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Testing the effectiveness of community-based conservation in conserving biodiversity, protecting ecosystem services, and improving human well-being in Madagascar

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ABSTRACT

This thesis is a scientific contribution towards evaluating the effectiveness of Community-based Conservation (CBC) in saving biodiversity, protecting ecosystem services and enhancing human well-being. The impact of CBC interventions carried out by Durrell Wildlife Conservation Trust over 109 villages in five conservation areas in Madagascar (Lake Alaotra, Baly Bay National Park, Menabe dry forest, Manombo rain forest, and Nosivolo River) since 1997, were retrospectively evaluated. The evaluation used a quasi-experimental design to contrast changes in a set of biodiversity and human wellbeing indicators in the intervention villages with 109 control villages, which were matched for a range of social and environmental attributes.

In Chapter 2, findings suggest that over the period 2000-2014 the CBC approach has impacted the incidence of fire, resulting in a lower rate of increase in fire frequency. Although CBC interventions were not able to reduce forest loss, the rate of deforestation in CBC villages has generally been maintained at lower levels than in control villages. Political disruption, population size and travel cost (access and distance) to the villages were identified as important contributing factors towards an increase in the severity of fires and deforestation while access to mobile phones may help mitigate the pressures.

In Chapter 3, results indicate that support to education through CBC interventions is significantly associated with improvements in educational attainment. However, analysis of the historical Index of Health Status at village level did not show evidence that provision of clean drinking water or other health interventions improved public health.

In terms of human well-being (Chapter 4), there is no evidence that CBC interventions have any positive impact on the Multidimensional Poverty Index. Since poverty has been identified as a key factor reducing happiness, mutual trust, and power to change local decision-making, the claim that CBC will be effective in enhancing subjective well-being cannot be supported by the evidence from this study.

According to the Index of Perception of Valued Ecosystem Services the declines in forest cover between 2000 and 2013 were observed by local people, with people in CBC villages demonstrating a greater propensity to note resulting changes in the provision of ecosystem services. This result could be of value when designing future CBC interventions.

Maximum Entropy modelling using a set of environmental GIS layers was performed in Chapter 5 for predicting geographic distribution zones of four globally threatened species living exclusively in the five study areas. Results suggested that over the period 2000-2014 there has been a decline in habitat suitability expressed by a decrease in probability of presence of the species. Vegetation cover is predicted to be the most important factor affecting the variability of species distribution range.

Potential factors responsible for the success of some actions and failure, others within the CBC approach are discussed and pragmatic recommendations are given at the end of the thesis. For example, transforming local associations into social enterprise could possibly motivate poorer households to join CBC efforts and thereby improve social and biodiversity impacts in the future.

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PREFACE

This thesis is structured into an Introduction, four data chapters, and a Discussion. The four data chapters (Chapter 2-5) are manuscripts in preparation to be submitted to scientific journals, and thus broadly formatted accordingly. It is also the intension to submit Chapter 6 (Discussion and concluding remarks) to a journal. The bibliography is listed at the end of each Chapter.

Supplementary material is found at the end of each chapter.

Paper 1: Evaluating the effectiveness of Community-based Conservation approaches in combating fires and deforestation in Madagascar

Expected journal: Biological Conservation

Paper 2: Evaluating the contribution of Community-based Conservation to local improvements in primary education and public health in Madagascar

Expected journal: Human Dimension of Wildlife

Paper 3: The potential of Community-based Conservation in enhancing human well-being and raising awareness of ecosystem services in Madagascar

Expected journal: Ecology and Society

Paper 4: Assessing the performance of Community-based Conservation in conserving habitats of globally threatened species in Madagascar

Expected Journal: Conservation Biology

GLOSSARY

AD: Anno Domini
ANOVA: Analysis of Variance
BC: Before Christ
CBC: Community-based Conservation
CBNRM: Community-Based Natural Resources Management
CEPE: Certificat d'Enseignement Primaire Elémentaire (Official primary school attainment)
CM: Co-management
CFM: Community Forest Management
CHD: Centre Hospitalier de District
CITES: Convention on International Trade in Endangered Species of wild Fauna and Flora
CPI: Corruption Perceptions Index
CSB: centre de Santé de Base
DGF: Direction Générale des Forêts
DREEF: Direction Régionale de l'Environnement, de l'Ecologie et des Forêts
DRPRH: Direction Régionale de la Pêche et Ressources Halieutiques
DSAPT: Direction des Systèmes des Aires Protégées Terrestres
Durrell: Durrell Wildlife Conservation Trust
FTM: Foiben-Taosarintanin'i Madagasikara
GCF: Gestion Contractualisée des Forêts
GEF: Global Environment Fund
GELOSE: Gestion Locale Sécurisée
GIS: Geographical Information System
GLM: Generalised Linear Model
GLMM: Generalised Linear Mixed Model
GPF: Gestion Participative des Forêts
GPS: Global Positioning System
JIRAMA: Jiro sy Rano Malagasy (Water and Electricity of Madagascar)
HDI: Human Development Index
ICDP: integrated conservation and development projects
INSTAT: Institute National de la Statistique
IUCN: International Union for Conservation of Nature
JIRAMA: Jiro sy Rano Malagasy
JOAC: Jersey Overseas Aid Commission
MDG: Millennium Development Goal
MODIS: Moderate Resolution Imaging Spectroradiometer
MOMA: Monitoring Matters
MPI: Multidimensional Poverty Index
MRPA: Managed Resources Protected Areas
NGO: Non-Governmental Organisation
NORDECO: Nordic Agency for Development and Ecology
OPHI: Oxford Poverty and Human Development Initiative
PCA: Principal Component Analysis
PMNR : Participatory Management of Natural Resources
RGA: Revenue Generating Activities
SAPM: Systeme des Aires Protégées de Madagascar
SDM: Species Distribution Modelling
UK: United Kingdom
UN: United Nations
UNDP: United Nations Development Programmes
UNEP: United Nations Environmental Programmes
USA: United States of America
WHO: World Health Organization
WHS: World Health Statistics
WWF: World Wide Fund for Nature
WWN: Word Wetlands Network

TABLE OF CONTENTS

Abstract **2**

Acknowledgements **3**

Preface **5**

Glossary **6**

Chapter 1: Introduction **9**

Background 9

Community-based Conservation 12

Aims of the study 25

The case study NGO: Durrell Wildlife Conservation Trust 26

Field study regions 27

Methods overview 34

Summary 45

Bibliography 45

Chapter 2 .... **52**

Paper 1: Evaluating the effectiveness of Community-based Conservation approaches in combating fires and deforestation in Madagascar **52**

Abstract 52

Introduction 53

Methods 59

Results 71

Discussion 79

Bibliography 86

Supplementary materials 90

Chapter 3 .... **94**

Paper 2: Evaluating the contribution of Community-based Conservation to local improvements in primary education and public health in Madagascar **94**

Abstract 94

Introduction 95

Methods 99

Results 113

Discussion 120

Bibliography 125

Supplementary materials 128

Chapter 4 .... **132**

Paper 3: The potential of Community-based Conservation in enhancing human well-being and raising awareness of ecosystem services in Madagascar **132**

Abstract 132

Introduction 133

Methods 140

Results 165

Discussion 183

Bibliography 188

Supplementary materials 194

Chapter 5 .... **196**

Paper 4: Assessing the performance of Community-based Conservation in conserving habitats of globally threatened species in Madagascar **196**

Abstract 196

Introduction 197

Methods 202

Results 215

Discussion 224

Bibliography 229

Supplementary materials 234

Chapter 6: Discussion and concluding remarks **244**

Abstract 244

Introduction 245

Beneficial impacts of Community-based Conservation 246

Problematic factors limiting the success of Community-based Conservation 248

Recommendations for more effective Community-based Conservation 254

Conclusion 263

Bibliography 264

Chapter 1: Introduction

Background

Biodiversity conservation actions in Madagascar have mainly been implemented in rural areas which play crucial socio-economic and cultural roles in the country. Rural areas represent villages and hamlets, most of the natural ecosystems, and sacred places such as tombs for ancestors. These rural areas also maintain the vast majority of the country's agricultural exploitation systems which contribute to the national economy.

The natural history of Madagascar

Map 1: Location of study areas

The island of Madagascar was isolated from the African mainland approximately 160 million years ago and broke away from India 65 million years ago. The first humans to colonise the 58 million hectare island were the Austronesians from the Sunda islands (a group of islands in the Malay archipelago), who arrived by outrigger canoes, between 200 BC and 500 AD (Crowther et al., 2016).

With at least 65 million years of isolation, Madagascar is renowned for its high diversity of species characterised by an exceptional level of endemicity. Exceptional levels of richness and endemicity combined with a high rate of habitat destruction resulted in Madagascar being recognised as a biodiversity hotspot in 1999 (Myers et al., 2000). All of the 103 extant lemur species (Mittermeier et al., 2010), 91% of the 384 reptile species, 98% of the 235 amphibian species (Glaw & Vences, 2007), 52% of the 310 bird species (Morris & Hawkins, 1998) and 80% of the 14,000 species of plants (Mayaux et al., 2000) are endemic to the island. However, since the arrival of humans around 2,350 years ago, Madagascar has lost more than 90% of its original forest with a high annual rate of deforestation amounting to 1.95%/year from 1990 to 2000 and 1.28%/year from 2000 to 2005 (Harper et al., 2007).

Increasing human occupation over the past 1,800 years has resulted in significant damage to Madagascar's forests and wetlands, resulting in widespread deterioration of the natural environment and dramatic increase in the use of fire (Burns et al., 2016). As a consequence, many of the natural ecosystems are highly threatened by illegal activities such as timber exploitation, slash and burn agriculture and fires. These threats are amplified by increasing poverty.

Governance and lifestyle

The Republic of Madagascar is a multiparty democracy, with 22 regions, 119 districts, 1,579 communes and 17,544 'fokontany', the smallest administrative division (INSTAT, 2010). Madagascar has a tradition of limited autonomy at village level associated with the institution of the 'fokonolona' - a village council composed of village elders and other local notables. The term fokontany, meaning village or group of villages, refers to a political subdivision, specific to Madagascar, organised through a local elected or appointed body. First established in 1975, the fokontany is based on the area inhabited by and used by a fokonolona, a network of individuals and families connected by relationship obligation. The importance of the fokonolona derives from its traditional role in maintaining order in the village and providing social and economic assistance to the village.

There has been no national demographic census since 2008 but the present population of the island is estimated at ~23.0 million compared with 11.2 million in 1990. The ethnic origin of the population is diverse and complex, reflecting the heterogeneity of the settlers who have arrived in Madagascar since its first colonisation. While the Malagasy language is spoken by eighteen different ethnic groups, the population as a whole is often considered to be Francophone, though only about 7% of the population in fact understand and speak French.

Respect for traditional culture which is deeply connected to the natural environment is widespread, and a high level of social cohesion produces strong social networks.

Poverty and conservation

The Republic of Madagascar has very high levels of poverty, with a multidimensional poverty index that increased from 0.35 in 2008 to 0.41 in 2011 (Alkire et al., 2013), about 80% of people live in rural areas and rely on natural resources to survive. The degree of inequality in the distribution of family income is high with a Gini index of 40.6% (0: perfect equality, 100: perfect inequality) (World Bank, 2015a). In terms of human development, in 2014 Madagascar was ranked 154 out of 155 countries, with a low Human Development Index (HDI) of 0.51 (UK 0.907, USA 0.915). The country has a high corruption index of 32, ranked 153 out of 188 (Transparency International, 2015) indicating a serious level of corruption in the public sector. Some 88% of inhabitants live below the international poverty datum line (UNDP, 2014). The average life expectancy is 66 years for men and 63 years for women, which is low compared to other countries (WHS and WHO 2015).

The low GDP of the country (10 billion USD) (World Bank, 2015b) has a significant impact on the management of natural resources. One reason is that 80% of Madagascar's fuel energy depends on wood, which is used for cooking, causing over-exploitation of the forest resources. Another reason is that rich people tend to acquire new farmland by exploiting forest, mangroves and marsh areas. Poor and rich families benefit very unequally from using the natural resources which have been rapidly declining during the last 15 years. The main pressures on natural resources are slash-and-burn agriculture, tree felling for firewood, charcoal and illegal timber exploitation, all of which cause loss and destruction of natural habitats. The government has difficulty in controlling illegal timber exploitation; therefore, many of the species are under serious threat of extinction.

The poor have often been accused of destroying resources. However, the rich people often pay the poor for planting crops on cleared forest land leading to the suggestion that the poor have jobs for their subsistence whilst the rich have the land and harvest. Some conservation managers argued therefore that conservation of biodiversity must take into account the current social inequality that exists and in particular the livelihood and food security needs of local communities. Against the backdrop of increasing human population, poverty and habitat destruction, there is an endless and intensified debate about the underlying rationales for biodiversity conservation in Madagascar.

Community-based Conservation (CBC)

Evolution of conservation approach

The joint IUCN/WWF/UNEP World Conservation Strategy defined conservation as the maintenance of essential ecological processes and life-support systems, the preservation of genetic diversity, and the sustainable utilisation of species and ecosystems (IUCN, WWF, UNEP, 1980). They pointed out that conservation is therefore a process to be cross-sectorally applied but not an activity sector in its own right. Since establishment of the first National Park in the world (Yellowstone National Park, United States 8,983sqkm) in 1872, the conservation approach has evolved. Strict protection of biodiversity proved to be impossible in isolation (Kandziora et al., 2012). It became apparent that people and wildlife were interdependent so that their needs are addressed together (Campbell & Vainio-Mattila, 2003; Berkes, 2007). The involvement of people in conservation and management activities grew across time. By the late 1980s, the Community-based Conservation (CBC) approach was developed in a number of countries around the world, reversing top-down conservation policies driven by central governments. CBC aims to place local culture at its centre and focuses on the people who would experience the benefits of conservation. It was a natural follow-on from the integrated conservation and development projects (ICDP) led by the World Wide Fund for Nature (WWF) in the mid-1980s, which were specifically set-up to meet development and conservation goals related to the national protected areas network (Hugues & Flintan, 2001).

Definition of CBC

Western and Wright (1995) simply defined CBC as natural resources or biodiversity protection by, for, and with local communities, but pointed out that there is no need to give a precise definition of CBC as it involves a range of activities practiced in different countries. However, it is important to note that CBC aims at implementing harmonious coexistence of people and nature, as different from strict protectionism and separation of people and nature. Community-based Conservation is therefore a pluralistic approach to biodiversity protection, with multiple objectives, starting from the ground up which involves networks and linkages across various levels of organisation (Berkes, 2007). Slightly different from ICDP (see below), CBC aims at establishing clear linkage between conservation and livelihood, by putting local people in the centre of the management structure (Campbell & Vainio-Mattila, 2003), rather than increasing benefits from alternative livelihood activities around protected areas.

Community conservation activities usually known as CBC are also sometimes called 'locally based conservation', 'community led management', and 'community based management'.

Since late 1980s, the CBC approach has been widely adopted in the belief that this is the most effective way to promote and deliver conservation, while at the same time tackling issues of human well-being that have a direct impact on the local environment. These concerns include demographic issues, high rates of illiteracy, the rights of indigenous people, poverty, and lack of resources, corruption and poor governance. For this reason, poorer and less developed countries seeking ways to reduce human pressures on the local environment have been at the forefront of the development of the CBC approach. It is argued that with this approach, the potential to empower members of local communities, build capacity, and change attitudes enables them to take charge of the management of their natural resources or protected areas. These promised outcomes have influenced many governments in developing countries including Madagascar to prioritise the CBC approach in the management of natural resources.

Typology of CBC

The following main types of CBC have been used to develop the current model:

1. Integrated Conservation and Development Projects (ICDP)

2. Co-management, joint/mixed/collaborative management, or Participatory Management of Natural Resources (PMNR)

3. Community-Based Natural Resources Management (CBNRM)

4. Community Forest Management (CFM)

1. Integrated Conservation and Development Projects ICDP)

ICDPs occur around protected area and have a dual and equal focus on biological conservation and human development. Their main goal is to link conservation and development such that each fosters the other, providing benefits from alternative livelihood activities outside the protected areas (Hugues & Flintan, 2001). However, the community has no management responsibility for the protected area. For example, local communities are given cash to dis-incentivise destruction of forest.

2. Co-management or participatory management of natural resources (PMNR)

Conservation NGOs, regional government services and local community manage the natural resources (mainly within protected areas) together. The management committee can be semi-administrative but receive substantial financial and technical support from NGOs in the development of conservation strategy and planning of activities. This approach emphasises the establishment of the permanent partnership between the civil society and local authorities to manage and monitor natural resources, reports on irregularities and steers public discussions on the issues arising in the forests (Borrini, 2000). The PMNR which is mainly based on collaboration and exchange of knowledge, is often a temporary approach until local people have full ability to sustainably manage and monitor their natural resources.

2. Community-Based Natural Resources Management (CBNRM)

CBNRM refers to the collective use and management of natural resources in rural areas by a group of people with a self-defined, distinct identity, using communally owned facilities (Piers, 2006) i.e the focus of CBNRM is not to implement institutions for managing common property resources. Local communities are defined by their tight spatial boundaries of jurisdiction and responsibilities, by their distinct and integrated social structure and common interests, can manage their natural resources in an efficient, equitable, and sustainable way. Thus, the idea of CBNRM has evolved through time and been specific to particular countries.

3. Community Forest Management (CFM)

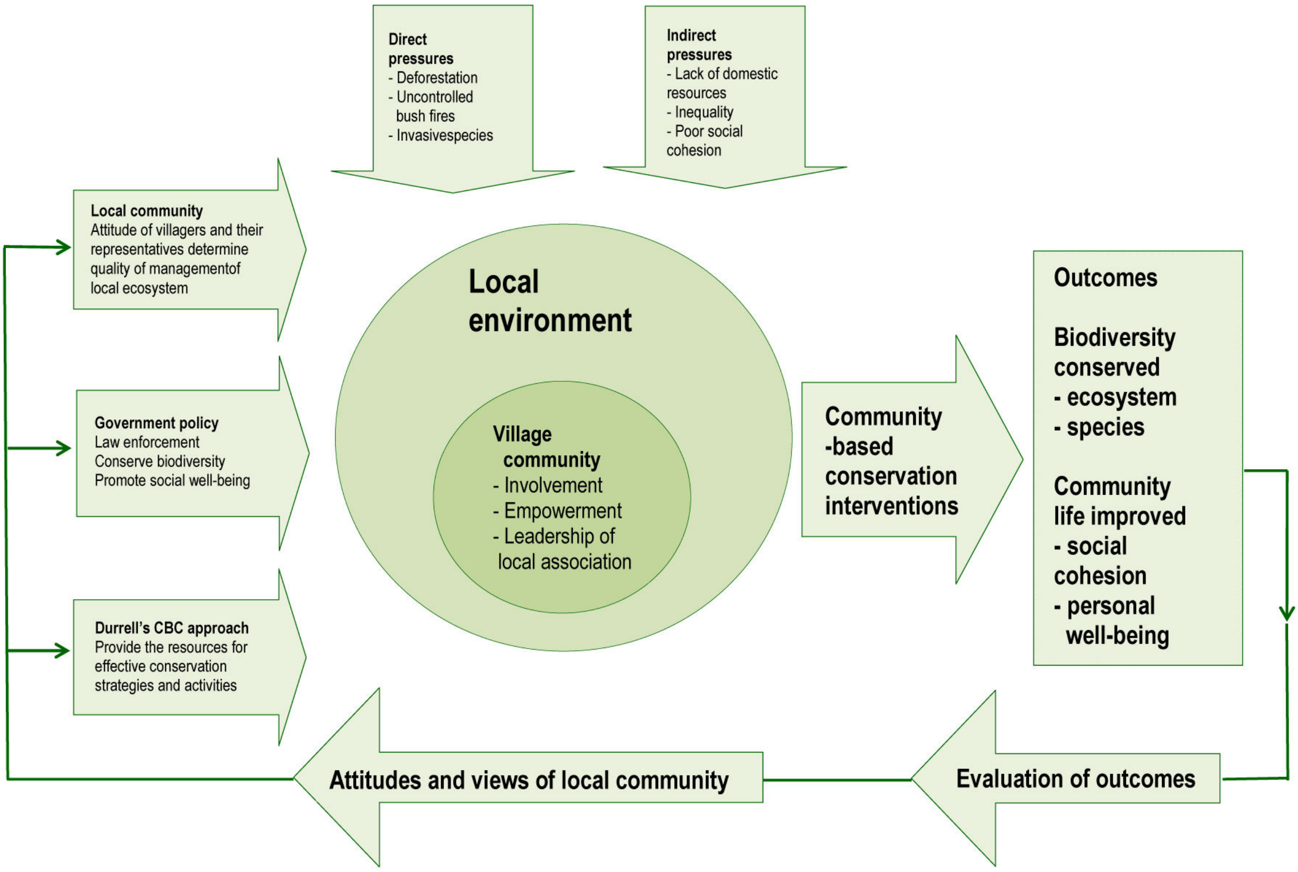
CFM is based on a legal framework providing communities with the official right and contractual agreement to manage natural resources within their traditional terroir (Rasolofoson et al., 2016). In the case of Madagascar, this refers to the official management transfer of forests from regional government (Minsitry of the Environment, Ecology and Forests) to the local association (VOI: Vondron'Olona Ifotony), with approval and oversight of the local authority (Commune). A new environmental law approved CFM in 1996 (cf paragraph about Madagascar conservation policy page 18-19).

Conceptual model

Various different NGOs have their own concept as to how CBC should best be operated and where the emphasis between community and biodiversity should lie. CBC in Madagascar as practiced by Durrell, actually combines elements of all four earlier versions of CBC mentioned above. The current approach emphasises the interaction between local people and their environment, in order to reduce biodiversity threats whilst improving social well-being (see Fig. 1 for a conceptual model). It also emphasises the provision of tools and resources, rather than cash, to meet the researched needs of individual communities. The main objective is to engender voluntary engagement of the majority of local people to protect the environment through a simple change of attitude without necessarily having a formal contract.

In Madagascar where the state has limited financial resources, the delivery of community conservation relies upon three main actors: the local communities, the government, and the NGOs. The synchronisation of the actions of these three actors often guarantees the accomplishment of the community conservation projects. CBC projects tend to have two main goals: to conserve natural habitats including threatened species and to improve local communities' well-being. CBC which aims to place local culture at its centre requires frequent contact and meetings with local communities to integrate them in conservation actions and to provide information that improves their knowledge about management for conservation.

In this study, it is assumed that the success of CBC relies upon a number of interlinked factors including the attitude of the community members, the quality of governance, the transparency in law enforcement (in Madagascar, the representatives of state have the sole authority to enforce official regulation), and the continuity of adequate technical/financial support from conservation managers.



Developed by the author, June 2016

Figure 1. Conceptual model for Durrell's Community-based Conservation approach

Community conservation policy in Madagascar

Between Madagascar's independence in 1960 and 1995, the government's approach to conservation was largely based on coercive measures. In response to ever dwindling biodiversity and large rates of land degradation in Madagascar, there was in 1996 a radical change of policy relating to the management of natural resources. Under the National Law Ref 96-025 in 1996, the Government of Madagascar officially transferred the management of natural resources to local communities. This allows local community users of natural resources to manage a piece of forest or wetland within their traditional *terroir* if they wish. This resulted until 2014, in the creation of 1,019 management transfer contracts covering 15% of the national forest cover (Rasolofoson et al., 2016), including GELOSE[1] and GCF[2] agreements which are applicable to forests, wildlife, pastures and lakes (Rasolofoson et al., 2016). Under those two types of management contracts, local communities are able to control the resource management through the local and traditional regulation 'dina' governed by the traditional chief of the village.

During the 2003 World Park Congress in Durban, the Government of Madagascar decided to expand the size of protected areas from 1.7 million hectares to 6 million hectares. The purpose was to cover about 10% of the country so that Madagascar could contribute to the 7th goal of the United Nations Millennium Development Goal (i.e. ensure environmental sustainability) and the 2010 UN's Convention on Biological Diversity (CBD) 'to achieve a reduction of the current rate of biodiversity loss at the global, regional and national level, as a contribution to poverty alleviation and to the benefit of all life in earth'. That vision (known as Durban vision) required the Ministry of Environment and Forests along with 32 conservation NGOs, including Durrell to create 93 new protected areas that received official permanent decree in July 2015. The goal was to manage these new protected areas under IUCN (International Union for Conservation of Nature) category V and VI, which aims to allow local people to be involved in conservation and monitoring processes; in effect to create a large-scale CBC approach.

Known potential limitations of CBC

CBC schemes have been widely adopted and become the choice of biodiversity conservation organisations in many countries, including Madagascar. Members of local communities are mobilised and empowered to achieve conservation and monitoring activities by offering incentives such as the construction or renovation of village schools, digging new wells, fitting taps for clean drinking water or other practical initiatives that

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[1] GELOSE: Gestion Locale Sécurisée - *Secured Local Management*
[2] GCF: Gestion Contractualisée des Forêts - *Contracted Forest Management*

reinforce social cohesion, while at the same time providing training in monitoring and management of the local environment. However, their success, both in terms of their ability to conserve biodiversity and support and improve personal well-being, is still poorly understood and there has been criticism of the failure to produce sufficient evidence of their success (Garcia & Lescuyer, 2008). There is a lack of conditionality in the arrangement between local community and its environmental management performance, and the support they receive. The CBC approach has also been criticised for being overly complex in its implementation, and too ambitious in its aims often trying to address many challenges simultaneously (Danielsen et al., 2006). Conservation NGOs have also been accused of becoming too development-focused, sometimes spending more resources on improving human well-being than on biodiversity conservation.

Possible limitations of CBC that have therefore been recognised include the challenges of delivering dual conservation and development goals with limited budgets, the lack of understanding of the interactions between environment, human wellbeing and local institutions. It has also been suggested that tradeoffs between conservation and development could result in delegitimising conservation as a priority and thereby reducing conservation effectiveness (McShane & Wells, 2004).

Other limitations

A quantitative understanding of the full impact of CBC projects is essential for the current and future development of successful long term conservation strategies. To date, conservationists have often depended on intuition and anecdote to guide the design of conservation intervention (Ferraro & Pattanayak, 2006) and they have encountered considerable difficulty in finding the right data or metrics to evaluate success or failure. There is a widely shared view that developing any one simple and practical method for measuring CBC effectiveness will inevitably be problematic since contexts can differ significantly from one country to another, and multidisciplinary expertise is required. However, judging the effectiveness of conservation interventions is essential to ensuring that scarcecost efficiency in achieving conservation outcomes.

Importance of evaluating impacts

Measuring CBC effectiveness

How effective are CBC approaches? Do they achieve the aim of being good for human well-being and good for biodiversity conservation at the same time? Or does one aspect (e.g. human well-being) get favoured above the other? And what aspects of well-being benefit by this approach? Similarly, are there particular aspects of biodiversity that benefit? These questions whilst pertinent and timely, as yet remain unanswered. The reason for this is mainly due to the lack of long-term quantitative studies to assess the impact of conservation projects and this represents an important knowledge gap (Ferraro & Pattanayak, 2006). Consequently, in recent years a number of relevant international initiatives and studies have been set up in an attempt to develop new methodologies to evaluate conservation generally and CBC in particular with mixed results. For example, in 1999 the Threats Reduction concept was developed (Salafsky & Margoluis 1999) to evaluate the effectiveness of conservation projects; and in 2013, Brooks et al. (2013) conducted a systematic review and multilevel analysis to assess impacts of CBC projects.

There have also been a number of case studies such as Glew et al. (2010) that examined the effectiveness of CBC in North Kenya. However, the majority of these studies are qualitative and there are very few published studies where the goals of biodiversity conservation have been considered alongside understanding the impact of educational, economic and health programmes.

Similarly, there are few studies that have evaluated the impact of Protected Areas and Payment for Ecosystem Services (PES) on biodiversity conservation or human well-being: Clements & Milner-Gulland (2015) applied a matching method to understanding the social and environmental impact of a protected area network and PES in Cambodia; they found that both PES and Protected Areas delivered environmental benefits in relation to a reduction of deforestation rates. But they also discovered that Protected Areas had very limited impact on human wellbeing, and the effectiveness of PES depended on the level of money invested per household. Andam et al. (2010) who used quasi-experimental matching methods to evaluate the effect of Protected Areas on levels of poverty in Costa Rica and Thailand, realised that the poorer economy observed within neighbouring communities was not due in any way to the Protected Areas. Finally, Rasolofoson et al. (2015), who studied the effectiveness of community forest management in reducing deforestation in Madagascar found no evidence of success.

Socio-political structure of Madagascar

There are 17,544 fokontany in Madagascar and they are the fourth level official administrative division, after Regions, Districts and Communes. Every fokontany is required to have a public primary school. Every commune, or group of fokontany, will have a health centre, a gendarmerie (police station) and a taxi-brousse service. A commune designated as 'chef-lieu de district' will have a population of at least 10,000 inhabitants. Whilst a typical commune will have a level 1 or 2 health centre (Centre de Santé de Base I or II), a district will have a Centre Hospitalier de District (CHD level 1) providing a reasonable quality of healthcare up to surgery for appendicitis. A 'chef-lieu de region' will have better equipped health centre (CHD level 2), with capacity for more complex treatments such as stomach or intestinal surgery. A chef-lieu de district is required to have at least one public high school, a post office, representatives of government services (Environment and Forests, Fisheries, Farming, Agriculture), a gendarmerie and a market operating at least once a week. In addition, a chef-lieu de district will generally have mobile phone reception, electricity supply, and mutual micro-credit cooperative capable of supporting local development projects. Villages closer to a chef-lieu de district are likely to have better law enforcement than more remote villages.

System of Protected Areas

The System of Protected Areas of Madagascar (SAPM) comprises two groups: existing Protected Areas, managed by Madagascar National Parks (MNP); and New Protected Areas designated after the 2003 Durban vision. Each protected area has a management plan, environmental and social impact assessment, environmental permit, and a social and safeguard plan aimed at meeting social and environmental goals. Management plans are based on official zoning, with three distinct zones: a Strict Conservation zone (~30%); a Controlled Use zone (~40%); and a sustainable Development zone (~30%). This zoning determines the types of activity that are authorised or restricted in each zone, directly related to anthropogenic pressures such as fires and timber felling that result in forest loss and habitat fragmentation.

Fires are strictly forbidden within any Protected Area. Within a Controlled Use zone, tree felling, mainly for construction timber and domestic fuel, requires special authorisation from the Regional Environment and Forest Service. Within a Sustainable Development zone the use of any natural resources requires approval from the formal Local Association in charge of the management. Public consultation organised through village meetings from local to regional level is required to ensure that a majority of the inhabitants agree with the plan for the Protected Area. The outcome of the consultation process is recorded on an official boundary map as defined by the official protection decree.

Provision of ecosystem services

Madagascar has five distinct ecoregions (humid forest, central highlands, dry deciduous forests, succulent woodland, spiny thicket) (Burgess, 2004), each one providing services that are culturally, socially and economically essential for people's livelihoods (Lowry et al., 1997). The greatest direct social benefits derived from both dry and rain forests include wood for fuel, wood for house and furniture construction, charcoal, food products (yams, fruits, and nuts) and medicinal plants. Wetlands are also important (river, lake, mangrove and marsh) in the provision of transport, water for drinking, washing and irrigation, fish, reeds and mangrove wood for construction and craft work.

In terms of direct economic benefits people can earn a living collecting timber for sale, felling trees for domestic fuel (charcoal), collecting honey from bees for sale in the public market, or medicinal plants on which many people rely. In wetland areas fishermen benefit from the sale of fish, crabs, oysters and crayfish; in other areas reeds or mangrove wood can be sold for handicrafts and construction.

The majority of Malagasy people share the cultural belief, linked to respect for their ancestors, that natural undisturbed forest has a moral or sacred value. Graves are often located in the forest and certain species of tree such as *Givotia* sp and *Dalbergia* sp are reserved for making biers and coffins for funeral ceremonies which gives additional historical significance to forest sites. It is widely believed that if forest or other sacred sites are violated they will not provide their important service of respect to the ancestors, lose their value to the people, and eventually disappear. In addition, in many locations specific native plants or wild animals are used in important ceremonies and afforded special protection due to a belief that they will bring about a successful harvest or good health.

Aims of the study

Through a case study of CBC projects in Madagascar led by the conservation NGO Durrell Wildlife Conservation Trust (Durrell), this thesis aims to determine whether CBC is effective in reducing threats, protecting biodiversity, maintaining ecosystem services and enhancing human well-being.

I retrospectively evaluated the extent to which the implemented community based conservation projects in five conservation sites (Alaotra, Menabe, Manombo, Baly and Nosivolo) have been successful in reducing the incidence of fires, habitat fragmentation, and forest loss, and in improving social cohesion, health, education and poverty levels in local communities. This was performed through a quasi-experimental design by contrasting a series of environmental and social indicators in CBC intervention villages with control villages that were matched for environmental and social conditions at the beginning of the CBC intervention. A combination of remote-sensing data, government social datasets and a household survey were used to characterise the environmental and social indicators.

The following research questions were addressed:

- How effective are the community based conservation projects in meeting biodiversity, ecosystem services and well-being goals?
- Which institutional and socio-economic factors can determine the effectiveness of those projects?

Findings from this study will provide a better understanding of the effectiveness of community based conservation in achieving biodiversity and social goals. They will inform decision making and policy at regional and national level and assist in designing likely successful projects in future.

Main hypotheses

Compared with control villages, it was hypothesised that the Durrell project villages that have undergone community-based conservation projects:

1. Maintain higher levels of biodiversity by protecting greater suitable habitat for endangered species,
2. Have higher provision of ecosystem services,
3. Experience reduced levels of ecosystem degradation,
4. Have communities with higher levels of human wellbeing,
5. Have greater social cohesion and stable governance.

The case study NGO: Durrell Wildlife Conservation Trust

Durrell is a British organisation founded by Gerald Durrell in Jersey in 1959. Durrell delivers intensive conservation actions for endangered species in 16 countries across the world including Mauritius, India, Caribbean and Comoros. These field conservation projects are supported by captive breeding programmes at Jersey Zoo and conservation training initiatives conducted both in Jersey and in range countries. With 42 employees across the country, Madagascar is the largest of Durrell's programme.

Durrell started to work in Madagascar in 1986 for Ploughshare tortoise conservation at Cap Sada, Baly Bay National Park by implementing a captive breeding centre in Ampijoroa (Ankarafantsika National Park). The organisation progressively expanded its interventions and decided to introduce community based conservation from 1997 across all sites to reduce pressures and better manage natural resources. The community conservation was enhanced further by participatory ecological monitoring through organisation of annual inter-village environmental competitions which started in 2001. Durrell is now one of pioneer NGOs in terms of community-led conservation projects in Madagascar. It has seven conservation sites across the island: Lake Alaotra, Menabe dry forest, Nosivolo River, Manombo moist forest, Baly Bay National Park and, Bealanana lakes and Ampijoroa. Bealanana and Ampijoroa are not included in this thesis because Bealanana is a new intervention site following the recent rediscovery of Madagascar Pochard by The Peregrine Fund, and Ampijoroa is mostly for captive breeding of endangered species.

Durrell has been working with local communities in Madagascar to promote biodiversity conservation and sustainable use of natural resources for more than 15 years. Long term programmes at village level have involved substantial investments of staff time, cash and other resources to deliver community-based conservation.

Field study regions

Five study regions (Map 1) were selected for the study as follows:

1. Alaotra watershed

The Alaotra wetlands are located in central eastern Madagascar (48.40E-17.55S). Lake Alaotra, situated at 750m above sea level (asl) is 20,000 hectares and has an average depth of 2-4m. Surrounding the lake are 23,000 hectares of marshes dominated by papyrus *Cyperus madagascariensis* and reeds *Phragmites communis* and 120,000 hectares of rice-fields within a watershed encompassing 722,500 hectares that was designated as Ramsar site in 2003 (Andrianandrasana et al., 2005). This region has high conservation value due to the presence of a site-endemic Critically Endangered primate, the Alaotran gentle lemur *Hapalemur alaotrensis* which is believed to be in long-term decline (Ralainasolo et al., 2006; Ratsimbazafy et al., 2013) and one the 25 most endangered primates in the world (Schwitzer et al., 2015). A population of a species of globally threatened euplerid carnivore, *Salanoia concolor*, is known to inhabit Alaotra's marshlands. This population is believed by one author to be sufficiently distinct to be considered a new species *Salanoia durrelli* (Durbin et al., 2010) but this is not widely supported (S. Goodman, pers. comm.). The two Madagascar-endemic bird species Alaotra little grebe *Tachybaptus rufolavatus* and Madagascar pochard *Aythya innotata* are believed to be now extinct from the site with the grebe now probably fully extinct, probably because of exotic fish introduction, habitat destruction and by catch of the local subsistence fisheries. Of the 50 waterbird species recorded at the lake (Langrand, 1995), eight are Madagascar endemics. Six fish species, indigenous to Madagascar, can be found at Lake Alaotra (Pidgeon, 1996). The endemic fauna of Alaotra is severely threatened due to major environmental changes including habitat degradation, over-fishing, competition and predation by introduced fish species (Copsey et al., 2009), siltation from erosion (Bakoariniaina et al., 2006), pollution by human waste, fertilisers and pesticides and especially invasion of introduced aquatic plants. The survival of *Hapalemur alaotrensis* is highly uncertain due to increased habitat loss caused mainly by marshland fires and a growing agricultural pressure (Rendigs et al., 2015).

The human population living in the Alaotra watershed has increased from 109,000 in 1960 (Pidgeon, 1996) to approximately 800,000 people in 2012, the majority of whom rely on fishing and rice farming for their livelihood. The Alaotra region is the most important rice production area in the country and one of the most important inland fisheries. Since a peak in the 1960s of 4,000 tonnes (Pidgeon, 1996), annual fish catches have declined to around 2,000 tonnes in 2002 (Andrianandrasana et al., 2005), 800 tonnes in 2012 and about 450 tonnes in 2015 (DRRHP, 2016), probably as a result of over-fishing, acidification and other changes related to introduced species and siltation. The number of fishermen increased from 1,000 in 1963 (Pidgeon, 1996) to 4,000 in 2003 to approximately 12,000 in 2016 (DRRHP, 2016).

In order to save the biodiversity of the area, in 1997 Durrell began Community-based Conservation actions with festivities known as ‘fetin’ny zetra’ aimed at building trust with local communities. Between 1997 and 2012, a variety of community-based projects were implemented in 32 villages surrounding the lake. The first management transfer of an area of marsh was implemented in 1999. Then Durrell started to implement the first annual inter-village competition in 2001. From that year, prizes were given as materials to each of the villages for improving education and public health conditions and also for reinforcing social cohesion and increasing income. In 2011, local monitoring was expanded from annual participatory ecological monitoring to regular patrols. Some 96 local monitor volunteers were engaged to run village patrols on wetlands once a week. Lake Alaotra was officially designated as a temporary protected area in 2007 and received a permanent protection decree in 2016.

2. Menabe dry forests

The deciduous and dry forests of western Madagascar (44.69E, 19.97S) are one of the richest and most unique tropical dry forests in the world (Guillaumet, 1984). The Menabe Antimena Protected Area (210,000 hectares) represents the largest remaining dry deciduous forest block in Madagascar. It is characterised by a very high rate of endemism with several site-endemic species such as the flat-tailed tortoise *Pyxis planicauda*, the giant jumping rat *Hypogeomys antimena*, and the narrow-striped mongoose *Mungotictis decemlineata decemlineata* (Young et al., 2008). Menabe is home to one of the most well-known forested landscapes in Madagascar characterised by baobab trees *Adansonia* spp. However, this habitat has been heavily impacted by deforestation and is now severely fragmented because of timber harvesting, and slash and burn agriculture (mainly peanuts and maize). By 1990, only 2.8% of the original extent of the forest was estimated to remain (Smith, 1997), making this study region one of the highest conservation priorities in Madagascar (Ganzhorn et al., 2001). The overall rate of deforestation in Menabe is 0.7% per year from 1973 until 2010 but it increased from 1.5% to a maximum of 3.3% per year between 2008 and 2010 (Zinner et al., 2014). Within the Menabe Antimena Forest is Bedo Lake, classified as a Ramsar site in 2007. Lake Bedo hosts at least 34 waterbird species such as the nationally-endemic Madagascar Teal *Anas bernieri*, Madagascar heron *Ardea humbloti*, Madagascar plover *Charadrius thoracicus*, and migratory waterbirds like the greater flamingo *Phoenicopterus roseus* and lesser flamingo *Phoenicopterus minor.* It is also home to the endangered Madagascar big-headed turtle *Erymnochelys madagascariensis* (Rere) and the largest endemic carnivore *Cryptoprocta ferrox* (Fosa). This region is a major source of protein (prawns, crabs and fish) for the adjacent human communities, who also graze cattle there due to the availability of water and shade from adjacent forests.

Durrell initiated CBC interventions in Menabe in 2000 by supporting local environmental associations. The first official management transfer was GPF (participative management of forests) in Tsitakabasia in 2002. The Government classified Menabe Antimena dry forest as a new protected area in 2005, and then designated the NGO Fanamby as manager. In 2010, ten villages around the new protected area received their official management transfer under GCF (contracted management of forests). Durrell's community conservation activities in Antsalova district (complex Tsimembo new protected area) began in 2011. The effectiveness of local patrols was studied in Menabe between 2007 and 2009 through MOMA (Monitoring Matters) project with NORDECO Denmark by comparing biodiversity and threats data collected by local patrollers and scientists. No significant difference was found between quality of data collected by scientists and local community between 2007 and 2009 (Danielsen et al., 2014). The Community-based PES (Payment for Ecosystem Services) implemented by Durrell in Menabe was generally successful but presented a lack of adequate benefits to local people due to high agricultural opportunity costs, weak governance, and evidence of sub-groups of people who receive excessive benefits (Sommerville et al., 2009). The approach also had limited impact on people's attitude and behaviour change (Sommerville et al., 2010). Therefore, CBC and local monitoring were strengthened in 2011, and 132 local volunteer monitors were engaged to carry out village patrols once a week

3. Nosivolo River

Located between the Mahanoro and Marolambo Districts in East of Madagascar, Nosivolo (48.11E, 20.04S) is probably the most important river for fresh water fish conservation in Madagascar. Durrell's CBC started in this region in 2005. The Nosivolo River Protected Area (7,083 hectares) is home to 19 endemic fish species, four of which *Oxilapia polli*, *Ptychochromoides katria*, *Bedotia* sp *zono*, *Bedotia* sp1. *nosivolo* are locally endemic and believed to qualify as Critically Endangered.

Nosivolo River, 220km in length, is very rocky and has high flow regulation. Its source is the Fandriana Marolambo humid forest corridor and it flows into the Mangoro River before reaching the Indian Ocean. There are at least 80 villages with 150,000 inhabitants living along the River, 80% of them rely on subsistence farming including slash and burn agriculture. Fragments of rain forest within Nosivolo River Protected Area (Vohibe, Vohitrambo) are home to rare species of lemur such as *Prolemur simus*. The most severe threats are deforestation of the watershed, agriculture on the river banks, and traditional gold mining in the river. The Nosivolo watershed is degraded and highly invaded by secondary vegetation dominated by *Ravenala madagascariensis*. The eastern region of Madagascar presents a relatively high rate of deforestation (2.19%/year) between 1990 and 2000, reducing to 0.53%/year between 2000 and 2005 (Moat & Smith, 2007).

The native fish conservation project in Nosivolo River began in 2005. Creation of local associations was encouraged. Local associations started to set up strict conservation areas known as 'no fishing zones' measuring 1-1.5km long in each village. They also convinced the authorities to implement a long period of 5 months of closure every year to protect the fish in the river. In 2010, Nosivolo River was designated as a temporary protected area and a Ramsar site (358,511 hectares) in a bid to conserve both the river and fish stocks. Nosivolo is the first river Ramsar site in the country. It was awarded the Blue Wetlands globe award by the World Wetlands Networks 2012.

4. Manombo humid forest

Located in the south east of Madagascar, in Farafangana district (47.70E, 23.00S), Manombo rain forest is an important area for lemur conservation. Manombo is divided in two parts: the Special Reserve (5,270 hectares) managed by Madagascar National Parks, and the Classified Forest (1,750 hectares) managed by the Ministry of Environment and forests. It is home to eight lemur species: *Microcebus jollyae, Hapalemur meridionalis, Daubentonia madagascariensis, Cheirogaleus major, Avahi ramanantsoavanai, Lepilemur jamesorum, Eulermur cinereiceps, and Variecia variegata editorum*. These last three are Critically Endangered (Schwitzer et al., 2013). Local people are not allowed to have management transfer in those two parts of forests. However, thanks to collaboration between Durrell and MNP they were given the responsibility to regularly monitor biodiversity and anthropogenic pressures to help with the management and to make sure they were aware of the environmental changes. The main anthropogenic pressures in Manombo are: illegal timber exploitation for fournitures, construction and canoe fabrication, lemur hunting, and slash and burn agriculture.

Durrell's CBC intervention in Manombo Special Reserve and Classified Forest started in 2006 and involves seven villages. Creation of local associations in each village was supported, together with development and social activities aimed at improving people's livelihoods and reinforcing social cohesion. In 2011, 66 local monitors were engaged to carry out weekly patrols in the forests of this area. Since 2014, this classified forest is managed by the local association Tany Maitso.

5. Baly Bay National Park

Baly Bay in western Madagascar (45.30E, 16.09S) was the first Durrell field conservation site in 1993 looking to conserve the Ploughshare tortoise *Astrochelys yniphora*, one of the rarest tortoises in the world (Walker et al., 2015). With a wild population size of less than 400 adults remaining, this species is endemic to Madagascar and is confined to Baly Bay National Park, 63,000 hectares, in the North East of the country. This species lives in a mosaic dominated by bamboo shrub vegetation, which is vulnerable to fire (Andrianandrasana, 2001). Despite the national protection under both endangered species (no collection allowed) and national park legislation (no collection allowed), as well as international protection (under CITES as an Appendix I listed species), *Astrochelys yniphora* remains threatened by bush fires and illegal collection. In recent years, this species has suffered considerable pressures from both destruction of habitat (Pedrono, 2008) and from illegal collection and export for the international pet trade. Approximately 86 individuals of this species were seized and exported illegally mainly to South East Asia between 2010 and 2013 (Shepherd et al., 2013). Between 1998 and 2015, Durrell released about 100 captive born individuals of *Astrochelys yniphora* to maintain the population at a well-protected site within the National Park.

Since about 1996, further Community-based Conservation interventions have been implemented with villagers empowered through training to effectively manage their local natural resources. In 2005, Durrell initiated the inter-village competition through which prizes were spent on development and social activities. In 2010, the local monitoring was strengthened by engaging 30 local monitors to carry out patrols across Baly Bay National Park to reduce illegal collection of the ploughshare tortoise.

Methods overview

Selection of indicators

In the five study sites Durrell supports 109 villages through working with local associations or local communities. About 30 intervention villages manage the natural resources under official management contracts. Support to these associations is provided in several ways to make sure that they have the capacity to manage the natural resources. These forms of support can be divided into seven categories: support for good governance of natural resources; support for primary education; support for revenue generating activities (RGA) such as fishing, handicraft and agriculture; support for public health; support for social items to promote social cohesion; support for media and communication; and support for village patrol or participatory ecological monitoring.

Each of the seven categories aims for clear outcomes in each village. For example, support for good governance of natural resources aims to empower people to reduce pressures on their natural resources, by preventing activities such as illegal tree cutting, fires and slash and burn. Support to primary education is believed to improve school attendance and attainment. Support to revenue generating activities is intended to increase household income, reduce poverty levels, and increase village ownership of assets. Support for public health is expected to increase access to clean drinking water and reduce rates of disease in the village. Support to social cohesion and communication aims to build trust, enhance solidarity, raise public awareness, improve transparency, reduce corruption and improve law enforcement. Support to regional government services aims to increase official surveillance and controls, and improve law enforcement. Finally, support for village patrols or participatory ecological monitoring is intended to reduce the number of people entering the forest (strict conservation zone) and reduce human pressures as a direct effect.

Study design

A number of reviews and design replication studies (Bloom et al., 2005; Cook et al., 2008; Ferraro & Miranda, 2014; Glazerman et al., 2002; Shadish et al., 2011) have addressed the question of the performance of quasi-experiments - in particular under what circumstances are they likely to perform as well as true randomised experiments. Meeting the following conditions has been shown to greatly increase the likelihood of the study producing valid results: i) the intervention and comparison groups are similar in observable pre-intervention characteristics including demographic factors, geographical location, and pre-program outcome measures; ii) outcome data was collected in the same way for both intervention and comparison groups; iii) groups are similar in motivation; iv) statistical methods such as propensity score matching are used to adjust for minor pre-intervention differences between groups (Bloom et al., 2005; Ferraro & Hanauer, 2014a).

In this study conditions ii, iii and iv were fully met. As far as condition i is concerned the aim ideally would have been to identify the 109 control villages for which data best matched the data on the 109 intervention villages across the whole range of outcome variables (fire, deforestation, cattle, MPI, health and education). In practice, this was not possible because it would have required obtaining data on 1,370 potential control villages in 9 districts - a task way beyond the available resources of time and funding. Rasolofoson et al. (2016) and Bowler et al. (2012) also experienced the same limitations in their CBC effectiveness evaluation studies. It should be pointed out that although control villages and intervention villages were in most cases sufficiently well matched to provide a clear counterfactual, in some instances this will not have been the case. Despite our best efforts, there will likely have been some pre-existing difference in some of the outcome variables between control villages and intervention villages. In order to minimise the effect of pre-existing difference, analysis throughout the thesis has been based on rates of change in outcome variables rather than absolute values.

These conditions have been met in the design of this retrospective evaluation of Durrell CBC projects. Firstly, intervention and comparison villages within sites are very similar; Second outcome data was collected in an identical way for both groups using questionnaires, government records and remote sensing; Third, the only selection criterion for the CBC intervention to be applied was the presence of particular biodiversity features in fokontany, so villagers are likely to be similar; Fourth, matching methods have been used.

The fokontany is the level of organisation at which the Durrell projects are implemented and disaggregated social response variables are available from a range of government data sources. In this study 109 fokontany-level interventions were studied. Each fokontany (i.e. the village plus surrounding land which is used or managed by the community) has a known spatial extent from the Madagascar's statistics agency INSTAT (Institut National de la Statistique) and the National Geographical and Hydrographical Institute (FTM). These can be expressed as polygons in a GIS which has the advantage that environmental response variables can be calculated from earth observation data using zonal statistics.

Timeframe and assumptions

The time frame for this study is 30 years from 1982 to 2013 for chapter 3, but 15 years (2000 to 2014) for chapter 2, 4 and 5. Annual data is available over this time interval due to the fact that both Durrell records and government records are annual and not further subdivided.

Since no replicated controlled experiment had taken place within the Durrell programme and in order to draw valid conclusions regarding the effectiveness of their CBC interventions, it was necessary to create a retrospective quasi-experimental design. In part, this was achieved by selecting 109 appropriate control villages from 1,370 potential control villages (all the other villages within each study region) that had not undergone CBC. By comparing results between the 109 control villages with the 109 villages that had undergone CBC by Durrell, it was possible to provide a quantitative comparison and thus test the effectiveness of Durrell conservation intervention. On average CBC interventions started around 2000. It was important to match control to project villages by using these covariates in the year 2000. The 30 year timeframe is long enough to measure the social and environmental indicators in each village before and after the CBC interventions.

As described by Ferraro (2009), quasi-experimental design involves selecting groups within which a variable is tested without any random pre-selection process. Quasi experimental design has proved to be a useful way of addressing evaluation questions regarding the effectiveness and impact of programs (Gribbons & Herman, 1997).

Identification of covariates

Propensity score matching, implemented in the R packages Matchit (Ho et al., 2011) and Optmatch (Hansen & Klopfer, 2006), was used to select the most appropriate control village from the set of potential controls. In each site, an equal number of control villages to the number of intervention villages was selected so that the difference in propensity scores calculated from six covariates between project villages and the selected controls was minimised.

The following covariates are used to match controls to project villages:

- study area (geographical districts) in which control villages were selected

- population size in 2004 by fokontany from INSTAT
- proportion of forest cover in 2000 using Kew Vegetation atlas of Madagascar (Moat and Smith 2008)
- accessibility = relative travel time to nearest chef-lieu district of greater than 10,000 people
- fokontany area
- zonal mean fokontany elevation by GTOPO data 1km resolution

Most of the covariates were available in the year 2000. At this baseline year, the potential covariates such as forest cover are not yet affected by Durrell activities.

Justification of choice of covariates

Study areas were carefully selected as covariate because each has its own unique geographic, environmental and socio-economic conditions. Therefore, selecting control villages within each study area helped understand the impact of CBC in each region and also provided the best matching conditions.

Human population size is an important covariate since it can considerably affect utilisation of natural resources which influence response variables such as forest loss and frequency of burning.

Proportion of forest cover was chosen as an important covariate to match CBC with control villages because it indicates availability and level of protection of natural resources in villages.

Travel cost as measured by travel time along tracks and roads to the nearest chef-lieu de district town, is also chosen as an important covariate because it may in part explain the success of conservation and development activities. A chef-lieu de district is populated by at least 10,000 people, and usually has a CHD health centre, a public high school, a post office, representatives of government services (Environment and forests, fisheries, farming, agriculture), a police station (gendarmerie) and a weekly operational market with high demand. In addition, it usually has GSM reception, electricity supply and mutual micro-credit that may provide support to local development projects. With the same amount of support, villages closer to chef-lieu de district can have faster economic growth, improved education and health conditions, and better law enforcement than those further away, because they can easily sell agricultural or fishing products.

Fokontany area (sqkm) is a key covariate since it can considerably affect the effectiveness of local associations in managing natural resources. It is easier to manage smaller areas of forest than large areas. Management of a large area of natural resource requires more physical effort and better strategy through use of a management plan.

Mean fokontany elevation (metres) is also selected as one of the covariates because NGO support to villages located at a high altitude where most people rely solely on agriculture is very different to support for a village at low elevation which is close to a river and where people rely mainly on fishing. In addition, villages situated at low altitude are more prone to receive the impact of forest destruction from high altitude activity such as erosion and siltation which in turn affects rice farming and fishing.

Testing the difference between control and project villages

T-tests were used in each site to confirm whether there were any significant differences between the set of Durrell and control villages on any of the covariates. With two exceptions (elevation in Baly Bay and travel cost in Alaotra), the optimal matching procedure selected sets of villages which were not significantly different from each other.

Table 1. Results of T Tests (control villages vs project villages)

Site	covariates	n	t	P	sig
Menabe	Population	40	0.3367	0.7386	ns
	Area sqkm	40	-0.2758	0.7847	ns

	Forest proportion	40	-0.4295	0.67	ns
	Mean elevation	40	-0.1402	0.8893	ns
	Travel cost	40	-1.0318	0.3087	ns
Baly	Population	16	1.6166	0.1349	ns
	Area sqkm	16	-0.4931	0.6296	ns
	Forest proportion	16	0.5776	0.5729	ns
	Mean elevation	16	3.3436	0.00904	*
	Travel cost	16	-0.9864	0.3427	ns
Alaotra	Population	64	-0.9017	0.3709	ns
	Area sqkm	64	0.5033	0.6166	ns
	Forest proportion	64	1.0864	0.2837	ns
	Mean elevation	64	1.1074	0.2731	ns
	Travel cost	64	2.0415	0.04641	*
Nosivolo	Population	84	-1.29	0.2007	ns
	Area sqkm	84	0.8171	0.4165	ns
	Forest proportion	84	1.4077	0.1646	ns
	Mean elevation	84	1.2657	0.2096	ns
	Travel cost	84	1.208	0.231	ns
Manombo	Population	14	-0.1105	0.9143	ns
	Area sqkm	14	-0.6195	0.5499	ns
	Forest proportion	14	-0.5896	0.5668	ns
	Mean elevation	14	0.1068	0.9176	ns
	Travel cost	14	-0.9146	0.383	ns

Data collection

Data gathering was an important part of this study, with significant quality caveats. It relied upon the approval of local and regional government officials, and depended on the quality of the 15 interviewers, the sincerity of interviewees, the contribution of local authorities and especially the willingness of local people to help. The flow chart below summarises the process of data collection adopted to evaluate the effectiveness of CBC in combating fires and deforestation (chapter 2), in improving education and public health (chapter 3), in enhancing human well-being and raising awareness of ecosystem services in Madagascar (chapter 4), and in conserving habitat for globally threatened species (chapter 5).

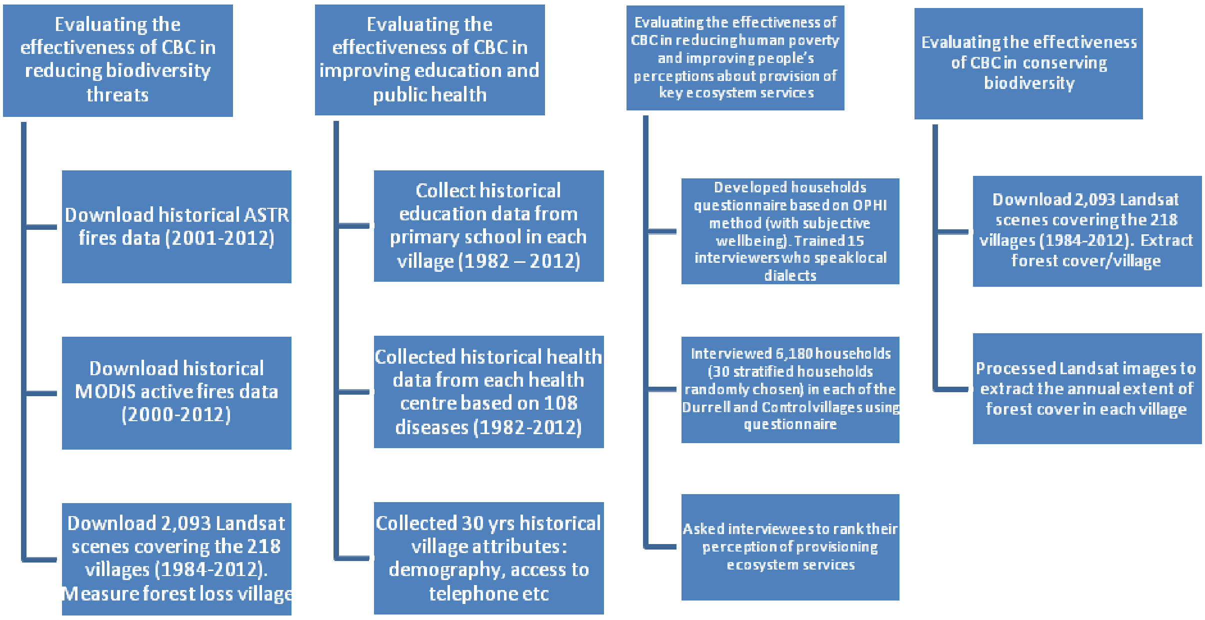

Figure 2. Process of data collection

Data analysis process and operated software

Each chapter draws on a large data source. Data were grouped and analysed as summarised in the flow chart below to meet the assigned objectives.

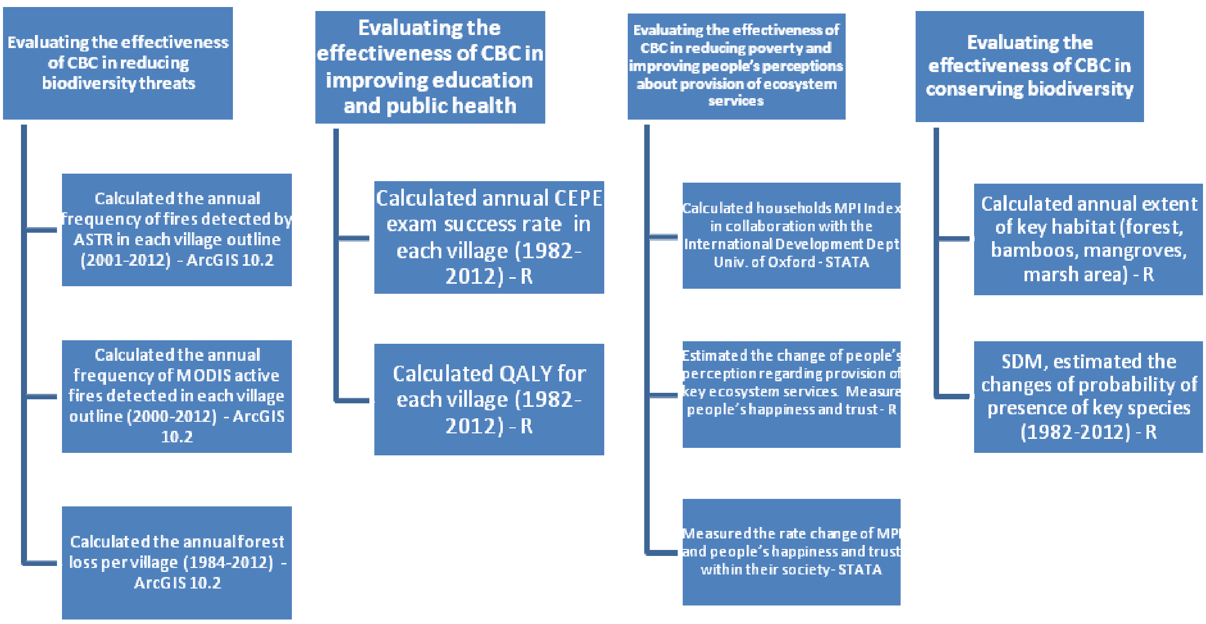

Figure 3. Process of data analysis

Research variables

Dependent variables

The response variables in this study are three main types: threats, social and biodiversity. Threats responses include annual fire frequency and the rate of deforestation. Social responses include annual school attainment, MPI (Multidimensional Poverty Index), happiness, power to change decision making, mutual trust in the society, Index of health status, and people's perception to valued ecosystem services (quantity of water, fish, wood for construction etc). Biodiversity responses include annual forest cover, the habitat suitability and probability of presence of globally threatened species. Individual datasets are described in more detail in the relevant chapters.

MODEL STRUCTURE: RESPONSE ~ YEAR | DURRELL + VILLAGE ATTRIBUTES

The response variable (e.g. fires, education,) may vary with time and the rate of change in a response may depend on whether a Durrell project is being carried out, or how long Durrell ran CBC interventions in the village, or how many Durrell interventions occurred. Some attributes of the village such as population size and presence of a police station can affect the dependent variables.

Explanatory variables

The CBC intervention main explanatory variables will be represented in three different ways.

First, as a 0/1 factor i.e. Durrell absent from the village in that year or Durrell implementing some project in the village in the year. Second, as a 0/1 factor, the presence or absence of a particular type of intervention such as drinking water source improvements in that village in that year; third, as a multiple level factor, the number of Durrell interventions on each component of CBC approach in that village in that year.

Overall Durrell has implemented the following activities: support for primary education, improvement of health, development of revenue generating activities, support for local monitoring of biodiversity, support for good local governance, support to regional government services, support for social items (big cooking pots, etc), support for environment visits, village meeting, media broadcasts.

The following **village attributes** by year have also been used as fixed factors: number of inhabitants, number of households, presence/absence of direct taxi-brousse to town, presence/absence of GSM reception, presence/absence of operational primary schools, presence/absence of operational secondary schools, distance to nearest health centre (CSB) (kilometres), distance to nearest market (kilometres), frequency of local market, presence/absence of electricity supply (JIRAMA), number of generators in the village, presence/absence of access to internet, distance to nearest commune office (kilometres), distance to nearest Police station (kilometres), and fokontany area.

Compliance with Ethical Standards

Avoidance of possible conflict of interest

I have for 16 years (2001 - 2017) worked as coordinator of ecological monitoring and Protected Areas at Durrell Wildlife Madagascar Programme. In this role, I have been responsible for the development and implementation of CBC programmes including community-management of protected areas at five Durrell sites. As far as research is concerned, my work has involved the development of data collection methodology and questionnaires, and the training of the enumerators who carried out household surveys. It is important therefore to emphasise the clear separation I have succeeded in maintaining between my work as a member of Durrell staff and my use of research data in developing this doctoral thesis. My supervisors, the Long Term Ecology Lab (Department of

Zoology) and the Oxford Poverty and Human Development Initiatives (Department of International Development) were involved in research design and continuousely aware of the progress in data analysis. In analysing and utilising the research data I have made every effort to maintain a strictly impartial and neutral position with respect to findings that might reflect the relative effectiveness of Durrell's CBC programmes. Household, health, village attributes and education data were all entered by independent cyber café personel based in Antananarivo before they were doublechecked at another cyber café in Ambatondrazaka, to minimise mistakes and typing errors.

Protection of respondent identity

In collecting and utilising the research data, a number of measures were taken to protect respondents' identities. It is accepted practice in programme evaluations to mislead respondents by not explicitly informing them of the name of the organisation being evaluated in order to minimise bias (Mabry, 1999). As far as the health survey is concerned, patients' names recorded by clinics were not obtained as part of the research data. In the case of the household survey, names of heads of household were included with the raw data in order to facilitate possible further research in the future. However, names of respondents were not used during analysis and presentation of the household data for the purposes of this thesis. Overall, it can be said that there is no linkage between respondents' names and responses anywhere within this thesis.

Informed consent, incentives and personal interests

During the household survey, no incentive was offered to respondents either in money or in kind. Respondents had no expectation of reward either for participating in the survey or for providing any particular kind of information. Enumerators were aware that they were being paid by Durrell to carry out the survey, but they were briefed to avoid any mention of Durrell during the interviews. Chef fokontany and respondents were informed through the enumerators’ official authorisations from local authorities (ordres de mission) that the purpose of the household survey was to determine the current socio-economic status of the village (not the household) in order to ascertain the possible need for future provision of services. Once this thesis is approved by the University, each village will be informed about their environmental and socio-economic situation.

Summary

In future, CBC is expected to play a major role in determining the management of natural resources in Madagascar. Conservation NGOs have been credited with helping the government in Madagascar succeed in meeting the target of expanding the size of protected areas, covering 10% of the country, as promised at the 2003 Durban World Park Congress. Some 88 New Protected Areas, including four out of the five sites featured in the present study, received official permanent decree in July 2015. The majority of them will join the 44% of the world’s protected areas which are already governed under co-management within the IUCN categories V and VI (Zimmerer et al., 2004). Those categories of Protected Area specify the use of natural resources that a local community can extract sustainably (Gardner et al., 2013). It is vital therefore, to understand whether, and to what extent local communities can contribute to improved management of natural resources, and to assess the evidence for effectiveness of CBC. The overarching aim of this thesis is to provide a quantitative evidence base to do this.

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Chapter 2

Paper 1: Evaluating the effectiveness of Community-based Conservation approaches in combating fires and deforestation in Madagascar

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Abstract

Much of the world's biodiversity is found in developing countries where people and infrastructure are negatively affected by poverty, where law enforcement is inadequate and good governance of natural resources are often a low priority. To meet these challenges and carry out successful conservation activities in these countries, government environment agencies and conservation NGOs have been striving to develop effective approaches for mitigating the most severe anthropogenic threats, whilst maintaining continuity in their operations. In this paper, we retrospectively investigate the effectiveness of one of those approaches - Community-based Conservation (CBC), as carried out in Madagascar by the conservation NGO Durrell Wildlife Conservation Trust. We test how effective this approach has been in reducing fires and deforestation at five key biodiversity sites across the island. We examine the annual frequency of MODIS-detected (Moderate Resolution Imaging Spectroradiometer) fires, and annual rate of deforestation, acquired from the Hansen et al (2013) forest cover data between 2000 and 2014, and referencing 109 intervention villages against 109 matched control villages. Generalised Linear Mixed Effects Models were used to examine the fixed and random factors predicting variations in these threats. Our findings suggest that the CBC approach has impacted the incidence of fire around intervention villages resulting in a lower rate of increase in fire frequency compared with control villages over the period 2000-2014. And in addition, although CBC interventions were not able to directly reduce deforestation, the rate of deforestation in CBC villages has generally been maintained at a lower level than in control villages. Findings from this study also suggest that some factors such as political disruption, population size and travel cost (accessibility and distance) from villages to nearest town are important contributing factors towards increased severity of fires and deforestation while access to mobile phones is associated with reduced level of these threats. We conclude that CBC success in reducing fire and deforestation is site specific but if managed with adequate resources, in a context of appropriate policy and a strong institutional framework, it can be an effective tool in habitat conservation.

Keywords: Local community, biodiversity, threats, conservation, effectiveness

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Introduction

The tropical forests of Madagascar are among the top priority areas in the world for biodiversity conservation (Myers et al., 2000). However, mitigating the severe anthropogenic threats in the country still defeats the best efforts of conservation biologists, park managers and government officials. In addition to the impact of climate change that parches wetland areas and destabilises water regimes, severe anthropogenic threats in Madagascar include fires closely linked to slash-and-burn agriculture and illegal land seizures, tree felling related to illegal commercialisation of timber, and smuggling of iconic species mainly to supply the illegal international pet trade. The issues are complex since at least 80% of the population of Madagascar live in rural areas and are heavily dependent on forests and wetlands for their survival, for example for wood for cooking fuel and construction, fishing, medicinal plants, cattle farming and agriculture. Those families who are permanently in poverty, i.e. with a high Multidimensional Poverty Index of 0.42 (Alkire & Santos, 2010), and a low Human

Development Index of 0.27 (UNDP, 2015) live without basic infrastructure or other significant assets. Most parents are fully occupied with day-to-day subsistence and the struggle to feed their children. Additionally, Madagascar has a high level of corruption with an index rating of 32 (0: highly corrupt, 100: very clean). Its ranking of 123 out of 167 countries (Transparency International, 2015) indicates a serious level of corruption in the public sector. The country also has a high youth illiteracy rate of 35% (UNICEF, 2015), and marked discrepancies in the distribution of family income. These factors tend to exacerbate the already high level of social inequality, expressed by a Gini index of 40.6% (0: perfect equality, 100: perfect inequality) (World Bank, 2015a), widen the gap between urban and rural communities and between rich and poor families. This often results in uneven spread of ineffectual law enforcement, undermining effective management of natural resources.

Madagascar is renowned for its high diversity of species characterised by an exceptional level of endemicity due to its c.65 million years of isolation. Endemic to the island are all of the 103 extant lemur species (Mittermeier et al., 2010); 91% of the 384 reptile species; 98% of the 235 amphibian species (Glaw & Vences, 2007); 52% of the 310 bird species (Morris & Hawkins, 1998); and 80% of the 14,000 species of plants (Mayaux et al., 2000). However, since the arrival of humans around 2,350 years ago, the country has lost more than 90% of its original forest with a high annual rate of deforestation up to 1.95% per year from 1990 to 2000 and 1.28% per year from 2000 to 2005 (Harper et al., 2007). These figures have increased again between 2008 and 2014 (Global Forest Watch, 2015). If the rate of environmental deterioration continues over the coming decades the impact will be devastating since many of the emblematic species that make Madagascar unique are facing serious risk of extinction. This will pose a major risk to the livelihoods of future generations that rely upon the biodiversity for their livelihoods. The question of how to halt the decline of Madagascar's biodiversity remains unresolved to date and as a consequence, many ecosystems in the country are facing serious risk of collapse due to complex environmental issues, and about 57,000 hectares of the island's natural forest are ravaged mainly by fire every year (FAO, 2015a).

Developing an appropriate conservation strategy requires a clear understanding of the drivers of the most severe threats and quantitative evaluation of the effectiveness of the approaches that have been used in the past. Community-based Conservation (CBC) is a participatory approach that promotes the harmonious interactive relationship that potentially exists between local people and their environment, with the intention of reducing biodiversity threats while improving social well-being. CBC is based on the premise that conservation and development interests should be served simultaneously (Berkes, 2004) and that humans must use or protect natural resources sustainably in order to continue to benefit from ecosystem services. CBC is an appropriate approach in the context of Madagascar as conservation programmes cannot easily be implemented without involving the local communities in the process. Traditionally, local people have a strong cultural and economic attachment to their environment but the harmonious relationship between people and wildlife may have to be encouraged and nurtured over time. The previous government's conservation approach was implemented with armed and uniformed paramilitary forest guards ('gardes forestiers') having a presence in each of the 114 districts was amended in the early 1990s. An international movement in the 1980s promoted rights of indigenous people to manage and use their own natural resources. That movement led to the implementation in Madagascar in the mid-1980s of the integrated conservation and development projects (ICDP) led by the World Wide Fund for Nature (WWF) (Hugues & Flintan, 2001), and later to the passing of Law 96-025 in 1996, enabling local communities to manage an agreed area under an official management contract. As a result, CBC has been widely adopted by more than 30 conservation NGOs in Madagascar with the aim of reducing anthropogenic threats to biodiversity.

Durrell Wildlife Conservation Trust (Durrell) has used the CBC approach in its Madagascar programme since around the year 1997, to help protect and conserve endangered species. Durrell's CBC approach is based on the principle of offering support in the following areas of activity: primary education; clean drinking water provision; good management of natural resources; revenue generating activity; social cohesion; and local monitoring. In this paper, we report on the results of the effectiveness of the CBC projects in terms of reduction of severe threats such as fires and deforestation, focussing on five key conservation sites: Lake Alaotra, Baly Bay, Manombo rain forest, Menabe dry forest, and Nosivolo River, representative of Madagascar's most important ecosystems (Table 1). These study regions are components of the national Protected Areas network, the majority of which is co-managed together with the local communities under IUCN category V.

Evaluating CBC intervention is challenging not only because it requires multidisciplinary skills (socioeconomic, anthropological, and scientific), but also because it involves cost. Biodiversity monitoring is of course important, but collecting monitoring data is typically time-consuming, difficult and expensive (Salafsky & Margoluis, 1999), but the cost of conservation evaluation should ideally never be greater than the cost of conservation action (Danielsen et al., 2006). That creates a problem because while conservation NGOs need to understand their own effectiveness, at the same time they must maintain focus both on managing their conservation activities and on securing the funding necessary to ensure their continued existence. Most conservation NGOs rely on short-term external funding and often rely solely on intuition and anecdote to guide the design of conservation programmes (Ferraro & Pattanayak, 2006). The majority of conservation NGOs in Madagascar did not therefore commence their interventions from the starting point of an experimental design model to assess their success by using proper control village comparisons.

Many methods have been used to measure the impact of conservation activity in protecting areas against fires or deforestation. Few publications however have focussed on CBC in this regard, and studies focussing on the effectiveness of CBC at regional level, which would be more helpful to inform future conservation programmes, are scarce. In recent literature, there have been a few studies evaluating CBC and its impact on both human well-being and biodiversity conservation. For example, matching methods (Rubin, 1974) have been used to understand the environmental impacts of a network of protected areas in Cambodia (Clements & Milner-Gulland, 2015) and Costa Rica (Andam et al., 2008). In another study, a comparison analysis was used to determine the effectiveness of the community forest management project in reducing deforestation in Madagascar (Rasolofoson et al. 2015) and Nilsson et al. (2016) studied the effectiveness of a CBC programme in changing attitudes.

In this study we used a quasi-experimental design with a propensity score matching method (Peikes et al., 2008) to measure the likely impact of CBC in reducing severe threats, by comparing the difference between CBC villages and matched control villages over the past 15 years. This study tracks in retrospect what did and did not work, but also focusses on testing the solution rather than merely identifying problems. We used both the MODIS global fire alerts and the Hansen global forest cover data (Hansen et al., 2013) as outcome variables indicating the annual variation of fire frequency and deforestation rate in each area of land managed by the village. Thus, the aim was to use the difference between CBC villages and non-CBC villages in fire incidence and forest loss to indicate the effectiveness of CBC in impacting these threats.

This study involves 218 villages (109 CBC and 109 Control) located around the five Durrell sites. We used Generalised Linear Mixed Effects Models to test the effects of fixed and random variables on the variation of the annual fire frequency and rate of deforestation from 2000 to 2014. Four random intercept models were carried out to measure the changing pattern of fire and deforestation across time and to evaluate the rate of increase and decrease. The contributions of the seven fixed effects including the travel cost (a measure of accessibility i.e. relative travel time to the nearest chef-lieu district), population size, number of cattle per capita, presence/absence of mobile phone network, the presence/absence of the CBC itself, evapotranspiration, and concurrent political disorder were also examined to better understand the annual variation in the fire and deforestation rates (the last two factors were not considered for analysis of deforestation). Each of those potential explanatory variables has a direct relationship with the use of natural resources in each village and should therefore highlight the effectiveness of CBC. We also looked at the role of political disruption in exacerbating the impact of fires and deforestation.

An important aspect of this study is that the data is a free resource, available in accessible form from the Ministry of Environment, Ecology and Forests. Knowing the effectiveness of CBC in reducing fires and deforestation is crucial for conservation managers in developing future sustainable conservation strategies with a greater potential for successfully achieving their aims.

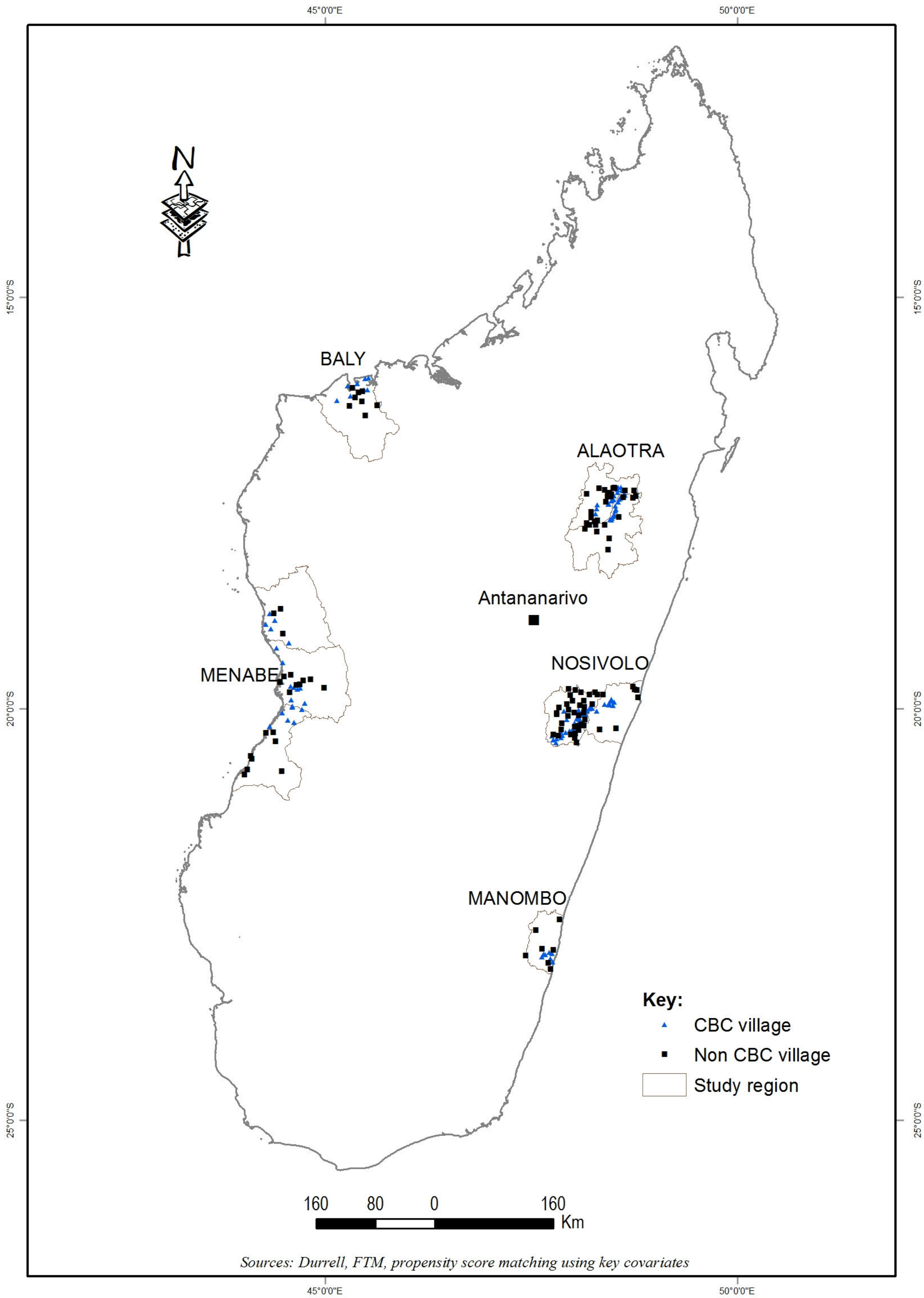
Methods

Study areas

We aimed to assess the effectiveness of conservation projects in reducing severe threats across five important conservation sites in Madagascar. The key features of these study areas are described in table 2.

Table 2. Description of five study regions

Study area	Alaotra	Baly Bay	Manombo	Menabe	Nosivolo
Region	Alaotra Mangoro	Boeny	Atsimo Atsinanana	Menabe, Melaky	Atsinanana
CBC start date	1997	1996	2006	2000	2005
District	Ambatondrazaka, Amparafaravola	Soalala	Farafangana	Antsalova, Belo/Tsiribihina, Morondava	Mahanoro, Marolambo
N. of villages	32	8	7	20	42
Population size (2007)	103,824	16,509	11,073	38,718	72,919
# active local monitors	96	79	66	108	105
Habitat types	Wetlands: Lake, marsh area	Bamboo, dry forest	Rain forest	Dense dry forest, mangroves	Wetlands: River
Climate	Semi humid, moderately hot	Dry, hot	Humid	Dry, hot	Humid, moderately hot
Elevation (m)	795.6	40.7	38.7	35.5	592.9
Protected Area size (hectares)	42,478	63,000	7,090	210,000	6,781
Status	New Protected Area	National Park	2 blocks: Special Reserve & classified forest	New protected Area, Special Reserve	New protected Area
IUCN category	V	II	IV	III, IV, V (multi-category)	V
Key species	*Hapalemur alaotre*nsis (Alaotran gentle lemur)	*Astrochelys yniphora* (Plougshare tortoise)	Lemurs: 8 species. Ex. *Eulemur cinereiceps, Variecia v. editorum*	*Hypogeomys antime*na (Giant jumping rat), *Pyxis planicauda* (Flat tailed tortoise)	Fishes: *Oxilapia polli, Ptychochromoides katria*, *Bedotia* sp zono, *Bedotia* sp1
Main pressures	Burning, illegal rice farming, illegal fishing	Tortoise smuggling, fires	Illegal logging, fires	Illegal logging, slash and burn agriculture, fires	Illegal gold mining, slash and burn agriculture



Map 2. Location of the five study regions and matched villages

Sample unit

Sample units used in this study are 'fokontany' or 'village'. A typical fokontany will have one main village, known as the chef-lieu-fokontany and may also contain a small number of subsidiary hamlets. With a population of about 1000-5000 inhabitants, a fokontany typically covers approximately 30 square kilometres of land. This is the level of organisation at which the Durrell projects are implemented, and for which disaggregated social response variables are available from government data sources. Each of the 109 intervention villages has a recently identified spatial boundary from the Madagascar statistics agency INSTAT (Institut National de la Statistique) and the National geographical and hydrographical institute FTM (Foiben-Taosarintanin'i Madagasikara). They were expressed as polygons in a GIS (Geographical Information System). With this method, environmental response variables can be calculated from earth observation data using zonal statistics. INSTAT provided an authoritative list of all fokontany and time-series of population size for each of them. The study time step is annual, which is the finest temporal resolution of both the Durrell records and government records.

Since money was never given directly to local people in Durrell CBC projects (in order to avoid conflicts of interest) and since detailed financial information was not available, it was assumed that a CBC intervention would have had a value in material support or equipment worth more than 200GBP (minimum amount for a CBC project). In a given village that budget was spent on primary education, revenue generating activity, social cohesion, public health, or participatory monitoring as determined by villagers themselves. These projects are important to the community and should have impact on the attitudes of local people, resulting in an eventual reduction of threats.

Selection of Durrell CBC villages

Typically, CBC interventions in the 109 villages started around the year 2000 (average start date in the five study regions), and it was important to match control to project villages using the covariates in that year. Durrell villages were chosen in terms of the area of occupancy of priority species of conservation concern (Table 2) in each region. Thus, main villages situated closer to the habitat, where people can have direct influence on the management, were targeted first. This evaluation study is carried out approximately 14 years after the start date of the CBC interventions.

Selection of control villages

Quasi-experimental design is a useful method for evaluating effectiveness and probable impact of programmes if no replicated controlled experiment has been implemented at the start of the interventions (Gribbons & Herman, 1997). The following six covariates were used to create propensity scores to match controls to project villages: study area, fokontany population size in 2004 from INSTAT; the proportion of forest cover in 2000 using the Kew Vegetation atlas of Madagascar (Moat & Smith, 2007); travel cost calculated as relative travel time to nearest chef-lieu district of greater than 10,000 people; the surface area of each fokontany; and the zonal mean elevation for each fokontany acquired from GTOPO[3] 1km resolution. Those covariates were available for the year 2000 when the villages were not yet affected by Durrell activities.

Using R packages *Matchit* (Ho et al., 2011) and *Optmatch* (Hansen & Klopfer, 2006), propensity scores were matched to select 109 most appropriate control villages from the 1,370 potential control villages that had not undergone CBC in the intervention regions. For each study region, a number of control villages equal to the number of intervention villages were selected so that the difference in propensity scores between them was

[3] GTOPO is a digital elevation model for the world, developed by the U.S. Geological Survey (USGS)

minimised. By comparing results from non-CBC villages with the CBC villages, it was possible to provide a quantitative comparison and thus test the effectiveness of Durrell conservation interventions.

Village attributes

For these given study regions, data on village attributes were collected at the level of village or fokontany, the smallest administrative division in Madagascar. Five village attributes were obtained for this study: population size, number of cattle per capita, cost/ distance, access to public transport (taxi-brousse), and access to mobile phone network. Data were collected by fifteen trained local interviewers (2-4 per study region), local dialect speakers, who received their training in field methods in June 2013. All villages are officially headed by a designated or elected fokontany president (depending on the constitution of successive Republics), but also have traditional village chiefs. Each fokontany keeps records of statistics on people and cattle. The interviewers, equipped with regional government papers proving the purpose of their visit, spent time with the fokontany presidents, collecting historical numbers of inhabitants, immigrants and cattle. Data collection was preceded by a courtesy visit to district heads and traditional authorities to obtain their approval. The travel cost (accessibility) to each village was calculated on Arc GIS 10.2 (ESRI, 2013), based on the distance to the nearest town (chef lieu de district) and road quality.

Fire frequency data

Two digital fire data sets were downloaded from two key sources to determine the fire frequency over the period 2000-2014 in the five study regions. The first was provided by the five/six channel scanning radiometer AVHRR/2 and AVHRR/3 (Advanced Very High Resolution Radiometer) on board the US National Oceanic and Atmospheric Administration (NOAA) satellite. AVHRR reflectance and brightness temperature data was processed using the contextual fire-detection algorithm of Flasse & Ceccato (1996). The AVHRR which is administered jointly by NOAA and NASA (National Aeronautics and Space Administration) remotely detects the earth surface temperature from 833 or 870 kilometres using reflectance of pixels. The resolution is 1.1km and these data which are collected every day have been recorded continuously since 1981.

The second set of fire data came from the Near Real-Time active fire alerts that have been distributed by NASA FIRMS (Fire Information for Resource Management System) since 1999. They come from two instruments MODIS (Moderate Resolution Imaging Spectroradiometer) and VIIRS (Visible Infrared Imaging Radiometer Suite). The MODIS instrument is on board NASA's Earth Observing System (EOS) Terra (EOS AM) and Aqua (EOS PM) satellites orbiting the earth from about 705km altitude on a daily basis. A MODIS active fire location represents the centre of a 1km pixel that is flagged by the algorithm as containing one or more fires within the pixel size of fire detected (Giglio et al., 2003). Using ArcGIS 10.2, those fire data were overlayed with each polygon of the 218 villages, and then inclusively clipped to extract the values. The annual fire frequency per village was calculated from the number of pixels that represented fire each year, divided by the area of the village.

Deforestation data

In order to estimate the annual rate of deforestation, the proportion of annual forest cover of each village had to be calculated by dividing the forest cover in each village by the size of the village. The rate of deforestation in any one year was calculated from the difference between the number of pixels that were forest in the year before and became non-forest in the year after. The methods used for calculating the rate of deforestation generally follows Hansen et al. (2009) and Margono et al. (2012). Grid files of historical forest cover data (2000-2014), from three tiles located at 10S040E, 20S040E and

10S050E covering Madagascar (30m resolution), were downloaded from the global forest change dataset developed by (Hansen et al., 2013). These data which are projected in WGS 84 comprise a raster of tree canopy cover for year 2000, forest cover loss, forest cover gain (2000-2012), and the year of gross forest cover loss event. Using Arc GIS 10.2, these grid files were assembled in a mosaic, then clipped to match the boundary of Madagascar, before overlapping them with the polygon shape files of our 218 study villages. Python scripts implemented in Arc GIS 10.2 were written to reclassify the year of gross forest cover loss grid file (2000-2014) to disaggregate the raster into individual annual forest loss. Batch Zonal statistics function was then used to extract full statistical variables of the annual forest loss in each village. The extent of deforestation per village was expressed by the number of pixels of forest loss multiplied by 0.09 hectares, which corresponds to the size of each pixel.

Forest cover data

In ArcGIS 10.2 we developed a mask for the 2001 Hansen forest and multiplied that with the Hansen tree canopy cover for year 2000 to acquire the forest proportion value for each pixel in 2001. Hansen forest cover data were projected in Albers equal-area conic projection, or Albers projection, to keep the same size of pixels and provide more accurate calculation of the areas. The sampling technique used during projection was *Bilinear* for raster files with percentage data and *Nearest Neighbour* for those with binary (0/1) values pixel to ensure maximum accuracy. Using the Python script, we followed the same approach to acquire the forest proportion for the years 2002 to 2014 before we reclassified them into an individual binary raster file of annual forest/non-forest map. Any pixel that had more than 50% forest cover was considered forest - the same threshold was used by Hansen et al. (2013) in their classification - but we also applied this to the Kew Madagascar vegetation data when we calculated the forest proportion in

2000 for each village, as one of the matching covariates. Each raster file was checked with the corresponding recent Landsat scenes covering each study region. VBA (Visual Basic for Applications) macro in Microsoft Excel was used to bring together the annual forest loss data per village per year before analysing them in R.

Field visits and aerial surveys

Aerial surveys at an elevation of 330 metres were conducted in Baly Bay from 2005 to 2007 in collaboration with the German Technical Cooperation (GTZ: Gesellschaft für Technische Zusammenarbeit); in Menabe from 2005 to 2008 with the Aviation sans Frontières Belgique (ASF); in Nosivolo in 2003 and 2005 and in Alaotra in 2004, 2005 and 2007 both with the Mission Aviation Fellowship (MAF) Madagascar. Composite mosaic of Landsat images of each site, aerial photos and GPS receiver were used during the aerial surveys. They helped ground truth the accuracy of the classification when we processed the annual Hansen forest data (2000-2014).

Statistical methods

Table 3. Description of the potential explanatory variables that may explains the variation of fire

Potential explanatory variables	Type	Time period available	Source	Hypothesised correlation with Fire and deforestation
Year	Continuous	2000-2014	-	Negative. We hypothesised that there should be a decrease of fires and deforestation across time in CBC villages
Presence of CBC intervention	Binary (0 absent, 1 present)	1996-2014	Durrell (put together in 2014)	Negative. We expect that the presence of CBC should discourage people to burn and destroy forest/marsh area
§ Political disruption	Binary (0 absent, 1 present)	1982-2014	Government (central), 2015	Positive: unhappiness, lack of law enforcement, less respect to government officials, not enough financial resources
Population size	Continuous (count)	1982-2014	Village attribute collected during fieldwork (2013-2014)	Positive: People need land. More people means higher demand of food and land
Number of cattle per capita (ratio with the human population size)	Continuous	1982-2014	Village attribute collected during fieldwork (2013-2014)	Positive: More cattle should require more grazing land. Fire is used for renewing grass
Travel cost (accessibility: distance to nearest town)	Continuous	1982-2014	GIS FTM (acquired in 2013)	Positive: Far away village may have higher deforestation because they are far away from police station and government officials to enforce law in case of illegal activity. However, difficult access to market may also discourage slash and burn agriculture.
Access to mobile phone network (binary 0/1)	Binary (0 absent, 1 present)	1982-2014	Village attribute collected during fieldwork in 2013	Negative: Communication of illegal activity to government is faster if the village has mobile phone coverage
§Evapotranspiration (ET) in kg/sqm	Continuous	2000-2014	MODIS (NASA) - downloaded in 2016	Negative: Increase of ET would raise humidity and reduce the combustibility of vegetation. ET regulates the water cycle and should reduce the probability of fire and slash and burn agriculture
Access to regular taxi brousse (public bus)	Binary (0 absent, 1 present)	1982-2014	Village attribute collected during fieldwork (2013-2014)	Negative: The presence of direct taxi-brousse going to town facilitates visit of government officials and may discourage illegal activities

§ Not considered for analysis of deforestation as they are not suitable

Description of the response variables

The statistical response variables are presented in the table below:

Table 4. Description of the response variables

Variable	Resolution	Type	Source
MODIS fire frequency/sqkm/year (2000-2014)	1km	Continuous	MODIS (FIRMS) NASA - downloaded in 2015
AVHRR fire frequency/sqkm/year (1982-2012)	1km	Continuous	AVHRR (NOAA, NASA) - downloaded in 2014
Rate of deforestation (2000-2014) in %	30m	Continuous	Calculated from (Hansen et al., 2013) historical forest cover

Principal Component Analysis

We undertook the Principal Component Analysis in R Studio 0.99.902 (R Core Team, 2012) looking at the main direction of variance in the data among the seven variables, including the fire frequency and deforestation response variable, and the continuous predictive variables such as temperature, village population size, forest proportion, evapotranspiration, elevation, travel cost (accessibility), number of cattle per capita, and area of the village. The PCA analysis allowed us to check the main direction of variance between all of the variables simultaneously. The PCA results were plotted in R using *ggplot2, plyr, scales, and grid* packages. Structured as time series, the fire data were plotted using *ggplot2* in R to build temporal graphs illustrating the annual variation of the two response variables 'fire frequency' and 'deforestation rate' overall and at each study region.

Validation of independent variables: correlation between explanatory variables was checked using Pearson matrix correlation using *corr* function in R in order to ensure that they are independent. Pearson correlation coefficient between variables were all less than 0.5.

Fitting Generalised Linear Mixed Effects Models with the data

Fire frequency and the rate of deforestation data are both proportions and fitting the models defied classical statistical procedures. We used Generalised Linear Mixed Effects Models (GLMM) that mix random and fixed effects using lme4 function (Bates et al., 2012) and *lmerTest* package in R (Kuznetsova et al., 2016) to statistically evaluate the effectiveness of CBC in influencing fires and deforestation. By incorporating random effects, GLMMs also allows us to generalise conclusions to times, places and threat as they provide a more flexible approach (Bolker et al., 2009). In this study, the variables 'study region' and 'village' were considered as nested random effects to make sure they do not cause any systematic or idiosyncratic influence on the variation of fire and deforestation. That is because the factor 'village' is hierarchically structured within 'study region' and difference between each of them can affect the variation. The fixed effects variables are: year (continuous) associated with the presence/absence of CBC (binary), the travel cost (continuous), the population size (continuous), the mean evapotranspiration (related with rainfall, humidity and temperature), number of cattle per capita (continuous), the presence/absence of political disruption (binary), and the access to mobile phone network (binary). Population size data were rescaled using rescale function in the scales package implemented in R because it was on a very different scale compared to the other variables. Square root rate transformation on fire frequency and ninth root (a root of degree 3) transformation of the rate of deforestation provided the best fitted model with normal distribution of residuals. We therefore have intercepts for 'study region' and 'village: study region' as well as by-study region and by-year random slopes for the effect of CBC.

Below are the best fitted models using restricted maximum likelihood (REML=False), isolating all fixed effects and evaluating the remaining variance due to random effects.

The null hypothesis Ho that we tested was that the temporal trend of fire frequency or rate of deforestation is the same for the two groups CBC intervention and non-CBC villages. That allows fitting the trend through year with interaction between treatment and year.

The three random intercept fitted models are:

Model 1*<-(lmer (Square root response ~ year + cattle per capita + mean ET + population size + mobile phone network + travel cost + political disruption+ (1|study region/village))*

Model 2*<-(lmer (Square root response ~ year +CBC+ cattle per capita + mean ET + population size + mobile phone network + travel cost + political disruption+(1|study region/village))*

Model 3*<-(lmer (Square root response ~ year *CBC+ cattle per capita + mean ET + population size + mobile phone network + travel cost + political disruption+(1|study region/village))*

The variable evapotranspiration was not included in the analysis of deforestation as it is hypothesised to have no direct effect on it. Model 1 has all of the fixed and random effects except CBC. Model 2 has also all of the fixed and random effects but with CBC as the main fixed effect while Model 3 has all fixed and random variables but with CBC associated with 'study region'. ANOVA (Analysis of variance) of the model 4 presented below was performed to examine the level of interaction between *study region* and the presence of CBC. Analysis of effectiveness of CBC in reducing fire and deforestation in each study region was examined when that interaction was significant.

Model 4*<-(lmer (Square root response ~ study region*CBC+ fixed effects + (1|village))*

P-value <0.05 corresponding to 95% confidence interval determines the significance of the effect each predictor has on fires or deforestation. Those models provided us full information about the estimates of intercepts, standard errors and importance of each variable in affecting fire. We visually inspected histogram and Q-Q plots of residuals after transformation to check normality of the distribution. The model selection criterion was based on AIC (Akaike's Information Criterion). The model that gave the lowest AIC value was chosen.

Results

Principal components analysis (PCA)

The PCA graphic (Fig. 4) shows the study regions Menabe, Baly and Manombo are the most similar and examination of the preliminary data indicates that this is probably demonstrating the similarities in high annual temperatures and largest number of cattle per capita, with highest rates of fire and deforestation. Situated at higher altitudes, Lake Alaotra and Nosivolo have the highest evapotranspiration and largest population size. The continuous variable most closely related to fire is temperature. Deforestation seems poorly correlated with fire frequency. The PCA graph also indicates that the increase in population size might be associated with the increase in deforestation while fire frequency is higher in places with higher temperature. Significance of these observations is discussed later within the result of multivariate analyses.

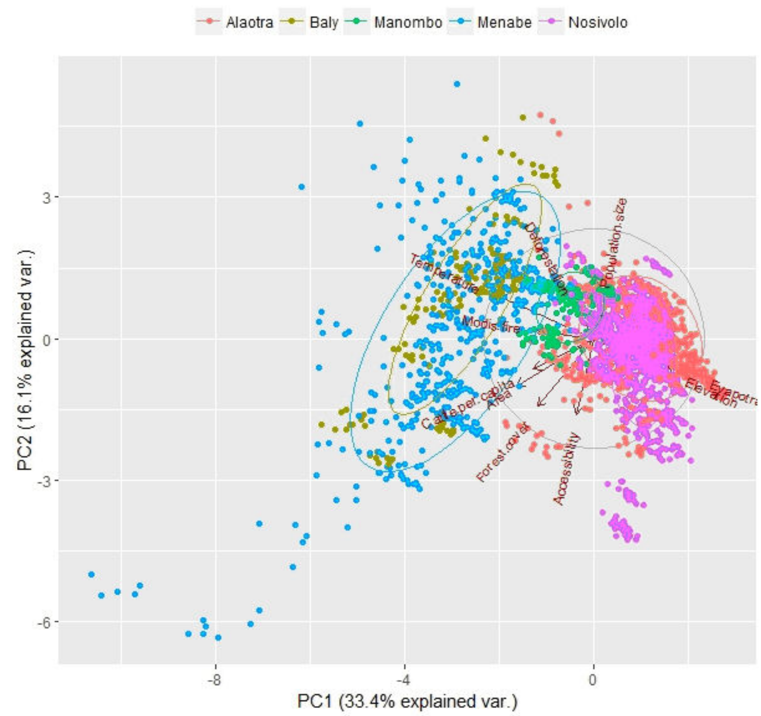
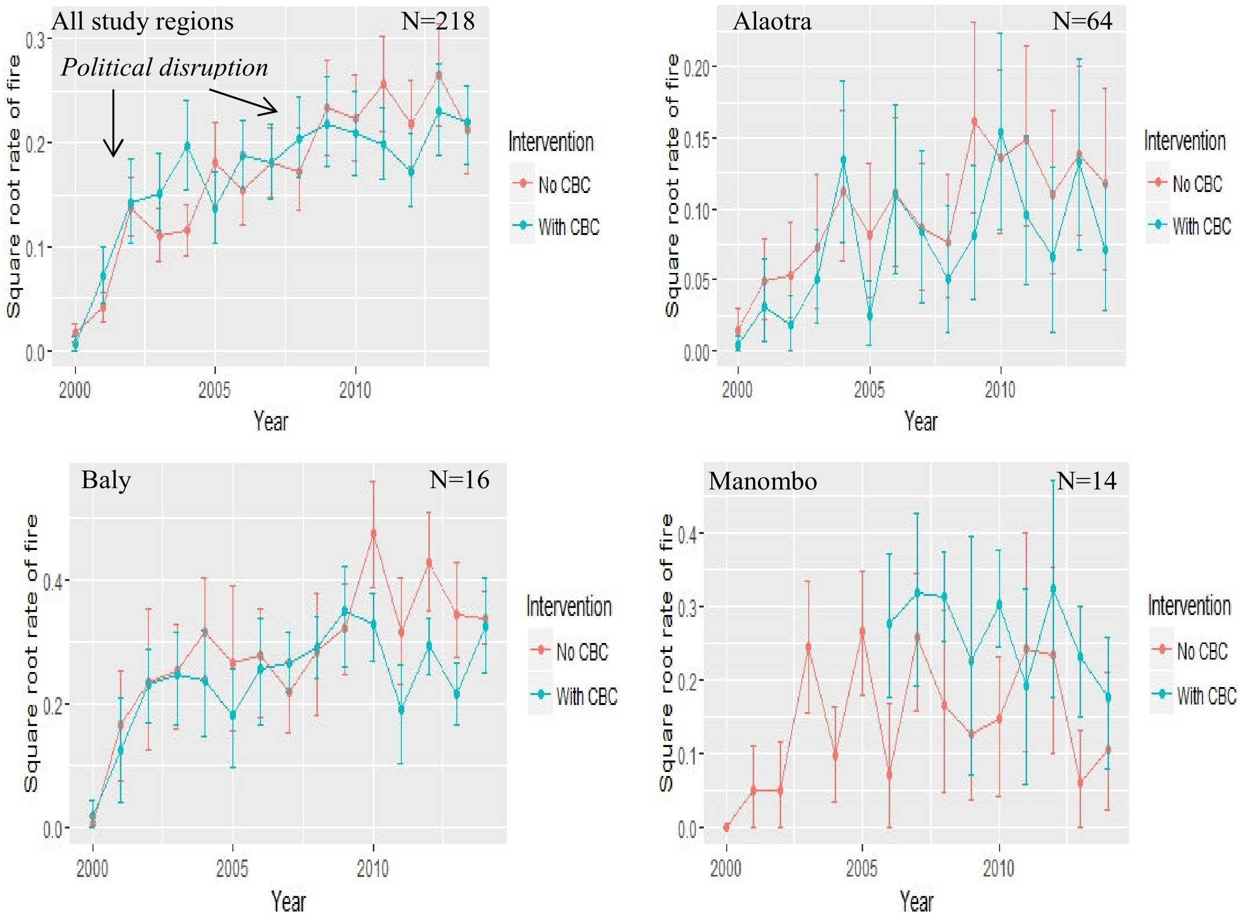


Figure 4. *PCA analysis: interaction between variables*

Changes in frequency of fires over time within CBC villages and non-CBC villages

Our analysis of MODIS fire frequency suggests that the increase of fire at national level between 2000 and 2014 is reflected in both CBC and non-CBC villages. CBC villages in Manombo and Nosivolo visibly have higher rates of annual fires frequency. The breaking points (where there is most significant change) coincide with the starting years of political disruption i.e. 2002 and 2009. The graphs below show that when fires increased in times of political disruption, they did not decrease again as expected (Fig. 5).



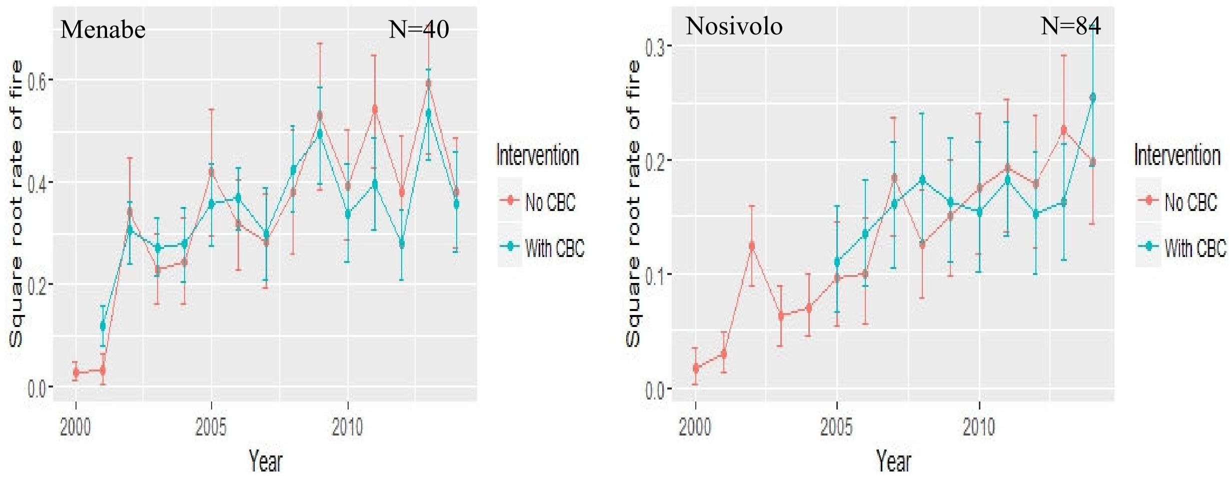


Figure 5. *Comparison of mean of the square root rate of fire per square kilometre over time between CBC villages and non-CBC villages using MODIS alert fire data. N is the number of villages in each study region*

Effectiveness of CBC in reducing fire frequency

The fixed effect *year* shows an overall positive slope, indicating a significant increase of fire with *year* by $1.249e^{-02}\pm1.004e^{-03}$ ($p<2e^{-16}$) in both CBC and non-CBC villages. On average CBC villages have $1.237e^{+01}\pm2.832^{e+00}$ higher fire frequencies than non-CBC villages. However, despite significant overall increase of fires across time, it is confirmed that compared to non-CBC villages, CBC villages have significantly shallower slope of increase with an estimate of $6.153e^{-03}\pm1.411e^{-03}$, $p=1.340e^{-05}$ (Table 5). Fires in CBC villages increased less steeply. With their positive estimates, the fixed effects such as political disruption and travel cost are significantly related to the increase of fire. The results also illustrate that villages with higher evapotranspiration and with access to mobile phones have significantly lower fire. Those two variables can play a major role in the reduction of fires.

Table 5. Fitted mixed effect model predicting the annual fire frequency

Fixed effects	Hypothesis	Estimate	Std. Error	Pr(>|t|)
Intercept		$-2.474e^{+01}$	$2.018e^{+00}$	$< 2e^{-16}$ ***
Year	Positive	$1.249e^{-02}$	$1.004e^{-03}$	$< 2e^{-16}$ ***
Presence of CBC	Negative	$1.237e^{+01}$	$2.832e^{+00}$	$1.30e^{-05}$ ***
# cattle per capita	Positive	$8.458e^{-03}$	$7.742e^{-03}$	0.275NS
Evapotranspiration	Negative	$-3.335e^{-05}$	$6.561e^{-06}$	$6.36e^{-07}$ ***
Population size	Positive	$1.172e^{-05}$	$6.911e^{-06}$	0.091NS

Access to mobile phone network	Negative	-2.532e^{-02}	9.399e^{-03}	0.007 **
Travel cost	Positive	7.868e^{-03}	3.956e^{-03}	0.048 *
Presence of political disruption	Positive	1.953e^{-02}	6.039e^{-03}	0.0012 **
Year: CBC present	Negative	-6.153e^{-03}	1.411e^{-03}	1.34e^{-05} ***

*Significance: *P<0.05; **P<0.001; ***P<0.0001*

Other effects on fire

The effect of *village* (which is nested into *study region*) has much higher variability (Std.Dev. 0.097) than the *study region* itself (Std.Dev. 0.056). As we expected there is more idiosyncratic difference between the 218 villages than between the five study regions. The remaining variability that could not be explained by those two random effects can be seen on residuals (Table 6).

Table 6. Variation of fire frequency explained by random effects

Groups	Name	Variance	Std.Dev.
Village: study region	(Intercept)	0.009	0.097
Site	(Intercept)	0.003	0.056
Residual		0.021	0.143

Interaction between sites and CBC intervention

Results of ANOVA on model 4 showed a no interaction between study region and the CBC interventions, with a non significant p-value p=0.237 (Table 7). The effectiveness of CBC intervention in reducing fires within each study region does not present great difference. However, we still present the results per study region below (details in appendix 2) as they may help improve the management at local level.

Table 7. Interaction between CBC intervention and study regions (fire)

Fixed effects	Sum Sq	Mean Sq	NumDF	DenDF	F.value	Pr(>F)
Site	1.249	0.312	4	228.94	14.596	1.238e^{-10} ***
Presence of CBC	0.228	0.228	1	312.02	10.652	0.0012 **
# cattle per capita	0.0004	0.0004	1	1680.34	0.018	0.892
Evapotranspiration	0.841	0.841	1	844.29	39.326	5.720e^{-10} ***
Population size	0.287	0.287	1	287.97	13.428	0.0003 ***
Access to mobile phone network	0.106	0.106	1	3009.22	4.960	0.026 *
Travel cost	0.156	0.157	1	188.85	7.318	0.007 **
Presence of political disruption	1.111	1.111	1	2928.32	51.952	7.205e^{-13} ***
Study region: CBC	0.119	0.030	4	404.38	1.389	0.237

Likely effects of CBC in reducing fire at each study region

Fire frequency in CBC villages is significantly higher at Manombo ($p=0.009$) and Nosivolo ($p=0.020$) compared to non-CBC villages (Appendix 2 - supplementary materials). The number of cattle per capita has no effect on fire except in Manombo where it can diminish it by $2.602e^{-1} \pm 1.025e^{-1}$ ($p=0.012$). Higher evapotranspiration is significantly associated with lower fire frequency in Alaotra ($p=3.110e^{-05}$), Menabe ($3.240e^{-06}$) but increases it by $6.628e^{-05} \pm 2.545e^{-05}$ at Nosivolo ($p=0.009$). Results per study region also reveal that the increase in population size is associated with increased fire at Manombo ($p=0.011$) whilst it has no significant effect in the other study regions. Remote villages have significant higher fire frequency in Alaotra ($p=1.270e^{-05}$) while the opposite is observed in Baly ($p=0.0257$). The increase of fire in Menabe seems strongly affected by political disruption, worsening it by $6.423e^{-02} \pm 1.693e^{-02}$ ($p<0.001$).

Correlation between fire and cattle per capita and deforestation

Surprisingly, in both CBC villages and non-CBC villages there was no correlation between the number of cattle per capita and the fire frequency. Despite a large decline of number of cows from around 0.45 cattle per capita in 1982 to 0.26 cattle per capita in 2012 in both groups (Fig. 6), after 2000, fire has dramatically increased from <0.01 alerts/sqkm per year in 1986 to >0.08/sqkm per year in 2012.

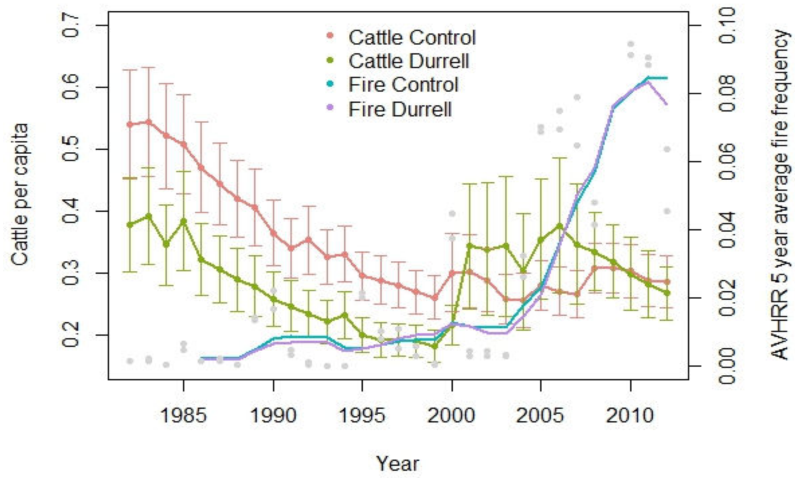


Figure 6. Interaction between fire and number of cattle per capita

Linear regressions that were carried out to verify correlation between fire frequency and cattle per capita revealed that they are poorly correlated with a low Pearson coefficient R^2= 0.020, F-statistics 64.540 and significant p-value ($1.337e^{-15}$).

Changes in deforestation over time within CBC villages and control villages

Similar to annual fire frequency, the annual rate of deforestation in the 218 villages has generally increased from 2000 to 2014. CBC villages visibly show lower rates of deforestation. The CBC interventions were not able to halt the deforestation although the rate of deforestation in CBC villages has remained on average lower than in non-CBC villages until 2012. In Lake Alaotra, Baly Bay National Park and Menabe, the CBC villages visibly cleared less forest than non-CBC villages (Fig. 7).

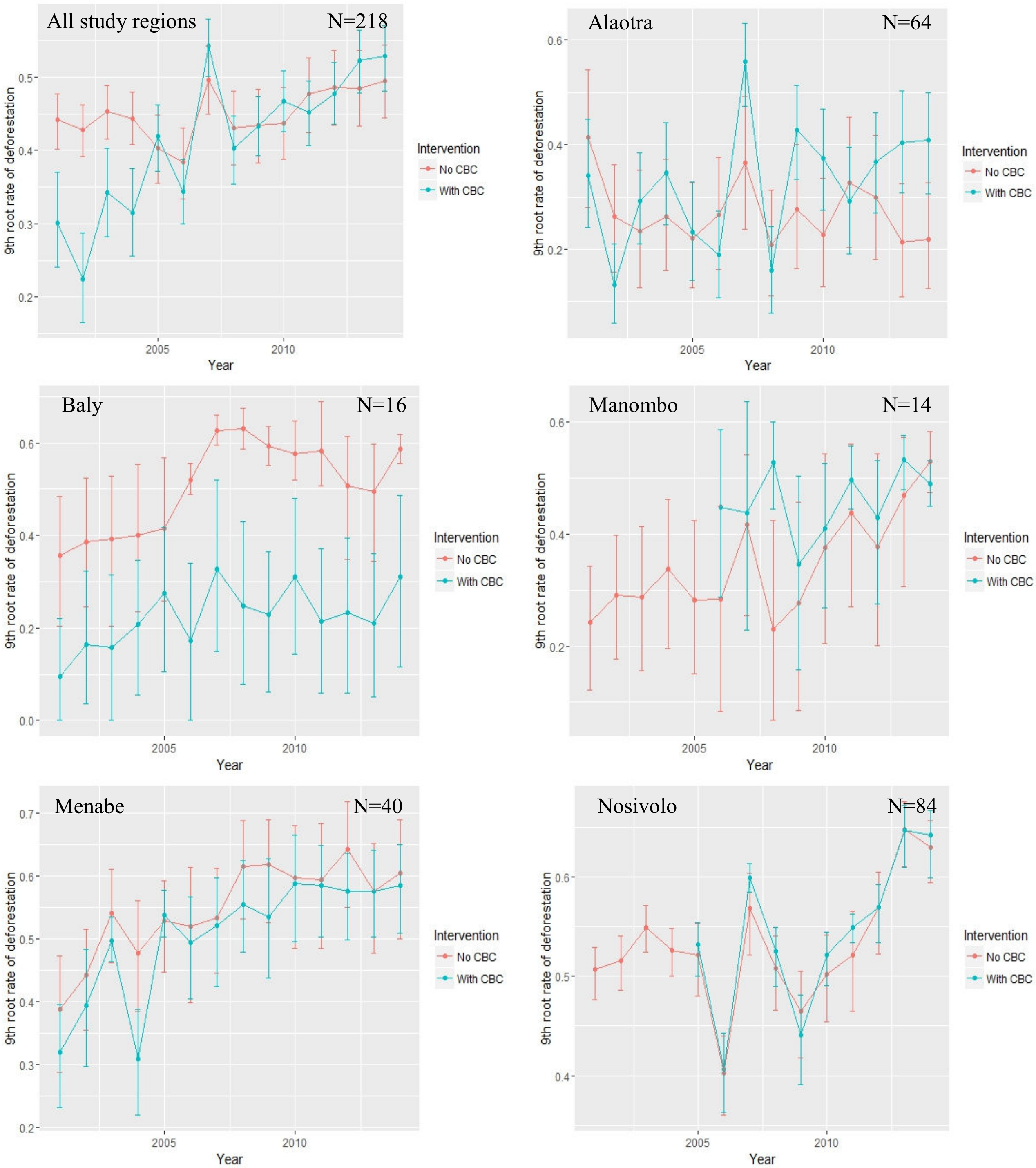


Figure 7. *Comparison of mean of the ninth root rate of deforestation (in %) over time between CBC villages and non-CBC villages using Hansen forest cover change data. N is the number of villages in each site*

Effectiveness of CBC in reducing deforestation

The fixed effect *year* presents an overall positive slope (estimate $5.312e^{-03} \pm 1.190e^{-03}$), indicating increase of deforestation over time ($p=8.360e^{-06}$). On average between 2000 and 2014, CBC villages have $1.524e^{+01} \pm 3.427e^{+00}$ less deforestation than non-CBC villages ($p=9.080e^{-06}$). However, our results reveal that CBC villages have significantly steeper slope of deforestation than non-CBC villages with an estimate of $7.580e^{-03} \pm 1.707e^{-03}$ ($p=9.340e^{-06}$). The deforestation rate in CBC villages generally increased more steeply. The fixed effects *population size* and *travel cost* are significantly related with the increase of deforestation rate, respectively making it $1.961e^{-05} \pm 9.928e^{-06}$ and $1.175e^{-02} \pm 5.948e^{-03}$ higher (Table 8).

Table 8. Fitted mixed effects model predicting the annual deforestation

Fixed effects	Hypothesis	Estimate	Std. Error	Pr(>|t|)
Year	Positive	$5.312e^{-03}$	$1.190e^{-03}$	$8.36e^{-06}$ ***
Presence of CBC	Negative	$-1.524e^{+01}$	$3.427e^{+00}$	$9.08e^{-06}$ ***
# cattle per capita	Positive	$1.590e^{-02}$	$9.586e^{-03}$	0.0973 NS
Population size	Positive	$1.961e^{-05}$	$9.928e^{-06}$	0.0490 *
Access to mobile phone network	Negative	$4.132e^{-03}$	$1.114e^{-02}$	0.7107 NS
Travel cost	Positive	$1.175e^{-02}$	$5.948e^{-03}$	0.0495 *
Year: CBC present	Negative	$7.580e^{-03}$	$1.707e^{-03}$	$9.34e^{-06}$ ***

*Significance: *P<0.05; **P<0.001; ***P<0.0001*

Other effects on deforestation

As with the model predicting the annual fire frequency, the result (Table 9) indicates that the random effect *village* (which is nested into *study region*) has much higher variability (SD 0.152) than *study region* (SD 0.099). This means that there is more idiosyncratic difference between the villages than between the study regions. The remaining variability that could not be explained by the two random effects village and study region can be seen on residuals.

Table 9. Variation of deforestation rate explained by random effects

Groups	Name	Variance	Std.Dev.
Village: study region	(Intercept)	0.0232	0.15224
Site	(Intercept)	0.0010	0.099
Residual		0.0263	0.162

Interaction between 'study region' and 'CBC interventions'

Results of ANOVA on model 4 (Table 10) reveals that there is a significant and strong interaction between the CBC intervention and study region ($p=8.39e^{-06}$). That indicates the need to look at the effectiveness of CBC intervention in reducing deforestation in each study region.

Table 10. Interaction between CBC intervention and study region (deforestation)

Fixed effects	Sum Sq	Mean Sq	NumDF	DenDF	F.value	Pr(>F)
Study region	3.595	0.899	4	231.340	33.471	$< 2.2e^{-16}$ ***
Presence CBC	0.017	0.0166	1	280.710	0.618	0.432
# cattle per capita	0.010	0.0103	1	2237.620	0.382	0.537
Population size	0.348	0.348	1	407.470	12.975	0.0004 ***
Access to mobile phone network	0.694	0.694	1	2889.250	25.858	$3.91e^{-07}$ ***
Travel cost	0.232	0.232	1	220.140	8.632	0.004 **
Study region: CBC	0.805	0.201	4	353.150	7.493	$8.39e^{-06}$ ***

*Significance: *P<0.05; **P<0.001; ***P<0.0001*

Likely effects of CBC in reducing the rate of deforestation at each study region

There is a significant increase of deforestation rate in Baly (p=0.0397), Manombo (p=0.0035), Menabe ($p=1.19e^{-05}$), and Nosivolo ($p=1.24^{e-14}$). Within the same period, Alaotra presented a decrease in deforestation rate with a p-value p=0.029. CBC villages have significant lower rate of deforestation in Baly ($p=1.90e^{-06}$) and Menabe (p=0.05). The slope of increase of the rate of deforestation within CBC villages is significantly higher in Alaotra ($p=2.22e^{-05}$) and Nosivolo ($p=2.03e^{-06}$) (appendix 3 - supplementary materials).

Discussion

This project set out to evaluate the effectiveness of CBC in reducing habitat threats by comparing the rate of fires and deforestation between CBC and non-CBC villages between 2000 and 2014. Three questions were addressed: How does fire frequency compare between CBC villages and non-CBC villages? How does the rate of deforestation compare between them? What other factors contribute to the variation of fire and deforestation in the two groups, given the actions associated with CBC? Exploration of those questions will help conservation managers improve the effectiveness of CBC towards better management of natural resources.

Difference in fire frequency between CBC and non-CBC villages

Despite an increase in fire, in both the CBC and non-CBC villages, a positive effect of CBC was detected on the rate of increase rather than on its frequency per square kilometre. Thus, fire frequency increased less steeply in CBC villages, suggesting that with continual CBC intervention the habitats will be less impacted by fires.

In Madagascar, farmers use fires to renew the grassland every dry season so fires and cattle grazing have for years been associated and held responsible for much of the deforestation. However, we did not find evidence of positive correlation between number of cattle and fire frequency. Fire has for a long time been acknowledged as an important factor damaging the Earth's ecosystems and climate because it severely alters the landscape and vegetation patterns, and emits large amounts of greenhouse gas into the atmosphere (Kaufman et al., 1998). Even though fire has been part of the natural process of evolution of the earth, occurring for more than 400 million years (Bowman et al., 2009), reducing fire and deforestation is often the primary objective for conservation managers (Kapos et al., 2008). Taking action to effectively combat fires needs to be initiated at the local level especially in areas where the interaction between local people and wildlife is high and fire can be an expression of local people's attitude. In the case of Madagascar, achieving such a goal is a challenge because fire has long played a role in traditional culture (Kull, 2000) and it is also a cost effective way to clear land for agriculture or cattle farming. Some form of co-management is likely to be the only solution to reduce fire and deforestation in Madagascar (Kull, 2000). Additionally, the national land tenure regulations are complex and people are tempted to use fire as a method of marking land ownership. Hence, global or national strategy to preserve natural ecosystems need to understand these complex issues if they are to provide effective measures to prevent fires.

Difference in rate of deforestation between CBC and non-CBC villages

Results from the present study indicate an increase in deforestation during the period 2000-2014 in both CBC and non-CBC villages. Compared to control villages, the CBC villages had a lower overall level of deforestation, but a faster rate of increase due to the very high level of deforestation detected in CBC villages during the last three years of the study period (2012 -2014) (Fig. 7).

According to Global Forest Watch (2015), deforestation increased in Madagascar between 2000 and 2014, and an evaluation study conducted by Rasolofoson et al. (2015) across Madagascar between 2000 and 2010 found little evidence that community forest management resulted in reducing deforestation rates.

Building on these studies, maps were developed for one of the Durrell study areas (Menabe dry forest) showing a five year cumulative sequence of forest loss, clearly illustrating the severity of deforestation between 2000 and 2014 (appendix 1, supplementary materials). From this, the general conclusion was reached that, as in the aforementioned studies, CBC was not successful in reducing deforestation in Madagascar for reasons that are complex: it seems likely that forests in CBC villages, all of which have official protected status, would be targeted because they offer higher quality timber from large diameter trees, and more non timber forest products, and are therefore more useful, and of greater commercial value, to land owners. Moreover with deforestation advancing rapidly, protected areas are increasingly becoming a final refuge for biodiversity (Laurance et al., 2012).

The lower overall level of deforestation observed in CBC villages compared with non-CBC villages may be the result of different initial conditions back in 2000 when control villages appeared to have a higher deforestation rate than CBC villages. However, findings for the period 2000 - 2012 may also indicate the success of CBC in raising public awareness and mobilising local communities by contributing support to local development projects. The aim of the CBC projects was to motivate local communities to change their attitudes and not convert so much of their local forest or marsh area into farmland, so the lower overall rates of deforestation in CBC villages seems to indicate a commitment to conservation on the part of the local community.

Monitoring deforestation can be a considerable challenge, requiring rigorous fieldwork, because some methods of slash-and-burn agriculture involve felling trees, leaving them on the land for one or two years as a sign of ownership, and finally burning them when their branches are combustible before planting crops. In such case the loss of trees would not be detected at the time of felling.

Other factors influencing fire and deforestation

A key finding from this study is that the incidence of political instabilities appears to correlate strongly with change in the frequency of fire (Fig. 5). The result unpins the importance of government commitment to conservation policies (Horning, 2008); political instability is one factor that worsens the issue of fires in both CBC and non-CBC villages. The reason for this finding might be explained in part by the fact that during periods of political disruption most of the government agencies are on strike, the administrative machinery is less active and there is a lack of resources due to the suspension of financial support from the international community. As result of these, government officials have difficulty in arranging field visits, and law enforcement is often weakened. The quality of community-based management depends on political stability, so when the law is not enforced local people are less able to control illegal activities that affect their natural resources. For example, the opportunity for slash and burn and illegal timber commercialisation is greater during political disruption. Local people are hoping for political negotiations through the mediation of national and regional bodies led respectively by the main churches and the SADC (Southern African Development Community).

The result that the number of cattle per capita which has declined considerably over the priod 2000-2014 (see Fig. 6), was not found to be a significant predictor of fires and deforestation was surprising. Similarly, the increase in population has no significant effect on the fire frequency - however, it was determined as an important variable increasing the rate of deforestation. We believe that the no correlation between increase of fire and the number of cattle per capita was probably because the proportion of people who own cattle decreased considerably over time. However, positive correlation observed between increase in deforestation and increase in demography may be explained by the fact that local people need more land to plant more crops to feed their families, but it may also be due to social inequality so that wealthier or more powerful groups are able to acquire land more easily than others. There is no doubt that population puts pressure on land use in Madagascar. Clark (2012) stated that Madagascar population growth is difficult to control, and there has been a four fold increase during the last 50 years, with an average of 4.6 children per woman.

The variable *travel cost* is identified as an important fixed effect contributing to higher fire frequency and higher rate of deforestation. This suggests that despite more difficult access to public market, people living in remote villages generally tend to burn and clear more forest, possibly in the knowledge that it would be hard logistically for authorities to control their activity and enforce the law. Related to this finding, it would appear that access to mobile phones is also a key fixed factor that can result in reduced fire severity. This is because a mobile phone is not only an indicator of status, but also a means of rapid communication in spreading news of fires and their causes.

In terms of abiotic/biotic factors influencing fires, the evapotranspiration is one of the important fixed effects influencing the apparent variation of fires. The evapotranspiration expresses the humidity in the atmosphere, due mainly to rain and temperature, and can significantly lower fire risk. The study period of 14 years is probably too short to assess the role of climate change in exacerbating the problem of fires, but it is important for conservation managers to recognise that evapotranspiration is an important predictor of fire.

Strength and limitations of this study

Strength

This study provides an important contribution to the improvement of conservation impact evaluation science. We demonstrated that the availability of free global time series dataset, such as MODIS-detected fires, AVHRR fires, Evapotranspiration and especially the Hansen forest cover, can cost-effectively help evaluate the impact of conservation programmes. This study also helped highlight the importance of the quasi experimental design to quantitatively assess conservation impacts over time and take into account the effects of confounding variables. Those two points may encourage conservation managers who have limited budget and could not start their work with a robust experimental design in place to evaluate their effectiveness.

Limitations

Each study region has different vegetation types, some of which are naturally too meagre to meet the threshold of 50% canopy cover per pixel of 30 x 30 metres as used by Hansen et al (2013). We suspect that some pixels of marsh vegetation in Lake Alaotra and also probably some bamboos scrub habitat in Baly Bay have been classified as non-forest due to that standard criterion. In addition, due to specific type of ecosystem (lake in Alaotra, river in Nosivolo, mangroves at Menabe and bamboos in Baly) it was often hard to find perfect control villages. We therefore had to rely on the best matched villages identified through matching of propensity scores calculated from the six covariates.

Lessons to be learned from this study

The Community-based Conservation approaches often attempt to understand many aspects of conservation issues in order to educate local people and communicate new land management proposals within a community. In Madagascar, the CBC approach has been widely used in attempting to reduce severe threats represented by fire and deforestation. Despite these efforts, the current study shows that CBC has not been able to prevent or reduce frequency of fires within intervention villages. CBC did not prevent people who would/could not assimilate new ideas about the environment, from destroying natural resources. That is a serious problem because in some places such as Lake Alaotra, Baly Bay and Menabe dry forest, the vegetation can be very combustible during the dry season and just a single fire can destroy thousands of hectares. In village meetings, local people especially members of local associations express their disappointment when they see other people destroying their natural resources and escaping without punishment. Despite strong cohesion of CBC communities' and their determination to protect their own management zone they lose motivation to continue protecting their area when they witness the collapse of their local ecosystem. However, evidence from this study does give some hope because it demonstrates that by implementing CBC conservation managers can at least significantly reduce the rate of increase of fire and maintain a lower rate of deforestation.

In conclusion, this study shows that the effectiveness of CBC in reducing the most severe threats to ecosystems in Madagascar is limited. However, our evidence suggests that overall CBC generally has a significant treatment effect making those threats less damaging. In overall terms, the effectiveness of CBC in Madagascar could be enhanced by improvements in law enforcement, a clearer and simpler land ownership policy, and more effective collaboration between authorities, development agencies and conservation NGOs.

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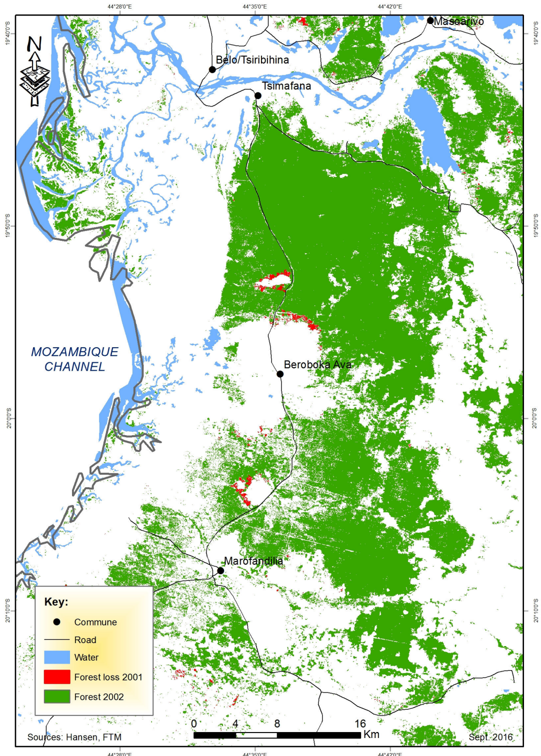
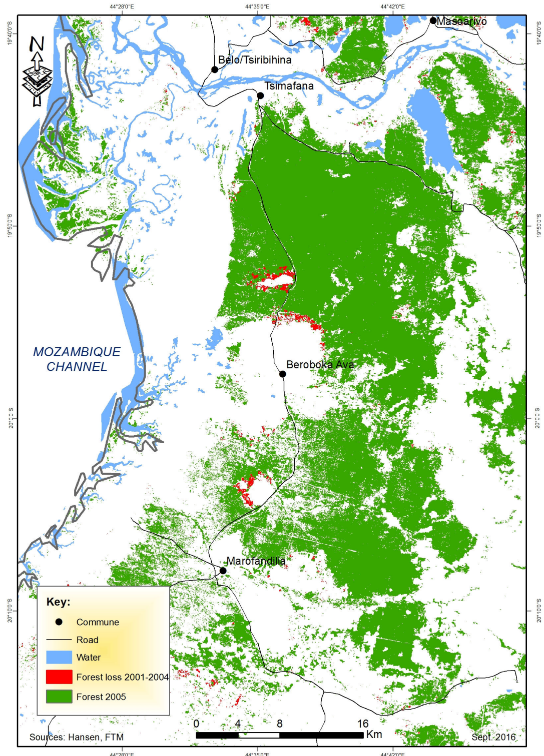
Supplementary materials

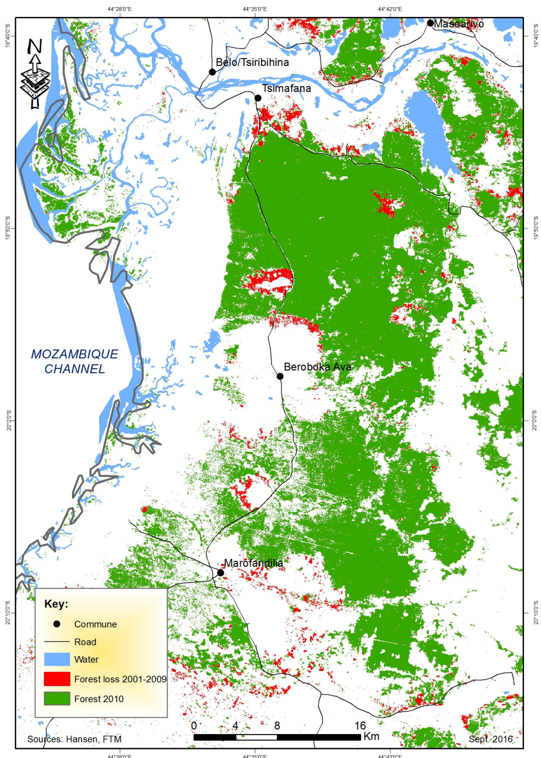
Appendix 1. Example of deforestation: cumulative forest loss at Menabe 2000-2013



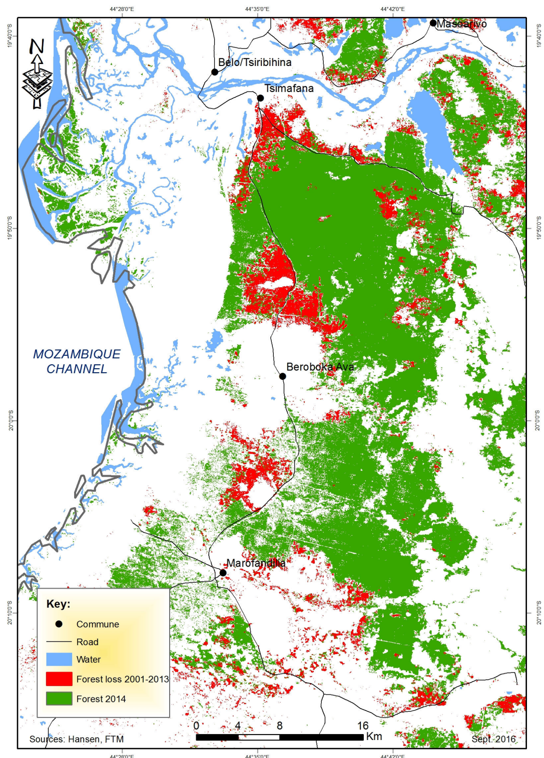
Forest loss in Menabe 2000-2002



Forest loss in Menabe 2000-2004



Forest loss in Menabe 2000-2009



Forest loss in Menabe 2000-2013

Appendix 2. Effects of CBC on fire in each study region

<table>
<tr><th>Fixed effects</th><th>Alaotra</th><th>Baly</th><th>Manombo</th><th>Menabe</th><th>Nosivolo</th></tr>
<tr><td>Year</td><td>Hypothesis: negative
Est.: 5.645e-03
Std. Error: 1.658e-03
Pr(>|t|): 0.000691 ***</td><td>Hypothesis: negative
Est.: 1.742e-02
Std. Error: 4.858e-03
Pr(>|t|): 0.000449 ***</td><td>Hypothesis: negative
Est.: 7.734e-03
Std. Error: 3.458e-03
Pr(>|t|): 0.02660 *</td><td>Hypothesis: negative
Est.: 1.659e-02
Std. Error: 3.644e-03
Pr(>|t|): 6.77e-06 ***</td><td>Hypothesis: negative
Est.: 1.467e-02
Std. Error: 1.481e-03
Pr(>|t|): < 2e-16 ***</td></tr>
<tr><td>CBC Yes</td><td>Hypothesis: negative
Est.: 1.806e+00
Std. Error: 3.466e+00
Pr(>|t|): 0.602401</td><td>Hypothesis: negative
Est.: 2.027e+01
Std. Error: 1.311e+01
Pr(>|t|): 0.124099</td><td>Hypothesis: negative
Est.: 4.130e+01
Std. Error: 1.558e+01
Pr(>|t|): 0.00867 **</td><td>Hypothesis: negative
Est.: -2.418e+01
Std. Error: 7.765e+00
Pr(>|t|): 0.1954</td><td>Hypothesis: negative
Est.: 1.358e+01
Std. Error : 5.845e+00
Pr(>|t|) : 0.02036 *</td></tr>
<tr><td>Cattle per capita</td><td>Hypothesis: positive
Est.: -6.746e-03
Std. Error: 1.823e-02
Pr(>|t|): 0.711450</td><td>Hypothesis: positive
Est.: 3.826e-02
Std. Error: 2.332e-02
Pr(>|t|): 0.119047</td><td>Hypothesis: positive
Est.: -2.602e-01
Std. Error: 1.025e-01
Pr(>|t|): 0.01223 *</td><td>Hypothesis: positive
Est.: 4.220e-03
Std. Error: 1.140e-02
Pr(>|t|): 0.711519</td><td>Hypothesis: positive
Est.: 1.455e-01
Std. Error : 1.064e-01
Pr(>|t|) : 0.17276</td></tr>
<tr><td>Mean ET</td><td>Hypothesis: negative
Est. : -4.194e-05
Std. Error: 9.819e-06
Pr(>|t|): 3.11e-05 ***</td><td>Hypothesis: negative
Est. : -2.345e-05
Std. Error: 1.727e-05
Pr(>|t|): 0.190449</td><td>Hypothesis: negative
Est. : 7.436e-06
Std. Error: 2.449e-05
Pr(>|t|): 0.76452</td><td>Hypothesis: negative
Est. : -8.744e-05
Std. Error: 1.852e-05
Pr(>|t|): 3.24e-06 ***</td><td>Hypothesis: negative
Est. : 6.628e-05
Std. Error: 2.545e-05
Pr(>|t|): 0.00948 **</td></tr>
<tr><td>Population size</td><td>Hypothesis: negative
Est. : 1.348e-05
Std. Error: 8.394e-06
Pr(>|t|): 0.112229</td><td>Hypothesis: negative
Est.: -7.349e-06
Std. Error: 8.028e-06
Pr(>|t|): 0.382207</td><td>Hypothesis: negative
Est.: 1.209e-04
Std. Error: 4.266e-05
Pr(>|t|): 0.01138 *</td><td>Hypothesis: negative
Est.: 7.688e-06
Std. Error: 2.851e-05
Pr(>|t|): 0.787718</td><td>Hypothesis: negative
Est.: 7.425e-06
Std. Error : 1.318e-05
Pr(>|t|) : 0.57441</td></tr>
<tr><td>Phone network Yes</td><td>Hypothesis: negative
Est. : -1.189e-02
Std. Error: 1.208e-02
Pr(>|t|): 0.325012</td><td>Hypothesis: negative
Est.: -4.398e-02
Std. Error: 3.645e-02
Pr(>|t|): 0.230585</td><td>Hypothesis: negative
Est.: 3.791e-02
Std. Error: 3.576e-02
Pr(>|t|): 0.29180</td><td>Hypothesis: negative
Est.: -3.747e-02
Std. Error: 2.762e-02
Pr(>|t|): 0.175488</td><td>Hypothesis: negative
Est.: -2.261e-02
Std. Error : 1.874e-02
Pr(>|t|) : 0.22786</td></tr>
<tr><td>Travel cost</td><td>Hypothesis: positive
Est. : 3.606e-02
Std. Error: 7.676e-03
Pr(>|t|): 1.27e-05 ***</td><td>Hypothesis: positive
Est. : -2.427e-02
Std. Error: 9.633e-03
Pr(>|t|): 0.025667 *</td><td>Hypothesis: positive
Est. : 1.446e-02
Std. Error: 1.316e-02
Pr(>|t|): 0.28640</td><td>Hypothesis: positive
Est. : -9.656e-03
Std. Error: 1.634e-02
Pr(>|t|): 0.558352</td><td>Hypothesis: positive
Est. : 6.920e-03
Std. Error: 3.947e-03
Pr(>|t|): 0.08317 .</td></tr>
<tr><td>Political crisis present</td><td>Hypothesis: negative
Est. : 7.240e-03
Std. Error: 8.577e-03
Pr(>|t|): 0.398804</td><td>Hypothesis: negative
Est. : 2.888e-02
Std. Error: 2.116e-02
Pr(>|t|): 0.174653</td><td>Hypothesis: negative
Est. : -3.012e-02
Std. Error: 2.337e-02
Pr(>|t|): 0.19891</td><td>Hypothesis: negative
Est. : 6.423e-02 Std. Error: 1.693e-02
Pr(>|t|): 0.000168 ***</td><td>Hypothesis: negative
Est. : 1.181e-02
Std. Error: 1.001e-02
Pr(>|t|): 0.23829</td></tr>
<tr><td>year: CBCYes</td><td>Hypothesis: negative
Est. : -8.697e-04
Std. Error: 1.727e-03
Pr(>|t|): 0.614772</td><td>Hypothesis: negative
Est. : -1.012e-02
Std. Error: 6.521e-03
Pr(>|t|): 0.122788</td><td>Hypothesis: negative
Est. : -2.053e-02
Std. Error: 7.756e-03
Pr(>|t|): 0.00878 **</td><td>Hypothesis: negative
Est. : -1.201e-02
Std. Error: 3.871e-03
Pr(>|t|): 0.002029 **</td><td>Hypothesis: negative
Est. : -6.758e-03
Std. Error: 2.910e-03
Pr(>|t|): 0.02039 *</td></tr>
</table>

Appendix 3. Effects of CBC on deforestation in each study region

<table>
<tr><th>Fixed effects</th><th>Alaotra</th><th>Baly</th><th>Manombo</th><th>Menabe</th><th>Nosivolo</th></tr>
<tr><td>Year</td><td>Hypothesis: negative
Est.: -8.019e-03
Std. Error: 3.670e-03
Pr(>|t|): 0.02918 *</td><td>Hypothesis: negative
Est.: 1.279e-02
Std. Error: 6.169e-03
Pr(>|t|): 0.0397 *</td><td>Hypothesis: negative
Est.: 1.444e-02
Std. Error: 4.858e-03
Pr(>|t|): 0.00354 **</td><td>Hypothesis: negative
Est.: 1.251e-02
Std. Error: 2.826e-03
Pr(>|t|): 1.19e-05 ***</td><td>Hypothesis: negative
Est.: 7.915e-03
Std. Error: 1.012e-03
Pr(>|t|): 1.24e-14 ***</td></tr>
<tr><td>CBC Yes</td><td>Hypothesis: negative
Est.: 3.378e+01
Std. Error: 7.936e+00
Pr(>|t|): 2.32e-05 ***</td><td>Hypothesis: negative
Est.: -1.787e+01
Std. Error: 3.732e+00
Pr(>|t|): 1.90e-06 ***</td><td>Hypothesis: negative
Est.: 1.854e+01
Std. Error: 1.865e+01
Pr(>|t|): 0.32137</td><td>Hypothesis: negative
Est.: -4.273e+00
Std. Error: 6.872e+00
Pr(>|t|): 0.0453*</td><td>Hypothesis: negative
Est.: 1.896e+01
Std. Error: 1.675e+01
Pr(>|t|): 0.2595</td></tr>
<tr><td>Cattle per capita</td><td>Hypothesis: positive
Est.: -3.305e-02
Std. Error: 4.442e-02</td><td>Hypothesis: positive
Est.: 5.381e-02
Std. Error: 4.975e-02</td><td>Hypothesis: positive
Est.: 3.528e-02
Std. Error: 1.344e-01</td><td>Hypothesis: positive
Est.: 1.289e-02
Std. Error: 9.454e-03</td><td>Hypothesis: positive
Est.: 1.189e-02
Std. Error: 9.434e-02</td></tr>
</table>

	Pr(>|t|): 0.45716	Pr(>|t|): 0.2836	Pr(>|t|): 0.79328	Pr(>|t|): 0.174	Pr(>|t|): 0.900
Population size	Hypothesis: negative Est. : 2.975e-05 Std. Error: 1.953e-05 Pr(>|t|): 0.13169	Hypothesis: negative Est. : 4.585e-05 Std. Error: 2.263e-05 Pr(>|t|): 0.0584 .	Hypothesis: negative Est. : 6.515e-05 Std. Error: 8.632e-05 Pr(>|t|): 0.45902	Hypothesis: negative Est. : -8.227e-06 Std. Error: 2.260e-05 Pr(>|t|): 0.716	Hypothesis: negative Est. : -2.328e-05 Std. Error: 1.421e-05 Pr(>|t|): 0.103
Phone network Yes	Hypothesis: negative Est. : 3.457e-02 Std. Error: 2.569e-02 Pr(>|t|): 0.17866	Hypothesis: negative Est. : -3.617e-02 Std. Error: 5.275e-02 Pr(>|t|): 0.4939	Hypothesis: negative Est. : -6.047e-04 Std. Error: 4.984e-02 Pr(>|t|): 0.99033	Hypothesis: negative Est. : 2.116e-02 Std. Error: 2.329e-02 Pr(>|t|): 0.364	Hypothesis: negative Est. : 5.535e-03 Std. Error: 1.344e-02 Pr(>|t|): 0.680
Travel cost	Hypothesis: positive Est. : 4.656e-02 Std. Error: 1.701e-02 Pr(>|t|): 0.00805 **	Hypothesis: positive Est. : 2.777e-02 Std. Error: 2.637e-02 Pr(>|t|): 0.3077	Hypothesis: positive Est. : 4.187e-02 Std. Error: 2.678e-02 Pr(>|t|): 0.13840	Hypothesis: positive Est. : -1.787e-03 Std. Error: 1.184e-02 Pr(>|t|): 0.881	Hypothesis: positive Est. : 5.246e-03 Std. Error: 4.903e-03 Pr(>|t|): 0.288
year: CBCYes	Hypothesis: positive Est. : 1.686e-02 Std. Error: 3.952e-03 Pr(>|t|): 2.22e-05 ***	Hypothesis: positive Est. : -9.558e-03 Std. Error: 8.336e-03 Pr(>|t|): 0.2535	Hypothesis: positive Est. : -9.197e-03 Std. Error: 9.283e-03 Pr(>|t|): 0.32312	Hypothesis: positive Est. : 2.106e-03 Std. Error: 3.422e-03 Pr(>|t|): 0.539	Hypothesis: positive Est. : 8.875e-03 Std. Error: 1.859e-03 Pr(>|t|): 2.03e-06 ***

Appendix 4: Matrix correlation of fixed effects for fire analysis

```
Formula: fire_sqrt ~ year * CBC + cattle_per_capita + mean_ET + popsize +
    phone_network + travel_cost + political_disruption + (1 | site/DisComFkt)
   Data: mydata

     AIC      BIC   logLik deviance df.resid
 -2707.0  -2628.8   1366.5  -2733.0     3020

Scaled residuals:
    Min      1Q  Median      3Q     Max
-3.2887 -0.6282 -0.1210  0.4793  4.6153

Random effects:
 Groups         Name        Variance Std.Dev.
 DisComFkt:site (Intercept) 0.009454 0.09723
 site           (Intercept) 0.003121 0.05587
 Residual                   0.020549 0.14335
Number of obs: 3033, groups:  DisComFkt:site, 216; site, 5

Fixed effects:
                          Estimate Std. Error        df t value Pr(>|t|)
(Intercept)             -2.474e+01  2.018e+00  2.933e+03 -12.261  < 2e-16 ***
year                     1.249e-02  1.004e-03  2.934e+03  12.444  < 2e-16 ***
CBCYes                   1.237e+01  2.832e+00  2.914e+03   4.368 1.30e-05 ***
cattle_per_capita        8.458e-03  7.742e-03  1.561e+03   1.092  0.27483
mean_ET                 -3.335e-05  6.561e-06  3.175e+02  -5.083 6.36e-07 ***
popsize                  1.172e-05  6.911e-06  2.692e+02   1.696  0.09105 .
phone_networkYes        -2.532e-02  9.399e-03  2.937e+03  -2.694  0.00711 **
travel_cost              7.868e-03  3.956e-03  2.059e+02   1.989  0.04803 *
political_disruptionPresent  1.953e-02  6.039e-03  2.828e+03   3.234  0.00124 **
year:CBCYes             -6.153e-03  1.411e-03  2.915e+03  -4.362 1.34e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) year   CBCYes cttl__ men_ET popsiz phn_nY trvl_c pltc_P
year        -1.000
CBCYes      -0.464  0.465
cttl_pr_cpt -0.055  0.052 -0.073
mean_ET     -0.205  0.187  0.003  0.093
popsize      0.162 -0.168 -0.005  0.104  0.054
```

```
phn_ntwrkYs  0.339 -0.341  0.062 -0.019  0.024 -0.085
travel_cost  0.069 -0.074  0.014 -0.095 -0.048  0.120  0.098
pltcl_crssP  0.278 -0.280  0.046 -0.006  0.059 -0.011 -0.055 -0.011
year:CBCYes  0.465 -0.466 -1.000  0.073 -0.004  0.005 -0.062 -0.014 -0.046
```

Appendix 5. Matrix correlation of fixed effect for deforestation analysis

```
Formula: defor_9 ~ year * CBC + cattle_per_capita + popsize + phone_network +
    travel_cost + (1 | site/DisComFkt)
   Data: mydata

     AIC      BIC   logLik deviance df.resid
 -1729.0  -1663.3    875.5  -1751.0     2879

Scaled residuals:
    Min      1Q  Median      3Q     Max
-3.8884 -0.3510  0.0252  0.3917  5.8647

Random effects:
 Groups         Name        Variance Std.Dev.
 DisComFkt:site (Intercept) 0.023177 0.15224
 site           (Intercept) 0.009819 0.09909
 Residual                   0.026281 0.16211
Number of obs: 2890, groups:  DisComFkt:site, 218; site, 5

Fixed effects:
                    Estimate Std. Error        df t value Pr(>|t|)
(Intercept)       -1.030e+01  2.383e+00  2.836e+03  -4.322 1.60e-05 ***
year               5.312e-03  1.190e-03  2.828e+03   4.464 8.36e-06 ***
CBCYes            -1.524e+01  3.427e+00  2.740e+03  -4.446 9.08e-06 ***
cattle_per_capita  1.590e-02  9.586e-03  2.240e+03   1.659   0.0973 .
popsize            1.961e-05  9.928e-06  3.357e+02   1.975   0.0490 *
phone_networkYes   4.132e-03  1.114e-02  2.890e+03   0.371   0.7107
travel_cost        1.175e-02  5.948e-03  2.177e+02   1.975   0.0495 *
year:CBCYes        7.580e-03  1.707e-03  2.742e+03   4.440 9.34e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) year   CBCYes cttl__ popsiz phn_nY trvl_c
year        -1.000
CBCYes      -0.525  0.523
cttl_pr_cpt -0.037  0.036 -0.078
popsize      0.222 -0.228  0.010  0.094
phn_ntwrkYs  0.392 -0.393  0.042 -0.038 -0.074
travel_cost  0.063 -0.070  0.010 -0.075  0.119  0.083
year:CBCYes  0.526 -0.525 -1.000  0.078 -0.010 -0.041 -0.010
```

Chapter 3

Paper 2: Evaluating the contribution of Community-based Conservation to local improvements in primary education and public health in Madagascar

---

Abstract

Local development initiatives by conservation managers are often overlooked although in developing countries such strategies can contribute significantly to the success of Community-based Conservation (CBC). This paper retrospectively evaluates the contribution of CBC interventions implemented by environmental charity Durrell Wildlife Conservation Trust (Durrell) to local improvements in primary education and public health in five key conservation areas in Madagascar. The study is based on data from 109 intervention villages and 109 control villages selected through propensity score matching. To assess the impact of Durrell's CBC interventions, education and health data over a thirty year period was analysed (1982-2012). The data included success rates in CEPE examinations (Certificat d' Enseignement Primaire Elémentaire) from each village, as well as patient and health statistics recorded by local public health centres. The results showed that the effectiveness of CBC interventions differs in each of the areas studied. On average, support to education through CBC interventions is associated with higher educational attainment. However, analysis of the Index of Health Status at village level did not show evidence that provision of clean drinking water or other health interventions measurably improved public health. We also examined the potential relationship between the two fixed factors of travel cost (accessibility and distance to nearest town), and the Multidimensional Poverty Index (MPI), and the quality of education and health. Our findings revealed that MPI status is not correlated with either education or health, while

travel cost was identified as a significant contributing factor lowering the Index of Health Status.

Keywords: local community, conservation, education, public health, evaluation

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Introduction

Community-based Conservation (CBC) is a participatory approach to conservation that emphasises the interaction between wildlife and local people, who are supported or incentivised to play a principal role in the management of natural resources on which they rely. The overall aim is to reduce biodiversity threats and achieve conservation goals whilst simultaneously working to improve human well-being (Berkes, 2004). CBC came into widespread use following the development of UNESCO's buffer zone concept in the late 1970s and the Integrated Conservation and Development Programmes (ICDP) promoted in the late 1980s (Hugues & Flintan, 2001). There is a well founded view that more attention should be given to biodiversity conservation activities designed to meet people's basic needs (Kaimowitz & Sheil, 2007). The approaches mentioned above are based on the principle that providing direct socioeconomic incentives would motivate local communities to preserve biodiversity in and around protected areas. The CBC approach is different however, in that it aims to set local communities at the centre of conservation management process, and to empower them to achieve the desired result rather than just the organisation mechanism (Campbell & Vainio-Mattila, 2003).

Brooks et al. (2006) noted that more involvement of local communities in the conservation process can generate greater attitudinal success which is an important factor for a successful conservation outcome. However, sustaining that involvement demands engagement with those communities over the long term as well as a commitment to providing substantial social benefits (Brooks et al., 2013).

A number of conservation NGOs in developing countries have instigated specific development-related interventions in the field of agriculture, education, revenue generating activities, and public health, under the assumption that if there is an improvement in the well-being of local communities who use the local natural resources, their conservation initiatives would be more successful and more sustainable. That approach has also often been formulated as a type of Payment for Ecosystem Services, in which members of a community are asked to work to conserve their local environment in exchange for receiving socio-economic support, under a formal or informal contract (Sommerville et al., 2011).

However, there is still poor knowledge of the success of these development-related interventions. There are generally two issues that arise: First, most conservation NGOs cannot afford the cost of determining the real outcomes of their conservation activities; these are perceived as too difficult to measure directly, and often too challenging to be achieved over the short timescale of funded projects (Jones, 2012). There is therefore a real need for the development of simpler measures to evaluate conservation success (Howe & Milner-Gulland, 2012). Moreover, conservation practitioners and community stakeholders who are familiar with local conditions need to be engaged as they would be the most appropriate people to monitor the effectiveness of conservation projects (Margoluis & Salafsky, 1998). Second, while conservation NGOs find it difficult to measure conservation outcomes, quantifying the socio-economic outcomes can be even more of a challenge. Not only does this require external technical capacity and adequate financial resources, but it normally is given a lower priority than the evaluation of the conservation activity itself.

Thus, despite the radical change of strategy and the practical efforts made by conservation managers to contribute to improved human well-being, there is often little evidence to show that integrating development and conservation projects have resulted in more effective and sustainable conservation (Salafsky & Margoluis, 1999). Without the means to measure outcomes, NGOs can do no more than estimate or assume the success of their interventions (Kapos et al., 2009), or rely on qualitative reports of the implementation of their interventions (Ferraro & Pattanayak, 2006). An additional issue is that many conservation NGOs, especially those that rely on short-term grants and external financial donors, are reluctant to report disappointing outcomes (Gratwicke et al., 2007). In summary, the development of robust CBC strategies has been held back because conservation managers have not been able adequately to learn from past failures (Saterson et al., 2004).

This retrospective study examines the case of Durrell Wildlife Conservation Trust (Durrell), an NGO that has worked in Madagascar on the conservation of critically endangered species since 1986. Since 1997, Durrell adopted the CBC approach in the five key conservation regions of Lake Alaotra, Baly Bay National Park, Manombo rainforest, Menabe dry forest, and Nosivolo River, involving members of local communities in the conservation and monitoring process of forests and wetlands by 109 villages. Durrell assisted government officials in implementing protected areas, raised public awareness, and empowered local associations through training and the offer of substantial incentives related to education and health in exchange for better management of the local environment.

Education support was provided in the form of building or refurbishing schools and supplying school materials while health interventions involved building public wells, water pumps, etc.; the local communities determined what kinds of development aid they received.

This study aimed to examine whether Durrell's CBC education and health-related interventions have impacted on annual school attainment and/or on the Index of Health Status in the intervention villages over 30 years (15 years before and after the inception of CBC). Since Durrell's support for public health was allocated mainly to provision of clean water, it was assumed that the impact of CBC interventions would be reflected in the burden of waterborne diseases and sanitation and hygiene-related diseases. However, the various waterborne diseases are interconnected and an initiative to improve one aspect of health can yield benefits in other aspects. We therefore decided to quantify the impact of health interventions on the Index of Health Status which is a more encompassing assessment of general public health.

The study covers the 30 year period 1982-2012, providing a good opportunity to review the impact of CBC interventions on a range of response variables, and to evaluate the situation before and after Durrell interventions in 109 villages. These results were compared to 109 control villages which had no intervention. The control villages were selected using a propensity score matching method (Peikes et al., 2008) since no random experimental design had been put in place by Durrell at the start of their interventions (see Chapter 1).

For both the CBC and non-CBC villages, the annual rates of success in the CEPE examinations (Certificat d'Enseignement Primaire Elémentaire) from each primary school in each village were examined to ascertain the impact of CBC on school attainment. Over the same time period the annual number of patients treated, broken down by the 108 types of illness listed by the Global Burden of Disease survey (IHME, 2013) were obtained from each CSB health centre (Centre de Santé de Base) in order to study the health status of the local community. We then examined the contribution of some potentially important explanatory variables such as travel cost and the

Multidimensional Poverty Index to the variation of the school attainment and health status.

There has been several previous studies, for example, Gardner et al. (2013), Clements et al. (2014) and McKinnon et al. (2016) that have tested the effectiveness of conservation programmes in improving general human well-being in different countries. However, the study presented here attempts to measure the effectiveness of one particular approach (CBC) in improving two elements of social well-being (educational attainment and public health) at the local scale.

In comparing the trends of school attainment and health status over time between intervention and non-intervention villages, we aim to elucidate whether CBC projects have contributed to the improvement in human well-being in the intervention villages. And in examining other factors such as travel cost (distance and access to nearest town), Multidimensional Poverty Index, and population size, we also sought to discover whether these factors had influenced the variation in education and health metrics. The intention is that findings from this study will help conservation managers using the CBC approach to learn from the successes or failures outlined, and to develop evidence-based conservation strategies for more sustainable management of natural resources.

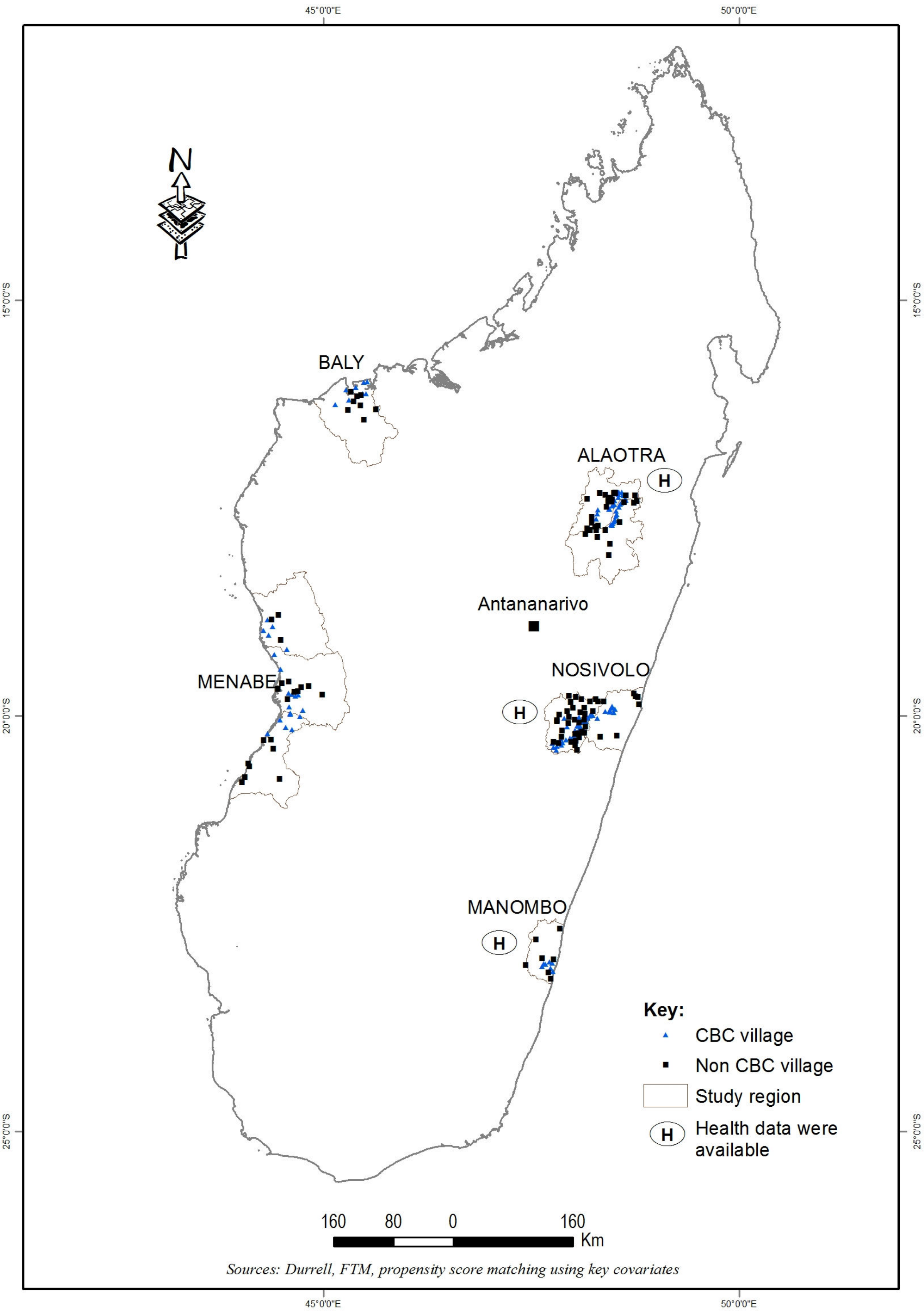
Methods

Study areas

The study was carried out in five CBC intervention areas: Lake Alaotra, Baly Bay National Parks, Manombo Special Reserve, Menabe dry forest and Nosivolo River (Table 11). All of them have Protected Area status but are managed under Community-Based Conservation.

Table 11. Description of the five study regions

Study region	Alaotra	Baly Bay	Manombo	Menabe	Nosivolo
Region	Alaotra Mangoro	Boeny	Atsimo Atsinanana	Menabe, Melaky	Atsinanana
District	Ambatondrazaka, Amparafaravola	Soalala	Farafangana	Antsalova, Belo/Tsiribihina, Morondava	Mahanoro, Marolambo
No village	32	8	7	20	42
Population size (2004)	103,824	16,509	11,073	38,718	72,919
Habitat types	Wetlands: Lake, marsh area	Bamboo, dry forest	Rain forest	Dense dry forest, mangroves	Wetlands: River
Date CBC start	1997	1996	2006	2000	2005
Climate	Semi humid, moderately hot	Dry, hot	Humid	Dry, hot	Humid, moderately hot
Elevation (m)	795.6	40.7	38.7	35.5	592.9
Protected Area size (hectares)	42,478	63,000	7,090	210,000	6,781
Status	New Protected Area	National Park	2 blocs: Special Res. & classif. forest	New protected area, Special Reserve	New protected areas
IUCN category	V	II	IV	III, IV, V (multi-category)	V
Key species	*Hapalemur alaotre*nsis (Alaotran gentle lemur)	*Astrochelys yniphora* (Plougshare tortoise)	Lemurs: 8 species. Ex. *Eulemur cinereiceps, Variecia v. editorum*	*Hypogeomys antime*na (Giant jumping rat), *Pyxis planicauda* (Flat tailed tortoise)	Fishes: *Oxilapia polli, Ptychochromoides katria*, *Bedotia* sp zono, *Bedotia* sp1
Main pressures	Burning, illegal rice farming, illegal fishing	Tortoise smuggling, fires	Illegal logging, fires	Illegal logging, slash and burn agriculture, fires	Illegal gold mining, slash and burn agriculture



Map 3. Location of the five study regions and matched villages

Sample unit

The sample unit is the 'fokontany', or village, the smallest administrative division in Madagascar. A typical fokontany will consist of one main village, known as the chef-lieu-fokontany, and a number of smaller hamlets. With a population size of between 1,000 and 5,000, a fokontany will cover approximately 30 square kilometres. The fokontany is the level of organisation at which the Durrell CBC projects are implemented, and disaggregated social response variables are available from government data sources. Each of the 109 intervention fokontany (hereafter 'CBC villages') has a recent known spatial boundary from the Madagascar statistics agency INSTAT (Institut National de la Statistique) and the national geographical and hydrographical institute FTM (Foiben-Taosarintanin'i Madagasikara). INSTAT provided an authoritative list of all fokontany and time-series of population size for each fokontany.

The study time-step is annual. Since some items of support from Durrell (for example a one-piece zinc roof, or a small quantity of water pipes) were not accounted for it was necessary to set a value threshold for education or health interventions of >200GBP of material support provided for one village in one year. That amount was the average minimum cost of an individual CBC project.

Selection of Durrell CBC villages

Typically, CBC interventions started around the year 2000, and it was important to match control villages to CBC villages using a set of covariates in that year. CBC villages were typically chosen as targets of CBC interventions due to their importance for supporting populations and habitat of various endangered species (Table 11) in each study region. The main villages situated closest to the habitat, where people could have direct influence on its management, were selected first. The number of intervention villages in each programme region grew gradually over time in accordance with prioritisation of activities and availability of funding. All villages are officially headed by a designated or elected fokontany president (depending on the constitution of successive Republics), but also have traditional village chiefs. Each fokontany keeps records of statistics on people and cattle.

Participatory ecological monitoring and inter-village competition

Participatory ecological monitoring has been used annually by Durrell to involve local communities in conservation and motivate them to positively change their attitude through prizes of inter-village competition. In annual participatory ecological monitoring exercises 10 volunteers from each village collect data on biodiversity and threats data in their management zone (Andrianandrasana et al., 2005). Results are then used to rank villages in each study region through inter-village competitions. Prizes are then awarded to villages in accordance with their needs for support for education, health, or revenue generating activities.

Education and health support provided

In broadest terms, there are two kinds of support that have been provided by Durrell for education and health over the past 15 years. To support education, Durrell has built or refurbished some 15 schools per year across the study regions, provided equipment such as school desks, new or re-roofed classrooms, new offices and environmental activities to broaden students' education. In support of health, Durrell has installed public wells, taps and water pumps to provide villages with clean drinking water, and constructed public toilets and washing areas. In addition, in some areas, Durrell has provided direct medical support. For example, in the Nosivolo River area Durrell worked with the regional health service to distribute anthelmintic praziquantel, used to treat bilharzias (schistosomiasis blood flukes) that affect more than 86% of school age children between 6 and 15 years old (Spencer et al., 2015).

Selection of control villages

In order to measure the effectiveness of Durrell's CBC initiatives it was necessary to create a retrospective quasi-experimental design (Gribbons & Herman, 1997) because no control village was allocated randomly prior to the start of the interventions. Durrell's CBC interventions took place in 109 villages across the five study regions and 109 appropriate control villages were selected from 1,370 potential control villages that did not receive CBC interventions. The 109 control villages were selected by propensity score matching; using R packages *Matchit* (Ho et al., 2011) and *Optmatch* (Hansen & Klopfer, 2006). In each study region, an equal number of control villages and CBC intervention villages were selected in order to minimise any difference in propensity scores. Six covariates were used to match control villages with CBC intervention villages: study area; population size in 2004 by fokontany from INSTAT; proportion of forest cover in 2000 using Kew Vegetation Atlas of Madagascar (Moat & Smith, 2007); accessibility, defined as the relative travel time to the nearest chef-lieu district of greater than 10,000 people; the area of the fokontany; and the zonal mean fokontany elevation by GTOPO data at 1km resolution. The covariates were all available for the year 2000, the year considered as baseline, in which villages were not yet affected by Durrell interventions.

Village attributes

Two village attributes (travel cost and population size) were used for performing Generalised Linear Mixed Effects Models (GLMM).

These were measured as follows:

The travel cost (measure in hour per kilometre) was calculated on Arc GIS 10.2 (ESRI, 2013), and related to road type (e.g. track, secondary road, national road) and distance to the nearest town (chef lieu de district). The latter was used to examine if the isolation of the villages affects school attainment and number of visits to clinic. The annual population size was used to estimate the Index of Health Status per capita per year based on the number of people diagnosed at the nearest health centre and their disease

Data were collected by fifteen trained local interviewers, local dialect speakers, who received their training in June 2013. The interviewers, equipped with official papers proving the purpose of their visit, spent time with the fokontany presidents, collecting historical numbers of inhabitants and immigrants. Data collection was preceded by a courtesy visit to district heads and traditional authorities to obtain their approval (appendix 4).

School attainment data

A form was developed to record the education data (appendix 4). CEPE (Certificat d'Enseignement Primaire Elémentaire) is the lowest level school certificate which children can obtain after passing the examination at the end of primary school (Primary schools offer five or six years of study, starting at age 6 or higher in rural areas). CEPE is a key metric, indicating the level of education of individuals, families and villages. Most parents living in rural areas want their children to obtain the CEPE which confers social status on those who hold it and are thus considered to be literate. Each fokontany must have a public primary school offering free education, to which the vast majority of parents will send their children. In cases where a current head teacher or health centre manager was not able to provide data due to missing archives, interviewers were asked to locate their predecessors and work with them to fill any gaps in the data.

Health centre records

To record the number of people diagnosed at health centres a health data form was also developed, based on the list of 108 internationally listed diseases at the Global Burden of Diseases (IHME, 2013) (appendix 5). Health centres 'Centres de Santé de Base' (CSB) are designated Level I or Level II according to their equipment and treatment capability. As Health Centres exist only at Commune level and above, it was necessary to disaggregate the number of patients per village by locating their village of origin. The data collection form was developed in Oxford, UK, translated into French, and checked with the Ministry of Public Health based in Antananarivo, Madagascar, before being used in the field. Authorisation from the regional offices of health in the Atsinanana, Atsimo Atsinanana and Alaotra Mangoro regions were obtained before data was collected from each Health Centre. The official records, which included dates, identities addresses (villages of origin), age and sex of each patient were consulted over a three week period in the presence of CSB health officials.

Missing health data and population size

It proved impossible to obtain satisfactory health data from two sites out of five (Baly Bay and Menabe) as many of their archives were lost in the devastating cyclones of 2004 and 2008. In addition, some health centres had to close due to lack of personnel. In the three study regions from which we had health data the accurate population size was missing in 9 out of 162 villages, from Alaotra and Nosivolo. Where health data was available but population size was not, it was decided to estimate missing population size values using the same rate of change through linear regression rather than omitting the health data.

Index of Health Status

The Index of Health Status is a source of data used in calculating the quality-adjusted life-year (QALY) measurement, a generic measurement of the Disease Burden at individual level. However the theoretical underpinnings and practical implications of QALY are controversial and still under debate within the medical community (Sassi, 2006). The Index of Health Status, which refers to the health of populations rather than individuals, following the 'health status unit years' approach developed originally by (Torrance, 1976) was adopted for use in this study. Since it was not possible to obtain individual health data for every village it was assumed that people only visit the clinic when they are unwell and that the number of annual Health Centre visits per village would express the level of ill-health of the village population, i.e. the Index of Health Status would reflect the number of Health Centre diagnoses.

The Index of Health Status per year per village was calculated using the equation below:

$$IHS = 1 - (\sum_{p-i}^{n} ni * ri : p)$$

In the equation above, n is the number of clinic visits, i is the disease (illness), p is the population size, and r is the discount rate (or disability weight) associated with the disease as described by the Global Burden of Disease per year per country (IHME, 2013). The Index of Health Status is therefore the health-related quality of life weighted to the relevant year of life. A village that has perfect health status throughout one year would have IHS=1 (0 visit to health centre in a year). IHS would be 0 if every person in the village made one health centre visit. Thus, an increase in IHS for a given village indicates an improvement in the health status of the inhabitants of that village.

Household survey

For this study a household survey was carried out in CBC villages and control villages using the Multidimensional Poverty Index (MPI) calculation method (Alkire & Santos, 2010). Heads of households were asked to recall their situation on assets, living standard, education and health in 2003, and 2008, as well as their more recent situation in 2013. A list of villagers from the Chef Fokontany was used to stratify the households by activity type and main source of income (e.g. agriculture, fishing, other). Thirty households per village, in both CBC and control villages were randomly selected proportional to the distribution of households. Fifteen interviewers, 2-4 per study region, interviewed a maximum of six households per day, for some 45-60 minutes per household. This allowed interviewers time to walk from hamlet to hamlet, depending on the households selected, without detaining interviewees too long. Interviewers worked in pairs to ensure there were enough checks and so that the information collected was of a sufficiently high quality, and that the experience of the respondent, whether the head of the household or the entire family, was enjoyable and satisfactory. Household data were recorded in a survey form (appendix 6) developed with the Oxford Poverty and Human Development Initiative (OPHI), based at the Department of International Development, University of Oxford, UK.

In total 5,258 households were interviewed: 1,520 from Alaotra; 392 from Baly; 372 from Manombo; 906 from Menabe and 2,069 from Nosivolo. Interviews were not conducted in 1,282 potentially selected villages due to various issues including logistics, insecurity and lack of available time.

Multidimensional Poverty Index

Multidimensional Poverty Index was chosen as one of the potential explanatory variables that may predict school attainment and the Index of Health Status. This variable is a proxy of the financial possibility of the household to send their children to school or to send sick person to health centre.

Developed by OPHI (see above), the Multidimensional Poverty Index (MPI) is a global measure of acute poverty which has been widely used across 184 countries and adopted by the United Nations Development Programme for their regular Human Development reports since 2011. The calculation of MPI is based on the three dimensions of Education, Health and Living Standard, spread over 10 indicators (years of schooling, child school attendance, child mortality, nutrition, electricity, improved sanitation, improved drinking water, flooring, cooking fuel, assets ownership) (appendix 3). The MPI identifies household deprivation indicators in order to generate a ‘poverty score’ $0<MPI<1$ (0 very rich, 1 very poor). The software STATA (STATA Corp LP, 2011) was used to calculate Multidimensional Poverty Index for each household by weighting each indicator. Averages of household MPI in 2003, 2008 and 2013 were aggregated into MPI per village to be used as one fixed effect in our multivariate analysis.

Statistical methods

Table 12. Description of potential explanatory variables

Potential explanatory variables	**Type**	**Time period available**	**Source**	**Hypothesised correlation with school attainment (metric: rate of success to CEPE exam) and with quality of health (metric: Index of health status)**
Presence of CBC education support	Binary (0 absent, 1 present)	1996-2014	Durrell	Positive: support such as school building/rehabilitation, equipments (blackboard, school desk, new roof etc) that eventually went to primary schools through CBC projects should increase the education attainment in CBC villages. We hypothesise that the results of CEPE should be positively correlated with CBC presence
Presence of CBC health support	Binary (0 absent, 1 present)	1996-2014	Durrell	Positive: we expect that the presence of CBC health interventions should improve people's health condition in CBC villages
Period (before and after the first implementation of education or health support)	Binary (before, after)	1982-2014	Durrell	Positive: we hypothesised an increase of education attainment and an increase of Index of Health Status after the first implementation of education or health intervention
Travel cost (distance to nearest town)	Continuous	1982-2014	GIS FTM	Negative: Schools situated far away from town would have fewer qualified teachers and fewer government official visits and controls from the regional directions office. Teachers also would need to be absent for 3-7 days every month walking to town in order to receive their salary. We hypothesise that high travel cost would lower school attainment For health, travel cost should be negatively correlated with Index of Health Status as sick people from remote villages would have to walk long distance towards health centre based at commune level
Multidimensional Poverty Index (MPI)	Continuous $0<MPI<1$	2003, 2008, 2013	Survey carried out on 5,258 households (30 households per village) in July-October 2013	Negative: We think that people with higher MPI would have less means to send their children to school, and lower motivation to educate children. Children would have limited school equipment

Response variables

The response variables are presented in the table below.

Table 13. Description of response variables

Variable	Unit	Availability	Type	Source
Result of CEPE exam	%	Annual per village	Continuous	Data collected from the headmaster of the school or the CISCO (Circonscription Scolaire) office
Index of Health Status	Index (0<IDB<1)	Annual per village	Continuous	Calculated from the annual number of sick people per village who presented at the clinic. List is based on based on the 108 international list of diseases listed at the Global Burden Disease. Data were collected from each health centre (CSB) disaggregated by village, by year

Structured as time series, the education and health data were plotted using *ggplot2* in R Studio 0.99.903 (R Core Team, 2012) to build temporal graphs illustrating the annual variation of the two response variables 'CEPE exam' and Index of Health Status overall and in each study region. We validated the list of explanatory variables by checking their independence. Correlation between explanatory variables was checked with Pearson matrix correlation using *corr* function in R in order to ensure that they were independent. Pearson correlation coefficient between our variables was less than 0.5.

Fitting Generalised Linear Mixed Effects Models

We used Generalised Linear Mixed Effects Models (GLMM) mixing random and fixed effects using lme4 function (Bates et al., 2012) and lmerTest package in R (Kuznetsova et al., 2016) to statistically assess the effectiveness of CBC in improving people's education and health. By incorporating random effects, GLMMs provide a more flexible approach to better understand the interaction between times, places and interventions (Bolker et al., 2009).

In this study, the variable ‘village’ was considered as a random effect to ensure that differences between villages had no systematic and idiosyncratic influence on the variation of education and health. The potential fixed effects were: period or time (binary: before or after the first implementation of CBC interventions in the village), associated with the presence/absence of education or health intervention (binary), the travel cost (continuous) and the Multidimensional Poverty Index (continuous). Square root rate transformation on rate of success in CEPE examination (educational attainment) and on the Index of disease burden provided the best fitted model with normal distribution of residuals. We therefore have intercepts for ‘village’ as well as by-study region and by-period random slopes for the effect of CBC education and health interventions.

The null hypothesis (Ho) we tested was that the rates of temporal education attainment and Index of Health Status before and after the intervention is the same for the two groups CBC and control villages. That allows fitting the trend through year with interaction between treatment and period.

Below are the best fitted models to the data using restricted maximum likelihood (REML=False), isolating all fixed effects and evaluating the remaining variance due to random effects.

The three random intercept fitted models were:

Model1<-(lmer (Square root response ~study region + period + travel_cost + MPI + (1|village), data=mydata))

*Model2<-(lmer (Square root response ~ study region * educ_support + period + travel_cost +MPI+ (1|village), data=mydata))*

*Model3<-(lmer (Square root response ~ study region + period * education support + travel_cost + MPI + (1|village), data=mydata))*

The three models have all of the fixed effects including *study region*, *period (time)*, *travel cost* and the *Multidimensional Poverty Index* (except Model 1 which excluded the CBC education support), and random effects (village). However, Model 2 considers interaction between study region and education or health interventions while Model 3 focuses on interaction between education or health interventions and the factor time (or period). Analyses of Variance (ANOVA) type III, with Satterthwaite approximation for degrees of freedom were performed on model 2 to check interaction between response variables and the study region. Differences in variation of response variables per study region were also assessed (see model below) to see if there was a significant interaction (P<0.005) between response variables and study region.

*Model study region<- (lmer (Square root response ~ period*education support + travel cost + MPI + (1|village), data=mydata_study region))*

A p-value of <0.05 (95% confidence interval) was used to determine the significance of each predictor on education or health. The models provide full information about the estimates of intercepts, standard errors and importance of each variable in affecting education and health. Histograms and Q-Q plots of residuals after transformation were also visually inspected to check normality of the distribution. Also In addition, we plotted residuals in function of time to ensure there was no temporal autocorrelation. The model selection criterion was based on AIC (Akaike's Information Criterion). The model that gave the lowest AIC value was chosen.

Results

Changes in rate of success in CEPE exam over time within CBC villages and non-CBC villages

Temporal graphs of education attainment below suggest that there is an increase of rate of success to CEPE exam in CBC and control villages between 1982 and 2012. All sites with the exception of Baly indicated that CBC sites had higher education attainment.

Alaotra has highest education attainment while Nosivolo probably has the fastest rate of increase during the study period (Fig. 8). In contrast Baly indicated lower school attainment in CBC villages compared to control villages. It should be noted, however, that Baly also has the poorest education archive and data prior to 2008 was not available.

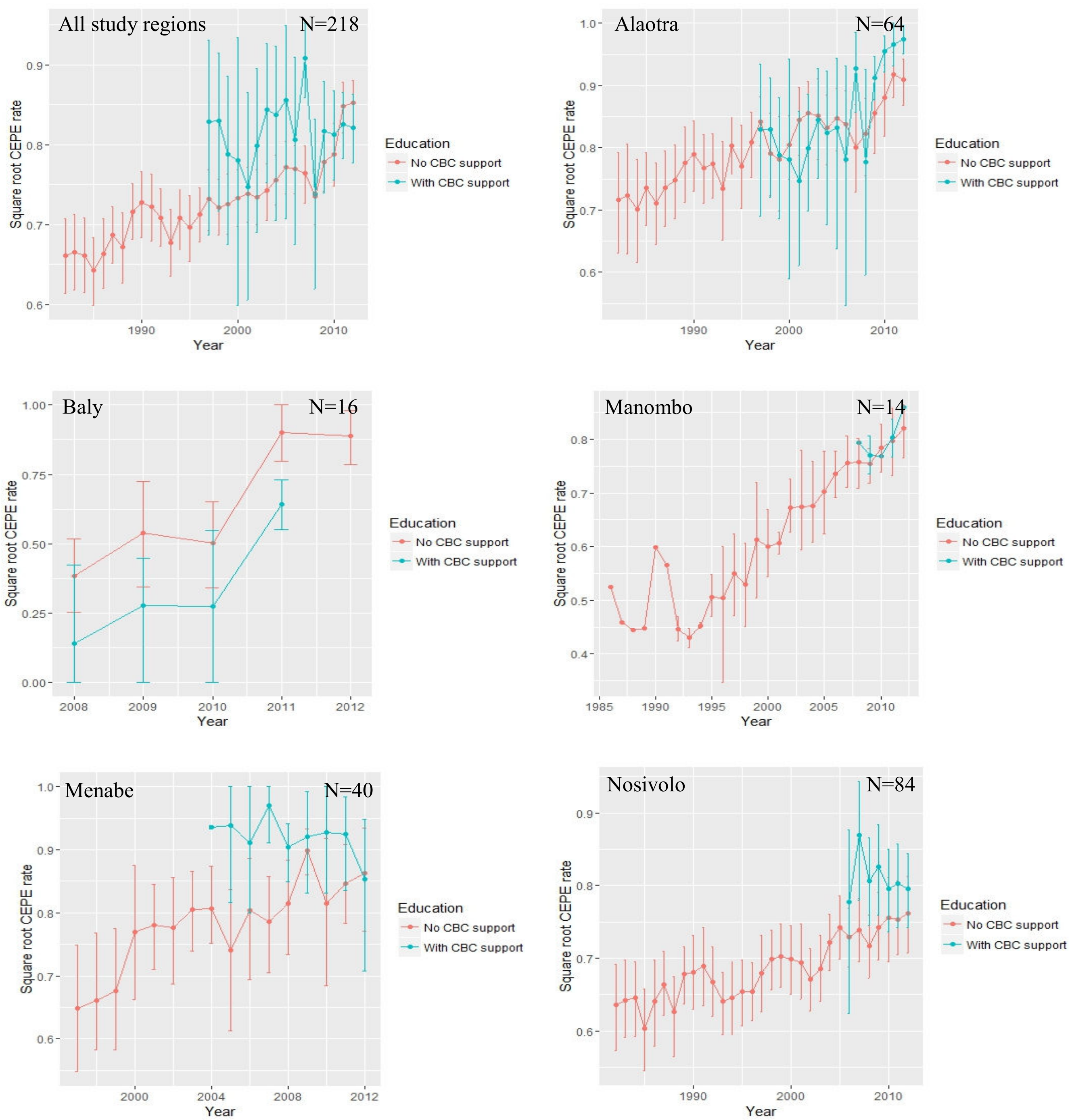


Figure 8. *Comparison of square root mean of CEPE exam over time between CBC villages and Control villages using results from each primary school. N is the number of villages in each study region*

Effectiveness of CBC in improving education attainment

When examining the effectiveness of CBC in improving education attainment, Model 3 which predicts interactions between education and time had the lowest AIC value and was the best fitted with the data showing normality of residuals. Specifically, this indicates an increase of the educational attainment over time ($p<0.001$) (Table 14). The fixed effect *education support* has overall positive slope, indicating that CBC villages that received education support have higher education attainment than control villages ($p=0.03$). The variable *travel cost* has a negative estimate suggesting that school attainment would decrease when travel cost increases, but the effect was not significant ($p=0.07$). Similarly, the Multidimensional Poverty Index has no relationship with education attainment ($p=0.91$).

The fixed effect *period 'Period before:education support Yes'* determines the interaction between rate of change of education attainment across time and presence of the education intervention. Results suggest that CBC villages and control villages have the same rate of increase in education attainment over time ($p=0.82$) so that it is clearly not just the time of education that is responsible for the differences apparent.

Table 14. Fitted mixed effects model predicting education attainment

Fixed effects variables^{+}	Hypothesis	Estimate	Std. Error	Pr(>|t|)
Intercept		8.63e^{-01}	2.88e^{-02}	< 2e^{-16} ***
Baly		-2.50e^{-01}	4.25e^{-02}	1.41e^{-08} ***
Manombo		-1.24e^{-01}	5.38e^{-02}	0.02 *
Menabe		-2.35e^{-03}	3.56e^{-02}	0.95
Nosivolo		-9.50e^{-02}	2.56e^{-02}	<0.01 ***
Period before		-7.20e^{-02}	6.48e^{-03}	< 2e^{-16} ***
Presence of education support	Positive	2.29e^{-02}	1.04e^{-02}	0.03 *
MPI	Negative	1.16e^{-02}	9.95e^{-02}	0.91
Travel cost	Negative	-9.08e^{-03}	5.06e^{-03}	0.07 .
Period before: education support Yes		1.37e^{-02}	5.95e^{-02}	0.82

*Significance: *P<0.05; **P<0.001; ***P<0.0001*

Other effects on education

Results show that the random effect *village* has high variability (SD 0.1525) indicating the existence of idiosyncratic differences between them. The remaining variability that is not explained by the random effect *village* can be seen on residuals (Table 15).

Table 15. Variation of education attainment explained by random effects

Groups	Name	Variance	Std.Dev.
Village	(Intercept)	0.01	0.11
Residual		0.02	0.15

Interaction between education intervention and study region

Results of ANOVA on model 2 suggest the existence of strong interaction between study region and the CBC education intervention with a p-value $p=4.08e^{-05}$ (Table 16). That justifies the need to verify the effectiveness of the education intervention in each study region.

Table 16. Result of ANOVA checking interaction between study region and education intervention

Fixed effects	Sum Sq	Mean Sq	NumDF	DenDF	F.value	Pr(>F)
Study region	1.30	0.33	4	270.4	14.09	$1.86e^{-10}$ ***
Education support	0.00011	0.00011	1	3380.5	0.01	0.94
Period	2.61	2.61	1	3314.6	112.73	$< 2.2e^{-16}$ ***
MPI	0.002	0.002	1	1174.1	0.090	0.76
Travel cost	0.07	0.07	1	170.6	3.156	0.08.
Study region: education support	0.59	0.15	4	3350.6	6.386	$4.08e^{-05}$ ***

*Significance: *P<0.05; **P<0.001; ***P<0.0001*

Likely effects of CBC in improving educational attainment in each study region

Analyses of impacts of CBC interventions on education in each study region are presented in Appendix 1. As effect of the intervention, the intervention villages have significantly higher educational attainment in Menabe (p<0.01) and in Nosivolo (p<0.01). The difference is not significant in Alaotra (p=0.69) and Manombo (p=0.53). Results also suggest that poorer households may have higher educational attainment in

Alaotra (p=0.04), and Menabe (p=0.05), while travel cost has a significant effect in lowering school attainment in Alaotra (p<0.01).

Changes in Index of Health Status over time within CBC and non-CBC villages

Temporal graphs of health quality below suggest that there is an overall decrease in the Index of Health Status over time both in CBC and non-CBC villages. Despite this overall decrease, a clear pattern showing the treatment effect is visible in Alaotra a year after the first health interventions around the lake in 1997. A big drop in Index of Health Status is observed in Manombo between 1982 and 1986 while an increase is observed at Nosivolo between 2007 and 2010 (Fig. 9).

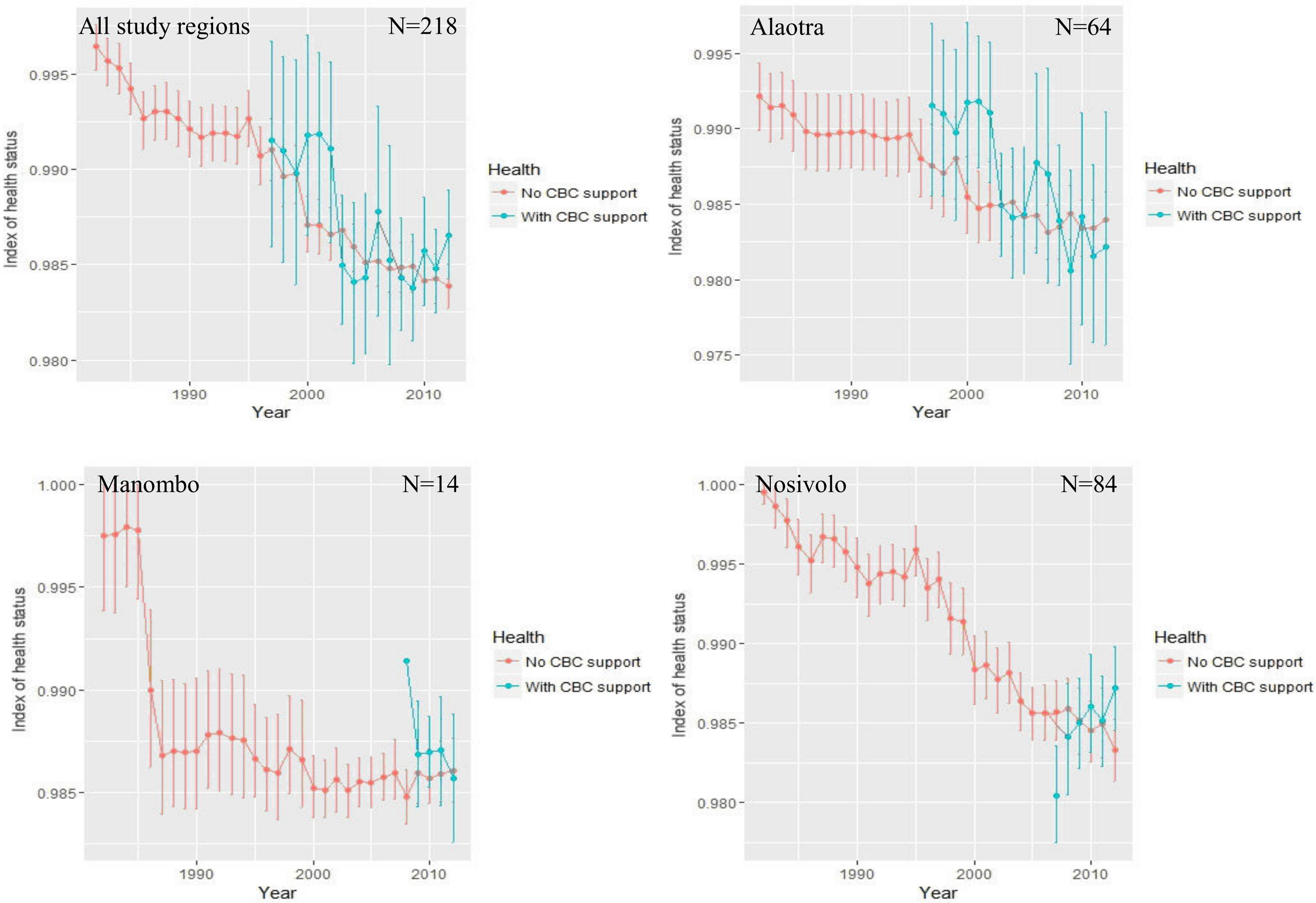


Figure 9. *Comparison of square root Index of Health Status over time between CBC villages and Control villages using results from health centres. N is the number of villages in each study region*

Comparison of the 14 most threatening diseases between CBC and non-CBC villages

Analysis of health data (1982-2012) from Alaotra, Manombo and Nosivolo indicate that malaria, respiratory infection, diarrhoea, dental problems and ascariasis are the top five threatening diseases in both CBC and control villages. The 14 most threatening diseases in each group are presented in Figure 4. Many of them are water borne or water related diseases. Control villages generally show a higher number of visits to the local health centre than treatment villages (Fig. 10). On average 25±7 patients per village per year from control villages were diagnosed with one of the listed diseases and treated at the health centre whilst the number for CBC villages was 15±5.

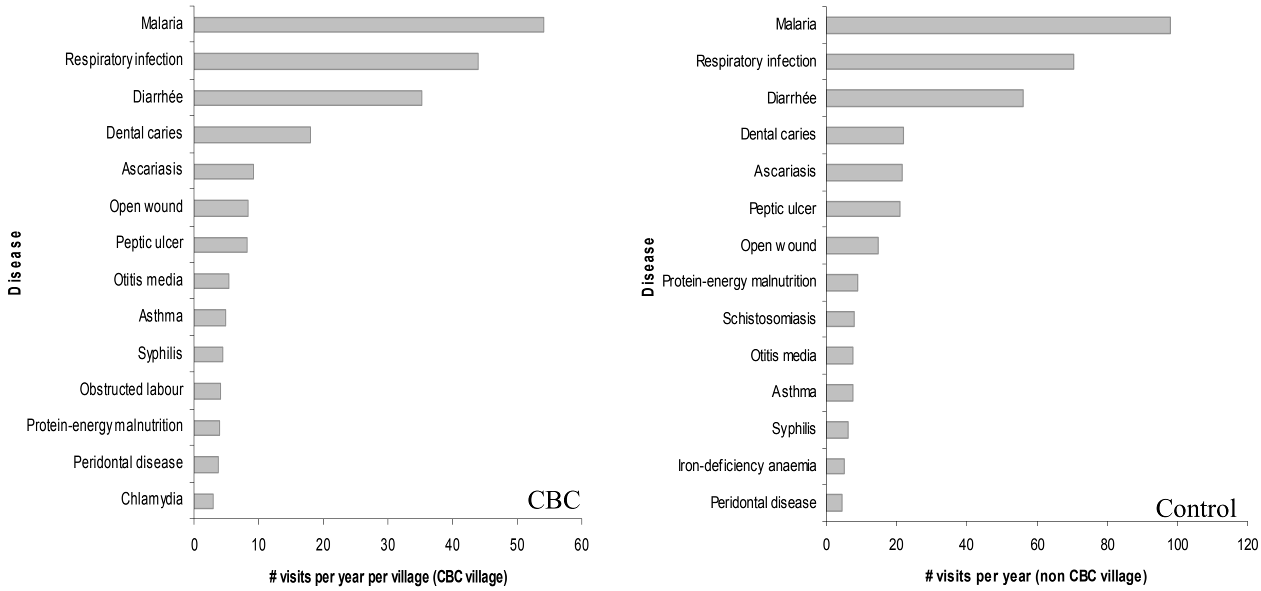


Figure 10. Comparison of the 14 most threatening diseases between CBC villages and control villages (based on number of visits at health centre per village per year)

Effectiveness of CBC in improving health status

Results suggest a decrease in Index of Health Status over time in both CBC and control villages ($p<2e^{-16}$). People in CBC villages and control villages have the same quality of health even after CBC interventions, meaning that CBC support on health had no measurable effect on the Index of Health Status (p=0.16). In terms of fixed effects, *travel* *cost* has negative effect on the Index of Health Status, lowering it by $6.56e^{-04} \pm 2.73e^{-04}$ (p=0.02), while Multidimensional Poverty Index has no impact (p=0.16). The analysis of interaction between *period* and *the presence of health intervention* shows that there is no difference between the rates in change of Index of Health Status between CBC and control villages (p=0.23). The Index of Health Status in both groups of villages decreases with the same slope (Table 17).

Table 17. Fitted mixed effects model predicting the Index of Health Status

Fixed effects variables⁺	Hypothesis	Estimate	Std. Error	Pr(>|t|)
Intercept		$9.88e^{-01}$	$1.58e^{-03}$	$<2e^{-16}$ ***
Manombo		$8.14e^{-04}$	$2.60e^{-03}$	0.75
Nosivolo		$3.26e^{-03}$	$1.38e^{-03}$	0.02 *
Period before	Positive	$6.31e^{-03}$	$2.36e^{-04}$	$<2e^{-16}$ ***
Health support	Positive	$6.17e^{-04}$	$4.43e^{-04}$	0.16
MPI	Negative	$-7.80e^{-03}$	$5.51e^{-03}$	0.16
Travel cost	Negative	$-6.56e^{-04}$	$2.73e^{-04}$	0.02 *
Period before: health support		$-2.62e^{-03}$	$2.19e^{-03}$	0.23

*Significance: *P<0.05; **P<0.001; ***P<0.0001*

Other effects

Analysis of random effects shows that the variable *village* has high variability (SD 0.006) indicating the idiosyncratic difference that exists between villages. The remaining variability that is not explained by the random effect village remains on residuals (Table 18).

Table 18. Variation in Index of Health Status explained by random effects

Groups	Name	Variance	Std.Dev.
Village	(Intercept)	3.64e-05	0.006
Residual		4.47e-05	0.007

Interaction between health intervention and study regions

Results of ANOVA on model 2 for heath indicate strong interaction between study region and the CBC health support with a p-value $p=7.24e^{-06}$ (Table 19). This finding is a good reason for the need to look at the effectiveness of the education intervention in each study region.

Table 19. Interaction between health intervention and study regions

Fixed effects	Sum Sq	Mean Sq	NumDF	DenDF	F.value	Pr(>F)
Study region	0.00007	0.000037	2	191.8	0.82	0.44
Health support	0.000264	0.000264	1	4644.3	5.95	0.01 *
Period	0.031276	0.031276	1	4627.7	703.15	$< 2.2e^{-16}$ ***
MPI	0.000090	0.000090	1	154.0	2.02	0.16
Travel cost	0.000253	0.000253	1	154.1	5.70	0.02 *
Study region: health support	0.001056	0.000528	2	4646.5	11.87	$7.23e^{-06}$ ***

*Significance: *P<0.05; **P<0.001; ***P<0.0001*

Likely effects of CBC in improving the Index of Health Status in each study region

The analysis per site helps evaluate the effectiveness of health interventions at each study region. CBC interventions had no effect on people's health at Manombo (p=0.29) and Nosivolo (p=0.87). However, on average CBC villages that received health support have higher quality of health than control villages (p=0.014). With negative estimates across all three study regions, the fixed effect Multidimensional Poverty Index tends to be associated lower Index of Health Status. However, Travel cost is associated with lower Index of Health Status in Nosivolo ($p=1.22e^{-06}$) and Alaotra (p=0.02) (Appendix 2, supplementary materials).

Discussion

This study aimed to measure the potential impacts over time of a range of education and health interventions as part of a Community-based Conservation (CBC) programme, comparing educational attainment and Indices of Health Status between 109 CBC and

109 non-CBC villages over the period 1982 to 2014. Three questions were addressed namely, i) how does educational attainment compare between CBC villages and non-CBC villages? ii) How does health compare between CBC villages and non-CBC villages? and iii) what other factors associated with CBC contribute to variation in educational attainment and Index of Health Status? Each will be discussed in turn.

Impact of CBC on educational attainment

The present study demonstrates an overall increase in educational attainment in both CBC and non-CBC villages between 1982 and 2014. Success rates in CEPE examinations prior to the first CBC interventions were significantly lower than those achieved later, indicating that the population in the regions studied were became better educated over time. This is consistent with overall improvements in primary education which has occurred at national level, as reported in UNESCO's World Data for Education, Madagascar section (UNESCO, 2011). However, our study also demonstrates that villages which received support for education through CBC interventions had significantly 0.02±0.01% higher primary education attainment. This confirms that CBC support for education had a considerable positive effect on educational attainment. This finding is important, as primary education aims to increase children's autonomy and build their capacity to participate actively in social development.

Impact of CBC on health

In comparison to the positive impact of CBC intervention on education, the study demonstrates that an overall decrease over time in the Index of Health Status from 0.996 to 0.983 has occurred over the past 30 years. This is expressed as an increase in number of people diagnosed and treated at Health Centres. It is assumed that an increase in the number of visits to Health Centres indicates a decrease in health status. This result therefore suggests that in terms of the Index of Health Status there is no significant difference between CBC villages and non-CBC villages. In other words, there is no measurable impact of the support delivered, including drinking water, public wells and taps, toilets, and washing facilities on the health status of people in CBC villages compared to control villages. In terms of actions to improve health, most of the CBC support went into provision of clean drinking water with the assumption was that this would have an impact on water-borne diseases such as *diarrhoea* and *ascariasis*. However, these two water-related diseases still came among the top five diseases recorded at the health centre in both CBC villages and control villages. That finding underlies the difficulty in finding suitable actions that improve health status at village level.

Other factors influencing educational attainment and Index of Health Status

The average Multidimensional Poverty Index rating for Madagascar is 4.2 (Alkire & Santos, 2010) indicating a high degree of poverty in many of the dimensions measured. The Multidimensional Poverty Index was therefore another factor examined because it indicates the financial capacity of the family to send children to school or sick individuals to the Health Centre. Financial status is crucial; even though teaching and medical treatment are ostensibly free, financial status determines whether parents buy school materials, food, or medication. However, results from this study indicate that financial status as revealed by the Multidimensional Poverty Index did not play a role in educational attainment or in health status as determined by the Index of Health Status.

Thus, it would appear that poverty did not prevent people from visiting the public health centre when necessary, or stop children from working hard at school.

Travel cost has no effect on education but has a negative effect on the Index of Health Status. The health index rating decreases significantly as travel cost increases. This may be due to the fact that while every village (fokontany) has a public primary school, only towns at the level of chef-lieu commune and upwards have health centre.

Limitations of this study

No data on number of teachers and medical staff

The present study would have been more robust if it had been possible to consider other contributing factors such as the teacher/pupil ratio per school per year, the medical doctor /patient ratio per health centre per year, as well as the qualifications of Health Centre and school staff. We also lacked data on the reliance on traditional medicine and medicinal plants. Efforts were made to collect these data but unfortunately the records were not adequate. It also appeared that the government provided many villages with free school materials (e.g. uniform) and free vaccination or free mosquito nets 3-4 times during the study period. However, they rarely arrived in the very remote villages according to local authorities. We could not track those kinds of support even though they may affect the variation of educational attainment and Index of Health Status.

Lack of financial data

It was not possible to quantify the level of education and health intervention into each village. It was only possible to determine presence/absence of the support due to lack of fokontany-level financial data. The availability of the annual amount of money spent on education and health support in each CBC village could have allowed a better understanding of how much investment is needed to deliver education outcomes.

Reliability of QALY for measuring health status in this study

Recognised as probably less relevant for measuring the quality of health for whole people in the village, we had to rely on the Index of Health Status. Also, debates are still ongoing about QALY with some medical researchers who suggest that QALY is needlessly complex for evaluating health interventions, and that a simple and disaggregated approach is needed (Cox et al., 1992) in (Drummond, 2007). Others suggest that QALY is probably too simplistic, raising issues over how community health outcomes can best be measured, and therefore should be replaced by a more comprehensive approach (Mehrez & Gafni, 1992).

Lessons learned for the improvement of CBC

When asked by Durrell to specify what type of support would most improve well-being in their village, local community members most frequently mentioned support for school infrastructure or teaching materials, and drinking water infrastructure, so it was assumed these are the incentives and rewards most likely to motivate a local community's collective engagement in conservation. Such incentives can also be considered as indirect payment for ecosystem services, since they require local people to make a commitment to respect the boundaries of management zones or protected areas and to restrict access to strict conservation zones.

The finding in our study confirms therefore that education support provided through CBC projects can be instrumental in raising educational attainment, is important. Villages situated in the highest biodiversity environments, with the strongest traditional cultural values, are most often small, inaccessible, and located at great distance from the city, and as a result are often ranked last in benefiting from government support, with fewer teachers and less adequate infrastructure. However, to be effective in protecting and conserving wildlife, it is with those villages that conservation NGOs adopting the CBC education approach must collaborate. An NGO offering the CBC approach is often seen as bringing new light and life to the village, opening it up to new information and technology, and providing villagers with an opportunity to broaden their knowledge and, within budget limitations, opening a channel to obtain support for village development projects.

This study employed a robust and methodological approach rarely used in conservation evaluation to retrospectively measure the impacts of CBC interventions on education and health. To ensure that their CBC initiatives are as effective as possible, conservation NGOs may need to increase the proportion of their budgets allocated to support for social development, and where possible to collaborate with development NGOs. It is hoped that the findings from this study of Durrell's CBC initiatives may help advance the conservation evaluation literature and support conservation managers in developing successful conservation strategies.

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Supplementary materials

Appendix 1. Effects of CBC education supports on education attainment in each study region

Fixed effects	Alaotra	Manombo	Menabe	Nosivolo
periodbefore	Hypothesis: negative Est.: -5.708e^{-02} Std. Error: 8.730e^{-03} Pr(>|t|): 9.24e^{-11} ***	Hypothesis: negative Est.: -0.16824 Std. Error: 0.01836 Pr(>|t|): 6.66e^{-16} ***	Hypothesis: negative Est.: -0.108854 Std. Error: 0.035025 Pr(>|t|): 0.00226 **	Hypothesis: negative Est.: -6.700e^{-02} Std. Error : 9.723e^{-03} Pr(>|t|) : 7.63^{e-12} ***
Education support	Hypothesis: positive Est.: 5.443e^{-03} Std. Error: 1.367e^{-02} Pr(>|t|): 0.69071	Hypothesis: positive Est.: -0.02337 Std. Error: 0.03748 Pr(>|t|): 0.534	Hypothesis: positive Est.: 0.086360 Std. Error: 0.030249 Pr(>|t|): 0.00507 **	Hypothesis: positive Est.: 5.651e^{-02} Std. Error : 1.702e^{-02} Pr(>|t|) : 0.000917 ***
Average MPI	Hypothesis: negative Est. : 4.570e^{-01} Std. Error: 2.122e^{-01} Pr(>|t|): 0.03552 *	Hypothesis: negative Est.: -0.35308 Std. Error: 0.25565 Pr(>|t|): 0.198	Hypothesis: negative Est.: 0.414169 Std. Error: 0.189734 Pr(>|t|): 0.04618 *	Hypothesis: negative Est.: -1.414e^{-01} Std. Error : 1.083e^{-01} Pr(>|t|) : 0.195522
Travel cost	Hypothesis: negative Est. : -3.842e^{-02} Std. Error: 1.219e^{-02} Pr(>|t|): 0.00258 **	Hypothesis: negative Est.: -0.00394 Std. Error: 0.01341 Pr(>|t|): 0.775	Hypothesis: negative Est.: -0.008075 Std. Error: 0.010264 Pr(>|t|): 0.44133	Hypothesis: negative Est.: -1.690e^{-04} Std. Error : 5.123e^{-03} Pr(>|t|) : 0.973776
periodbefore: educ_support Yes	Hypothesis: positive Est. : 1.403e^{-02} Std. Error: 5.286e^{-02} Pr(>|t|): 0.79076	-	-	-

Appendix 2. Effects of CBC health interventions on Index of Health Status in each study region

Fixed effects	Alaotra	Manombo	Nosivolo
Period before	Hypothesis: negative Est.: 5.102e^{-03} Std. Error: 2.788e^{-04} Pr(>|t|): <2^{e-16} ***	Hypothesis: negative Est.: 2.763e^{-03} Std. Error: 6.981e^{-04} Pr(>|t|): 8.88e^{-05} ***	Hypothesis: negative Est.: 8.004e^{-03} Std. Error : 3.946e^{-04} Pr(>|t|) : < 2^{e-16} ***
Health support	Hypothesis: positive Est.: 1.220e^{-03} Std. Error: 4.949e^{-04} Pr(>|t|): 0.0138 *	Hypothesis: positive Est.: 1.537e^{-03} Std. Error: 1.451e^{-03} Pr(>|t|): 0.2899	Hypothesis: positive Est.: -1.240e^{-04} Std. Error : 7.757e^{-04} Pr(>|t|) : 0.873
Average MPI	Hypothesis: negative Est. : -1.986e^{-02} Std. Error: 1.204e^{-02} Pr(>|t|): 0.1046	Hypothesis: negative Est.: -2.207e^{-02} Std. Error: 1.235e^{-02} Pr(>|t|): 0.0956 .	Hypothesis: negative Est.: -2.825e^{-03} Std. Error : 5.201e^{-03} Pr(>|t|) : 0.588
Travel cost	Hypothesis: negative Est. : -8.829e^{-04} Std. Error: 6.961e^{-04} Pr(>|t|): 0.02098	Hypothesis: negative Est.: 9.096e^{-04} Std. Error: 5.338e^{-04} Pr(>|t|): 0.1105	Hypothesis: negative Est.: -1.272e^{-03} Std. Error : 2.429e^{-04} Pr(>|t|) : 1.22e^{-06} ***
periodbefore: health_support Yes	Hypothesis: positive Est. : -2.516e^{-03} Std. Error: 1.806e^{-03} Pr(>|t|): 0.1636	-	-

Appendix 3. The dimensions, indicators, deprivation cut-offs and weights of the MPI

Dimensions of poverty	**Indicator**	**Deprived if…**
Education	Years of Schooling	No household member has completed five years of schooling.
	Child School Attendance	Any school-aged child is not attending school up to class 8.
Health	Child Mortality	Any child has died in the family.
	Nutrition	Any adult or child for whom there is nutritional information is malnourished.
Living Standard	Electricity	The household has no electricity.
	Improved Sanitation	The household's sanitation facility is not improved (according to MDG guidelines), or it is improved but shared with other households.
	Improved Drinking Water	The household does not have access to improved drinking water (according to MDG guidelines) or safe drinking water is more than a 30-minute walk from home, roundtrip.
	Flooring	The household has a dirt, sand or dung floor.
	Cooking Fuel	The household cooks with dung, wood or charcoal.
	Assets ownership	The household does not own more than one radio, TV, telephone, bike, motorbike or refrigerator and does not own a car or truck.

Source: Oxford Poverty and Human Development Initiative

Appendix 4. Village attributes and education data form

VILLAGE ATTRIBUTES AND EDUCATION

FIELD DATA FORM

Fokontany……………………………………..Commune…………………………………………District…………………………………………..

Name of the person in charge of data collection: ……………………………………………………………………………………………

Attributes	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Nb of immigrants																															
Population size Nb of cattle																															
Access to telephone (0/1)																															
Access to internet (0/1)																															
Access to electricity JIRAMA (0/1)																															
Access to water JIRAMA (0/1)																															
Nb of generator																															
Nb of solar panel (>1sqm)																															
Distance to nearest market -km																															
Distance to nearest health center (CSB)-km																															
Dist. to nearest police station -km																															
Dist. to chef-lieu Commune -km																															
Présence/absence taxi brousse (0/1)																															
Nb of NGOs																															

<u>Education</u>

Fokontany……………………………………..Commune…………………………………………District…………………………………………..

Name of the person in charge of data collection: …………………………………………………EPP:…………………………………

Attributes	1982	1983	1984	1985 1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Number of kids ≤6 yrs old																														
Number of kids who went to school																														
Rate CEPE exam (%)																														
Nb kids who could go to secondary school																														

Appendix 5. Health data form (108 types of disease)

MONITORING OF PUBLIC HEALTH CONDITION (Number of people who were sick, recorded at CSB)

Fokontany……………………………………………………………..……Commune…...............…………………………District……………………………………………..

Name, signature and position of the person who filled the form: …………………..….……...........……..........................CSB:………….......................................……Date...

Most frequent diseases	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Diarrhoea																															
Pertussis																															
Meningitis																															
Hepatitis B, C																															
Malaria																															
Lymphatic filariasis																															
Ascariasis																															
Protein-energy malnutrition																															
Dental caries																															
Open wound																															

Other diseases	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Tuberculosis																															
Syphilis																															
Chlamydia																															
Gonorrhoea																															
HIV																															
AIDS																															
Poliomyelitis																															
Diptheria																															
Measles																															
Tetanus																															
Trypanosomiasis																															
Chagas disease																															
Schistosomiasis																															
Leishmaniasis																															
Onchocerciasis																															
Leprosy																															
Dengue																															
Japanese encephalitis																															
Trachoma																															
Trichuriasis																															
Ancylostomiasis																															
Respiratory infections Respiratory infection																															
Otitis media																															
Maternal conditions Maternal haemorrhage																															
Maternal sepsis																															
Hypertension during pregnancy																															
Obstructed labour																															
Perinatal conditions Low birth weight																															
Birth asphyxia, birth trauma																															
Nutritional deficiencies Iodine deficiency																															
Vitamin A deficiency																															
Iron-deficiency anaemia																															
Cancer Mouth cancer																															
Oesophagus cancer																															
Stomach cancer																															
Colon, rectum cancer																															
Liver cancer																															
Pancrease cancer																															
Trachea, bronchus, lung cancer																															
Melanoma, other skin cancer																															
Terminal cancer (all types)																															
Breast cancer																															
Cervix cancer																															
Ovary cancer																															
Prostate cancer																															
Bladder cancer																															
Lymphoma																															
Leukaemia																															
Diabetes Diabetes mellitus																															
Neuro-psychiatric conditions Unipolar major depression																															
Bipolar disorder																															
Schizophrenia																															
Epilepsy																															
Alcoholism																															
Dementia																															
Parkinson disease																															
Multiple sclerosis																															
Drug addiction																															
Post-traumatic stress disorder																															
Obsessive compulsive disorder																															
Panic disorder																															
Eye diseases Glaucoma																															
Cataracts																															
Cardiovascular diseases Rheumatic heart disease																															
Ischaemic heart disease																															
Stroke																															
Inflamatory heart disease																															
Respiratory diseases																															
Chronic obstructive pulmonary disease																															
Asthma																															
Digestive diseases Peptic ulcer																															
Cirrhosis of the liver																															
Appendicitis																															
Genito-urinary diseases Nephritis and nephrosis																															
Benign prostatic hypertrophy																															
Musculo-skeletal diseases Rheumatoid arthritis																															
Osteoarthritis																															
Congential abnormalities Abdominal wall defect																															
Anencephaly																															
Anorectal atresia																															
Cleft lip																															
Cleft palette																															
Oesophageal atresia																															
Renal agenesis																															
Down syndrome																															
Congenital hear disease																															
Spina bifida																															
Oral conditions Peridontal disease																															
Edentulism																															
Injuries Poisoning																															
Fracture																															
Spinal cord injury																															
Dislocated shoulder, elbow, hip																															
Sprain																															
Intracranial injury																															
Amputation																															
Crushing																															
Burns																															
Injured nerves																															

CHAPTER 4

Paper 3: The potential of Community-based Conservation in enhancing human well-being and raising awareness of ecosystem services in Madagascar

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Abstract

Conservation managers in many developing countries undertake substantial conservation and development programmes aimed at empowering local communities to better manage natural resources and improve the provision of ecosystem services. However, very little is known about the impact of these development activities on human well-being at family or household level. In this paper, these issues are addressed through an investigation of the effectiveness of Community-based Conservation (CBC) programmes carried out by conservation NGO Durrell Wildlife Conservation Trust since 1997 in five key conservation areas in Madagascar. A total of 5,258 households, in 109 CBC intervention villages and 109 matched control villages in the five areas, were interviewed. The aim was to evaluate the impact of CBC support through revenue generating activities on poverty levels measured by the Multidimensional Poverty Index in 2003, 2008, and 2013. Data on key subjective well-being metrics, for example happiness, mutual trust, and the power to affect local decision-making, were also collected during the household survey. The results indicate that between 2003 and 2013 the majority of the households were multidimensionally poor and that there was no reduction in overall poverty during that period. There was no evidence that CBC interventions improved poverty levels, with CBC villages showing similar Multidimensional Poverty Index to Control villages throughout the intervention. Size of household was shown to be a major factor associated with elevated poverty levels, while subjective well-being was affected by the travel cost from the village to nearest town. Since poverty has been identified as a key factor in the reduction of happiness, mutual trust, and power to affect local decision-making, in this case the claim that CBC would be effective in enhancing human well-being was not supported. People living in CBC villages were shown to have a greater propensity to note changes in the provision of ecosystem services as a result of reduced forest cover, as measured by the Index of Perception of Valued Ecosystem Services, a fact that in the future could be of value when designing CBC interventions.

Keywords: Local community, Multidimensional Poverty Index, effectiveness, ecosystem services, local perception

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Introduction

Although the integration of conservation and development has long been under discussion (IUCN et al., 1980; Myers, 1992) only recently has attention specifically been paid to globally help alleviate human poverty through conservation of biodiversity (Roe et al., 2013). In fact the concept of enrolling conservation activities as a means of reducing poverty was not promoted on an international scale until 2002, the year in which the UN's Convention on Biological Diversity (CBD) set a target 'to achieve by 2010 a reduction of the current rate of biodiversity loss at the global, regional and national level, as a contribution to poverty alleviation and to the benefit of all life in earth' (Roe et al., 2013). Discussion of the CBD continues following the failure to achieve that objective, and questions remain as to whether conservation of biodiversity really can lead to poverty alleviation. Nevertheless, there are already some case studies that highlighted positive socioeconomic impacts of conservation on human well-being. For example, implementation of protected areas in Costa Rica and Thailand resulted in reduction of local poverty (Andam et al., 2010; Ferraro & Hanauer, 2014). Also development of tourism in the Okavango Delta in Botswana has led to improvement of local people's well-being (Mbaiwa, 2003). These studies have made some important preliminary findings but more robust evidence on the link between conservation and human well-being is needed if we are to better understand the synergies and trade-offs between conservation and development interventions (Hambler & Canney, 2013; McKinnon et al., 2016).

Community-based Conservation (CBC) is based on the rationale that conservation and development should be addressed simultaneously (Berkes, 2004). It is a participatory approach that places importance on the potential interaction and harmony between local communities and wildlife, with the aim of mitigating biodiversity threats while improving social well-being. The human-centric conservation approach that emerged during the last 30 years is sometimes known as 'new conservation' (Marvier, 2014). The theory behind this approach is that conservation activities tend to have a greater chance of succeeding if they involve local communities in the management and monitoring process (Brooks et al., 2006). In addition, it has been suggested that CBC approach is particularly appropriate in low income countries where the majority of people are affected by poverty and dependent on natural resources. Hugues & Flintan (2001) noted that CBC was widely practised following the global movement of the early 1980s, in which some indigenous people demanded the right to manage natural resources, and the subsequent adoption of Integrated Development and Conservation Programmes (ICDP) in the late 1980s.

Give a key goal of the CBC approach is to empower local communities, it is argued that placing them at the heart of management structures enable autonomy to choose and achieve their own objectives (Campbell & Vainio-Mattila, 2003). Many conservation NGOs have therefore in recent years made great efforts to empower local communities to debate and defend their own social and conservation aims to sustainably manage natural resources on the premise that people are more likely to take action if they feel they have the power to act (Handgraaf et al., 2008). Marvier, (2014) also argued for the importance of conservation benefiting the poorest in society, not just because it is the right thing to do, but because it is imperative for conservation success.

This paper examines the effectiveness of development activity as part of CBC programmes to enhance human well-being and raise awareness of ecosystem services carried out by Durrell Wildlife Conservation Trust in five key conservation areas in Madagascar since 1997. The study involves 109 intervention villages and 109 control villages in Lake Alaotra, Baly Bay National Park, Manombo rain forest, Menabe dry forest, and Nosivolo River, all of which have official protected area status. Madagascar has a low level of Gross Domestic Product (9,981 billion USD) (World Bank, 2015b), and a high level, 35%, of youth illiteracy (UNICEF, 2015). In addition there is known to be a high level of corruption, with an index rating of 32 (0: highly corrupt, 100: very clean) giving it a ranking of 123 out of 167 countries (Transparency International, 2015). These factors may have intensified the already high level of social inequality, expressed by a Gini index of 40.6% (0: perfect equality, 100: perfect inequality) (World Bank, 2015a), and widened the gap between rich and poor families. Madagascar is one of the 'bottom billion' countries (Collier, 2008) and it has failed to show a decrease in the Multidimensional Poverty Index between 2004 and 2009; 67% of people are multidimensionally poor (Alkire et al., 2015).

The Durrell CBC approach aims to empower local communities in three ways. First, by carrying out social-development activities through provision of clean drinking water for improved public health, and provision of teaching materials and school refurbishment to improve primary education. Second, by supporting micro-development projects, under the Revenue Generating Activities (RGA) scheme through provision of handicraft machines, legal fishing materials, small holder resources (poultry), agriculture inputs (onion, rice, and red potato), rice peeling machine, community transport (oxcart). And third, by supporting traditional customs such as *loadrano*[4]*, olobe* or *vavanjaka*[5] in order to contribute to social cohesion (provision of large cooking pots, garments and plates for traditional weddings or funeral festivities), and protecting taboos (e.g. *fady*[6], *andro ratsy - andro tsara*[7]) that are positive to preservation of the environment. This support for local development is contributed through regular three-monthly village meetings at which strongly delivered conservation messages ensure that local people fully understand what is required in return. The aim is clear - that these activities should lead to collective and individual socio-economic development in the intervention villages, genuinely improving people's well-being, building the capacity of the local community, and helping to maintain cultural traditions. Such support is likely to play a key role in improving local management of natural resources.

Most of the types of development support mentioned above could be considered as a form of Payments for Ecosystem Services (PES) under an informal non-binding contract, since recipients are given incentives with the express intention of motivating them to take active steps to conserve their local biodiversity (Sommerville et al., 2011). A recent study in Cambodia by Clements & Milner-Gulland (2015) demonstrated that the effectiveness of PES, and of Protected Areas, depends on the scale of payments received by local people. However, in the five Madagascar study regions this aspect of PES has not been confirmed, partly because payments were always in the form of development support, not in cash, and partly because the effectiveness of the activities was not evaluated.

[4] Annual traditional ceremony closing fishing for six months, often more respected than official fishing regulation

[5] Traditional authorities very respected in each village, all actions or meeting need their blessing

[6] *fady*: taboo (e.g. village meeting can not be organised on Thursday in many places)

[7] *andro ratsy*: bad day, *andro tsara*: good day (a traditional calendar highly respected at Anororo Alaotra. E.g. the village meeting or inauguration can never happen on bad day)

Human well-being is not only a matter of individuals' objective characteristics such as education level, health status, quality of standard of living, but involves subjective social and psychological factors such as happiness, trust, and anxiety, as well as individual measures of personal satisfaction in life (Sarvimäki, 2006; Alkire & Santos, 2010).

In order to assess the effectiveness of the Durrell CBC interventions in enhancing human well-being, data for the present study draws on surveys of 5,258 households, from control villages and intervention villages. The household is regarded as the most appropriate social unit for investigating livelihoods and for gaining an understanding of the implications of policy for the reduction of poverty (Ellis, 2000). The hypothesis underpinning the present study is that CBC activities carried out in the intervention villages will have resulted in improving quality of life at household level compared with households in control villages, and contributing to the socio-economic development of the village.

Understanding these socio-economic factors will help conservation NGOs in assessing what strategies are needed to increase their effectiveness and what level of optimism they might have in carrying out their activities. Though conservation evaluation budgets will often be limited (Salafsky & Margoluis, 1999; Garnett et al., 2007), and measuring effectiveness is likely to be a challenge for NGOs funded through short term grants (Jones, 2012), it is vitally important to learn from past successes and failures in order to develop potentially successful conservation strategies (Saterson et al., 2004). When conservation managers are aware of quantitatively measured outcomes they can avoid the dangers of relying on intuition or anecdote in making decisions for the future (Ferraro & Pattanayak, 2006), or reporting level of implementation to financial donors and decision makers, rather that the actual impacts (Ferraro & Pattanayak, 2006).

This paper quantifies changes in the economic status of the communities living in CBC villages contrasted with non-CBC villages as revealed by the Multidimensional Poverty Index in the years 2003, 2008 and 2013, approximately three years, five years and 13 years after the start of the interventions. The intention is to investigate whether CBC interventions succeeded in reducing the number of local communities living in extreme poverty, or at least moving some from the category of 'extreme' to 'less severe' category of poverty. A comparison of levels of happiness, trust and personal satisfaction of those in CBC and non-CBC villages is taken to be an indication of the potential effect of CBC on subjective social well-being.

The paper also examines people's views on the benefits they continuously receive from their local ecosystem. The concept of ecosystem services powerfully highlights humans' dependence on nature (Brauman et al., 2007) but to what extent do local rural-dwelling people in Madagascar really perceive and care about changes in their local ecosystem? This is important information if conservation NGOs are to be more successful in combating dysfunctional land management practices and uncontrolled ecosystem damage, such as the anthropogenic fires that have continued to cause rapid deterioration in the landscape of Madagascar (Burns et al., 2016).

Fourth-fifths of the developing world's food is produced by small-scale farms (FAO, 2015b). Food production is a matter of particular concern for Madagascar since 80% of the population live in rural areas and rely on small-holder family farms (INSTAT, 2010). Soil fertility and forest quality are interdependent as conversion of forest to pasture tends to reduce the nitrogen, clay, organic carbon, and nutrient contents of soils (Laurance et al., 1999). Local people need to be aware of the importance of maintaining their forests and wetlands which provide them not only with material and cultural resources but also contribute to local food security (Golden et al., 2016).

Burkhard et al. (2012) identify three main categories of ecosystem services: provisioning, regulating, and cultural, with the status of each determined by supply[8], demand[9] and the ecological footprint[10]. Provisioning services include all substantial products provided by ecosystems that people use for nutrition, processing and energy (Kandziora et al., 2012). For example, Madagascar's main energy problems are a growing shortage of fuel wood, used for most cooking, due to over-exploitation of the forest resources which provide 80% of its fuel energy, and the country's total dependence upon high-cost imports of oil and gas for its remaining needs (UNDP & World Bank, 1987). Regulating services include natural processes such as climate and water flow, and control of erosion to maintain soil fertility (Rodríguez-Loinaz et al., 2015). All five of the intervention areas have important wetland features (lakeshore, river, seashore, mangroves, and reed-beds) on which a large number of households rely for fishing, and where the productivity depends on the quality and quantity of the water (Wallace et al., 2016). Cultural services include intangible benefits, in the form of non-material, spiritual, religious or inspirational features of the ecosystem (Kandziora et al., 2013). In the case of Madagascar these include graves and other taboo structures of ancestral significance which play a key role in the protection of natural forests (Jones et al., 2008).

Ecosystem services in Madagascar are under threat and are degraded by human activity. There are enormous uncertainties about how, and on what scale the ecosystems will continue to provide benefits for the population, and how human activity will affect this provision (Farley & Costanza, 2010). The status of the ecosystem services is determined not only in terms of its provision of benefits, but also by human needs, and the level of provision demanded by the human community (Paetzold et al., 2010). This underlines the

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[8] Supply of ecosystem services refers to the capacity of the landscape to provide services within a given time period

[9] Demand for ecosystem services is the sum of all ecosystem services consumed over a given time period

[10] Ecosystem service footprint indicates the area needed to generate the ecosystem services within a time period

importance of understanding how local communities, the users of these natural resources, perceive any changes in the quantity or quality of key ecosystem services.

Knowing how local communities perceive the provision of valued ecosystem services will indicate how concerned they are about the quantity and quality of the goods and services provided by their local ecosystem. It will also help identify the best ways of persuading local communities to change land management practices and sustainably preserve natural resources. That will gear them toward mitigating the negative impacts of ecosystem use, and optimising the positive services (Ango et al., 2014).

This paper addresses the questions of whether CBC interventions have resulted in reducing poverty at household level, in enhancing people's subjective sense of well-being (in terms of happiness, mutual trust, and power to influence decision-making), and in enabling residents in CBC villages to become more aware of changes in local ecosystem services as compared with residents in control villages.

Methods

Study areas

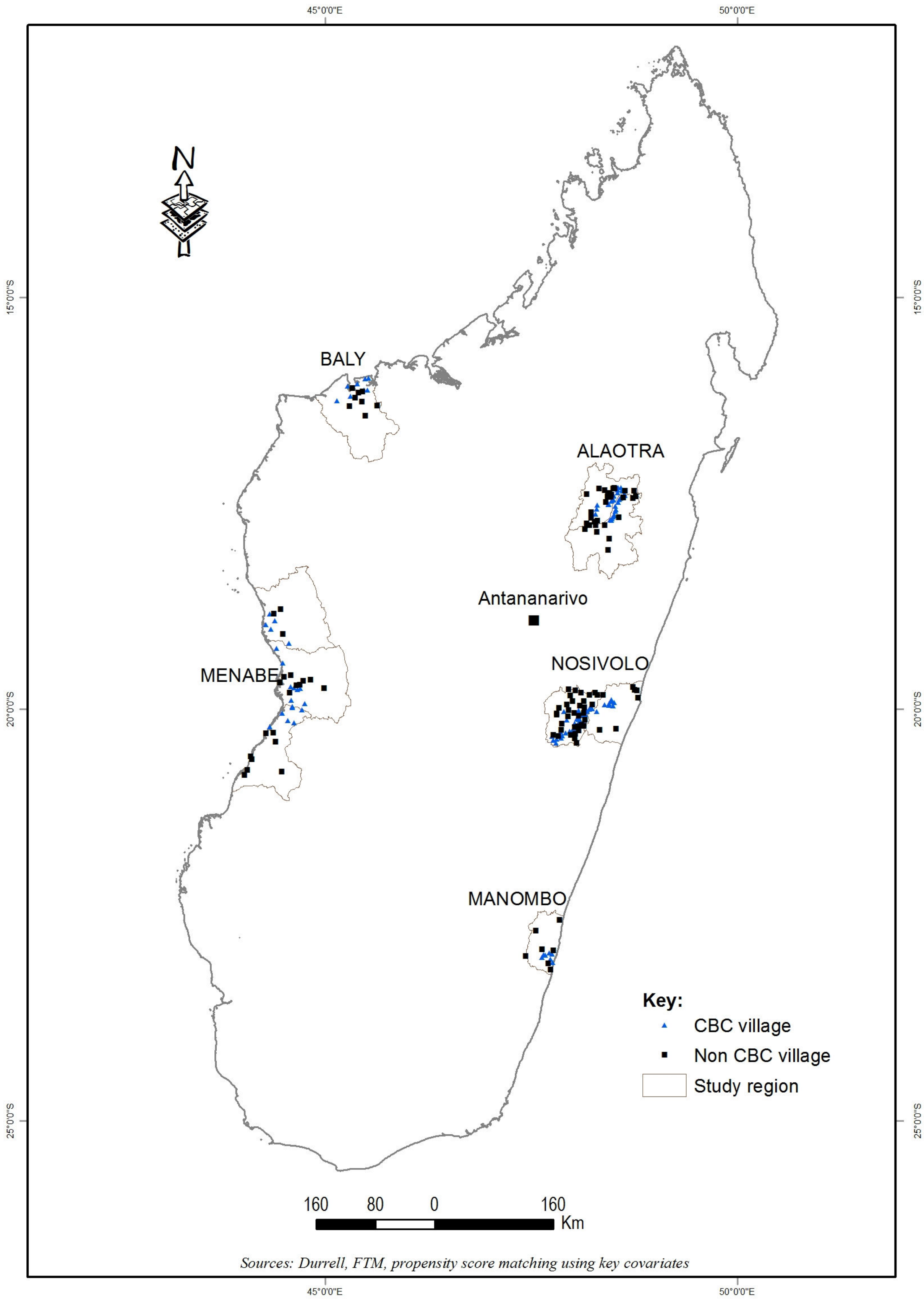
We aimed to investigate the impact of community-based conservation on human well-being and local perception of provisioning ecosystem services in five key conservation areas. The key features of these study areas are described in table 20.

No pre-intervention studies were possible, and we therefore rely on comparison of human well-being indicators between CBC villages and statistically-matched control villages to evaluate the impacts of the Community-based Conservation over time.

Table 20. Description of five study areas

Study region	Alaotra	Baly Bay	Manombo	Menabe	Nosivolo
Region	Alaotra Mangoro	Boeny	Atsimo Atsinanana	Menabe, Melaky	Atsinanana
District	Ambatondra-	Soalala	Farafangana	Antsalova,	Mahanoro,

	zaka, Amparafaravola			Belo/Tsiribihi., Morondava	Marolambo
N. of villages	32	8	7	20	42
CBC start date	1997	1996	2006	2000	2005
Population size (2007)	103,824	16,509	11,073	38,718	72,919
Ethnic group	Sihanaka	Sakalava	Antaisaka	Sakalava/Vezo	Betsimisaraka
# active local monitors	96	79	66	108	105
Habitat types	Wetlands: Lake, marsh area	Bamboo, dry forest	Rain forest	Dense dry forest, mangroves	Wetlands: River
Climate	Semi humid, moderately hot	Dry, hot	Humid	Dry, hot	Humid, moderately hot
Elevation (m)	795.6	40.7	38.7	35.5	592.9
Protected Area size (hectares)	42,478	63,000	7,090	210,000	6,781
Status	New Protected Area	National Park	2 blocks: Special Reserve & classified forest	New protected Area, Special Reserve	New protected Area
IUCN category	V	II	IV	III, IV, V (multi-category)	V
Key species	*Hapalemur alaotre*nsis (Alaotran gentle lemur)	*Astrochelys yniphora* (Plougshare tortoise)	Lemurs: 8 species. Ex. *Eulemur cinereiceps, Variecia v. editorum*	*Hypogeomys antime*na (Giant jumping rat), *Pyxis planicauda* (Flat tailed tortoise)	Fishes: *Oxilapia polli, Ptychochro-moides katria*, *Bedotia* sp zono, *Bedotia* sp1
Main pressures	Burning, illegal rice farming, illegal fishing	Tortoise smuggling, fires	Illegal logging, fires	Illegal logging, slash and burn agriculture, fires	Illegal gold mining, slash and burn agriculture



Map 4. Location of the five study regions **and matched villages**

Selection of Durrell CBC villages

Although the start date of Durrell's CBC interventions differed between the five regions, most of the work was initiated around the year 2000, and therefore it was important to match the control villages to the intervention villages using covariates for that year. In each area, the intervention villages were selected depending on the area of occupancy of priority species of conservation concern (Table 20). The most important villages, those situated closer to the habitat, where people could have a direct influence on the planned conservation management, were selected first. The number of intervention villages has also grown gradually over time, partly to match conservation priorities and available funding, and partly as knowledge about the species and its habitat increased and conservation strategies were progressively developed.

Selection of control villages

In order to measure the effectiveness of Durrell's CBC interventions a retrospective quasi-experimental design was developed in which results from the five study regions were compared. This approach was adopted because control villages had not been allocated on a random basis at the start of the interventions. Quasi-experimental design is a useful method for evaluating the effectiveness and probable impact of programmes if no replicable designed experiment had been implemented at the start of the intervention (Gribbons & Herman, 1997), which is the case in nearly all such programmes. The Durrell CBC interventions took place in 109 villages across the five study regions (Table 20). Some 109 matching control villages were selected from 1,370 potential control villages in which no CBC interventions had taken place. Propensity score matching, using social and environmental data to characterise each village as outlined below, was implemented in the R packages *Matchit* (Ho et al., 2011) and *Optmatch* (Hansen & Klopfer, 2006) to select control villages. For each study area, a number of control villages equal to the number of intervention villages were selected so that the difference in propensity scores was minimised.

The six covariates used to create propensity scores to match the control villages to the intervention villages were as follows: study area; population size in 2004 by fokontany from INSTAT (National Statistics Agency); the proportion of forest cover in 2000 using the Kew Vegetation atlas of Madagascar (Moat and Smith 2008); travel cost (the relative travel time to the nearest chef-lieu district of greater than 10,000 people); the fokontany area; and the zonal mean fokontany elevation, from GTOPO data (1km resolution).

Collection of village attributes data

For the five study regions, data on local community attributes were collected at the level of village or fokontany. Five attributes were featured in the survey for each village: population size, number of cattle per capita, travel cost, access to public transport (taxi-brousse), access to operational market, and access to a mobile phone network. Data were collected by fifteen trained local interviewers.

All villages are officially governed by a designated or elected fokontany president (depending on the constitution of successive Republics), but also have traditional village chiefs. Each fokontany keeps historical records of its human and cattle populations. Interviewers equipped with regional government papers proving the purpose of their visit spent time with the fokontany presidents, collecting population statistics. The data collection was preceded by courtesy visits to district heads and traditional authorities to obtain their approval. Travel costs (accessibility) to each village was calculated in Arc GIS 10.2 (ESRI, 2013), based on the distance to the nearest town (chef lieu de district) and on local road quality.

Sample unit: the household

The sample unit in the present study is the household. A typical household will have parents, sometimes grandparents, and 4-5 children (Clark, 2012), with the father or grand father as head of household. All family members who live under the same roof, and cook and eat together, are considered to be parts of a single household. Several households form a hamlet, while a group of hamlets form a fokontany or village with populations varying in size from 100 to 1,000 households. Most of Durrell's development support, aimed at improving education and health, was delivered at the level of the fokontany. However, support for Revenue Generating Activities was provided indirectly to households via the local associations. The associations, which are officially in charge of the management of natural resources such as forests, lakes, rivers or mangroves distribute them through sub-associations to households. A fishermen's sub-association, for example, would be given fishing materials such as nets and lines; a farmers' sub-association would be given agricultural tools or improved seeds; a sub-association of handcraft workers would be given a mini-workshop and sales equipment.

Since it was only possible to interview households on one occasion, in 2013, the household survey was designed to cover a 10 year period retrospectively, with the collected data subdivided at 5 year intervals - respondents were questioned about their experience and situation as they recalled them 10 years ago (in 2003), and 5 years ago (in 2008).

Development support linked to annual environmental competitions

Durrell's development support has often taken the form of rewards or prizes presented to local communities following annual inter-village competitions in which the status of local biodiversity, and the level of anthropogenic pressures within the local management zone, are assessed, compared and ranked. Data collection is carried out through participatory ecological monitoring exercises lasting from 3 to 5 days in which 6-10 volunteers and two trained technicians form village teams to collect data on key conservation targets and severe threats (Andrianandrasana et al., 2005).

The development support is presented to the local association in public following a brief ceremony attended by regional government officials, and often celebrated with quiz competitions and traditional singing and dancing. The results of the observations noted during the participatory ecological monitoring exercise are summarised publicly by the local monitors so that everyone is made aware of the situation and illegal activities are discussed in a transparent manner. Results of the annual inter-village competitions, including rankings and amounts of money received by each village, are usually announced by the senior authority present at the village meeting. Speeches by traditional and official authorities remind villagers of key environmental regulations, and after the meetings food donations are made to the community as a gesture of cohesion and solidarity. Durrell conservation workers use the opportunity to emphasize the important role played by the natural environment, brief villagers on significant changes in the local ecosystem, and ask for their commitment to improving their management practices. Associations have some three weeks to decide on the particular Revenue Generating Activities they plan to undertake and the type of development support they would prefer in view of the amount of prize money on offer.

Respect for local culture and traditional organisation

Aspects of traditional culture including taboos and *fady*[11], and the respect accorded to ancestors and to traditional leaders such as *Olobe*, *Vavanjaka* or *Tangalamena*[12] (Dez, 1959) are all carefully observed during the course of CBC interventions, to ensure that a

[11] *Fady* in Malagasy culture refers to a wide range of cultural prohibitions or taboos
[12] *Olobe*, *Vavanjaka* and *Tangalamena* refer to traditional leaders in each village whose function gives the exclusive right to invoke ancestors in order to implement wisdom in the society

good working relationship is maintained with local people. Local associations are given full technical support in determining their management zones, and these are mutually decided and publicly discussed at village meetings so that people are in full agreement with the rules and procedures. Where possible, a traditional *dina* convention is convened to give official support to the defining of management zones. In the Lake Alaotra Protected Area, these zones cover 90% of the reed beds, and in the Menabe Protected Area they cover 65% of the dry forest and mangroves. In Baly Bay National Park and the Manombo Special Reserve the proportion of the areas managed under official management transfer is smaller as the natural resources in those areas are already officially managed by Madagascar National Parks. As required under the Madagascar government's Law 96/025, 30 June 1996 (Government of Madagascar, 1996), three categories of management were specified for implementation in each zone. Strict Conservation Areas (30%) are areas with important cultural features such as graves, sacred springs and caves, and tree species used for making coffins, as well as areas with a high density of critically endangered species. Limited Use Areas (40%) are mainly designated for fishing, medicinal plants and NTFP. In Sustainable Development Zones (30%) the collection of wood for fuel and construction, and papyrus for domestic materials and handcrafts are permitted. Three sets of plans are drawn up and agreed for each protected area: a 5 year management plan for the conservation of target species; a 5 year social and environmental impact assessment which leads to an official environmental permit; and a 5-year social and safeguard plan to ensure that the creation of the protected area also contributes to the alleviation of poverty. These plans are subject to public discussion and approval by the local community.

Amount of development support provided

Under Durrell's development support policy, in order to reduce possible conflicts of interest CBC funds have never been given directly to individuals. In the absence of complete detailed financial records, it has been assumed for the purposes of this paper that a typical CBC intervention will have had a value in material support or equipment in the order of some 200GBP (minimum amount for a CBC project). In a typical village that budget will have been spent on primary education, revenue generating activity, social cohesion, public health, or participatory monitoring. During field visits to randomly chosen CBC villages, CBC village meetings were attended and development support projects such as roof repairs, new school desks, or public water taps, were observed.

These types of support are of considerable value and importance to the community, and they are deliberately intended to positively influence attitudes among local people and thus eventually result in the reduction of threats to target species. Local associations representing a majority of members of the village community take responsibility for deciding on development support priorities (equipment such as a rice husking machine or oxcart for loan or hire to households in the village), and for managing and distributing the donated support through the medium of public village meetings.

Selection of households interviewed in the village

In each CBC intervention village and control village 30 households were chosen by stratified random selection, and a list of villagers from the Chef Fokontany was used to categorise the households by the type of activity providing the main source of income: agriculture, fishing or 'other' ('other' could include collection of salt, honey, or other non-timber forest product, managing livestock, running a small shop, or making charcoal, etc). To ensure that responses reflected the views of everyone in the village the number of households selected for each category of activity was proportional to the distribution of that activity throughout the whole village population.

In total 5,258 households were interviewed: 1,520 from Alaotra; 392 from Baly; 372 from Manombo; 906 from Menabe and 2,069 from Nosivolo. Interviews were not conducted in 1,282 potentially selected households for various reasons including problems of logistics, insecurity and lack of available time.

Household survey

As part of the process of evaluating the impact of Durrell's CBC interventions a household survey was carried out in both intervention and control villages using the Multidimensional Poverty Index (MPI) methodology (see below) (Alkire & Santos, 2010). Fifteen interviewers (between two and four per study region) interviewed up to six households per day, spending some 45 to 60 minutes per household. This allowed interviewers enough time to walk between hamlets and locate the selected households without detaining interviewees too long. Interviewers worked in pairs to ensure there were adequate checks, that the data collected was of a sufficiently high quality, and that the experience of the respondent, whether the head of the household or the entire family, was enjoyable and satisfactory. All interviewers were local dialect speakers who were given their training in field methods in June 2013.

Household data were recorded on a survey form (appendix 1) developed with the Oxford Poverty and Human Development Initiative (OPHI), based at the Department of International Development, University of Oxford, UK.

Multidimensional Poverty Index

The Multidimensional Poverty Index (MPI) developed by OPHI is a global measure of acute poverty which has been widely used across 184 countries and adopted by the United Nations Development Programme for their regular Human Development reports since 2011. The methodology of MPI (Alkire & Santos, 2010) is based on the assessment of poverty in terms of the three dimensions of Education, Health and Living Standards, spread over 10 indicators (years of schooling, child school attendance, child mortality, nutrition, availability of electricity, improved sanitation, improved drinking water, flooring, cooking fuel, and asset ownership) (appendix 1). The MPI identifies household deprivation indicators by generating a 'poverty score' 0<MPI<1 (0 very rich, 1 very poor). For the present study, the software STATA 13.0 (STATA Corp LP, 2011) was used to calculate the MPI for each household by weighting each indicator.

Weighting of Multidimensional Poverty indicators

The value of MPI C-vector shows the level of deprivation of each household in each indicator and depends on the structure of weights applied to the indicators, along with the type/level of deprivations that the interviewees were experiencing (Alkire et al., 2015). For example, the living standard indicators weight 0.055. Two deprivations in living standards would give 0.111 while three deprivations in living standard or one in education or one in health MPI score would give 0.167. Four deprivations in living standard or one in education/health and one in living standard would increase the index into 0.222. The Index increases with the number of deprivations. MPI equals to 1 if the household is deprived in all indicators.

Measuring assets and quality of life

The household survey collected detailed information on the assets and quality of life of each household were collected. Heads of household were asked whether the household owned a car, track, tractor, radio, TV, fridge, oxcart, hand tractors, pirogue, bicycle, motorcycle or a parcel of land greater than 500sqm. Questions also covered the type of flooring in the house (cement, wooden planks, plastic, tree bark, mat), the type of cooking fuel used (wood, charcoal), the type of energy used for lighting, (candles, proper electricity JIRAMA[13], oil, solar panel, paraffin, or battery powered 'Chinese lamp'). Households were also checked for sanitation (own toilet, shared toilet or no toilet) and source of drinking water (river, spring, well, pump or tap). Additional data was gathered on age of household (based on the year of the traditional wedding), ages of household members, number of people in the household with a CEPE (Certificat d'Enseignement Pédagogique Elémentaire), and the number of children less than five years who had died during the past five years.

Measuring subjective well-being

Material conditions such as income, standard of living, food consumption and ownership of assets affect subjective well-being (Dolan et al., 2008). Similarly, health status, employment, social contact and security affect life satisfaction (Boarini et al., 2013). The social and development elements of CBC are intended to impact on three dimensions of subjective well-being: *happiness*, about a sense of having the *power to influence decision-making*, and the *mutual trust* within the local community. Those three dimensions are part of the key elements of subjective human well-being (OECD, 2013, Alkire et al., 2015).

Happiness is seen as an expression of life satisfaction; mutual trust in local community reflects the strength of social cohesion; and a sense of power to influence decision-making indicates both a willingness to change and a sense of responsibility. The dimensions of subjective well-being were investigated in the household interviews carried out in both CBC villages and non-CBC villages.

Table 22 shows the likely effects of CBC interventions on these subjective dimensions of well-being. In the statistical analyses, the effects of key explanatory variables such as the Multidimensional Poverty Index, the travel cost and the household size on subjective

[13] JIRAMA: Jiro sy Rano Malagasy (Electricity and Water for Madagascar)

well-being were checked. The MPI is used as an explanatory variable only if poverty analysis indicates that CBC has no significant influence on it.

Happiness

The level of happiness was checked one time only (2013) as it was not possible to ask respondents how happy did they feel 10 years ago or five years ago. Humans are goal-oriented by nature, according to Aristotle, and the continuous striving for enjoyment of the good dominates all our lives (Creel, 1983). The level of an individual's happiness (*eudaemonia* in Greek) is determined by the degree to which he or she makes a positive judgement on the overall quality of his or her life as a whole (Veenhoven, 2015). In the current study, it was hypothesised that festive village meetings, animated by traditional dancing, shared food, an entertaining public quiz, and the donating of valued development support delivered in the form of annual inter-village environmental competition prizes, will have contributed to an increase in overall happiness among the residents of the CBC intervention villages.

To assess happiness levels in the household survey, heads of households were asked a closed question '*Overall how happy did you feel yesterday?*' (see appendix 1) with four graded response options: *Very happy*; *Moderately*; *Somewhat*; *Not at all happy*. This primary scale of happiness measurement is based on a standard method described in the World Database of Happiness (Veenhoven, 2015).

Power to influence decision-making

In the society in general, and within a community, power can be defined as the ability to influence or outright control the attitude of others (Handgraaf et al., 2008). In their study of society and politics (French & Raven, 1959) describe five bases of power: legitimate power, referent power, expert power, reward power, and coercive power. As already mentioned in the introduction, the aim of CBC is to instil in local communities the referent power[14] to choose, defend, and achieve their own social and conservation goals.

Respondents in the household survey in both CBC villages and non-CBC villages were asked '*Do you think people like yourself can change things in society if they want to?*' (Appendix 1). Response options were: *Yes very easily, Yes but with a bit of difficulty, Yes but with great difficulty, No way*.

Responses were expected to reflect the intended impact of CBC on local people's feelings of social responsibility. Changes in individuals' perceptions of power over time were also checked in the interviews by asking them to recall their perceived power to influence decision-making in 2003, 2008 as well as 2013.

Mutual trust in the local community

Trust can be considered as a kind of social intelligence that enables individuals to assess the degree of risk they may face in social situations, for example from theft or other crimes (Yamagishi, 2001). In this study trust was assessed as way to measure the strength of social cohesion in each village, with the expectation that people in CBC villages may have a higher degree of confidence in the local community and better relationship with their neighbours. In the household interview, respondents were asked: '*If you left something (e.g. a bicycle) outside the house at night, do you think it will still be there in the morning?'* (Appendix 1). With two response options (Yes, the bicycle will still be there, and No, the bicycle will disappear) answers indicated the degree to which the respondents have trust in their local community.

Comparison of answers from households in CBC villages and non-CBC villages would highlight whether or not CBC villages showed a higher level of social cohesion. The relationship between levels of trust and Multidimensional Poverty Index ratings was

[14] Referent power aims to enhance the ability of individuals to attract others, and to build loyalty in order to achieve desired outcomes.

examined because trust has real, practical economic value in the form of increased efficiency (Arrow, 1974).

Identifying ecosystem services of importance to local people

A list was developed of the 10 most relevant ecosystem services in the five study areas, based on information gathered at village meetings. Local people expressed interest in fuelwood, non-timber forest products (NTFP), construction wood, fish, agriculture yields, valued cultural features, quality and available quantity of water, cattle grazing, and bush meat - all key indicators illustrating the link between provisioning, regulating, and cultural services (Müller & Burkhard, 2012). The list of key indicators was developed in the same way as the list of biodiversity, threats, and social indicators identified in order to carry out participatory ecological monitoring and local village patrols (Danielsen et al., 2006). In the household survey interviews, respondents were asked to rank the importance of each ecosystem service to their livelihood on a scale of 0 - 3 (0= none, 1= low, 2= medium, and 3= high). Ranking was based on the relevance of each service to the household.

Measuring the capacity of local communities to perceive changes in provision of valued ecosystem services

In the household survey, respondents were asked to give an opinion on changes in the quantity and quality of the 10 most relevant types of ecosystem services mentioned above. The provision of each ecosystem service was ranked between 0 and 3 (0= none, 1= low, 2= medium, 3= high) according to people's perceptions of the quantity or quality of provision over time. Households were asked to give their perceptions as of 2013 (the year of the interview) but also to recall the situation as it was in 2003 and 2008. Average scores per year per household were calculated to give an Index of Perception of Valued Ecosystem Services (IPVES). Differences in IPVES scores reflected the perceptions of local communities of any decrease or increase in the provisioning of local ecosystem services. In view of the fact that there is a great variety of ecosystem service assessment frameworks and quantification methods (Burkhard et al., 2014), it should be pointed out that the method described above was adapted from (Rodríguez-Loinaz et al., 2015) who developed the Multiple Ecosystem Services Landscape Index (MESLI) for measuring landscape multifunctionality at local scales.

Comparing the Index of Perception of Valued Ecosystem Services (IPVES) and changes in forest cover

In order to verify whether local people perceived changes in their local environment, actual changes in forest cover (per village, per year) were compared with changes in IPVES indicators (per village, per year). It was assumed that IPVES scores for 2003 reflected the decrease in forest cover between 2000 and 2003; that IPVES scores for 2008 reflected the decrease in forest cover between 2004 and 2008; and that IPVES scores for 2013 reflected the decrease in forest cover between 2009 and 2013. All ten valued provisioning ecosystem services are forest-related; therefore, it is appropriate for forest loss to be considered as indicating changes in provisioning, justifying comparison with people's perceptions of change. The hypothesis was that people in CBC intervention villages would be better able than those in non-CBC villages to detect changes of forest-related provisioning services such as wood for fuel and construction.

Forest cover data

Grid files of historical forest cover data (2000-2014), from three tiles located at 10S040E, 20S040E and 10S050E covering Madagascar (30m resolution), were downloaded from the global forest change data developed by (Hansen et al., 2013). Those data which are projected in WGS 84 comprise a raster of tree canopy cover for year 2000, forest cover loss, forest cover gain (2000-2012), and the year of gross forest cover loss event. Using ArcGIS10.2, these grid files were assembled in a mosaic, then clipped to match the Madagascar boundary, before overlapping them with the polygon shape files of our 218 study villages. The extent of forest per village was expressed by the number of pixels of forest multiplied by 0.09 hectares which corresponds to the size of each pixel. The methods used for calculating forest cover generally follows Hansen et al. (2009) and Margono et al. (2012). A mask for the forest cover in 2001 was developed and correlated with the tree canopy cover for the year 2000 to acquire the forest proportion value for each pixel in 2001.

Forest cover data were projected in Albers equal-area conic projection, or Albers projection (named after Heinrich C. Albers 1972) to keep the same size of pixels and provide more accurate calculation of the areas. Any pixel that had more than 50% forest cover was considered forest - the same threshold was used by Hansen et al. (2013) in their classification - but also applied to the Kew vegetation data for estimating the forest proportion in 2000 for each village.

Statistical methods

Six statistical analyses were performed to investigate the impact of Community-based Conservation on human well-being and local perceptions of valued ecosystem services.

Test 1: *Effect of CBC interventions on poverty levels, as measured by the Multidimensional Poverty Index*

Test 2: *Effect of CBC interventions on local people's happiness*

Test 3: *Effect of CBC on people's perceived power to influence decision-making within the community so that they feel more responsible and able influence decision making within society*

Test 4: *Effect of CBC on social cohesion (by measuring 'mutual trust' within community as a proxy)*

Test 5: *Effect of CBC on changes in the rate of forest cover (forest per square kilometre)*

Test 6: *Effect of CBC on people's perception of valued ecosystem services (by using Index of Perception of Valued Ecosystem Services)*

Description of the potential explanatory variables for all analyses are presented in three different tables; the first (Table 21) for analysing the impact of Community-based Conservation on Multidimensional Poverty Index; the second (Table 22) for the analysis of the possible impacts of CBC on subjective human well-being factors; and the third (Table 23) for the relationship between CBC interventions and the Index of Perception of Valued Ecosystem Services. Response variables for those tests are described in table 5.

The co-linearity between explanatory variables was checked using *corr* function for Pearson matrix correlation in R in order to ensure that they are independent. Pearson correlation coefficient between our variables was less than 0.5.

Table 21. Description of the potential explanatory variables that may explain the variation of Multidimensional Poverty Index

Potential explanatory variables	Type	Time period available	Source	Hypothesised correlation with MPI
Period (2003, 2008, 2013)	Categorical (2003: phase 1, 2008: phase 2, 2013: phase 3)	-	Household survey in 2013	Negative. We hypothesised that there should be a decrease in MPI (improvement of quality of life) across time
Presence of CBC intervention	Binary (0 absent, 1 present)	2003, 2008, 2013	Durrell (put together in 2014)	Negative. Development support delivered through CBC should improve the quality of life (decrease in the MPI)
§ Number of cattle owned by the household	Continuous	2003, 2008, 2013	Household survey in 2013	Negative: More cattle should be associated with lower MPI, meaning higher wealth
Travel cost (accessibility: distance to nearest town)	Continuous	2003, 2008, 2013	GIS FTM (acquired in 2013)	Positive: Far away village are usually far from operational market and should have less chance to get rid of poverty. Cost distance should make MPI higher
Sex of the head of household	Binary (man, woman)	2003, 2008, 2013	Household survey in 2013	Agriculture and fishing work might be physically hard for women to carry out. We suspect that households led by men would have lower poverty (higher MPI)
Type of activity of the households	Categorical (agriculture, fishing, others)	2003, 2008, 2013	Household survey in 2013	Given that most of the agricultures are on non-commercial small family farm, we hypothesised that fishermen may have more chance to increase well-being, with lower MPI
Size of household	Continuous	2003, 2008, 2013	Household survey in 2013	Positive: More people in the household should mean more people to feed. We hypothesise that the larger size household may have lower chance to get rid of poverty, making MPI higher. However more people in the household can also mean more energy available to achieve greater agriculture work
Age of household (based on the year of traditional wedding of the head of household)	Continuous	2003, 2008, 2013	Household survey in 2013	Negative: The older households had more time to improve their well-being and should have lower MPI

§ The number of cattle can be included in the model because it was not used in the calculation of Multidimensional Poverty Index

Table 22. Description of the potential explanatory variables that may predict the variation of subjective well-being factors

Potential explanatory variables	Type	Time period available	Source	Hypothesised correlation with subjective well-being: Happiness, trust, power to influence decision
§Period (2003, 2008, 2013)	Categorical/factor	-	Household survey in 2013	Positive: Proportion of people who fell happiness, trust, more power to influence decision should increase across time
Presence of CBC intervention	Binary (0 absent, 1 present)	2003, 2008, 2013	Household survey in 2013	Positive: Socio-cultural and development actions through CBC should increase proportion of people who feel happier safer. And we hypothesise that CBC has empowered people to make them fill that everyone can have voice in influencing decision within the society.
Multidimensional Poverty Index	Continuous	2003, 2008, 2013	Calculated from household survey data	Negative: Increase in Multidimensional Poverty Index should be associated with a reduction of happiness, trust and power to influence decision in the village. Poorer people should have lower subjective well-being.
Number of cattle owned by the household	Continuous	2003, 2008, 2013	Village attribute collected during fieldwork (2013-2014)	Positive: High number of cattle owned by the household should be associated with higher happiness and higher power to influence decision in the society Negative (Trust): Household that have more cattle may feel less safe due to risk of bandits (rustling issue)
Travel cost (accessibility: distance to nearest town)	Continuous	2003, 2008, 2013	GIS FTM (acquired in 2013)	Negative: Remote villages may have fewer distractions causing reduction of happiness and confidence to influence decision making. Households located in far away villages may feel less safe because the risk of bandits attack can be higher and the police station and authority are not directly reachable
Type of activity of the households	Categorical: fishing, agriculture, other	2003, 2008, 2013	Household survey in 2013	We hypothesise that people who rely on fishing may experience higher happiness than the other activities because they can make money every day
Size of household	Continuous	2003, 2008, 2013	Household survey in 2013	Positive: Larger household size can be more animated and stronger connection, resulting in higher happiness. They may also fell safer because it is more difficult to steal things from larger household. Larger size of household may have higher power to influence decision in the village especially if they are not very poor.
Age of household (proxy reflecting the age of the head of the household)	Continuous	2003, 2008, 2013		Negative (happiness-power): Older households may have higher happiness and power to change decision in the village especially if they have less poverty Negative (trust). They may feel less safe as due to

§ Not considered for analysis of happiness as it was measured one time only (2013)

Table 23. Description of the potential explanatory variables that may predict the variation in rate of forest cover and Index of Perception of Valued Ecosystem Services

Potential explanatory variables	Type	Time period available	Source	Hypothesised correlation with forest cover and Index of Perception of Valued Ecosystem Services (IPVES)
§Period (1: 2000-2003, 2: 2004-2008, 3:2009-2013)	Categorical/factor	-	Household survey in 2013	Negative: Our hypothesis is that there is forest loss over time and that local people Have noticed the reduction of quantity or quality of services provided by the ecosystem
Presence of CBC intervention	Binary (0 absent, 1 present)	1996-2014	Household survey in 2013	Positive: we expect that CBC villages have lower and slower forest loss compared to control villages. However, people in CBC villages may have higher sensitivity/knowledge to perceive changes in provision of goods and services by the local landscape
Travel cost (accessibility: distance to nearest town)	Continuous	2003, 2008, 2013	GIS FTM (acquired in 2013)	Positive: Remote villages may have higher rate of forest cover (per square kilometre) with better knowledge about the changes in provision of valued ecosystem services

§The variable 'year' is called period in this paper as it was treated as a factor

Description of the response variables

The statistical response variables for the six statistical analyses are presented in the table below:

Table 24. Description of the response variables (household level)

Analysis of impact	Response variable	Availability	Type	Source
Objective human well-being	Multidimensional Poverty Index	2003, 2008, 2013	Continuous	Household survey in 2013
Subjective human well-being	Happiness	2013	Ordinal	Household survey in 2013
	Power to influence decision making within society	2013	Ordinal	Household survey in 2013
	Trust	2003, 2008, 2013	Binary	Household survey in 2013
Perceived provision of ecosystem services	Rate of forest cover, 30m resolution	2000-2014	Continuous	Hansen et al (2013)
	Index of Perception of Valued Ecosystem Services	2003, 2008, 2013	Continuous	Household survey in 2013

Principal Component Analysis

Principal Component Analysis was performed in R Studio 0.99.903 (R Core Team, 2012) to look at the interrelationships among the 18 continuous variables, including the Index of Perception of Ecosystem Services, evapotranspiration, area of forest cover, rate of deforestation, elevation, fire frequency, travel cost (access to town where government agencies are based), Multidimensional Poverty Index, population size, number of cattle per capita, education attainment, duration of CBC implementation (number of years), number of generator, distance from the village to nearest market, distance to health centre, distance to police station, distance to Commune office, and the number of other NGOs that intervened in each village. The PCA allowed us to simultaneously check the main direction of variance of each variable. Results of PCA were plotted in R using *ggplot2, plyr, scales,* and *grid* packages while significance of interactions are tested statistically using Generalised Linear Mixed Effects Models (GLMM).

Fitting Generalized Linear Mixed Effects Models

We undertook GLMM that mix random and fixed effects using lme4 function (Bates et al., 2012) and lmerTest package in R (Kuznetsova et al., 2016) to statistically evaluate the contribution of CBC in reducing people's Multidimensional Poverty Index, increasing their Index of Perception of Ecosystem Services in 2003, 2008, 2013, and to test the changes in rate of forest cover. These are the only continuous response variables in this paper. By incorporating random effects, GLMM provided a more flexible approach that helps generalise conclusions about the likelihood of causal effects (Bolker et al., 2009). The variables 'study region' and 'household' were considered as nested random effects to ensure that they do not cause any systematic or idiosyncratic influence on the variation of the Multidimensional Poverty Index, forest cover, and the average Index of Perception of Ecosystem Services. That is because the factor 'household' is hierarchically structured within 'village' and 'study region' and the difference between each of them can affect the variation.

The potential fixed effects are: period (year 2003, 2008, 2013 treated as factor) associated with the presence/absence of CBC (binary), the type of activity (categorical), the sex of the head of household (dichotomous), the size of the household (continuous), and the travel cost (continuous). We therefore had intercepts for each potential fixed effect as well as by period and by 'CBC: period' showing random slopes for the likely effect of CBC on Multidimensional Poverty Index and on the Index of Perception of Ecosystem Services per period.

Below are the best fitted linear models using restricted maximum likelihood (REML=False), isolating all fixed effects and evaluating the remaining variance due to random effects. The null hypothesis Ho that we tested was that the temporal trend of fire frequency or rate of deforestation is the same for the two groups CBC intervention and non-CBC villages. That allows fitting the trend through year with interaction between treatment and year.

Table 25. Statistical tests for Generalised Linear Mixed Effects Models

Analysis	Null hypothesis	R package	Model
1. Effect of CBC on Multidimensional Poverty Index	Households in CBC villages and non-CBC villages have the same MPI	lme4, lmerTest	Lmer (formula = MPI ~ period * CBC + activity + sex + household size + #cattle household + travel cost + (1 | site/village) Data = mydata)
5. Effect of CBC on annual rate of forest cover	CBC villages and non-CBC villages have same slope of forest cover change	lme4, lmerTest	Lmer (formula = Rate forest cover ~ CBC* period + travel cost + (1 | site/village) Data = mydata)
6. Effect of CBC on people's perception of valued ecosystem services	People in CBC villages and non-CBC villages have the same capacity in detecting changes of valued ecosystem services	lme4, lmerTest	Lmer (formula = IPVES ~ period * CBC + travel cost + (1 | site/village) Data = mydata)

Normality of residuals was checked by visualising histograms of distribution and Q-Q plots to ensure that the models are well fitted. Transformation of the Multidimensional Poverty Index was not necessary because it was already quasi-normally distributed. However, ninth root transformation and arcsine were respectively performed with the Index of Perception of Valued Ecosystem Services and the rate of forest cover because residuals of their models did not have normal distribution.

Fitting Ordinal logistic regression for Likert-type data

Likert items are used to measure respondents' attitude to a particular question or statement (Jacoby & Matell, 1971). Ordinal logistic regression for Likert-type data was undertaken to analyse the likely effect of CBC on people's degree of happiness and level of power in changing decision-making within society. *Happiness* and *power to change* are ordinal response data since we can only state that one score is higher than another but not the distance between each score. During the household survey, interviewees' responses about happiness were restricted to 'very happy', 'moderately', 'somewhat' and 'not at all' while their responses about power to change were closed to 'yes very easily', 'yes with a bit of difficulty', 'yes with great difficulty' and 'no way'.

The explanatory variables are the presence/absence of CBC, the Multidimensional Poverty Index, the type of activity, the number of cattle owned by the household, the sex of the head of household, the size of the household and travel cost.

Table 26. Statistical tests for ordinal logistic regression

Analysis	Null hypothesis	R package	Model
Effect of CBC on people's happiness	Households in CBC villages and non-CBC villages have the same level of happiness	Foreign, MASS, Hmisc, reshape2	**Step 1:** Call: polr(formula = Happiness level~CBC + MPI +activity + sex + household size + #cattle household + travel cost, data = mydata, Hess=T) **Step 2 to calculate p-value:** coeffs <- coef(summary(model_r)) p <- pnorm(abs(coeffs[, "t value"]), lower.tail = FALSE) * 2 cbind(coeffs, "p value" = round(p,3))

Effect of CBC on people's power to influence decision making in the village	Head of households in CBC and non-CBC villages have the same feeling in terms of power to change decision	Foreign, MASS, Hmisc, reshape2	**Step 1:**
			Call: polr (formula = Influence power ~ CBC * period + MPI + Household age + Household size + #cattle household + Travel cost,
			data = mydata, Hess = T)
			Step 2 to calculate p-value:
			coeffs <- coef(summary(model_r))
			p <- pnorm (abs (coeffs[, "t value"]), lower.tail = FALSE) * 2
			cbind (coeffs, "p value" = round(p,3))

Fitting Logit regression with Generalised Linear Models

Given that the *trust* response is dichotomous (yes or no), we used Logit Regression (Hosmer & Lemeshow, 2000) with Generalised Linear Model function (binomial family) to evaluate the contribution of CBC interventions in implementing trust within society. The explanatory variables are: period (year 2003, 2008, 2013 treated as factor) associated with the presence/absence of CBC, the Multidimensional Poverty Index, the presence/absence of case of theft experience by the household (dichotomous), and the travel cost.

Table 27. Statistical test for Logit regression using Generalised Linear Models

Analysis	Null hypothesis	R package	Model
4. Effect of CBC on trust within society	People in CBC villages and non-CBC villages have the same feeling about 'trust'	library(aod) library(Rcpp)	glm (formula = Trust ~ CBC * Period + MPI + travel cost, family = "binomial", data=mydata)

The interaction between happiness and period could not be analysed because happiness data exist in 2013 only. A p-value of <0.05 determines the significance of the effect each predictor has on fires or deforestation. Those models provided us full information about the estimates of intercepts, standard errors and importance of each variable in affecting fire. We visually inspected histogram and Q-Q plots of residuals after transformation to check normality of the distribution. The model selection criterion was based on AIC (Akaike's Information Criterion). The model that gave the lowest AIC value was chosen.

Results

Principal components analysis (PCA)

The PCA was used explore the overall structure of the multi-dimensional fokontany dataset. Figure 11 shows a high degree of clustering on the principal components among fokontany within each of the five study regions. This is to be expected as the study regions differ in their overall level of poverty as well as in major environmental gradients.

The PCA shows that villages in Nosivolo are typically very remote (high travel cost), most fokontany in the Alaotra basin are at relatively high elevation, and fokontany in Baly bay are large relative to those in the other study regions.

This clustered pattern within sites means that the five independent study regions can be considered as replicates and strengthens the external validity of conclusions which can be drawn from the GLMMs (see below) which use study region as a fixed factor.

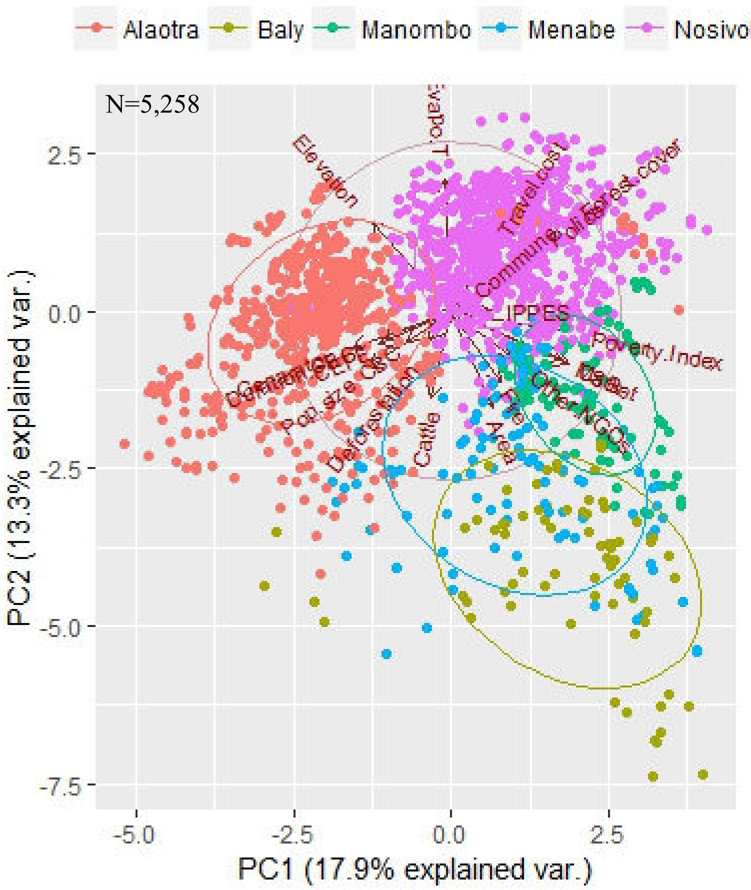


Figure 11. *PCA analysis: interaction between variables*

Effects of Community-based Conservation on people's level of poverty

Overall Poverty Index within the five study areas and changes over time

Box plots below indicate that a large majority of the surveyed households in the five study regions are multidimensionally poor, with a Multidimensional Poverty Index greater than 0.33 (Fig. 12). On average Alaotra is the wealthiest region with lowest Multidimensional Poverty Index. However, even in Alaotra, the median line is observed just below the Multidimensional poverty line, indicating that more than 50% of households have MPI≥0.28. More than 50% of households in Manombo live in severe poverty with MPI≥0.6, worse quality of life than people on average in Niger, the multidimensionally poorest country in the world (Alkire et al., 2013). Despite some outliers, Baly and Menabe have similar poverty score where households generally present equal Multidimensional Poverty Index (MPI=0.43). Data also show an overall increase of Multidimensional Poverty Index between 2003 and 2008.

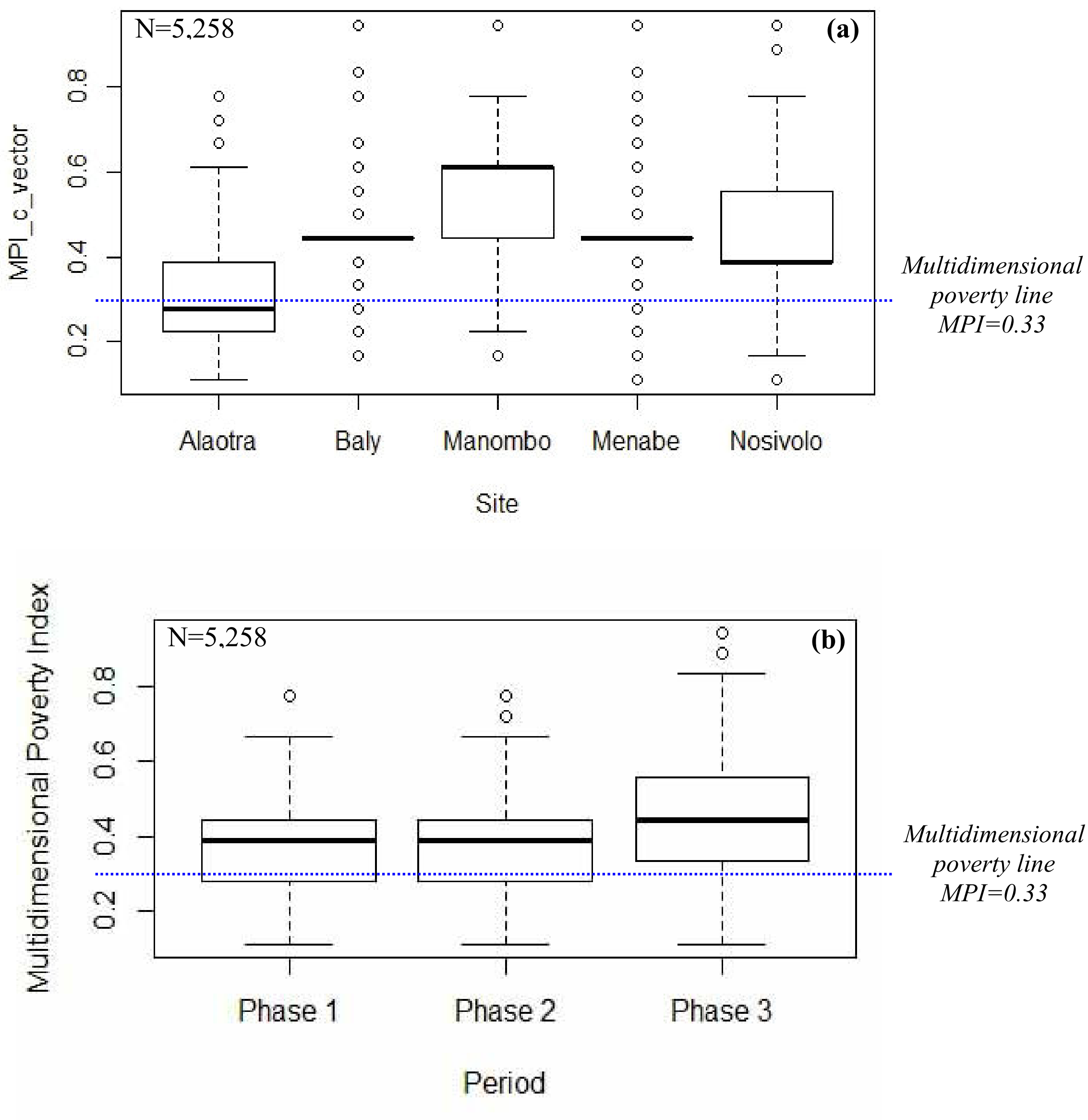


Figure 12. *Overall Multidimensional Poverty Index in the five study regions and change over time (2003-2008-2013). (a) Average of the Multidimensional Poverty Index at each study area, (b) Changes of the Multidimensional Poverty Index over time*

The bar plot below (Fig. 13) compares the Multidimensional Poverty Index (MPI) between households in CBC villages and non-CBC villages. The vast majority of households in CBC and non-CBC villages have a MPI value around 0.444, very close from the 2004 national Multidimensional 0.413 as illustrated by Alkire & Santos (2010). The graph shows that there are probably fewer multidimensionally poor people (MPI>0.33) in non-CBC villages than in CBC villages. Evidence of this is checked in the multivariate analysis (Table 28).

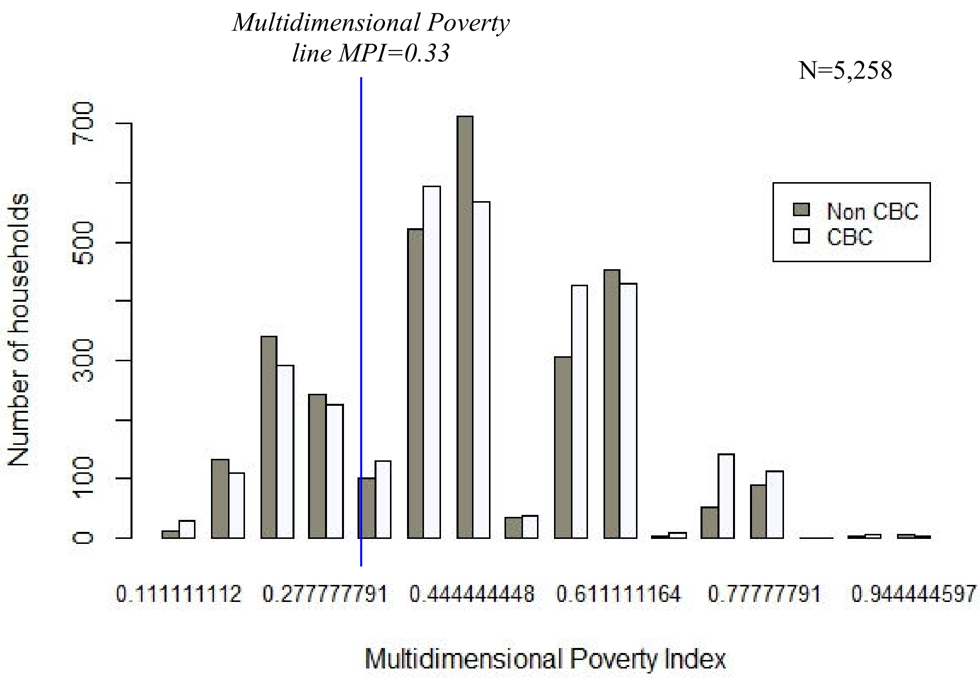


Figure 13. *Distribution of household per Multidimensional Poverty Index values by household (High scores show high poverty)*

Changes in Multidimensional Poverty Index per study areas between control and intervention villages (2003, 2008, 2013)

The scatter plot with different sized points below (Fig. 14) indicates that the number of households that live under multidimensional poverty may have increased in both CBC villages and non-CBC villages across all study areas between 2003 and 2013. The most deprived households had an MPI around 0.75 in 2003 and that has increased to 0.9 in 2013. More households (especially in Manombo and Nosivolo) live under severe poverty in CBC and non-CBC villages. Households in control villages in Baly seem to be experiencing higher poverty than households in CBC villages while the opposite is observed in Alaotra.

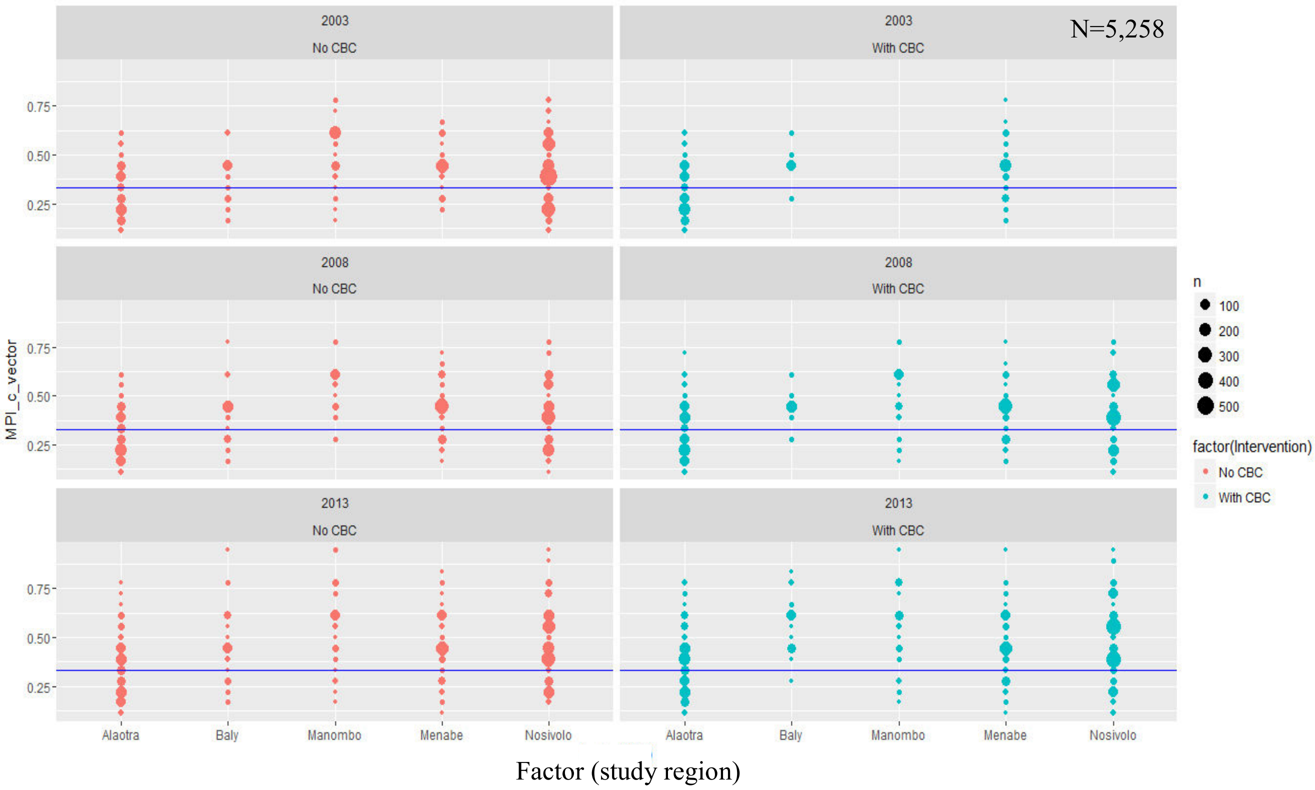


Figure 14. *Comparison of mean of Multidimensional Poverty Index over time between CBC villages and non-CBC villages using household survey data from the five study regions*

Contribution of Community-based Conservation to poverty alleviation

There was no change of Multidimensional Poverty Index in CBC and non-CBC villages between 2003 and 2008 (period 2) (Table 28). However, the Multidimensional Poverty Index did increase by $3.652e^{-02} \pm 3.280e^{-03}$ ($p<2e^{-16}$) between 2008 and 2013 (period 3). No significant difference of the Multidimensional Poverty Index ($p=0.474$) is detected between households in CBC villages and non-CBC villages. Fishermen may have experienced less poverty compared to farmers and others with nearly significant reduction in Multidimensional Poverty Index ($p=0.062$) over time.

The increasing size of the household is associated with higher levels of poverty (p=0.015), making bigger families poorer with $9.809e^{-04}\pm4.028e^{-04}$ significantly higher Multidimensional Poverty Index. There was no significant effect of travel cost on poverty. Analysis of interaction between CBC interventions and time (year) shows that despite some non significant improvement of the economy of the households between 2003 and 2008 (reduction of MPI by $-2.006e^{-03}\pm4.694e^{-03}$, p=0.669) the CBC villages have experienced $1.205e^{-02}\pm4.562e^{-03}$ higher poverty between 2008 and 2013 (p=0.008).

Table 28. Fitted mixed effect model predicting the MPI

Fixed effects	Hypothesis	Estimate	Std. Error	Pr(>|t|)
Period Phase 2	Negative	$-4.019e^{-03}$	$3.353e^{-03}$	0.231
Period Phase 3	Negative	$3.652e^{-02}$	$3.280e^{-03}$	$< 2e^{-16}$ ***
Treatment CBC	Negative	$5.951e^{-03}$	$8.302e^{-03}$	0.474
Activity agriculture	Negative	$-2.338e^{-01}$	$1.145e^{-01}$	0.041 *
Activity fishing	Negative	$-2.130e^{-01}$	$1.145e^{-01}$	0.063 .
Activity other	Negative	$-2.556e^{-01}$	$1.145e^{-01}$	0.026 *
Sex Man	Negative	$9.799e^{-02}$	$4.737e^{-02}$	0.039 *
Sex Woman	Negative	$3.401e^{-02}$	$2.785e^{-03}$	$< 2e^{-16}$ ***
Household size	Positive	$9.809e^{-04}$	$4.028e^{-04}$	0.015 *
# cattle per household	Negative	$-2.221e^{-04}$	$8.630e^{-05}$	0.010 *
Travel cost	Positive	$3.308e^{-03}$	$2.126e^{-03}$	0.121
Period Phase 2: CBC	Negative	$-2.006e^{-03}$	$4.694e^{-03}$	0.669
Period Phase 3: CBC	Negative	$1.205e^{-02}$	$4.562e^{-03}$	0.008 **

*Significance: *P<0.05; **P<0.001; ***P<0.0001*

Other effects on Multidimensional Poverty Index

The statistical effect of idiosyncratic differences between random variables *village* and *study region* are avoided by including them in the model. Most of the variability is explained by their high Standard Deviations (0.078 for study region and 0.054 for village). The remaining variability that is not explained by the random effects is seen on residuals (table 29).

Table 29. Variation of Multidimensional Poverty Index explained by random effects

Groups	Variance	Std.Dev.
Village : Study region	0.003	0.054
Study region	0.006	0.075
Residual	0.013	0.114

Effectiveness of CBC in increasing people's happiness

Overall happiness within the five study regions

The bar chart below (Fig. 15) compares the level of happiness of heads of households between CBC and non-CBC villages. The majority of people feel moderately or somewhat happy while less than 10% of household heads feel very happy. A high proportion of people considered themselves unhappy indicating that the happiness is generally low in both CBC villages and non-CBC villages. 'Somewhat happy' and 'not at all happy' together represent more than 60% of the interviewed people, and that the difference between CBC villages and non-CBC villages is not obvious.

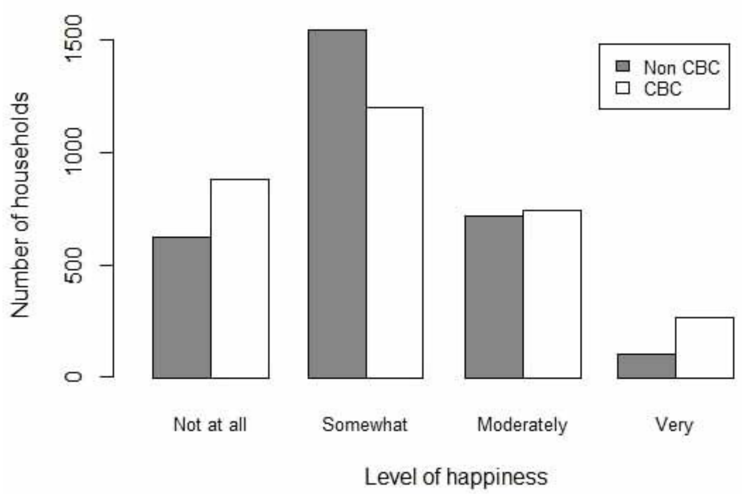


Figure 15. *Comparison of level of happiness between households in CBC villages and non-CBC villages*

According to the Mann-Whitney test (Wilcoxon rank sum with continuity correction: p= 0.741); there was no difference in happiness levels between CBC villages and non-CBC villages. This is also evident from the bar chart above which indicates no obvious difference of happiness between households in CBC villages and non-CBC villages.

Relationship between happiness and poverty

The graph below (Fig. 16) illustrates the interaction between Multidimensional Poverty Index shown as scatter plot and happiness presented as box plot in household level. It suggests that the Multidimensional Poverty Index might be an important predictor contributing to decrease in happiness. The case might be different from region to region but in general the less poor people tend to have higher happiness. For example, most of the poor households in the five study regions are unhappy or ‘somewhat’ happy.

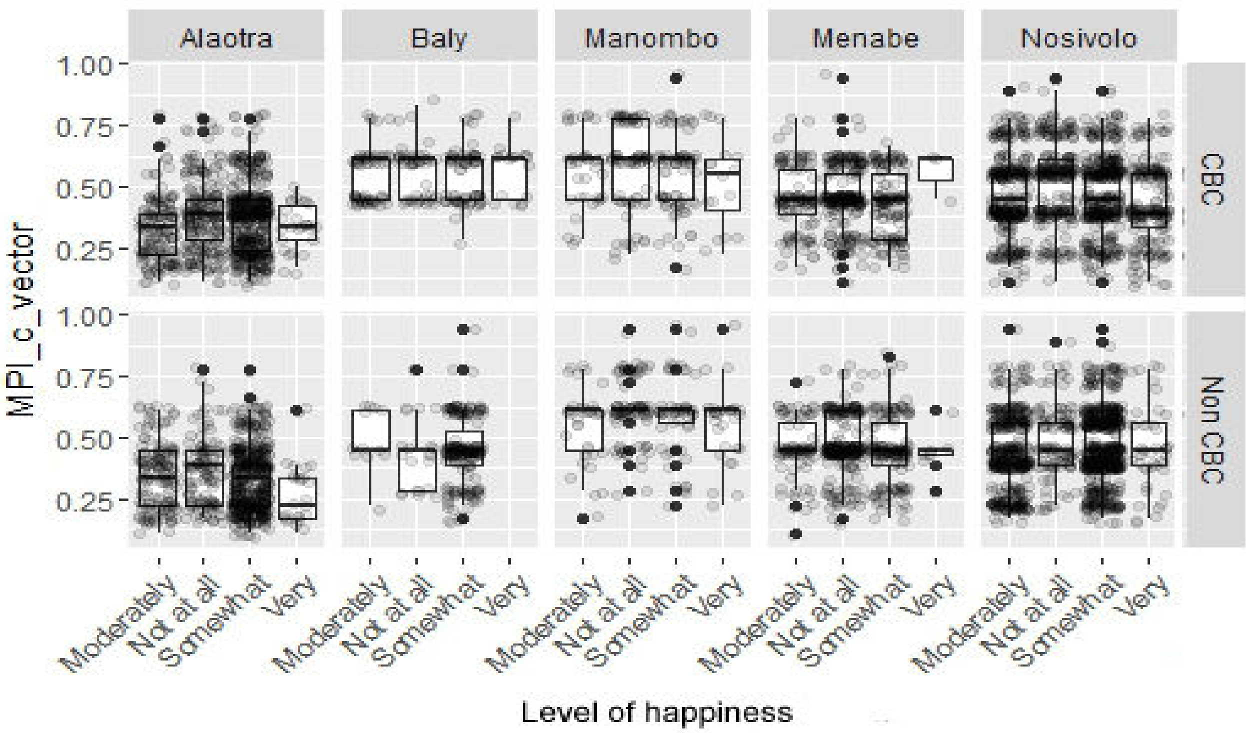


Figure 16. *Relationship between happiness and poverty (N=5,258)*

Effect of CBC on happiness and other potential predictors

No significant difference in happiness scores (p=0.135) was observed between households in CBC villages and those in control villages (Table 30). The Multidimensional Poverty Index and travel cost represent the most important contributing factors lowering happiness in household level, both in CBC villages and non-CBC villages. The MPI may have lowered the happiness score by -0.529±0.155 (p=0.001), while the travel cost reduced it by -0.145±0.013 ($p<2e^{-16}$). The other factors such as the number of cattle per capita, size of the household and the type of activity do not seem to have significant impact on happiness. However, households led by women tend to have higher happiness with $p<2e^{-16}$.

Table 30. Fitted Ordinal logistic regression model for Likert-type data predicting happiness

Fixed effects	Hypothesis	Estimate	Std. Error	Pr(>|t|)
Treatment CBC	Positive	-0.072	0.048	0.135
MPI	Negative	-0.529	0.155	0.001***
Activity Agriculture	Positive	-1.621	1.780	0.363
Activity Fishing	Positive	-1.771	1.782	0.320
Activity Other	Positive	-1.634	1.781	0.359
Sex Man	Positive	1.124	1.259	0.372
Sex Woman	Positive	0.315	0.069	$<2e^{-16}$***
Household size	Positive	-0.007	0.009	0.438
# cattle per household	Positive	0.003	0.003	0.292
Travel cost	Negative	-0.145	0.013	$<2e^{-16}$***
Moderately | Not at all		-3.459	1.783	0.052.
Not at all | Somewhat		-2.333	1.783	0.191
Somewhat | Very		0.482	1.782	0.787

*Significance: *P<0.05; **P<0.001; ***P<0.0001*

Effect of CBC on people's power to influence decision making within society

Overall level of power to change decision making

Bar plots (Fig. 17) below indicate that the majority of households both in CBC villages and non-CBC villages do not think they are able to change the local decision making even if they want to. More than 60% of the interviewed households believe that there is no way to change decisions, or if they can, they will face great difficulty to change it. However, 36% of the households are positive and believe they can influence local decision making very easily, or with a bit of difficulty. Overall, there is no obvious difference between 'power to change' in CBC villages and non-CBC villages even though CBC villages seem to have higher number of households who said they can change decision very easily. However, examining the changes in people's feeling in CBC villages over time, there is an apparent drop of confidence indicated by the increase of number of people who, between 2008 and 2013, firmly believe there has been no way to change decisions between 2008 and 2013.

All period 2003-2008-2013 (N=5,258)

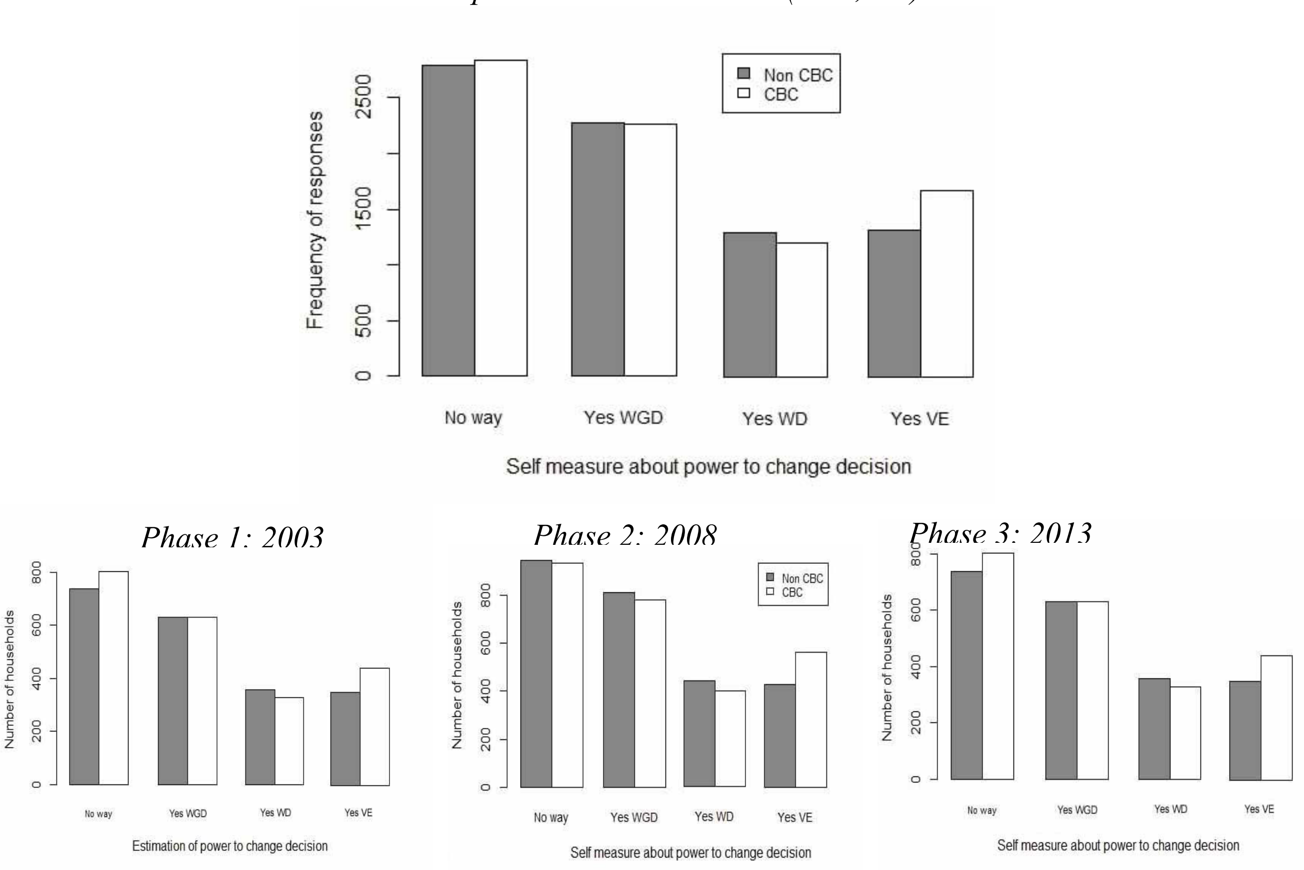


Figure 17. *Comparison of self measure of power in influencing decision making between CBC villages and non-CBC villages in 2003, 2008, 2013. Yes VE: yes very easy, Yes WD: yes with a bit of difficulty, Yes WGD: yes with great difficulty*

Relationship between multidimensional poverty and power to change decision

The interaction between the Multidimensional Poverty Index of the households and their power to change decisions in society is shown in Figure 18. Visual inspection suggests that poverty is an important factor predicting people's confidence about their ability to change local decisions. The richer households tend to believe that they can influence decisions while the majority who are poorer think there is no way to change it or the change can happen but with great difficulty. No obvious difference is observed between CBC villages and non-CBC villages across the five study regions. Despite overall multidimensional poverty, people in Nosivolo probably have the highest confidence about their capacity to change local decisions if the majority want to.

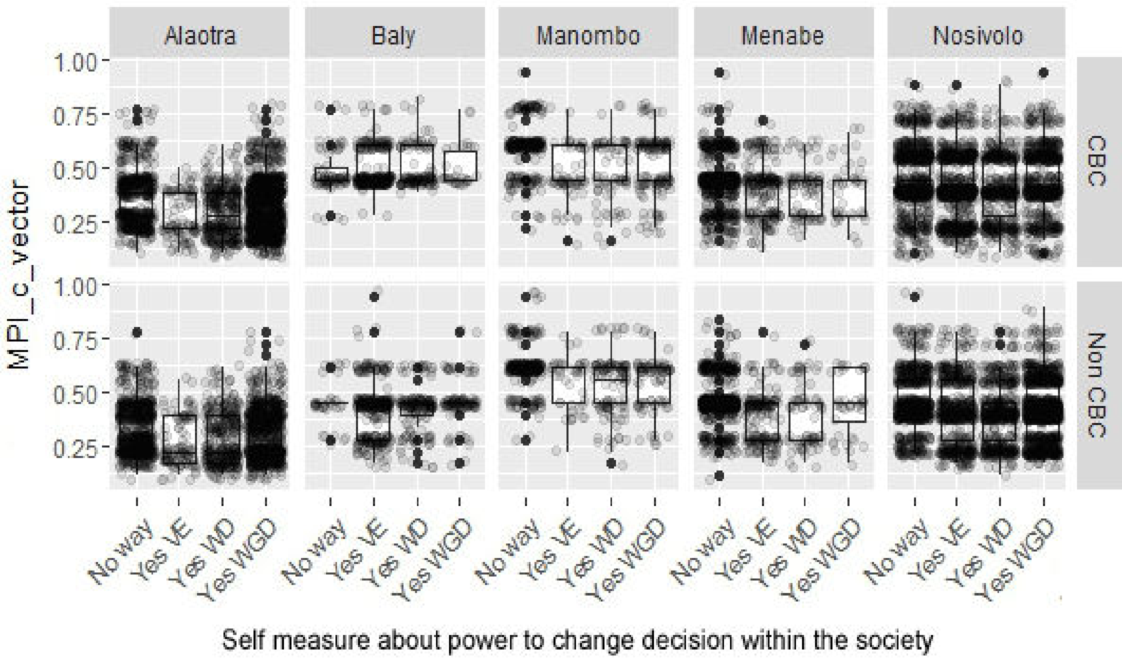


Figure 18. *Relationship between multidimensional poverty and power to change decision*

Effectiveness of CBC in empowering local communities

There was no significant difference in people's power to change decisions between CBC villages and non-CBC villages. No significant change also was observed between 2003 and 2013. Results indicate consistent causation between some fixed effects and the response variable. The Multidimensional Poverty Index, number of cattle per capita and travel cost appear to be important contributing factors lowering the power to change local decisions (p<0.001). However, the age of household is associated with higher power to change decisions in society (p<0.001).

Table 31. Fitted Ordinal logistic regression model for Likert-type data predicting people's power to influence decision-making

Fixed effects	Hypothesis	Estimate	Std. Error	Pr(>|t|)
Treatment CBC		-0.101	0.056	0.072
Period Phase 2	Positive	0.028	0.054	0.611
Period Phase 3	Positive	0.060	0.053	0.261
MPI	Negative	-2.293	0.105	p<0.001***
Household size	Positive	0.005	0.006	0.402
# cattle household	Positive	-0.0060	0.001	p<0.001***
Household age	Positive	0.019	0.001	p<0.001***
Travel cost	Negative	-0.060	0.008	p<0.001***
Treatment CBC: Period Phase 2	Positive	0.041	0.075	0.591

Treatment CBC: Period Phase 3	Positive	0.114	0.073	0.119
No way|Yes VE		-1.303	0.070	p<0.001
Yes VE|Yes WD		-0.477	0.070	p<0.001
Yes WD|Yes WGD		0.243	0.069	p<0.001

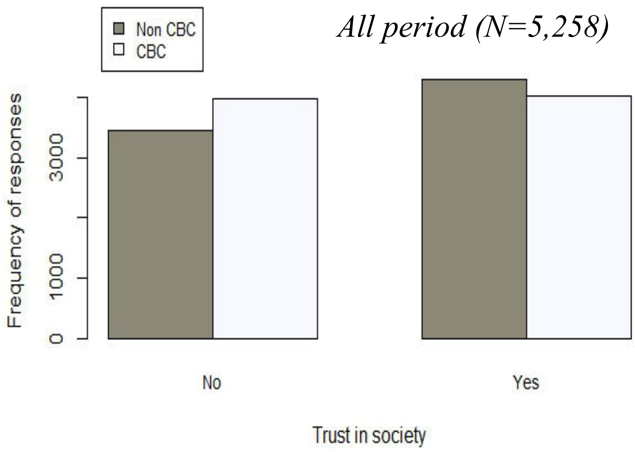
*Significance: *P<0.05; **P<0.001; ***P<0.0001*

Likely effectiveness of Community-based Conservation in reinforcing social cohesion (trust)

Level of trust within society in 2003, 2008 and 2013 in CBC villages and non-CBC villages

The overall changes of people's feelings about mutual trust in society between CBC villages and non-CBC villages in 2003, 2008 and 2013 is shown in Fig. 19. Households in non-CBC villages, especially in 2008, visibly have higher trust than those in CBC villages but the test of significance (Table 32) indicates no difference except for the year 2008 during which trust was lower in CBC villages. It is also observed that the proportion of people who do not trust the society has gradually increased between 2003 and 2013 both in CBC villages and non-CBC villages.

All period (N=5,258)



Phase 1: 2003 *Phase 2: 2008* *Phase 3: 2013*

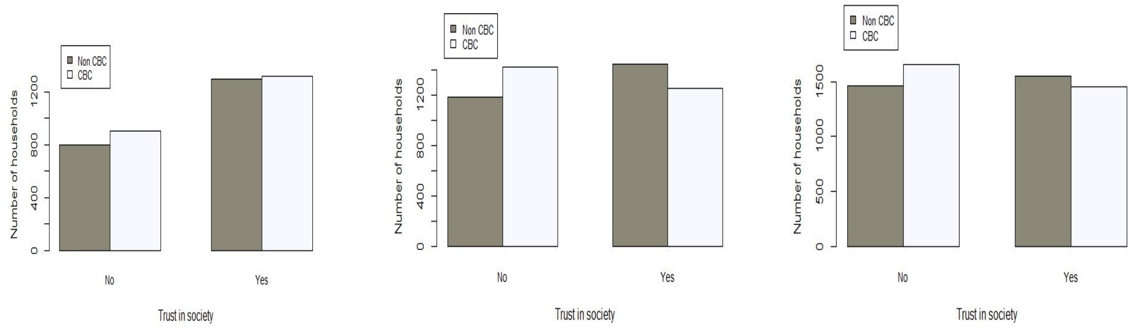


Figure 19. *Comparison of mutual trust in society between households in CBC villages and non-CBC villages. Yes: A bicycle left outside during the night will still be there in the morning, No: The bicycle left outside during the night will be stolen in the morning*

Relationship between multidimensional poverty and trust in society

The graph below attempts to detect the link between poverty and trust within society and compares the situation between CBC villages and non-CBC villages. It is observed that the Multidimensional Poverty Index might be an important contributor to lowering trust. No obvious difference is observed between CBC villages and non-CBC villages. However, the less poor households seem to have higher confidence in society. That can be visibly noticed in Alaotra, Baly and Nosivolo.

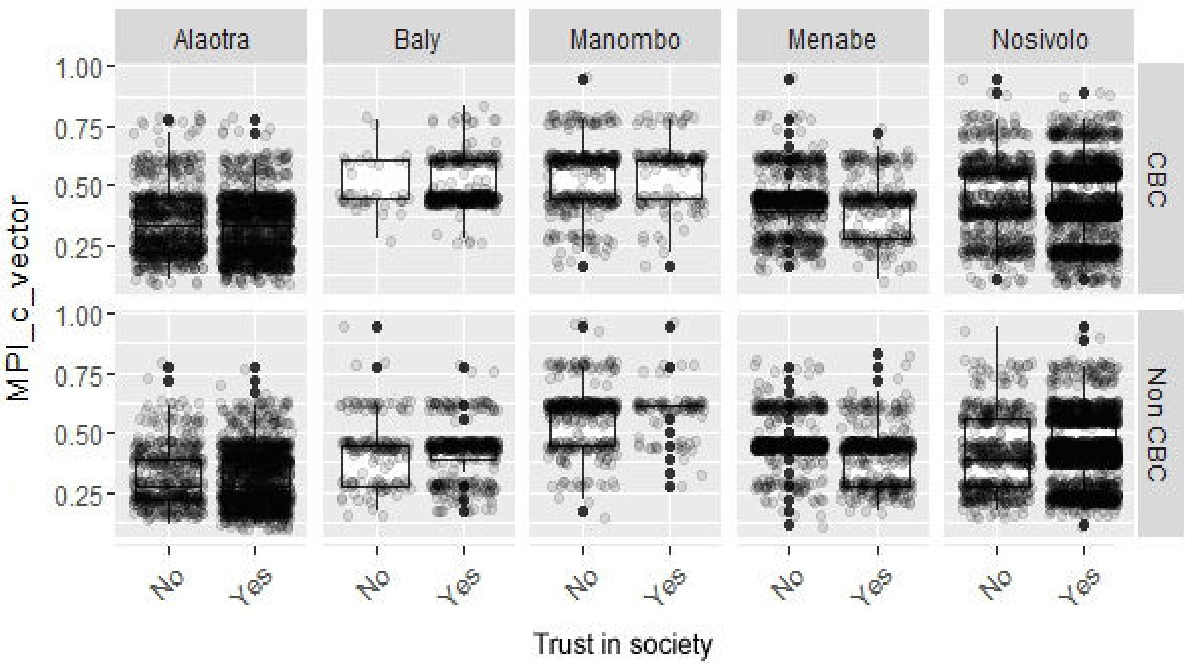


Figure 20. *Comparison of relationship between poverty and trust within society in CBC villages and non-CBC villages (N=5,258)*

Contribution of Community-based Conservation to reinforcement of social cohesion within society

There was no difference of trust between households in CBC villages and non-CBC villages (p=0.134) (Table 32); in fact, a decrease in trust is observed between 2003 and 2008 ($p=1.650e^{-06}$), with stronger decline in 2013 ($p=8.430e^{-11}$). The Multidimensional Poverty Index is an important factor destroying trust in society ($p<2e^{-16}$). Between 2003 and 2008, people in CBC villages perceived a decline in trust.

Table 32. Fitted Logit regression with Generalised Linear Model predicting trust in society

Fixed effects	Hypothesis	Estimate	Std. Error	Pr(>|t|)
(Intercept)		1.020	0.067	< 2e-16 ***
Treatment CBC	Positive	-0.09	0.063	0.134
Period Phase 2	Positive	-0.287	0.060	$1.65e^{-06}$ ***
Period Phase 3	Positive	-0.378	0.058	8.43^{e-11} ***
MPI	Positive	-1.127	0.114	$< 2^{e-16}$ ***
Treatment CBC: Phase 2	Positive	-0.232	0.083	0.005 **
Treatment CBC: Phase 3	Positive	-0.070	0.081	0.385

*Significance: *P<0.05; **P<0.001; ***P<0.0001*

Analysis 5: Effect of CBC on people's attention in detecting changes in provision of ecosystem services

Changes in rate of forest cover between 2000 and 2014

There is a clear pattern showing gradual loss of forest over time in all study regions, both in CBC villages and non-CBC villages. CBC villages visibly have a higher rate of forest cover than control villages but the result of statistical tests through GLMM does not confirm this overall difference (Table 33). The decrease in forest cover is steeper in Menabe and Nosivolo, especially after 2008 (Fig. 21).

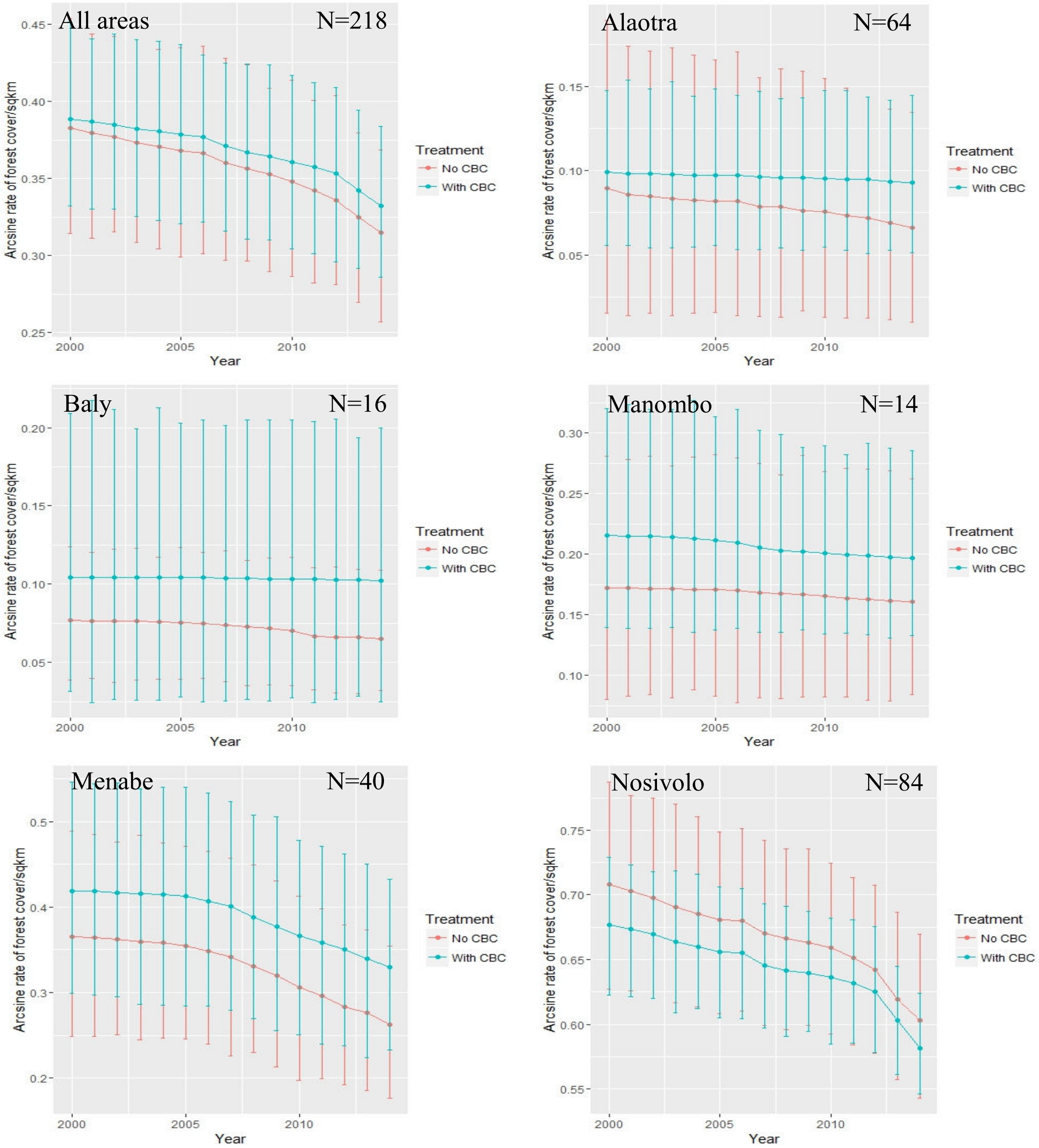


Figure 21. *Comparison of mean of arcsine rate of forest cover (per square kilometre) over time between CBC villages and non-CBC villages using Hansen forest cover change data. N is the number of villages*

Forest loss over time between the two groups

On average, there is no difference in extent of forest cover per square kilometre between CBC villages and non-CBC villages (p=0.766) (Table 33). The extent of forest cover in both groups has significantly declined ($p=1.78e^{-15}$) between 2003 and 2008 (period 1) and then further declines are apparent until 2013. The extent of forest cover increases with the distance and access to nearest town. Travel cost was associated with higher forest cover (p=0.004). The difference in rate of change in forest cover between CBC and non-CBC villages is significant in Period 3 (2009-2013) during which CBC villages presented a higher decrease (p<0.001).

Table 33. Fitted mixed effect model predicting the annual forest cover change

Fixed effects	Hypothesis	Estimate	Std. Error	Pr(>|t|)
Intercept		$2.375e^{-01}$	$9.874e^{-02}$	0.054 .
Presence of CBC	Positive	$7.904e^{-03}$	$2.656e^{-02}$	0.766
Period Phase 2 (2003-2008)	Positive	$-1.378e^{-02}$	$1.725e^{-03}$	$1.78e^{-15}$ ***
Period Phase 3 (2009-2013)	Positive	$-4.161e^{-02}$	$1.660e^{-03}$	$< 2e^{-16}$ ***
Travel cost	Positive	$2.083e^{-02}$	$7.205e^{-03}$	0.004 **
CBC:period Phase 2	Positive	$3.090e^{-03}$	$2.439e^{-03}$	0.205
CBC:period Phase 3	Positive	$7.841e^{-03}$	$2.347e^{-03}$	<0.001 ***

*Significance: *P<0.05; **P<0.001; ***P<0.0001*

Importance of ecosystem services

The bar plot below (Fig. 22) summarises respondents answer about the importance of each ecosystem service to household livelihoods. By order of importance, people ranked the 10 valued ecosystem services as follows: fuel wood, construction wood, fish, Non Timber Forest Products, water quality, water quantity, agriculture yields, cultural value, cattle grazing, and bush meat as the least important.

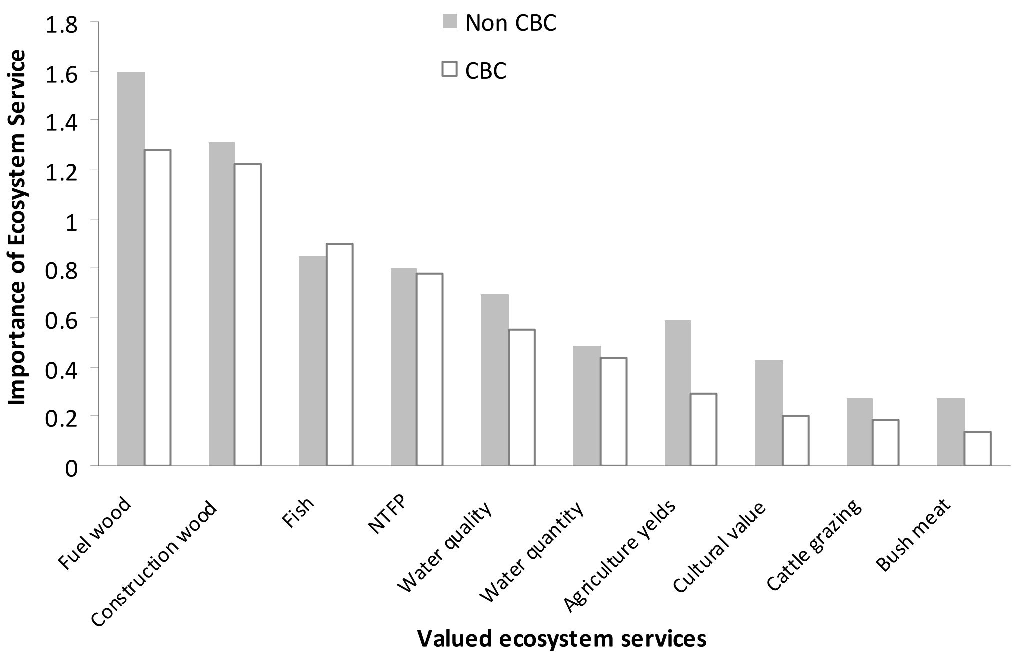


Figure 22. *Overall importance of provisioning ecosystem services to households (Scale of importance of the ecosystem services: 0: none, 3: very high)*

Comparison of perceived changes of ecosystem services

Changes in people's perception of the provision of valued ecosystem services are summarised in box plots (Fig. 25). Households in CBC villages seem to generally have a lower Index of Perception of Valued Ecosystem Service (IPVES).

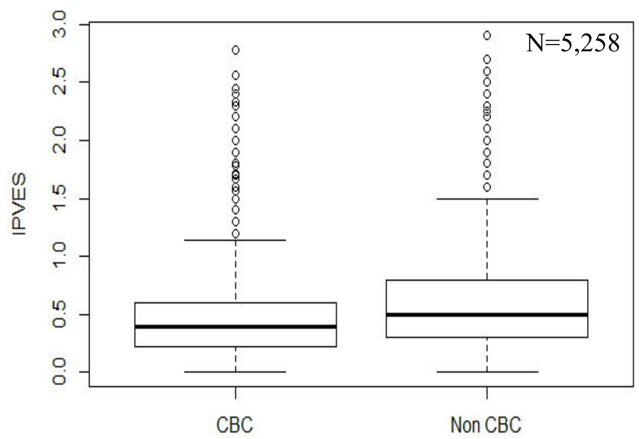
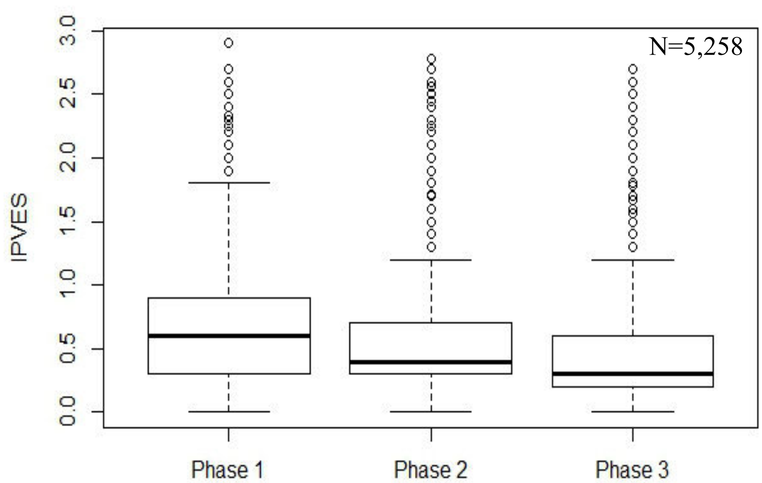


Figure 23. *Comparison of perception in provision of valued ecosystem services between CBC villages and non-CBC villages*

Changes of the Index of perception in provision of valued ecosystem services

The following box plots (Fig. 24) indicate people's perception about changes in provision of valued ecosystem services in both CBC villages and non-CBC villages between 2003 and 2013. Overall, the Index of Perception of Valued Ecosystem Services (IPVES) declined from 2003 (phase 1) to 2013 (phase 3) with a possible stronger decrease between phase 1 and phase 2 (2008).



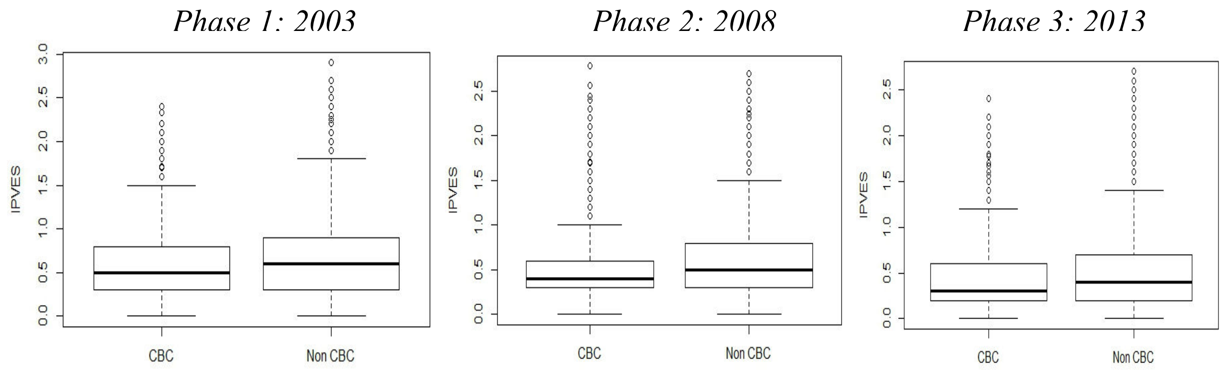


Figure 24. *Comparison of Index of Perception in Provision of Valued Ecosystem Services (IPVES) between CBC villages and non-CBC villages during phase 1:2000-2003, phase 2: 2004-2008, phase 3: 2009-2013*

Effectiveness of Community-based Conservation on people's perception of valued ecosystem services

The difference in Index of Perception of Valued Ecosystem Services between CBC villages and non-CBC villages was nearly significant (p=0.068) in which interviewed people in CBC villages mentioned a lower estimation of quality and quantity of valued ecosystem services provided by their local ecosystems (Table 34). Overall, interviewed people noticed a significant drop of provision of valued ecosystem services between 2003 and 2013. In period 2 (2009-2013) the Index of Perception of Valued Ecosystem Services in CBC villages has significantly dropped further.

Table 34. Fitted mixed effect model predicting the Index of Perception of Valued Ecosystem Services

Fixed effects	Hypothesis	Estimate	Std. Error	Pr(>|t|)
Intercept		$8.101e^{-01}$	$9.017e^{-02}$	<0.001 ***
Presence of CBC	Negative	$-6.466e^{-02}$	$3.530e^{-02}$	0.068.
Period Phase 2	Negative	$-5.065e^{-02}$	$4.255e^{-03}$	< $2e^{-16}$ ***
Period Phase 3	Negative	$-1.166e^{-01}$	$4.150e^{-03}$	< $2e^{-16}$ ***
Travel cost	Positive	$2.524e^{-03}$	$9.640e^{-03}$	0.794
CBC:period Phase 2	Negative	$-7.389e^{-03}$	$5.959e^{-03}$	0.215
CBC:period Phase 3	Negative	$-1.289e^{-02}$	$5.801e^{-03}$	0.026 *

*Significance: *P<0.05; **P<0.001; ***P<0.0001*

Discussion

This paper reports on an assessment of the effectiveness of Community-based Conservation (CBC) initiatives in improving objective and subjective human well-being, and in creating local awareness of key valued ecosystem services in Madagascar.

Potential contribution of Community-based Conservation to reducing poverty

Poverty as measured by the Multidimensional Poverty Index (MPI) has gradually increased between 2003 and 2013 and many households, especially in the four study regions of Baly, Manombo, Menabe and Nosivolo, remain in severe poverty, indicated by a score of MPI>0.6. In the 218 villages studied, CBC development support, for education and public health, and in particular for revenue generating activities, has not been sufficient to achieve substantial alleviation of poverty. No significant difference in Multidimensional Poverty Index scores was found between households in CBC villages and control villages. Three reasons may have caused this result. First, people are extremely poor and it is challenging for a CBC programme to measurably improve the economy. The budget (approximately 2,500GBP per village per year) spent by Durrell was probably too small to alleviate poverty and greater investment on development projects is required. Second, poor people were not motivated to engage with the CBC interventions (or stopped from joining) because they did not see the benefits of being part of the process. And third, there was perhaps an implementation issue which marginalised and discouraged the poorest households (e.g. domination of the local association by some families).

Size of household has been noted as a key factor in high levels of poverty, with larger families being significantly poorer. In Madagascar there has been a four-fold increase in population over the last 50 years, with an average family size of 4.6 children per woman, and for the economy to improve this population growth needs to be reduced through voluntary measures (Clark, 2012).

A further factor likely to contribute to poverty is political instability. This was not included in the analysis, however, because the variable ‘year’ (2003, 2008, and 2013) could only be treated as a factor but not as continuous variable. Nevertheless, Collier (2008) emphasised the strong relationship between politics and the economy, noting that some governments in Africa are under a threat of political instability not so much because of some ‘Africa effect’ but because of poverty. Effective governance from local to national level, the coordination of socio-economic and development activity, and the control of corruption, low tax payment, and lack of law enforcement and transparency, are all keys to escaping the poverty trap. Although Madagascar has received international financial aid over many years, economic performance has remained weak (Horning, 2008). Despite international support, efforts to achieve sustainable development have failed to alleviate poverty and almost none of the eight 2000-2015 United Nations Millennium Development Goals have been achieved (Waeber et al., 2016).

Potential contribution of Community-based Conservation to improving individual subjective well-being

Happiness: The happiness score in CBC villages was no higher than in control villages, indicating that the community animation activities introduced into village meetings (traditional dancing, singing, public quizzes) were not sufficient to enhance subjective well-being among local people. Poverty, as measured by the Multidimensional Poverty Index, and the cost of travel (increasing people’s sense of isolation) were identified as important factors contributing to people’s dissatisfaction with their overall quality of life, a key measure of individual happiness (Veenhoven, 2015). Also, the low level of satisfaction experienced by people living in remote villages seems likely to be related to a lack of local distraction or to a lack of security.

Power to influence decision-making: There was no difference in the responses of people in CBC villages and those in control villages when they were questioned as to whether they felt they had any power to influence decision-making in their local community. This implies that CBC efforts to try to empower local associations to be better able to defend and achieve their own development goals have not been successful. The Multidimensional Poverty Index scores and cost of local travel are indicators of people's lack of power to influence local decision-making. Age of head of household, however, is correlated with a greater sense of power to influence change. These results support Handgraaf et al. (2008) who noted that if you are poor and weak, your capacity to influence the attitude of the others will be low.

Mutual trust: Trust plays a very important role in society in general and particularly within local communities although its full importance is rarely acknowledged until it begins to break down, threatening the stability of social relationships (Cook, 2001). People's trust in their local community generally diminished between 2003 and 2013. Between 2003 and 2008, CBC interventions were associated with a decline in mutual trust in the villages. As with the analysis of happiness and the power to influence decision-making, Multidimensional Poverty Index scores were correlated with a reduction in mutual trust; poorer people feel less secure. Mutual trust was measured as proxy for social cohesion in the village, but it can also be an indicator of peace and security in the local community. The Global Index of Peace, developed by the Institute of Economics and Peace, shows that between 2008 and 2013, out of 163 countries

Madagascar fell from a position of the 38th safest country (score 1630[15]) to the 90th safest (score 2,074) (IEP, 2013), and the decline in mutual trust might be linked to, or caused by, an increase in insecurity across the whole country.

Local people's capacity to perceive changes in provision from valued ecosystem services

Saving forests and wetlands helps to protect the services of ecological systems and the natural capital which contribute so much to human welfare (Costanza et al., 1997). The present analysis of annual extent of forest cover (218 villages) showed a decrease in forest cover per square kilometre between 2000 and 2014. Deforestation was more severe between 2009 and 2014, a period during which the CBC villages were significantly affected. Compared to control villages, the decline in forest cover in CBC villages was faster during that period. That might be because the CBC forests were more targeted by illegal loggers and slash and burn operators due to their higher quality wood, more non timber forest products and therefore more commercial value to own the land. Laurance et al. (2012) stated that with the current high level of deforestation, protected areas are increasingly becoming a final refuge for biodiversity. Other reasons might be that nationally Madagascar lost 1.97 million hectares of forest between 2001 and 2014 (Global Forest Watch, 2015) and conservation efforts generally failed to reduce deforestation despite the expansion of the protected areas network (Waeber et al., 2016). The loss of forest has led to a decrease in provision of ecosystem services as shown by the Index of Perception of Valued Ecosystem Services. That situation is not unique to Madagascar; despite considerable success in the establishment of protected areas, around the world, the rate of species extinction due to human activity remains high (Hambler & Canney, 2013; Pimm & Raven, 2000).

[15] Increase in Global Index of Peace score means decrease in peace in the country

The data from the household surveys carried out for the present study indicate that people are well aware of the importance of ecosystem services and of their dependence on them. Fuel wood, construction wood, fish, non-timber forest products, and water quality were ranked as the top five priority services. Respondents also noted a significant decrease in provision of valued ecosystem services between 2000 and 2013 which corresponds with the decrease in rate of forest cover loss during the same period. The more severe deforestation that may have occurred in CBC villages between 2009 and 2014 was noted by local people who in interviews scored lower on the Index of Perception of Valued Ecosystem Services. Their perceptions were presumably due not only to the fact that the decrease actually happened and that they witnessed it, experiencing greater difficulty in finding fuel wood and construction wood, but also due to the fact that many of the CBC villages are officially in charge of the management of their forests or wetlands. Additionally, people in CBC villages may have seen many examples of situations where laws were disregarded and natural resources are exploited.

Lessons to be gained from this study

This paper has highlighted the fact that improving people's well-being is challenging and depends very much on the extent to which government policies are implemented locally. The positive intercept of CBC interventions in the Multidimensional Poverty Index model (GLMM) indicated that there was no negative effect of CBC on people's objective well-being. In other words, the CBC approach which enforces restrictions in the use of natural resources, due to implementation of a protected area or an official management transfer, did not worsen the existing poverty. The strong link between objective and subjective human well-being was clear. CBC interventions alone were not sufficient to successfully achieve significant development goals, leaving natural resources facing an uncertain future. It is likely that CBC interventions could have a greater impact in

Madagascar if carried out with more resources, greater cooperation between agencies, and with stronger government policies fully implemented at local level. Collier (2008) asserts that the issue of inadequate governance in the 'bottom billion' countries is not seen by developed countries as a problem in which they should be directly involved, and therefore they do little to help. He also proposes that support for the 'bottom billion' countries should not be merely in the form of increased aid, but should lead on to fair trade as well. Successfully combining conservation and development may depend on governments performing better at managing international aid and coordinating support through regional services and local authorities.

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Supplementary materials

Appendix 1. Household survey questionnaire

Questionnaire for household surveys

1. Description

Date of interview	
# Household	
Name head of household, sex	
Household date of birth (month, year)	
Location (village, hamlet)	
Fokontany	
Commune	
District	

Name and signature of the interviewer:

2. Activities of the household

	2013	2008	2003
Main activity (agriculture, farming, fishing, others)			
Number of zebu			
Number of household members			

3. Age of household members in 2013

Age	0-5 years	6-14 years	15-30 years	30-59 years	≥60 years
Number					
Sex					

4. Multidimensional Poverty Index

Dimension	Indicator	Questions	2013	2008	2003
Education	Years of Schooling	How many household members who have completed five years of schooling?			
	Child School Attendance	How many school-aged children who have attended school in years 1 to 8?			
Health	Mortality	How many children less than 6 years old died?			
	Nutrition	How many Kapoaka does the family cook every day?*			
Standard of Living	Electricity	What type of electricity is used in the household?			
	Sanitation	What type of sanitation facility is used by the household? (mention if it shared with the other households)			
	Water	What type of drinking water: JIRAMA, public water pomp, public water point, well, river, lake? Distance to clean drinking water: <30mn, >30mn walking from home			
	Floor	What is the characteristic of floor: wood, tiles, cement, dirty, sandy or dungy?			
	Cooking Fuel	What type of cooking fuel used by the household: JIRAMA, solar power, dung, charcoal, wood?			
	Assets	What are assets in the house: car, truck, tractor, radio, TV, motorbike, refrigerator, plough, 'kubota', pirogue, land more than $500m^2$?			

*Malnutrition: a kid eats 0.5 kapoaka of rice and an adult eats 1kapoaka of rice every day

5. Empowerment

Questions	2013				2008				2003			
	Yes very easily	Yes with a little bit of difficulty	Yes with a great difficulty	No	Yes very easily	Yes with a little bit of difficulty	Yes with a great difficulty	No	Yes very easily	Yes with a little bit of difficulty	Yes with a great difficulty	No
Do you feel people like yourself can change things (decision) in your community if they want to?												

6. Trust and social cohesion

Questions	2008-2013	2003-2007
Did somebody steal animals or crops from someone in the household?		
Did somebody steal things such as pirogue, bicycle in the household?		
In the year, how is the security?		
If you left something outside the house at night, do you think that it is still there in the morning?		

7. Perceived provision of valued ecosystem services

Type of provisioning ecosystem services	Importance to the household			2013				2008				2003			
Construction wood	Low	Medium	High	None	low	medium	high	None	low	medium	high	None	low	medium	high
Fuel wood (dead wood)															
NTFP (Non Timber Forest Products): honey, medicinal plants, cosmetics, yam															
Bush meat															
Fish															
Agriculture yields															
Cultural value (traditional)															
Drinking water quantity															
Drinking water quality															
Zebu grazing															

8. Subjective wellbeing 2013

Questions	Not at all	Somewhat	Moderately	Very
Overall, how satisfied are you with your life nowadays?				
Overall, to what extend do you feel the things you do in your life are worthwhile?				
Overall, how happy did you feel yesterday?				
Overall, how anxious did you feel yesterday?				

Chapter 5

Paper 4: Assessing the performance of Community-based Conservation in conserving habitats of globally threatened species in Madagascar

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Abstract

In Madagascar, an alarming number of species are at serious risk of extinction due to anthropogenic damage to the environment. Due to a lack of robust evaluations, the most effective conservation approach to prevent species extinction in such socio-economic and environmental contexts remains to be determined. This paper reports on an investigation of the performance of Community-based Conservation, as carried out by conservation charity Durrell Wildlife Conservation Trust in Madagascar since 1997, for protecting globally threatened species in four conservation areas. Spatial analyses using Maximum Entropy Species Distribution Modelling were carried out to examine changes over time in the habitats of Alaotran gentle lemur *Hapalemur alaotrensis* in Alaotra, ploughshare tortoise *Astrochelys yniphora* in Baly Bay, grey-headed lemur *Eulemur cinereiceps* in Manombo, and Malagasy giant jumping rat *Hypogeomys antimena* in Menabe. The aim was to determine the effectiveness of community-based conservation activities over the past ~14 years in protecting the habitat to support these species and associated with this, the mean probability of the occurrence of these species.

Results show a decrease between 2000 and 2014 in the mean probability of occurrence of all four species, with highest declines indicated for *Eulemur cinereiceps* (-9.7%) and *Hapalemur alaotrensis* (-9.5%). The importance of vegetation cover for the survival of each species is highlighted, and the models suggest a need for protecting more suitable habitats in the surrounding areas. Furthermore, a large number of individuals and groups

live in, or have moved to, habitats outside the Strict Conservation Zones of the recently established Protected Areas in each of the four sites. The zoning of these Protected Areas needs therefore to be updated to incorporate more suitable habitat into the Strict Conservation Zones.

Keywords: Community-based Conservation, endangered species, habitat suitability, species distribution modelling, probability of presence

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Introduction

Protecting globally threatened species from extinction and saving biological diversity for maintaining ecosystem services are typically the two principal goals of all conservation approaches (Turner et al., 2007). This is mainly because high biodiversity is often associated with more resilient ecological interactions. Despite notable global and regional conservation efforts during the last two decades, human-induced trends in habitat degradation and species extinctions are very alarming (Pimm et al., 2014). In 2016, it was reported that 26% of mammals, 13.5% of birds and 42% of amphibians assessed according to the IUCN Redlist are threatened with extinction (IUCN, 2016). Thomas et al. (2004) predicted that on the basis of plausible climate-change scenarios, 15-37% of species and taxa will be committed to extinction by 2050. However, there are still important knowledge-gaps regarding the best way to save biodiversity while the size of human population keeps increasing. Conservation managers struggle to determine how to halt habitat degradation and prevent species extinction; Community-based Conservation is one approach that has been suggested to achieve this aim.

Since the industrial revolution in the 1800s, humans have altered the environment, pushing the earth to enter into the 'Antropocene', a new epoch in the global evolution (Steffen et al., 2011). Mainly due to human activities, many species has gone extinct and the biosphere is threatening to enter a new era of extinction that will mark the planet's history (Williams et al., 2015). Climate change amplifies that situation so that aquatic species such as frogs, fish and water birds, as well as island-based species are at higher risk of extinction than others (Thomas et al., 2004).

Madagascar's highly diverse and often unique ecosystems are under extreme threat due to these anthropogenic activities and are therefore of global conservation concern (Myers et al., 2000). It has been estimated that the country has lost 90% of its original forest since the arrival of humans about 2,350 years ago (Harper et al., 2007). Large-bodied Madagascar-endemic vertebrates such as giant lemurs *Archaeoindris fontoynontii*, *Megaladapis edwardsi*, and *Megaladapis grandidieri* have already gone extinct, most of which vanished about 1,000 years ago (Crowley et al., 2016).

Currently, a number of nationally endemic taxa are under very high levels of extinction risk. For example, of the 111 lemur species of Madagascar, 24 are currently listed as Critically Endangered, 49 are classified as Endangered and 20 are Vulnerable (IUCN, 2016). It has been suggested that maintaining remaining habitats inside protected areas is one of the most important strategies to safeguard relatively intact ecosystems (Balmford et al., 2002) and provide the best protection for the threatened taxa.

In developing countries such as Madagascar, where rural people suffer high levels of poverty but also rely heavily on ecosystem services, Community-based Conservation (CBC) is the most common approach chosen by many conservation managers to help stop the decline in biodiversity and protect critical biodiversity ecosystems. CBC is defined as a participatory approach that emphasises the interaction between local people and their environment, in order to reduce biodiversity threats whilst improving social well-being. This is because CBC aims to harmonise relationships between people and wildlife and seeks to put local people in the centre of management so that they can oversee and take charge of their own local environment.

Succeeding with conservation programmes in Madagascar is challenging not only because the infrastructure such as road, electricity supply and telephones are inadequate (INSTAT, 2010), but also because 65% of people, who are mainly based in rural areas, are very poor, deprived of the most basic needs (Alkire et al., 2013), and rely strongly on natural resources to survive. The main pressures are slash and burn agriculture and illegal tree felling resulting in a high annual deforestation rate of 1.95% per year from 1990 to 2000 and 1.28% per year from 2000 to 2005 (Smith, 1997; Harper et al., 2007) and a loss of around 1.97 million hectares of forest between 2001 and 2014 (Global Forest Watch, 2015). These factors highlight the anthropogenic threats which in practice, both government and conservation NGOs, find it very difficult to control.

Due to expensive imported fuel and gas, most of the households in Madagascar rely on fuel wood and charcoal for cooking, and paraffin for lighting. Only about 15% of households use proper electricity with low energy consumption of 79 kilowatt-hour/capita per year compared to 5,942 kilowatt-hour/capita per year in Europe (Energypedia, 2015). A lack of finance and insufficient infrastructure limits the use of renewable energy, such as solar panel and wind turbine, to only 0.2% of total consumption (Eglitis, 2016). Additionally, 44% of people are illiterate; the level of corruption is high affecting the management of key sectors such as land ownership, tax payment, species trafficking and illegal timber commercialisation. The existing high social inequality, expressed as a Gini index of 40.6% (0: perfect equality, 100: perfect inequality) (World Bank, 2015a) also make conservation work difficult as it may result in unequal law enforcement by exacerbating the difference between poor and rich families.

This paper presents the results of a study that aimed to retrospectively investigate the effectiveness of the Community-based Conservation carried out by the conservation charity Durrell Wildlife Conservation Trust since 1997 in conserving key biodiversity in four conservation areas in Madagascar: Baly Bay National Park, Lake Alaotra New Protected Area, Menabe dry forest New Protected area, and Manombo rain forest Special Reserve/Classified Forest. A single flagship species from each site was studied namely i) the Alaotran gentle lemur *Hapalemur alaotrensis* (CR) endemic to Alaotra, being the only primate that lives exclusively in swamp vegetation (Mutschler & Feistner, 1995), and one out of the 25 most threatened primates (Schwitzer et al., 2015); ii) the Malagasy giant jumping rat *Hypogeomys antimena* (EN), a rodent endemic to the Menabe region (Sommer, 1997); iii) the ploughshare tortoise *Astrochelys yniphora* (CR), the world's rarest tortoise (Walker et al., 2015; Pedrono & Sarovy, 2000) endemic to Baly Bay region (Curl et al., 1985; Smith et al., 1999); and iv) the *Eulemur cinereiceps* (CR) for which the Manombo forest is 10-18% of its remaining habitat (Irwin et al., 2005, Johnson et al., 2011), classified in 2007 as one of the primates most in peril (Mittermeier et al., 2007).

All four species have undergone significant decline in population size over time due mainly to massive habitat loss driven by agricultural incursion, fires, wood-cutting and illegal logging. The case of *Astrochelys yniphora* is different as it is seriously threatened by international traffic for the illegal pet trade (Shepherd et al., 2013), and hence is classified as the most threatened reptile in the world (Walker et al., 2015). The aim of this study is to quantify changes in the characteristics of their natural habitats, modelled using known locations of the species recorded between 2000 and 2014.

The four study areas in this paper became part of the System of Protected Areas in Madagascar (SAPM) after the government officially approved the expansion of the country's protected areas from 1.7 million hectares to 6 million hectares in July 2015. At least 75% of the newly created protected areas are under IUCN categories V and VI (MEEF, 2016), which involve local communities in the management and monitoring process. Each area has a 5-year management plan, focussing on 6-8 conservation targets including key species, key habitat or key customs, developed under The Nature Conservancy Enhanced 5-S[16] Project management process (TNC, 2004).

The individual management plans have official zones approved by the local communities and stakeholders, splitting the area into three categories of conservation zones: Strict Conservation Zone (~30% of total area), Controlled Use Zone (~40%), and Sustainable Development Zone (~30%). They are accompanied by a 5-year social and safeguard plan for ensuring that the protected area does not cause any negative social or economic impacts on people. On top of the protected areas status, many of the Durrell intervention villages (e.g. 28 in Alaotra, 19 in Menabe) have official forest management transfer under GELOSE or GCF[17], according to law 96-025 (Government of Madagascar, 1996). These management transfers are located inside the protected areas and they have the same conservation targets and official zoning so that there is no conflict between the two statuses.

A detailed knowledge of a species' geographic distribution, and the ecological and biophysical factors that shape these distributions, helps conservation managers develop more robust conservation strategies to reduce anthropogenic threats. However, many biodiversity data are incomplete and gathered from biased sampling, and it is therefore important to follow inferential procedures that provide reliable predictions of species' geographic distributions (Soberon, 1999). In this study, we used Species Distribution Modelling to model the distributions of four target species and assess how these have

[16] The Nature Conservancy 5-S: Systems, Stresses, Sources, Strategies, Success
[17] GELOSE: Gestion Locale Sécurisée - *Secured Local Management*, GCF: Gestion Contractualisée des Forêts - *Contracted Forest Management*

changes since 2000 to address three questions: 1. How safe are Critically Endangered species in areas where the Community-based Conservation approach has been implemented for more than 10 years? 2. What changes happened to characteristics of the suitable habitat (quality and quality) over time? 3. What predominant ecological factors can explain the presence of the species in their habitat?

It is hoped that by understanding these questions and thus the relationship between the implemented management, the characteristics of habitat and the observation of the species will enable development of more robust conservation strategies in the future to increase the effectiveness of CBC.

Methods

Community-based Conservation

Community Based Conservation (CBC) was developed in many countries from the late 1980s onwards, reversing the top-down conservation policy driven mainly by governments. It followed on from the integrated conservation and development projects (ICDP) initiated by the World Wide Fund for Nature (WWF) in the mid-1980s, which were implemented to meet conservation and development goals around protected areas (Hugues & Flintan, 2001). Although CBC is based on the rationale that conservation and development should be achieved together (Berkes, 2004), it is slightly different from ICDP as it gives more responsibility to local communities by placing them in the centre of conservation management, in order to empower them to achieve conservation goals (Campbell & Vainio-Mattila, 2003).

CBC includes frequent village meetings to discuss conservation of the local ecosystem, but also support to micro-development projects focussed on education, health and revenue generating activities in each intervention village.

Study areas

We aimed at investigating the effectiveness of Community-based Conservation in conserving four endangered species located in four key conservation areas: Lac Alaotra Protected Area (42,478 hectares), Menabe dry forest Protected Area (210,000 hectares), Manombo Special Reserve and Classified Forest (7,090 hectares) and Baly Bay National Park (63,000 hectares) (Map 5). Alaotra received temporary status of protection in 2007 and permanent protection in 2015. Menabe received temporary protection status in 2006 and permanent decree of protection in 2015. Baly Bay has been designated as a National Park since 1998 while Manombo Special Reserve was implemented since 1962.

Community-based Conservation (CBC) has been used by Durrell and partners to protect ecosystems and key biodiversity (flagship species) since 1996 in Baly Bay, 1997 in Alaotra, 2000 in Menabe, and 2006 in Manombo.

Species records

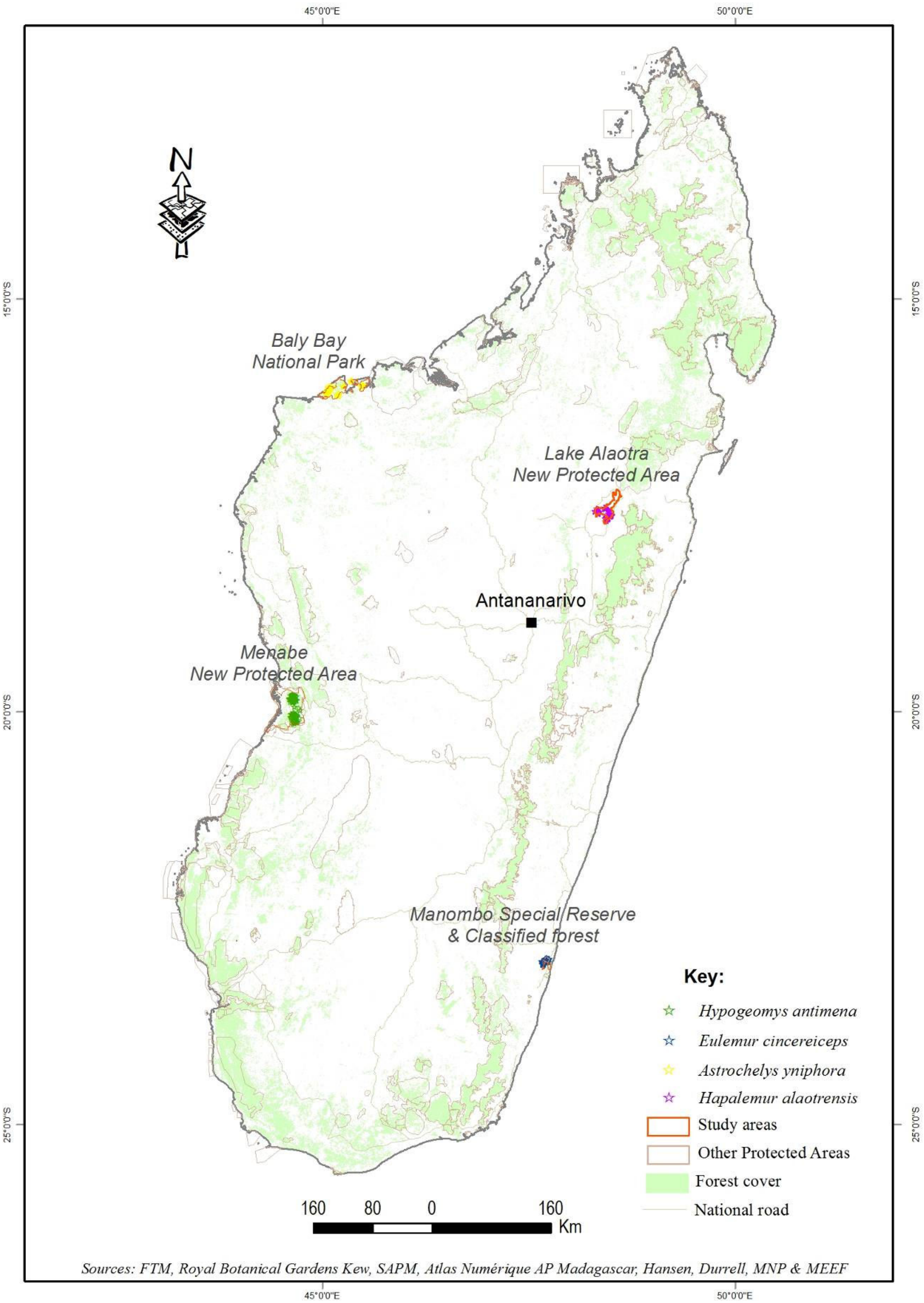
Records of target species observations (direct sightings) were collected either during targeted surveys or opportunistically during other activities over a number of years (Table 35). Data were collected by Durrell biologists with support from local guides or local monitors from each village.

Table 35. Year of data collection per species

Species	CBC intervention area	Year of data collection
Hapalemur alaotrensis	Alaotra	2001-2005, 2007
Astrochelys yniphora	Baly Bay	1999-2004, 2007-2013
Eulemur cinereiceps	Manombo	2008-2012
Hypogeomys antimena	Menabe	2003-2005, 2007, 2009, 2011, 2014

Source: Durrell Madagascar scientific team (2016)

The map 5 below indicates location of each key species in each study region. The key ecological features of these species are described in Table 36.



Map 5. Location of the key species in each study area

Table 36. Description of the four endangered species in this study

Species	***Hapalemur alaotrensis***	***Astrochelys yniphora***	***Eulemur cinereiceps***	***Hypogeomys antimena***
Vernacular name	Alaotran Gentle Lemur	Ploughshare tortoise	Gray-headed Lemur	Malagasy Giant Jumping Rat
Offspring per year	1-2	≤1 clutch/female with 2-3 eggs/ clutch	1-2	1-2
Known as	Dense marsh dependant, mainly with *Phragmites communis* and *Cyperus madagascariensis*	Dense bamboo dependant but uses mosaic of habitats	Rain forest dependant but can easily adapt with secondary forest	Dense dry-deciduous forest dependant
IUCN Red List category (2016)	Critically Endangered	Critically Endangered	Critically Endangered	Endangered
Population trend (IUCN)	Decreasing	Decreasing	Decreasing	Decreasing
Social life	Social, groups of 3-9 individuals	Solitary	Social, groups of 3-9 individuals	Monogamous pairs, possible 2 pairs per active borrow
Estimated wild population size	2,000 individuals	600 individuals	605±143 individuals	36,000
Approx. adult body weight	1.45 kg	22kg	2-2.5kg	1kg
Approx. adult body size	50cm	51cm	60cm	30cm
Locomotion	Brachiator: this species can easily swing, grasp and walk on stems of papyrus and Phragmites	Slow walker	Brachiator: this species can easily swing and grasp on stems of papyrus and Phragmites	Fast moving inside the burrow and on ground surface under forest canopy
Type	Marshreal	Terrestrial	Arboreal	Underground (burrow) – terrestrial
Natural habitat	Reed-beds dominated by *papyrus madagascariensis* and *Phragmites communis* on fresh water wetlands	Bamboo shrub dominated by *Perrierbambos madagascariensis* but can use dry deciduous forest	Rain evergreen forest dominated by *Anthostema madagascariense*, *Dypsis* spp, and *Diospyros* spp.	Active burrow under dry forest dominated by *Givotia madagascariensis*, *Adansonia* sp,
Height of the habitats	3.5-5 metres above ground	4.5-6 metres above ground	7-10 metres above ground	≤2 metres underground (but use forest litter - never climbs tree)
Diet	Folivorous	Folivorous	Frugivorous	Frugivorous
Behaviour	Cathemeral	Diurnal with hibernation in the winter	Cathemeral	Crepuscular to nocturnal
Status of the habitat	New Protected Area IUCN category V	National Park, IUCN category II	2 blocks: Special Reserve IUCN category IV & classified forest	New Protected Area IUCN category V, Special Reserve category IV
Climate	Semi humid, moderately hot	Dry, hot	Humid	Dry, hot
Main pressures	Habitat loss due to fire and illegal rice farming	Smuggling, traffic, fires	Habitat loss due to illegal logging, fire	Habitat loss due to illegal logging, slash and burn agriculture
References	Mutschler & Feistner (1995), Mutschler (2003)	Juvik et al. (1981); Pedrono et al. (2001); Smith et al. (1999).	Johnson et al. (2008); Irwin et al. (2005); Mittermeier et al. (2006); Ralainasolo et al. (2008); Johnson et al. (2011)	Sommer (1997); Sommer et al. (2002); Young et al. (2008).

Implementation of Community-based Conservation in the villages

Durrell's CBC interventions were initiated in 1996 in Baly Bay, 1997 in Alaotra, 2000 in Menabe, and 2006 in Manombo. In each of the four areas the intervention villages were chosen according to the distance to the relevant species area of occupancy (Table 36). Interventions started in villages situated closer to the species' habitat, where people could have a direct influence on the planned conservation management. The number of intervention villages has grown gradually over time, partly to match conservation activity priorities and the available funding, and partly as knowledge about the species and its habitat increased and therefore the extent of the intervention increased.

Environmental festivals were initially organised to build trust and relationship with local people and to liaise people's social and cultural life with the importance of the wildlife. Formalisation of local environmental associations was supported so that they could officially manage their traditional *terroir*. *Terroir* refers to a natural local ecosystem intended to bring mainly agricultural resources and productions for the local community (Brunschwig et al., 2004). In Madagascar *terroir* is linked to a local area where all exploitation systems used by the people in the village can be found. It often has tombs of the ancestors. At least four big village meetings attended by local authorities and government officials were organised in each village every year, to discuss progress of the conservation strategies.

Participatory ecological monitoring and local patrols

Within the CBC approach, an annual participatory ecological monitoring event, taking the form of inter-village environmental competitions was carried out since 2000 in Alaotra, 2004 in Menabe, 2005 in Baly, 2006 in Nosivolo and 2007 in Manombo. This was in addition to six volunteers per village and two government technicians to regularly collect data on biodiversity and threats in the area of land managed by each village, on an annual basis. Biodiversity in this monitoring effort included a set of key animal species and their habitats while threats investigated included all illegal activities such as tree felling, fire, poaching, and slash and burn agriculture.

In 2011, the participatory ecological monitoring programmes in each intervention area were expanded and changed into weekly local patrols controlled by local associations. Some 96 local monitors are active in Alaotra, 108 in Menabe, 68 in Nosivolo and 79 in Baly Bay, all wearing uniform, and all having received training in field observation to report results of their observation to regional government officials and authorities.
Outcomes of the annual participatory monitoring were reported by local monitors during public meetings so that people became aware of the environmental changes in their area over time. The meetings remain a good opportunity to debate publicly the status of each target species and the management of illegal activities. Data collected by local patrols helped build the Durrell species database, used in the present study.

Protection status and delegation of management

Two types of protected areas exist in Madagascar, the existing Protected Areas (1.7 million hectares) already managed by Madagascar National Parks, and the New Protected Areas (~4.7 million hectares) recently granted official protected area status until July 2015. This expansion of the size of Protected Areas resulted from a radical government decision announced during the IUCN 2003 World Parks Congress at Durban, and reinforced during the 2014 IUCN World Parks Congress at Sydney. Two of the areas used in this study (Baly Bay National Park and Manombo Special Reserve) are part of the existing protected areas while Lac Alaotra and Menabe belong to New Protected Areas. The government delegated the management of most of these new protected areas, which are mainly IUCN category IV and V, to conservation NGOs that technically and financially supported their implementation. For instance, Alaotra has been officially managed by Durrell since 2007 while Menabe is managed by the Fanamby NGO since 2006.

Protected area zoning

The Protected Area creation process, developed by the Ministry of the Environment, Ecology and Forests, requires a series of public consultations to check peoples' initiative and gather their opinions to develop a broadly supported management zones. The zoning of each protected area is therefore based on a balance between conservation and development. Information from conservation biologists and researchers was used to select the strict conservation areas while information about local peoples' livelihoods was used to select the best core zone. The zoning has to maintain a corridor for species so that animals can disperse. Activities like hunting, fire and tree felling are strictly forbidden inside the strict conservation zones.

Local communities were reminded about the official zoning and environmental regulations related to each zone at quarterly public village meetings attended by local authorities and regional government officials. The local associations were given the responsibility to manage their area, and monitor compliance for the zoning by engaging six local monitors per village to carry out a weekly survey of biodiversity and pressures.

Species records

Species data used in this study come from Durrell records. They were collected by biologists who monitored species populations in each area, using line transects to collect observations of the animals themselves or their signs (e.g. active burrows of giant jumping rats) and also by local patrollers as mentioned above. The table below shows the method of data collection for each species.

Table 37. Species data collection

Species	Period	# observers per team	Type of transect	Transect size or length/team	By	Survey time
Hapalemur alaotrensis	Jan.-Mar.	2	Line (direct sightings)	5,000m-8,000m	Canoe	5am-11am
Astrochelys yniphora	Oct.-Apr.	11	Line (direct sightings)	100m x 1,000m *spaced 10m/pers.*	foot	7.30am-11am, 2.30pm-5pm
Eulemur cinereiceps	Dec.-Feb., May-Aug.	2	Line (direct sightings)	800m-1,600m	foot	5.30am-10.30am, 3.30pm-6.30pm
Hypogeomys antimena	Feb.-Mar., Jul.-Sep.	2	Line (location of active burrows)	2,500m	foot	5.30am-10.30am, 3.30pm-6.30pm

Environmental layers

Forest cover

We combined the Madagascar Atlas Vegetation developed by the Royal Botanic Gardens Kew in 2000 (Moat & Smith, 2007) with the Hansen time series forest loss data both at 30m resolution (Hansen et al., 2013). Using Arc GIS 10.3, all pixels in the Kew vegetation map were multiplied with the annual Hansen forest cover data to produce an annual vegetation map with an additional class of deforested land. We then sampled the deforestation maps for the correct year for each species observation. This enabled production of an annual habitat vegetation map that better expressed the land cover change in each study area. We predicted that forest cover is the most important variable explaining the presence of the species, as it should represent the natural habitat of the species. The Alaotra marsh area which is dominated by reed-beds (papyrus and Phragmites) was already classified as forest in the Hansen maps.

Elevation, slope and aspect

Topographic data (elevation) for Madagascar, at 30 metres resolution, were extracted from the NASA Shuttle Radar Topography Mission (SRTM). Aspect and slope were derived from the elevation data using *r.slope.aspect* tool in GRASS Program 7.0.5 (GRASS Development Team, 2016).

Proximity to nearest settlement

We used equal-area projection for calculating the proximity to nearest settlement for each pixel. It is the Euclidian distance from each pixel to the nearest village, expressed in units of 100m, but also a proxy for the level of human disturbance. This variable was chosen because we hypothesised that species' habitat is less disturbed if villages are farther away.

Bioclimatic variables

We wanted to use bioclimatic data (temperature and precipitations) from the WorldClim Global Climate data developed by Hijmans et al. (2005), at 1km resolution. They derived from the monthly temperature and rainfall values in order to generate biologically significant variables for species distribution modelling. The bioclimatic data are comprised of annual trends (e.g. mean annual temperature, annual precipitation), seasonality (e.g., annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g. temperature of the coldest and warmest month, and precipitation of the wet and dry quarters). However, the extreme or limiting environmental factors were removed from the analysis due to two reasons. First, they were calculated from different granularity from other variables, and second, they were highly correlated with other variables.

Soil

We also intended to use the soil data (Batjes, 2016) mapped at 1km resolution which come from the International Soil Reference and Information Centre (ISRIC), the International Soil Science Society (ISSS) and UNESCO. The dataset considered 20 soil properties including the quantity of nitrogen, pH (H_20), aluminium saturation, proportion of coarse fragments (> 2 mm), bulk density, calcium carbonate content etc, commonly used for land evaluation and agro-ecological zoning. The parameters '*particle size* *distribution*' expressed as the proportion of sand, silt and clay in each pixel may have been very useful in predicting the distribution of *Astrochelys yniphora* and *Hypogeomys antimena* which might be the most soil dependent species among the four. However, we had to remove the soil variables since the spatial resolution of the maps were so poor it represented little or no variation across each of the study sites.

Preparation for Species Distribution Modelling

Environmental layers were downloaded as raster format from global data (see Table 38). Using *vector-to-raster* function in Idrisi Selva 17.2 program (CLARK LABS, 2013), all vector data were converted into 'raster' to facilitate spatialisation of the environmental layers with the species. We then used ArcGIS 10.3 (ESRI, 2013) to clip each raster file with the Madagascar boundary and displayed them along with other layers such as roads, streams and villages.

We checked the pair-wise correlation of all variables before running the final model, and removed those that had a correlation coefficient greater than 0.5 in the background sample. For example, for Alaotra, elevation had to be removed because it was highly correlated with slope, which was the least correlated with the other variables.

Species Distribution Modelling

Based on the method developed by (Hijmans & Elith, 2016), four steps were followed in the Species Distribution Modelling. Using Arc GIS 10.3 (ESRI, 2013), we compiled the locations of the occurrence of the species (longitude and latitude) based on field data collected by Durrell's biologists. We extracted from spatial databases (global data) the values of environmental predictor variables per pixel in each study area. We fitted the models to find similarity between pixels covered by the sites of occurrence and the other non-visited pixels. And finally, we predicted the geographic distribution and probability of presence of the species. This helped estimate the contribution of each variable to the variation of the distribution of each species.

Characteristics of all environmental layers

In the analysis, five environmental layers were retained. The source, time period availability and the spatial resolution are described in the Table 38.

Table 38. Environmental layers

Variable	Source	Time period available	Resolution
Forest cover	Kew Vegetation Atlas of Madagascar multiplied with the Hansen forest cover data	2000-2014	30m
Elevation	Global Multi-resolution Terrain Elevation data	2000-2014	250m
Slope	Derived from Elevation data using r.slope.aspect tool in GRASS 7.0.5	2000-2014	250m
Aspect	Derived from Elevation data using r.slope.aspect tool in GRASS 7.0.5	2000-2014	250m
Proximity to nearest settlement (x100m)	Calculated from the distance from the pixel to the nearest village (crow flies distance)	2000-2014	1km

Maximum Entropy Modelling (Maxent)

Species surveys rarely cover the whole habitat, and distribution data often have no information about the failure to detect the species. That is because many locations in the habitat may not have been surveyed or surveys have failed to detected species when present. We used Maximum-Entropy Techniques 'Maxent' (Phillips et al., 2004) to predict the species' geographic distribution. Maxent estimates the target distribution by finding the distribution of maximum entropy, where pixels have the same ecological characteristics (based on the value of each environmental layer) as the area where the species was observed.

Maxent functionality using *dismo*, *rgdal*, *raster* and *rJava* packages implemented in R Studio 0.99.903 (R Core Team, 2012) was used to analyse the spatial pattern of the suitable habitat for the key species over time. The outputs of Maxent are twofold: a plot predicting the contribution of each environmental layer to explain the variation of the species presence within its range, and a grid file in geotiff showing the probability of presence of the species.

Model evaluation and quantitative measure of change of habitat suitability

The method of Hijmans & Elith (2016) was used to evaluate the quality of the final models:

- Examining the plots, does the model subjectively make sense and do interactions between variables look ecologically sensible?

- Does the prediction of the geographic range of each species seem reasonable? (The predicted distribution was visualised on Arc GIS 10.3)

The temporal changes of habitat suitability were examined by comparing the average of the probabilities of presence of the species inside strict conservation zones between 2000 and 2014. That was achieved by using *zonal statistics* function implemented in Arc GIS 10.3 to extract the individual probability of presence per pixel and calculate the average. We processed visual inspection of the change of the habitat suitability per study area by reclassifying the raster of probability of presence into a binary file of lower or higher than half of the highest probability. For example, if the highest probability of presence was 0.8, a threshold of 0.4 was taken to display the likely range of distribution for the species.

Table 39. Hypotheses related to contribution of each environmental layer in predicting the presence of the species

Potential explanatory variables	***Hapalemur alaotrensis***	***Astrochelys yniphora***	***Eulemur cinereiceps***	***Hypogeomys antimena***
Forest cover	The presence of the species is more than 50% associated with the vegetation cover (high percentage forest cover). Good or medium quality marsh area is required	The presence of the species is more than 40% associated with the vegetation cover (bamboo shrub or mosaic of habitat). High quality forest is not required	The presence of the species is more than 70% associated with the vegetation cover even though previous studies (Johnson et al., 2008) demonstrated that this species is comfortable with degraded habitat	The presence of active burrows is more than 80% associated with the vegetation cover. High quality of dry forest is required to support the species
Slope	Flat habitat at 750 meters of altitude	The species will be comfortable with some shallow slopes in its habitat	The species is comfortable with shallow slope	This species often requires flat habitat to build burrows
Elevation	Elevation will not explain very much variability of the distribution because the habitat is flat	Elevation might be important as the strict conservations areas have very different altitude	Elevation might be important as some places are hilly around Manombo	The elevation will not be an important predictor due to flattening of the habitat
Aspect[18]	Hypothesised as not a very important predictor for *Hapalemur alatrensis* and *Astrochelys yniphora*		Possible potential predictor for *Eulemur cinereiceps* as the habitat can be on steep and the lemur may prefer the sunny (East) version in the morning	Hypothesised as not a very important predictor for *Hypogeomys antimena*
Proximity to the nearest settlements (distance from species/habitat to village)	We hypothesised that the chance to see the species is higher in habitats situated farther from villages			

[18] Aspect: The compass direction that a slope faces (East, West, South, North)

Response variables include two continuous variables: the extent of the species distribution and the contribution of each environmental layer to the variability of the probability of presence of the species (Table 40)

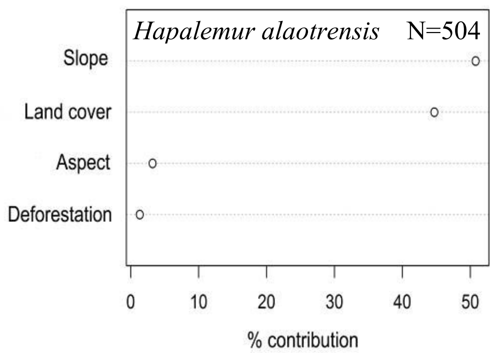
Table 40. Response variables

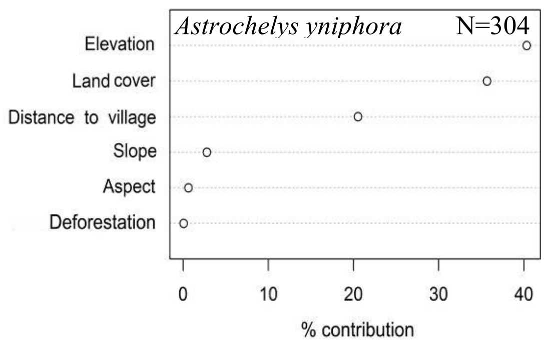
Variable	Type	Frequency	Unit
Extent of the species distribution area	Continuous	Annual	Hectares
Contribution of each environmental layer in the variation of the distribution	Continuous	Annual	%

Results

Contribution of the environmental layers to the distribution of the species

Figure 25 below shows the contribution of each environmental layer to predicting the variability of the distribution area of each species. Results suggest that land cover is the most important variable determining the area of distribution of *Hypogeomys antimena* (80%) and *Eulemur cinereiceps* (50%) respectively within Menabe dry forest and Manombo rain forest. Slope is predicted to play important role in shaping the distribution area of *Hapalemur alaotrensis* (50%) in the reed beds of Lake Alaotra while the elevation is highly associated with the presence of the ploughshare tortoise at Baly Bay National Park.





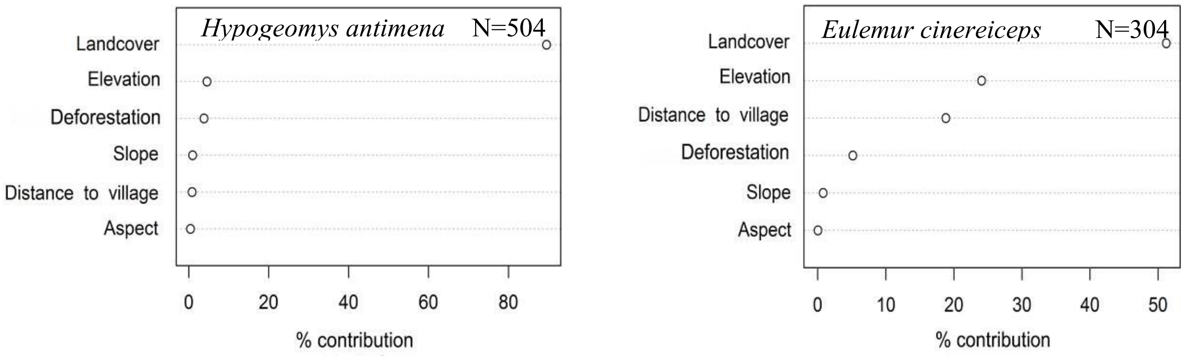
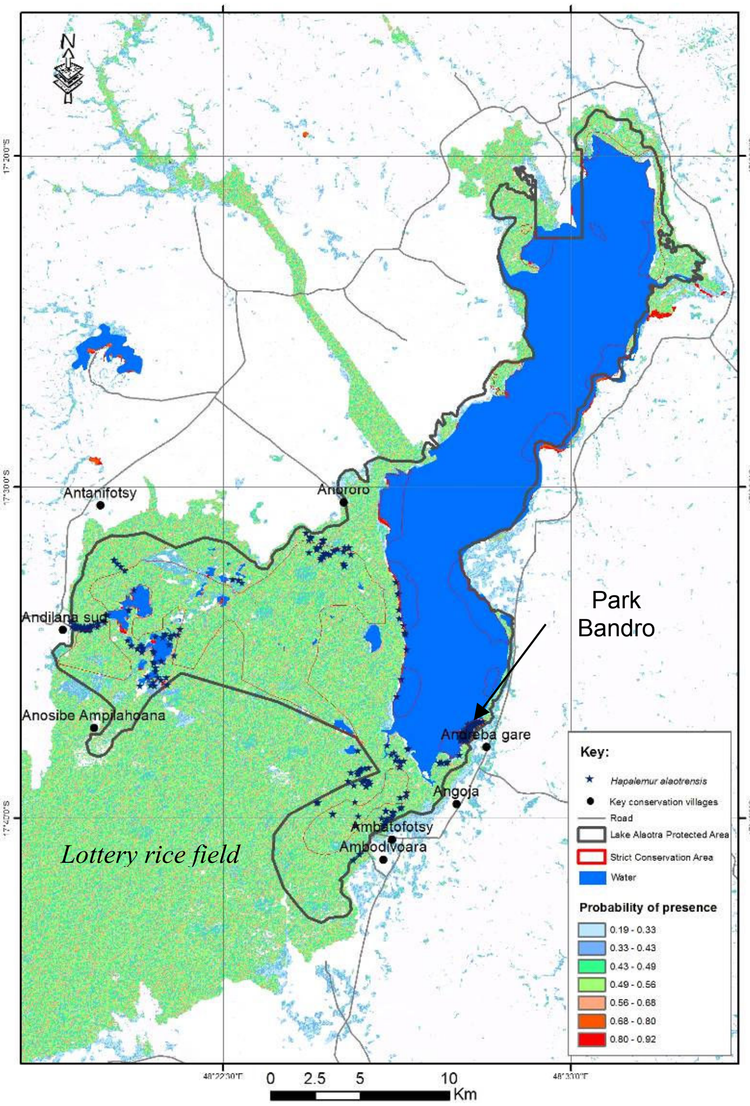


Figure 25. Contribution of the environmental layers to the variation of the species distribution areas

Predicted change in the geographical range of the species over time

Hapalemur alaotrensis

Result shows that the range of *Hapalemur alaotrensis* (with a probability of presence p>0.45, half the highest) did not present significant change between 2000 and 2014 (appendices 5 and 6). The lottery rice field located in the South West of Lake Alaotra unexpectedly presented similar habitat suitability as the natural marsh area inside the Protected Area (Map 6). The probability of presence of *Hapalemur alaotrensis* is predicted to be higher (p>0.8) along river banks or on the edge of lakes dominated by Phragmites. More than 40% of the records of groups of *Hapalemur alaotrensis* were detected outside the strict conservation zones. They were observed in the area that can be used for fishing. The probability of presence of *Hapalemur alaotrensis* inside strict conservation zones varied between 0.40 and 0.56.

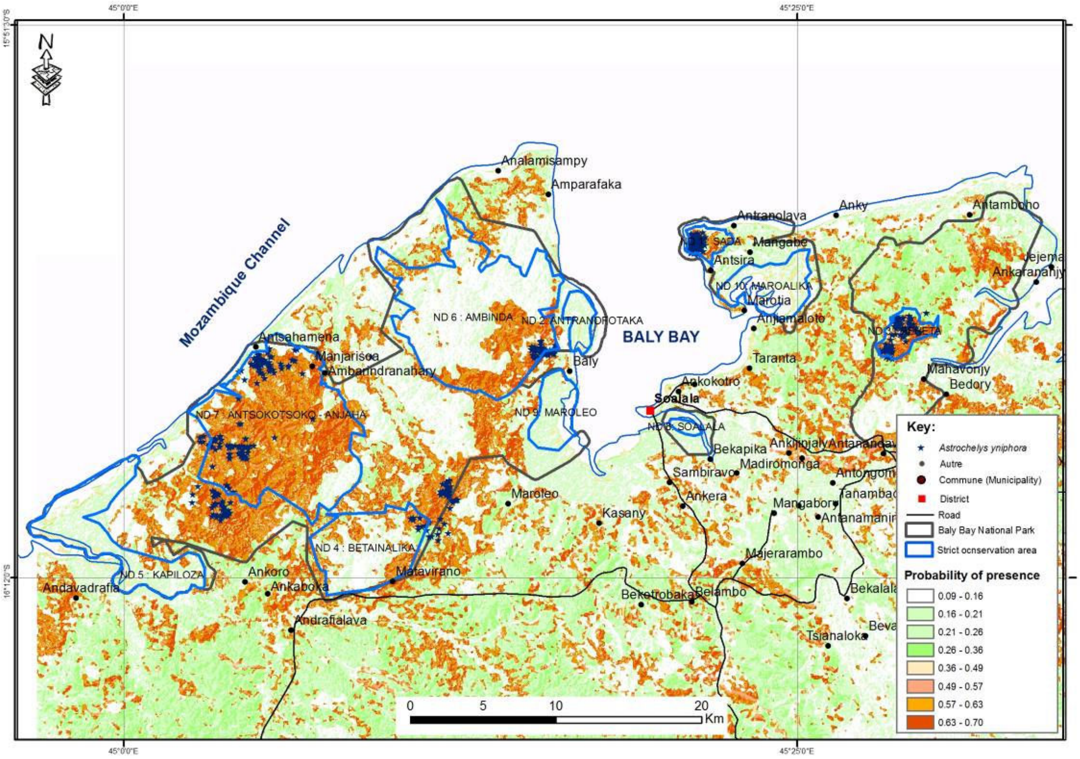


Map 6. Predicted distribution of suitable habitat for *Hapalemur alaotrensis*. Maxent output based on Kew vegetation map 2000, species location 2000-2007 and other variables

Astrochelys yniphora

High probability of presence of *Astrochelys yniphora* ($p>0.5$) is associated with bamboo scrub vegetation situated at altitudes of 10 to 50 metres above sea level. The strict conservation zone of Antsokotsoko Anjaha (*Noyau Dur 7*) represents the largest suitable habitat patch for this species. Some 23 individuals were observed outside of the Antsokotsoko-Anjaha strict conservation area (Map 7).

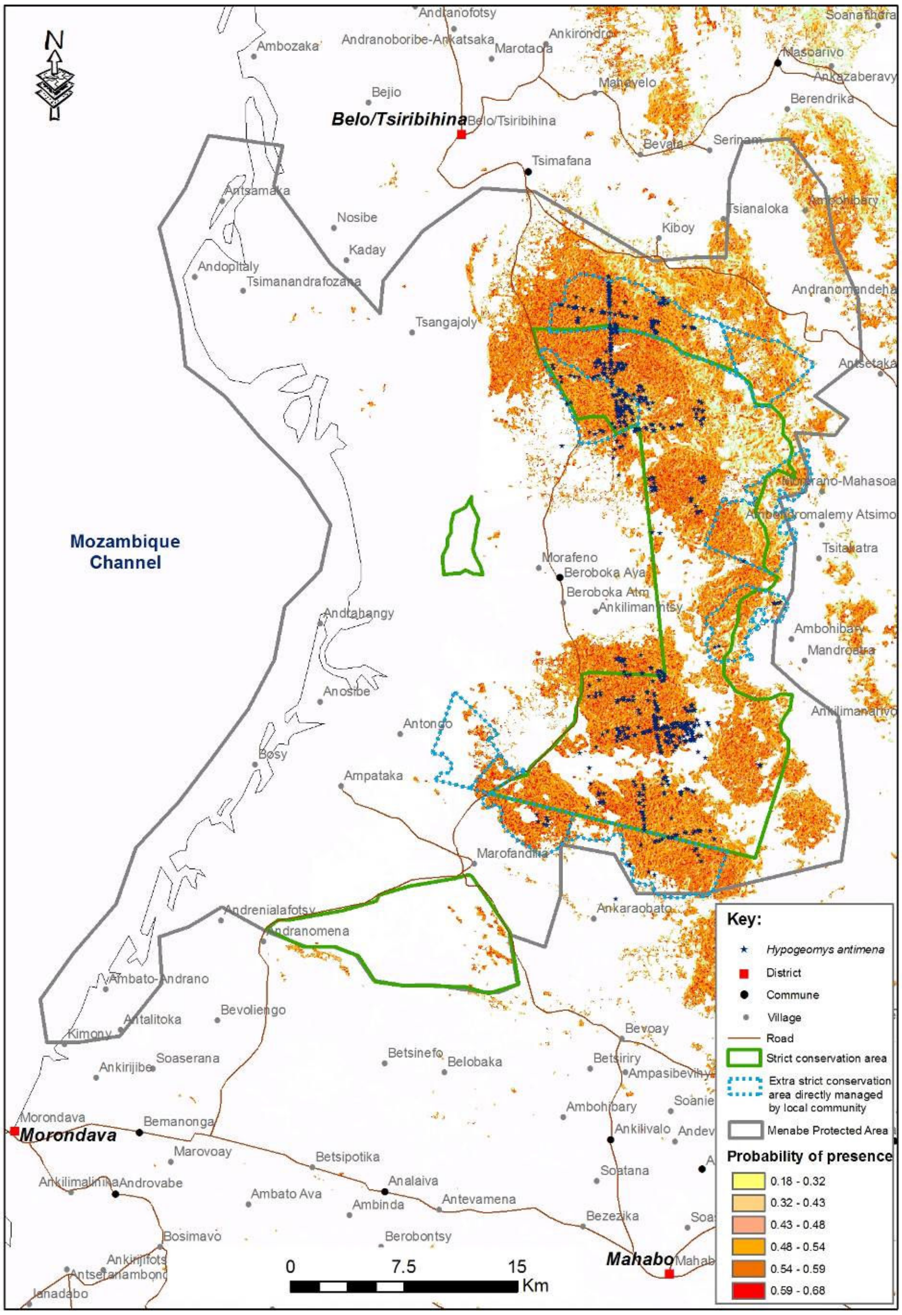
Four patches of bamboo scrub located west of Amparafaka, west of Beaboaly and south of Antamboho and a zone located to the south west of Baly present high suitability even though the species has not been found there (Map 7). Locations of the observational transects suggests that those places may have never been visited. There has been no substantial change in the extent of suitable habitat for this species between 2000 and 2014 (for probability of presence p>0.35).



Map 7. Predicted distribution of suitable habitat for *Astrochelys yniphora*. Maxent output based on Kew vegetation map 2000, species locations 2000-2007.

Hypogeomys antimena

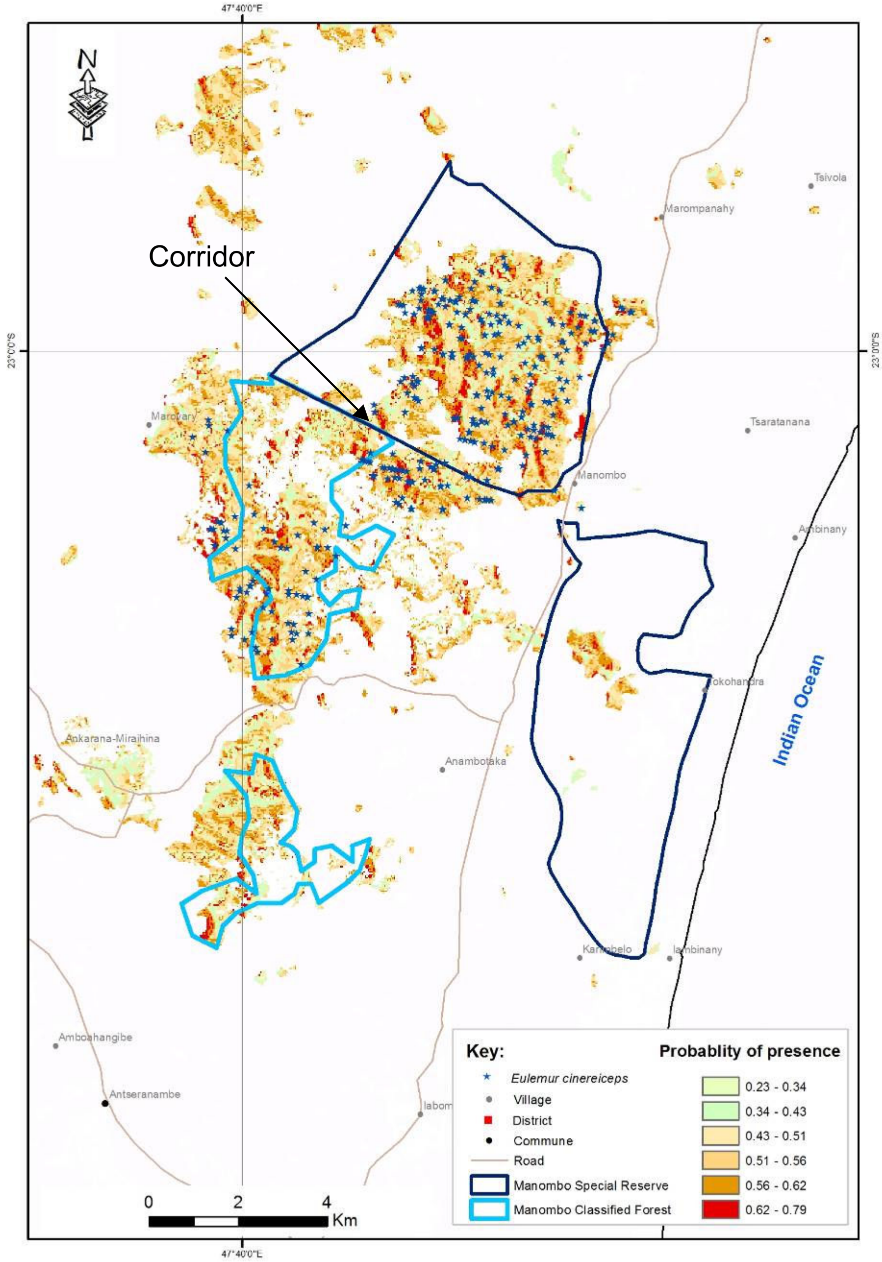
Despite decrease in the extent of forest cover between 2000 and 2014 (found in our previous studies), the area with a probability of presence p>35% (half the highest) suggested no significant change in size of suitable habitat for *Hypogeomys antimena* (Map 8). However, visual inspections of the maps suggest that the suitable habitat was more fragmented and patchy in 2014. More than 50 active burrows of giant jumping rat were found outside the official strict management zones but they were located in the extra strict conservation zones managed by the surrounding villages. A patch of forest situated north east of the Protected Area presented relatively high habitat suitability and needs field exploration.



Map 8. Predicted distribution of *Hypogeomys antimena*. Maxent output based on Kew vegetation map 2000, species locations in 2000-2007 and other variables

Eulemur cinereiceps

There was no significant change in habitat suitability for *Eulemur cinereiceps* in the Special Reserve between 2000 and 2014 even though the probability of presence declined in the southern part, North of the Classified Forest. However, examination of pixels that have a probability of presence $p>0.4$ indicate that the classified forest lost at least 15% of the suitable habitat over the period 2000-2014. The groups of *Eulemur cinereiceps* that inhabited the Classified Forest zone are observed in pixels with lower probability of presence. Some other areas situated to the north east of Manombo are potentially suitable ($p \sim 0.5$) for the species. The predicted chance to detect the species in the corridor between the Special Reserve and the Classified forest declined during the period of study (Map 9). That threatens the connection of groups of *Eulemur cinereiceps* between the Classified Forest zone and the Special Reserve.



Map 9. Predicted distribution of *Eulemur cinereiceps*. Maxent output based on Kew vegetation map 2000, species locations 2000-2007 and other variables

Changes in species' probability of presence inside strict conservation zones

Hapalemur alaotrensis

Between 2000 and 2014, the probability of presence of *Hapalemur alaotrensis* inside strict conservation zones and the marsh areas for fishing only, decreased by 9.5%. The overall probability of presence for *Hapalemur alaotrensis* was predicted to be 0.41 in 2000 and 0.37 in 2014 (Table 41). The strict conservation zones located on islands (e.g. Vondrobe near Park Bandro Andreba, see Map 6) are less suitable than the larger strict conservation zones. There is a risk that the Park Bandro Andreba is completely isolated from the rest of the habitat. The zones for fishing only and the strict conservation zones have almost the same probability of presence.

Table 41. Changes in probability of presence of *Hapalemur alaotrensis* 2000-2014

	2000		**2014**		
ALAOTRA	**Mean P of presence**	**Stand. Dev.**	**Mean P of presence**	**Stand. Dev.**	**Conclusion**
Strict Conservation zone	0.49	0.17	0.42	0.16	Decrease in probability of presence by 9.5%
Zone for fishing only	0.44	0.23	0.41	0.23	
Strict Conservation zone on island only	0.33	0.37	0.32	0.37	
Mean	**0.41**	**0.27**	**0.37**	**0.27**	

Astrochelys yniphora

Maxent models suggested that the probability of presence for *Astrochelys yniphora*, inside Baly Bay National Park decreased by 2.09% between 2000 and 2014. The strict conservation zone of Antsokotsoko-Anjaha located in West of the Park (Map 7) presented the highest probability of presence (p=0.52). Zones close to or dominated by mangroves (low altitude) such as ND2: Antranofotaka and ND 8: Soalala presented the lowest chance of survival for the species and the greatest decrease in quality of habitat.

Table 42. Changes in probability of presence of *Astrochelys yniphora* 2000-2014

	2000		**2014**		
BALY	**MEAN**	**Stand. Dev.**	**MEAN**	**Stand. Dev.**	**Conclusion**
ND 1 [19]: Sada	0.428	0.214	0.428	0.214	Decrease by 2.09% in probability of presence/habitat suitability
ND 2: Antranofotaka	0.170	0.082	0.160	0.082	
ND 3: Beheta	0.517	0.183	0.516	0.184	
ND 4: Betainalika	0.305	0.218	0.299	0.218	
ND 5: Kapiloza	0.179	0.133	0.153	0.133	
ND 6: Ambinda	0.276	0.217	0.276	0.217	
ND 7: Antsokotsoko - Anjaha	0.518	0.191	0.517	0.191	
ND 8: Soalala	0.156	0.085	0.146	0.085	
ND 9: Maroleo	0.159	0.092	0.159	0.092	
ND 10: Maroalika	0.157	0.130	0.157	0.130	
Mean	**0.287**	**0.15**	**0.254**	**0.155**	

[19] ND stands for *Noyau Dur* which means Strict Conservation zone inside Baly Bay National Park

Hypogeomys antimena

The mean probability of presence in the extra strict conservation zones managed directly by local communities was predicted to have been higher compared to the official strict conservation area. However, the decrease in probability of presence of *Hypogeomys antimena* in the strict conservation area managed by local communities was greater (8.8%) than in the official strict conservation zones (2.9%). Strict conservation zones (ZCSB)[20] within the areas managed by local associations at Tsitakabasia, Ankoraobato and Lambokely presented the highest chance of survival for *Hypogeomys antimena* in 2000. That changed to Tsitakabasia, Lambokely and Kiboy in 2014 (Table 43). Ampataka has the least suitable habitat for the species with a probability of presence p=0.16 in 2000 which declined to p=0.12 in 2014.

Table 43. Changes in probability of presence of *Hypogeomys antimena* 2000-2014

	2000		**2014**		
MENABE	**Mean P of presence**	**Stand. Dev.**	**Mean P of presence**	**Stand. Dev.**	**Conclusion**
Strict conservation zone (PA)	0.34	0.24	0.33	0.24	Decrease by 2.9% of the probability of presence
Extra strict conservation area managed by local communities	**Mean P of presence**	**Stand. Dev.**	**Mean P of presence**	**Stand. Dev.**	**Conclusion**
ZCSB Anketrevo	0.43	0.17	0.42	0.18	Decrease by 8.8% in probability of presence
ZCSB Mandroatsy	0.40	0.20	0.39	0.21	
ZCSB Kirindy	0.46	0.19	0.44	0.21	
ZCSB Lambokely	0.52	0.08	0.50	0.12	
ZCSB Ampataka	0.16	0.19	0.12	0.18	
ZCSB Kiboy	0.50	0.11	0.45	0.18	
ZCSB Tsianaloky	0.42	0.19	0.36	0.23	
ZCSB Tsitakabasia	0.54	0.05	0.54	0.07	
ZCSB Ankoraobato	0.53	0.09	0.43	0.22	
ZCSB Marofandilia	0.50	0.16	0.44	0.22	
Mean	**0.45**	**0.14**	**0.41**	**0.18**	

[20] ZCSB: Zone Stricte pour la Conservation de la Biodiversité (Zones for strict conservation of biodiversity) - they are part of the official management transfers within Menabe Protected Areas

Eulemur cinereiceps

The Maxent model for *Eulemur cinereiceps* suggested that the Special Reserve in Manombo is at least two times more suitable than the Classified Forest. Both zones presented a decrease in probability of presence of the species. The overall probability of *Eulemur cinereiceps* presence in the Manombo forest declined by 9.7% between 2000 and 2014 (Table 44).

Table 44. Changes in probability of presence of *Eulemur cinereiceps* 2000-2014

	2000		**2014**		
MANOMBO	**Mean P of presence**	**Stand. Dev.**	**Mean P of presence**	**Stand. Dev.**	**Conclusion**
Special Reserve	0.43	0.19	0.37	0.21	Decrease by 9.7% of the probability of presence
Classified Forest	0.19	0.25	0.18	0.25	
Mean	**0.31**	**0.22**	**0.28**	**0.23**	

Discussion

This paper aimed to test the effectiveness of Community-based Conservation in conserving the habitat of four selected target species in four regions in Madagascar from 2000 to 2014. The changes in the suitability of the habitat for these globally endangered species in four Community-based Conservation intervention areas over time were quantified. That helped identify the predominant ecological factors that best predict the presence of the species in their area of distribution.

Predominant factors predicting species distribution range

Land cover type was identified as the strongest predictor of species occurrence in our models even though it explained less variability than slope and elevation in the case of *Hapalemur alaotrensis* and *Astrochelys yniphora*. Elevation, slope, and aspect did not change between our 2000 and 2014 models, so the differences that we saw in the predicted model outputs could be explained by differences in land cover due to time series deforestation in the Hansen data.

Results indicated that the proximity to nearest settlement played a considerable role in predicting the area of distribution for *Astrochelys yniphora* and *Eulemur cinereiceps*.

The predicted chance to see those species increased with the distance between them and people. That finding may indicate that humans represent a threat to the species, may be because presence of people is often associated with disturbance, noise, habitat destruction and hunting. The variable proximity to nearest settlement was not an important predictor for the other two species *Hapalemur alaotrensis* and *Hypogeomys antimena*. It was not included in the Alaotra model due to a co-linearity issue, and for Menabe it was not a good explanatory variable compared with the others.

Decline in probability of presence

The mean probability of species occurrence in the four CBC intervention areas declined between 2000 and 2014. A stronger decline was predicted for *Eulemur cinereiceps* in Manombo (9.7%) and *Hapalemur alaotrensis* in Alaotra (9.5%) while it was 2.09% for *Astrochelys yniphora* in Baly Bay National Park and an average of 5.9% for *Hypogeomys antimena* in Menabe. The decrease in the presence of the species in all cases indicates a deterioration of their conservation status which was mainly caused by degradation and loss of habitat, except in the case of *Astrochelys yniphora* which has been heavily impacted by poaching as a result of an escalation in illegal pet trade during the last six years (Walker et al., 2015).

Importance of conservation zones outside official strict conservation

Comparison of the probability of presence of *Hypogeomys antimena* between the official strict conservation zones and the areas managed by local communities highlighted the importance of management transfers and locally-based management as part of a CBC approach. The chance to detect giant jumping rat active burrows was predicted to be higher in the areas outside of strict conservation zones and therefore landscapes directly managed by local communities. In the case of Manombo, despite the largely higher habitat suitability at the Special Reserve, it was also observed that the Classified Forest, despite being more degraded, could still play a major role in conservation of the species.

Limitations

Species data were collected irregularly and not with the same effort and methods. This can severely limit the value and power of distribution models (Hernandez et al., 2006). That was a limitation because if sampling effort and design was the same in every survey we could perform a detailed comparison of the number of species observed and draw conclusions about species trends through time which would be a more powerful evaluation for the conservation intervention (Henderson & Southwood, 2016).

Due mainly to logistical limitations, it is often difficult to survey the species across its entire habitat (at least if bias is to be avoided, every area within its range has an equal probability of being surveyed). A considerable proportion of habitat may not have been surveyed. For example, in Baly Bay, a patch representing about 35% of the suitable habitat has never been surveyed due to difficulty of access into the bamboo shrub habitat. More than 20% of Alaotra marsh area also has never been surveyed due to access issues. That is a problem because the quality of the model is dependent on the quality of the input data. An uneven sampling effort means that observations may be skewed to certain habitat types or locations which are typically easier to access.

We had to rely on the national vegetation map developed by Kew Botanic Gardens and Hansen due to non-existence of a regional vegetation map. That limited the power of our models because they might not capture local complexity of land use in each study area. For example, the probability of presence of *Hapalemur alaotrensis* may completely differ between papyrus-dominated and Phragmites-dominated marsh vegetation. Also, the bamboo vegetation and the mosaic of bamboo shrub habitat in

Baly Bay may present very different suitability levels. In future, the use of a suitable land cover map that is specific to each intervention area will make a big difference. It should be recognised that evidence from models is often controversial and correlational and more autecological studies should ideally be performed on each species, time and funds permitting.

Challenge due to lack of comparison indicators

It was challenging to measure the performance of CBC in conserving habitat of the endangered species because there are no obvious comparable situations, let alone suitable counterfactual. It was hard to find which indicators to compare as temporal comparisons were not possible. Spatial comparison could be made by examining the difference between trends of habitat suitability between Strict Conservation Zones and the community-managed zones (management transfers). However, this was not possible because they are not really comparable as local communities are not directly involved in management of strict conservation zones at Baly Bay National Park and Manombo Special Reserve that are managed by Madagascar National Parks. Nevertheless, all management units including strict conservation zones are co-managed in the New Protected Areas of Lake Alaotra and Menabe.

Conclusion

This study examined the impact of CBC on the protection of natural habitat for four selected threatened species. The changes over time in the characteristics of the suitable habitat (quality and quality) were therefore studied and the most predominant ecological factors that most explain the presence of the species in their habitat were analysed.

Results from this study suggest that the effectiveness of CBC in conserving suitable habitat for threatened species is limited. This is because the quality of habitat is impacted by the increase in severe threats (fire, deforestation) over time (see Chapter 2). The CBC interventions have different levels of impacts in each of the four study regions but in general they did not halt the decrease in quality of habitat. All four species studied presented decline in probability of presence/occurrence. Also, this study confirmed the importance of the vegetation cover in terms of explaining the variation of the probability of occurrence of the species, and the key role played by the official management transfers, directly managed by local communities, in conservation.

Interestingly, results of this study indicated that other areas beyond the CBC interventions zones might be highly suitable for some species and need field verification. Those areas are predicted to have similar habitat characteristics as the pixels where the species was observed. They can also serve as potential areas for future reintroduction of the species if necessary in the future.

A high number of individuals (or groups) of species were recorded outside strict conservation zones. The zoning of some protected areas (e.g. Alaotra, Menabe) may need updating in order to include an increase in the effectiveness of a Protected Area in conserving the habitat of endangered species. Discussion with local communities should be carried out to change the zoning in order to include the most suitable habitats with highest probability of presence of the species in the strict conservation zones.

Conservation managers in Madagascar have strived to implement protected areas in the hope that an official protection status for the habitat would improve conservation effectiveness. However, they were generally unsuccessful in reducing forest loss despite the expansion of the protected areas network (Waeber et al., 2016). Pimm & Raven (2000) noted that due to human activity, this alarming situation can be found widely around the world because protected area status alone often cannot reduce the rate of species extinction. There is a clear need to change protected area policy and reinforce laws to better protect strict conservations zones.

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Supplementary materials

Appendix 1. *Hapalemur alaotrensis* (Lake Alaotra, Central Eastern of Madagascar)

Species IUCN ID		9676
Kingdom	ANIMALIA	
Phylum	CHORDATA	
Class	MAMMALIA	
Order	PRIMATES	
Family	LEMURIDAE	
Genus	*Hapalemur*	
Species	*Alaotrensis*	
Authority	Rumpler (1975)	
Synonyms	*Hapalemur griseus* subspecies *alaotrensis*	
Common names (Eng)	Alaotra Reed Lemur, Lac Alaotra Bamboo Lemur, Alaotran Gentle Lemur, Lake Alaotra Gentle Lemur	
Red List status	CR	
Red List criteria	A2cd	
Red List criteria version		3.1
Year assessed		2014
Population trend	Decreasing	
Petitioned	N	

Source: IUCN 2016

Appendix 2. *Astrochelys yniphora* (Baly Bay National Park, North West of Madagascar)

Species ID		9016
Kingdom	ANIMALIA	
Phylum	CHORDATA	
Class	REPTILIA	
Order	TESTUDINES	
Family	TESTUDINIDAE	
Genus	*Astrochelys*	
Species	*Yniphora*	
Authority	Vaillant (1885)	
Synonyms	*Angonoka yniphora* | *Geochelone yniphora*|*Testudo yniphora*	
Common names (Eng)	Ploughshare Tortoise, Madagascar Tortoise, Angonoka, Madagascar Angulated Tortoise	
Red List status	CR	
Red List criteria	A4ad; B2ab(v); C1; E	
Red List criteria version		3.1
Year assessed		2008
Population trend	Decreasing	
Petitioned	N	

Source: IUCN 2016

Appendix 3. *Eulemur cinereiceps* (Manombo Special Reserve, South East of Madagascar)

Species ID	
Kingdom	ANIMALIA
Phylum	CHORDATA
Class	MAMMALIA
Order	PRIMATES

Family	LEMURIDAE
Genus	*Eulemur*
Species	*Cinereiceps*
Authority	A. Grandidier & Milne-Edwards (1890)
Synonyms	*Eulemur albocollaris* | *Eulemur albocollaris* |*Eulemur fulvus* subspecies albocollaris
Common names (Eng)	White-collared Lemur, White-collared Brown Lemur, Grey-headed Lemur
Red List status	CR
Red List criteria	A4cde
Red List criteria version	3.1
Year assessed	2014
Population trend	Decreasing
Petitioned	N

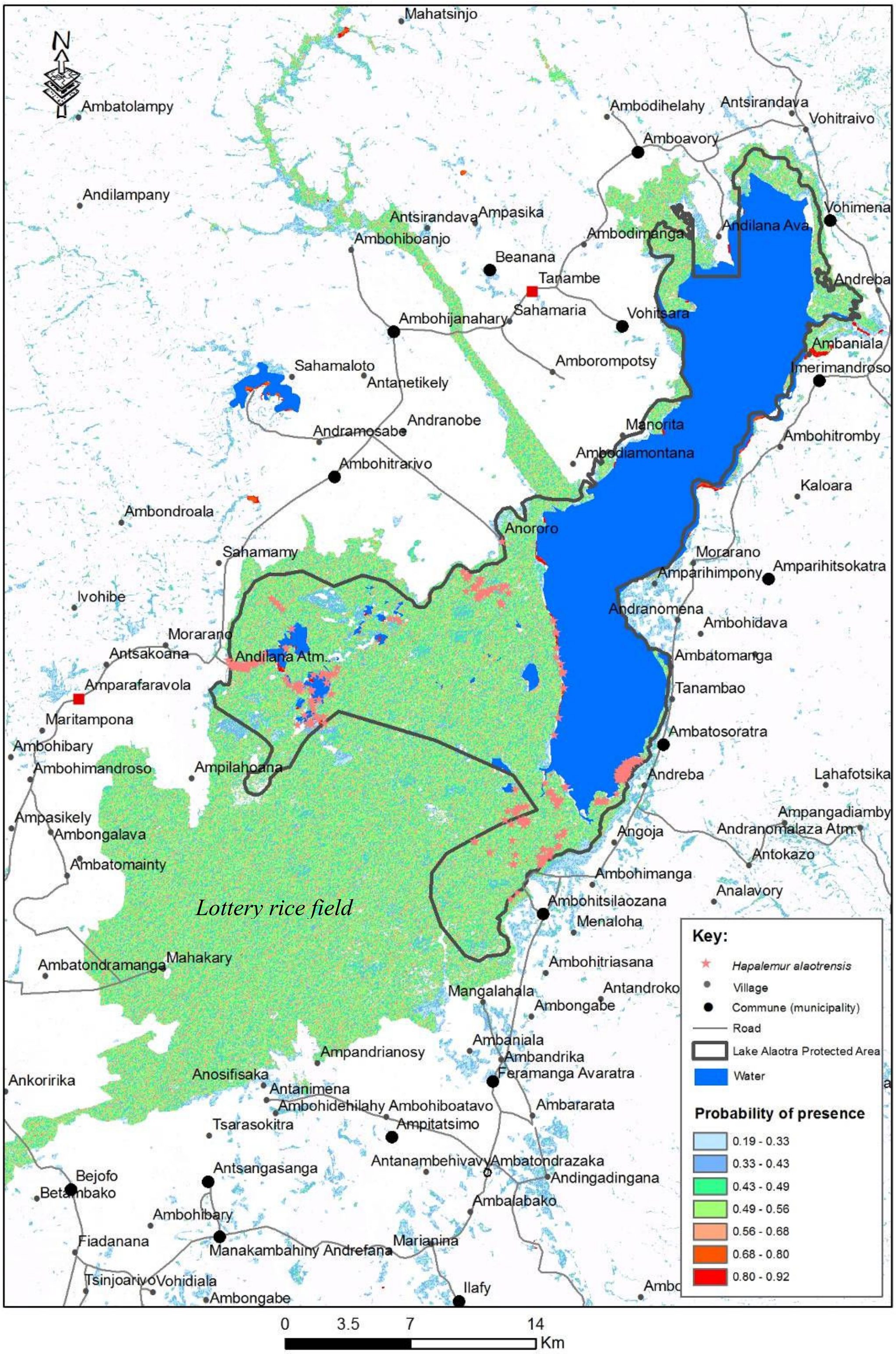
Source: IUCN 2016

Appendix 4. *Hypogeomys antimena* (Menabe, West of Madagascar)

Species ID	10714
Kingdom	ANIMALIA
Phylum	CHORDATA
Class	MAMMALIA
Order	RODENTIA
Family	NESOMYIDAE
Genus	*Hypogeomys*
Species	*Antimena*
Authority	A. Grandidier, 1869
Synonyms	
Common names (Eng)	Malagasy Giant Jumping Rat, Malagasy Giant Rat
Red List status	EN
Red List criteria	B1ab (iii, v)
Red List criteria version	3.1
Year assessed	2008
Population trend	Decreasing
Petitioned	N

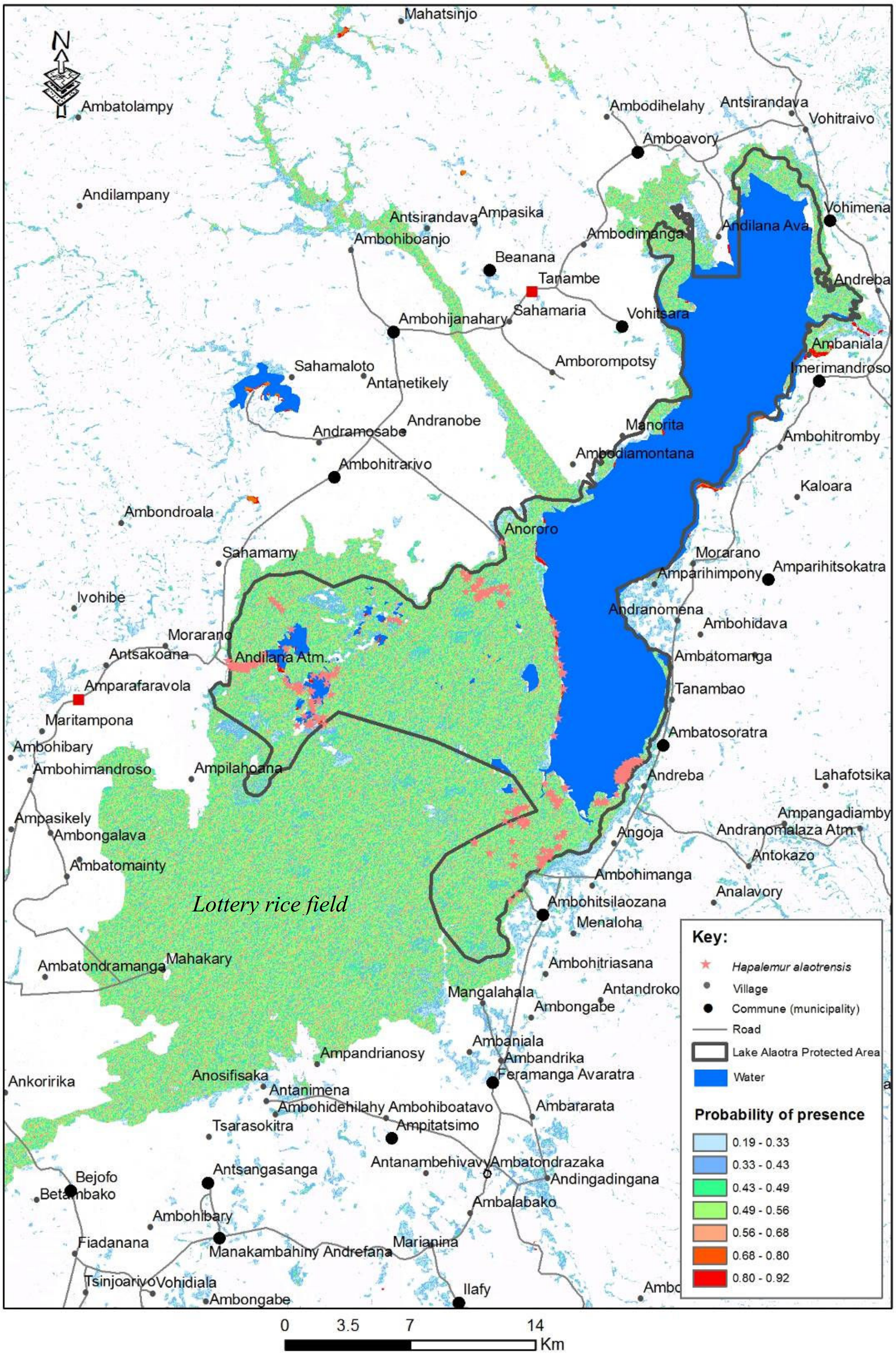
Source: IUCN 2016

Appendix 5. Predicted distribution of *Hapalemur alaotrensis* 2000



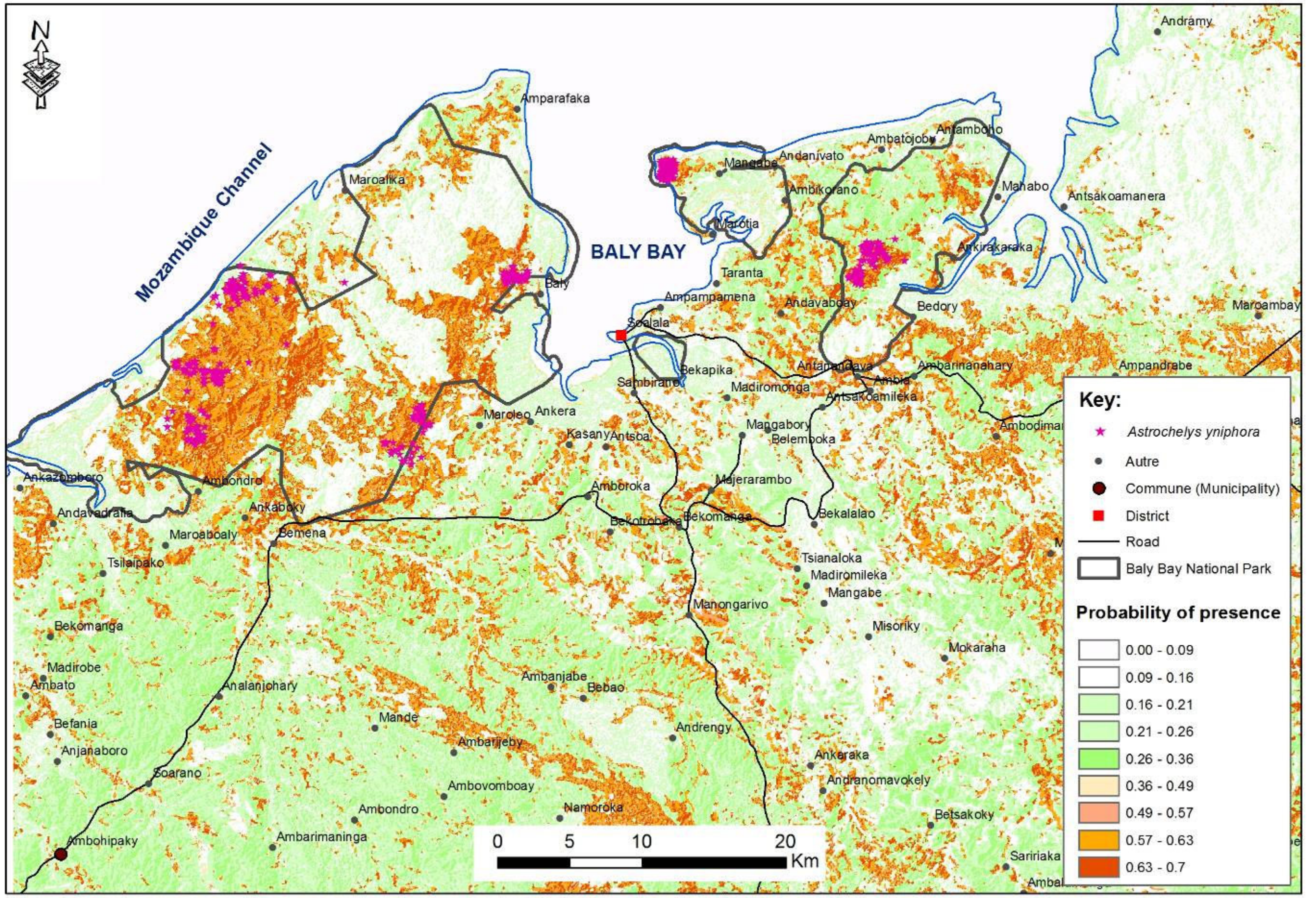
Predicted distribution of *Hapalemur alaotrensis* in 2000. Maxent result based on Kew vegetation map, occurrence presence in 2000-2007 and other environmental layers

Appendix 6. Predicted distribution of *Hapalemur alaotrensis* 2014



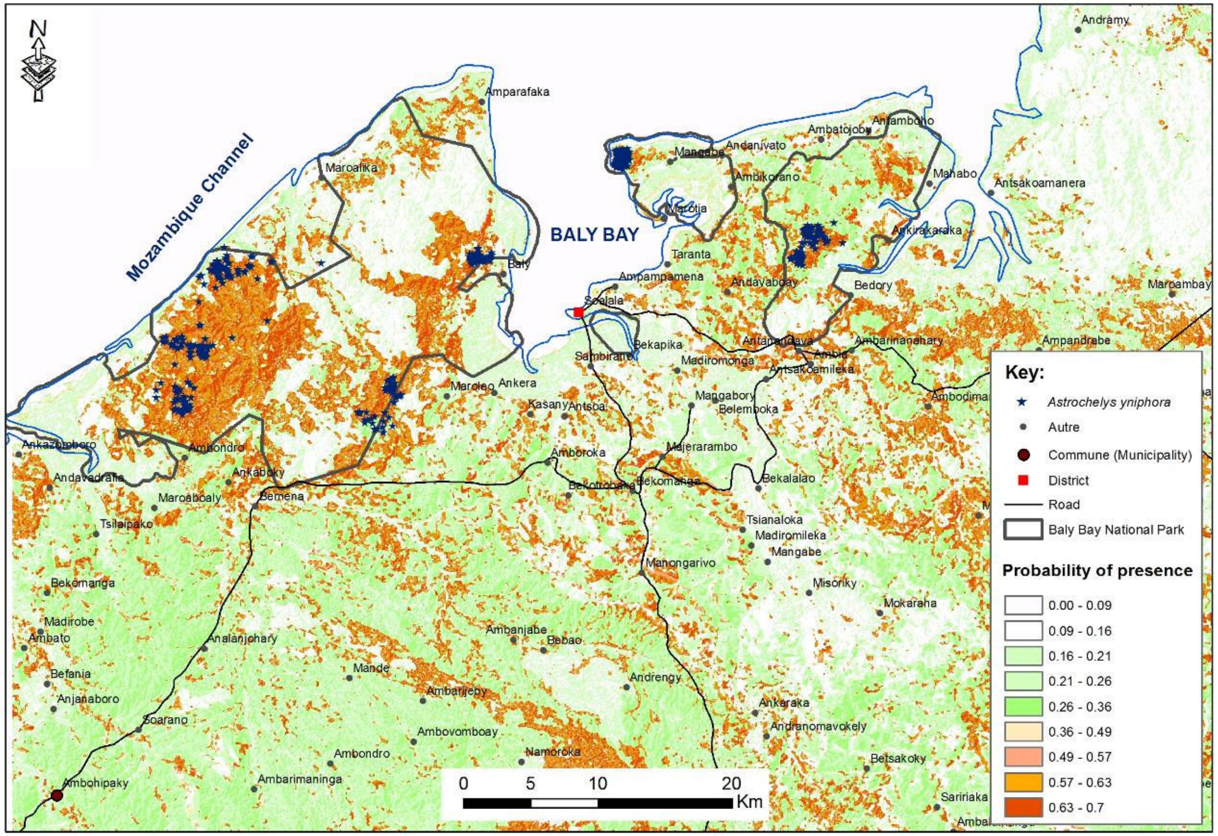
Predicted distribution of *Hapalemur alaotrensis* in 2014. Maxent result based on Kew vegetation map, Hansen deforestation, species records between 2000-2007 and other environmental layers

Appendix 7. Predicted distribution of *Astrochelys yniphora* 2000



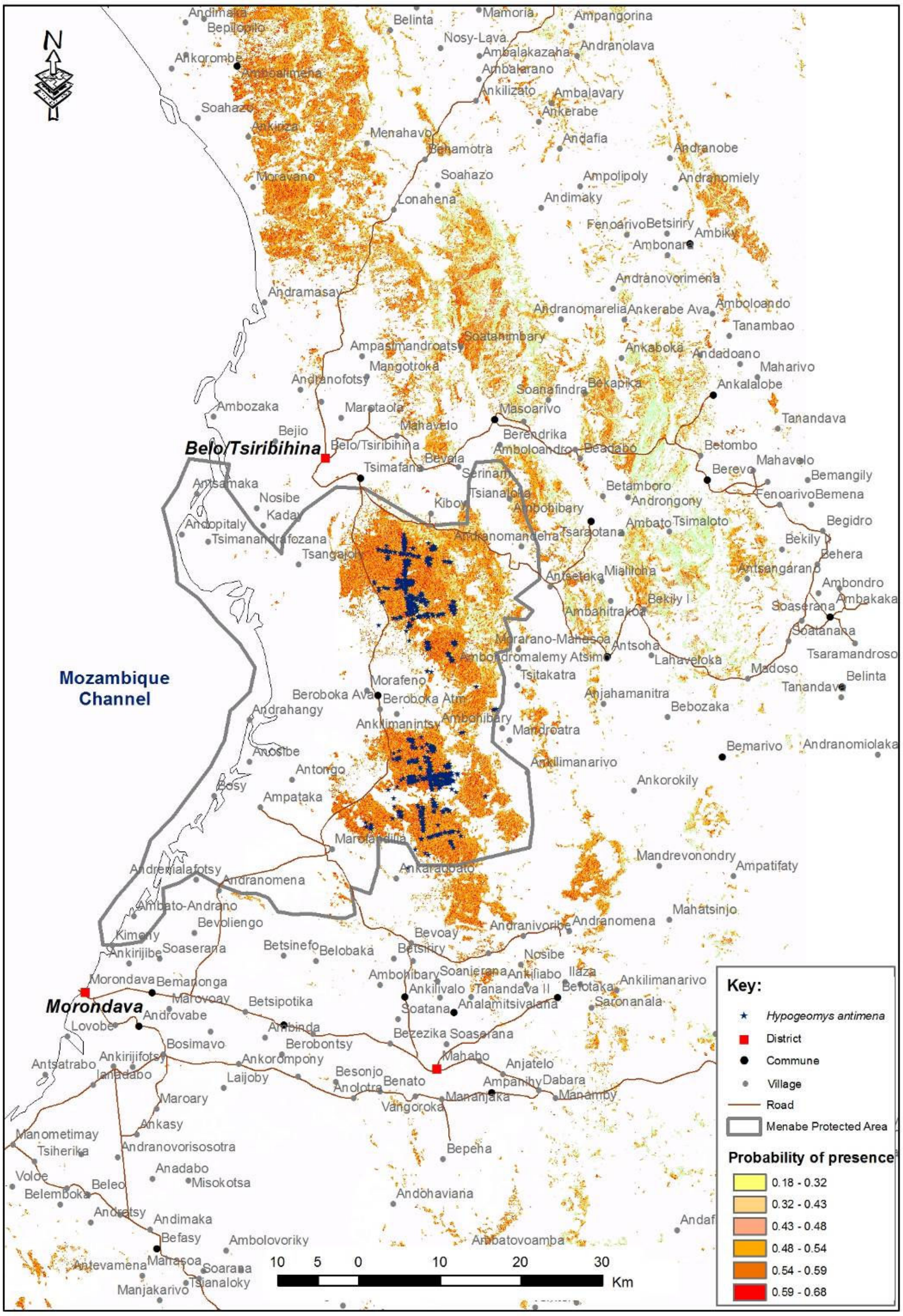
Predicted distribution of *Astrochelys yniphora* in 2000. Maxent result based on Kew vegetation map, Hansen deforestation, species records between 2000-2007 and other environmental layers

Appendix 8. Predicted distribution of *Astrochelys yniphora* 2014



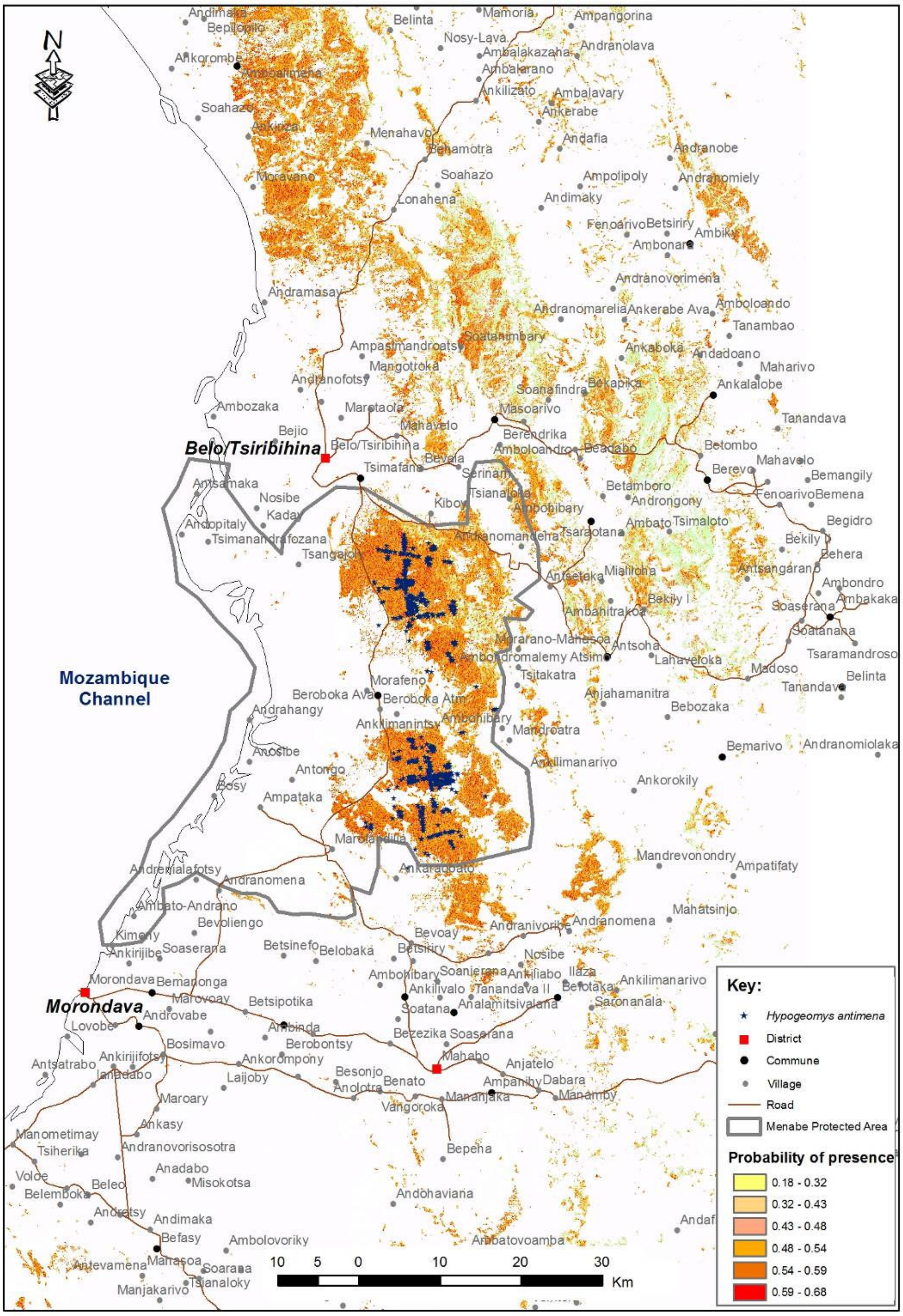
Predicted distribution of *Astrochelys yniphora* in 2014. Maxent result based on Kew vegetation map, Hansen deforestation, species records between 2000-2007 and other environmental layers

Appendix 9. Predicted distribution of *Hypogeomys antimena* 2000



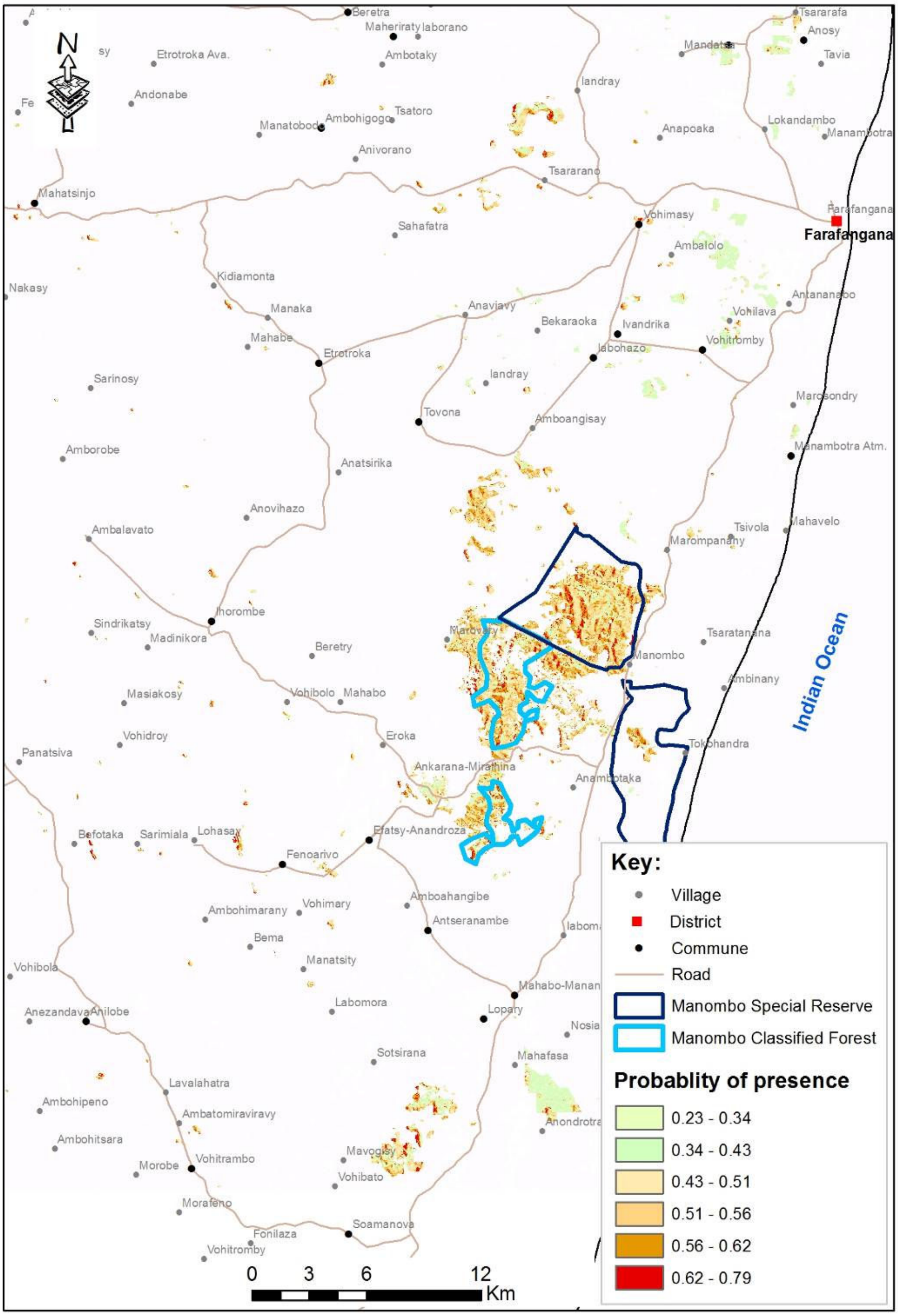
Predicted distribution of *Hypogeomys antinema* in 2000. Maxent result based on Kew vegetation map, Hansen deforestation, species records between 2000-2007 and other environmental layers

Appendix 10. Predicted distribution of *Hypogeomys antimena* 2014



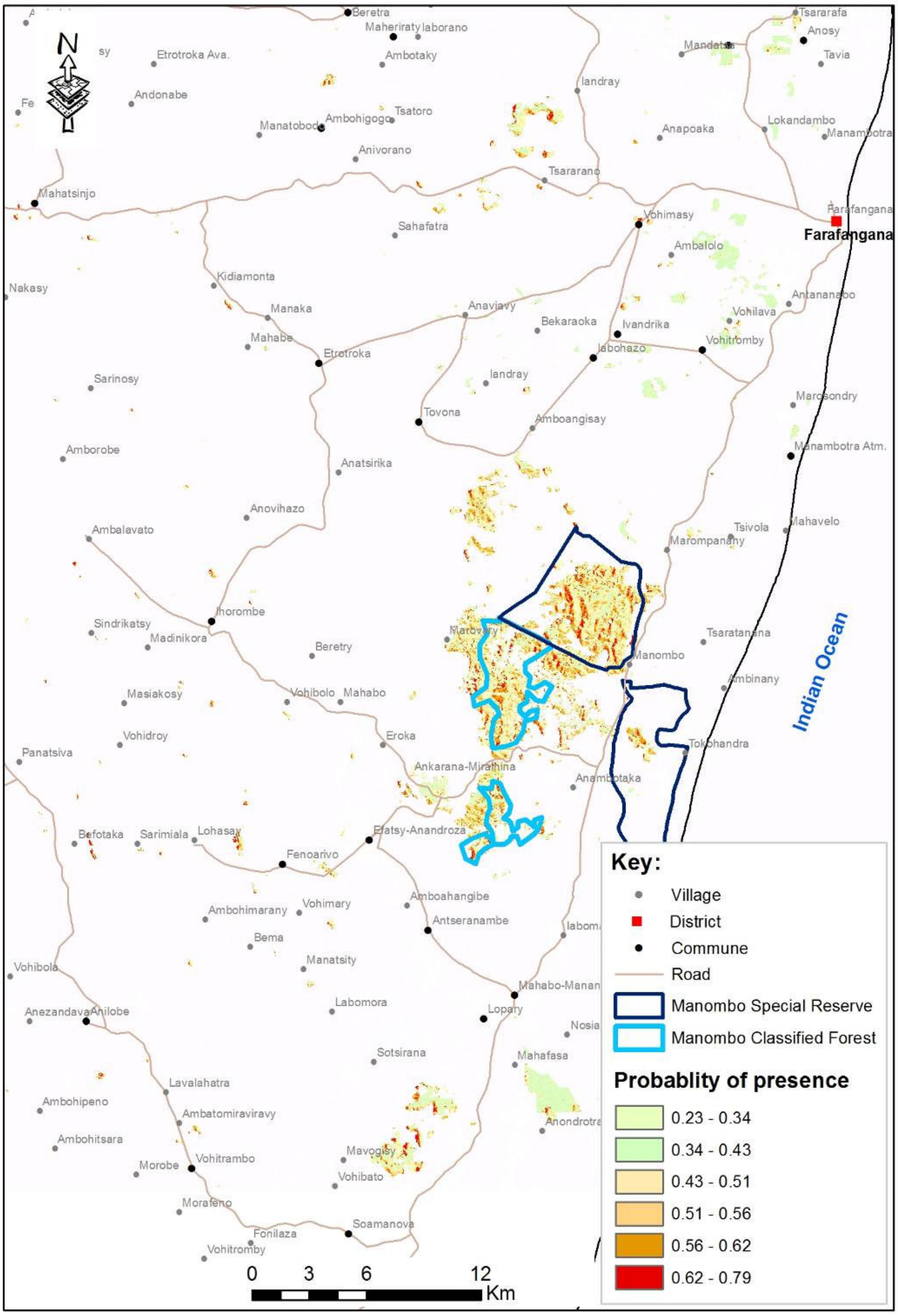
Predicted distribution of *Hypogeomys antinema* in 2014. Maxent result based on Kew vegetation map, Hansen deforestation, species records between 2000-2007 and other environmental layers

Appendix 11. Predicted distribution of *Eulemur cinereiceps* 2000



Predicted distribution of *Eulemur cinereiceps* in 2000. Maxent result based on Kew vegetation map, Hansen deforestation, species records between 2000-2007 and other environmental layers

Appendix 12. Predicted distribution of *Eulemur cinereiceps* 2014



Predicted distribution of *Eulemur cinereiceps* in 2014. Maxent result based on Kew vegetation map, Hansen deforestation, species records between 2000-2007 and other environmental layers

Chapter 6: Discussion and concluding remarks

Abstract

This thesis aimed to examine the effectiveness of Community-based Conservation (CBC) programmes in Madagascar over the period 2000 - 2014. In total 109 villages were examined that had had CBC programmes implemented by Durrell during this time. In these villages, temporal changes to biodiversity threats (fire and deforestation) and human well-being indicators (health, education and happiness) were measured over time. A similar set of measurements was then undertaken in 109 villages of comparable size which had not had implementation of CBC programmes. A summary of results presented in this concluding chapter detail both the successes and less successful aspects of CBC programmes and provide pointers for future structuring and management of such initiatives. The effectiveness of CBC programmes on reducing loss of threatened species was also examined - again with the results demonstrating some important pointers for current and future conservation practice and management.

Our study demonstrated that CBC programmes were successful in two key areas in terms of threat namely reducing the rate of increase in fire frequency and maintaining a lower rate of deforestation in area surrounding the intervention villages. In terms of human well-being, the presence of CBC interventions was associated with higher educational attainment and a greater propensity to take notice of changes in forest cover and the importance and provision of forest-based ecosystem services.

Less successful aspects of the CBC programmes included the fact that burning and deforestation continued in all regions and there was no evidence that implementation of

CBC programmes had a significant positive impact on alleviating poverty at the household level, or improving people's health and subjective wellbeing. Species Distribution Modelling also revealed that all four threatened species studied (*Hapalemur alaotrensis, Astrochelys yniphora, Hypogeomys antimena, and Eulemur cinereiceps*) present a degradation of suitable habitat and thus a decline in probability of presence between 2000 and 2014.

Although conservation and human well-being outcomes indicate that Durrell's CBC programmes have not been as successful as originally anticipated, results from this study can provide a clear evidence-base to more effective conservation practice by redefining goals, refining strategies, investing in more intensive interventions, and developing active collaboration between local stakeholders. This concluding chapter examines the relationship between key socio-economic and political factors in the context of implementing CBC programmes at village level, and presents realistic recommendations that should produce more successful outcomes in the future. In particular, it argues that the transformation of local associations into a form of social enterprise would be likely to motivate and empower people impacted by poverty, the majority in village populations, by giving them a direct interest in contributing to the success of conservation programmes and contributing to greater awareness of the value to the wider community of ecosystem services, generally, and biodiversity specifically.

Keywords: Governance, conservation impact, social impact, effectiveness, social enterprises

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Introduction

This chapter reviews overall findings from the retrospective evaluation of the effectiveness of Community-Based Conservation in conserving biodiversity, protecting ecosystem services and enhancing human well being in Madagascar. It highlights the findings on the positive effects of Community Based Conservation (CBC), the apparent inadequacies of this approach, and based upon these robust evaluation data, offers recommendations to make CBC more effective and efficient in the future.

The core findings of this thesis, discussed in detail in earlier chapters and summarised here, highlight the inter-dependence of people and their environment in Madagascar, where most people are poor and extremely dependent upon services provided by the often degraded ecosystems in which they live. Communities in Madagascar remain desperately in need of effective conservation and development strategies and more robust evidence to support decision-making. Despite limited, often considered insufficient, resources, NGOs have contributed to addressing these problems, and have a central role to play in conservation and development programmes in the future.

The results from this study highlight what we can learn from the positive and negative results of CBC, and what conservation managers can do to increase the chances of success in future interventions.

Beneficial impacts of Community-based Conservation

Why was the rate of increase in fire around CBC intervention villages lower?

In this study, we assumed that all fires are anthropogenic. Fire is a direct indicator of local communities' attitude. Our retrospective evaluation showed that the rate of increase in fire frequency within CBC villages was lower compared to control villages between 2000 and 2014. This evidence will enable conservation managers to develop more robust strategies towards higher conservation success.

Environmental factors such as floods (e.g. the case of Lake Alaotra in April 2005) and low precipitation may have reduced the probability of fire. However, in general I found that there was less fire only if people did not burn forest. The decision to burn forest or not burn it depends strongly on the extent to which local people are aware of environmental laws and their conviction about the negative impacts of fires on their life. Lower increase in fire frequency in CBC villages can be interpreted as result of higher quality of governance and greater awareness amongst villagers, brought about by village meeting discussions which focussed on prevention of fire.

Why was higher school attainment associated with CBC intervention villages?

The higher primary education attainment found in CBC intervention villages likely has two main explanations. First, when questioned about the village's development priorities, and made aware of the amount of money available, local people tended to prioritise education interventions such as building a school. At least 40% of Durrell's CBC financial support was allocated to education programmes. This supports the notion that most local people may have known that, at the level of support offered, it would be more realistic to invest in primary education rather than attempting to alleviate poverty through income-generating schemes. Second, the mark required to obtain the CEPE (Certificat d'Enseignement Primaire Elémentaire) exam is decided each year by the Ministry of Education and changes of threshold could have caused a variation in the educational attainment in each study area. Data on mark thresholds were not available for analysis.

Why was there a greater propensity for villagers to perceive changes in forest cover and provision of ecosystem services in CBC villages?

The people living in the CBC villages were expected to feel a greater attachment to natural resources, and to have a greater sensitivity to environmental change, as they have been exposed to the thinking behind CBC. Most of them are already in charge of the management of their local environment under official local management contract GELOSE or GCF. They use natural resources regularly, rely on them, and will from time to time witness illegal activity. For example, people living in CBC villages around Lake

Alaotra quickly noticed extension of ricefields or degradation of the lake (change in colour due to siltation). They also noticed increase in the number of fishermen or illegal fishing activities, such as the hundreds of lines of *Phragmites communis* illegally planted in the lake to trap fish or mark out land for future illegal rice farming. Local people around Manombo who keep watch on the number of small timber processing workshops in the forest, and those in Menabe who see the unpreventable slash and burn agriculture and illicit timber exploitation, will be able to provide more accurate assessments of forest loss.

No impact of Community-based Conservation on human poverty and disease burden

Severe poverty hampers achieving conservation goals

Poverty is directly related to human population growth (Birdsall et al., 2003) which in turn, was identified in this study as an important predictive factor worsening deforestation. The development support activities carried out as part of CBC programmes were not effective in alleviating poverty. Despite their understanding of the important role played by ecosystem services, local people affected by severe poverty are forced to focus on the immediate problem of how to feed the family today rather that how to save forest or wetlands for future generations. For example, at village meetings attended in Menabe, an area plagued by cattle stealing and related insecurity, it was clear that members of the local community found it impossible to consider conservation matters when confronting the hard day to day realities of severe poverty and insecurity.

It is important to note that the households' Multidimensional Poverty Indices in both CBC and control villages remained the same between 2003 and 2008 but presented an increase between 2008 and 2013. This importantly indicates there were no detectable negative impacts of CBC on people's poverty levels.

No impact of CBC on public health

The data in this study indicated an increase in the number of people who went to a clinic both in CBC and non-CBC villages. There was no evidence that the health support provided by Durrell (mainly on drinking water and toilet facilities) had impact on index of the health status. That index of Health status which was based on the number of people diagnosed at each health centre decreased during the study period (increase of people who went to health centre). However, it was difficult to decide if it was a positive or negative outcome as an increase could mean that the local community had greater access to modern medicine although it can also mean that more people are ill in the village.

Unproven factors likely to limit the potential success of Community-based Conservation

Based on long-term field experience, the problematic factors described below, which were not part of this evaluation study, are believed to limit the effectiveness of CBC.

Lack of practical cooperation between conservation managers

One observation from this study is that the level of collaboration between conservation managers around the study regions may have been too weak to address challenging environmental issues. Despite a substantial collective effort during the process of creating the Protected Areas (2003-2013), there has been little real collaboration on achieving successful management of natural resources or mitigating threats to biodiversity. Although the Regional Direction of Environment, Ecology and Forests, and the regional authorities collate conservation managers' annual plans, conservation managers tend to work in isolation. Many of them prefer to engage consultants to help carry out multidisciplinary activities rather than seeking help from each other. The problem of biodiversity loss is so great, that unless real collaboration is achieved, no long-term solution will ever be found. Collaboration and knowledge management will contribute to better understanding of the problem of biodiversity loss, and therefore should contribute to greater conservation success.

Lack of genuine partnership between conservation NGOs may have weakened overall governance of Protected Areas

Unavailability of government officials is also perceived as an issue - especially in terms of law enforcement which in turns makes the control of fire and deforestation very difficult. Conservation NGOs are often swamped with demands for their services and must prioritise in their planning. In addition, there often appears to be competition between conservation managers (LJ Rakotoniaina, *pers. comm.*), either for reputation or for funding, and the lack of genuine partnership, notable at both national and regional levels, appears to add to the difficulties of government bodies, limiting their ability to focus on the most serious environmental issues. This isolationist behaviour is exacerbated by NGO acting in pursuit of their own particular priorities putting pressure on government bodies to support these particular activities.

The extent to which government personnel are motivated to cooperate can sometimes depend as much on how they are treated by NGO staff as on the importance of the action required. Developing mutual conservation goals and coordinated planning are essential conditions for achieving long term success, and these are undermined by the lack of coordination found in the study. Furthermore, if there is insufficient collaboration between conservation NGOs, it will be even more difficult to build strong cooperation with development NGOs.

Inability of local associations to persuade the majority of villagers to change their attitudes

Examination of the membership size of local associations in four key villages per study area showed an annual decline in number of members over the last 10 years. For example, in 2013, local associations in Menabe constituted an average of 27% of the inhabitants of each CBC village, down from 53% in 2003. In Lake Alaotra the membership of most of the local environmental associations in the four key villages of Andilana, Anororo, Andreba and Ambodivoara, has significantly reduced in recent times, an indication that many association members were demotivated or disappointed, losing their interest in continuing as members, and giving up their participation in CBC activity. CBC interventions cannot make a significant impact when they involve only a small minority of households in the village. Unfortunately, it was not possible to check the attendance list of all village meetings to assess changes over time in level of participation.

Possible marginalisation of very poor households from conservation activity

It seems likely that poor households who generally expressed low happiness were not always fully integrated into the CBC process. Poor households, the majority in most villages, should be given more support than more advantaged households. In a socio-economic and rural environment study in India, Kerr (2002) found that watershed development needs to be designed with a full understanding of environmental services otherwise they may favour landholders but harm landless and poor people. If CBC projects in Madagascar are focussed on relatively small groups in the village, it is also likely that this group will be comprised of some people who are good leaders, but by others looking to benefit from being members. CBC programmes may attract opportunists, some of them wealthy individuals involved in illegal activity and knowledgeable about environmental law. In such cases CBC programmes might actually aid them in expanding their illegal slash and burn or land-grab activities and avoiding law enforcement. This could further depress the poorer people who may abandon their involvement in the CBC process which has brought no significant improvement into their lives (Fig. 26).

Inadequate law enforcement encourages illegal activities

After poverty, the lack of law enforcement is probably the most challenging issue preventing the success of CBC. It is probably futile for conservation managers to ask local people to better manage their natural resources when they witness other people who damage or destroy their environment with impunity. Those who are able to exploit their environment are seen to benefit from acquiring more land and speedily harvesting their crops, thanks to the fertility of the soil, regardless of the damage they do. When local people voice their suspicions of corruption in the management of illegal activities, local associations and patrollers often complain that despite submission of reports to Durrell, regional government officials and authorities, the law is not enforced. That weakens the authority of the local associations, and sometimes of the local officials. It is impractical and unrealistic for NGOs to ask the majority of the inhabitants of a village to aspire to some long term collective benefit from wise stewardship of the environment if a small minority can demonstrate that being outside the local association can bring more immediate short term benefits. Two main issues follow directly from this situation: the demotivation and disempowerment of local association members, and the impossibility of applying local '*dina*' conventions.

Summary of challenges limiting the success of the Community-based Conservation

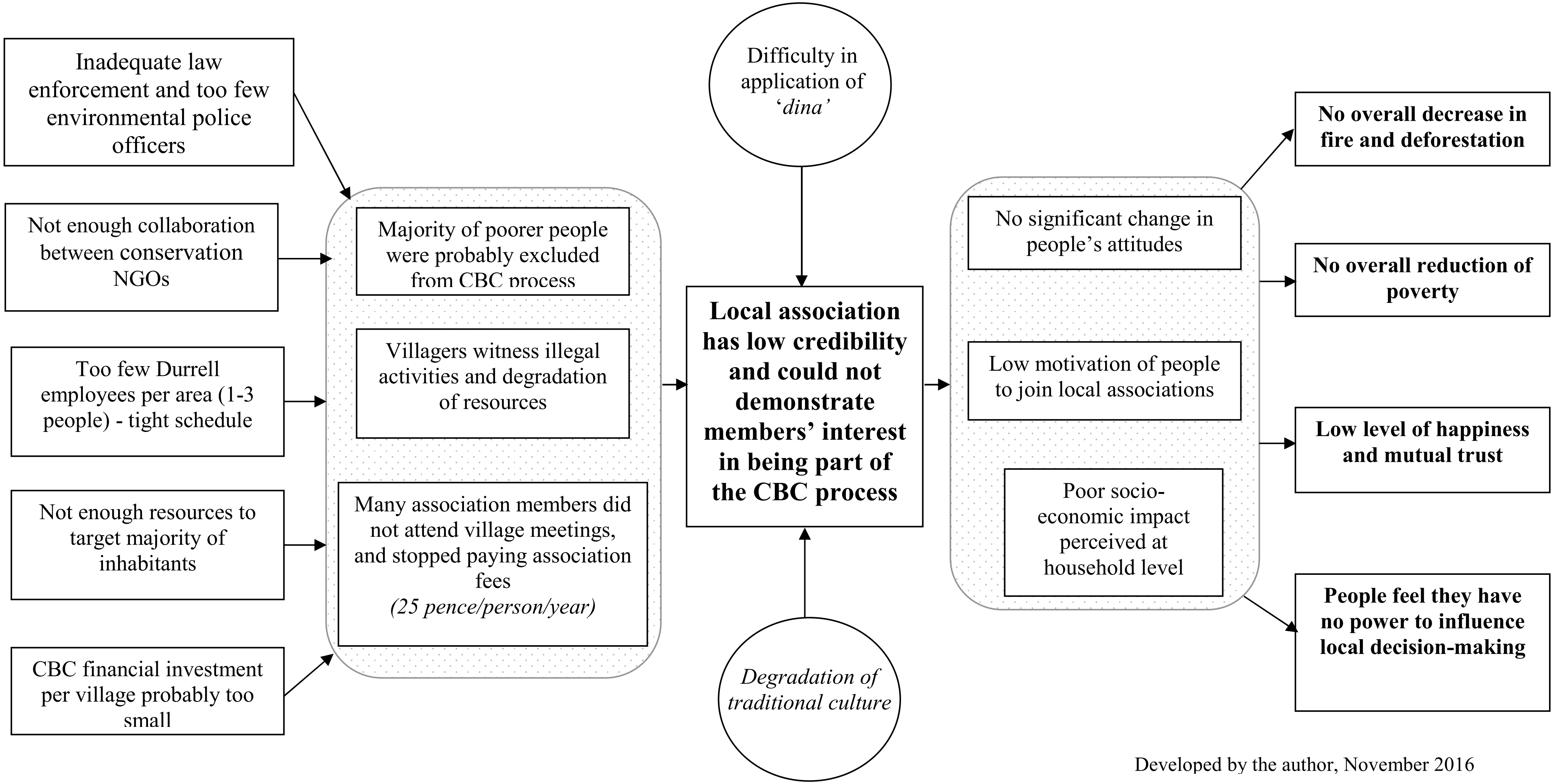


Figure 26. Diagram summarising challenges faced by Community-based Conservation

Recommendations for more effective Community-based Conservation

Results from this study show the challenges in achieving effective CBC and the following are practical recommendations that may improve the implementations towards reduction of anthropogenic threats and improvement of human well-being through CBC interventions.

1. Explore the possibility of transforming local associations into social enterprises

If local associations are not able to demonstrate the benefits of membership they will have difficulty in providing strong leadership in the village and in convincing the majority of people of the importance of protecting and not damaging their natural environment. Changing the status of a local association into a social enterprise could give it greater financial credibility and ability to develop local business model based on main production activity, and thus motivate people to join. In contrast to a simple local association, a social enterprise would be able to receive funding from conservation NGOs or other donors and at the same time engage in some low impact revenue-generating activity with the benefits equitably shared. This could enable conservation NGOs to develop stronger local structures better able to achieve their conservation and development goals. A condition could be that any surplus raised would be reinvested in the social enterprise itself with the aim of helping members improve their livelihood. A social enterprise would have a bank account to manage all financial dealings including annual contributions from members and any trading surplus. It is not clear whether Malagasy government policy would allow a social enterprise (e.g. cooperative) to officially manage a tract of forest or wetland under the existing form of management transfer.

Promote greater autonomy of local communities

There is good reason to think that a local structure in the form of an autonomous social enterprise would be effective in addressing social and environmental issues. Conservation NGOs would maintain their technical support while promoting independence and autonomy of the social enterprise in order to achieve greater effectiveness at village level. Once capacity is built, the management of development support and regular payment of local monitors, for example, could be delegated to the social enterprise. Handing over these responsibilities could free up conservation NGO staff, allowing them time to focus on the most serious issues and to make more frequent visits to villages. That in turn could lead to a deeper engagement on the part of the social enterprise, giving it a greater voice in the coordination and management of the social and environmental work. The conservation NGO would work with the social enterprise, raising and providing funds to upgrade the scale of support.

2. Focus on poorer households thereby targeting the majority to ensure equitable share of surpluses

There would seem to be a reasonable probability that if people could clearly see that they would receive a meaningful benefit they would be interested in participating in a social enterprise project. In practice, it is hard to make a difference in a village if the majority of the inhabitants, the poorest people, are not interested in being part of the process. Poorer households, especially those directly affected by the implementation of the new protected areas, should be targeted and offered particular privileges. They need to be convinced that the main purpose of the social enterprise is to help alleviate poverty and to protect the environment at the same time. The usual problem of local management lies in the risk of corruption, which deters people from participating because of their fear of not benefiting from the project. This could be resolved by democratically electing leaders who share the values and concerns of the local communities, and by acting in their interest to alleviate human poverty and to promote biodiversity. The social enterprise would be representative of the majority of village inhabitants and not of minority or NGO interests.

3. Coordinate mutual goals for conservation NGOs

The lack of appropriate collaboration between conservation NGOs could be resolved by agreeing mutual goals at regional level. Goals should be developed from clear Theory of Change (TOC)[21] (Weiss, 1995), developed by the collaborating NGOs, using measurable indicators that can be evaluated regularly. The aim would be to harmonise the various interventions taking place in each village and to emphasise the complementarity between NGOs. All objectives must fit with the existing regional development plan and the five-year management plan of the protected areas.

4. Invest more resources (people and money)

Investing more money in each area could achieve greater conservation and social impact at village level. For example, tripling the budget to 120,000 GBP per area per year would increase support per village to about 6,000 GBP per village per year, appropriate amount to achieve tangible actions that can persuade local people. Where most support over the last 15 years has been allocated to collective benefits, such as schools, public markets, and public wells and water pumps, it is important to consider investing more at household level in order to achieve a greater impact. That approach would target people who are really affected by the creation of protected areas. That is another reason for which relying on social enterprises to manage local development projects would ensure the appropriateness and relevance of the invested or implemented projects. Selection of projects should be based on a deeper analysis of the socio-economic situation of the households in each village. Collaboration between the social enterprise and regional

[21] According to Weiss (1995), a Theory of Change is a theory of how and why an initiative works

micro-credit banks could be explored to see whether implementation of a loan system could help boost the development activity. The social enterprise could be designated as credit guarantor for the poorer households, which in their turn would be engaged and motivated to work harder.

5. Reinforce environmental education in schools

Educating children to develop greater environmental awareness and sense of responsibility is likely to be considerably easier than altering the habits of adults. That would boost the effectiveness of CBC in 15-20 years time. Closer collaboration with the Ministry of National Education is needed to integrate environmental education into primary schools. Teachers should be trained to teach pupils the importance of conservation and protection of the environment. For example, the notion of ecosystem services provided by their local environment could be explored with pupils at primary school level. Environmental education programmes would operate in parallel with CBC interventions to ensure a positive relationship between development support and the status of local biodiversity (Hambler & Canney, 2013). Additionally, an increase in female education will help in family planning, which would help sustain local development. That will help control population growth.

6. Focus on fewer intervention areas or villages

Where NGO's financial and personnel resources are limited, reducing the number of areas targeted, or the number of intervention villages is an option to increase CBC effectiveness. This presents an ethical issue since some historical engagement with people and species would have to be brought to a close. On the other hand, this would allow for increased effort to be invested in a smaller number of intervention villages and thus the prospect of achieving greater impact in the most vulnerable areas. Reducing the number of intervention areas would in practice be more feasible than reducing the number of villages because all households affected by the establishment of a protected area are entitled to compensation in the form of a micro-development support. Excluding them from conservation and development projects could potentially pose a threat to the management of the protected area since they would be less likely to respect the existing zoning.

7. Improve law enforcement through the 'Joint Control Committee' and 'civic societies'

All of the five areas studied have official protected area status zoning and management plans that have to be legally respected while meeting conservation objectives. Fair law enforcement is a good indicator of good governance, and will motivate local people to change their attitudes and respect the protected areas. The governance structures around the protected area management need to interact fully with the regional-level law-enforcement bodies. Working closely with the '*Joined Control Committee*'[22] and '*civic societies*', proper implementation of both existing structures would increase the likelihood being able to enforce environmental laws and bring those engaged in illegal activities to justice. The '*Joint Control Committee'* already exists officially in each district, while civil societies are scarce at regional level. Establishment of '*civic societies'* at regional level is to be encouraged where they do not yet exist. By working with those structures, the risk of corruption is reduced, and statements written to tribunals are better validated all of which would help conservation managers in achieving their goals more successfully.

8. Diversify social activities to promote enjoyment and social solidarity

Greater efforts are needed to build stronger trust and solidarity at village level. In addition to the environmental competitions featured at village meetings, enlivened by

[22] Presided by the Chef District, the *Joined Control Committee* is comprised of policemen, local authorities, and key regional government agencies. The committee deals with illegal activities such as fire and illegal land grabbing, and can write official statement recognised by the tribunal.

public quizzes and traditional dancing, extending social activities such as regular sport and traditional music competitions could provide an element of enjoyment for the village as well as promoting social cohesion. A greater subjective sense of well-being could help motivate local people to share mutual goals and engage more positively with their local environment. Such activities could provide opportunities for people to learn more about changes in their local environment.

9. Evaluate successes and failures regularly, and the communicate findings

This study demonstrated that a quasi-experimental design employing matched control villages can help evaluate the effectiveness of conservation programmes when a randomised controlled experiment was not possible at the beginning of the intervention. Using a quasi-experimental design, we were able to determine the counterfactual effect of CBC, showing that the situation would be worse if CBC actions did not occur.

The social and biodiversity impacts of Community-based Conservation need to be measured regularly, re-visiting the same households and the same control villages used in this study, and asking similar questions, in order to learn from past successes and failures. That will avoid method-drift issue that may cause inconsistency of the data (Hambler & Canney, 2013).

Results of evaluations need to be communicated through local media and reported to government officials so that all interested parties are kept informed on progress. Results need also to be translated into Malagasy and posted in public places such as local authority offices and health centres. Mutual conservation and development goals and strategies could then be adapted using the results of the evaluation.

10. Strengthen leadership

The lack of leadership is probably the other main problem causing failure of conservation work in Madagascar. How to persuade the majority of people to conserve the environment? Who will lead? Manolis et al. (2009) noted that leadership is a critical tool for expanding the influence of conservation science. They also mentioned that recent advances in leadership concepts are underutilised and conservation science is not yet fully integrated into policy, management, and society.

It is suggested that a new form of leadership is needed to mobilise conservation biology into a more effective discipline that is able to communicate the full scope of the problem to society at large. Many conservation scientists shy away from the term leadership as they think leadership is for top organisational or political positions only (Gordon & Berry, 2006).

Additional (but more specific) recommendations that may improve Durrell's CBC

Based on these observations, I suggest that the following policy-based initiatives are proposed as playing an important role in improving the effectiveness of CBC:

i) Strengthen the connection between local monitors and local associations

Since 2011, weekly patrols carried out by local monitors to monitor key biodiversity and threats have been part of CBC intervention across all study regions. Firstly, despite the enthusiasm of the majority of local monitors (Earle, 2016), there was no reduction of threats, and that is because the success of local patrols depends mainly on the effectiveness of law enforcement. Secondly, the six local monitors per village who volunteered (or were chosen) to run weekly patrols through the strict conservation areas received some privileges not available to ordinary members of the local associations. They were given technical training on data collection, \$3.00 per person/patrol (2-3 patrols a month) directly paid by Durrell, uniforms and other materials such as cameras and mobile phones. In some villages that situation may create some jealousy as local monitors were seen to be too privileged while their work brought no tangible benefits for the association. They were not able to put a stop to illegal activity by sanctioning those who continued to violate environmental laws.

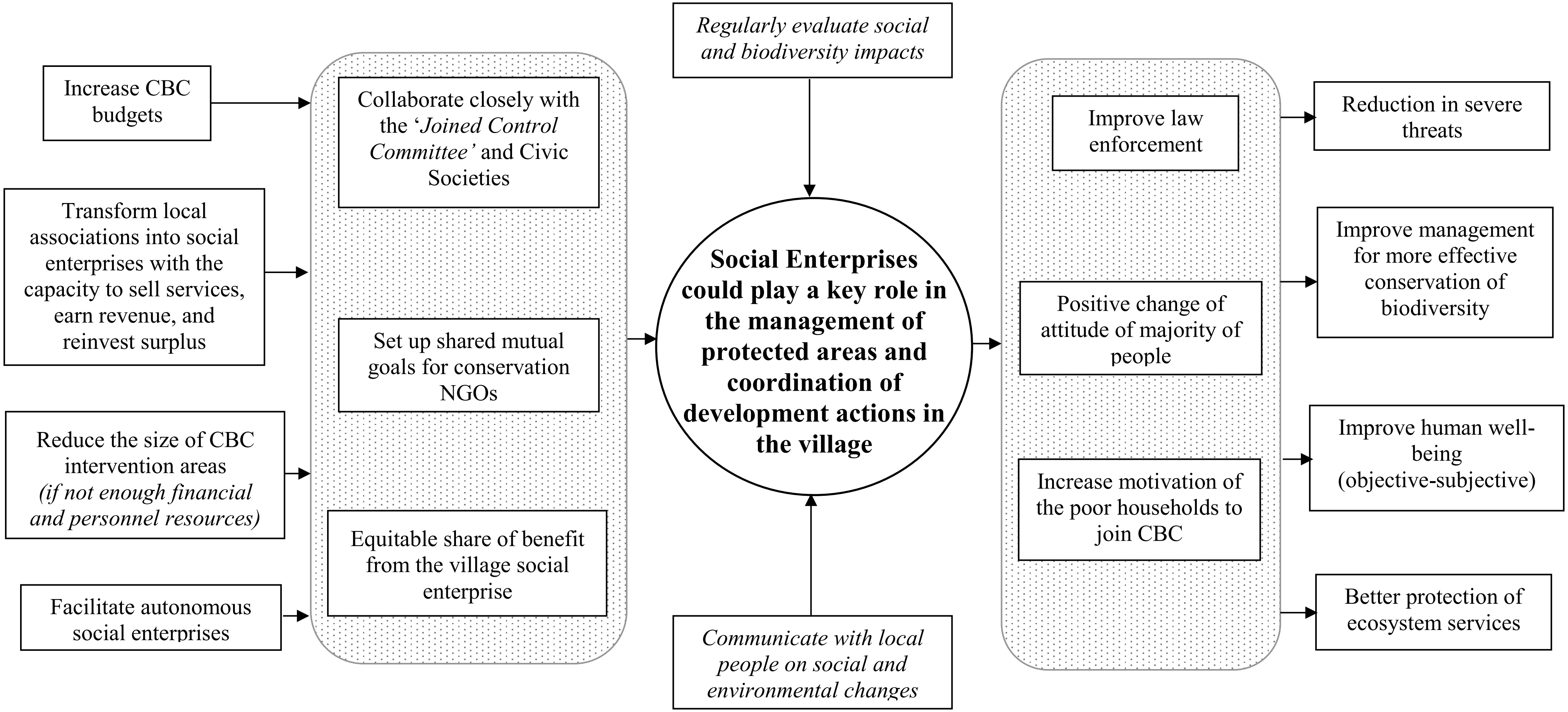
ii) Increase financial investment in Community-based Conservation

It was not possible to obtain the exact historical cost of Community-Based Conservation per village per year in the five study areas. However, based on grant records it is estimated that about 100,000 GBP per area per year was spent on CBC. Alaotra, with 32 villages, was the most expensive as it has the largest village populations. In general, the money was allocated mainly to primary education interventions, health and revenue generating activities. When divided, for example, among 32 villages, each village would receive net material support worth 2,500 GBP per year, which is likely to be too small an amount to achieve tangible conservation and social outcomes. Furthermore, some of the projects were under-funded for two-three years resulting in irregular payments.

iii) Increase the number of field staff employed to implement change

Durrell employed 12 staff members in the field responsible for administration and technical work: two in Alaotra, three in Menabe, one in Manombo, two in Nosivolo and four in Baly Bay. This number of staff is likely too small to carry out substantial social and conservation activities at village level, with too big a work-load and not have enough time to focus on the problems of individual villages. Increasing the number of field staff to five technicians per intervention area would make a big difference in terms of raising the effectiveness of CBC.

Summary of a new strategy for greater effectiveness in Community-based Conservation



Developed by the author, November 2016

Figure 27. Summary of new strategy for higher effectiveness of Community-based Conservation

Conclusion

The effectiveness of CBC can generally be determined by three main components: adequate resources, adequate planning and real participation of locals. However, many of the factors that influence the effectiveness of Community-based Conservation, such as political disorder, inadequate law enforcement, human poverty and land tenure issues, are difficult to measure, quantify and predict. Most conservation managers have limited influence over these third or confounding factors which are so strongly dependent on government policy and effective administration. However, I have suggested ways (Fig. 27) to help increase the effectiveness of CBC as an approach with the potential to achieve sustainable conservation and development at the same time. If effective, the approach can also enhance local people's subjective sense of well-being which in turn can lead to a collective change of attitudes at village level. Local people would be more willing to participate in NGO-initiated activity if they felt they would benefit from conservation, and the implementation of protected areas.

The potential for securing funding such as REDD-plus[23] should be explored to financially support the CBC approach since it aims, through reductions in rates of deforestation, to contribute to a reduction in greenhouse gas emissions, and to the global alleviation of poverty. CBC interventions may well benefit from the increasing awareness of climate change and adopt as an aim the direct support of households through the provision of renewable energy technology and adapted agriculture. In the future, awarding some enthusiastic local monitors with the ability to write official statements would probably give local people higher confidence that they actually

[23] REDD-plus refers to 'reduction of emissions of CO_2 from deforestation and forest degradation in developing countries, and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries'

contribute to law enforcement to help mitigating human-driven threats at the local level. That will also increase faith and the hope that they will benefit from conservation in the long term.

In addition to these practical recommendations to improve the strategy for CBC projects, the following research topics are suggested as areas that build on the work undertaken for this thesis:

- Evaluate the effect of local patrols on conservation
- Assess the changes in ecological characteristics of suitable habitat for threatened species over time
- Identify the best way to achieve strong social cohesion and people's behavioural change at village level
- Focus on one conservation area and quantify the weight of CBC activities in each village, then look at the interaction between implemented activities and social and biodiversity impacts
- Quantify the impact of corruption on environmental law enforcement
- Evaluate the impact of the lack of collaboration between NGOs on effectiveness of conservation and development projects
- Determine the appropriate cost of CBC to achieve substantial conservation and development impact in each intervention area

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