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Locating elephant corridors between Saadani National Park and the Wami-Mbiki Wildlife Management Area, Tanzania

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Abstract

Although more than 40% of Tanzania mainland is managed for nature conservation, protected areas are increasingly becoming isolated because of rapid habitat degradation in the matrix in between. Knowledge on corridors connecting the protected areas is urgently needed. We assessed the area between Saadani National Park and Wami-Mbiki Wildlife Management Area, combining interviews about wildlife occurrences from 20 villages in the area with least-cost landscape modelling with African elephants (*Loxodonta africana*) as the focal species. The interviews suggested that, in contrast to earlier assumptions, migration of elephants or the presence of one or more independent elephant populations still exists in the unprotected area between Saadani and Wami-Mbiki. A combination of the interview results and multiple least-cost models showed three corridors in the area. The corridor along the Wami river is the most important one, the area between Miono and Mandera was identified as an impeding zone. Management decisions on the wildlife corridors to be protected will require further in-depth research in the three specified corridor zones. Apart from providing insights into elephant movement ecology, the approach may be useful for localizing corridors elsewhere in eastern Africa.

Key words: African elephant, connectivity, conservation, indigenous knowledge, least-cost modelling, Tanzania

Résumé

Alors que plus de 40% de la superficie de la Tanzanie sont gérés dans un but de conservation de la nature, les aires protégées y sont de plus en plus isolées à cause de la dégradation rapide des habitats dans la matrice qui les relie. Il faut d'urgence étudier les corridors qui relient entre elles les aires protégées. Nous avons étudié la zone située entre le PN de Saadani et l'Aire de gestion de la faune sauvage de Wami-Mbiki, combinant des interviews au sujet de la présence de la faune sauvage dans 20 villages de cette zone avec une modélisation à moindre coût du paysage, en utilisant les éléphants (*Loxodonta africana*) comme espèce focale. Les interviews ont suggéré que, contrairement à des hypothèses précédentes, la migration des éléphants existerait encore ou qu'il y aurait encore une ou plusieurs populations indépendantes présentes dans la partie non protégée comprise entre ces deux aires protégées. Les résultats des interviews et les multiples modèles à moindre coût ont révélé l'existence de trois corridors dans la région. Celui qui se trouve le long de la rivière Wami est le plus important, et il apparaît que la zone comprise entre Miono et Mandera constituerait une barriére. Les décisions en matière de gestion des corridors de faune sauvage exigeront d'autres études plus approfondies dans les trois corridors identifiés. Cette approche ne donnera pas seulement un aperçu de l'écologie des déplacements des éléphants, mais elle pourrait aussi être utile pour localiser d'autres corridors ailleurs en Afrique de l'Est.

Introduction

Worldwide, connectivity between protected areas is decreasing rapidly, leading protected areas to be at risk of becoming ecological islands (Soule, Wilcox & Holtby, 1979). Land conversion, artificial barriers, hunting and

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the transmission of diseases from domestic animals and humans to wildlife all play an important role in connectivity, but the ultimate drivers of protected area isolation in Africa are rapid human population growth, economic expansion, political misgovernment and poverty (Newmark, 2008). In Tanzania, more than 40% of the terrestrial surface area is managed for conservation under a protected area system (TNRF, 2012). Some of these protected areas are currently connected by ecological corridors through which exchange of wildlife takes place (Jones, Caro & Davenport, 2009a). Jones, Caro & Davenport (2009a) define a wildlife corridor as ‘an unprotected area between two or more protected areas either (i) through which animals are known or believed to move, (ii) that are connected by (or can potentially be reconnected by) natural vegetation, or both (i) and (ii) together’. However, many of these corridors are disappearing quickly (Newmark, 1996; Jones, Caro & Davenport, 2009a; Jones *et al.*, 2009b). Caro, Jones & Davenport (2009) conclude that nationwide surveys, acquiring knowledge on existing wildlife movement corridors, should be conducted as soon as possible, regardless of the quality of information on corridors and the difficulties in collating data; the lack of systematic evidence about corridors is less important when opportunities for habitat connectivity are being lost at such a fast pace. Several wildlife corridor conservation projects have already been undertaken in Tanzania (Baldus *et al.*, 2003; Kikoti, Griffin & Pamphil, 2010).

This study focuses on wildlife linkages between Saadani National Park and Wami-Mbiki Wildlife Management Area, for which the limited available documentation required further evaluation (Jones, Caro & Davenport, 2009a). We used two different approaches to investigate whether there is movement of mammals between both protected areas and, if so, where the corridor areas could be located. Participatory research (Kemmis & McTaggart, 2000) was used to gather the existing indigenous knowledge on animal movements. Least-cost models were used to model optimal corridor routes (Cushman *et al.*, 2013). Although Beier, Majka & Newell (2009) recommend using multiple and diverse focal species to design wildlife linkages, Epps *et al.* (2011) conclude that conserving African elephant’s movement corridors could effectively preserve habitat and potential landscape linkages for other large mammal species. As, in Tanzania, wildlife corridors are also often identified through their use by large charismatic species (Jones, Caro & Davenport, 2009a), for example African elephant and wild dog (*Lycaon pictus*) (Mduma *et al.*, 2012), this study focused on the former.

Methods

Study area

Gazetted in 2005, Saadani National Park (1100 km^2, below referred to as ‘Saadani’) is located along the Indian Ocean, 100 km north of Dar es Salaam. Conservation practices started in 1969 when the Saadani Game Reserve was constituted (Baldus, Roetticher & Broska, 2001). The Wami-Mbiki Wildlife Management Area (4000 km^2, ‘Wami-Mbiki’), located 50 km west of Saadani, was designated in 1997 and is an aggregation of areas of community land in which local people have usage rights over the wildlife resources (Wilfred, 2010). The study area encompassed a wide area between Saadani and Wami-Mbiki, including three administrative regions: Morogoro (SW), Tanga (N) and Pwani (SE). The area is intersected, north to south, by the Chalinze-Arusha Highway (A14) and numerous villages and settlements along the highway. The Wami is the most important river in the area flowing east through the centre of Wami-Mbiki towards the southern tip of Saadani. The climate is warm with a mean daily temperature of 25°C and mean annual rainfall of over 1000 mm. (TAWIRI, 2010).

Village interviews

We conducted interviews between 6 August and 13 September 2011 in twenty villages, with Saadani rangers and with managers of Kisampa camp, a private conservation area adjacent to Saadani. We focused on villages near the borders of both Saadani and Wami-Mbiki, near the A14 highway and near the Wami river. In each village, we interviewed members of the Village Natural Resources Committee and (around Wami-Mbiki) the game scouts. We used ‘semi-structured’ interviews (cf. Danielsen, 2008). These interviews start with a number of predefined, open questions, which could give lead to a discussion or new questions depending on the responses of the interviewees. With the help of a translator, we conducted the interviews in Swahili. The most important questions were which mammal species the villagers observed within the village boundaries and where and when most of the animals were seen. We also asked the interviewees if they knew whether there was a ‘path or route used by wild animals’ from their village to Wami-Mbiki or Saadani and if so, where the route was located and by which species it was used. If not, we queried interviewees about the factors preventing such animal movement.

The results from interviews differed in quality or credibility, for instance because few people were present or because many of the interviewees turned out to be not very knowledgeable about the presence or movement of animals. To account for this difference in quality, we introduced a 'credibility score' based on criteria-based content analysis (Steller, Koehnken & Raskin, 1989). This assessment is based on several criteria such as the interviewees' professional activities, the accuracy with which they could differentiate between two resembling species or how sure they were about the routes they mentioned. The score varies between 1 (unreliable) and 3 (very reliable).

We asked the villagers to indicate on a map places where animals were seen within their village land and places where animals are presumed to go. When no information was available on the location of migrating animals inside the village boundaries, the centre of the village was used. To create a map with interview corridors, we connected all locations mentioned by straight lines. Because of this approach, the location of the interview corridors on the map is nor quantitative nor spatially explicit, and most corridors between Saadani and Wami-Mbiki are composed of several partial stretches, mentioned by different villages. The width of the corridor on the map represents its likelihood score, calculated as the sum of the credibility scores of the villages where the corridor (stretch) was mentioned.

Least-cost modelling

Least-cost modelling (LC, we used Cost-Distance in ArcGIS 9.3 (ESRI, 2008)) is an approach to calculate 'effective distance', a measure for distance modified with the cost to move between habitat patches based on detailed geographical information on the landscape as well as behavioural aspects of the organisms studied (Adriaensen *et al.*, 2003; Cushman *et al.*, 2013). In an LC model, the ecological cost of moving through a specific land-use class is translated into a landscape resistance map. To create an integrated land-use layer, we combined several GIS layers, each representing specific aspects of the landscape that may be relevant for the movement of elephants through the area, in one raster map. In the resistance map, each grid cell (0.0001 degrees, i.e. approximately 10 m) has to be assigned a resistance value, representing the permeability of the land-use class for the movement of an elephant. Ideally, assigning resistance values (R) to specific land-use classes should be based on empirical data on dispersal of the focal species through all possible landscape elements, or derivatives thereof (cf. Zeller, McGarigal & Whiteley, 2012; Cushman *et al.*, 2013). However, such information is lacking for the African elephant. Therefore, we assigned all resulting land-use classes to one of six conceptual resistance classes ranging from prime movement habitat to full barrier (Table 1). We did not weigh resistance values for the presence of other landscape elements (cf. Beier, Majka & Spencer, 2008), but a set of rules determined whether a layer's resistance class (see below, Results) had priority over the resistance class based on underlying layers, and the grid cell changed resistance class accordingly. We assigned this resistance class based on a literature study (Appendix S1) and the personal opinion of experts in elephant ecology. In turn, we attributed a fixed set of resistance values, ranging from 1 to 2000 (Table 1) to the six resistance classes to create the resistance layer. We asked the experts to assign a resistance class to each of the land-use categories, depicting the relative cost for the African elephant to travel through or just to be in that landscape element, including an indication of their level of confidence (1–5, 'guessing' to 'very sure'). We assigned the final consensus resistance classes based on a weighted average of the resistance classes based on the literature and determined by the experts. Because literature-based models are known to perform better than expert-based models (Clevenger *et al.*, 2002), we gave the literature-based set of resistance classes twice the maximum confidence weight (10). Besides a resistance map, the LC model also requires a source map. We used four source points, located in areas known to have high elephant activity (A. Kikoti, pers.

Table 1 Resistance classes and values (R)

Rank	*R*	Resistance class
1	1	Prime movement habitat
2	5	Secondary habitat for movement
3	20	Limited negative influence on movement, but is not preferred either
4	100	Impeding effect on the movement
5	500	Strong impeding effect on the movement (barrier)
6	2000	Impermeable (full) barrier

comm.): one in Wami-Mbiki and three in Saadani (North, Centre and South).

The basic outcome of an LC model is a cost layer in which the value of each cell is defined as the least effort (minimal cumulative cost) in moving over the resistance layer to the source patch/cell or *vice versa*. The least-cost value is a measure for the overall landscape resistance of the total trajectory between two patches in the landscape (the 'least-cost path') or the effort an individual has to exert to move between both patches (Adriaensen *et al.*, 2003). The cost and length of the least-cost path can be used to compare model outcomes. However, because least-cost paths do not give any indication of variation in values around the path or elsewhere in the landscape, we calculated a corridor layer (Cushman *et al.*, 2013). In a corridor layer, the value of each cell represents the minimal cost to move, via that cell, from the source area to a defined target area (not to the cell itself). In a relative corridor layer, cell values can be percentages above the (minimal) value of cells in the least-cost path itself. In all corridor maps, we presented functional corridors as zones with values maximum 5% above the least-cost path value. Zones with higher cost values are considered to have a lower chance of being part of functional corridors and are therefore considered less suitable for conservation planning (cf. Adriaensen *et al.*, 2007).

Results

Village interviews

Elephant sightings were reported in nineteen of the 21 interview locations (90.5 per cent), mostly in the wet season and especially in or around the village forest. In most of these villages, elephants were seen during the latest wet season or more recently. Villages where the latest sighting dated from longer ago were all located close to the A14 highway (Fig. 1). Many of the interviewed villages indicated that elephants migrate towards Saadani (60 per cent of the villages) and Wami-Mbiki (65%, Table 2).

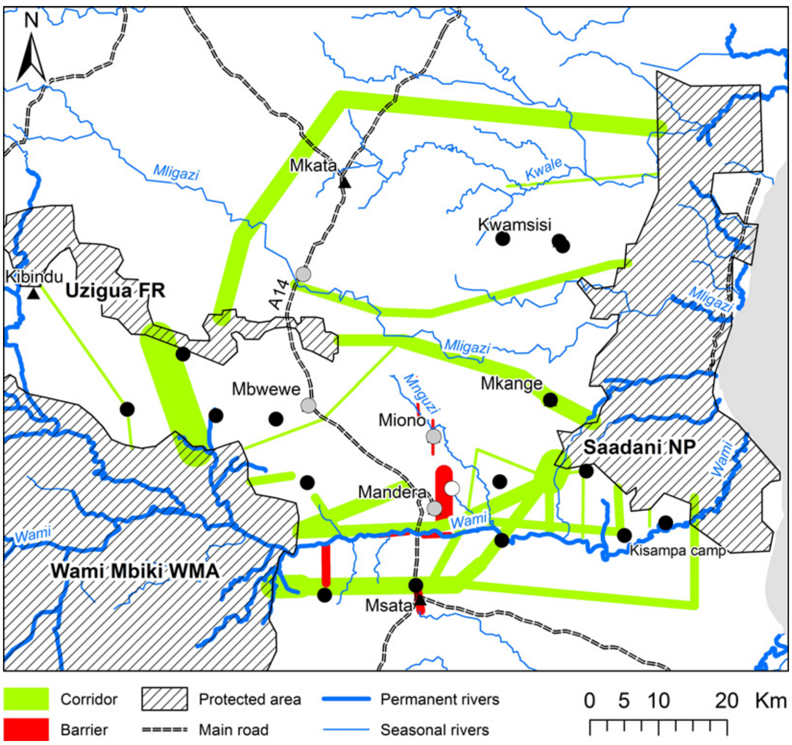

Fig 1 Study area including Saadani National Park, Wami-Mbiki Wildlife Management Area and Uzigua Forest Reserve. Elephant corridors and barriers according to the interviewees. The thickness of the vectors refers to the likelihood score (see text). Only ward villages are named (triangles). All interview locations are indicated: no elephants reported (white dot), elephants seen recently (black dots) and last elephant sightings dating from before the last wet season (grey dots)

Table 2 Overview of the answers to the questions concerning the presence and movement of elephants

Question		Pongwe Msungura[a]	Pongwe Kiona[a]	Kifuleta[a]	Kwaruhombo[a]	Kwamsanja[a]	Mihuga	Mandera	Gongo	Matipwili	Kihangaiko	Mkoko	Mbwewe	Miono	Kwamduma	Kisampa	Mkange	Kwamsisi	Kwedikabu	Pozo	Manga
When do you see the elephants most often?	Wet season	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X		X	X	
	Dry season								X	X		X				X		X			X
Where do you see most of the elephants?	Forest			X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Farmland	X	X	X	X	X			X			X	X								
	Bush											X	X					X	X		
When was the last time you saw an elephant?	'you can see them even now'					X	X		X	X	X	X				X		X	X		
	Week ago		X	X											X						
	Last wet season	X			X												X			X	
	Longer ago							X					X	X							X
Are there elephants migrating to or from SNP?		N	Y	N	D	N	Y	Y	Y	Y	D	Y	N	Y	Y	D	Y	Y	Y	Y	N
Are there elephants migrating to or from WM?		Y	Y	Y	Y	Y	N	Y	D	Y	Y	D	Y	Y	Y	Y	N	D	Y	D	N
Do elephants cross the A14 highway?		N	Y	N	D	N	Y	Y	Y	Y	Y	D	Y	Y	Y	D	N	Y	Y	D	N
CREDIBILITY		2	3	1	3	1	3	2	1	1	1	2	1	1	2	2	1	1	3	1	1

Y, yes; N, no; D, don't know.

Note that the village of Kilemera was excluded, as the interviewees could not give any information concerning elephants.

[a]Villages also interviewed by Danielsen (2008), only for Kifuleta we have different results concerning movement towards Saadani.

Based on the interviews, three main elephant corridors can be identified (Fig. 1). One starting in the south of Saadani and following the southern as well as the northern bank of the Wami river. The second one, starting in the centre of Saadani, follows the Mligazi river towards Uzigua Forest Reserve. The last one starts in the north of Saadani, continues west along the Kwale river and its tributaries, and after it passes the A14 north of Mkata it continues south to Wami-Mbiki via the Uzigua Forest Reserve. The Miono-Mandera-Mbwewe triangle was indicated by the interviewees as a zone that obstructs wildlife movement. Interviewees in Mandera thought that animals were not able to pass the Wami in the wet season, and interviewees in a village near Msata said never to have seen animals near the river.

Least-cost model

As habitat preferences of African elephants change during the season (Loarie, van Aarde & Pimm, 2009; Mpanduji, East & Hofer, 2009), we created resistance maps for both dry and wet season (Table 3). In the land-use layer, we included information on land cover, roads, rivers and protection areas (Appendix S2, Table S1). For rivers, we made a distinction based on their effect on animal movement; a (relative) physical barrier ('Rivers') on the one hand and a source of water ('River buffer') on the other hand. The literature and experts agreed on the importance and relevance of the aspects used in this layer ('Land cover', 'Roads', 'Rivers', 'River buffers' and 'Protection status'); we therefore used it to make the consensus model (C). Next, we made two more models, each including the previous layer plus, respectively, 'Slope' and 'Human disturbance' (C + S and C + HD). Because at , present elephant movement seems to be driven by human disturbance rather than by land cover (cf. Graham *et al.*, 2009; Epps *et al.*, 2013) we made an additional model (HD) with only 'Human disturbance' and 'Protection status' with a separate set of resistance values and no seasonal effect (Table 3).

Table 3 Consensus resistance classes and rules for both wet and dry season

	Wet	Dry		Wet	Dry
Land cover			Roads		
Bare ground	100	100	Main road	500	500
Crop[a]	20	20	Trail	20	20
Crop (irrigated)	20	20	Rivers		
Crop (rice)	100	100	Permanent river	500	100
Crop (sisal)	100	100	Seasonal river	100	−1 rank
Closed forest	5	5	River buffers		
Evergreen forest	5	5	Permanent river buffer	−1 rank	−2 ranks
Open forest	1	1	Seasonal river buffer	−1 rank	−1 rank
Grassland	1	5	Protected area		
Open marsh	20	5	Protected area	−1 rank	−1 rank
Marsh + shrub	20	5	Slope		
Marsh + tree	20	5	15°–30°	+1 rank	+1 rank
Shore	100	100	>30°	2000	2000
Natural shrub	5	5	Human disturbance		
Salt marsh + shrub	100	20	>40% cultivated	=*R* 'crop'	=*R* 'crop'
Salt marsh + tree	100	20	15–40% cultivated	−1 rank	−1 rank
Urban	500	500	Human disturbance only model		
Woody	5	5	Protected area	1	
			Noncultivated area outside protected area/cultivated area inside protected area	5	
			15–40% cultivated	20	
			≥40% cultivated	100	

[a]Because of less consensus on the resistance values of 'crop', we did run the models with the value for crop one rank up/down (R = 100 and 5), which did not change the qualitative characteristics of the resulting functional corridors (results not shown).

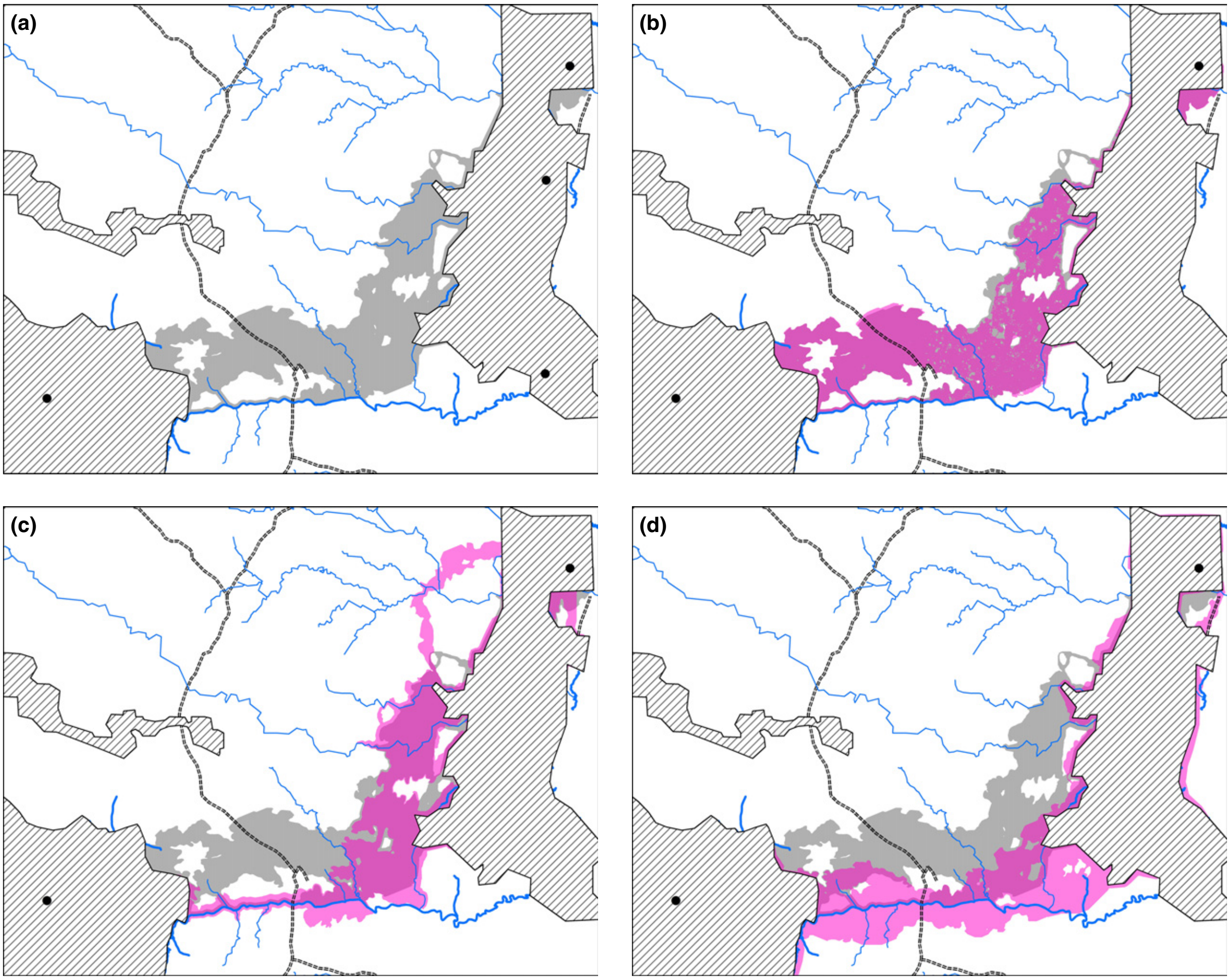

Fig 2 Five per cent corridors (ESRI, 2008; Cushman *et al.*, 2013) for the wet season models going to Saadani North (northernmost point; for reference, source points Saadani Centre and South are indicated in 2a). (a) consensus model only (grey in all four maps); (b) consensus model and consensus + slope model (purple); (c) consensus model and consensus + human disturbance model (purple); (d) consensus model and human disturbance only model (purple). For corridor maps of all models, see Appendix S3, Supporting Information

Corridor maps

Figure 2 shows the 5% corridors for the wet season models going from Wami-Mbiki to Saadani North. Complete corridor maps towards all three sources in Saadani are shown in Appendix S3. The values of the least-cost paths of all models are summarized in Table S2. To quantify the effect of the addition of both 'Slope' and 'Human disturbance' to the consensus model, we calculated the average overlap of the corridors outside protected areas for the C versus the C + S and C + HD model and for the C + HD versus the HD model. In all C models, there was a wide functional corridor zone running east-west between Miono and Mandera and a narrower one along the Wami river (Fig. 2a). Besides a slight increase in cost values, adding 'Slope' to the C model resulted in strongly overlapping corridor zones (C/C + S 90.53%, C + S/C 97.39%; Fig. 2b,). In the C + HD models (Fig. 2c), all corridors in general followed the Wami river. In contrast to the previous models, the human disturbance models avoided the area between Miono and Mandera, resulting in a reduced overlap of both models (C/C + HD 43.28% and C + HD/C 66.59%). The human disturbance only models (Fig. 2d) showed the same pattern as the C + HD models, but have a wider 5% zone (C + HD/HD 62.52%, HD/C + HD 42.49%).

Discussion

Based on interviews with Saadani park rangers and villagers at Saadani village and Matipwili, Sumerlin & Gritzner (2007) concluded that there could be elephant movement following the Wami river to the west. Unpublished data from interviews conducted in the study area from 2003 to 2007 suggest that the most important corridor is located in the area along the Mligazi river (C.L. Nahonyo, pers. comm.). In 2009, on the other hand, the Saadani–Wami-Mbiki corridor was expected to be in an extreme condition ('probably less than 2 years remaining', Jones, Caro & Davenport, 2009a), based on interviews in five villages north-east of Wami-Mbiki (Danielsen, 2008). Our interviews in the same villages confirmed this, except for one village (Kifuleta) where respondents now do believe there is animal movement towards Saadani (Table 2).

Our results were similar to those from interviews conducted by Jones *et al.* (2009b) in the Nyanganja corridor. Eighty per cent of the respondents reported elephants on their farms in 2009 (in our case 90%, within the village boundaries). In both studies, most animals were seen in the wet season, and only about 30% reported wildlife conflicts. Based on this low perception of conflict compared with the percentage reporting elephants, Jones *et al.* (2009b) suggested that the elephants mostly travel rapidly across the area, without pausing to raid crops. Our results, showing that elephants were reported to be seen in nineteen of the 21 interview locations and several routes were described, contrast with the conclusion by Danielsen (2008), who considered this corridor as good as closed. As preliminary data show that over 80% of elephants collared in Wami-Mbiki and Saadani were confined within the protected areas (Kikoti, 2011), our results could suggest that there may be one or more independent elephant populations in the unprotected area between Saadani and Wami-Mbiki (which is not uncommon in Tanzania, cf. Kikoti, 2009).

All models studied show a functional corridor along the Wami (as was also reported by Sumerlin & Gritzner, 2007), indicating that the Wami corridor holds a very strategic position in maintaining connectivity between Saadani and Wami-Mbiki, and maybe even suggesting that it could be sufficient for all elephant populations in Saadani, even for populations that start their movement in the north of the national park. All models show a functional corridor around the Wami between Wami-Mbiki and the area east of the Mnguzi river, while only in some C + HD models, the 5% zone extends further downstream (Appendix S3).

The Mligazi river corridor from the interviews is visible as a zone of moderate, but lower than the surrounding landscape, cost in the C and C + S models running towards central and northern Saadani. In contrast, the Mligazi corridor is a zone of high resistance in the C + HD models. This is due to the presence of agricultural area in that zone, which is considered a proxy for human disturbance in the C + HD models. The area of the third corridor, according to the survey following the Mkwale river, could not be considered as functional corridor area according to any of the LC models. In this respect, it is also important to note that the Uzigua Forest Reserve was not used as a source patch in our models, while for elephants, it can perhaps still serve as a source patch or important stepping stone. All C and C + S models show a relatively wide functional corridor in the zone between Miono and Mandera. This contrasts strongly with the results of the interviews in which this zone was identified as a barrier to wildlife movement. However, in all C + HD and HD models (including human disturbance), this area is indicated as a high-cost zone. In contrast to other studies (e.g. Epps *et al.*, 2013), slope did not play a crucial role in the location of corridors. This can be due to characteristics of our study area with only scattered peaks (scattered patches of high resistance are known to have little impact on cost layers, Adriaensen *et al.* (2003)), and we would therefore advise including this factor when analysing other study areas. Because elephants are mostly observed in wet season, it could be sufficient to focus on the wet season models.

To conclude, based on interviews, three corridors may be present in the area between Saadani and Wami-Mbiki: a corridor along the Wami, which was also predicted by all LC models, a corridor along the Mligazi river predicted by models without human disturbance only, and a corridor along the Mkwale river not shown in any of the LC models. The human disturbance models also predicted the barrier zone between Miono and Mandera. This again shows the importance of running multiple scenarios to evaluate the sensitivity of the models for different aspects of the landscape (cf. Beier, Majka & Newell, 2009). A discussion of the current threats and potential protection for each corridor falls beyond the scope of our study and would require additional information on, for example socio-economic and political aspects. Management decisions on the wildlife corridors to be protected will require further in-depth research in the three specified corridor zones.

Given the importance of human disturbance, land-use planning in cooperation with local communities and community-based protection will be an indispensable step in the conservation of corridors (Goldman, 2003, 2009; Schuerholz & Baldus, 2007; Kaswamila & Songorwa, 2009; Jones *et al.*, 2012). Our study has shown that least-cost modelling, validated by village interviews, may be a useful and timely tool to localize wildlife corridors.

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Supporting information

Additional Supporting Information may be found in the online version of this article:

Appendix S1 Literature study: consulted papers.
Appendix S2 Least – cost model.
Appendix S3 Results Least-Cost models.
Table S1 GIS theme layers used to construct the land-use map.
Table S2 Values and length of the least-cost paths of each model. The length is expressed as the number of grid cells (0.0001 degrees wide, i.e. approximately 10 metres).