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Combining Deforestation and Species Distribution Models to Improve Measures of Chimpanzee Conservation Impacts of REDD: A Case Study from Ntakata Mountains, Western Tanzania

Rebecca Dickson [1,*], Marc Baker [2], Noémie Bonnin [3], David Shoch [1], Benjamin Rifkin [1], Fiona A. Stewart [3,4] and Alex K. Piel [4,*]

1 TerraCarbon, Charlottesville, VA 22902, USA; david.shoch@terracarbon.com (D.S.); ben.rifkin@terracarbon.com (B.R.)
2 Carbon Tanzania, Arusha 99132, Tanzania; marc@carbontanzania.com
3 School of Biological and Environmental Sciences, Liverpool John Moores University, Liverpool L33AF, UK; noemiie.bonnin@gmail.com (N.B.); f.stewart@ucl.ac.uk (F.A.S.)
4 Department of Anthropology, University College London, London WC1H OBW, UK
* Correspondence: rebecca.dickson@terracarbon.com (R.D.); a.piel@ucl.ac.uk (A.K.P.)

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Abstract: Projects to reduce emissions from deforestation and degradation (REDD) are designed to reduce carbon emissions through avoided deforestation and degradation, and in many cases, to produce additional community and biodiversity conservation co-benefits. While these co-benefits can be significant, quantifying conservation impacts has been challenging, and most projects use simple species presence to demonstrate positive biodiversity impact. Some of the same tools applied in the quantification of climate mitigation benefits have relevance and potential application to estimating co-benefits for biodiversity conservation. In western Tanzania, most chimpanzees live outside of national park boundaries, and thus face threats from human activity, including competition for suitable habitat. Through a case study of the Ntakata Mountains REDD project in western Tanzania, we demonstrate a combined application of deforestation modelling with species distribution models to assess forest conservation benefits in terms of avoided carbon emissions and improved chimpanzee habitat. The application of such tools is a novel approach that we argue permits the better design of future REDD projects for biodiversity co-benefits. This approach also enables project developers to produce the more manageable, accurate and cost-effective monitoring, reporting and verification of project impacts that are critical to verification under carbon standards.

Keywords: East Africa; great ape; co-benefits; conservation; carbon project

1. Introduction

Climate mitigation projects to reduce emissions from deforestation and degradation (REDD) have been piloted since the mid-1990s, and currently are implemented globally on over 70 projects registered under the Verified Carbon Standard (VCS) alone [1]. VCS is the most widely used standard for carbon accounting. Many of these projects are also registered under the Climate, Community and Biodiversity Standard (CCB), committing to the generation and reporting of positive impacts in select community and biodiversity indicators. These co-benefits tend to be difficult to define and measure, particularly biodiversity indicators, for which monitoring on many REDD projects has been restricted to simple assessments of species' presence/absence [1]. The demonstration of co-benefits is critical to driving voluntary carbon market finance to conservation efforts, and tools are needed to improve the measuring, tracking and reporting of the conservation impacts of REDD projects. This study demonstrates tools that improve how projects measure biodiversity co-benefits that can be widely applied in REDD and CCB projects.

Approximately fifteen percent of the world's terrestrial surface is under some form of formal protection [2]. Although critical, protected areas will not alone secure the conservation of biodiversity, effective conservation must also focus on other forms of protection such as community-based conservation programs [3] and payments for ecosystem services [4] as well as connectivity between these areas [5]. Maintaining and protecting lands and landscape connectivity, defined as the extent to which a landscape facilitates or impedes the movements of organisms [6] is a major challenge in Tanzania [7]. While Tanzania protects 27% of its land area under National Parks, Forest Reserves and Game Reserves, the connectivity of these reserve areas is under significant threat [7,8]. When habitat is fragmented, the absence of connectivity between these reserve areas can result in compromised genetic variability within isolated wildlife populations due to a lack of immigration, an inability of dwindling wildlife populations to be rescued from local extinction, and reduced opportunities for range shifts in response to global climate change [7]. Connectivity can be analysed within the changing landscape matrix over time for the further improvement of its utility for protective area design [9], but this exploration is beyond the scope of the current study. Tanzania is one of the only countries in Africa to clearly identify its wildlife corridors, providing clear targets for conservation interventions. Carbon Tanzania (CT) is a small registered Tanzanian company headquartered in Arusha that works with communities to preserve natural forests. Their work supports wider landscape conservation through the development and implementation of REDD projects within villages in wildlife corridors and the dispersal areas of high conservation priority. Ensuring communities are involved in the development and operation of these types of conservation activities, and receive payments linked to those successes, has been shown to create positive outcomes both for local livelihoods and land use change [10,11]. In this sense, REDD projects produce similar benefits to government-based protected areas, whilst simultaneously avoiding time-intensive legislative processes and implementing costly formal protection requirements (e.g., infrastructure, ranger stations, etc.).

An increasingly common means of identifying conservation priority areas is through building species distribution models (SDMs) [12,13], which are a widely used tool to assess the impact of climate and land use changes on biodiversity distribution [14]. These models utilize known species' occurrence records and environmental variables to identify environmental conditions that are associated with species presence. Modelling algorithms can then be used to predict species distributions across space and time [15]. Different statistical (e.g., generalized linear models (GLMs) and generalized additive models (GAMs)) and machine-learning (e.g., maximum entropy (MAXENT) and random forest (RF)) algorithms are widely available through many software packages (e.g., [16,17]) to expedite the analysis of the resulting data. SDMs have become a popular tool in quantitative ecology [18] and offer potential to support conservation planning (e.g., [19,20]). For example, [19] showed that orangutan poaching by humans in Kalimantan, Indonesia, was more likely in villages that experienced variable seasonality and those further from oil palm plantations, helping conservationists better design protective strategies. These types of spatially explicit models can be critical for guiding conservation efforts.

Although the primary objective of REDD projects is to measure and monitor carbon emissions related to forest cover change, they can also help to achieve other regional conservation needs. Specifically, they can ensure the protection of suitable habitats for target species, which can facilitate species' persistence and increase overall ecosystem resilience [8]. Chimpanzees (*Pan troglodytes schweinfurthii*), like all great ape species, have experienced a dramatic decline in population size in recent decades [21]. In Tanzania, 90% of the 2000–3000 remaining chimpanzees are found within the Greater Mahale Ecosystem (GME), the majority of which live at low densities outside of national parks [22,23]. The Ntakata Mountains REDD project area falls within this important region and offers the opportunity to link forest protection with chimpanzee habitat conservation, and to test the tools for monitoring these joint outcomes. The GME region and the Ntakata project area, specifically, are experiencing dramatic landscape changes. The loss, degradation, and fragmentation of suitable habitat impede animal movements, reducing the potential for dispersal and therefore population viability [24]. Linking the analysis of historic and predicted land cover change that is required in REDD project development with SDMs provides a measure of how suitable habitat has changed as well as a window into likely changes in the future. By leveraging the predicted forest cover change data typically used for modelling the carbon benefit of prevented deforestation, conservationists can substantially improve the predictive abilities of SDMs for wildlife of special conservation concern. For the development of the Ntakata REDD project in western Tanzania, CT used SDMs, in combination with predictive forest cover change modelling, to assess the expected impacts of the project activities for chimpanzee conservation. The objective of this study is to demonstrate how the incorporation of SDMs to REDD project development, design and monitoring can improve the conservation outcomes of these projects.

2. Materials and Methods

2.1. Study Area

The Ntakata Mountains REDD Project (NMRP) was initiated in May 2017 by CT and was validated through the Verified Carbon Standard VM0007 methodology and triple gold Climate Community and Biodiversity standard. The overall aim of the project was to engage and support local communities in the protection of their village land forest reserves in order to contribute to the conservation of important wildlife habitat and to mitigate climate change. The project covers 204,807 forested hectares, located in Tanganyika District, in western Tanzania (Figure 1), an area experiencing dramatic landscape changes over the past decade, with detrimental effects on forests and critically important species such as chimpanzees [25]. This mosaic ecosystem is dominated by miombo-woodland, interspersed with thin strips of riparian forest and offers an important diversity of resources for chimpanzees but is under several pressures. Habitat loss occurs primarily through settlement expansion and conversion to agriculture as well as grazing by pastoralists, mining, and the development of new infrastructure (e.g., roads). These factors all negatively impact the landscape, with consequences for water resources and livelihoods as well as for wildlife conservation [23,26].

Tanzania represents the eastern and southern limits of chimpanzee distribution and hosts two of the longest studies of their behaviour (Gombe National Park: [27]; Mahale Mountains National Park: [28]). As with all species of great apes, chimpanzees are classified as endangered by the International Union for Conservation of Nature (IUCN) (one subspecies, Western Chimpanzees *P. t. verus* is classified as critically endangered—[21]). However, several surveys have now revealed that 75% of Tanzania's chimpanzees live outside of two National Parks, with the majority (~1500) living in the Greater Mahale Ecosystem (GME) [23,28–30]. The loss of habitat in the region is especially alarming given that chimpanzees in this area are found at extremely low densities [31], with chimpanzee communities likely covering extremely large home ranges to access widely distributed food sources [32,33]. Chimpanzees rely on large expanses of habitat to maintain their fission-fusion sociality, whereby all individuals of a chimpanzee community are never found together. Instead, individuals form smaller sub-groups (known as 'parties') that are temporally and spatially ephemeral [34]. Therefore, sufficient suitable habitat and corridors to facilitate movement throughout the landscape are critical to chimpanzee survival.

The Ntakata project area is located between S05.55′–06.30′ and E30.10′–30.50′ (GCS WGS84) with an altitude range from 800 to 2000 m. The habitat is typical of the Zambezian (miombo) Woodland Ecoregion characterised by *Brachystegia* and *Julbernardia* spp. which provide a high-quality habitat for a variety of threatened mammal species, including chimpanzees, African wild dog (*Lycaon pictus*) and the savanna elephant (*Loxodonta africana africana*). Covering 204,807 ha, the project area connects Mahale Mountain National Park (MMNP) and the Tongwe West Forest Reserve (TWFR).

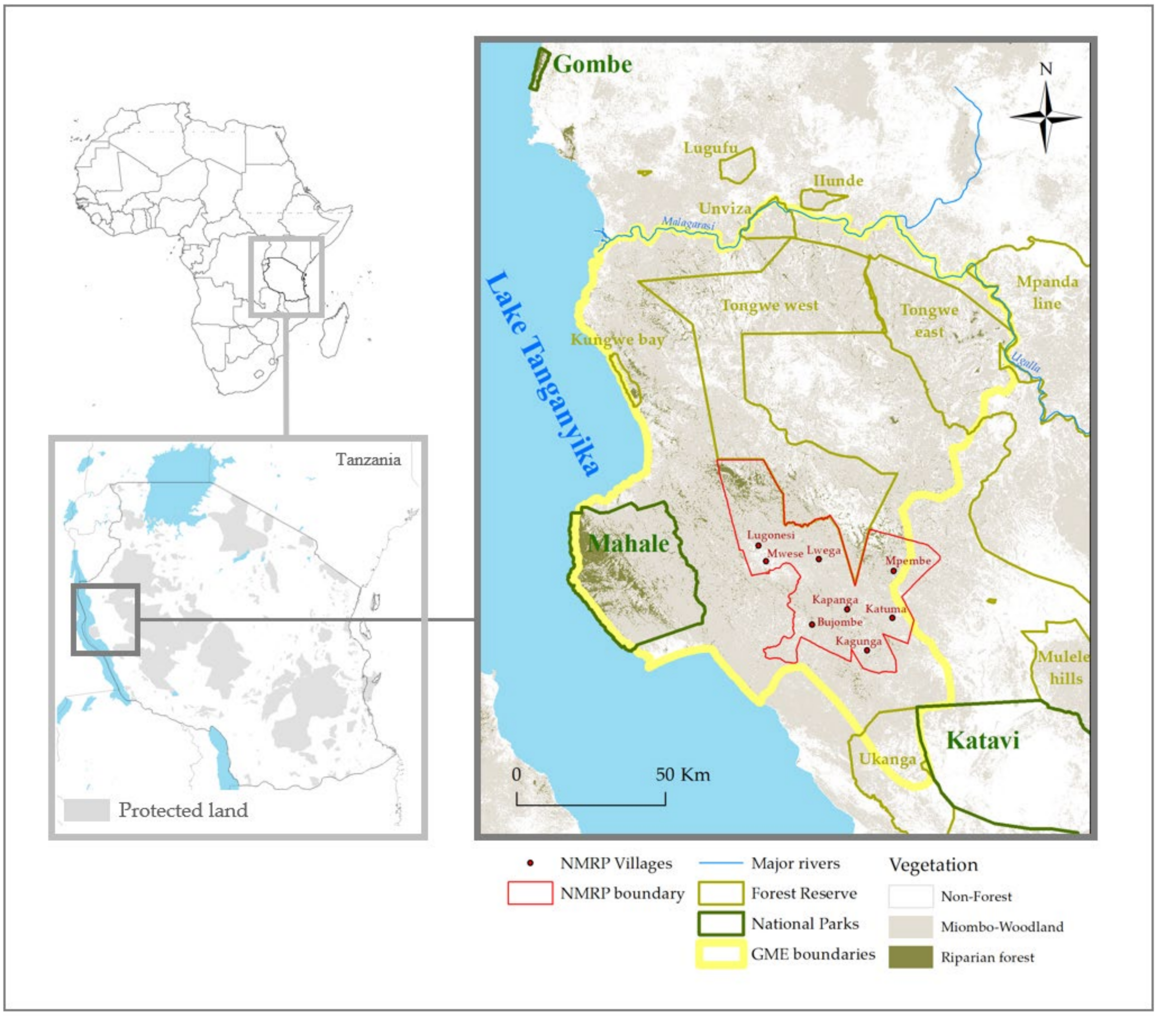

Figure 1. Location of Ntakata (REDD) project in Tanzania. All maps are in projection WGS84 UTM Zone 36S.

There are two clear seasons across the region, with a wet season from November to April, and a dry season from May to October. Average rainfall is 1800 mm/year with temperatures ranging from 18 to 32 °C depending on the altitude and time of year. The region is characterized by forest lined hills, miombo woodlands and thin strips of gallery forest, typically in valley bottoms. There are also patches of seasonally inundated grasslands, wooded grasslands, rocky outcrops and expansive tracts of native bamboo woodlands, especially along the eastern border of MMNP [35]. The Greater Mahale Ecosystem is framed by Lake Tanganyika in the west and by major rivers—Malagarasi in the north, Ugalla in the east—as well as smaller riverine systems that flow into Lake Tanganyika. The REDD project works within eight villages: Bujombe, Kagunga, Kapanga, Katuma, Lugonesi, Lwega, Mpembe, and Mwese with a total human population that was reported as 16,990 according to the most recent Tanzania National Census of 2012. The total population in 2020 is potentially twice this. There is a diverse mixture of cultural groups within the project area, both more recent arrivals, following a more pastoralist and agriculturalist lifestyle as well as Tongwe and Bende peoples (Village Land Use Plans (VLUP) see [36]). This cultural diversity has an impact on the participatory land use planning process that include grazing areas and spiritually important sites, all of which disallow the cutting of trees ((VLUP) see [36]).

Carbon Tanzania, in partnership with The Tuungane Program, a partnership between The Nature Conservancy and Pathfinder International, and the Tanganyika District Government, identified eight villages that protected part of the core area for chimpanzee distribution and connected the landscape, between MMNP and the TWFR. These partners supported the participatory development of (VLUP) within these eight villages, which was then followed by the development of Village Land Forest Reserves through participatory forest management (PFM), decentralising the management of these forests to the village governments. As is typical in these scenarios, there is a significant lack of revenue to support forest management and provide a viable option for people to earn revenue other than to deforest the landscape; this is where the Ntakata REDD project plays an important role. By channelling carbon finance to support both protection and to encourage village communities to conserve their natural resources, CT provides significant fiscal benefits to ensure forest protection. Thus, protecting forests, and the chimpanzee habitat, is transformed from being perceived as lost potential revenue into an economically viable option for local communities [36].

2.2. Land Cover Change and Predictions

The NMRP was developed as a joint Verified Carbon Standard (VCS) and Climate, Community and Biodiversity Alliance (CCBA) project, applying the VCS VM0007 Methodology Framework (REDD-MF) v.1.5 for accounting the impacts of avoiding unplanned (un-authorized) deforestation. As required by VM0007, we developed a 10-year projection of deforestation in a baseline (without conservation activities) scenario on the basis of historical (2007–2017) forest cover change, assessed via the land cover classification of Landsat imagery. We derived annual estimates of deforestation within the region by calculating the historical rate from 2007 to 2017. This historical rate of deforestation was projected forward to 2027, and allocated across the landscape on the basis of spatially-explicit variables correlated with past forest cover change (e.g., elevation, land tenure and distance to infrastructure) [36]. We conducted spatial analysis with the IDRISI TERRSET software [37] and the Land Change Modeler (LCM) which is an integrated software environment. LCM is a spatially-explicit modelling tool that we used to model the location of deforestation projected in the baseline for both the project area and the region surrounding the project area where deforestation is most likely to shift to, referred to as the leakage belt. The spatial modelling used a multi-layer perceptron neural network to predict the likelihood of deforestation spatially based on historical correlations. The current land cover map (2017) and predicted land cover (2027) we used to inform the location of forest cover in SDM (Figure 2).

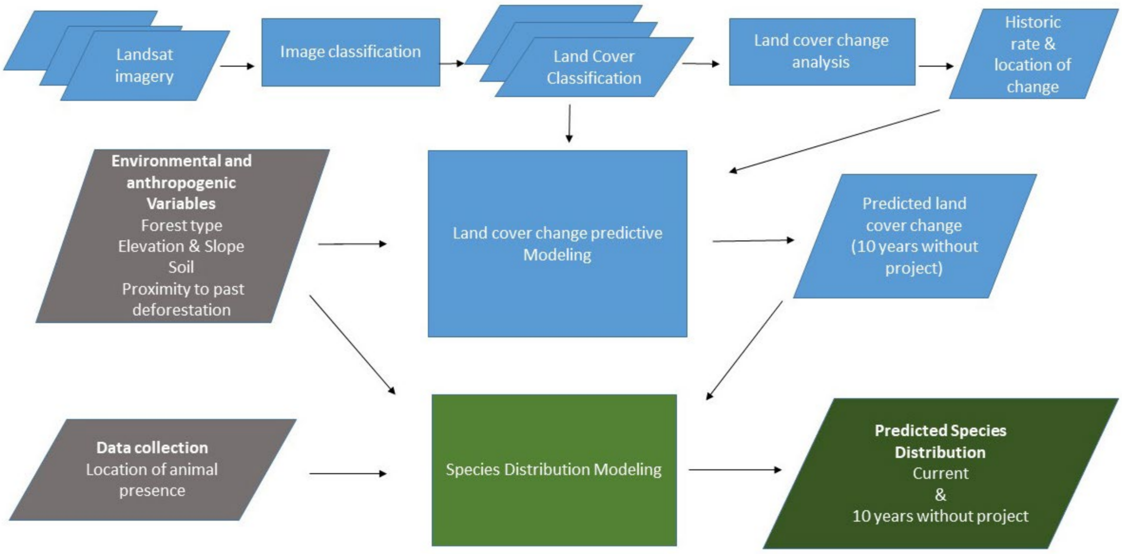

Figure 2. Data sources and processing flow. Blue components are all required for REDD project development. The green components are additional analyses used for Climate, Community and Biodiversity Standard (CCB) validation.

3. Species Distribution Modelling Framework

3.1. Occurrence Data

We based our species distribution model on chimpanzee presence records collected between 2008 and 2017 during surveys led by the Greater Mahale Ecosystem Research and Conservation Project (GMERC). Survey teams collected data on 11,622 chimpanzee observations: nests (84%), faeces (11%), feeding remains (2%), direct observations (2% of the total observations), prints (1%), and tools (<1%) through a combination of transects and reconnaissance walks. Whereas line transects follow a pre-determined bearing and distance [38], reconnaissance walks vary in distance and direction, targeting areas of wildlife presence, disturbance, etc. [39]. We accounted for an unequal sampling effort by spatial filtering and manipulating our presence records [40], resulting in 2328 occurrence points used in the final model (Figure S1). For spatial filtering, we used Spatial Rarefy Tool in the SDM ToolBox v2.2 under ArcGIS 10.7 (ArcGIS, ESRI, Redlands, CA, USA) to allow only one record per 60 × 60 m. We chose this value to allow sampling bias reduction and to keep a high spatial resolution on how landscape features impact chimpanzee distribution. Because records were still heavily biased toward the GMERC long-term field site, we further reduced the number of records in this area to obtain a similar density as the average density of the total covered area [40].

3.2. Predictor Variables

We used a set of four biophysical variables fitted at 30-m resolution as predictors for chimpanzee distribution: vegetation type, distance from the closed forest, elevation and distance from steep slope (NASA Satellite Radar Topography Mission data derived). Vegetation type, including the distinction of closed and open forest, we derived from a Landsat based classification of forest/non-forest updated with a more detailed reclassification of forest into closed forest and open forest. The resulting land-cover map comprised three classes representing non-forest, open forest and closed forest. For a future time slice, we used a 2027 land-cover projection (forest/non-forest) that was developed in the land cover prediction modelling, to predict deforestation. We then reclassified deforested areas to non-forest from the 2017 final land-cover map to create a three-class land-cover map representing 2027. Each predictor variable we selected based on their importance for chimpanzee ecology. Chimpanzees are highly dependent upon fruiting trees representing their primary food source [41]. Such trees exhibit seasonal fruiting patterns, where chimpanzees track their productivity, namely primarily in the woodlands "(i.e., open forest)" during the dry season and the riparian forests "(i.e., closed forest)" during the wet season [42]. Annually, chimpanzees range across these vegetation types [43]. Although chimpanzees are found within a wide range of altitudes throughout Africa (up to 2900 m in Rwanda [44]), there is an important relationship with altitude when looking at the national scale (relationship between chimpanzee presence and altitude follows a bell-shaped curve) [44,45], which probably acts as a proxy for suitable climate condition and fruiting tree distribution [46]. Finally, chimpanzees in western Tanzania build nests for overnight sleep preferentially on steep slopes [47]. We checked predictor variables for multicollinearity using the 'usdm' package in R [48,49] and detected no signal of a collinearity problem (VIF < 1.3).

3.3. SDMs Approach

We used an ensemble of species distribution model algorithms in order to minimize the uncertainty associated with single modelling techniques when projecting to a different time period [50,51]. We used random forests, generalized boosted models and MAXENT, which have each been shown to perform well when modelling species distributions [15,52,53]. We used the default settings in the biomod2 R package (Version 3.3-7) for each algorithm [17,54]. We fit our model with 10,000 pseudo absences randomly sampled from the background extent [55], and replicated five runs with 70% of occurrences randomly selected for model training and cross-validation, and the remaining 30% set aside for model testing and independent validation. We used two approaches to evaluate the model performance, the receiver operating characteristics, to determine an area under the curve (AUC) and the True Skill Statistic (TSS). Models are considered to have reliable prediction performances with AUC values > 0.70 [56] and TSS values > 0.40 [57]. Therefore, our ensemble models retained only models with AUC and TSS scores of >0.70 and >0.40, respectively, and the contribution of each of the selected models to the final ensemble was proportional to its goodness-of-fit statistics. This procedure minimizes uncertainties since weak models receive less weight in the final ensemble. To help measure suitability change across years, the continuous prediction outputs were converted to the presence/absence maps using the sensitivity-specificity sum maximizer threshold for TSS (e.g., cut-off point [56]). The continuous outputs are available in the Supplementary Materials.

4. Results

The NMRP started in 2017 and the ongoing monitoring of multiple project benefits reveals that the project has reduced forest cover loss, reduced the loss of important chimpanzee habitat as well as generating multiple benefits to the well-being of the communities. These benefits include revenue which is mainly used for education and health, specifically medical insurance to community members, the building of school classrooms, improving specialist medical provision, and governance [58]. The use of species distribution modelling for chimpanzees provides a means to tangibly measure these conservation impacts. Our species distribution model indicated that 6984 km^2 of the GME was suitable in 2017 of which 1168 km^2 was found within the NMRP boundaries (Figure 3). The fit of the final chimpanzee species distribution model was 0.833 for TSS and 0.966 for AUC, indicating excellent prediction. The predictive accuracy of individual models ranged from 0.787 to 0.791 for TSS and from 0.945 to 0.948 for AUC, depending on the algorithm (Table S1).The contribution of each variable to the model was as follows: distance from the riparian forest (45.7%), distance from the steep slope (44.9%), elevation (7.5%) and vegetation type (1.8%). The response curves produced by the model are presented in Figure S2. Under current deforestation predictions, in the absence of conservation interventions, we predict that more than 339 km^2 of suitable habitat will be lost by 2027, of which 162 km^2 was found within the NMRP area, representing a reduction of more than 12% of suitable habitat within the project area (Figure 3).

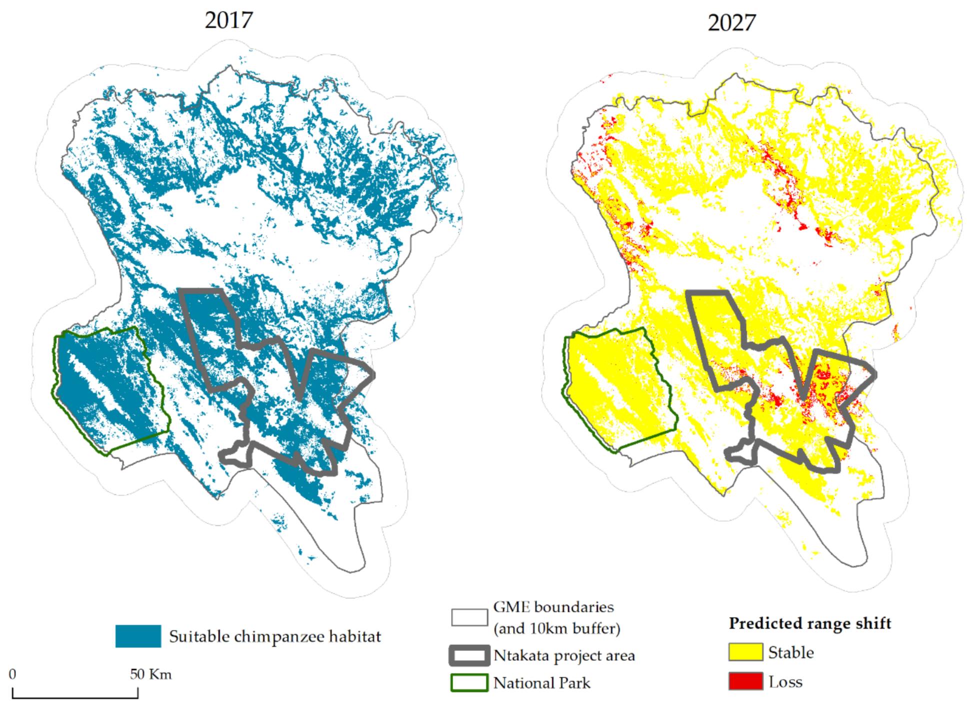

Figure 3. Habitat suitability maps for 2017 and 2027 within the Greater Mahale Ecosystem (GME). All maps in projection WGS84 UTM Zone 36S.

Forest cover change analysis shows that from 2017 to 2019 (Figure 4), significant forest cover change was avoided (>20,000 ha based on predicted change) of which an estimated 2804 ha was suitable chimpanzee habitat. The conservation efforts in the eight villages in Ntakata are financed by revenue from the REDD project.

The project has supported the communities through capacity development and increased knowledge through training and education on REDD (708 people), project governance (268 people), forest management (36 Village Game Scouts (VGS)) as well as reproductive health (884 couples). The project also provided employment for 45 villagers as project manager, Village Game Scouts and Carbon Champions, thus providing immediate income to them and their families. In total, 2825 individuals participated in this work. The 173 patrols during that period also served to protect natural resources, which the community relies on daily for firewood, clean water, as well as grazing and medicinal uses [58].

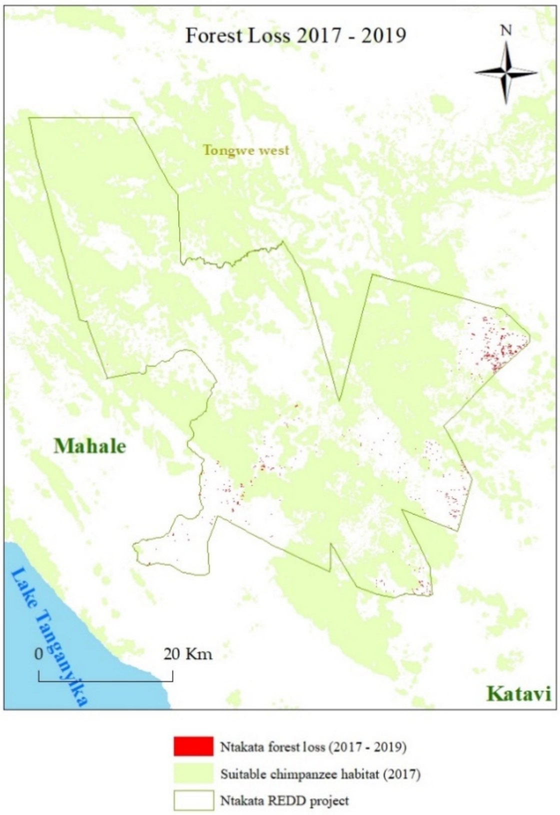

Figure 4. Forest cover loss during the period 2017–2019 in the Ntakata Moutains REDD project (NMRP). All maps are in projection WGS84 UTM Zone 36S.

5. Discussion

Chimpanzee populations across their geographic distribution have been in dramatic decline for decades [21], with the western sub-species decreasing by as much as 80% since 1990 [59]. With the majority of chimpanzees now living outside of protected areas in Tanzania, promoting alternate ways to protect their habitat is critical. Providing communities with financial incentives for forest conservation through REDD projects is one promising approach that CT is implementing in the NMRP, and demonstrating the benefits of using SDMs for measuring and monitoring the impacts of these projects is a step forward for understanding conservation outcomes.

Species distribution modelling is an increasingly widely applied and robust tool for understanding habitat suitability for wildlife [15]. Relying on empirical data to explain and predict the distributions of species, it provides a precise suitability surface at a fine scale. Nonetheless, numerous elements are reason for caution. First, survey data used to build the model were not collected systematically, with sites chosen because of their likeliness to host chimpanzees. More importantly, most of the data points represent chimpanzee nests, not actual encounters. As such, these occurrence data are skewed towards sleeping sites rather than chimpanzee presence. Thus, it is possible that our predictions have underestimated the importance of some environmental variables for feeding and travelling, and therefore the suitability of certain habitats. Furthermore, with chimpanzees adapting their diet to the extreme seasonality of the ecosystem [42], temporal variation of habitat suitability also remains to be examined.

Here, we choose to derive our suitability map using an ensemble modelling, which reduce uncertainty associated with each single algorithm [50]. However, other modelling techniques such as the hierarchical occurrence model can account for the imperfect detection of individuals and might reduce the bias associated with our sampling design [60].

Developing and operating long-term landscape conservation under REDD programs requires monitoring the climate, biodiversity and community impacts. Biodiversity monitoring, required by the VCS-Climate Community and Biodiversity (CCB) standard to verify a project's impacts, should be scientifically rigorous, but at the same time, be practical, achievable, and cost effective. For REDD projects at landscape scales, and especially those monitoring highly mobile species like chimpanzees, significant challenges are posed with traditional, demanding ground-based techniques, such as line transects [44,61]. Furthermore, the complex social system of chimpanzees and their elusive nature means that these apes are usually censused with indirect methods (e.g., nest counts) that are labour intensive [62]. These rely on correction factors like nest decay rate that vary widely depending on the location, season, etc., leading to imprecise and inaccurate estimates [61]. Since they are rarely all together, not only can it take years to identify all the individuals within a single chimpanzee community, but line-based transects often under-estimate population sizes [63]. Instead of designing entirely disconnected methods for monitoring the biodiversity impacts of the project, CT developed protocols to leverage the rigorous process of monitoring deforestation as already required by the REDD methodology. As land cover data are updated, CT, in turn, updates suitable chimpanzee habitat. Village Game Scouts (VGS) patrol and collect data on forest degradation, agricultural activity, poaching incidents, and chimpanzee sightings or nests using a SMART (spatial monitoring and reporting tool) [64]. As VGS patrols add to the collection of chimpanzee data over time, these data can be used to further refine or update the SDM. Therefore, the use of SDMs both lowers the cost of future monitoring requirements while providing accurate, continuous chimpanzee habitat data that might not otherwise be financially and/or logistically attainable.

REDD projects are required to be monitored at the minimum every five years [65], though CT intends to monitor every year. The first two years of monitoring results indicate that the project activities have thus far been successful as measured by the avoided deforestation and protection of chimpanzee habitat. The less than 1.5% of forest cover change detected across the Ntakata project area shows that reduced deforestation is occurring (Figure 4). Continued annual monitoring of the project area will aid in rapid adaptive response by the village communities and CT to prevent further forest cover and chimpanzee habitat loss.

Patrolling and data collection by VGS monitors forest protection whilst revenue paid to both district and village governments ensures that community members identify the benefits of forest protection. Carbon Tanzania works directly with the village governments as the primary interface, thus utilizing existing governance structures, whilst Tuungane aims to improve local governance through seminars and workshops that bring district and village government leaders together to discuss accountability and transparency, specifically on revenue sharing. As a result of the implementation of a range of project activities, the NMRP is estimated to generate approximately 572,754 tCO_2e (average per year over the 10 year crediting period) in GHG emissions reductions on an average annual basis. The NMRP adopts participatory developed land use plans as part of the overall project scheme, so there is the full integration of community views and priorities in the project design [36]. In addition to land use planning, communities also contributed input on how the project will support development in the village. During village meetings with the project team, they have raised various suggestions for how financial flows from carbon revenues could be used most effectively in their village. For instance, in the village of Mwese, representatives prioritized housing for teachers, nurses, and doctors. The NMRP is thus designed in such a way that each village can set its own priorities and spending plan according to the perceived needs. Financial planning happens every six months, where villages present records of how they spent previously paid revenue and CT informs the village governments what the next payment will be.

6. Conclusions

Traditional approaches to community conservation have often failed to provide forest adjacent communities with the direct and clearly defined financial benefits needed to ensure improved land management [4,66]. Without significant financial support at a community level, forest resources are often monetised by both individuals and communities to meet their financial needs: needs that are ubiquitous, such as health and education. The role of REDD in supporting land management plans through results-based payments, as is the case in Ntakata, ensures that priority chimpanzee habitat and connectivity across the landscape is both protected within land management plans and provides significant revenue to meet community needs.

The limitations of REDD have been studied in the past, however, many of these studies, [67] have predominantly focused on UNFCCC REDD approaches and REDD implementation by government agencies that develop and follow their own procedures [68]. The limitations of these approaches on forest conservation in Tanzania are well documented and beyond the scope of this paper [69]. One of the key limitations of REDD relates to site selection, which includes understanding the cultural setting, drivers of deforestation and legal pre-conditions of a potential project area. These factors influence the additionality argument, and have impacts on methodology choices and project implementation. Non-state REDD initiatives, like NMRP, follow international standards and approaches such as VCS-CCB, which ensure rigour within the emission accounting and ex-post measurement of results. Certification under these standards ensures marketability, saleability and therefore, the long-term financial sustainability so critical to this approach. In addition, REDD is correctly understood to be an unsuitable approach to areas where the primary causes of deforestation are charcoal production and illegal timber cutting. In the case of the Ntakata Mountains REDD project, similar to other forests in Tanzania, 81% of deforestation is driven by shifting cultivation, considerably more than charcoal at 12% [70]. Site selection is a critical part of NMRP, as Ntakata forest (which covers only 8% of the Ntakata REDD project area) has been of historical importance to the Bende/Tongwe people, a forest-dwelling tribe, the Bende/Tongwe who have long relied on this forest for various uses, e.g., medicinal plants, religious ceremonies, etc. [71]. It is the tribes' sustainable land use practices that have protected the area to date. However, western Tanzania is increasingly drawing people from other regions in Tanzania [72], transforming a once tribally homogenous region into a culturally diverse one. As such, the current approach of land use planning and improved forest management legalizes the conversion of land to multiple uses, where the protected areas generate sustainable revenue and multiple land use zones allow for grazing and agriculture.

We recognize that this particular region has robust institutional backing for research and collaboration between multiple organizations, which may not be readily available to REDD projects in other regions of the world, and SDMs require specific expertise. Still, REDD projects generate a wealth of data on forest cover and quality that are financed by carbon revenue, which can be used to aid academic research and inform other conservation benefits. For example, leveraging the required land cover change analysis (both historic change and predicted) from REDD projects provides greater predictive capacity to SDMs.

Species distribution modelling can be incorporated at all stages of REDD projects to quantify project impacts as well as to improve approaches to monitoring. SDMs provide project developers and communities with a prioritization of critical habitat areas, which can improve project design and even assist in the identification of important project locations. During project development, land cover classification and predictive modelling required by REDD methodologies, can be leveraged to improve SDM and understand likely future habitat scenarios (Figure 2). After project implementation, SDMs can be included in monitoring to measure project impacts.

For REDD projects like Ntakata, developing monitoring approaches that are complex and expensive may be difficult to replicate for verification and presents a risk to its longevity. Whilst partnerships with conservation organizations that are able to support monitoring activities work in the early stages of a project, developing strategies that can be maintained by communities in the long term is needed. A failure to achieve monitoring targets that make it feasible to verify the project and ensure issuance can cause a failure of revenue flow to communities.

We propose that SDMs present a cost-effective way of providing meaningful data for annual verification events and could be expanded to multiple species in other landscapes within Tanzania where habitat loss and fragmentation are the primary reason for species declines.

Supplementary Materials: The following are available online at http://www.mdpi.com/1999-4907/11/11/1195/s1, Figure S1: Locations of the occurrence points used in the final habitat suitability model, Table S1: Predictive accuracy and standard deviation (SD) of the 5 replicates for the 3 algorithms t, Figure S2: Response curves derived by the ensemble prediction.

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