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Full Length Research Paper

Spatial correlates of land-use changes in the Maasai-Steppe of Tanzania: Implications for conservation and environmental planning

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Spatially explicit models are becoming increasingly important tools for simulating land-use change. In this study, we formulated and tested models that incorporated spatial correlates of agricultural expansion and used them to predict local- and landscape-scale patterns of agricultural land-use change and its implications in the Maasai-Steppe of Northern Tanzania. We evaluated the relationship between agricultural land-use and its spatial correlates using Multiple Logistic Regression on data derived from satellite imageries for the year 2000. We then examined the implications of the agricultural land-use change on the range and migratory corridors of key migratory wildlife species within the context of wildlife conservation and land-use planning. Our results showed that, biophysical variables provide the primary conditions for land-cover conversions to agriculture. There was a strong overlap between lands suitable for agriculture, wildlife migratory corridors and the wet season dispersal areas. Expanding cultivation towards protected areas severely restricted wildlife movements to dispersal areas outside parks by blocking their migratory corridors. Further, the global model used for the prediction of probability of land-conversions to agriculture suggested future expansions will be constrained by values of the biophysical variables analysed here. The rapidity of rangeland conversions to farming in the study area presents a major threat to wildlife conservation and disrupts the ecosystems viability in supporting its rich biodiversity and the agro-pastoral livelihood. There is urgency for pursuing land-use strategies and plans, which are both profitable and sustainable for the agro-pastoral communities and the wildlife. The plans should address the different land-use options by considering current and future trends, implications and the ease for their cohabitation as analysed in this study.

Key words: Spatial, modelling, land-use, agro-pastoral, wildlife, corridors.

INTRODUCTION

Environmental management and land-use planning need information about the dynamics of land use (Verburg et al., 2002), since land-use activities can impact significantly on natural resources. In many developing countries, particularly in the sub-Saharan Africa, this information is often lacking, making planning a difficult exercise (FAO, 2009). Habitat loss and fragmentation that result from land-use changes are major factors contributing to the decline of many biological populations (Dale et al., 1998; Salas et al., 2000). Forest cutting, agricultural practices (Geist and Lambin, 2002; Linderman et al., 2005; Etter et al., 2006), urban and industrial expansion (Dale et al., 1998), road development and alteration of waterways (Houghton, 1994; Li et al., 2004) are amongst common human land-use activities that can significantly alter the land cover (Etter et al., 2006) and hence adversely affect biodiversity

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(Serneels and Lambin, 2001a; Reid et al., 2008; Ogutu et al., 2009).

Land-use change studies are central to environmental management, biodiversity conservation, ecosystem services and livelihoods (Lambin et al*.,* 2000; Verburg et al., 2002; Turner et al., 2007). The increasing availability of satellite imagery and geographic information system (GIS) technologies allows for expanded interdisciplinary inquiry into various forces underlying land-use change and their implications (Hunter et al., 2003). Empirical diagnostic models of land-cover/use change can be developed from remote sensing data and used to facilitate identification of major processes of change, characterization of land use dynamics (Mertens and Lambin, 1999) and anticipation of where future changes are more likely to occur. Consequently, models of land-use change combined with dynamic modelling are becoming increasingly important tools for simulating land-use change using empirically quantified relations between land-use and its driving factors (Mertens and Lambin, 2000; Serneels and Lambin, 2001b).

East Africa has lost more than half of its wildlife in the last 30 years (Stoner et al., 2006; Western et al*.,* 2009). In Tanzania, wildlife are declining in all the major wildlife areas and ecosystems, including national parks and game reserves (TNRF, 2008). Most of this is driven by high human population growth in the rural areas, changing economic realities and policies (Homewood et al., 2006; Norton-Griffiths and Said, in press, Msoffe et al., 2011). However, for wildlife to be conserved successfully outside protected areas, it should legally generate income for local communities who bear the cost of supporting wildlife. This is currently not the case in most of rural Tanzania, for example, (TNRF, 2008). As a result, many protected areas in East Africa are becoming “islands” in a sea of farms (Borner, 1985; Newmark, 1996). Land use in northern Tanzania is changing rapidly and in unplanned fashion – from extensive rangelands to a patchwork containing commercial farms, subsistence plots and settlements (FAO, 2009). The growing populations, expanding economies and increasing urbanization in areas of high biodiversity demand multiple objectives in land use planning. It also requires sufficient information to allow land managers to explore various land use options and evaluate impacts of alternative land-use strategies and the structure of trade-offs between various land uses and development objectives (Dale et al., 1998).

In this study, we formulated and tested models that incorporate spatial correlates of agricultural expansion and used them to predict local- and landscape-scale patterns of distribution of agricultural land-use and its implications for wildlife conservation in the Maasai-Steppe ecosystem of Northern Tanzania in 2000. Specifically, we evaluated the relationship between land-use change and its spatial correlates using multiple logistic regression analysis (MLR) on data derived from satellite imagery for the year 2000 when agricultural expansion was high (Msoffe et al., 2011). MLR indicates the probability that a given grid cell undergoes land-use conversion to agriculture conditional on the set of driving factors (Mertens and Lambin, 2000; Serneels and Lambin, 2001b). We hypothesized that areas in close proximity to villages (formal settlements in rural areas of Tanzania), roads, rivers and protected area boundaries were more likely are to be converted to agriculture. Further, we examined the implications of the agricultural land-use change on the range and migration corridors of key migratory wildlife species within the context of wildlife conservation and land-use planning.

MATERIALS AND METHODS

Study area

The Maasai-Steppe is one of the richest wildlife areas in East Africa and is well known for its migration of wildebeest (*Connochaetes taurinus*), zebra (*Equus burchelli*) and elephant (*Loxodonta Africana*) (Lamprey, 1964). Tarangire National Park (TNP) is at the heart of the ecosystem and contains the Tarangire River, the only source of water in the dry season, along which majority of the large mammals, including the migratory herbivores congregate (Lamprey, 1963). At the onset of the rains, these animals disperse away from TNP to areas in the north, north east and south east of the surrounding ecosystem (Figure 1) (Lamprey, 1964).

Ecologically, the Maasai-Steppe is an important stronghold for the wildlife and pastoralists of northern Tanzania (Lamprey, 1963). It contains the second-largest population of migratory wild ungulates in East Africa (second only to the Serengeti-Mara ecosystem) as well as the largest population of elephants in Northern Tanzania (Douglas-Hamilton, 1987; Foley, 2002). The Simanjiro plains is one of the most important wet season dispersal and calving areas for wildebeest and zebra (Kahurananga and Silkilwasha, 1997; TCP, 1998). Large concentrations of wildlife and domestic animals including cattle, sheep, goats and donkey share pasture in this area at various times of the year, especially the wet season (Mwalyosi, 1992; Voeten, 1999). However, the rapidly growing human population, expanding cultivation and settlements in these plains are progressively excluding wildlife and livestock.

Data and methods

We derived spatial datasets from remotely-sensed imagery, radio-collared animals and geographic information system (GIS) layers and used the datasets to examine implications of land use changes and its drivers on wildlife habitats and distribution. The biophysical predictors of land use change were rainfall, slope, distances to the nearest village (town), road, river and protected area (parks) boundary. The GIS layers of the study area, protected areas, villages/towns, and data on the ranges of migratory wildlife derived from radio-collared animals were obtained from the GIS centre of the Tarangire National Park. The GIS layers for roads and rivers were acquired from the Surveying and Mapping Division of Tanzania based on 1:50,000 topographic maps. Elevation data were derived from a Digital Elevation Model (DEM) of 90 m resolution obtained from the Shuttle Radar Topographic Mission (SRTM). Data on rainfall (annual precipitation) were extracted from the Almanac Characterization Tool (ACTS) database (Mud Springs Geographers, 2002).

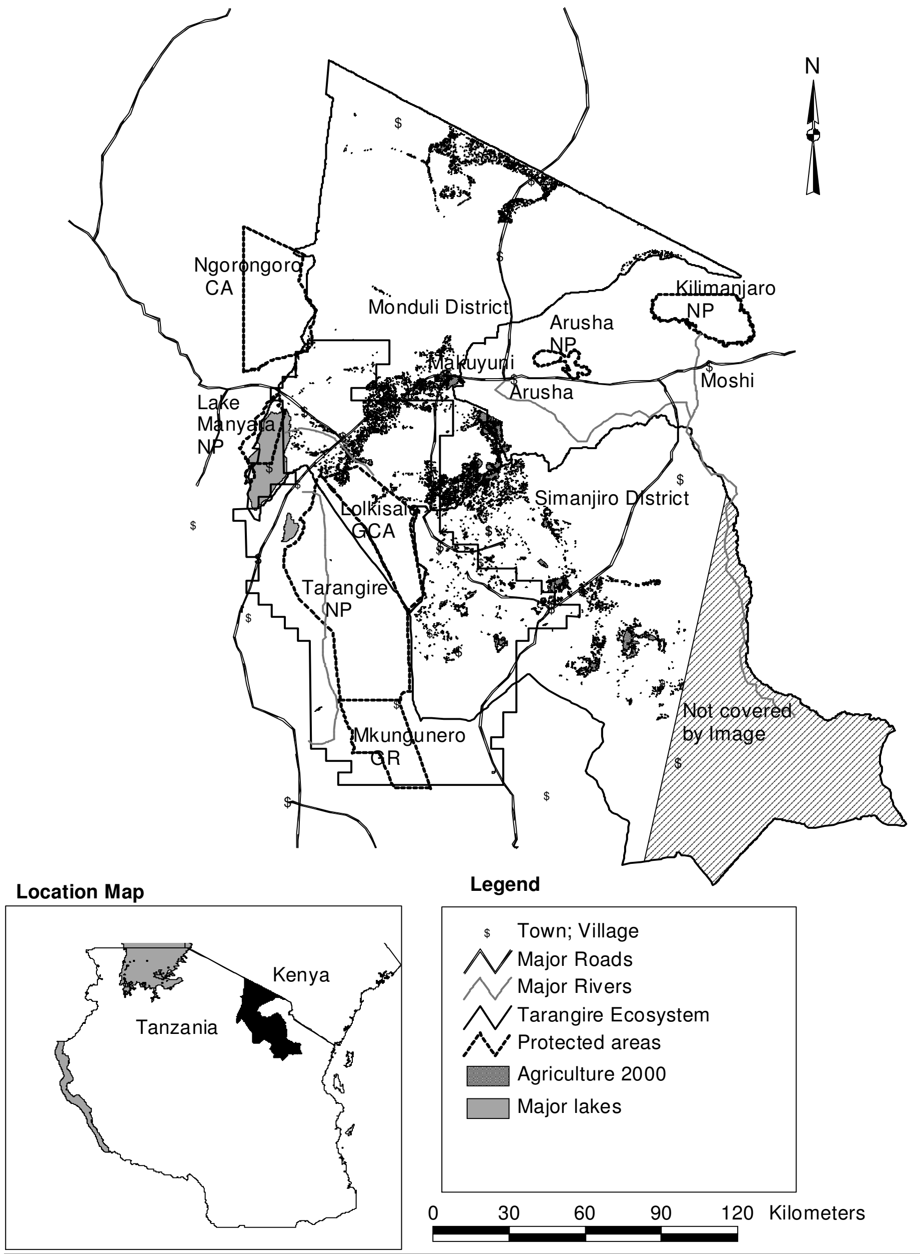

Figure 1. Map showing the study area and administrative boundaries and baseline conditions in 2000; main protected areas, town-villages, major roads, rivers and the agricultural expansion in the two districts of Simanjiro and Monduli, Northern Tanzania. NP, National Park; GR, Game Reserve; CA, Conservation Area; GCA, Game Controlled Area.

Deriving land use changes

Remote sensing data were extracted from satellite images, acquired from the USGS. The images were Landsat ETM+, Path/Row 168/62 and 168/63 of 2000 (Msoffe et al. 2011).

Statistical and spatial analyses

We used a MLR model to evaluate the relative significance of factors influencing the probability of occurrence of agriculture in the study area. The MLR model was used to estimate coefficients of explanatory variables with the presence (1) or absence (0) of agriculture in each grid cell in the year 2000 as the dependent variable. We generated grids of 300 m $\times$ 300 m cells which were determined by the minimum parcel size of cultivated land. We overlaid this grid with a GIS layer for agriculture and assigned 1 to grid cells with agriculture and 0 otherwise.

The MLR model was fitted using restricted pseudo-likelihood in the Statistical Analysis System (SAS) GLIMMIX procedure (SAS Institute, 2006). For each of the six variables; namely annual precipitation, slope, distances to the nearest village (town), road, river and park (protected area), we first ran the univariate regressions using the linear, quadratic without a linear term and the

Table 1. Information-theoretic model selection of a *priori* candidate models explaining the presence of cultivation in Simanjiro and Monduli Districts in 2000 and the bio-physical variables included in each model.

S/N	Predictors in model†	AIC value	AIC difference (ΔAIC)	Akaike weights (w_i)	Rank
1	annpre, annpre^2	227886.1	0.000	1	1
2	annpre^2	233558.6	5672.464	0	3
3	annpre	232287.3	4401.195	0	2
4	dsttwn, dsttwn^2	230178.1	0.000	1	1
5	dsttwn^2	230180.1	1.950	0	2
6	dsttwn	230909.0	731.023	0	3
7	dstpark, dstpark^2	240635.6	0.000	1	1
8	dstpark^2	240999.8	364.226	0	3
9	dstpark	240803.6	168.063	0	2
10	dstrd, dstrd^2	235409.2	0.000	1	1
11	dstrd^2	236431.1	1021.841	0	3
12	dstrd	235504.5	95.320	0	2
13	dstrv, dstrv^2	240149.6	0.000	1	1
14	dstrv^2	240357.4	207.812	0	2
15	dstrv	240723.4	573.859	0	3
16	slpdgre, slpdgre^2	239767.9	0.000	1	1
17	slpdgre^2	241178.9	1411.043	0	2
18	slpdgre	241186.4	1418.466	0	3

†annpre ,Annual precipitation; dsttwn, distance to town (village); dstpark, distance to park; dstrd, distance to road; dstrv, distance to river; slpdgre, slope in degrees.

standard quadratic model including a linear term. For each model, we computed the Akaike Information Criteria (AIC) value and Akaike weights (Burnham and Anderson, 2001). We then fitted the model with interaction terms, added and retained extra variables in the model only if this improved the value of the AIC (Burnham and Anderson, 2002). The procedure was repeated until all the explanatory variables had been considered.

Models were compared using ΔAIC, the difference between AIC for each individual model and the model with the lowest observed AIC value. Under this framework, the model with the smallest AIC value is interpreted as having the best fit to the data. Models with ΔAIC ≤2 suggests substantial evidence for the model, values between 3 and 7 indicate that the model has considerably less support, whereas ΔAIC >10 indicates that the model is very unlikely (Burnham and Anderson, 2002). We presumed that parameters with good support would have high Akaike weights (near 1) since that parameter would be included in most of the better models. Finally, the Goodness-of-fit test was used to assess the global model fit statistics (Anderson and Burnham, 2002). We then used the Hawth's Analysis Tool (an extension for ARCGIS- ArcMap) for the analysis of animal movements (range) from the radio-collaring data of key migratory species in the Tarangire ecosystem (Beyer 2004). The data were from 10 wildebeest and 13 zebra collared between 1995 and 1997 (OIKOS, 2002). We first created the minimum convex polygons to characterize the range of the radio-collared animals based on spatial locations derived from the Global Positioning System (GPS). We then used the Batch Fixed Kernel Density Estimator to derive a set of percentage volume contours/maps showing the intensities of habitat use within the range of the collared animals. To analyse the relationship between the range/habitat of the key migratory species and agricultural land-use, we overlaid maps derived from the radio-collared animals (range-extent), their migratory routes and the spatial agriculture in 2000 in the study area. We calculated the area of overlap between the range used by the key migratory wildlife species and the agricultural land-use to assess the extent of natural habitat lost to cultivation. Finally we overlaid the migratory corridors and the key habitat/range of the species to assess and classify the status of the corridors as open, threatened, or blocked.

RESULTS

Comparisons of the individual variable models indicated that quadratic models were better supported than linear ones. Table 1 shows the 18 candidate models we considered, their AIC, ΔAIC, Akaike weights and the rank order of the models. The standard quadratic models with precipitation (model 1), distance to the nearest town (model 4), park (model 7), road (model 10), river (model 13) and slope (model 16) had the highest support in the data. These models thus had the highest Akaike weights (100%) and were ranked as the best models. For the full model shown in Table 2, only significant interactions ($p<0.05$) were retained.

Patterns of spatial distribution of cultivation and the biophysical variables

There was a humped distribution between the likelihood of agriculture and precipitation (Figure 2). The probability of presence of agriculture increased significantly with increasing rainfall from around 300 mm to a peak ($p \approx 0.22$) around 800 mm of rainfall and declined with further increase in rainfall. The probability of presence of

Table 2. Results of the multiple logistic regression of the probability of presence of cultivated farms against biophysical predictor variables for the Simanjiro and Monduli District of Northern Tanzania based on the Satellite remote sensing imagery for 2000.

Effect	NDF	DDF	F	P> F
Annpre	1	320427	2731.65	<0.00001
annpre× annpre	1	320427	1952.56	<0.00001
Slpdgre	1	320427	644.24	<0.00001
Slpdgre × slpdgre	1	320427	977.75	<0.00001
dstrd × dstrd	1	320427	1115.79	<0.00001
slpdgre ×dstrd	1	320427	73.55	<0.00001
dstrv × dstrv	1	320427	19.78	<0.00001
Dsttwn	1	320427	50.17	<0.00001
dsttwn × dsttwn	1	320427	415.68	<0.00001
dstrd × dsttwn	1	320427	212.94	<0.00001
dstrv × dsttwn	1	320427	3012.44	<0.00001
Dstpark	1	320427	1682.33	<0.00001
dstpark × dstpark	1	320427	216.10	<0.00001
dstrv × dstpark	1	320427	160.17	<0.00001
dstrd × dstpark	1	320427	1392.83	<0.00001
dsttwn × dstpark	1	320427	1914.56	<0.00001
slpdgre × dstrd × dstrv	1	320427	108.56	<0.00001

[†]annpre , Annual precipitation; dsttwn, distance to town (village); dstpark, distance to park; dstrd, distance to road; dstrv, distance to river; slpdgre, slope in degrees.NDF and DDF are the numerator and denominator degrees of freedom for the F-test, respectively.

agriculture relative to terrain slope (Figure 2) shows that cultivation was most likely to be practised in areas with slopes of about 10°. The probability of agriculture dropped consistently for areas with slopes lower or higher than 10° ($p \approx 0.18$).

The relationship between presence of agriculture and distance to the nearest village (town) declined exponentially with increasing distance from villages (Figure 2). The probability for cultivation was highest ($p \approx 0.22$) within 0-10 km of villages. Similarly, the probability of finding agriculture declined exponentially with increasing distance from roads and was highest ($p \approx 0.17$) within 5-20 km from the nearest road (Figure 2). The relationship between presence of agriculture and distance from the nearest river was concave and was highest ($p \approx 0.16$) nearest to (0-5 km) and farthest from (40-45 km) the nearest river and lowest at about 30 km from the nearest river (Figure 2). The probability of finding agriculture as a function of distance from the nearest park also showed a humped distribution with a non-zero probability for agriculture ($p \approx 0.08$) apparent up to 20 km inside the nearest protected area. The probability for cultivation initially increased with increasing distance up to about 30 km from the nearest protected area boundary and then declined steadily with further increase in distance (Figure 2). When all the variables in the best univariate models were combined into a global multivariate model, it was apparent that the probability of finding agriculture was highest near rivers and towns, areas receiving high rainfall and near villages located near parks (Table 2). The probability of occurrence of agriculture in the Maasai-Steppe was significantly associated with areas of high agricultural potential irrespective of their protection status or importance as wildlife ranges.

The goodness-of-fit tests showed that the global model had good explanatory power. The Hosmer-Lemeshow test statistic (which includes three asymptotically equivalent Chi-Square tests, that is, the Likelihood Ratio, Score and Wald) were highly significant ($p<0.0001$), supporting the fitted global model. The maximum-rescaled R-Square, (Nagelkerke, 1991) was 0.19. The association of the predicted probabilities and the observed responses were 76.5% concordant and 23.1% discordant. The high level of concordance (agreement) is particularly important as it implies that the model reliably represents the processes underlying the patterns observed in this study (Hunter et al., 2003).

Mapping the probability of agricultural conversion and wildlife range

The probability map generated from the logistic regression model shows the relative likelihood of conversion to agriculture for the rangeland across the Maasai-Steppe (Figure 3b). The map is based on the biophysical landscape variables which showed significant correlation with agricultural presence in 2000 and retained in the

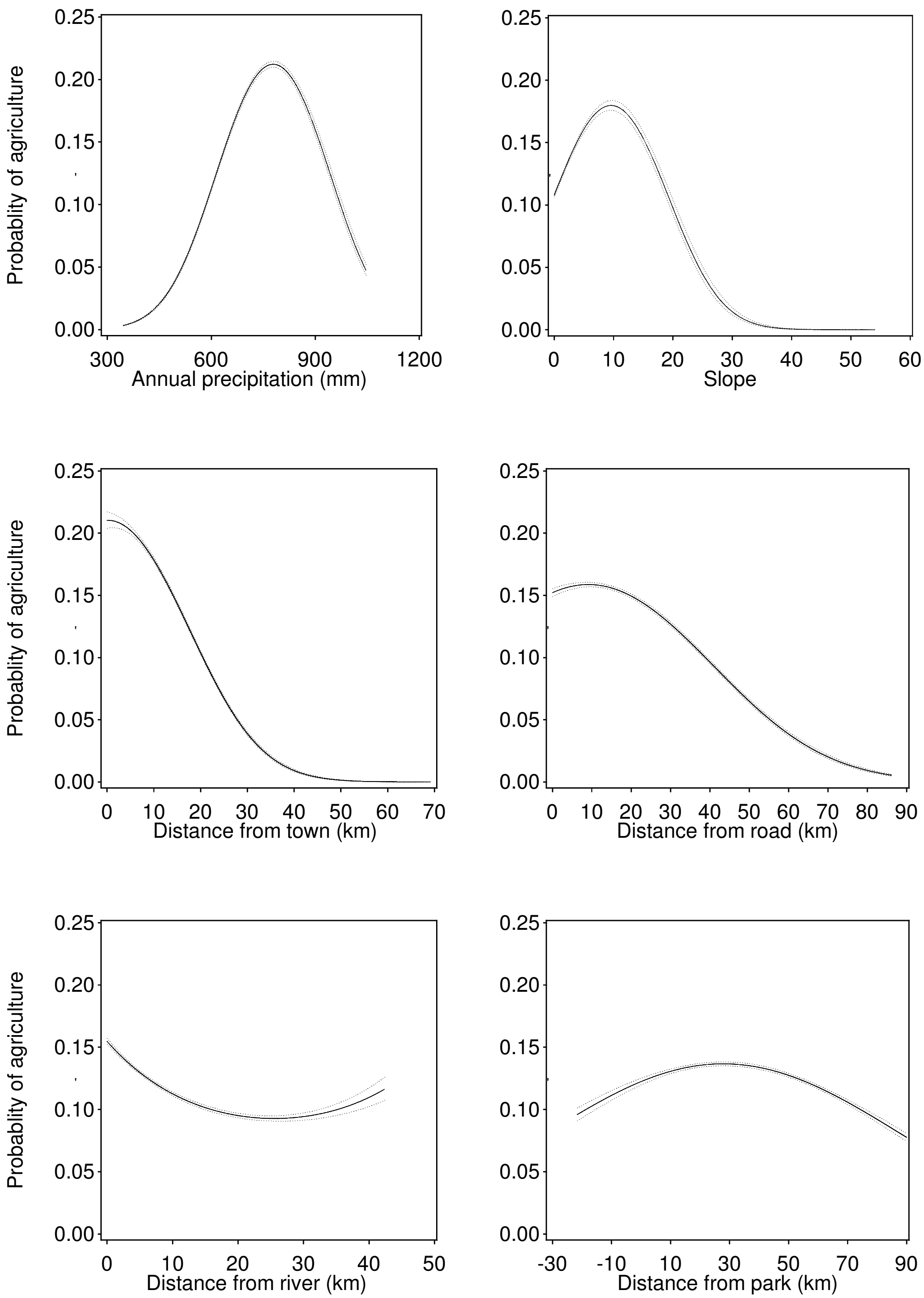

Figure 2. The relationship between the probability of presence of cultivation in 2000 and the biophysical variables in the Maasai-Steppe of Northern Tanzania.

the global multivariate model. The global multiple logistic regression equation used to predict the probability of cultivation in each pixel in the study area suggests how future expansion of agriculture in this region will be constrained by values of the biophysical variables analysed here. Further, the overlay of probability maps of agricultural occurrence and key migratory wildlife range and corridors from the radio-collaring data showed that approximately 13% of the range area for wildebeest and zebra had been converted to farms by 2000 (Figure 4).

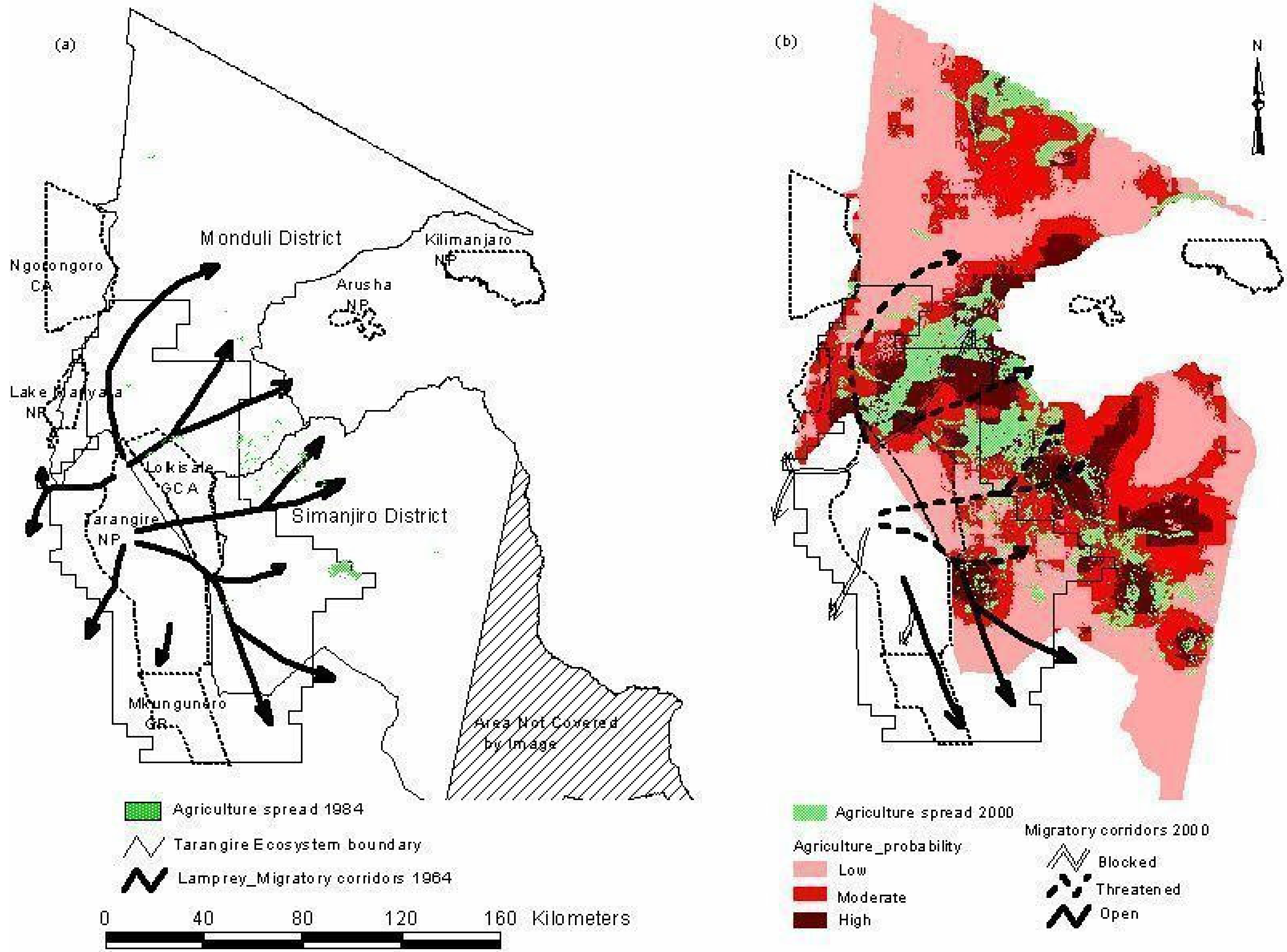

Figure 3. (a) Spatial distribution of agriculture in 1984 and wildlife migration corridors described by Lamprey in 1964. (b) Spatial distribution of agriculture in 2000 and the probability of further conversion to agriculture overlaid with the migratory wildlife corridors in the study area in 2000.

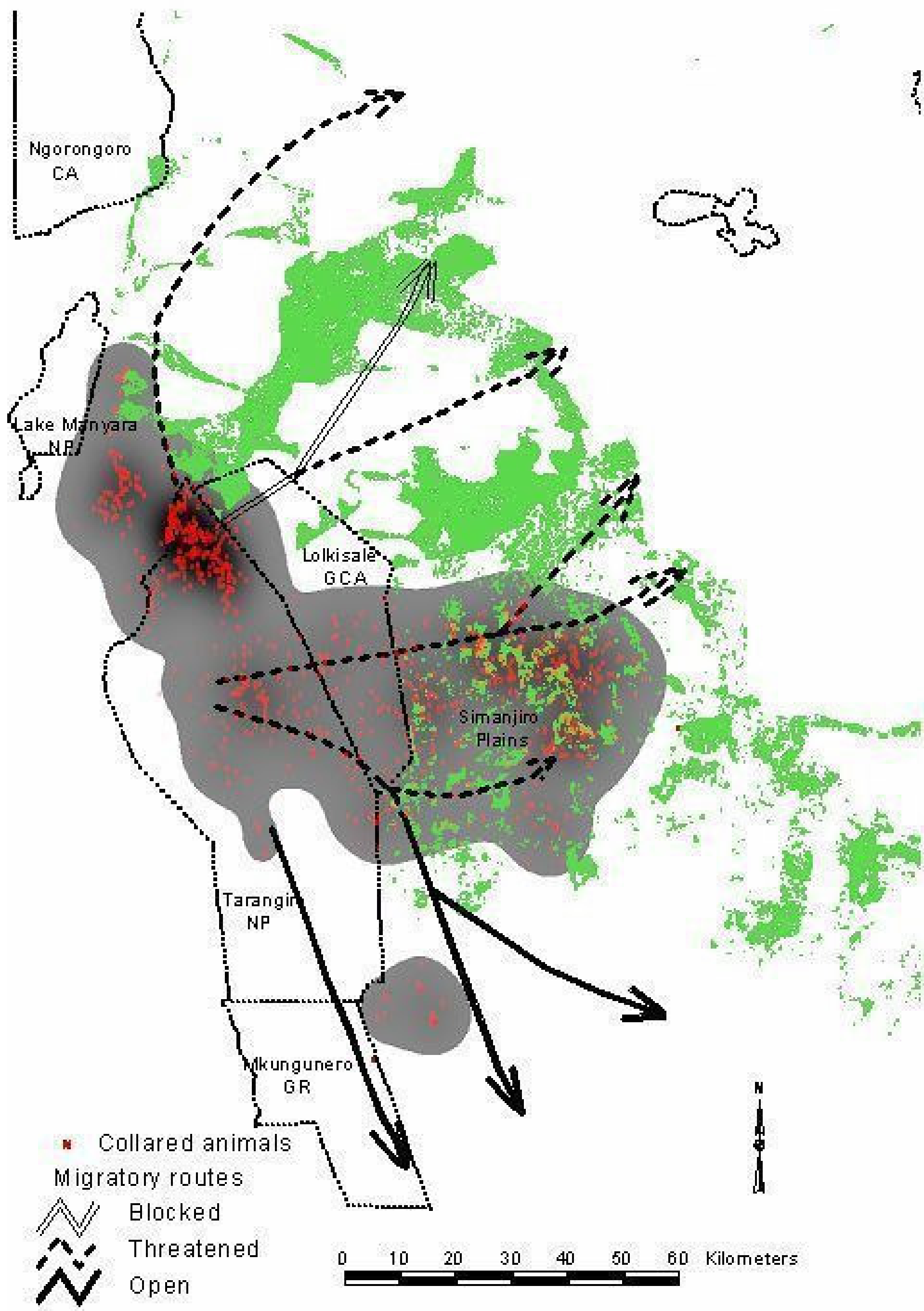

Figure 4. Wet season range of the two key migratory species in gray-tone based on data from radio-collared wildebeest (n=10) and zebra (n=13) overlaid with cultivated farms in 2000.

Four of the remaining five migratory wildlife corridors described by Lamprey in 1963 (Lamprey, 1964; Figure 3a) are seriously threatened with blockage (Figure 3b). The first, in the north-east, the Kwakuchinja wildlife corridor, is used mainly by wildebeest and zebra from TNP to Manyara Ranch and Lake Manyara National Park. The second, the corridor from TNP through Lolkisale Game Controlled Area up to Losimingori Mountains, is used mainly by Elephants. The third corridor lying to the east and running from TNP to the Simanjiro Plains is used mainly by wildebeest and zebra moving to and from their calving grounds. And the fourth one, lying south-east from TNP to Loibor-Siret and Kimotorok villages is used by wildebeest, zebra and elephants. All these four corridors are currently being converted to extensive cultivation and settlements in the Tarangire ecosystem as indicated in Figure 3b.

DISCUSSION

In this paper, we show the existence of a strong overlap between lands suitable for agriculture and the main wildlife corridors and the wet season dispersal areas. Our results confirm and reinforce the earlier findings of (Borner, 1985; OIKOS, 2002; Msoffe et al., 2011) that agricultural encroachment is the single most important factor which blocked four of the nine wildlife corridors described by Lamprey (1964) in the early 1960's. A new insight from this study is that four of the remaining five corridors also overlap with areas highly suitable for agriculture. The conversion to farming is occurring haphazardly leading to patchy and fragmented habitats, which cannot support many ecologically viable processes required by the migratory species. Clearly, expanding cultivation towards protected areas severely restricts wildlife movements to dispersal areas outside parks by blocking their corridors.

The assessment of potential for agriculture was based on two land suitability models. The first, a deductive bio-physical land suitability model, considered rainfall and the topography, predicted a somewhat larger area suitable than the second model. The second model, an empirical model, considered, apart from rainfall and slope steep-ness, other factors such as distance to settlements and roads. The second model indicated that infrastructure played an additional important role. Biophysical variables provide the primary conditions that distinguish land suitable from that unsuitable for agriculture. Within this context, socio-political and economic drivers of land-associated decisions concerning where to develop infrastructure and prioritize which lands will be converted are made. The political dimension is clear when we realize that infrastructure plays an overriding role, and its development is largely determined by governments at national and international levels. Indeed, roads do not emerge at random, but are mostly the result of deliberate development planning. Hence, governments would have the possibility to decide not to develop roads.

These observations have been made by other studies (Mertens and Lambin, 1997; Serneels and Lambin, 2001b; Jasinski, et al., 2005; Etter et al., 2006). However, most of these studies found that access to roads and markets were much more important in relation to land-cover conversions to agriculture and deforestation, whereas this study showed that villages were, statistically speaking, more significantly related to agricultural presence/land-conversions than distance to roads. Villages were strategically located near rivers and water points where they also coincide with wildlife use of these areas particularly during the dry season. This unplanned land use is highlighted in this study by the diffuse distri-bution of agriculture. And as more villages are settled, this problem will become greater and inimical to conservation endeavors and politically and economically much more costly to solve. Consequently, as more land is put under agriculture the range for both wildlife and livestock become increasingly diminished (FAO, 2009).

The diminishing range size implies that small stochastic events such as droughts could affect larger proportions of livestock and wildlife populations, especially so for mammals that directly threaten human lives, compete with humans for resources and/or are restricted inside artificial boundaries (Thuiller et al., 2006). Recent aerial surveys in the Tarangire-Ecosystem revealed extreme declines in numbers of the key migratory wildlife species, most notably wildebeest, whose numbers dropped from about 43,000 in 1988 to a mere 5,000 in 2001 (TAWIRI, 2001). Long-term studies in other pastoral lands with large migratory populations in East Africa such as the Maasai Mara (Ottichilo et al., 2001; Ogutu et al., 2009), and Athi-Kaputiei (Reid et al., 2008) ecosystems of Kenya have also implicated agricultural expansion, loss of wet season dispersal ranges, expansion of settlements and urban development as primarily responsible for massive declines by populations of migratory wildebeest and other ungulates. Concerted efforts are being made in the Athi-Kaputiei and the Mara to develop innovative ways for keeping the land open for wildlife and pastoral livestock and consolidating small individual land parcels to form conservancies (Reid et al., 2008; Griffiths et al., 2008).

In conclusion, in this study we have used remotely sensed data and statistics to build models that allow us to predict where land-cover conversions are most likely to take place in the future and hence anticipate their associated impacts. Although some of these conversions have already occurred, more areas suitable for agriculture are still available that could soon be cultivated. Hence, governments may have contributed to the observed blockage of the remaining five migration routes because of its central role in road development and planning. Similarly, land tenure is a major driver affecting where settlements develop, and governments, through spatial planning and land tenure arrangements influence the location of settlements. It is questionable however whether such policy instruments would still be effective given the high political and economic costs of relocating large-scale settlements or cultivation.

Our maps reveal that settlements in agricultural lands were dispersed all over the wildlife dispersal areas in 2000. Removing people from wildlife dispersal areas might be difficult once they have settled, as many of the settlers received official titles from the village government. However, land fragmentation has negative impacts on both of wildlife conservation and tourism, one of the biggest revenue earner for the Tanzanian govern-ment (TNRF, 2008). The government needs to develop strategies at both national and village levels that integrate the development needs of land, tourism, forestry and livestock sectors. It is imperative to integrate wildlife conservation needs with pastoral livestock production and broad development goals because wildlife and livestock both depend on the same resources and compete with farmers for land (TNRF, 2008).

A major challenge for contemporary decision-makers is to develop forward-looking strategies that incorporate what is currently happening on the ground between neighboring villages and districts. Decision-makers also need to know what is happening where, what the causes of land use changes are and what alternative options are available in order to effectively plan land use, monitor impacts and learn and adjust the plans and strategy to meet their intended goals. Complete loss of wildlife dispersal areas and corridors will reduce protected areas to ecological islands where sustainable conservation of the species may not be possible even through active management strategies (Ottichilo et al., 2000; Newmark, 2008). There is a need to pursue land-use plans that are both profitable and sustainable for communities but also compatible with wildlife conservation. The plans need to address the different land uses strategies in order to alter the observed trends and ease their cohabitation. It should limit the expansion of agriculture into key wildlife habitats, given the constraints of soil fertility and water in these semi-arid rangelands. More important, the plan should be able to support sustainable pastoralism and livestock which is the most productive use of these lands (FAO, 2009). And finally, the government should invest in and encourage use of simple methods of participatory land-use planning. When communities have accurate information on the pluses and minuses of farming, livestock keeping, wildlife, or other livelihood strategies, they can best zone their land for different activities. The process of modelling land development scenarios presented here demonstrates a potentially useful tool for policy makers, allowing for estimation and visualization of the land-use implications in conservation planning, land-use planning and policy decisions.

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