1. Introduction

Deforestation is occurring at an unprecedented rate (Hansen et al., 2013). This extensive forest loss represents a major threat to wildlife, which face subsequent challenges to adapt and respond to novel rates, types and scales of disturbance (Haddad et al., 2015). Fifteen percent of the world's terrestrial surfaces are now under some form of protection (IUCN and UNEP-WCMC, 2018). However, the establishment of isolated reserves will not alone suffice for the conservation of biodiversity. Effective conservation must consider connectivity between these areas (Rudnick et al., 2012). Landscape connectivity is defined as the extent to which a landscape facilitates or impedes the movements of organisms (Taylor et al., 1993). If dispersal routes are blocked or degraded, genetic exchange between remaining populations will be reduced or lost, increasing the level of inbreeding and genetic drift in small populations (Young and Clarke, 2000). Such effects eventually compromise adaptive potential and reduce fitness, accelerating extinction of small populations (e.g. Gilpin and Soulé, 1986). Maintaining connectivity confers ecosystems with greater resilience to disturbance and ultimately facilitates species persistence (Crooks and Sanjayan, 2006).

Landscape connectivity models can help highlight important areas on which to focus conservation efforts. These models use estimates of landscape resistance (the degree to which landscape features facilitate or impede animal movement) to predict the likelihood of connectivity between habitat patches (Taylor et al., 2006). Several studies have now shown the potential of landscape connectivity modelling to identify priority areas and support conservation planning of a wide range of species, from herptiles (e.g. Mui et al., 2017) and birds (e.g. Rayfield et al., 2016), to small (e.g. Fabrizio et al., 2019) and large mammals (e.g. Roever et al., 2013), including great ape species (Freeman et al., 2019; Vanthomme et al., 2019).

As with all the other species of great apes, chimpanzees are classified either as Endangered (Nigeria-Cameroon chimpanzees *P. t. ellioti*, central chimpanzees *P. t. troglodytes*, and eastern chimpanzees *P. t. schweinfurthii)* or Critically Endangered (Western Chimpanzees *P. t. verus*) by the International Union for Conservation of Nature (www.iucnredlist.org). Tanzania represents the eastern and southern limit of chimpanzee distribution and hosts two of the longest studies of their behaviour (Gombe National Park: Pusey et al., 2007; and Mahale Mountains National Park: Nakamura et al., 2015; Fig. 1). However, several surveys have now revealed that 75% of Tanzanian chimpanzees live outside of these two National Parks, with the majority (~1 500) inhabiting the Greater Mahale Ecosystem (GME) (Kano et al., 1999; Nakamura et al., 2013; Piel and Stewart, 2014; Plumptre et al., 2010; Yoshikawa et al., 2008). This mosaic ecosystem dominated by miombo-woodland (i.e. deciduous trees and shrubs with grass understory and discontinuous canopy) interspersed with riparian forest offers an important diversity of resources for chimpanzees but is under several pressures. Habitat loss through settlement expansion and conversion to agriculture represents the primary threat to chimpanzees within the ecosystem, followed by annual

burning, logging, and poaching (Moyer et al., 2006; Piel and Stewart, 2014). Monitoring the impact of habitat loss on remaining chimpanzee populations is logistically challenging given that chimpanzees in this area are found at extremely low densities (Piel et al., 2015a). Remote sensing technologies can help to overcome these challenges by providing precise and accurate data across broad spatial and temporal scales (Marvin et al., 2016).

The GME has previously been regarded as one ecosystem that supports one continuous chimpanzee population (Inoue et al., 2011), however, other studies have highlighted potential barriers which may limit chimpanzee movement between northern and southern populations (Bonnin et al., 2015; Moyer et al., 2006; Piel et al., 2013; Rudicell et al., 2011). Given the long generation time of chimpanzees, the genetic consequences of recent habitat destruction have the potential to manifest decades into the future and have long-lasting effects on the genetic diversity of the remaining populations (Landguth et al., 2010).
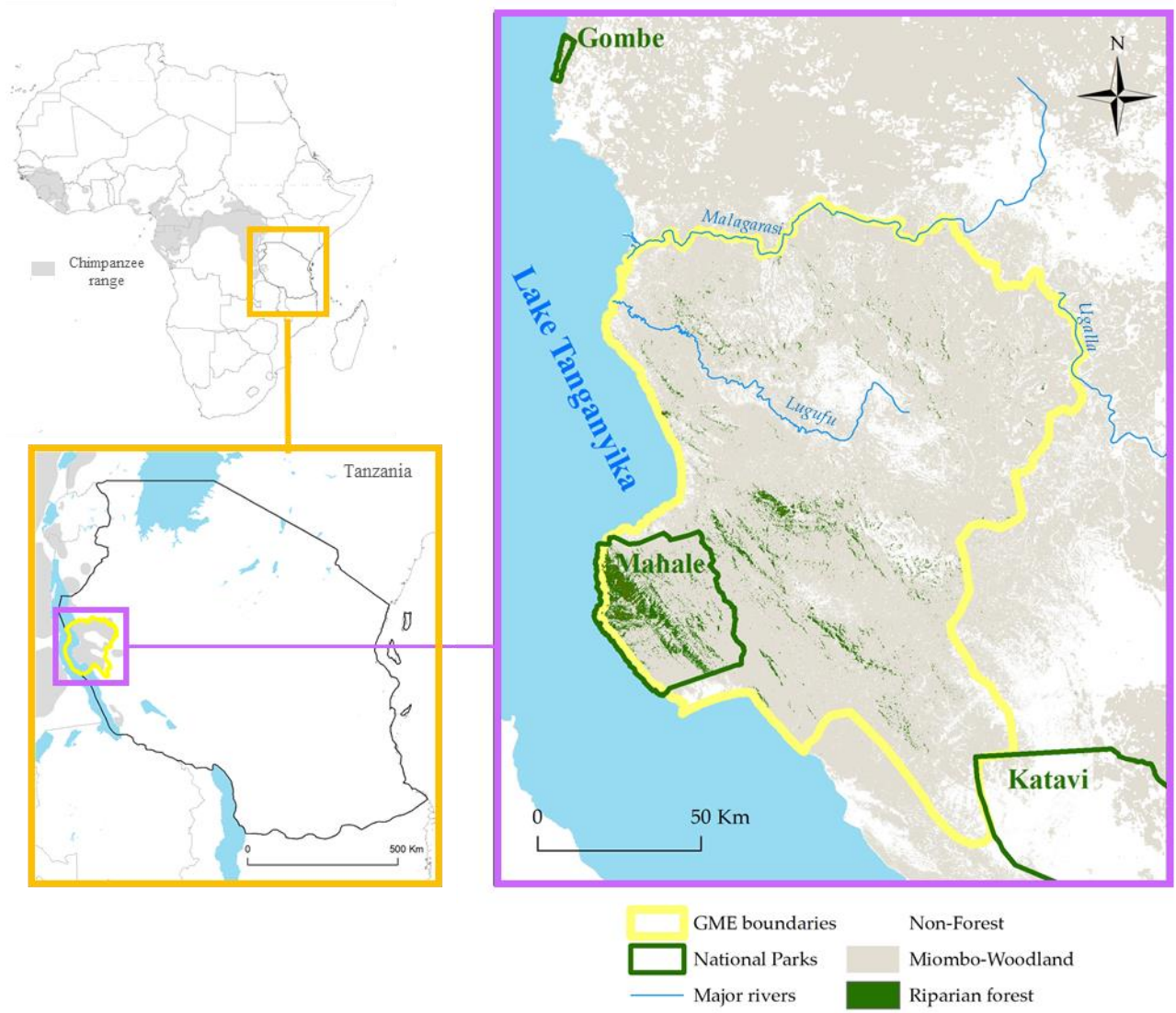
In this study, we aimed to (1) develop a habitat suitability model to create an index of habitat selection by chimpanzees within the GME; (2) map functional habitat connectivity independently of any a priori habitat patches or populations using circuit theory and our resulting habitat selection model; finally (3) evaluate the impact of forest loss on habitat connectivity by using remote sensing data from 1973 and a land-cover projection for 2027. We hypothesised the GME to be connected by multiple area of high connectivity values in 1973. We also expected a reduction in connectivity associated with forest loss, now isolating the northern and southern populations. Our results provide key information on where to focus conservation efforts, not only to protect current chimpanzee habitat, but also areas critical for connectivity that might be classified as only moderately suitable for chimpanzee habitat. Identified areas of high likelihood of chimpanzee movement can be used by conservationists to support detailed conservation planning needs of local human communities and chimpanzees.

2. Methods

2.1. Study area

The GME is a ≈ 18 000 km² region in western Tanzania, bordered to the north by the Malagarasi river, to the south by Katavi National Park, to the east by the Ugalla river and to the west by Lake Tanganyika (Fig. 1). The area is dominated by miombo-woodland (*Brachystegia* and *Julbernardia*, Fabaceae) with small patches of riparian forest, swamp, bamboo and grassland. The topography consists of broad valleys separated by steep mountains and flat plateaus ranging from 900 to 2 500 m above sea level. The GME represents the southern and eastern extreme of chimpanzee distribution and is one of the driest habitats in which they are found (Moore, 1992). The area includes the Mahale Mountains National Park (MMNP), which protects a high level of biodiversity, although it has been estimated that 75% of the chimpanzee population lives outside of MMNP (Moyer et al., 2006). Since 2005, the Greater Mahale Ecosystem Research and Conservation Project (GMERC) in collaboration with The Nature Conservancy (TNC), Frankfurt Zoological Society (FZS), the Jane Goodall Institute (JGI), Tanzania Wildlife Research Institute (TAWIRI), Tanzania National Parks (TANAPA) and District government partners have led

82 surveys to monitor chimpanzee populations. To account for potential chimpanzee
83 movement along the edges of the GME, we drew a 20km buffer around the GME
84 boundary.

85

86 **Figure 1:** Location and map of the GME

87 *2.2. Environmental variables*

88 We selected five biophysical variables to integrate into our species distribution model:
89 Vegetation type, proportion of riparian forest, distance from riparian forest, elevation and
90 distance from steep slopes.

91 We found that riparian forests are not well resolved by existing canopy cover products
92 and since these forests are an essential component of chimpanzee habitat, we developed
93 our own canopy cover product using Landsat spectral metrics derived from 16-day
94 Landsat 7 ETM+ and Landsat 8 OLI image composites as outlined in Potapov et al., (2020).
95 For a detailed explanation and evaluation of our product, we refer the reader to the
96 Supplementary Material (Appendix S1). Our product represents canopy cover for the year
97 2000. We defined riparian forest as areas with tree canopy cover > 70% and miombo-

The resulting land-cover map comprised three types representing non-forest, miombo-
woodland and riparian forest, the latter two being the main chimpanzee habitats in the
GME. Distance from riparian forest was calculated such that each grid value reflected the
linear distance from riparian forest (riparian forest pixels getting a zero value). We used
these landscape features because chimpanzees are highly dependent upon trees, many of
which host important food sources (Nishida et al., 1983; Piel et al., 2017) and for their role
as shelter e.g. nesting sites (Stewart et al., 2011). We extracted elevation and distance from
steep slopes (> 20 degrees) from a Shuttle Radar Topographic Mission (SRTM) layer (30 m
resolution; http://earthexplorer.usgs.gov) (Pintea & Plumptre 2006; Jantz et al. 2016). We
included topographic measures because altitude has an influence on chimpanzee
distribution (Fitzgerald et al., 2018; Plumptre et al., 2010). Elevation may act as a proxy for
suitable climatic conditions, affecting nesting site preference and food resource
distribution (Jantz et al., 2016). Moreover, in western Tanzania, studies have shown that
nesting sites are associated with steep slopes (Hernandez-Aguilar, 2009; Pintea and
Plumptre, 2006; Stewart, 2011). We fitted all four variables at 60 m resolution and
accounted for chimpanzee responses to vegetation type at a larger scale by creating a new
layer reflecting the proportion of riparian forest within a 30.8 km² neighbourhood, using
focal statistics in ArcGIS Desktop. We used 30.8 km², as this represents the average home
range size based on three habituated chimpanzee communities in the GME (55km² at Issa,
Piel and Stewart, unpublished data; 27.4 km2 for M-group (MMNP), Nakamura et al., 2015
and 10km² for K-group (MMNP), Nishida, 2011). We did not include settlements or roads
as a predictor variable because of the difficulty of accessing reliable data for 1973. We
checked for collinearity by estimating the variance inflation factor (VIF; values>3
considered highly correlated predictors (Zuur et al. 2010)). We did not find
multicollinearity among our five predictor variables (VIF <1.3) and thus used all predictors
for further analyses.

141 *2.3. Land-cover change projections*

142 For future time periods, we used a model of predicted deforestation by 2027 developed for
143 the Ntakata REDD project (Shoch et al., 2019) which used Multi-Layer Perceptron neural
144 network to predict the likelihood of deforestation based on historical deforestation
145 occurring between 2007 and 2017. Predicted deforestation was used to create land-cover
146 map representing 2027 by reclassifying forest pixels mapped in 2017 to non-forest in 2027
147 where deforestation was projected.

148 *2.4. Habitat suitability modelling*

149 We decided to base our resistance values on a habitat suitability model, which is a
150 preferred alternative to expert opinion when empirical data on animal movement or
151 genetic distance are insufficient or not available (Beier et al., 2008; Stevenson-Holt et al.,
152 2014). To build our model, we used evidence of chimpanzee presence from surveys led by
153 GMERC between 2008 and 2020. By a combination of transects and reconnaissance walks
154 we have documented over 11 947 observations of chimpanzee presence (direct
155 observations, vocalizations, feces, feeding remains, nests, prints, and tools). For our
156 analysis, we removed vocalizations as chimpanzee calls can be heard up to 3km (Piel,
157 2014) and our modelling resolution is 60 m. In order to reduce spatial bias caused by
158 unequal sampling effort, we followed Kramer-Schadt et al.'s (2013) recommendations and
159 used spatial filtering and balancing of occurrence data, to reduce spatial autocorrelation.
160 For spatial filtering, we used Spatial Rarefy Tool in the SDM ToolBox v2.2 under ArcGIS
161 10.7 (Brown, 2014) to allow only one record per 60 x 60m. We chose this value to allow
162 sampling bias reduction and to keep a high spatial resolution on how landscape features
163 impact chimpanzee distribution. After spatial filtering, records were still heavily biased
164 towards the Issa valley, the GMERC long-term field site (Piel et al., 2015b). We thus further
165 reduced the number of records in Issa by randomly selecting 90 records to produce a
166 sample with the same density as the average density of the total covered area (Kramer-
167 Schadt et al., 2013). This resulted in N= 2 554 occurrence points used to train the final
168 model (Appendix S2, Fig. S2.1).

169 We used an ensemble of species distribution model algorithms because this approach
170 reduces the uncertainty associated with relying on a single method when projecting to a
171 different time period (Araújo and New, 2007; Buisson et al., 2010). We applied three
172 algorithms that have been shown to perform well when modelling species distributions:
173 Random Forests (RF), Generalised Boosted Models (GBM) and MAXENT (Elith, J. et al.,
174 2006; Elith and Graham, 2009). We used the default settings in the biomod2 package
175 (Version 3.3-7)] in the open-source software R (v. 3.6.1; http://www.R-project.org/) for
176 each algorithm (Thuiller et al., 2016)

177 We sampled 10 000 pseudo-absence records at random from the background extent,
178 excluding cells with previously removed true-presence points due to spatial filtering and
179 balancing of occurrences. We randomly divided the original dataset, using 70% to
180 construct the models and 30% to validate their accuracy. We replicated five runs to obtain
181 a robust estimate and tested accuracy using the Area Under the Curve (AUC). Only

182   models with AUC values equal to or greater than 0.9 were included in our final ensemble,
183   with the contribution of each model proportional to its goodness-of-fit statistics. The True
184   Skill Statistic (TSS) was also calculated for our final ensemble as an additional measure of
185   accuracy (Allouche et al., 2006).

186   We derived resistance values using a negative exponential function of the suitability
187   model output (Keeley et al., 2017, 2016; Mateo-Sánchez et al., 2015; Trainor et al., 2013).

188
$$r = \ 100^{1-SDM}$$

189   where r is the resistance value of a given cell and SDM is the suitability value associated to
190   the cell. This transformation takes into consideration that during long-distance movements
191   animals might be able to move through areas that would be classified as moderately
192   suitable in the home range.

193   *2.5. Circuit-based connectivity modelling*

194   We developed landscape connectivity maps using electricity circuit theory implemented
195   through Circuitscape 4.0.5 (Mcrae et al., 2008) using the pairwise mode which considers
196   conductance across all pairs of nodes in the study area. We decided to focus on circuit
197   theory rather than other commonly used modelling approaches (e.g. least-cost analysis)
198   because of its success to quantify animal movement and gene flow (Dickson et al., 2018)
199   and because of its ability to create a quantitative proxy of probabilities of connectivity
200   across an entire surface without the need to define focal patches. We followed the method
201   of Koen et al., (2014) to develop landscape connectivity maps that were independent of a
202   priori source or destination locations by randomly placing regularly distanced nodes
203   around a 40 km buffer perimeter (20% of the max length of the GME). To identify the
204   optimum number of nodes required to generate an unbiased landscape-scale permeability
205   map, we created 10 current density maps using 10–100 nodes at intervals of 10. We
206   selected 10 000 cells randomly in each current density map and used Pearson correlation to
207   compare estimates extracted from each current density map (i.e. 10 to 90 nodes) with
208   estimates from the full current density map (developed using 100 nodes). We considered
209   that our modelling was sufficient when the curve comparing correlation coefficients to the
210   number of node pairs reached an asymptote.

211   To help delineate the area of highest likelihood of chimpanzee movement, we selected all
212   pixels with the highest current density quartile (Vanthomme et al., 2019), which for the
213   purposes of this study, we term "current flow corridors". To test the sensitivity of the
214   identified corridors to the choice of our quartile threshold, we also used geometrical
215   interval classification and selected all pixels in the upper class (Ersoy et al., 2019) (resulting
216   maps are presented in supplementary material).

217   **3. Results**

218   The fit of the final chimpanzee habitat suitability model was 0.817 for TSS and 0.971 for
219   AUC, thus indicating a high level of predictive power. Predictive accuracy of individual
220   models ranged from 0.744 (+/-0.010) to 0.776 (+/-0.009) for TSS and from 0.937 (+/-0.004) to
221   0.950 (+/-0.003) for AUC, depending on the algorithm. On average, RF models performed

222　best compared to GBM and MAXENT models (Table. S1). The contribution of each
223　variable to the model was as follows: distance from steep slope (46.4%), distance from
224　riparian forest (31.6%), proportion of riparian forest (11.2%), elevation (6.1%) and
225　vegetation type (4.7%). The response curves produced by the model indicate that the
226　relative probability of chimpanzee occurrence decreases with distance from steep slopes as
227　well as with distance form riparian forest whereas it increases with proportion of riparian
228　forest. Regarding elevation, chimpanzees were most likely found between 1000 and 1850
229　m. Further, probability of presence was highest in riparian forest and lowest in non-
230　forested areas; miombo-woodland showed intermediate probabilities (Appendix S2, Fig.
231　S2.2).

232　Thirty node pairs were sufficient to generate unbiased connectivity maps (Appendix S2,
233　Fig. S2.3). The current density map derived from Circuitscape reflects relative probability
234　of movement, with areas of high current density representing higher probability of
235　movement. The GME appears to be connected by several current flow corridors facilitating
236　chimpanzee movement in 1973 (Fig. 2; Appendix S2, Fig. S2.4).

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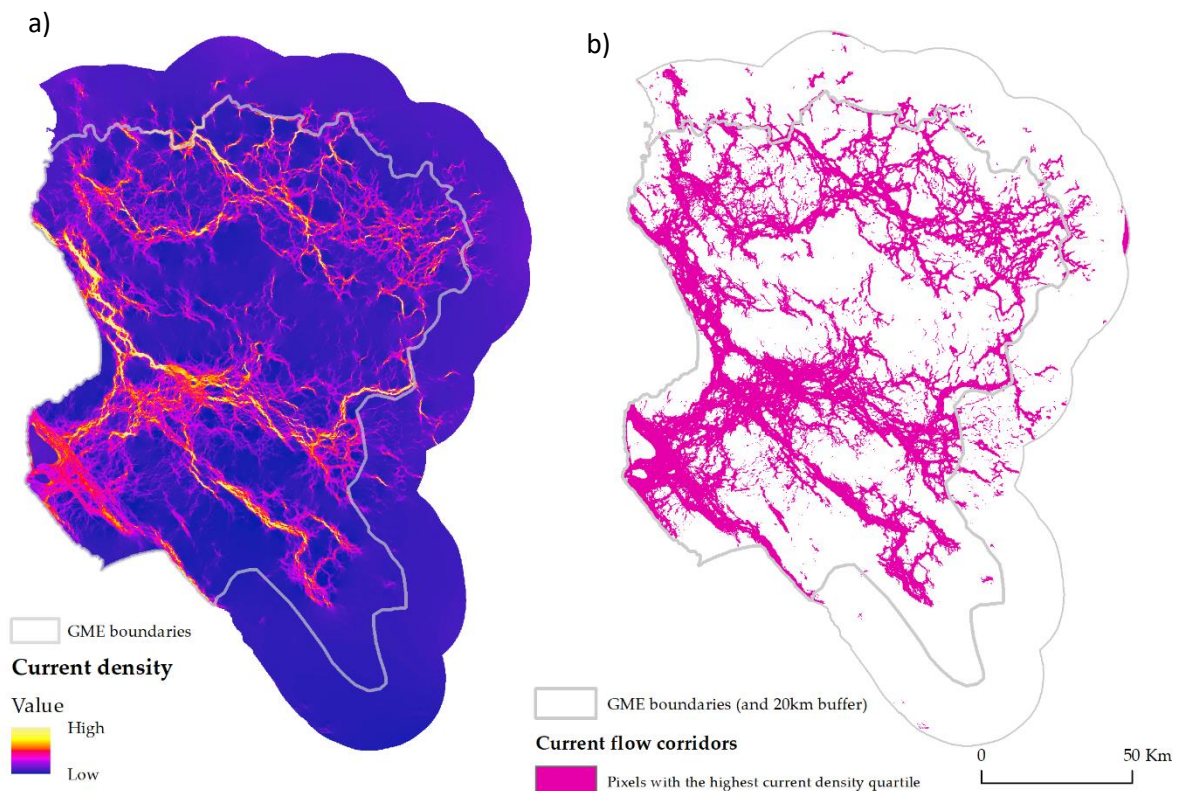
238

239　**Figure 2:** Habitat connectivity maps derived from Circuitscape for 1973 a) Current density
240　map, b) current flow corridors

241　Although the pattern of landscape connectivity remained broadly similar over time
242　(Appendix S2, Fig. S2.5), a reduction in current density is observed for 1 966.7 km²
243　between 1973 and 2019. This reduction is impacting both current flow corridors linking the
244　northern and southern GME (Fig. 3a). When projecting to 2027, we predict 2 152.3 km²

245 further decline, severely impacting the western current flow corridor linking the northern
246 and southern GME and affecting a large area in the south-east of the GME (Fig. 3b).
247 Increase in current flow is also observed for both time periods corresponding to
248 displacement of probability of movement.
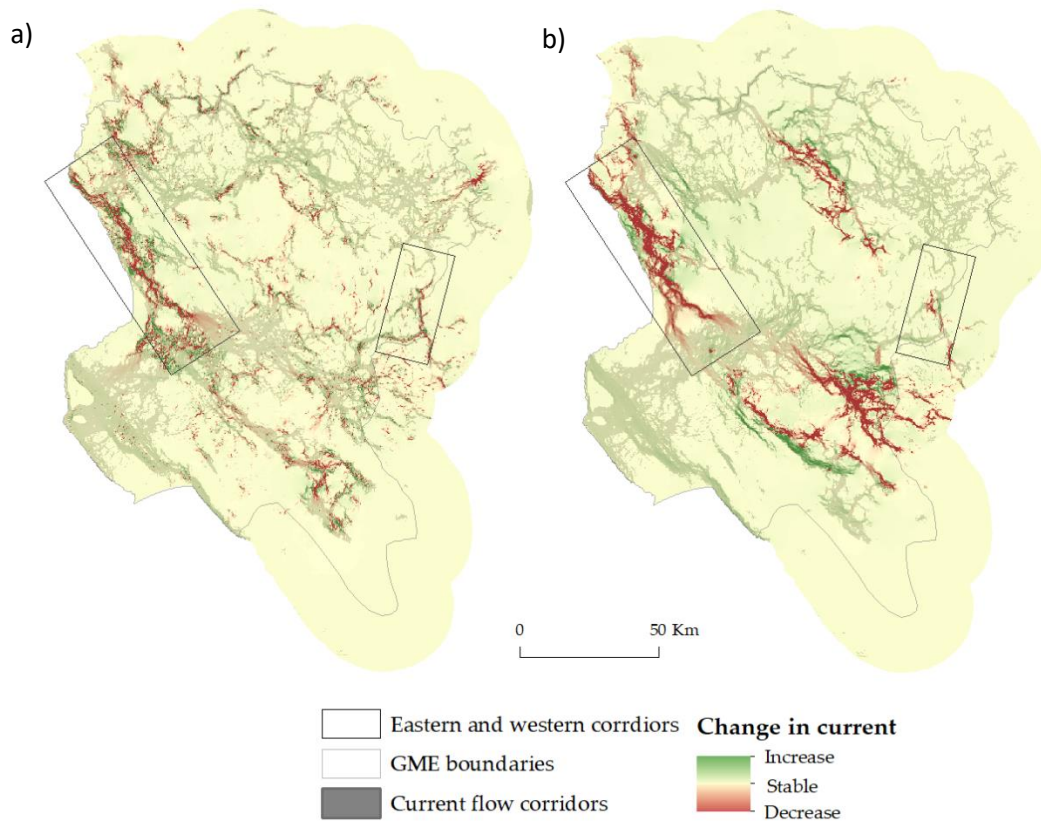
249
250 **Figure 3:** Current density change between a) 1973 and 2019, b) 2019 and 2027
251

4. Discussion

253 Landscape connectivity is of central importance to maintain population viability,
254 especially in increasingly anthropogenically disturbed landscapes. We used circuit theory
255 to assess chimpanzee habitat connectivity within the GME, an area containing nearly the
256 entire free-ranging population of Tanzania's chimpanzees (Plumptre et al., 2010). Our
257 results suggest that the ecosystem was linked by a series of corridors showing a relatively
258 high probability of chimpanzee movement in 1973. This result is consistent with previous
259 population genetic analyses suggesting recent gene flow throughout the GME (Inoue et al.,
260 2011). Our analysis also reveals a reduction of connectivity impacting the two current flow
261 corridors linking the northern and southern GME. Mishamo, a refugee settlement
262 established in 1981 to host 35 000 Burundian refugees was hypothesised to separate the
263 ecosystem or at least hinder chimpanzee movement between the northern and the
264 southern population of the GME (Moyer et al., 2006; Piel and Stewart, 2015; Rudicell et al.,
265 2011). However, our 1973 model shows that the central part of the ecosystem was already
266 unsuitable for chimpanzees prior to the establishment of this settlement (Appendix S2, Fig.
267 S2.6). This result is supported by Kano's (1971) early work on chimpanzee distribution in

Tanzania, when he reported no chimpanzees in the Lugufu basin (location of Mishamo establishment) following his extensive 1965-1967 surveys. The Lugufu Basin/Mishamo region is mainly flat and was dominated by Miombo-woodland and grassland (Bomans et al., 1981), whereas surveys indicate that chimpanzees select hilly areas with riparian forests (Hernandez-aguilar, 2006; Kano, 1972; Moyer et al., 2006; Ogawa et al., 2013; Piel and Stewart, 2014, this study). While the Mishamo refugee settlement expansion occurred outside of chimpanzee habitat, the impact of increased human population density cannot be overlooked. It is likely that the establishment of the refugee settlement and the arrival of tens of thousands of people to the region has increased pressure on forests through consumption of firewood, charcoal production, conversion of land for agriculture and poaching (Jambiya et al., 2007; Ogawa et al., 2013, 2006a, 2006b; Whitaker, 1999).

A survey led 40 years after Kano's first expedition reported a reduction in chimpanzee density in each revisited area within the GME, but no extinction of local populations (Yoshikawa et al., 2008). Following surveys from Piel et al. (2015a) reported similar pattern and found an overall decline in mean chimpanzee nest density between 2007 and 2014 in the northern GME (previously identified as the Masito-Ugalla Ecosystem, MUE) and an association between habitat loss and a decline in chimpanzee density. Our analysis of Landsat images reveals a total forest (i.e. riparian forest and miombo-woodland) decline of 1 677 km^2 between 1973 and 2017 (Fig. 4). Surprisingly, vegetation type contributes relatively little to our model (4.7%) and deforestation of miombo-woodland did not have a large impact on our landscape connectivity change. Instead, destruction of entire blocks of riparian forests were responsible for the observed reduction of connectivity between 1973 and 2017 and have disproportionately affected current flow corridors. Although travelling through more open miombo-woodland without nearby riparian forests may represent a higher risk of predation, miombo-woodland could still have been used by chimpanzees to a certain extent to reach sparsely distributed resources. The significant deforestation of miombo-woodland in the centre of the GME and settling of thousands of humans in the area is now likely to prevent any chimpanzee movements. This is particularly alarming given that the Shoch et al. (2019) model predicts another 2 426 km^2 of forest to be lost by 2027, threatening a large area in the south-east of the GME (Fig. 3b; Fig. 4). The consequences of habitat loss in this area will have a devastating impact on chimpanzees, not only reducing suitable habitat, but also an area of high movement probability. This area falls within the Ntakata REDD project boundaries, a project initiated in May 2017 with the goals of engaging and supporting local communities in the protection of their village land forest reserves (Shoch et al., 2019). By providing support for community patrols and monitoring by village game scouts, we are hopeful that this approach results in increased conservation of this large, critical area of for chimpanzees.
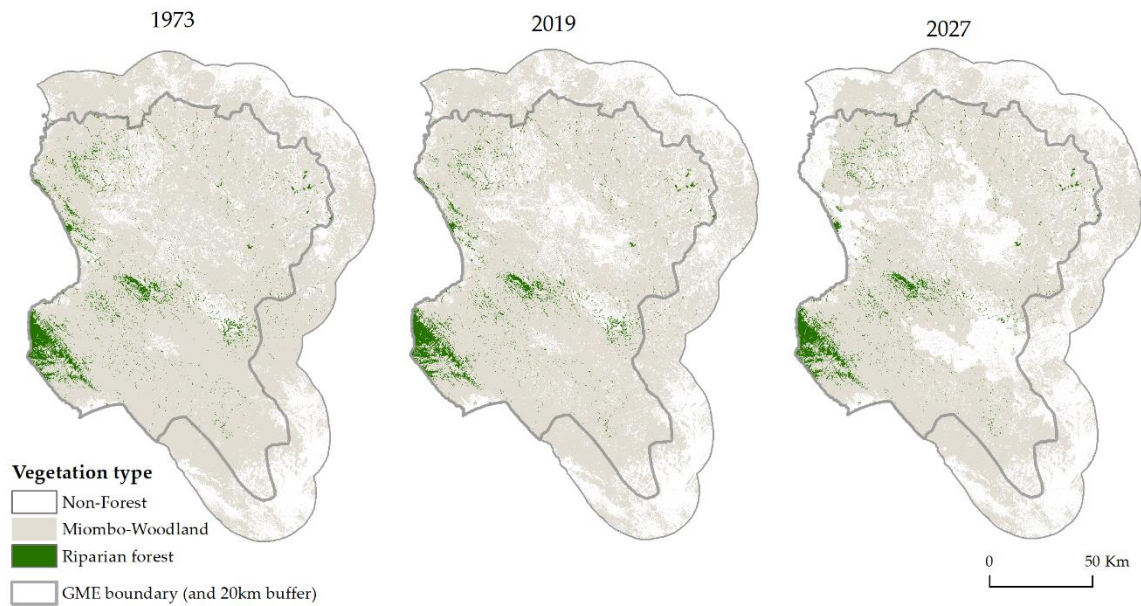
1973   2019   2027

Figure 4: Vegetation change from 1973 to 2027

Along with forest loss, the Mpanda-Uvinza road may have potentially played a role in the current density reduction within the eastern corridor. Splitting the ecosystem, the road crosses the only migration route available for movement of individuals from eastern MUE to the south (Fig. 5 Box b). Even though chimpanzees have been reported crossing and even using roads (Cibot et al., 2015; Hockings et al., 2006), roads can impede animal movement through mortality during crossing (McLennan and Asiimwe, 2016). Probably impacting chimpanzees more than the road itself, the associated deforestation enabled by easier access to forest resources is affecting habitat at a larger scale (Laurance et al., 2009; Palminteri et al., 2019; this study). Although this road was already established in 1973 (Kano, 1971), increases in traffic and other associated anthropogenic pressures may have negatively impacted animal movement. Chimpanzee presence has been reported on both sides of the road in the north of the ecosystem (Piel and Stewart, 2014), however, chimpanzee movement across the road still needs to be confirmed. Investigations into what extent this road and its associated land use change limit chimpanzee movement and thus gene flow will have important implications for conservation, especially because the (currently, dirt) road is now in the process of being paved (NB pers. obs). The Ilagala-Mahale road running to the west of the ecosystem may also have deleterious impacts on chimpanzee habitat and movement. Its construction in 2006 was correlated with a dramatic increase in forest loss and construction plans foresee an extension of the road to the south of MMNP (Palminteri et al., 2019). Our model highlights critical areas for chimpanzees and could be used for the development of detailed land use planning along the road. By establishing new village forest reserves and wildlife crossing structures across developing roads in these critical areas for chimpanzee movements we could help maintain movement and balance needs of local communities and chimpanzees (Gloyne and Clevenger, 2001; Lasch et al., 2011; Plumptre et al., 2010; TAWIRI, 2018).
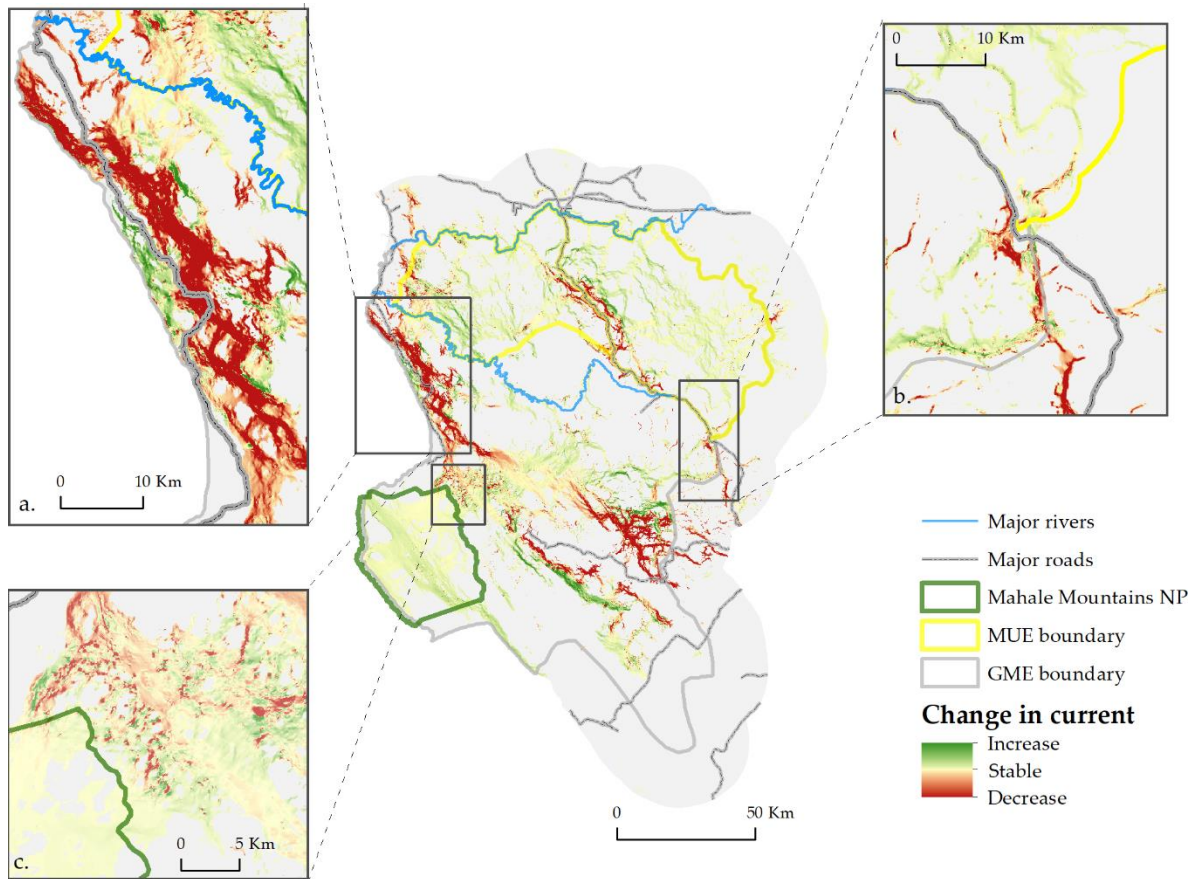
Figure 5: Priority areas to maintain connectivity for chimpanzee conservation within the GME. Background represents current density change between 1973 and 2027 within current flow corridors delineated for 1973. Box a. western corridor running through the Lugufu river; Box b. eastern corridor crossing Uvinza-Mpanda road; Box c. corridor allowing movement in/out Mahale Mountains NP

Large rivers may also act as barriers to animal movement (e.g. Eriksson et al. 2004). The GME is bordered by a large river, the Malagarasi, to the north, and segmented by the Lugufu river running through the north west of the ecosystem (Fig. 5 Box a). Inoue et al. (2013) proposed the Malagarasi river to be a major biogeographical boundary preventing chimpanzee movement into the GME from the north, however circumstantial evidence suggests that chimpanzees can move across the 100m wide river using natural, shallow fords, which together with further genetic evidence, suggests that the river does not form a complete barrier to gene flow (Piel et al., 2013). The Lugufu river is only 15 m wide (at its widest), and so may similarly allow some movement across it, especially in the dry season; however, more investigation is needed. Given the extreme seasonality of the ecosystem, with a six month dry season (<100 mm of rainfall/month), temporal variation of connectivity also remains to be examined. Variation of river flow and depth could result in temporal barriers to chimpanzee movement (Eriksson et al., 2004), but also affect the availability of water resources from smaller streams. Other resources such as plants also show important seasonal variation and are known to influence chimpanzee ranging patterns (Doran, 1997; Hasegawa, 1990; Wrangham, 1977). Adding phenological data (e.g.

resource availability) to our model would allow a better understanding of chimpanzee movement within this extremely seasonal ecosystem.

Here we chose to derive resistance values from habitat suitability modelling, which is recommended over expert opinion although often underperforms compared to direct movement data or genetic methods when sufficient genetic data are available (Beier et al., 2008; Stevenson-Holt et al., 2014). Less biased and more data-driven than expert opinion, habitat suitability modelling allow the creation of a more precise resistance surface at a fine-scale. However, our occurrence data are skewed towards sleeping sites, with nest locations comprising 81% of our presence points. This may explain the major contribution of steep slopes to our model as chimpanzee nests are often associated with steep slopes within the ecosystem (Hernandez-Aguilar, 2009; Stewart, 2011), whereas feeding and travel behaviour is likely not. Similarly, the importance of distance from riparian forest may represent sleeping site preferences although chimpanzees use miombo-woodland extensively for feeding and travelling (Hernandez-Aguilar, 2009; Nishida, 1989). Further work integrating genetic data (e.g. landscape genetic analysis) will help us better understand how landscape features impact chimpanzee movement across the GME.

Our models have confirmed historical connectivity throughout the GME and have highlighted priority areas for chimpanzee conservation in Tanzania. First, our results revealed potential corridors linking the northern and southern population of the GME (Fig. 5 Box a. and b). Additional ground surveys and genetic analysis could confirm whether chimpanzee movement is possible along this potential corridor and if there is genetic exchange. Our model also identified corridors to the north-east of MMNP (Fig. 5 Box c). Previous surveys have confirmed chimpanzee presence in this area in 2011-2012 (Piel and Stewart, 2014). However, as for the eastern and western corridors linking the northern and southern population of the GME, increasing anthropogenic pressure and associated deforestation is threatening this corridor. We recommend focusing conservation efforts on maintaining riparian forest, which is not only necessary for chimpanzee survival, but also essential for the provision of natural resources on which local livelihoods depend. Our model supports evidence of large areas within the GME that are suitable for chimpanzee habitat and movement. Preference of GME chimpanzees for steep terrain may have allowed their continued persistence, as such areas are difficult for humans to access and are less favourable for conversion to other land-uses (Heinicke et al., 2019; Kinnaird et al., 2003). By maintaining and possibly enhancing connectivity identified in this study and giving priority to those areas currently under threat, we are optimistic that Tanzania can continue to host a large viable population of chimpanzees.

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