of them 'playing their roles' in the role playing games we had co-designed with them (e.g., Reibelt et al. 2017). As a result, this started the second iteration of the project, the exploration phase, with the second field visit aiming at filling these gaps (Figure 4). Not only did participants take home the photographs, but the players also took home the game sheets. It is our assumption that, by combining the photographer's and the actors' views through this iteration, we can obtain a fuller representation of the social-ecological-economical system. The photographs and game sheets taken home will also allow the local participants to enrich further iterations with more details for a better understanding of the system (Figure 2). We expect surprises to emerge from these interactions between the villagers, the researchers and the photographer. In a longer project (e.g., longer than the three years of the AlaReLa project), we would continue doing iterations like these, i.e. field and feedback, for as long as the participatory project lasts. We should then eventually approach saturation—where no new topic emerges from the photography nor from the interviews. We will then enter project closure.

The importance of having an external person to the place, traditions, and culture comes from their ability to see things that the actors may be too involved to notice. The iteration aspect of the method ensures that the local actors can question their views by confronting them with the ones of the photographer and researchers. Although it is unsure whether local farmers will change their habits, at least they might develop a different view about them. The pictures in this sense act like the games. Then the 'western eye' is completed by their views and it stops being entirely external. In addition, the final artistic work and the exhibitions were achieved in collaboration with a Malagasy photographer from An-

Box 1. Ethnophotography in environmental sciences.

What: Ethnophotography helps to put faces behind the scientific findings. It provides communication alternatives in the realms of environmental sciences and related topics. The modus operandi is inspired by ethnography and includes long stays in the field, close collaboration with scientists, and participatory photography with local and regional stakeholders and thus differs from classic documentary photography. The outcomes encompass coherent series of images bridging the gap between science and art; photography in support of scientific results and science brought to the mainstream via photography. The photographer connects the scientists and the local stakeholders to lessen the 'white coat syndrome'. The photography is used alongside other forms of research and engagement—interviews, participant observation, participatory modeling via role-playing games—to foster transdisciplinarity. At the core, it uses photography as a medium to confront the perceptions of researchers and stakeholders. The participatory approach associates an unconditional positive attitude derived from the field of facilitation and observant participation. Coupled with the scientific project workshops of participatory modeling, the photographer documents the daily life and work of the inhabitants, the researchers in the field and their interactions with locals. He therefore integrates their visions and perceptions of the landscape, its resources and actors during the shooting process. This is done through discussions with the 'models' about the way they want to be portrayed during specific iteration workshops. Instant photography is also performed in order to get a quick feedback, but also to give back to the locals as well as using their image and knowledge (e.g., at conferences or in articles).

How: We created the concept of iteration workshops to converge to a set of shared visions. These iterations were done with the local people on-site and with all national and international stakeholders, building on iterations over iterations. During a first visit in each of the sites of the project, the photographer built a corpus of images with his personal view on the encountered situations and vision, biased with personal background and the limited time of this first stay. During further visits we organized the iteration workshops, showing the locals the first harvest of pictures and asking them to reflect on it in order to help portray them and their lives in a more accurate way. The basic question was: "this is what the photographer saw, what did he miss?" Therefore, and with the stakeholders' input, we entered a new phase of photography in which we built upon the visions previously missed to create a shared vision. The locals then act as 'fixers' but with their own agenda, which is the way they want to be represented. The resulting pictures were then used in exhibitions during scientific conferences to foster discussions and bring non-stereotyped visions from the fields but also in other non-scientific loci (art gallery, cultural centers) to give visibility to the general public about environmental sciences, local people's daily lives and concerns.

Why: The upgraded sets of pictures are then given to the stakeholders (through the exhibitions or booklets) as take home messages representing the adapted vision of the landscape seen by a camera with eyes from the scientists, photographer and stakeholders. This becomes a boundary object that can be used in negotiation and to trigger further thought processes. We observed that these photographs, sometimes together with the game sheet for the stakeholders having participated to game sessions, have been pinned on the house walls, thus entering the household and more importantly the mental models and decision making. These multidisciplinary take home messages take a new path towards the understanding of landscapes, the interactions of the various stakeholders in the landscape, and also the way they will explain omitted visions in further iterations of the process. It also helps local actors to realize they have something important in the environment and a way of life that they should treasure and protect.

tananarivo, bringing in yet another point of view, in this case one that shares the same culture with the actors but comes from a different location. During exhibitions in the Ambatondrazaka region research sites, school children (primary and secondary levels) were invited to visit and interact with the photographers and the researchers. They played games and exchanged views about the photographic representation of the Alaotra landscape and activities that are theirs. One of the positive outcomes was that many expressed that this event had helped them realize the importance of their environment and culture. Some even discovered aspects of their environment they were unaware of, such as the diversity of fishing techniques.

EPILOGUE

Complexity is overwhelming. Embracing it requires being able to think on the multiple causal links and feedback loops between all the different components of the system that interact, and allow for change in common understanding. It requires time and the possibility to devote attention to problems beyond the immediate needs or the day-to-day activities. It needs seeing things we do not normally pay attention to. It calls for a space of freedom where the multiple aspects of the problems at stake can be approached in a non-threatening environment. Photography allows us to create a common visual representation of the world as seen from multiple eyes. The models (games) we co-design give depth to these images, allowing to define the linkages and interactions between the different elements of a social-ecological system. The game sessions make participants more aware that they are part of a bigger system by showing them physical zones (ecosystems) as well as the diversity of stakeholders. The impact of games is less in the actual outcome of changes in ecosystems, but rather in the empowerment of the people. It allows them to gain consciousness of the decision making process. People can choose amongst several options with the awareness that their decisions act upon two dimensions of the social-ecological system, which are inherently linked and interconnected, their livelihood situation, and the physical system. The games we play let us tell narratives about how things work and how they could work. Together, researchers, villagers, conservationists, decision makers and photographer are engaged in an iterative dialogue of narratives and visuals, and thus are com-

Figure 3. Three types of photography: analogies, digitals, instants. [left] A black and white picture of the daily life of the Alaotra region, with a strong artistic parti-prix. [middle] A documentation of a role-playing game session based on land conservation, linking NGO staff with local government, in a NGO headquarter. [right] Use of instant photography, leaving some pictures to the people who accepted to enter discussions and share their time and knowledge.

Figure 4. Complementing the social-ecological landscape through photography. [left] From the first visit, some fishermen paddle back to the Andreba harbor at dawn, meeting with fish collectors. [middle] a fisherman during the iteration workshop; he stated that he would like to see fishermen actually in the act of fishing as there are many different techniques used on the Alaotra lake. [right] Following the fisherman's feedback, a picture of one of the fishing techniques.

plementing but also exploring possible futures of their social-ecological landscapes to make better decisions today. Every decision matters and has consequences 'further down' in time and space, even the decision to do nothing. One cannot change the world by taking pictures and playing games, but the way people think can be changed by showing them different points of views, and then "the ball is in their hands".

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Inventaire et typologie floristique des milieux lentiques dans le district de Vohipeno

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RÉSUMÉ

L'écologie des macrophytes (plantes aquatiques visibles à l'œil nu) est peu étudiée à Madagascar. L'écosystème aquatique du district de Vohipeno (Région Vatovavy Fitovinany) n'a fait l'objet d'étude que pendant la période coloniale de 1921 à 1936. Les objectifs de cette étude sont d'améliorer la connaissance sur les macrophytes et d'établir une typologie floristique des zones humides malgaches. Au total, 43 espèces réparties entre 34 genres et 19 familles ont été recensées. Les valeurs de l'indice de Shannon Weaver ont montré une faible diversité mais une distribution hétérogène. L'analyse du coefficient de similarité de Sorensen a révélé une ressemblance entre certains sites. L'Analyse Factorielle des Correspondances (AFC) met en exergue quatre groupements de végétaux appuyés par la Classification Ascendante Hiérarchique (CAH).

ABSTRACT

The ecology of macrophytes (aquatic plants) has not been extensively studied in Madagascar. The aquatic ecosystem of the district of Vohipeno (Vatovavy Fitovinany) was last studied during the colonial period 1921 to 1936. The objectives of this study were to improve the knowledge on macrophytes and to make a floristic typology of Malagasy wetlands. In total 43 species distributed between 34 genera and 19 families were recorded. The Shannon Weaver index showed low diversity but a heterogeneous distribution. The Sorensen coefficient analysis revealed resemblances between certain sites. Correspondence Analysis (CA) highlighted four vegetation groups and was supported by Hierarchical Clustering (HCPC).

INTRODUCTION

La flore aquatique malgache est diversifiée tant au niveau familial qu'au niveau spécifique. Elle comprend 338 espèces dont 128 endémiques (Ranarijaona 1999). À titre de comparaison on compte 81 espèces en Australie, 29 espèces en Inde, 116 espèces en Asie, plus de 100 espèces en Europe et plus de 400 espèces dans l'ensemble des zones tropicales (Cook 1996, Ranarijaona 2009). Le recensement le plus récent de Madagascar date de 2017, comprenant 388 espèces, 226 genres et 85 familles (Phillipson et al. 2018). En ce qui concerne l'inventaire floristique des plantes aquatiques (macrophytes) à Vohipeno, le dernier inventaire effectué date de la période coloniale de 1921 à 1936 selon l'ouvrage « Flore de Madagascar et des Comores » (Humbert 1967). La connaissance sur la flore aquatique de Madagascar est très ancienne. Cependant, à l'exception de cet inventaire, aucune étude n'a été menée sur la flore aquatique du district de Vohipeno.

Il existe un lien étroit entre la population locale et les macrophytes. C'est le cas pour l'espèce *Typhonodorum lindleyanum*, qui sert de nourriture à de nombreuses communautés (Sambo 2010). Les macrophytes constituent une source de revenu notable dans la région de Vohipeno, servant de matières premières pour l'artisanat et la vannerie (fabrication de nattes, chapeaux etc..) et la construction. Mais ce niveau d'exploitation perturbe l'écologie des macrophytes, entrainant la vulnérabilité de leurs écosystèmes (OFEV 2009). La conversion en rizières est le principal facteur de perturbation dans les zones humides à Madagascar (Kull 2012, Bamford et al. 2017, Phillipson et al. 2018) : l'exploitation des zones humides en zone de culture, notamment pour le riz, est très importante et la superficie naturelle des macrophytes régresse. Tous ces faits justifient le choix de la présente étude dont le but est d'améliorer les connaissances sur les macrophytes malgaches à travers des inventaires et des études de typologies des milieux lentiques (eaux stagnantes) du district de Vohipeno. Le district de Vohipeno est caractérisé par une population très dense avec plus de 98,8 hab/km^2 (CREAM 2013) sur une superficie de 1050 km^2. Les pressions générées par l'homme influencent les zones humides de Vohipeno. La majorité de la population locale est constituée d'agriculteurs et pousse certaines zones telles que les marais à être converties en rizières. La pêche est une activité relativement importante également et certains lacs sont affectés par la surexploitation. La culture de rente (café, litchi, girofle, etc…) constitue également une source de revenue pour la population locale. Selon la division phytogéographique de Madagascar, la partie orientale de Madagascar (y compris Vohipeno) est caractérisée par une forte pluviométrie pouvant parfois atteindre plus de 3000 mm (Moat & Smith 2007). Ces dernières années, de fortes précipitations entraînant des inondations dans cette partie de l'île ont eu des conséquences néfastes pour la production agricole.

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MATÉRIELS ET MÉTHODES

SITES D'ÉTUDE. Le district de Vohipeno se situe entre E47° 50' 25,08", S22° 21' 15,264" dans la province de Fianarantsoa, région Vatovavy Fitovinany (Figure 1). Dix sites ont fait l'objet de cette étude à savoir les marais Ambakamasay (s1), Angaditany (s9), Beafo (s10) et les lacs Andranomavo (s2), Ambato (s3), Ampandroananakara (s4), Alagna (s5), Ekarimbary (s6), Ranomenabe (s7) et Emasomaso (s8). Le climat de la côte sud-est est tropical sous l'influence de l'Alizé. Nos zones d'étude de la commune urbaine de Vohipeno et de la commune rurale d'Ivato ont un climat similaire. La période la plus froide est entre le mois de juillet et le mois d'août (16 °C). Le district de Vohipeno est caractérisé par une température moyenne annuelle de 24 °C. La température maximale peut dépasser les 30°C entre le mois de décembre et le mois d'avril. Les précipitations annuelles sont abondantes et varient entre 1245 mm et 2504 mm. La pluviométrie est importante du mois de décembre à avril (1230 mm) et généralement faible de juin à novembre (Direction Générale de la Météorologie 2015). Le sol de la région est composé d'alluvion et de sable et représente un terrain de type volcanique du crétacé (FTM 2000). Sur le bas fond, des sols ferralitiques rajeunis à structure plus ou moins dégradée peuvent être distingués, ainsi que des sols anciens indurés et concrétionnées (FTM 2000).

COLLECTES DE DONNÉES. Plusieurs matériels ont été utilisés pour effectuer les travaux de terrain : un GPS, un appareil photo, de vieux papiers journaux et une presse à herbier. La plante entière a été collectée. Tous les spécimens collectés ont été identifiés dans l'herbarium de Parc Botanique et Zoologique de Tsimbazaza (PBZT), Antananarivo et celui de Mahajanga (Université de Mahajanga). Une vérification des noms scientifiques a été réalisée sur le site web tropicos.org.

RELEVÉ ÉCOLOGIQUE. Chaque relevé a été échantillonné dans un milieu relativement homogène à l'aide d'un quadrat de 1 m^2. Dans les relevés échantillonnés, chaque taxon a été désigné par son taux de couverture végétale avec les indices d'abondance-dominance adoptés par Braun-Blanquet (1965). Les cinq échelles d'abondance dominance correspondantes sont les suivantes : r) un individu isolé par rapport à la surface échantillonnée ; +) désigne une couverture du taxon faible ; 1) couverture inférieure à 5 % ; 2) couverture entre 5 et 25 % ; 3) couverture entre 25 à 50 % ; 4) couverture entre 50 à 75 % et 5) couverture supérieure à 75 %.

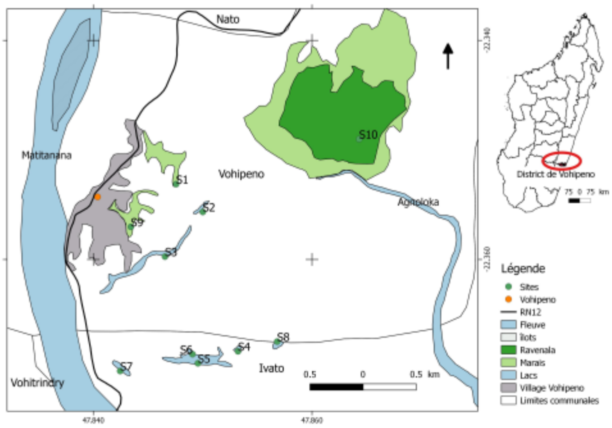

Figure 1. Le district de Vohipeno se situe entre E047° 50' 25,08", S22° 21' 15,264" dans la province de Fianarantsoa, région Vatovavy Fitovinany.

INDICE DE DIVERSITÉ. L'indice de Shannon (H') (Shannon 1948, Shannon & Weaver 1949), issu de la théorie de l'information, sert à évaluer l'importance de la diversité spécifique dans une station donnée. Cet indice évalue le nombre d'espèces présentes dans un relevé i et tient compte du recouvrement de différentes espèces dans le relevé j. La valeur de cet indice est d'autant plus petite que le nombre de taxon est bas (Vanpeene et al. 1998). La formule suivante permet de calculer ces valeurs.

$$H' = -\sum_{i=1}^{S} p_i \, log_2 p_i$$

pi désigne le recouvrement moyen relatif (RM%) de chaque taxon d'un relevé sur le recouvrement total (RT%) dans l'ensemble des relevés (pi=RM%/RT%).

L'indice de « régularité » ou « d'équitabilité de Pielou» complète cette approche. Cet indice permet de déterminer si la répartition des espèces est équitable ou au contraire si une seule espèce domine. Cet indice est exprimé par le rapport entre l'indice de diversité de Shannon H' et la diversité maximale H'max. Il convient de noter que le logarithme utilisé est le logarithme de base 2.

$$J' = \frac{H'}{H'max}$$

J' étant l'indice de régularité de Pielou

H'max le logarithme de base 2 du nombre de taxon total dans l'ensemble de site.

ÉTUDE COMPARATIVE. Cette étude comparative est la base du test de similarité et permet de déterminer l'affinité floristique entre les sites. Pour permettre le calcul de ce test, la formule suivante a été empruntée à Sorensen (1948).

$$Cs = \frac{2c}{a + b}$$

Ce coefficient de similitude « Cs » est le rapport entre le double du nombre d'espèces communes « c » à deux stations différentes et la somme du nombre total d'espèces des sites « a » et « b ». Si la valeur du coefficient « Cs » dépasse 0,5 les deux sites concernés sont dits similaires.

TRAITEMENTS ET ANALYSES DES DONNÉES. L'objectif de cette analyse est d'identifier les groupements floristiques qui caractérisent un site. Les données brutes ont été arrangées en utilisant Excel puis importées dans le logiciel R version 3.4.1 pour le traitement. L'AFC a été utilisé pour les données semi-quantitatives (Benzecri 1973, Meddour 2010) avec l'utilisation de code binaire pour chaque taxon (1 si le taxon est présent et 0 sinon). L'AFC (Analyse Factorielle des Correspondances) et la CAH (Classification Ascendante Hiérarchique) sont complémentaires. Le premier explique les différents gradients et le second les scinde et regroupe les sites et les espèces ayant les mêmes caractéristiques écologiques (Benhissoune et al. 2005). Les cartes des sites ont été faites à l'aide du logiciel QGIS version 2.18.

RÉSULTATS

DIVERSITÉ FLORISTIQUE. Au total, 43 espèces ont été recensées. Elles sont réparties entre 34 genres et 19 familles. Les familles les plus représentées sont les Cyperaceae avec une proportion de 39,5 %. Viennent ensuite les Poaceae (11,6 %), Araceae (6,9 %), Onagraceae (4,7 %) et Lentibulariaceae (4,7 %). On trouve 18 familles dans les marais. Elles regroupent 28 genres et 34 espèces. Dix-sept espèces seulement sont typiques des marais (soit 39,5 %). Au niveau des lacs les 26 espèces recensées sont réparties entre 21 genres et 13 familles. Neuf espèces sont typiques des lacs (soit 20,9 %). Le nombre d'espèces communes est de 17 (soit 39,5 %).

INDICE DE DIVERSITÉ. Les valeurs issues de l'indice de Shannon (H') (Tableau 1) montre que la diversité des plantes aquatiques et semi-aquatiques dans les marais tels qu'Ambakamasay (s1), Beafo (s10) ainsi que dans les lacs tels qu'Alagna (s5) et Ranomenabe (s7) est d'un niveau moyen. En revanche, cette valeur est faible dans d'autres sites, ce qui signifie que leur diversité est faible.

L'indice de régularité de Pielou (J') est très faible dans le lac Ambato (s3) (J' < 0,6), moyen (0,6 < J' < 0,8) dans les lacs et marais des sites s1 (Ambakamasay), s9 (Angaditany), s10 (Beafo), s6 (Ekarimbary) et, enfin, relativement élevé (J' > 0,8) dans les sites s5 (Alagna) et s7 (Ranomenabe).

ÉTUDE COMPARATIVE. Le cortège floristique du lac Alagna (s5) montre une affinité dans les sites s6, s7, s8 et s10. Ce dernier a aussi une affinité floristique dans les sites s1, s5, s6 et s8. Les espèces communes sont plus nombreuses dans ces sites que dans d'autres.

ANALYSE MULTIVARIÉE. Les deux premiers axes expliquent 45,2 % de l'inertie totale (Figure 2). L'analyse du premier axe (F1 : 25,9 %) permet d'écarter le marais Angaditany (s9, 78,8 %) sur le côté positif. Le marais est caractérisé par une longue durée d'inondation. Ses espèces caractéristiques sont *Azolla pinnata*, *Marsilea minuta*, *Commelina diffusa*, *Lemna paucicostata* et *Oryza sativa*.

L'analyse du second axe factoriel (F2 : 19,4 %) permet d'isoler deux sites. Le lac Ranomenabe (s7, 23,9 %) situé sur le côté négatif et le marais Ambakamasay (s1, 58,6 %) sur le côté positif. L'axe F2 détermine le gradient de la profondeur croissante entre les deux sites. Le marais Ambakamasay est caractérisé par des espèces telles que *Coix lacryma-jobi*, *Colocasia esculenta*, *Blyxa* sp, *Cyperus pectinatus*, *Echinochloa pyramidalis*, *Hydrocotyle vulgaris*, *Lepironia articulata*, *Rhynchospora corymbosa* et *Rhynchospora chinensis*.

La classification ascendante hiérarchique (CAH) scinde les sites en quatre groupes. Le premier groupe (groupe A) concerne le marais Angaditany (s9). Ce marais réunit les espèces caractéristiques des zones inondées en permanence. Le second groupe (groupe B) explique la variation de la profondeur du marais Ambakamasay (s1). Le troisième groupe (groupe C) met en évidence les espèces supra aquatiques. Ce sont les espèces qui se rencontrent souvent au niveau de la berge des plans d'eaux. Le quatrième groupe (groupe D) réunit les sites où les espèces peuvent coloniser les parties inondées et exondées.

Table 1. Indice de Shannon-Weaver avec transformation au pourcentage à la médiane de Van Der Maarel (1979) du coefficient d'Abondance Dominance de Braun-Blanquet. Les cellules grisées indiquent les valeurs importantes de cette mesure.

Indice	H'	H'max	J'
s1	3,2	4,46	0,72
s2	1,26	1,58	0,79
s3	1,1	2,58	0,43
s4	1,55	1,58	0,98
s5	3,29	3,58	0,97
s6	2,45	3,58	0,68
s7	3,62	4	0,91
s8	2,94	3,32	0,88
s9	1,89	2,81	0,68
s10	3,12	4,09	0,76

DISCUSSION

Quarante-trois espèces ont été recensées dans les dix lacs et marais inspectés. Cette richesse est marquée par les espèces appartenant à la famille des Cypreraceae. Cette famille est également plus représentée dans d'autres régions de Madagascar telle que la nouvelle aire protégée d'Antrema, le lac Kinkony (Maharombaka et al. 2012, Ramiandrisoa 2015). Le taxon y est aussi élevé variant de 30 à 50 espèces. Les sites échantillonnés dans le district de Vohipeno possèdent une richesse floristique élevée selon leur indice de diversité biologique. Les valeurs obtenues par l'indice de régularité de Pielou indiquent que les taxons se répartissent plus équitablement d'un site à l'autre, indiquant une hétérogénéité floristique. L'affinité floristique est très significative entre les sites s5, s6, s7, s8 ainsi qu'entre les sites s6 et s7. Cette forte similarité de la composition floristique est due à la faible distance qui sépare ces zones humides. Les zones marécageuses sont plus riches en macrophytes que les zones lacustres. Cependant, le marais Beafo (s10) possède presque tous les taxons rencontrés dans les lacs ainsi que dans le marais Ambakamasay (s1). Ces macrophytes sont distribués selon leurs affinités aux types de substrats ainsi que la situation géographique.

Les lacs ont souvent une surface en eau libre et les macrophytes peuplent leurs berges. Les berges du lac Ranomenabe ont une faible humidité et les espèces qui les caractérisent sont *Schoenoplectus juncoides* et *Fimbristylis littoralis*. Ces espèces sont souvent rencontrées dans les rizières et sont parfois qualifiées d'adventices. Au niveau des marais, la profondeur de l'eau est variable. Les parties temporairement inondées sont colonisées par des espèces telles que *Coix lacryma-jobi*, *Rhynchospora corymbosa*, *Lepironia articulata* et *Hydrocotyle vulgaris*. Certaines espèces sont cultivées, comme *Colocasia esculenta*. D'autres espèces se rencontrent dans les zones un peu plus profondes représentées par des hydrophytes telles que *Pistia stratiotes*, *Lemna paucicostata* et *Azolla pinnata*. Certaines espèces hydrophytes comme *Azolla pinnata* contribuent à l'enrichissement du substrat en éléments nutritifs notamment en Azote (Roger 1991). La profondeur et la durée d'inondation sont les paramètres déterminant la répartition des espèces du district de Vohipeno. Le marais Angaditany est marqué par une profondeur assez importante. Le lac Ranomenabe met en avant les espèces caractéristiques des berges et des rizières telles que *Schoenoplectus juncoides* et *Fimbristylis littoralis*.

Les facteurs influençant la répartition des macrophytes sont relativement similaires dans diverses régions de Madagascar notamment dans la partie orientale de la grande île. La nature du substrat, la profondeur et le taux de composés chimiques de l'eau influencent la distribution des plantes aquatiques (Ranarijaona 2007). La conversion des marais en zone agricole a pris une ampleur considérable comme évoqué par Ranarijaona (2007) et Lammers et al. (2015) sur le lac Alaotra. Ceci est également le cas dans la région Vatovavy Fitovinany particulièrement dans le district de Vohipeno.

CONCLUSION

La richesse floristique est importante dans le district de Vohipeno (région Vatovavy Fitovinany). Au total, 43 espèces ont été recensées. Elles sont réparties entre 34 genres et 19 familles. L'activité humaine est aussi importante dans le district étant donné que la majorité de la population locale est composées d'agriculteurs. L'analyse factorielle a permis d'identifier deux facteurs déterminant la répartition des macrophytes des lacs et marais du district de Vohipeno, soit la durée d'inondation et la profondeur. Ces sites d'études cibles n'ont jamais fait l'objet d'inventaire ni d'étude écologique. Cette étude a permis la collecte de nouvelles données ainsi que la mise à jour des connaissances sur la richesse floristique des sites et la répartition géographique des macrophytes.

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