Biological Conservation 142 (2009) 2807–2811

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Short communication

Realities of documenting wildlife corridors in tropical countries

Tim Caro [a,b,*], Trevor Jones [c,d], Tim R.B. Davenport [e]

[a] Department of Wildlife, Fish and Conservation Biology, University of California, Davis, CA 95616, USA
[b] Tanzania Wildlife Research Institute, P.O. Box 661, Arusha, Tanzania
[c] Udzungwa Ecological Monitoring Centre, P.O. Box 99, Mang'ula, Tanzania
[d] Animal and Environmental Research Group, Department of Life Sciences, Anglia Ruskin University, Cambridge CB1 1PT, UK
[e] Wildlife Conservation Society, P.O. Box 1475, Mbeya, Tanzania

ARTICLE INFO

Article history:
Received 10 March 2009
Received in revised form 1 June 2009
Accepted 10 June 2009
Available online 5 July 2009

Keywords:
Connectivity
Protected areas
Tanzania
Wildlife corridors

ABSTRACT

Connectivity is regarded as vital in conservation planning but the whereabouts of remaining wildlife corridors and dispersal areas in most tropical countries are poorly documented. With local experts, we compiled an annotated list of the most important wildlife corridors remaining on mainland Tanzania, information on the status of each corridor, wildlife using these corridors, and threats to them. We discovered that the concept of a wildlife corridor differs greatly between different people working in the same country, so we divided these into five working categories. The most common categories were those identified by known movements of animals between two protected areas, or simply proposed connections between important habitats. In Tanzania, the majority of documented corridors now seem to be in a critical condition, that is, they may have less than 5 years remaining before they disappear, judging by current rates of land use change. Five corridors are in extreme condition and could disappear within 2 years unless immediate action is taken. These pressing problems – and our experience in Tanzania – indicate that surveys of remaining wildlife corridors may need urgent documentation in other countries too and that collators should maintain loose definitions of corridors, accept data of variable quality and give information to authorities as soon as possible in order to maximize the chances of saving these conservation assets.

1. Introduction

Terrestrial wildlife corridors are usually defined in two ways, either functionally as an area used by animals to pass from one 'habitat patch' to another; or structurally, as an area that connects two patches of suitable habitat by passing through a matrix of unsuitable habitat (Hilty et al., 2006). Wildlife corridors may be important for five reasons. (i) If an animal or plant population declines to a low level or becomes extinct in one area or habitat patch, individuals from another patch can immigrate and rescue that population from local extinction. (ii) If a small population is isolated, it can lose genetic variation over the long term and suffer from inbreeding. A corridor allows immigrants to import new genetic material into isolated populations. (iii) A corridor increases the area and diversity of habitats over and above the area of the two habitat patches that it connects. (iv) If the habitat of one area becomes unsuitable (e.g., because of climate change), organisms (both plants and animals) can move along corridors to reach more suitable habitat, and in a sense be 'rescued'. (v) Some protected areas do not encompass the range of ecosystem requirements needed by certain species. Migrating species, for example, move outside and/or between protected areas and may use corridors for this purpose (Dobson et al., 1999; Crooks and Sanjayan, 2006).

While conservation scientists recognize the importance of connectivity for wildlife (Beier and Noss, 1998), specific information on major nationally important wildlife corridors is often widely dispersed because knowledge resides with research scientists, protected area managers and local people who have little contact with each other. It is therefore very difficult for central government authorities to gain a comprehensive picture of wildlife corridors to formulate and prioritize policies (Sanderson et al., 2006).

In Tanzania, a megadiversity tropical country (Mittermeier et al., 2003), many protected areas are rapidly becoming isolated (Newmark, 2008). The reasons behind this include a growing human population and concomitant land use shifts towards agriculture, infrastructure, and settlement in previously unpopulated areas. Yet at the same time, people depend increasingly on protected areas for the ecosystem services that they provide (e.g., clean and abundant water for domestic, agricultural and industrial use, hydroelectricity) and are benefiting from revenue generated by protected area tourism. Since the opportunities for establishing, maintaining or managing corridors between protected areas are

* Corresponding author. Address: Department of Wildlife, Fish and Conservation Biology, University of California, Davis, CA 95616, USA.
E-mail address: tmcaro@ucdavis.edu (T. Caro).

0006-3207/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biocon.2009.06.011

rapidly diminishing, and information on remaining wildlife corridors is being lost as historical animal movements are forgotten, we tried to document remaining corridors using expert opinion and grey literature. This exercise resembles Noss and Daly's (2006) "seat of the pants approach" which uses intuitive and opportunistic methods of assessment, based on subjective best guesses, existing knowledge or expert opinion. Specifically, we set out to compile a comprehensive list of all the remaining wildlife corridors in Tanzania to highlight the challenges and opportunities faced in connecting protected areas across the country (Jones et al., 2009). In so doing, we uncovered a number of salutary points that pertain to identifying corridors at a national scale, and which should therefore be of interest to others embarking on such large scale analyses.

2. Methods

We introduced the idea of collecting information on wildlife corridors to attendees of the December 2007 Tanzania Wildlife Research Institute Conference in Arusha, Tanzania. Email requests were also sent out opportunistically to government officers, university research scientists, NGO personnel and conservation area managers across the country for information on the location, status, use and threats to each corridor. We expanded our list of contacts (and corridors) as information accumulated. In the few situations in which we received no response we went to grey literature. On the basis of these reports, we subjectively classified corridors into *Extreme* denoting probably less than 2 years remaining; *Critical*, probably less than 5 years remaining; and *Moderate*, less than 20 years remaining.

3. Results

3.1. Types of wildlife corridor in Tanzania

We found that wildlife corridors are discussed in five different ways by wildlife managers, scientists and interested parties in Tanzania; these probably apply in other tropical countries too. We placed each corridor described from mainland Tanzania into one of these categories (Jones et al., 2009), and the criteria are elucidated below and in Table 1.

A. Unconfirmed corridors. These are the most poorly documented type of corridor. They consist of two sub-categories: (a) known historical migration routes of particular species, usually elephants *Loxodonta africana*, where it is unclear if these routes are still in use or (b) the shortest distance between two protected areas across which animals could travel. In contrast to the next two categories, current land use is not taken into account.

B. Uncultivated lands between protected areas without documentation on animal movement. These are usually patches of natural vegetation that lie between two protected areas, or sometimes a string of lightly protected forest reserves or wildlife management areas (see Caro et al., 2009) between larger protected areas. For almost all such corridors, it is not known whether any population actually uses them to move between the protected areas. Furthermore, habitat suitability and population sizes of species living in these corridors are unknown. Such corridors may, however, be essential in the future if habitat in one of the protected areas becomes modified and/or unsuitable, for example through climate change, oil exploration or mining. These areas may also be very important for wildlife already, e.g., forest-dwelling birds that will not cross open spaces (Newmark, 2006), but this is not yet documented.

C. Continuous or semi-continuous uncultivated land between protected areas with anecdotal information on animal movements. These consist of uncultivated patches or networks of one or more forest reserves that lie between two larger protected areas. Additionally one or more species are believed to move through them, although there are no systematic observations. In Tanzania, this type of corridor often focuses on elephant movements.

D. Known animal movement routes between two protected areas. Irrespective of habitat (and therefore in contrast to C), documented movements of large animals, usually elephants, across a habitat that connects two protected areas; the habitat may be legally protected, or agricultural land, or both. Information is obtained from transect surveys or by radio telemetry as reported in the conventional or grey literature, or by personal communication in the case of ongoing unpublished research.

E. Potential connectivity of important habitats. Formally proposed corridor areas linking fragmented or threatened habitat patches that contain endangered species as specified by an NGO or government agency. A lack of cultivation between patches, usually highland forest, is often a key factor in corridor identification (in contrast to A (b)). Management of such corridors may involve forest restoration projects.

3.2. Characteristics of wildlife corridors in Tanzania

We documented a total of thirty-one wildlife corridors (Table 2 and Fig. 1). Their location was somewhat biased towards places where research has been more concentrated, hence there were a number in the Eastern Arc Mountains and the northern savannas. We found that 16.1% were type A (unconfirmed), 3.2% were type B (land connection), 12.9% were type C (land connection plus movements), 41.9% were type D (known routes) and 25.8% were type E (proposed). Five were classified as in extreme condition, 18 as critical and eight as in moderate condition.

4. Discussion

This compilation of all the major wildlife corridors in a tropical country, Tanzania, highlights three issues. First, the concept of a wildlife corridor differs greatly between different people and it includes shortest routes, only remaining routes, routes based on expert knowledge of certain species, and observations of animal sign. This parallels Noss and Daly's (2006) discussion of the ways in which corridors are identified in the real world. They highlighted the following methods: (i) the most direct logical route between

Table 1
Requisite information to categorise types of corridors described in this study.

Type of corridor	Requires information on wildlife habitat	Requires anecdotal information on animal movements	Requires systematic information on animal movements	Formally proposed by agency
A. Unconfirmed		X		
B. Land connection	X			
C. Land connection plus movements	X	X		
D. Known routes		X	X	
E. Proposed	X			X

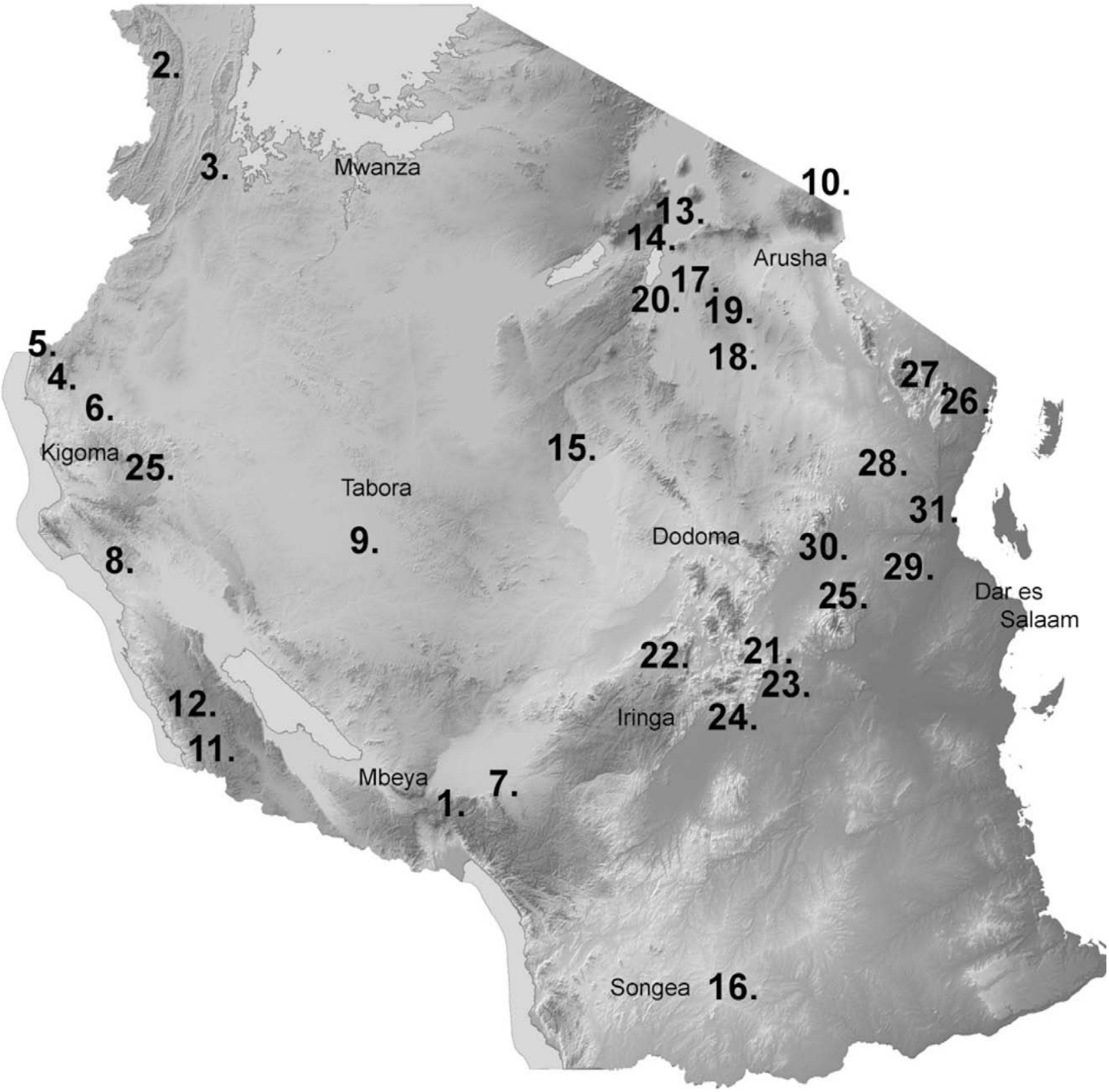

Fig. 1. Summary map of locations of wildlife corridors in mainland Tanzania.

core areas, (ii) the only remaining routes in highly modified landscapes, (iii) routes that incorporate sites of conservation interest, (iv) routes based on expert knowledge of particular species, and (v) combinations of expert-based approaches that incorporate several species' movements, conservation opportunities, landscape data, and consideration of ecological processes. Our categories lean heavily on their approaches (i) and (iv) but also include (ii), e.g., Manyara–Ngorongoro, and (v), e.g., several highland forest corridors. Our exercise also includes their empirical approaches that rely on animal presence, movements and signs, and occasionally radio telemetry but do not yet involve modeling techniques such as least-cost path analysis or routes based on spatially explicit population modeling. Such methods may, however, be employed as specific corridor management strategies are developed. Our main message is that using several locally relevant definitions of what constitutes a corridor is very helpful; for example, elephant movements were an important component in the Tanzanian context.

Second, we found that most corridors in Tanzania are in the category of known animal movement routes between two protected areas (type D), or are proposed connections of important habitats (type E); in Tanzania, the latter being dominated by proposals in the Eastern Arc and Southern Highlands chain of mountains. Aside from proposed corridors, most descriptions of connectivity in this relatively well-surveyed tropical country are based on known animal movement routes. These movements, however, derive from anecdotal observations rather than systematic monitoring of individually-known animals. Indeed, there are few instances where radio telemetry been used to follow species (such as elephants) between protected areas. Moreover, well established modeling and GIS methodologies used to establish connectivity in other areas of the world (e.g., Carroll, 2006) are only in their infancy in Tanzania. This may well be true in other tropical nations too, but we maintain that lack of systematic evidence about corridors does not matter when opportunities for habitat connectivity are being lost at such a fast pace.

Table 2
Summary table of important corridors in mainland Tanzania.[a]

Corridor	No.[b]	Region(s)	Type[c]	Urgency
Bujingijila (Mt. Rungwe-Livingstone)	1	Mbeya	E	Critical
Burigi-Akagera (Rwanda)	2	Kagera	B	Critical
Burigi-Moyowosi/Kigosi	3	Kagera, Shinyanga, Kigoma	C	Critical
Gombe-Kwitanga	4	Kigoma	E	Critical
Gombe-Mukungu-Rukamabasi	5	Kigoma	E	Critical
Greater Gombe Ecosystem-Masito-Ugalla	6	Kigoma	D	Moderate
Igando-Igawa	7	Iringa	D	Critical
Katavi-Mahale	8	Rukwa, Kigoma	C	Moderate
Katavi-Rungwa	9	Rukwa, Mbeya, Iringa	D	Critical
Kilimanjaro-Amboseli (Kenya) (Kitendeni)	10	Kilimanjaro, Arusha	E	Critical
Loazi-Kalambo	11	Rukwa	D	Extreme
Loazi-Lwafi	12	Rukwa	D	Moderate
Manyara Ranch-Lake Natron	13	Manyara	D	Extreme
Manyara–Ngorongoro (upper Kitete/Selela)	14	Arusha, Manyara	C	Critical
Muhezi-Swaga Swaga	15	Dodoma	D	Moderate
Selous-Niassa (Mozambique)	16	Ruvuma	D	Moderate
Tarangire-Makuyuni (Makuyuni)	17	Manyara	D	Moderate
Tarangire-Mkungunero/Kimotorok	18	Manyara	D	Critical
Tarangire-Simanjiro Plains	19	Manyara, Arusha	D	Critical
Tarangire-Manyara (Kwakuchinja)	20	Manyara	C	Critical
Udzungwa-Mikumi	21	Morogoro	D	Critical
Udzungwa-Ruaha	22	Iringa	D	Extreme
Udzungwa-Selous	23	Iringa, Morogoro	E	Critical
Uzungwa Scarp-Kilombero NR (Mngeta)	24	Iringa, Morogoro	E	Critical
Uluguru North–South	25	Morogoro	E	Critical
Usambaras, East (Derema)	26	Tanga	E	Critical
Usambaras, West	27	Tanga	A	Moderate
Wami Mbiki-Handeni/ Southern Masai Steppe	28	Morogoro, Tanga	A	Critical
Wami Mbiki-Jukumu/Gonabis/Northern Selous	29	Morogoro	A	Extreme
Wami Mbiki-Mikumi	30	Morogoro	A	Extreme
Wami Mbiki-Saadani	31	Morogoro	A	Extreme

[a] See Jones et al. (2009) for full bibliography.
[b] Numbers refer to Fig. 1.
[c] A, unconfirmed corridor; B, uncultivated lands between protected areas without documentation on animal movement; C, continuous or semi-continuous uncultivate land between protected areas with anecdotal information on animal movements; D, known animal movement routes between two protected areas; and E, potential connectivity of important habitats.

Our third finding pertains specifically to Tanzania. Alarmingly, we discovered that the majority of documented corridors in the country are in poor condition, and many are critical, meaning that they may have less than five years remaining (up to the year 2013) before they disappear, judging on current rates of habitat change. Annual human population growth rates in Tanzania are high and significantly higher in wards <5 km from protected areas (C. Packer, pers. comm.); and, compared to forest losses in eight other east and southern African nations (surface area of forest lost as proportion of total area of country) between 1990 and 2005, Tanzania matched Zimbabwe in suffering the worst losses (http://www/fao.org/forestry/32185/en/). Based on reports and authors' visits, five Tanzanian corridors are in an extreme condition and will disappear within an estimated two years without intervention. These are the Loazi–Lwafi corridor, the Ngorongoro–Manyara corridor, the Udzungwa-Selous corridor(s), the Wami Mbiki-Mikumi corridor, and the Wami Mbiki-Saadani corridor (Fig. 1). Most corridors are being destroyed by rapid agricultural expansion, increased bushmeat trade and road building, and poor governance. Unless action is taken to manage these activities in a way that considers both human and wildlife needs, human–wildlife conflict will increase and Tanzania's protected areas will become geographically and genetically isolated islands. This will have serious economic and environmental implications for the next generation of Tanzanians. Tanzanian authorities recognize these constraints and welcomed the Jones et al. (2009) report to the extent of sending a copy to the Office of the President.

Our general conclusions are that nationwide surveys of this sort should be conducted immediately in other tropical countries, regardless of the quality of information on corridors and the difficulties in collating data from a wide array of disparate and hard-to-contact sources. Second, it is important to maintain loose definitions of corridors in any such compilation, and to present data to central authorities rapidly given the current pace of land use change.

Acknowledgements

We thank the Tanzania Wildlife Research Institute for cooperation and the Wildlife Conservation Society for funding. We are grateful to the following individuals and organizations who provided information on the various corridors: the Animal Behaviour Research Unit (Mikumi National Park), Biharamulo District Natural Resources Office, Cartography Unit, Geography Department, University of Dar es Salaam, A. Cauldwell, P. Coppolillo, T. Danielsen, K. Doody, C. Epps, C. Foley, L. Foley, R. Hahn, J.J. Halperin, S. Hassan, B. Mbano, S. Mduma, N. McWilliam, D.G. Mpanduji, F. Mofulu, D. Moyer, A. Mtui, B. Mutayoba, R. Nielsen, W. Ntongani, H. Olff, L. Pintea, F. Rovero, and Selous-Niassa Wildlife Corridor Group. We thank two anonymous reviewers for comments.

References

Beier, P., Noss, R.F., 1998. Do habitat corridors provide connectivity? Conservation Biology 12, 1241–1252.
Caro, T., Gardner, T.A., Stoner, C., Fitzherbert, E., Davenport, T.R.B., 2009. Assessing the effectiveness of protected areas: paradoxes call for pluralism in evaluating conservation performance. Diversity and Distributions 15, 178–182.
Carroll, C., 2006. Linking connectivity to viability: insights from spatially explicit population models of large carnivores. In: Crooks, K.R., Sanjayan, M. (Eds.), Connectivity Conservation. Cambridge University Press, Cambridge, pp. 369–389.

Crooks, K.R., Sanjayan, M. (Eds.), 2006. Connectivity Conservation. Cambridge University Press, Cambridge.
Dobson, A., Ralls, K., Foster, M., Soule, M.E., Simberloff, D., Doak, D., Estes, J.A., Mills, L.S., Mattson, D., Dirzo, R., Arita, H., Ryan, S., Norse, E.A., Noss, R.F., Johns, D., 1999. Corridors: reconnecting fragmented landscapes. In: Soule, M.E., Terborgh, J. (Eds.), Continental Conservation: Scientific Foundations of Regional Reserve Networks. Island Press, Washington, DC, pp. 129–170.
Hilty, J.A., Lidicker Jr., W.Z., Merelender, A.M., 2006. Corridor Ecology: The Science and Practice of Linking Landscapes for Biodiversity Conservation. Island Press, Washington.
Jones, T., Caro, T., Davenport, T.R.B. (Eds.), 2009. Wildlife Corridors in Tanzania. Unpublished Report. Tanzania Wildlife Research Institute (TAWIRI), Arusha, 60pp.
Mittermeier, R.A., Mittermeier, C.A., Brooks, T.M., Pilgrim, J., Konstant, W.R., da Fonesca, G.A.B., Kormos, C., 2003. Wilderness and biodiversity conservation. Proceedings of the National Academy of Sciences, USA 100, 10309–10313.
Newmark, W.D., 2006. A 16-year study of forest disturbance and understory bird community structure and composition in Tanzania. Conservation Biology 20, 122–134.
Newmark, W.D., 2008. Isolation of African protected areas. Frontiers in Ecology and Environment 6, 321–328.
Noss, R.F., Daly, K.M., 2006. Incorporating connectivity into broad-scale conservation planning. In: Crooks, K.R., Sanjayan, M. (Eds.), Connectivity Conservation. Cambridge University Press, Cambridge, pp. 587–619.
Sanderson, J., da Fonesca, G.A.B., Galindo-Leal, C., Alger, K., Inchausty, V.H., Morrison, K., Rylands, A., 2006. Escaping the minimalist trap: design and implementation of large-scale biodiversity corridors. In: Crooks, K.R., Sanjayan, M. (Eds.), Connectivity Conservation. Cambridge University Press, Cambridge, pp. 620–648.