Kalahari Wildlife Landscape Connectivity Analysis

Phase 2 (Final) Report

For

UNITED NATIONS DEVELOPMENT PROGRAMME

Kgalagadi-Ghanzi Drylands Ecosystem Project

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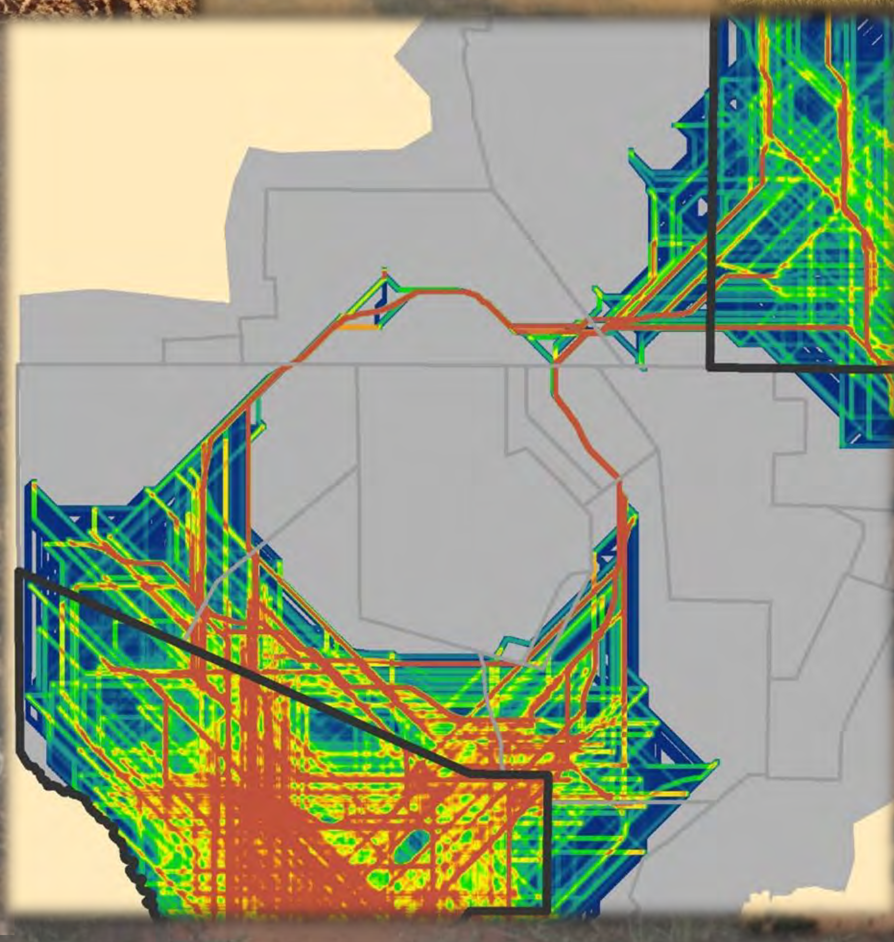

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Acronyms and Abbreviations

AOI	Area of Interest (aka KWLCA study area)
BTO	Botswana Tourism Organization
CFDA	Communal First Development Area
CGA	Communal Grazing Area
CI	Conservation International
CKGR	Central Kalahari Game Reserve
DWNP	Department of Wildlife and National Parks
GEF	Global Environment Fund
GPS	Global Positioning System
GH	Ghanzi District
HS	Habitat Suitability
ILUMP	Integrated Land Use Management Plan
KD	Kgalagadi District
KGDEP	Kgalagadi and Ghanzi Drylands Ecosystem Project
KW	Kweneng District
KWLCA	Kalahari Wildlife Landscape Connectivity Analysis
KTP	Kgalagadi Transfrontier Park
LB	Land Board
PA	Protected Area
PAR	Pastoral/Arable/Residential
RAD	Remote Area Dweller
RNLUP	Review of National Land Use Map
RoW	Right-of-Way
SO	Southern District
TEK	Traditional Ecological Knowledge
TGLP	Tribal Grazing Lands Policy
ToR	Terms of Reference
UNDP	United Nations Development Programme
UNICOR	Universal Corridor Network Simulator
VHF	Very High Frequency
WKCC	Western Kgalagadi Conservation Corridor
WMA	Wildlife Management Area

Highlights Summary - Key Findings

1. Three most disturbance-sensitive Kalahari wildlife species experienced an average 45% habitat suitability loss to agricultural expansion in the study area from pre-settlement to present day and will experience an additional 20% loss soon due to expansion already planned but not yet enacted.

2. Present time models predict all three disturbance-sensitive species retain connections across the landscape linking populations between protected area cores. The strongest connection is shown by gemsbok which maintains a continuous population through the central corridor. Recent developments appear to have nearly pushed the western corridor past the viable threshold for most disturbance-sensitive species due to agricultural encroachment squeezing two pinchpoints: one between Ranyane and Ncaang's RAD development zone, the other between misallocated cattleposts in southern GH11 WMA north of Hunhukwe and Bere/Kacgae RAD development zones.

3. Land board allocation of waterpoints inside WMAs generally, including the RAD 20-km radius development zones specifically, is the most urgent threat to Kalahari wildlife landscape connectivity. Botswana's current land planning development trajectory (Scenario 11), which includes all intended future agricultural developments which are known (i.e. WMA rezonings, fenced ranch and farm expansions, allocated and applied for waterpoints including those within 20 km radius RAD development zones and otherwise) will fragment the Kalahari ecosystem into two pieces, isolating KTP and CKGR cores from each other. The significant level of loss will probably isolate other large wildlife species, not only those most sensitive to disturbance. Following through this current development trajectory would produce a resolute failure to meet the KGDEP Component #3 goal, and jeopardization of wildlife population persistence and wildlife-based land uses in WMAs.

4. An alternative development path is proposed (Scenario 14) within which land planners shift those limited agricultural occurrences encroaching most harmfully into sensitive wildlife corridors, along with poorly planned future expansion, to strategic alternative development zones instead. The result is a landscape optimization wherein agricultural land use intensifies in areas least critical to wildlife while enhancing core areas and connectivity. Notably, this alternative development option accommodates an equivalent increase in agricultural activity to that in the current land planning trajectory. It represents the minimal mitigation necessary to salvage functional landscape connectivity for the complete free-ranging Kalahari wildlife community.

Executive Summary

Introduction:

The purpose of the KWLCA presented in this report is to provide the best possible evidence-based guidance to the ILUMP process so that the KGDEP and Botswana's Government have the prerequisite spatial knowledge to achieve their goal of securing wildlife corridors between KTP and CKGR. The KWLCA thus informs KGDEP Component Goal #3.

A useful definition of wildlife 'corridors' is:
"habitats that are typically long relative to their width . . . The main goal of corridors is to facilitate movement of individuals, through both dispersal and migration, so that gene flow and diversity are maintained between local populations" (https://conservationcorridor.org).
Another is:
"a linear habitat, embedded in a dissimilar matrix, that connects two or more larger blocks of habitat and that is proposed for conservation on the grounds that it will enhance or maintain the viability of specific wildlife populations in the habitat blocks" (Beier and Noss 1998).
While 'Corridor' denotes a specific feature of a landscape that is categorically defined (i.e. it either supports movement of a particular species, or it does not), 'Connectivity' differs slightly in that it is typically in reference to broader areas of landscape (which may include several corridors) and is more of a continuous rather than categorical concept (i.e. areas with lower or higher connectivity) which, importantly, can be quantified.

We set out to definitively, quantitatively answer the question: What are the limits to agricultural encroachment in this landscape which maintains population connectivity between protected area cores for the three most disturbance-sensitive wildlife species and therefore presumably the complete free-ranging wildlife community in Botswana's Kalahari? More simply stated, "How much agricultural encroachment into the Kalahari is too much?" We strive to provide, in this report, a detailed spatially explicit answer for land planners of what must be done, at the minimum, to maintain landscape connectivity through Kgalagadi and Ghanzi Districts that will conserve the full community of native free-ranging Kalahari wildlife into the future.

Methods:

We analyzed new spatial data - both wildlife locational and anthropogenic landscape data – at levels of resolution not possible before. We subjected these data to the most state-of-the-art landscape connectivity analysis possible at present time, to elucidate an implementable landscape solution to the human-wildlife interface problem facing the Kalahari.

KWLCA Phase 1 concluded by settling on 3 species as umbrella representatives of the Kalahari wildlife community ideal for Phase 2 modeling. Several reasons guided this conclusion, but mainly gemsbok and eland had remarkably strong habitat suitability models indicating that their spatial distribution in relation to cattleposts (modeled at finer resolution as kraals density) is highly predictable and consistent across the landscape. Kraals represent precisely the overwhelming human land use influence in this Kalahari landscape, that which is going to change in the future, and that which Botswana's government in fact has control over through the process of landboard waterpoint allocations. Future changes in this landscape are largely iterations of where waterpoints can or will be allocated and thus where cattleposts are allowed to be developed, and where they should or will not (note we use 'borehole' and 'waterpoint' synonymously). These changes to the cattlepost (i.e. kraal clusters) landscape was the major element of future scenarios modelling, in addition to lesser changes to land use boundaries and fencing such as new ranch blocks and that along highways.

To model future kraals that do not yet exist, we first studied the spatial pattern of existing kraals as they develop in the vicinity of waterpoints. We estimated a simple model that best explained the number of kraals and their spatial distribution in relation to a waterpoint. We applied this model to simulate cattleposts in the future scenarios, that is, where new waterpoints would be allocated or new ranches would be developed, the cluster of new kraals developing around those new waterpoints was simulated using the best fit model so that their number and distribution in relation to the waterpoint would be as spatially realistic as possible.

Detailed descriptions of each scenario are provided in Section 3.2 so that land planners have all the spatial information they need to implement and realize any given scenario. Nine scenarios looked at discrete elements of landscape change in isolation. This was done so decision-makers can appreciate the quantitative gains or losses to wildlife habitat and landscape connectivity of these different land use options in isolation. The final four future scenarios were comprised of combinations of, and where necessary modifications to, the previous nine changes studied in isolation. These final four can be considered alternative cumulative development pathways or alternative futures. Scenario 11 represents the business as usual trajectory wherein all known to be planned or lobbied agricultural expansion is enacted. Thereafter, Scenarios 12-14 represent an iterative process whereby we sought minimal mitigation to the agricultural landscape necessary to salvage connectivity for all 3 disturbance-sensitive species through at least 1 of 2 wildlife corridors.

We applied two wildlife movement-based connectivity modelling approaches (resistant kernel and factorial least cost paths) to each scenario to predict and quantify changes to the connectivity landscape. Resistance surfaces formed the foundation of these connectivity models, and these were derived from the occurrence probability (HS) models of Phase 1. So, following through the analysis steps in simple terms, HS surfaces for each of 3 species were first updated following the alterations to the high-resolution anthropogenic landscape characterizing each scenario. Then, the resultant HS layers were essentially 'inverted' to produce resistance layers (i.e. areas of low HS became high resistance to wildlife movement through the landscape and vice versa). In addition to the effects of kraals, roads and fences were also included in the resistance surfaces based on empirical data regarding their barrier and filter effects on movement of these focal species in this ecosystem. Finally, virtual animals were populated into the resistance landscape in proportion to their occurrence probability and coded to move according to their maximum lifetime displacement estimated empirically from telemetry collar data. Movement distances were coded as cost units, each of > 17,000,000 pixels within the AOI having a resistance cost associated with it, various calculations of the many millions of least-cost neighboring pixel moves essentially generating the UNICOR kernel and least cost factorial connectivity outputs.

Key Findings:

Before present time or future scenarios, we first provide a valuable look into the past landscape to establish a correct perspective. That perspective is to remind ourselves that although the AOI is the core free-ranging Kalahari ecosystem remaining in southern Africa, we are not dealing with a pristine Eden. We removed all human land use variables (e.g. kraals, fenced enclosures, roads, land use types) from the Phase 1 HS models and re-ran them only with the background natural landscape variables (e.g. soils, pans, precipitation, tree cover, greenness). This modeling the past showed us that the three most disturbance-sensitive wildlife species have experienced average 45% loss of habitat suitability across the AOI since pre-settlement to present time. This is a remarkable level of encroachment and landscape alteration already, especially as the AOI over which that 45% loss to the key conservation-sensitive species is measured includes the two large and relatively pristine PAs.

Modeling of the present time landscape predicts all three disturbance-sensitive species currently maintain at least tenuous population connectivity between the two PAs. The lion least cost path model generated a surprising prediction of connection not through the least-disturbed area of southern GH10/11 but along the Okwa valley through GH9 CGA. This discovery unfortunately came too late in the analyses to explore mitigative options for the rezoned GH10/11 ranch layouts. Such mitigation would, however, be worth pursuing, and if there is interest then we could provide further spatial guidance than supplied in this report.

Scenario 11 is the modeled future according to today's current plans for agricultural expansion. In Scenario 11 there is no effort to modify the present plans which land boards have in place already nor attempt to balance agricultural expansion with wildlife landscape needs. It includes such changes to the agricultural landscape, much of it potentially imminent, as: all fenced ranch layouts including recently rezoned areas of GH10/11 and SO2 plus fencing all other existing ranch layouts (TGLP/CFDA/RAD blocks), all waterpoints allocated by KD and GH Land Boards but not yet drilled or developed plus those in application (vetted according to LB spatial allocation policies), allocation of RAD waterpoints out to full 20km radii of RAD settlements in WMAs, complete loss of relatively narrow buffer WMAs KD5/11, and a strip of fenced ranches straddling the Kang-Hukuntsi highway. The combination of this cumulative business-as-usual trajectory results in a bleak Kalahari landscape broken into two from the perspective of wildlife. Populations loose access to areas in between the PAs and shrink back to cores. Shrunken WMAs adjacent to PAs remain viable wildlife habitats (KD1/2/12/15 and GH10), while those in between (KD5/6 and GH11/13) likely collapse into irrelevance in terms of wildlife use.

Scenarios 12-14 are alternative development pathways to Scenario 11 that incrementally optimize the core and connectivity landscape with the least possible mitigative effort and compromise to planned agricultural expansion, thus balancing agricultural ambitions with the needs of free-ranging wildlife. Contrasting with the haphazard encroachment into some sensitive wildlife areas characterizing Scenario 11, in Scenarios 12-14 planned agricultural expansion is strategically reallocated to areas less important for wildlife. Notably, in the final iteration (Scenario 14), the total alternative area proposed for agricultural expansion equates to that necessarily mitigated to rescue the wildlife landscape.

Scenario 14 is the only one that restores connectivity for all 3 disturbance-sensitive species through two functioning corridor habitat linkages between KTP and CKGR. It therefore defines the minimal mitigative effort necessary to achieve KGDEP Component Goal 3.

Examining specific land use changes in isolation (Scenarios 2-10) allowed us, for example, to pinpoint the disproportionate quantitative gains to the wildlife landscape from relatively modest interventions like deactivating the undesirable encroachment inside southern GH11 WMA (7.7% improvement to overall landscape least cost path connectivity for gemsbok) and "low-hanging fruit" such as removing the deteriorated wildlife-friendly fence (13.3% improvement to overall landscape least cost path connectivity for gemsbok).

Recommendations:

The minimal mitigative effort necessary to achieve KGDEP Component Goal #3 requires:

1. **Kang-Hukuntsi 'wildlife-friendly' fence deactivation/removal.**
2. **Gazettement of and no further waterpoint encroachment into WMAs, including KD5/11.**
3. **Withholding development of the most southerly row of ranches in the rezoned GH11 layout (i.e. maintaining that area as WMA).**
4. **Modification of select RAD community 20-km radius development zones around Zutshwa, Ngwatle, Ukwi, Ncaang, Bere, Kacgae as per Scenarios 5 and 14, and implementing the prescribed alternative development zones to accommodate future expansion offset from the selected reduced RAD development zones.**
5. **Deactivation/relocation of Ranyane and select cattlepost encroachment into southern GH11, KD6 and KD12 WMAs to alternative development zones as per Scenarios 9, 10 and 14.**

Implementing any of the above mitigations will help improve landscape connectivity. Implementing all of them (Scenario 14) is predicted to restore wildlife population connectivity through two landscape corridors – both central and western. Implementing all of them together, as per Scenario 14 is, as the scenario modeling shows, the minimal action necessary to restore landscape connectivity for the full suite of Kalahari wildlife species.

Together with the above, the following is also necessary to maintain landscape connectivity:

6. **Resist any and all future fencing proposals along transportation routes that bisect wildlife corridors, namely the Trans-Kalahari between Palamakoloi and Bere-Kacgae, and the Kang-Hukuntsi highway where it passes through KD5/6/12 WMAs.** As the KWLCA shows, despite good intentions even the 'wildlife-friendly' fence poses a formidable barrier to large grazing antelope movements. Enhance interpretive signage along highways that bisect wildlife corridors (A2 TransKalahari and Kang-Hukuntsi) to affect motorist behavior and raise awareness and appreciation of Botswana's free-ranging wildlife landscape.

In addition to the above listed, the following is also recommended:

7. Implement firebreaks/cutlines or at least visible 4x4 tracks along WMA-CGA boundaries as defined in Section 4.5.3.1. Enhance anti-poaching effort along these long cattlepost frontier interfaces.
8. Gazette all WMAs and facilitate development of land use management plans for each.
9. Expand the Green Preserve and associated wilderness trail concept to include the central corridor in addition to the western corridor. Encourage a diversification of natural resource economies for RAD communities in WMAs, not one option vs another (i.e. hunting vs photographic tourism). Facilitate rather than hinder private/NGO partnerships with communities and investment in community development and various natural resource-based economic projects (including tourism). Provide latitude and unrestrictive ToRs for creative solutions in marginal areas with unique constraints rather than one-size-fits-all policy, and restrict BTO or other government interference in community-private sector partnerships.
10. Diligently vet and mitigate future proposals of agricultural expansion that threaten WMA integrity, particularly at the pinchpoints of landscape connectivity described in Section 4.4. This

includes individual waterpoint applications. Scenario 14 is the limit of such encroachment at these vulnerable pinchpoints.

Conclusion:

The perspective provided by past, present and future windows into the landscape lead to the conclusion that now is the last realistic opportunity to conserve the Kalahari landscape for free-ranging wildlife before critical thresholds are passed. The science is clear; Botswana's government now must choose which future scenario to pursue. This report provides all the necessary details for land planners to implement whichever chosen scenario.

Acknowledgements

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Firstly, the landmark wildlife track-based geodatabase would have been simply unattainable in its scope and accuracy without the exceptional skill and discipline of traditional Kalahari trackers whom have led and assisted data collection over the years. We exalt their discipline, great concern for data accuracy and completeness, and their continued enthusiasm for conservation despite present hardships. We thank Panana Sebati of Ngwatle, the late Tebere Dane of Zutshwa, Njoxlau Kashe of Bere, the late !Nate "Shortie" Brahman of Bere, and the late Horekwe "Karoha" Langwane of Kacgae, in particular for their disproportionate efforts. In the field we additionally thank Julia Burger. For research permissions we are grateful to Botswana's Ministry of Environment, Natural Resources Conservation, and Tourism, and its Department of Wildlife and National Parks. We thank Kgalagadi and Ghanzi District Land Boards and government departments for sharing land use databases. We thank Laila Bahaa-el-din for work on landscape layers and Marie-Charlotte Gielen for GIS support. We thank Corinne Itten and Comanis Foundation for funding support throughout.

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1 INTRODUCTION

The Government of Botswana, with the support of the United Nations Development Programme (UNDP) is undertaking a Global Environment Fund (GEF)-financed project entitled “Managing the human-wildlife interface to sustain the flow of agro-ecosystem services and prevent illegal wildlife trafficking in the Kgalagadi and Ghanzi Drylands”, more simply known as the Kgalagadi and Ghanzi Drylands Ecosystem Project (KGDEP).

Key to the KGDEP is development of an Integrated Land Use Management Plan (ILUMP) for Kgalagadi and Ghanzi Districts. These two Districts (along with lesser parts of Southern and Kweneng Districts) comprise what remains of the core free-ranging Kalahari wildlife landscape in southern Africa. The main objective of the ILUMP is to address the competition and conflict between land uses in this landscape and to provide a framework for maintaining wildlife movement corridors between Kgalagadi Transfrontier Park (KTP) and Central Kalahari Game Reserve (CKGR).

Accordingly, a project area expert consultant was procured to conduct a quantitative Kalahari wildlife landscape connectivity analysis (KWLCA) to generate the appropriate spatially explicit guidance for the ILUMP that ensures the KGDEP achieves its component goals. The KWLCA requires computationally intensive state-of-the-art landscape modelling, so the consultant necessarily collaborated with leading world experts at EcoAnalytica LLC, a world-leading ecological modeling and informatics consultancy based in the United States.

The Inception Report for the KWLCA (May 2021) described the background, objectives, methodology and proposed timeline for the KWLCA, as well as initial ideas for integration with the early phase Situational Analysis of the ILUMP.

Phase 1 Report (February 2022) described the actual methodological approaches taken in detail, including the wildlife and landscape data, steps involved in their processing, and the analyses workflow to produce the results. Phase 1 results were presented predominantly in the form of habitat suitability maps for 32 wildlife species, including predictive performance measures of the models, models structure with variables coefficients and strengths, along with plsmo spline plots showing responses to specific variables. We provided tentative inferences about the current state of wildlife core areas and connectivity from these results and argued the subset of species selection for Phase 2 connectivity modelling and scenario planning.

The present Phase 2 (Final) Report builds upon Phase 1, taking the KWLCA forward in two major ways. Firstly, whereas Phase 1 habitat suitability modelling analyzed static wildlife locations in relation to landscape variables, Phase 2 connectivity analyses incorporate wildlife movement, to evaluate population connectivity with respect to paths, costs and success of moving across the landscape. Secondly, whereas Phase 1 analyses were confined to the near-present time, in Phase 2 we analyze the future, by manipulating or changing the landscape according to land use options and measuring those resultant scenarios on wildlife in terms of both habitat suitability and landscape connectivity. It is well recognized that the future trajectory of this landscape is agricultural expansion. KGDEP Component 3 goal is "Integrated landscape planning in the conservation areas and SLM practices in communal lands [to] secure wildlife corridors and increase productivity of rangelands respectively, reducing competition between land-uses and increasing integrity of the Kalahari ecosystem" (UNDP 2017). Scenario modelling presented in this Phase 2 report therefore focusses on various iterations and permutations of agricultural expansion (and limited restoration), so that land planners may weigh the various options with respect to their consequences upon the wildlife landscape.

Phase 2 (Final) Report continues from where Phase 1 Report left off. Although this report is constructed so to be comprehensible in and of itself, it will be more appropriately utilized for land planning when studied together with Phase 1 Report.

The Deliverables for Phase 2 reporting from the ToRs are reiterated here:

- Predictions in high resolution spatial detail (mapping) of the existing species-specific wildlife connectivity landscape including the remaining core areas and functional corridors linking KTP and CKGR.
- Spatial prioritization and assessment of value of each management unit and ranking of core areas and corridors for importance for key individual species and all species jointly.
- Evaluation of the impact of a limited set of future scenarios (e.g. expansion of boreholes-cattleposts within 20 km WMA village development radii) on core area and corridor integrity.
- Application of the UNICOR modelling and scenario planning to provide guidance on:
    - The spatial limits of tolerable encroachment beyond which each corridor likely ceases to function;
    - Prioritized restoration actions (e.g. particular borehole deactivation/repurposing) that will maximize wildlife corridor and core area integrity; and
    - Potential areas where industrial/agricultural development might occur without negatively impacting wildlife corridor and core area integrity

1.1 Concept Clarity - Understanding Connectivity and Corridors in the Kalahari context

There is tendency to conceptualize 'connectivity' and 'corridors' as relevant exclusively to the phenomenon of wildlife migration. Migration is defined as long-distance movement of animals on a seasonal or annual basis, thus implying regularity and predictability. It also implies the movement of entire populations or a large proportion of them. Most large herbivore migrations the world over have never been mapped in enough detail to guide effective conservation (Kauffman et al. 2021). The methods that researchers traditionally apply to the problem of mapping migrations, namely telemetry collaring, are practically limited to infinitesimal sample sizes and therefore usually insufficient for population-level inferences (Hebblewhite & Haydon 2010). The Kalahari is no exception. During the early 1990's, VHF-collared wildebeest moved long distances between CKGR and the Schwelle (Bonifica 1992). Over the 4-year study period one of those individuals even moved between the Nossob riverbed in KTP to the northeast of CKGR (K. Lindsay pers comm.), thus proving a KTP-CKGR link at the individual level. Overall, wildebeest movements appear to have some spatial regularity but are mainly influenced by annual rainfall; in good rainfall years they generally stay in the same area, in poor years they move. The more severe and cumulative the drought conditions, the farther animals move and in larger numbers. This seems to be the general pattern not just for wildebeest but for the other large Kalahari herbivores too, and even carnivores. Long-distance Kalahari movements occur for certain, but at the population level not what could be classified as 'migration'.

Importantly, migration is only but one pattern of movement relevant to landscape connectivity concerns for wildlife conservation. The lack of telemetry collaring evidence supporting the notion of a KTP-CKGR migration, or even either KTP/CKGR-Schwelle migration for any wildlife species is irrelevant to the general concern about Kalahari landscape connectivity for long-term population conservation and adaptation. Obsession with individual KTP-CKGR movements and the onus on telemetry collars to prove it, misses the point. Animals perhaps never 'migrated' between these two protected areas, strictly speaking.

The approach we have taken in the KWLCA is different. We do not assume seasonal or annual migration in the Kalahari. Our unique track-based sampling of wildlife occurrence and movement has captured a large proportion of wildlife populations, and spatial coverage is appropriate, compared to telemetry collaring studies. We sampled all potential corridor areas using track transects that bisected their widths, repeatedly, and especially at their narrowest pinchpoints. Thus, if wildlife move through these potential corridors then they had to cross the transects, and if they crossed the transects they were then detected with high probability. All of the locations sampled in our track survey revealed multi-species movements. It is difficult to see wildlife in the Kalahari, but their tracks are ubiquitous, and they do not lie. We thus analyzed tens of thousands of wildlife occurrences in relation to high resolution landscape layers (e.g. tens of thousands of kraal locations) to generate high performing predictive models that quantify the relative value of the continuous land surface from the perspective of wildlife. This is a first for the Kalahari, and arguably a great leap forward beyond the coarse-resolution aerial survey and traditional collaring approach characterized by samples of infinitesimal size relative to their populations, and strongly biased from the outset both spatially and by the individuals selected/capturable.

We do not imply that large herbivore migration, strictly defined, exists in the Kalahari nor that the corridors identified will fully conserve that phenomenon. Landscape connectivity through wildlife corridors as the KWLCA defines it relates to areas of appropriately sufficient habitat suitability which wildlife can and does access and utilize. As a consequence, populations are linked between protected area cores either by continuous distribution or irregular movements (e.g. individual dispersal, seasonal redistribution related to rainfall). Corridors also serve as potential conduits for long-term range shifts, i.e. climate-related adaptation.

Our selection of three disturbance-sensitive focal species for Phase 2 modelling perhaps exemplify three different characteristic examples of non-migratory movements for which landscape connectivity is pertinent. Gemsbok, presumably most resistant of large herbivores to the vagaries of inter-annual rainfall and therefore most sedentary, appears to have continuous populations throughout corridors of high habitat suitability. In this sense the corridors form relatively narrow and linear shapes to the gemsbok range relative to the cores. Eland on the other hand cannot be found continuously distributed throughout the corridors. Corridors in this sense would rather facilitate erratic movements of often large herds driven by food/moisture conditions as a result of seasonality and rainfall. In the third example, young male lions undertake long-distance dispersals to find new prides, and the corridors serve as the sufficient value habitat conduits of least resistance through the landscape ensuring the best probability of survival and mixing of genes between vulnerable core populations.

In all three cases landscape connectivity through the corridors enhances populations and their probability of long-term persistence. Connected landscapes are of universal relevance to conservation biology, well-grounded in theory and validated in field study. The concept is perhaps exceptionally relevant to the Kalahari ecosystem given these facts: a) loss of landscape connectivity due to erection of fencing caused drastic population die-offs of the most mobile large herbivore species (hartebeest and wildebeest) in historical times, and probably the loss of springbok treks as well; b) Kalahari wildlife have exceptional spatial demands relative their body masses (Keeping 2014), i.e. their environment seems to require them to move farther in their daily and lifetime activities than species from other ecosystems and continents.

Botswana conservation would benefit from disentangling the concepts of ‘migration’ and ‘connectivity/corridors’. The latter is best appreciated independently in the Kalahari context as highly relevant to dispersal, genetic exchange, facilitating access to spatially unpredictable resources, and climate change adaptation for continued evolution - all contributing to enhanced population persistence and reduced probability of extinction.

2 METHODOLOGY

2.1 Study Area

Once again, the KWLCA area of interest (AOI), consistent with Phase 1, is defined for reference:

The AOI encompasses the full extent of the remaining free-ranging wildlife landscape in between KTP and CKGR (Figure 1). It includes most of Kgalagadi District, much of Ghanzi District, and parts of Southern and Kweneng Districts. Present land use in between the two protected areas is largely comprised of unfenced Wildlife Management Areas (WMAs) and Communal Grazing Areas (CGAs), plus lesser portions enclosed with fencing as ranches, farms, and ploughing fields.

The AOI extent is bound by the international border fences with Namibia and South Africa in the west through southeast, by a reasonable buffer into Ghanzi District CGAs and TGLP ranch block in the northwest - and similarly in the east, and an acceptable distance into CKGR. The CKGR extent was determined as a tradeoff between our reluctance to over-extend modelling prediction in the northeast too far up the rainfall gradient with limited wildlife locational data on the one hand, and on the other hand the need to include a large enough core area of CKGR for source populations required in Phase 2 modelling.

The AOI is 170,128 square kilometres in extent.

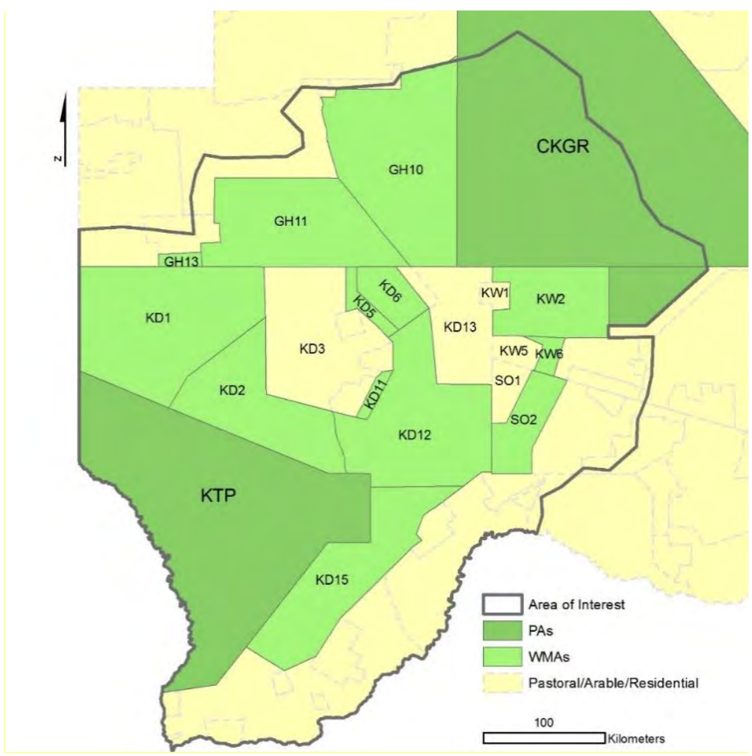


Figure 1 AOI for the KWLCA. Select land use blocks within the study extent are labelled with their alpha-numeric identifiers.

2.2 Connectivity Methods

Our goal of predicting population connectivity across the AOI was to analyze both the present time landscape and several future scenarios (as well as a snapshot of historical conditions as a baseline). These connectivity methods involved three broad stages: updating Phase 1 habitat suitability maps, estimating landscape resistance, and modelling resistant kernel and factorial least cost path connectivity.

The first was to update HS maps by modifying the agricultural landscape (including kraals layers and fenced enclosures) to generate new predictive HS surfaces according to scenario.

Secondly, these HS surfaces were then inverted to generate landscape resistance layers for each scenario. All fences and roads within the landscape, functioning variously as filters and barriers to wildlife movements, were incorporated to the resistance layers at this stage.

Finally, the resistance layers were applied to model both kernel and factorial least cost path connectivity.

2.2.1 Habitat Suitability updates

2.2.1.1 Modeling Kraals as Function of Distance and Density of Boreholes

The analysis presented in this report includes modeling habitat suitability in the current landscape and projecting changes in habitat suitability and connectivity in 13 alternative future scenarios. For these future scenarios we projected landscape changes and then recalculated the habitat suitability and connectivity that would be expected under these scenarios. One of the main landscape variables that affect both suitability and resistance to movement is the density of kraals in the landscape. Kraals, once again, are the steel fenced or thorn branch bomas into which livestock are periodically herded and contained in dense concentration. They develop in the vicinity of any human settlement in the Kalahari, and as clusters around any fixed point of water provision such as boreholes. They are therefore the appropriate point disturbance locations from which the synergistic effects of both livestock and people attenuate outwards into the surrounding landscape, which, most importantly, can be managed spatially by land boards via the allocation of waterpoints (boreholes). We have distinguished in the KWLCA between those kraals in the free-ranging wildlife landscape (NF = “not fenced”) and kraals that are inside of fenced farms and ranches (F = “fenced’).

Most scenarios involved changes to the number and distribution of kraals, and often the expansion of kraals which do not yet exist. To obtain realism in the future landscape and consistency in relation to wildlife HS models, we simulated expected numbers and patterns of kraals based on empirical samples from existing cattleposts. First, for each scenario the project team delineated the locations of new boreholes across the analysis area that reflect the expected number and distribution of new boreholes in that scenario. Second, as described in detail below, we then applied an empirical relationship between observed kraal numbers and locations relative to existing boreholes, each for KraalsF and KraalsNF respectively. Below we describe this observed empirical relationship and how it was estimated. In each scenario we used spatial statistical modeling in GIS to apply this relationship to simulate new kraals that would be expected to develop surrounding new boreholes in each scenario. Notably, the new hypothetical borehole allocations for each scenario around which KraalsNF were simulated followed land board policies for minimal spacing between points, specifically ≥ 6 km (KLB 2006). For new boreholes around which KraalsF were simulated, 3x3 km was applied as threshold size for fenced enclosures to receive an allocation at the centroid of the block. For every smaller enclosure, including planned KD small stock farms, two KraalsF were randomly distributed inside each enclosure using a random spatial tool in ArcGIS 10.x (ESRI 2012).

For each KraalsNF and KraalsF, we obtained data from samples of empirical borehole-cattlepost locations deemed most representative for those in the future scenarios. For KraalsNF, we drew from a sampled subset of 71 empirical cattlepost locations from the kraals layer developed for Phase 1 and discussed in section 2.3.1.1 of Phase 1 report. These particular cattleposts were selected based on their geographic proximity and span across the area relevant for connectivity in between KTP and CKGR where critical expansion occurs in the future scenarios. The spatial characteristics of kraals that cluster around this sample of cattleposts are, we suggest, the most representative of those future cattleposts to be developed given their proximity and therefore similar environmental and cultural conditions (i.e. kraals clusters will presumably develop in a similar manner locally, contrasted to cattleposts at the other end of the landscape in Kgalagadi South). The empirical sample is also representative of allocated waterpoint spacing that adhered to the minimal 6 km LB policies and therefore appropriate for modelling future cattleposts which are intended by land boards to follow a strict 6 km spacing (KD and GH Land Board agents pers comm.). To simulate KraalsF we drew from a sampled subset of 31 empirical locations inside ranches. A borehole centroid was identified for each sampled cattlepost (based on a visible location such as a pumphouse or borehole water tank) from which to spatially model the surrounding cluster of kraals.

To model the empirical relationship between boreholes and kraals we developed seven variables: kernel density of kraals at 1km to 6km by 1km and Euclidean distance to boreholes. We first fit splines to each of these to visualize the relationship between the occurrence of existing kraals and distance to and density of boreholes (Figures 2-8 below).

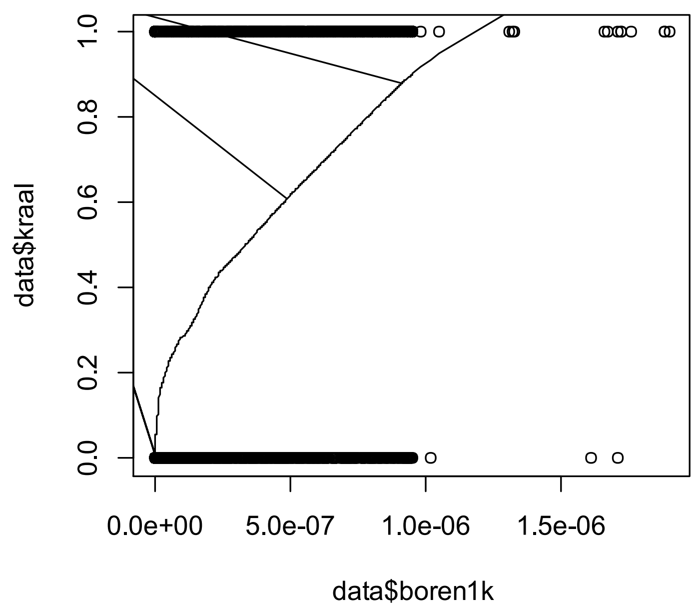


Figure 2 Relationship between kraal occurrence (probability on y axis) and density of boreholes within 1km (x axis).

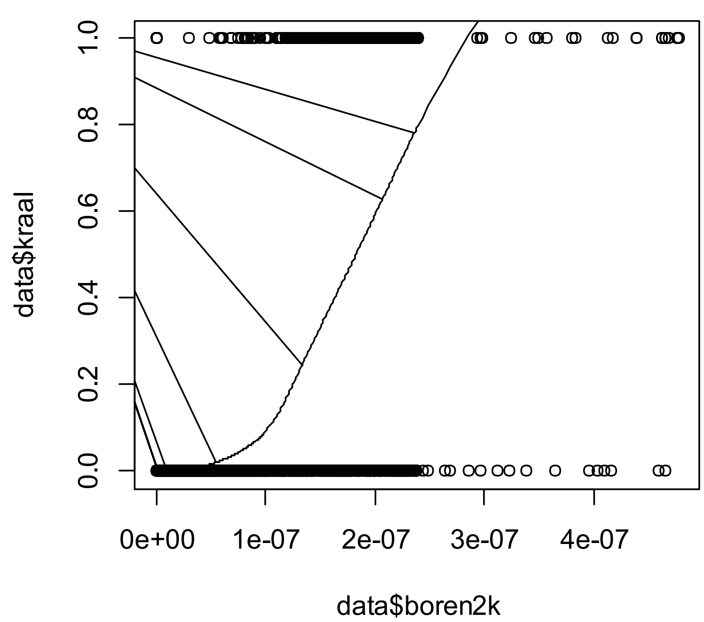


Figure 3 Relationship between kraal occurrence (probability on y axis) and density of boreholes within 2km (x axis).

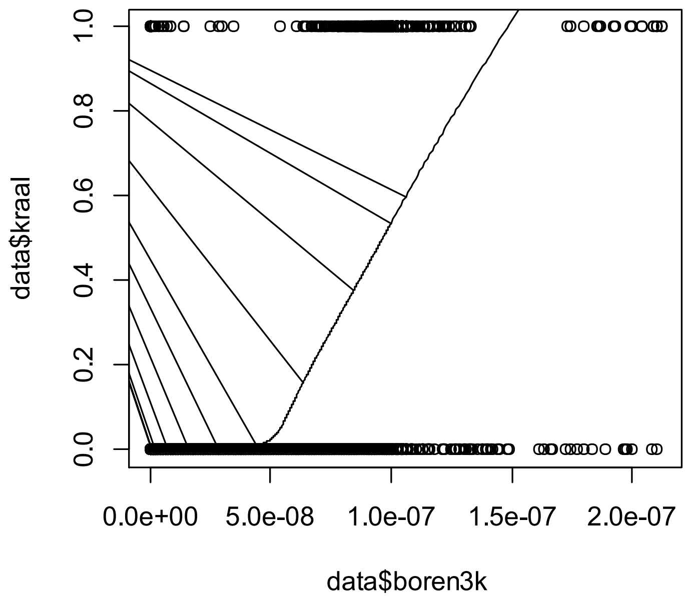


Figure 4 Relationship between kraal occurrence (probability on y axis) and density of boreholes within 3km (x axis)

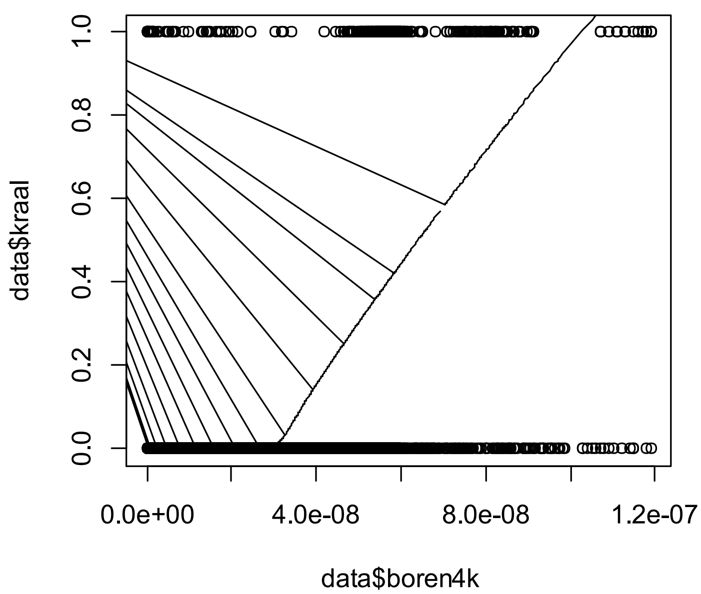


Figure 5 Relationship between kraal occurrence (probability on y axis) and density of boreholes within 4km (x axis).

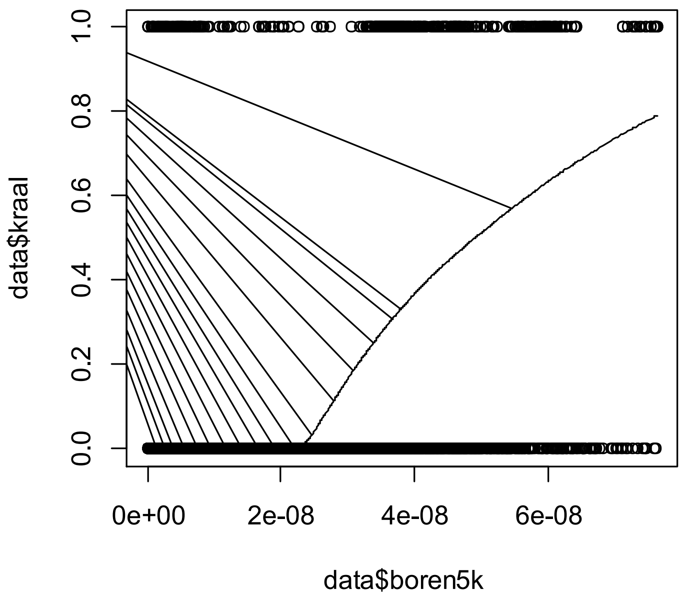


Figure 6 Relationship between kraal occurrence (probability on y axis) and density of boreholes within 6km (x axis).

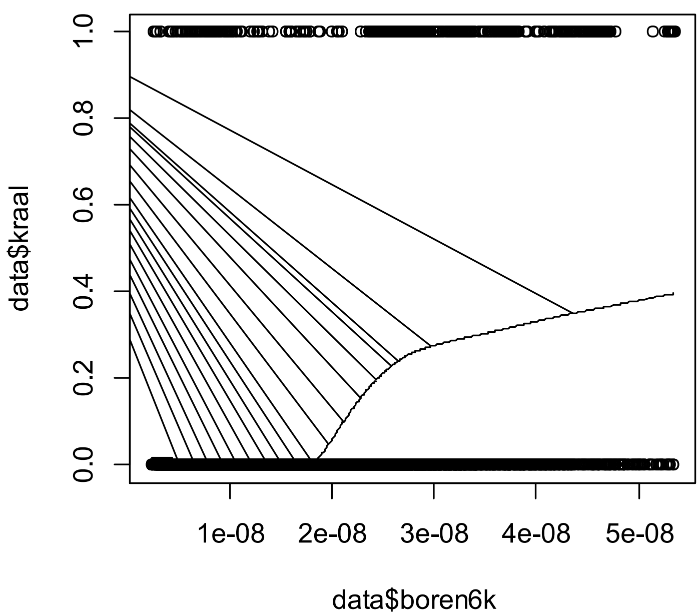


Figure 7 Relationship between kraal occurrence (probability on y axis) and density of boreholes within 6km (x axis).

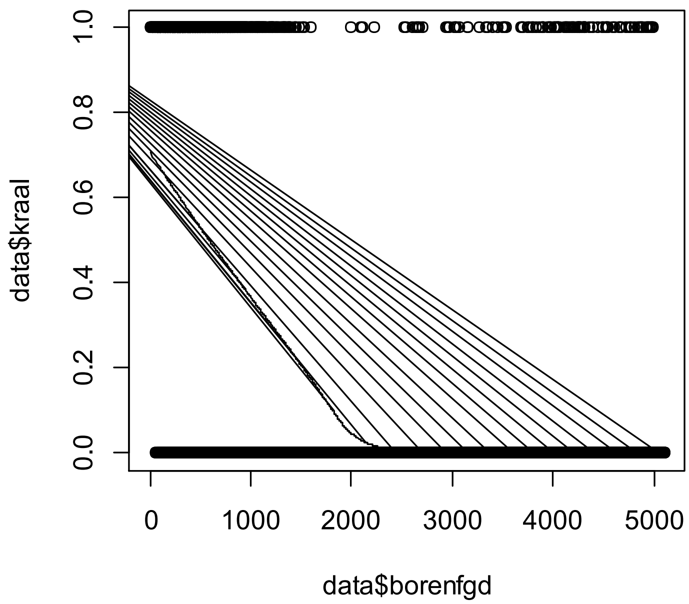


Figure 8 Relationship between kraal occurrence (probability on y axis) and distance to the nearest borehole (x axis).

Based on the splines, we used GLM logistic regression without any transformations, as the relationships are approximately linear. We fit each of the seven variables individually in single-variable models and ranked them by AIC. We used this to determine which variable is the best predictor and to choose the scale for kernel density, as different kernel density variables are highly correlated.

Table 1. AIC values for candidate logistic regression models predicting kraals as functions of density and distance to boreholes

Variables in Model	AIC
1k	4991.7
2k	4318.0
3k	5106.8
4k	6147.9
5k	7316.4
6k	8488.8

Based on this analysis we determined that the best scale for the kernel density is 2km. The two variable model including both distance and 2km kernel density is somewhat better than the single variable density model (AIC of 4302 vs 4318, a difference of 16 AIC units, meaning there is full support for the two-variable model). 58.45% of the deviance in kraal occurrence is explained by the model. This is a very good model for predicting kraals based on a combination of distance and 2km radius kernel density of boreholes.

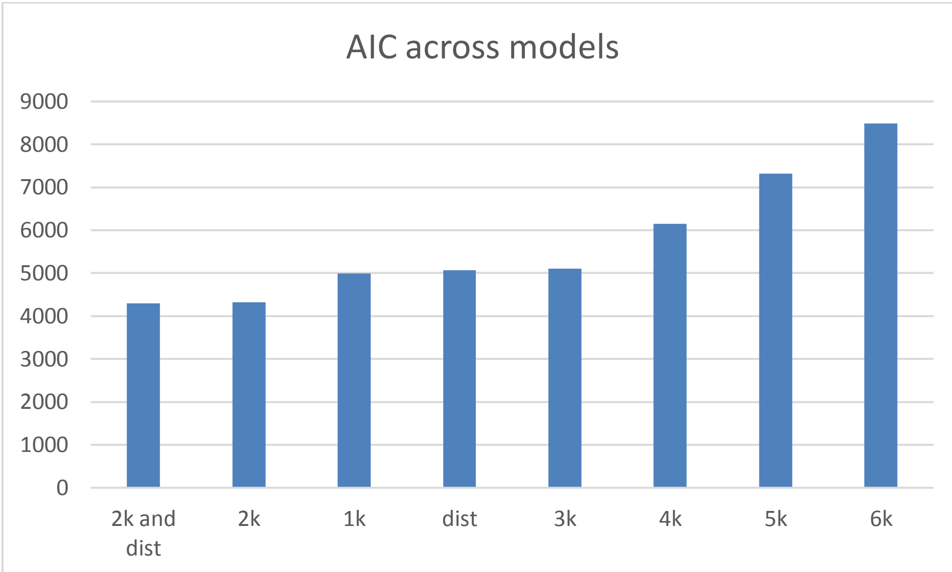


Figure 9 Plot of AIC value across models showing that the two variable mode with kernel density of boreholes at a 2km radius and distance to the nearest borehole has the lowest AIC value.

Box 1. The regression table showing coefficients we used to simulate probability of kraals in non-fenced areas around new boreholes.

```
Call:
glm(formula = kraal ~ borenfgd + boren2k, family = binomial(link = logit),
    data = data)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-4.1836  -0.1361  -0.1164  -0.0987   3.3425

Coefficients:
              Estimate Std. Error z value Pr(>|z|)
(Intercept) -6.314e+00  3.033e-01 -20.813  < 2e-16 ***
borenfgd     3.613e-04  8.514e-05   4.243  2.2e-05 ***
boren2k      3.223e+07  1.318e+06  24.459  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 10341.2  on 18226  degrees of freedom
Residual deviance:  4296.4  on 18224  degrees of freedom
AIC: 4302.4

Number of Fisher Scoring iterations: 7
```

The simulation of kraals in each scenario is done using the equation produced by this model (Box 1):

Z = -6.314 + (3.613e-04 * distance to borehole) + (3.223e+07 * kernel density of boreholes within 2km).

The probability of kraal occurrence is found by exponentiating this Z variable: p = exp(Z)/ (1 + exp(Z))

To simulate the occurrence of kraals around the boreholes projected in each scenario we first produced maps of the two predictor variables (distance to borehole and kernel density of boreholes at a 2km radius) for each scenario. We then applied the equations above to produce a map of the probability of occurrence of new kraals in the proximity of new boreholes. We then simulated the occurrence of kraals by selecting values greater than 0 from the difference between the simulated probability of kraal occurrence and a uniform random raster (following the methods developed by Cushman et al. 2017).

The rules we applied to the spacing of waterpoints at which kraals were then simulated was guided by discussion with Ghanzi and Kgalagadi Land Board agents and the Kgalagadi Land Management Policy (KLB 2006). This policy states specifically that waterpoint allocations must be:

- ≥ 6 km from one another
- ≥ 4 km from an unfenced WMA/PA boundary
- ≥ 3 km from a District Boundary

Numerous examples are to be found in both GH and KD LB databases indicating that the latter two rules have not been adhered to, although the first rule has. Whether this is a consequence of either LB deviating from their policy or private entities shifting locations on the ground is unimportant for our purposes of modelling future scenarios. What matters rather is the pattern that consistently emerges in practice, regardless of who may be responsible. Thus, in simulating new waterpoints/cattleposts we strictly adhered to the first rule but not the second or third. Simulated allocations were spaced 6 km apart at minimum, but allocations went right up to coincide with WMA and District boundaries to generate future predictions which are realistic.

2.2.2 Estimating Landscape Resistance

Most current methods of predicting population connectivity and mapping areas significant in facilitating animal movements begin with landscape resistance maps. Landscape resistance maps depict the cost of movement through any location in the landscape (pixel cell in a raster map) as a function of landscape features of that cell (e.g. high resistance might be assigned to a road or a body of water). In its most basic sense, landscape resistance reflects the local movement cost incurred by an animal. More formally, the resistance reflects the step-wise cost of moving through each cell for least-cost analyses (Singleton et al. 2002) or the relative probability of moving into the cell for circuit theory-based analyses (McRae et al. 2008).

Most published studies using landscape resistance maps have estimated resistance of landscape features to movement based on expert opinion alone (e.g. Compton et al. 2007). However, non-human species perceive landscapes in ways that may not correspond to human assumptions concerning connectivity and habitat quality. Using unvalidated expert opinion to develop resistance maps has been a major weakness of most past landscape resistance modelling efforts (Seoane et al. 2005).

We used habitat suitability combined with empirically estimated resistance due to fences of different kinds and roads to estimate landscape resistance. We used a negative exponential transformation of habitat suitability to predict resistance across the landscape as a function of habitat quality (following the method of Wan et al. 2019), which has been shown to be an optimal way to estimate resistance from habitat suitability (Mateo-Sanchez et al. 2015a,b). In this transformation we scaled resistance from 1 to 100 with a nonlinear form such that resistance to movement remained low when habitat was of high to intermediate quality. Also, given that it is known ecologically that lions are more mobile and risk averse than the antelope species, and that eland is more mobile than gemsbok, we used different exponential transformations for each species to estimate resistance as functions of habitat suitability:

```
gr <- (500^(-1 * p_gem) -0.002042734) * 100

er <- (999999999^(-1 * p_eland) - 2.035775e-09) * 100

lr <- (9999999999^(-1 * p_lion)- 1.941701e-08) * 100
```

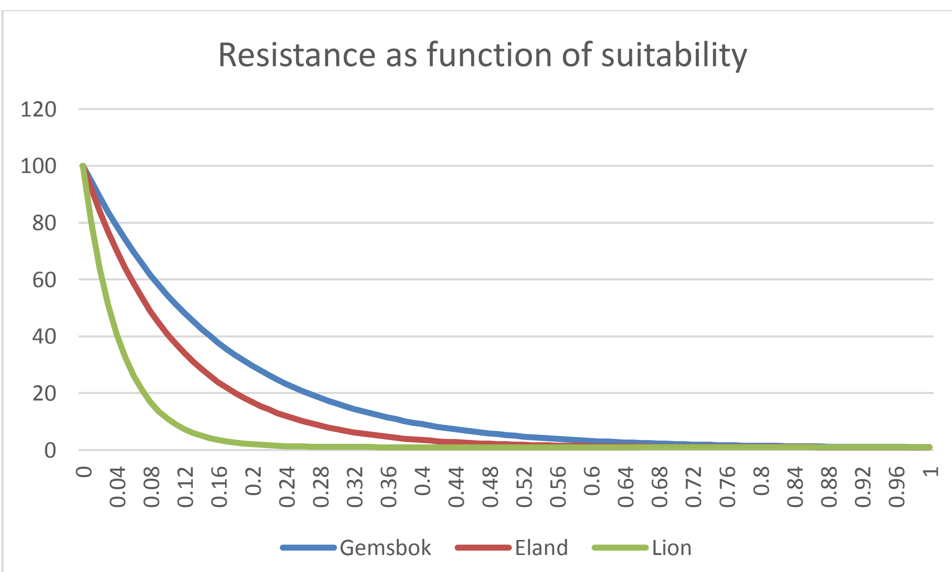


Figure 10 Plot of resistance (y axis) as a function of habitat suitability (x axis) for gemsbok, eland and lion.

For each species we also included differential resistance effects due to three kinds of fence and three kinds of roads (Tables 2 and 3).

Table 2. Fence resistance assigned to the three difference types for the three species gemsbok, eland and lion

Species	Wildlife & Border fences	Wildlife-friendly fence	All other fences
Gemsbok	1000	375	500
Eland	450	100	400
Lion	350	0	250

Table 3. Road resistance assigned to the three difference types for the three species gemsbok, eland and lion

Species	Tar road	Calcrete road	Sand road
Gemsbok	50	25	0
Eland	50	25	0
Lion	0	0	0

Resistance was predicted as the additive sum of the road, fence, and suitability resistance factors to produce a composite resistance across the landscape.

2.2.2.1 Fence resistance

Fences in and bordering the AOI were grouped into three categories: wildlife and border fences, wildlife-friendly fence, and all other fences not fitting into the first two categories. These categories were based on different fence structure causing differing movement resistance to the three target species. Wildlife and border fences include those which are typically the tallest, most densely wired, most frequently maintained, sometimes electrified, and sometimes multi-layered (i.e. more than a single fence line). They therefore create the greatest resistance. The single wildlife-friendly fence in the AOI spans both sides of the Kang-Hukuntsi tar road where it bisects the WMA for 31.5 km. This fence is designed to facilitate large antelope movements while hindering livestock, comprised of 3 equally spaced barbed wires - the top wire of which is 80 cm above ground level. All other fences is a miscellaneous category encompassing highway-side fences (excluding the wildlife-friendly fence) and fenced ranches, farms and other enclosures of various sizes, together representing an intermediate level of resistance between wildlife proof and wildlife-friendly fences. Fence design, condition and therefore resistance varies within this category, for example, at the extreme some private ranches have new game-proof fences while others have derelict livestock fences. However, up to date data on every fence line within the AOI was not available so assumption and simplification was necessary. Broadly and relatively speaking, this category does represent an intermediate level of large-bodied wildlife resistance. For example, highway-side fences are constructed of 125 cm high page wire plus a single barbed wire above at height 140 cm. Not only is this height too low to restrict high-jumping kudu and eland, but gates to off-highway accesses are often left open or removed, thus having some porosity for non-jumping species as well.

Fence resistances for species by category were determined based on direct observations in the AOI, discussions with trackers and game managers, and grey literature. We also had empirical data to draw from along the wildlife-friendly fence (Keeping et al. *in review*), described in the next subsection. From these data we assigned resistance values on the appropriate scale for the 3 different fence types among each species (Table 2).

2.2.2.1.1 wildlife-friendly fence data

Once during November 2016, and again during April 2018, we sampled both the wildlife-friendly fence line to the south of the Kang-Hukuntsi highway, and the old Kang-Hukuntsi sand road conveniently paralleling the highway to the north as a control transect. DK drove approximately 10 kph next to the fence while two certified Master Trackers (Cybertracker Conservation 2018) seated over the bonnet observed tracks of animals which had approached the fence from the north (tar road) in addition to animals which had approached from the south. Basic information including species, age of tracks estimated to the nearest 24 hr period, and GPS location were recorded in addition to examining animal behavior in more detail. When necessary, Master Trackers both back-tracked and forward-tracked the animal, until a clear story emerged for each wildlife-fence interaction. Details were explained while pointing out the track evidence, until they could be verified satisfactorily by DK. Additional data collected included the height of the top fence wire from ground level at every location that an animal attempted to cross the fence, or was deflected, measured using a folding ruler.

Of three Phase 2 target species, gemsbok had sufficient observations to empirically estimate wildlife-friendly fence resistance as the number of unsuccessful crossings (deflections) as percentage of total attempted (unsuccessful + successful) crossings. This value (74%) was transformed into the appropriate resistance scale and reported in Table 2.

2.2.2.2 Road resistance

Road resistances for species by category were similarly determined based on direct observations in the AOI, discussions with trackers, and empirical data. Gemsbok once again had adequate observations from replicate sampled transects along unfenced sections of the A2 Trans-Kalahari highway (Keeping et al. 2015) to estimate tar road resistance empirically. We compared track crossing rates over the A2 highway along the Palamakoloi to Lokalane section to mean track intersection rates on transects throughout areas of equivalent habitat suitability. Undisturbed transects had ten times the crossing rate as the tar road, so we set gemsbok tar road resistance accordingly on the appropriate scale. Gemsbok calcrete road resistance was set to half the tar road resistance, and sand road resistance a zero reference. Eland road resistances were set to match gemsbok, and lion were set to zero (Table 3). Unlike fence resistance which arises as a result of physical impediment to wildlife movement, road resistance emerges by virtue of disturbance caused by traffic. Eland and gemsbok movement over the A2 occurs almost exclusively after dark when traffic volume declines and the interval between passing vehicles increases up to 30 minutes (Keeping et al. 2015). By contrast, lions have been observed lounging next to the A2 (and other tar roads in Botswana) in daylight hours with apparent indifference to passing vehicles (Figure 11), supporting the low values chosen.

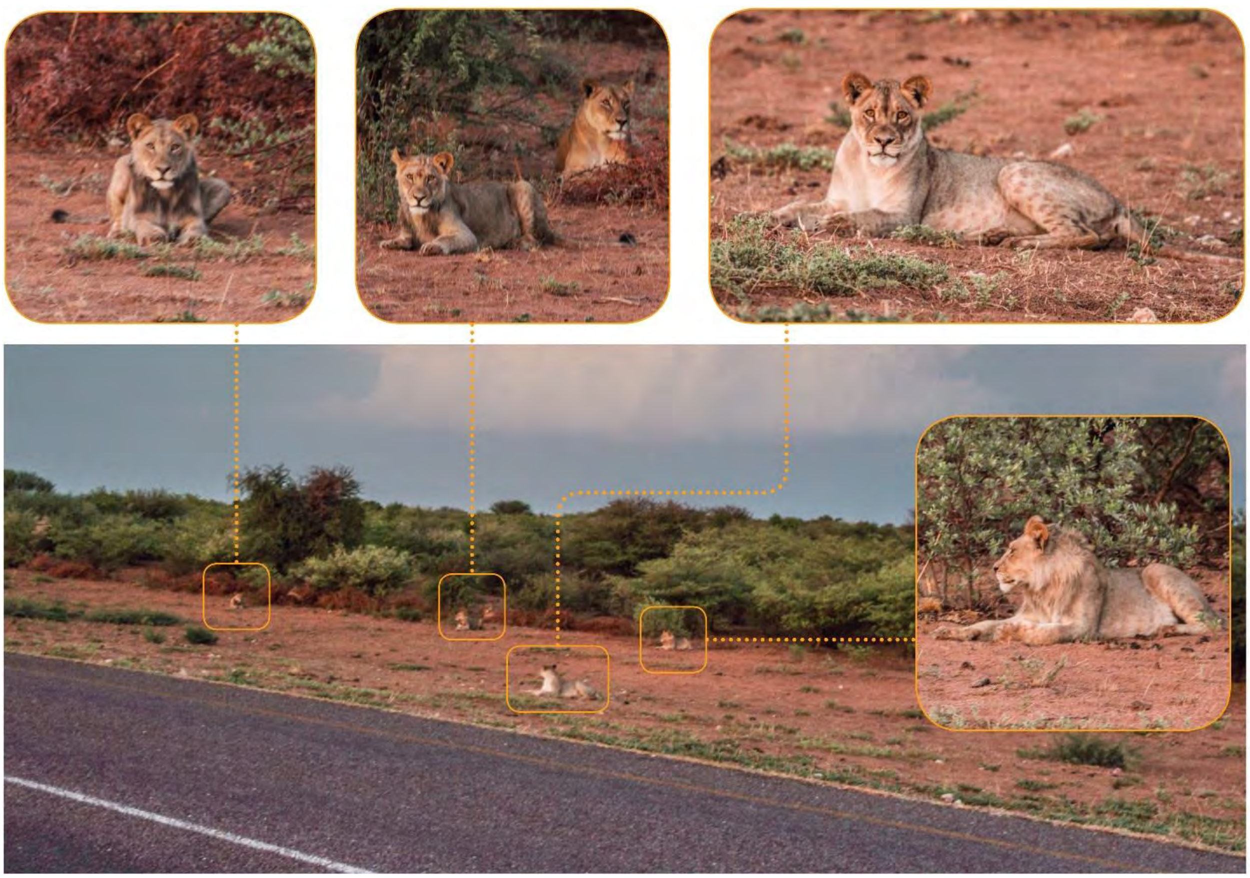


Figure 11 Lions in AOI at rest beside the A2 Trans-Kalahari highway near Takatshwane molapo approximately 20 km north of Bere village, November 2015.

2.2.3 Resistant Kernel and Factorial Least Cost Path Connectivity

While resistance is point specific, connectivity is route specific (Cushman et al. 2008). Therefore, while resistance models can provide the foundation for applied analyses of population connectivity, they do not, in themselves, provide sufficient information to evaluate the existence, strength and location of barriers and movement corridors. Connectivity must be evaluated with respect to the paths, costs and success of moving across a landscape.

The resistant kernel approach to connectivity modelling is based on least-cost dispersal from some defined set of sources. The model calculates the expected density of dispersing individuals in each pixel around the source, given the dispersal ability of the species, the nature of the dispersal function and the resistance of the landscape (Compton et al. 2007; Cushman et al. 2010b). Once the expected density around each source cell is calculated, the kernels surrounding all sources are summed to give the total expected density at each pixel. The results of the model are surfaces of expected density of dispersing organisms at any location in the landscape. The resistant kernel approach to modelling landscape connectivity has a number of advantages as a robust approach to assessing current population connectivity (Compton et al. 2007; Cushman et al. 2010b, 2011). First, unlike most approaches to mapping corridors, it is spatially synoptic and provides prediction and mapping of expected migration rates for every pixel in the whole study area, rather than only for a few selected 'linkage zones' (e.g. Compton et al. 2007). Second, scale dependency of dispersal ability can be directly included to assess how species of different vagilities will be affected by landscape change and fragmentation under a range of scenarios (e.g. Cushman et al. 2010b). Third, it is computationally efficient, enabling simulation and mapping at a fine spatial scale across large geographical extents (e.g. Cushman et al. 2010b, 2011).

The second connectivity method we used was the factorial least cost path approach (Cushman et al. 2009). One limitation of traditional LC path and LC corridor analyses is that they are limited to prediction of connectivity between single sources and single destinations. While this may be ideal in the case where one is interested in the lowest cost routes between two focal conservation areas, there are many situations where a more synoptic analysis of connectivity is valuable. For example, it may be that there is a need to calculate corridor connectivity between thousands of sources and a single destination (e.g. Cushman et al. 2010a) or between hundreds of sources and hundreds of destinations distributed across a complex landscape (e.g. Cushman et al. 2009, Cushman et al. 2011). This is what the factorial least cost path method does: it calculates the strength of the corridor network that links a large number of source points synoptically across the landscape.

The combination of resistant kernel and factorial least cost path is often used to compare methods and to provide complementary information, with resistant kernel providing synoptic information on the spatial pattern of movement density across the full landscape and the factorial least cost path method providing information on specific routes of highest connectivity between combinations of source points.

Connectivity predictions are a function of four things: 1) The resistance surface (as described above), 2) the algorithm used (resistant kernel and factorial least cost paths in this case), 3) the source points included in the analysis and 4) the dispersal distance threshold used (for methods like resistant kernel that are able to specify dispersal thresholds). In this analysis we used the resistance surfaces described above for gemsbok, eland and lion. We used the resistant kernel and factorial least cost path methods as implemented in the UNICOR software (Landguth et al. 2012). The source points were probabilistically simulated proportional to suitability for the three species. As we wanted a comparable baseline between species and among scenarios, and since the actual census population size is not known for each species, we chose to simulate 2000 source points for each species in the initial (S1) current scenario. These were selected by randomly choosing 2000 locations where the difference between the probability of occurrence and a uniform random number was greater than 0 (following the methods of Kumar et al. 2021). The dispersal distances chosen were in cost units (units of the resistance surface cost) and different for resistant kernel and factorial least cost path. For resistant kernel they were set to reflect typical maximum life-time displacement for each species, while for factorial least cost path they were given a value 4x this to reflect longer, less frequent but potentially important linkage pathways between pairs of source points. For resistant kernel the connectivity threshold distances were 90,000 for gemsbok, 150,000 for eland and 250,000 for lion, reflecting ability to traverse the landscape up to 90km, 150km and 250km for gemsbok, eland and lion respectively through optimal low resistance habitat. These values were informed by GPS and VHF collar data for 6 eland in the AOI moving over the period 1996-99 (The Environment and Development Group Oxford, 1999), and GPS collar data from 5 gemsbok moving over the period 2013-14 (Boyers et al. 2021). For factorial least cost path, in contrast, the threshold distances were 360,000, 600,000 and 1,000,000 cost units for gemsbok, eland and lion, respectively.

Resistance for alternative scenarios was created by combining the landscape layers for each scenario. For example, for each scenario we re-estimated habitat suitability and recreated fence layers reflecting any changes in fencing in that scenario. This resulted in unique resistance layers for each scenario. We also re-estimated source points for each scenario proportional to the sum of suitability. For example, if a scenario had 80% of the total sum suitability across the landscape for a species than the initial scenario (baseline S1) then the number of source points selected was 80% of 2000, or 1600. This was done to reflect how landscape changes reduce predicted population size, as indicated by total suitability across the landscape. This method was shown to accurately reflect the expected number of occurrences in a probabilistic occurrence model by Cushman et al. (2017).

For each scenario, therefore, we had a unique set of resistance and occurrence values. We then simulated resistant kernel connectivity for each scenario, produced maps of the kernel connectivity, computed the total sum of kernel value (an index of total connectivity across the landscape), computed difference maps between each scenario and the baseline S1 (to show where connectivity changes in the different scenarios, and computed the difference in total connectivity (sum of the kernel surfaces) between each scenario and the baseline S1 (which is an index of the total change in connectivity between each scenario and the current baseline condition.

Figure 12 broadly summarizes stages of spatial analysis done for the KWLCA. At the first step wildlife locational data were analyzed against comprehensive landscape data to estimate habitat suitability. This process was the extent of Phase 1, and repeated in Phase 2 for each species-scenario combination. The next two stages were exclusively done as part of Phase 2, that is the inversion of habitat suitability models to generate resistance surfaces, then finally the application of those resistance surfaces to UNICOR resistant kernel and factorial least cost path analyses.

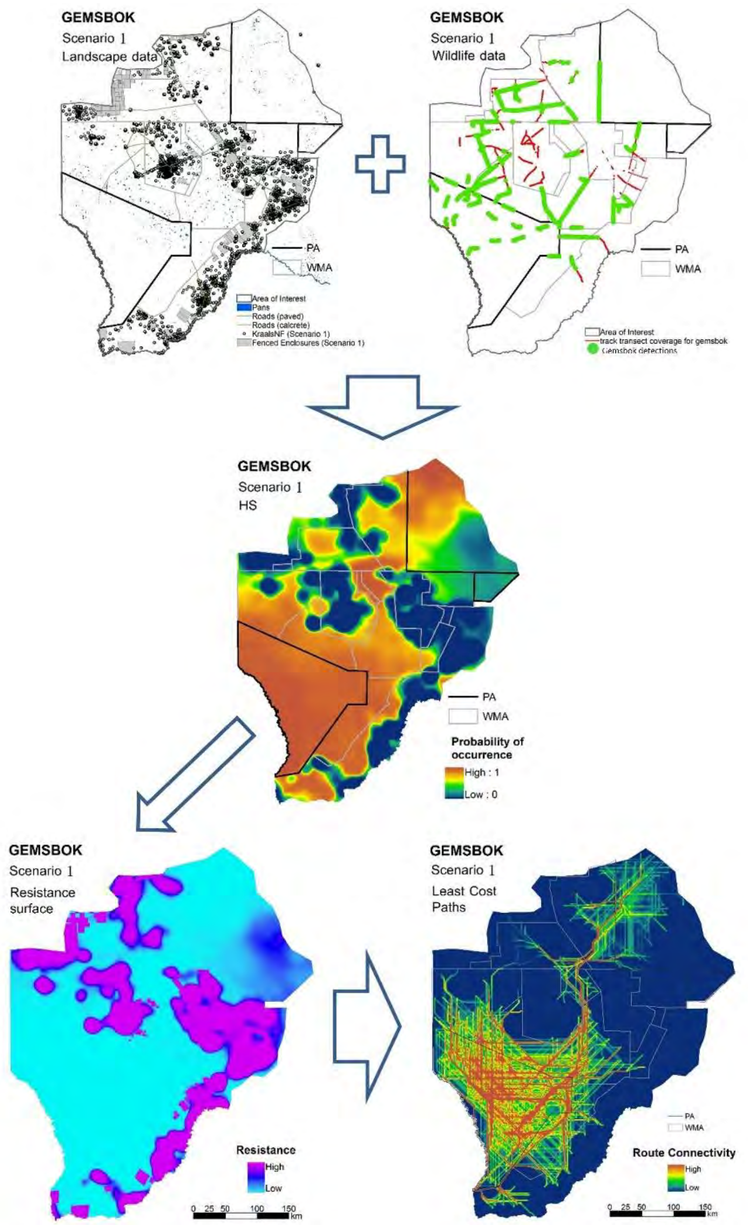


Figure 12 Basic stages of spatial processing involved for the KWLCA using gemsbok Scenario 1 for illustration.

3 SCENARIOS

3.1 Selection of Scenarios

The computationally intensive UNICOR analyses placed time constraints on the number of species-scenario combinations that could be analyzed. The first consideration in constructing future scenarios was to accommodate all the known (i.e. what could be determined from consultations with government stakeholders including Land Boards) planned, intended, proposed, and already allocated changes to the landscape. There are a host of such agricultural developments poised to affect precisely the remaining precarious corridors of wildlife connectivity. Ideally, each of these future changes to the landscape could be quantified to provide land planners with the most complete information with which to optimize their land planning decisions. Towards this end we strived to minimize the necessary species considered for each scenario in order to maximize the future scenarios information.

Excluding Scenario 0 (i.e. the existing Phase 1 HS models), we constructed 15 additional scenarios. For all 3 species, we updated HS models across all scenarios and quantified their differences between baseline and future scenarios. We ran UNICOR modeling for all 3 species on 6 of 15 scenarios only (Table 3). Nine future scenarios focused on discrete elements of landscape change (these elements were otherwise combined into the cumulative 'alternative development path' scenarios 11-14). For 8 of 9 scenarios highlighting specific changes in isolation, we ran UNICOR modeling for gemsbok only. This was to conserve computation yet sufficiently quantify relative losses/improvements to landscape connectivity, so to best serve land planners in their decision-making regarding landscape changes to avoid, as well as prioritized restoration actions that will maximize wildlife corridor and core area integrity.

Once again, our subset of 3 disturbance-sensitive wildlife species were selected in Phase 1 based on their highly performing predictive HS models which were determined in large part by their exceedingly strong spatial responses to livestock-human disturbance (i.e. KraalsNF/F density). Agricultural footprint is the overwhelming human land use influence on the Kalahari ecosystem. Future scenarios are primarily comprised of iterations of changes to KraalsNF/F variables and fenced enclosures within the AOI, plus lesser changes to land use and fence types (i.e. wildlife-friendly fence). Locations and types of roads stayed unchanged across scenarios. There was no mining spatial information to model, either present or future.

Settling on the final combination future scenarios 11-14, which can be considered alternative development pathways, was an iterative process whereby we sought minimal mitigation to the agricultural landscape necessary to salvage connectivity for all 3 disturbance-sensitive species via at least 1 of 2 wildlife corridors. Once again, as argued in Phase 1, we suggest that our 3 focal species which are the most disturbance-sensitive Kalahari wildlife serve as umbrellas in the sense that if we can be confident that their population connectivity will be maintained in a particular landscape scenario, we can subsequently safely assume connectivity maintenance for the rest of the wildlife community.

For the mitigative scenarios (5-6, 8-10, 12-14) we sought minimal but necessary changes to the landscape in consideration of political feasibility and expense, fully cognizant that the greater the pushback on the agricultural landscape, the least likely that future will be implemented. To compromise and increase implementational feasibility of alternative development paths wherein restoration actions will be required, we identified areas of the landscape where agricultural expansion can more safely occur that minimizes negative impact on wildlife corridor and core area integrity.

Table 4. Scenarios numbered and those to which UNICOR modeling applied indicated by species

	Scenarios															
	Baseline			Future												
Species	X	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Gemsbok			√	√	√	√	√	√	√	√	√	√	√	√	√	√
Eland			√	√									√	√	√	√
Lion			√	√									√	√	√	√

3.2 Scenarios Descriptions

For each scenario below we describe the key variables defining the state of the landscape, and any variables we made changes to. For simplicity and continuity, the changes made are described in relation to a previous scenario. To reduce clutter in illustrative maps, typically only KraalsNF (outside of fenced enclosures) are illustrated while those KraalsF inside fenced enclosures are not.

In cases that involve specific management action (e.g. retractions or relocations of allocated but undeveloped waterpoints, those in application, or already developed cattleposts), we provide the specific spatial details (coordinates) of the relevant locations, to remove ambiguity and best assist implementation by land managers. The figures provided are only supplementary visual guides; reference to the digital shapefiles for further geographic specificity to that provided in the text will be most helpful in land planning and assisting field implementation.

3.2.1 Scenario X – historical pre-settlement

Scenario X provides a retrospective of the pre-disturbance wildlife landscape. It is a look-back at the habitat suitability throughout the AOI for 3 most disturbance-sensitive species before there was any consequential human-livestock disturbance. This would be a period perhaps 200 years ago before pit-wells were dug at Hukuntsi pan allowing permanent settlement and growth in livestock numbers, rather at a time when human land use was affected by mobile hunter-gatherers only. However, the Scenario X picture would still be largely relevant 100 years ago, and even more recently, before the introduction of borehole technology into the Kalahari in the 1950's which relatively rapidly and extensively expanded the human-livestock spatial footprint (Perkins and Thomas 1993).

Scenario X was implemented by digitally removing all anthropogenic features from the landscape (kraals, fenced enclosures, human population, roads) and running the predictive habitat suitability models from Phase 1 for each of the 3 species. We suggest this is a meaningful baseline from which to quantify habitat loss and visualize fragmentation caused by pastoral expansion in the Kalahari. Such a reference framework is necessary for the correct perspective and appreciation of the fact that land planners of the ILUMP process are no longer dealing with a pristine Eden but rather a landscape that has already undergone pastoral encroachment to an extent that threatens fragmenting the free-ranging Kalahari ecosystem into two isolated pieces.

3.2.2 Scenario 0 – historical time of track data collection (- 10 years present)

Scenario 0 is identical to Phase 1 maps. This is the best representation of the landscape during the track data sampling period (2008-2018), which is slightly outdated already. It includes borehole allocations that were developed as operational cattleposts during the time of track data capture and excludes those which may have been long allocated but were undeveloped at the time. Figure 13 illustrates the key anthropogenic variables modeled in Scenario 0.

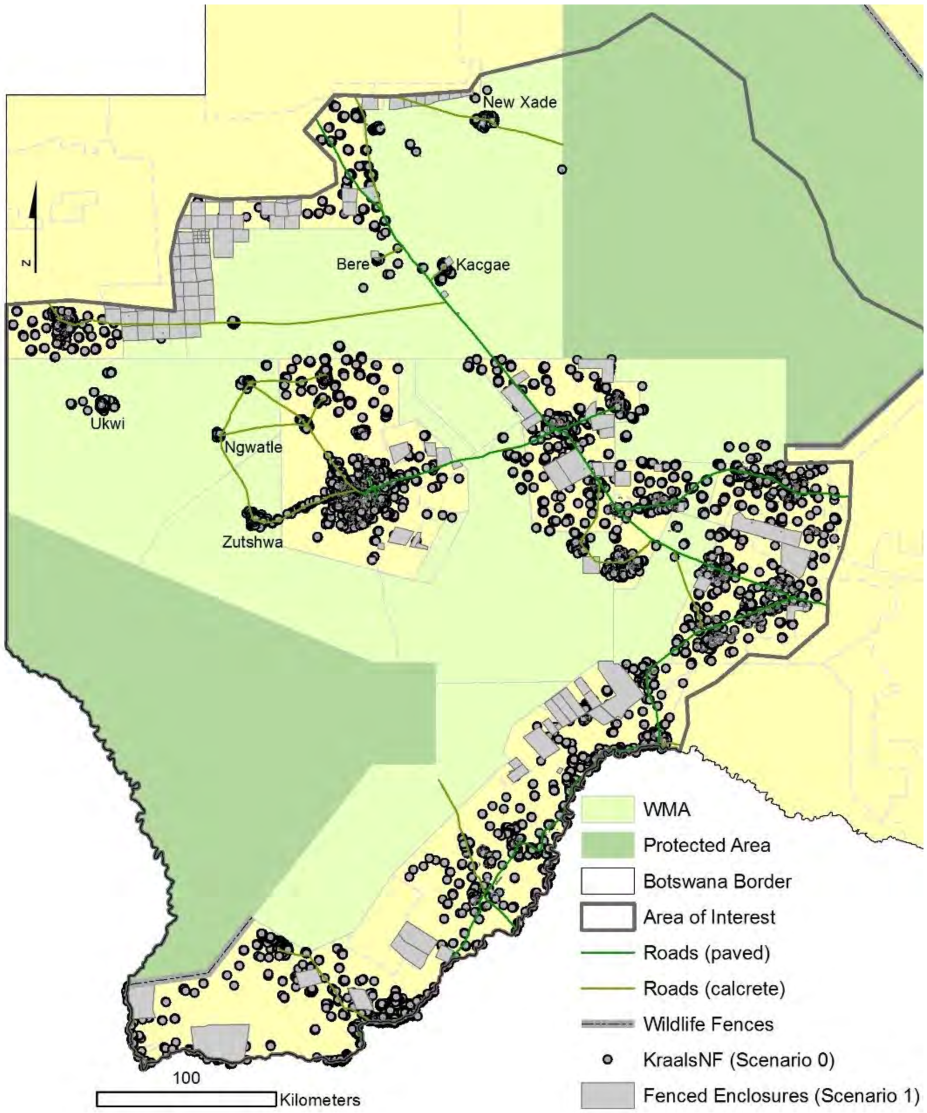


Figure 13 Scenario 0 extent of model variables KraalsNF, fenced enclosures, roads and wildlife fence at the AOI scale. Note fenced enclosures modeled between Scenario 0 and 1 are identical.

3.2.3 Scenario 1 – present time

Scenario 1 updates the Phase 1 habitat suitability maps (Scenario) 0 because a decade has already passed since much of the wildlife observational data were collected. Over the sampling period there was an increase in newly allocated boreholes, particularly among RAD communities situated in proximity to key areas of landscape connectivity. There is a lag effect between time of land board allocation and time these new locations are developed by individuals/syndicates into cattleposts that influence wildlife distributions. Although such developments are occurring continuously through time, and perhaps at different rates around different villages, we have done our best to categorically update the picture roughly 10 years ago (Scenario 0) to a present time (Scenario 1) picture of the landscape.

The key changes from Scenario 0 to 1 are a number of borehole allocations being developed into cattleposts, primarily within the 20 km RAD development radii of Ukwi (5 new cattleposts), Ncaang (5 new cattleposts), Bere (7 new cattleposts), Kacgae (6 new cattleposts), East Hanahai (7 new cattleposts) and New Xade (9 new cattleposts), plus few other new cattleposts in areas of the AOI not sensitive to landscape connectivity. These new locations added to Scenario 1 are shown in Figure 14.

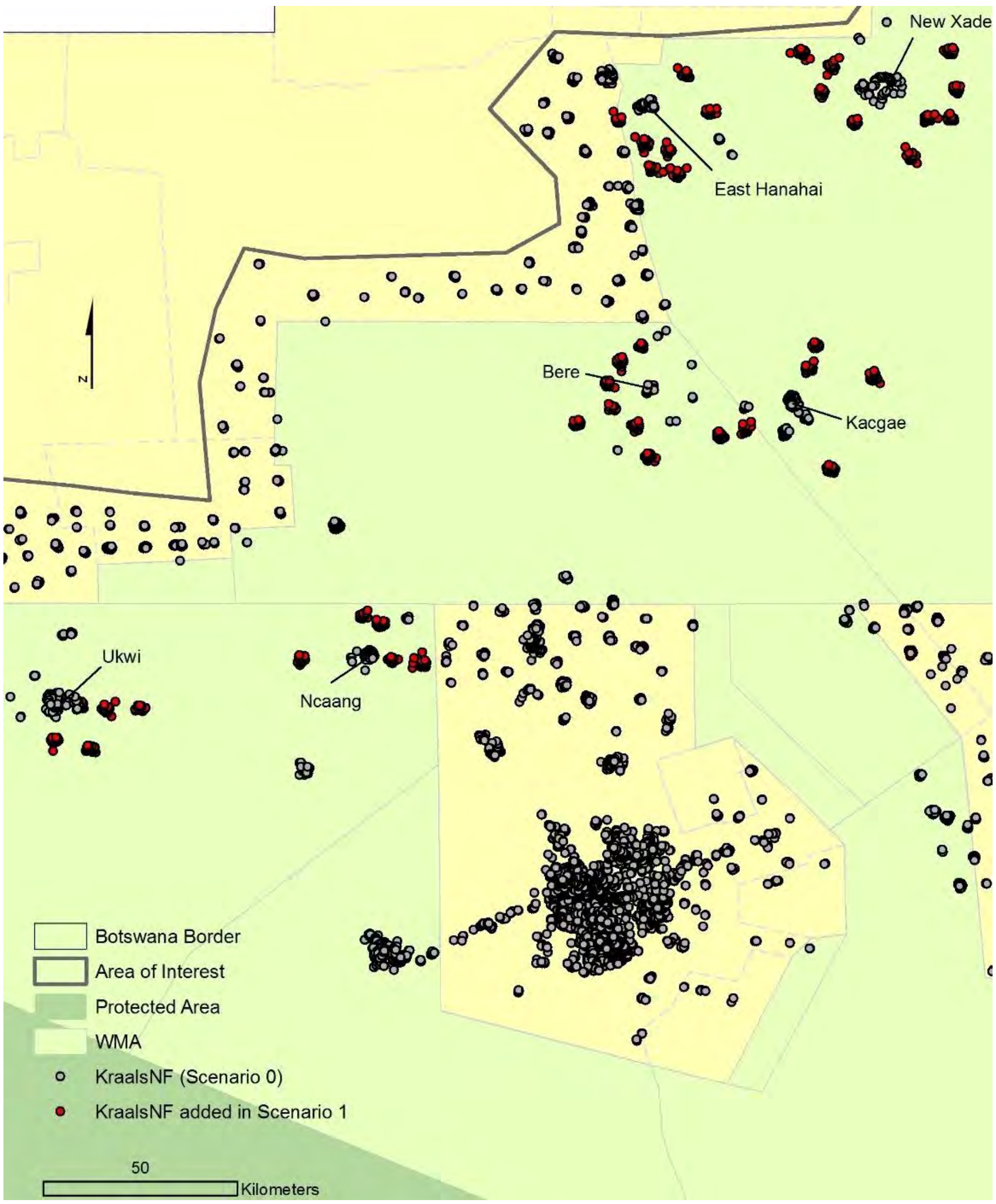


Figure 14 New cattleposts coming online (red points) in the intervening period between track data collection and present time, to update the KraalsNF layer from Scenario 0 (grey points) to Scenario 1 (i.e. grey + red points).

3.2.4 Scenario 2 – all designated and planned ranches fenced and operational

Scenario 2 provides the future view of the landscape wherein all designated ranch land use areas, as well as all planned expansion areas for enclosed livestock operations become fenced, developed and operational. This includes:

- Dezoning of WMAs SO2, KW6, and parts of GH11 and GH10, as per the Review of the National Land Use Map (2009). Rezoning with proposed fenced ranch layouts for affected areas of GH10/11 and SO2 (obtained from relevant Land Boards). Expansion of cattleposts within 20 km radii of 5 villages (Kokong, Motokwe, Mabutsane, Khakhea, Kokotsha) intruding into SO2 also included.

- Complete fencing of all designated CFDA/RAD/TGLP ranches land use blocks (e.g. KD8/9/10/18/21/22/25, SO4, KW8/9) including those ranches which may have long been allocated, but for whatever reason have been left unfenced. In Scenario 1, only fences that actually exist on the ground (known by satellite imagery or ground-truthing) were modelled to ensure realistic representation of the landscape. Here in Scenario 2, all areas intended to be fenced are brought online.

- Fencing and development of additional farms/ranches in Land Board spatial databases which have been allocated outside designated ranch land use zones such as within CGAs and sometimes intruding into WMAs. This includes development of recently designated RAD community ranches where applicable (e.g. north of Ukwi in KD1).

- Development of all small stock areas planned by Kgalagadi LB.

- Populating each fenced enclosure with simulated cattleposts (KraalsF clusters), or limited individual kraals for example in small stock enclosures, as described in Methods Section 2.2.1.1.

Note that the only element that changes between the Scenario 1 and 2 landscapes is fenced enclosures and associated KraalsF within them. All other landscape variables stay constant. The additional fenced enclosures added to the Scenario 2 landscape compared to Scenario 1 is best viewed in contrasting panels in Figure 15, and KraalsF inside those fenced enclosures in Figure 16.

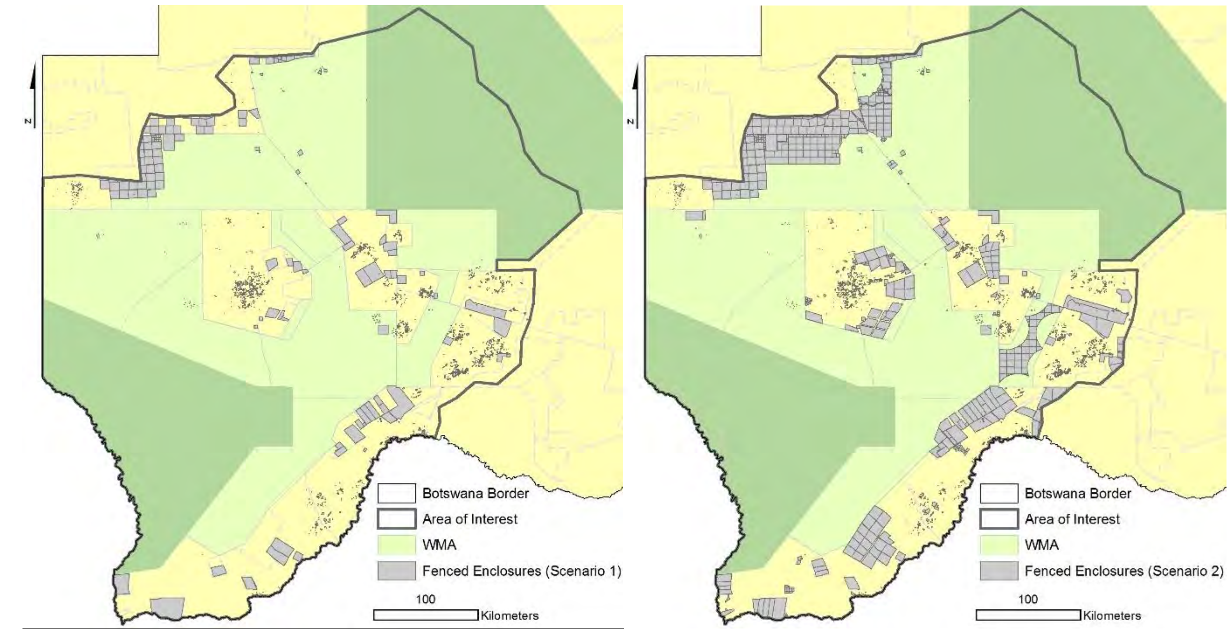


Figure 15 Extent of fenced enclosures in the Scenario 1 (present time) landscape (left panel) VS Scenario 2 landscape (right panel).

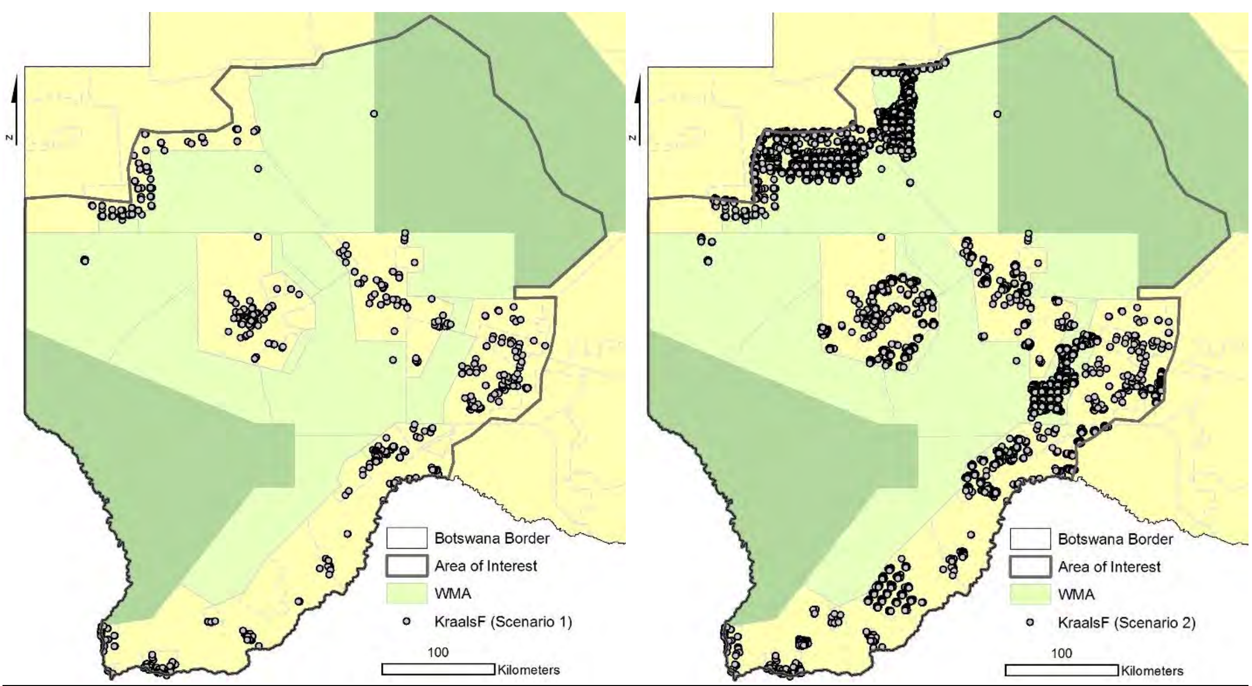


Figure 16 Extent of kraals within fenced enclosures (KraalsF) in the Scenario 1 (present time) landscape (left panel) VS Scenario 2 landscape (right panel).

3.2.5 Scenario 3 – all allocated and applied for boreholes developed into cattleposts

Scenario 3 is the future landscape after all waterpoint (borehole) locations in Kgalagadi and Ghanzi LB databases which have been allocated but remain undeveloped, plus applications received by Land Boards but not yet allocated, come online as cattleposts. All other landscape variables remain constant from Scenario 1.

In finalizing this future landscape of cattlepost expansion, we gave Land Boards the benefit of the doubt in vetting each point location according to their own policies (e.g. Kgalagadi Land Board 2006). Specifically, locations were rejected a) inside PA and WMA boundaries (both gazetted and ungazetted) unless falling within 20 km radii RAD development zones; and b) within < 6 km threshold proximity from an existing cattlepost or another allocation/application. There were many presumably application-stage locations within LB databases that violated the above rules, especially inside WMAs GH10/11/13. These were appropriately deleted from consideration in the landscape models, or their locations adjusted to comply with the proximity rules according to LB policy.

There are several examples of established cattleposts in the present time landscape that have deviated from such rules in the past. It is worth noting that if there continues to be deviation in the future, especially allocations inside WMA boundaries, the future reality will be worse, potentially much worse, in terms of landscape connectivity, than predicted in the connectivity outputs from modeled Scenario 3, and combination Scenarios 11-14.

Notably, however, we did not follow the policy criterion (Kgalagadi Land Board 2006) stating no allocations within </= 4 km of unfenced WMA boundaries, in Scenario 3 or any subsequent scenario development because, without assuming or laying blame on either LBs or applicants, clearly this criteria has not been adhered to in practice, either in the past nor recent allocations related to both CGA-WMA boundaries and the 20 km RAD development zone edges with the wider WMA(s). Since it has apparently not at all been adhered to in practice in the past, it is unrealistic to expect this pattern to change in the future. Since we are utmost concerned with realism in the modeled future scenarios, we adopt the pattern of waterpoint development in proximity to CGA-WMA borders expressed empirically, on the ground, to date.

Contrasting panels in Figure 17 shows the huge growth in cattleposts (KraalsNF) in the landscape as a result of waterpoint applications already in LB databases, compared to what has been developed on the ground at present time.

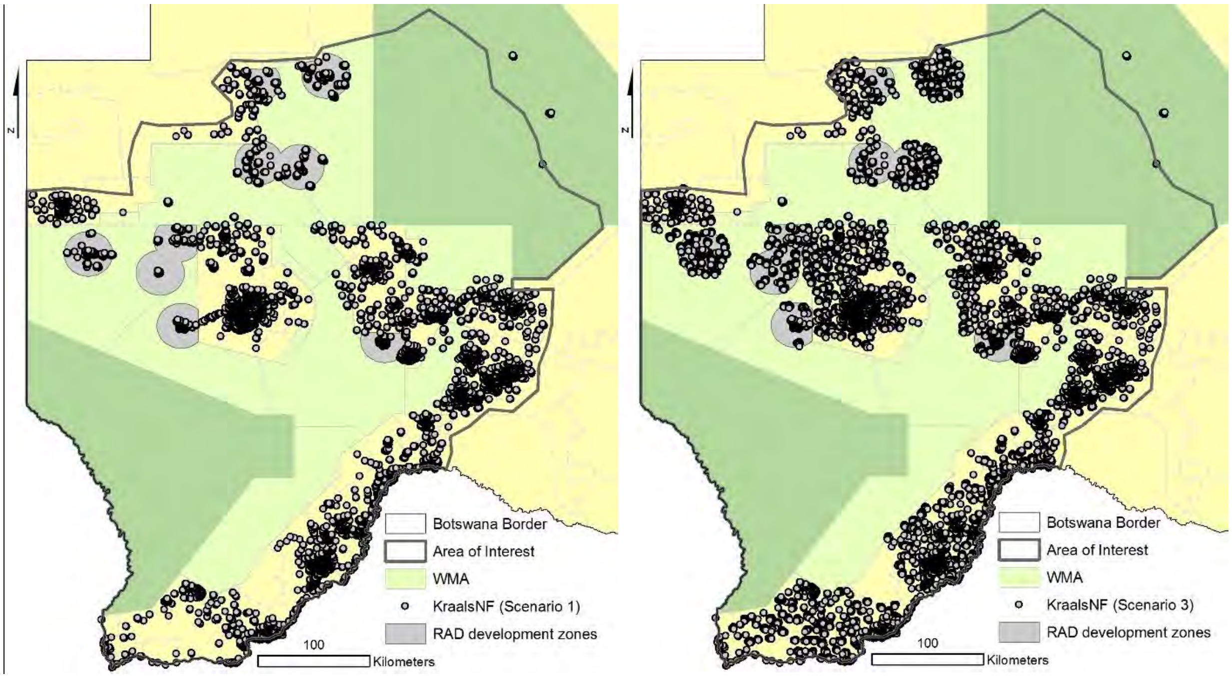


Figure 17 Extent of kraals in the free-ranging landscape (KraalsNF) in Scenario 1 (present time) (left panel) VS Scenario 3 (right panel). RAD development zones within WMAs are highlighted for reference. Expansion of KraalsNF in Scenario 3 are simulated clusters (cattleposts) populated to borehole locations in LB databases (allocated and applications) after vetting those locations according to proximity rules and land use boundaries following LB policy.

3.2.6 Scenario 4 – RAD 20 km radius zones developed

Scenario 4 shows the landscape wherein cattleposts proliferate to occupy all RAD zones within WMAs to their full 20km radius extents, as is the future intention according to LB policy (e.g. Kgalagadi Land Board 2006), and apparent from the allocations/applications in Scenario 3. The RAD development zones occur around 9 villages in the AOI, namely Ukwi, Ncaang, Ngwatle, Zutshwa, Bere, Kacgae, East Hanahai, New Xade, Inalegolo.

To generate Scenario 4 we first included all simulated KraalsNF from Scenario 3 within the 20 km radius development buffers, then populated the remaining spaces with additional simulated cattleposts located at hypothetical future borehole allocations following the minimal 6 km spacing rule. Thus, the only change in the landscape from Scenario 1 to 4 is the full occupation of RAD development zones with KraalsNF (Figure 18).

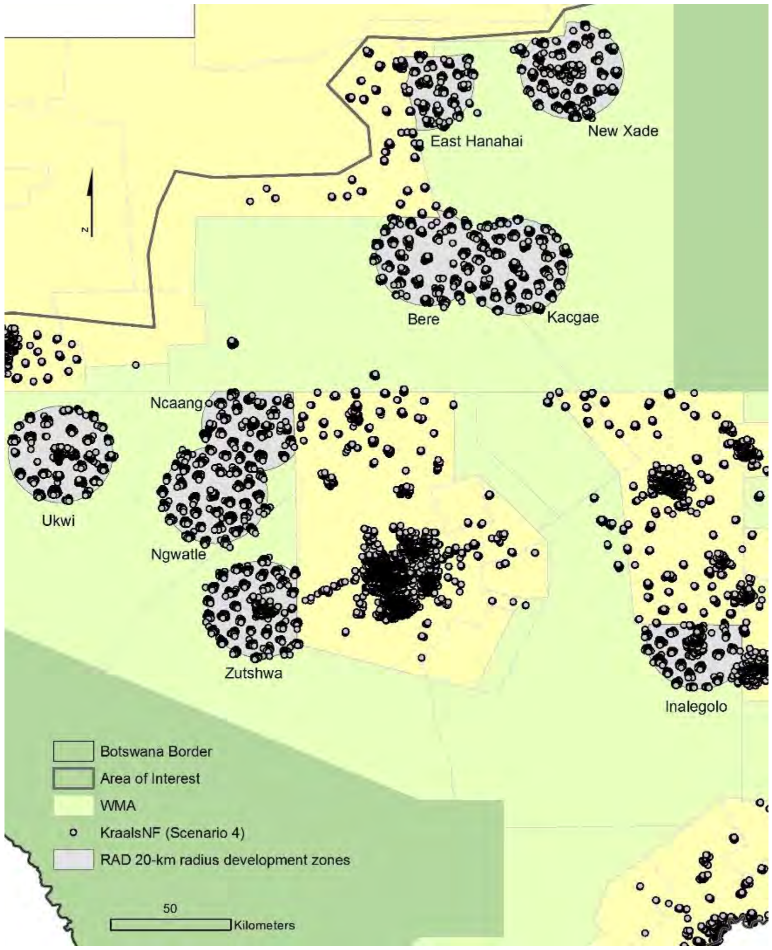


Figure 18 Extent of kraals in the free-ranging landscape (KraalsNF) in Scenario 4 when waterpoints proliferate to the full 20-km radius extent in the development zones around 9 RAD communities in the AOI.

3.2.7 Scenario 5 – alternative RAD zones and expansion polygons

Scenario 5 presents an alternative configuration of RAD development zones that is sensitive to wildlife landscape connectivity. To render Scenario 5 more politically feasible, we propose safer areas for RAD cattlepost expansion to off-set the relinquished portions of the 20 km radius development circles encroaching into sensitive wildlife corridors.

The 4 villages situated in the most sensitive areas for landscape connectivity are those nearest and adjacent the primary (southern) wildlife core area and hemming the western corridor, namely, Ukwi, Ncaang, Ngwatle and Zutshwa. For these 4 RAD villages we propose in Scenario 5 an approximately 50:50 compromise to their 20 km radius development zones, essentially proliferating livestock on one side of the village only, while keeping the conservation-sensitive side kraal-free to instead develop economic benefits from wildlife, wilderness and other conserved natural resources (Figure 19, Box 2).

To improve political feasibility, these 4 villages are offered adjacent areas on their respective livestock development-safe sides to accommodate/compensate future cattlepost expansion relinquished within the sensitive western corridor. These expansion polygons are nonetheless within KD1 and KD2 WMAs, just in areas less critical to core and connectivity maintenance (Figure 19, Box 3).

In Scenario 5 the 20 km radius development circle for Kacgae village is trimmed slightly to the south, southeast, and east, but not at the 50% level as the 4 previous villages. Nearby Kacgae, two safer expansion polygons are proposed: a triangular piece to the north and adjacent the rezoned ranch layout of Scenario 2, and a small piece in between the Bere and Kacgae 20 km radius circles (Figure 19, Boxes 2 and 3).

20 km radius development circles for RAD villages Bere, East Hanahai, New Xade and Inalegolo remain unmodified.

The total area of affected 20 km radius development circles (Ukwi, Ncaang, Ngwatle, Zutshwa, Kacgae) protruding into critical corridors withheld in Scenario 5 for wildlife conservation is 2,771.85 km^2 (Figure 19).

The total area of alternative expansion polygons to offset the portions of 20 km radius development circles relinquished for wildlife conservation is 1,973.75 km^2 (Figure 19).

Relinquished portions of RAD development zones around the 5 villages presently contain 9 active cattleposts (Table 5, Figure 20) and 34 undeveloped allocations and applications (Table 6, Figure 20) which would need to be relocated/reallocated. The alternative expansion polygons provide space for 50 allocations, respecting the minimal 6 km proximity spacing rule between new allocations within the polygon areas and those adjacent.

The only landscape variable that functionally changes in the Scenario 5 model compared to the Scenario 1 model is the KraalsNF variable. That layer changed in 2 ways: a) locations outside the modified RAD development zones (Tables 5-6) were removed, b) simulated cattleposts populated the extra spaces within the modified RAD development zones and alternative expansion zones not already filled by present cattleposts/allocations.

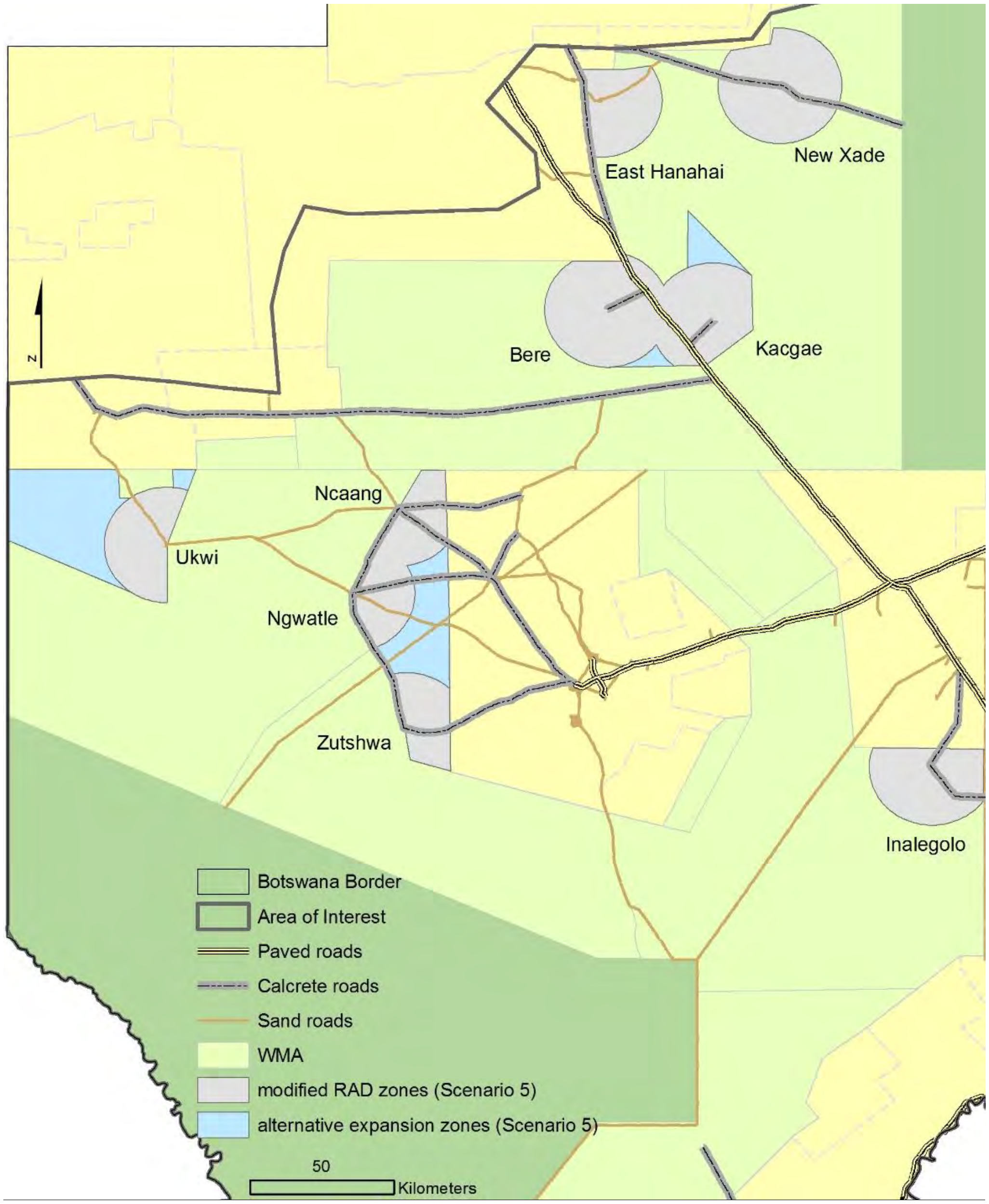


Figure 19 Scenario 5 modified RAD 20 km radius development zones and proposed alternative expansion zones, with roads for reference.

Box 2. – Spatial descriptions of modifications to 20 km radius development circles of 5 RAD villages for Scenario 5.

Zutshwa - continue the angle of the southern boundary of KD3 CGA in its WNW direction to intersect the 4x4 track south of Zutshwa. This track south of Zutshwa and the Zutshwa-Ngwatle road north of Zutshwa form the circle axis. Everything to the west and south of these lines described is removed.

Ngwatle – everything to the west of the Zutshwa-Ngwatle-Ncaang road(s) is removed.

Ncaang – the Ngwatle-Ncaang road, then a line continuing NE from Ncaang in the exact orientation as that road until it intersects the GH District boundary. Everything to the west of those lines, staying within KD District, is removed.

Ukwi – Axis straight south (180 deg) from centroid of village. Second line NNE from centroid goes directly to intersect the west boundary of GH13 (where it intersects KD District boundary). Everything to the east of those lines is removed.

Kacgae – horizontal line straight east from the bottom of the Bere 20 km radius circle (-23.001 degrees south) to Lone Tree gov camp enclosure. Continue easterly horizontal line (Line 1) to intersect the Kacgae 20 km radius circle in the SE (Intersection A). Line straight north (Line 2) from there intersecting the NE sector of the circle at 22.327, -22.714 (Intersection B). Diagonal line connecting Intersections A and B (Line 3). Everything to the outside of Lines 1-3 removed.

Box 3. – Spatial descriptions of proposed alternative agricultural expansion areas to off-set the grazing land relinquished from full 20 km radius development circles of 5 RAD villages for Scenario 5 (refer also Figure 19).

KD1 (Ukwi) – Straight line from the southern extent of the Ukwi 20 km radius WNW-wards (angle paralleling the KTP boundary to the south) to the Namibia border. Proposed area for expansion is then the polygon bound by this line to the south, Nam border west, GH District boundary north, Ukwi RAD ranch and Ukwi 20 km radius circle east. An additional smaller space is included to the east of the Ukwi RAD ranch bound by the ranch boundary to the west, 20 km radius circle south, new boundary of the modified development zone (which intersects GH13 boundary) east, and GH District boundary north.

KD1/2 (Ncaang/Ngwatle/Zutshwa) – Polygon bound by the extents of these three 20 km radius development circles, Zutshwa-Ngwatle road, and the western boundary of KD3 CGA.

GH10/11 (Kacgae) – There is a wedge of unutilized space between the extents of the Bere and Kacgae developments zones in the south, which is bound in the south no further than the south extent of the Bere 20 km radius. This area for expansion lies in GH11. An additional triangle polygon for expansion is proposed north of Kacgae in GH10 by making a line from Intersection B (see Box 1) NW to intersect the approximate northern boundary of the 3rd ranch block from the south in the proposed layout for the GH11 rezoned area. The triangular expansion polygon is thus bound by the extent of the rezoned ranch layout boundary to the west, the northern extent of the 20 km Kacgae development radius, and the new diagonal line in the east bordering the remaining WMA.

Table 5. Cattleposts in operation requiring relocation/compensation to achieve Scenario 5

District	Village Radius	Name	Coordinates (Decimal Degrees)
KD	Ukwi	Qonashe Masila Mayane	20.687882 -23.563381
KD	Ukwi	Bodibeng Syndicate	20.622969 -23.560763
KD	Ukwi	Legochwa Syndicate	20.571666 -23.664416
KD	Ukwi	Kasekometse Ping	20.554268 -23.560023
KD	Ncaang	Sebetse Oathotsa	21.064152 -23.450472
KD	Ncaang	Motsamai Mogogobi	21.208867 -23.347684
KD	Ncaang	Moxoso Modikele	21.249442 -23.366618
GH	Kacgae	KCQ_07	22.390933 -22.794520
GH	Kacgae	KCQ_11	22.292202 -23.006859

Table 6. LB allocations/applications not yet operational requiring relocation to achieve Scenario 5

District	Village Radius	Name	Coordinates (Decimal Degrees)
KD	Zutshwa	Legopelo Syndicate	21.281613 -24.289427
KD	Zutshwa	Lekgotla Edson Molefise	21.202208 -23.990318
KD	Zutshwa	Kopang syndicate	21.162267 -23.986895
KD	Ngwatle	Keikanyemang Tsatsi	20.969937 -23.812003
KD	Ngwatle	Moshonono Syndicate	21.009497 -23.774471
KD	Ngwatle	Tsatsing Lerumo	21.016598 -23.636519
KD	Ngwatle	Letlhare Syndicate	20.982109 -23.613188
KD	Ngwatle	Tutwane Syndicate	20.964865 -23.611160
KD	Ngwatle	Hula Rikhezwa Syndicate	20.926320 -23.595944
KD	Ngwatle	Prop shift Letsiriri	20.895889 -23.641590
KD	Ngwatle	Molapong Syndicate	21.101804 -23.621303
KD	Ngwatle	Motlhalawapitse	21.086588 -23.608117
KD	Ngwatle	Semolale proposed shift	21.118033 -23.560442
KD	Ncaang	Prop shift O.B Gaboitsiwe	21.145421 -23.512767
KD	Ncaang	Shetenge prop shift	21.098761 -23.479293
KD	Ncaang	<none>	21.035870 -23.492480
KD	Ncaang	Prop shift Nakalakgokong	21.100789 -23.366699
KD	Ncaang	Gemsbok prop shift	21.040942 -23.358584
KD	Ukwi	Thepologo Syndicate	20.527966 -23.727085
KD	Ukwi	Lemepe Syndicate	20.598717 -23.711109
KD	Ukwi	Mokwepa Syndicate	20.625534 -23.686574
KD	Ukwi	Hethole Syndicate	20.629528 -23.658616
KD	Ukwi	Prop shift Bochelo	20.655204 -23.610117
KD	Ukwi	Baikopanyi Syndicate	20.682021 -23.506843
KD	Ukwi	Basari Syndicate	20.659198 -23.453779
KD	Ukwi	Machobochobo syndicate	20.539948 -23.470326
KD	Kacgae	KCQ_13	22.138556 -23.022368

KD	Kacgae	KCQ_12	22.228421	-23.013060
KD	Kacgae	Mosewacheng Syndicate	22.247678	-22.958820
KD	Kacgae	Kamake Syndicate	22.340433	-22.968448
KD	Kacgae	KCQ_19	22.293895	-22.923516
KD	Kacgae	Tsogaobone Syndicate	22.368676	-22.920306
KD	Kacgae	Yecho Syndicate	22.377663	-22.850981
KD	Kacgae	KCQ_06	22.361051	-22.745337

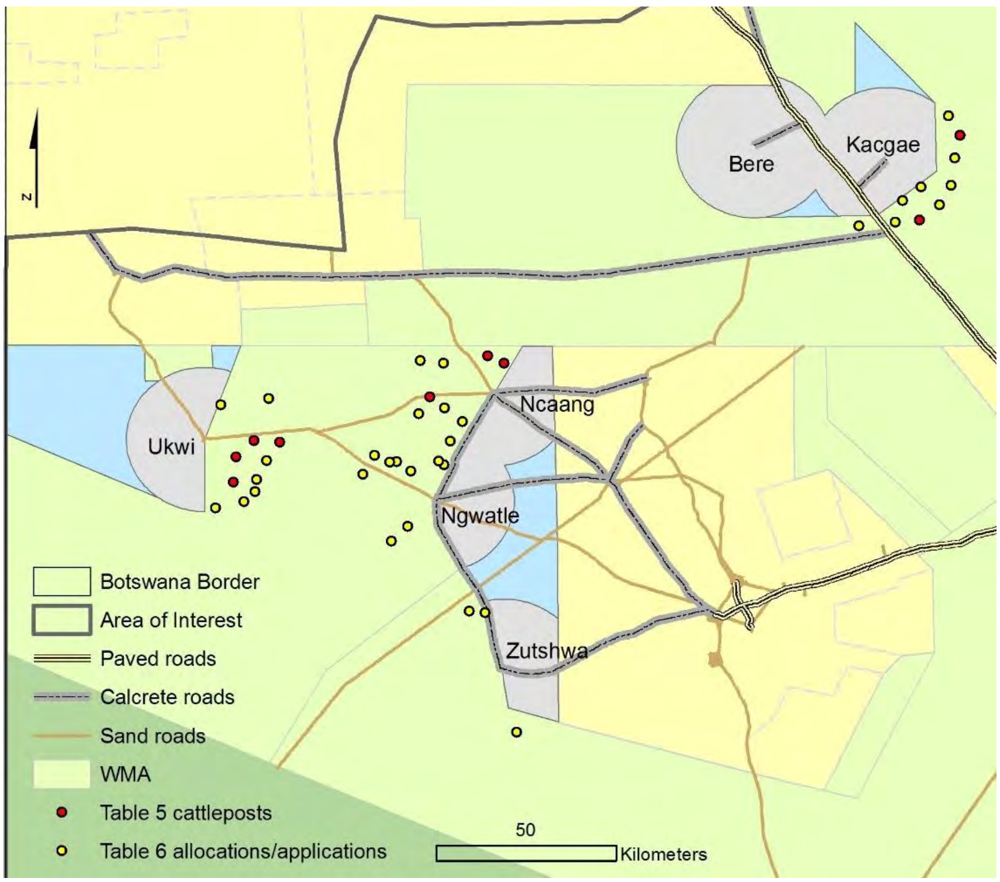


Figure 20 Locations of both established cattleposts removed from the model (Table 5, red) and waterpoint allocations/applications in LB databases removed from the model (Table 6, yellow) to achieve Scenario 5.

3.2.8 Scenario 6 – 2nd alternative RAD zones and expansion polygons

Scenario 6 is a slight modification from Scenario 5 whereby the 4 RAD villages in the western corridor (Zutshwa, Ngwatle, Ncaang, Ukwi) retain a 10 km radius circle for cattlepost expansion intruding into the wildlife space. The only modeled difference between the Scenario 5 and 6 is the addition of simulated cattleposts (KraalsNF) occupying the 10 km radius semi-circles protruding into the WMA beyond the modified RAD zones of those 4 villages (Figure 21).

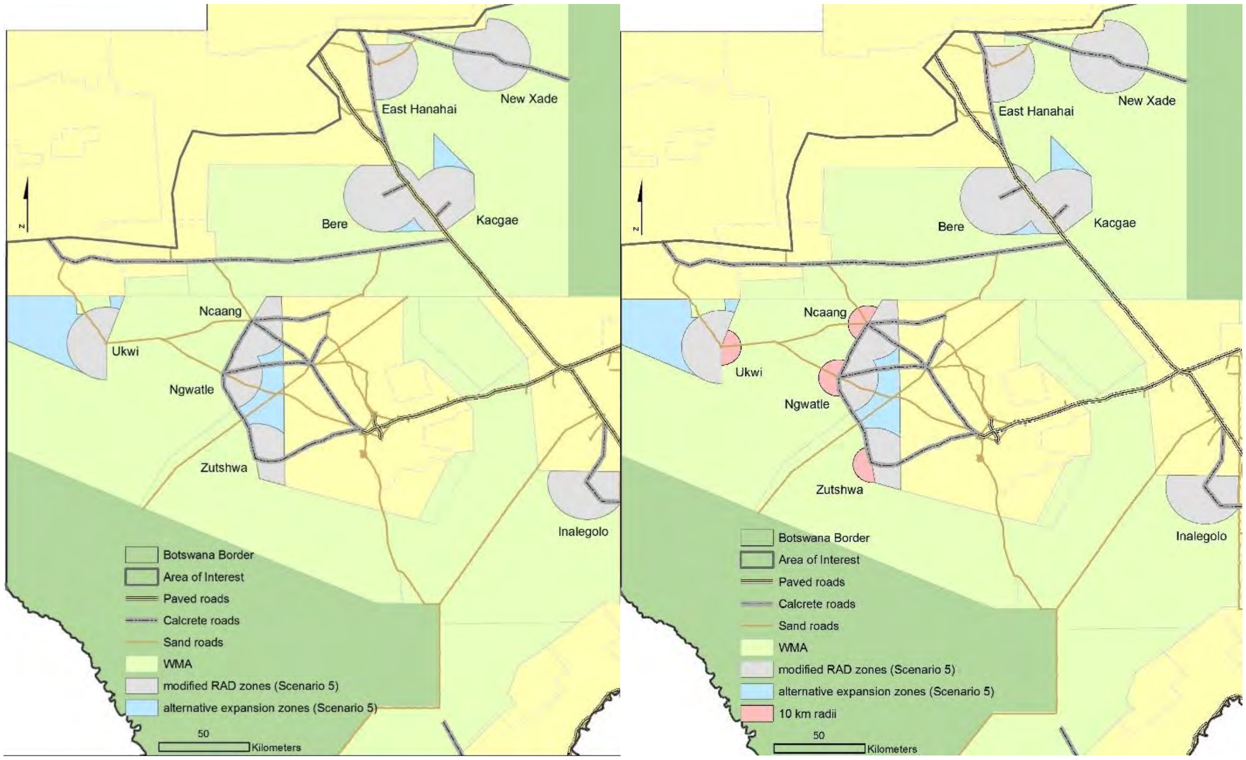


Figure 21 Scenario 5 (left panel) VS Scenario 6 (right panel) with additional 10 km radius zones intruding into western corridor from 4 villages in KD1/2.

Cattleposts in operation and LB allocations/applications requiring relocation for Scenario 6 can be found listed in Scenario 5 Tables 5-6 above, except for those locations retained within the 10 km radii (Tables 7-8).

Table 7. Cattleposts in operation retained within 10 km radii of 4 RAD villages in Scenario 6

District	Village Radius	Name	Coordinates (Decimal Degrees)
KD	Ukwi	Kasekometse Ping	20.554268 -23.560023
KD	Ncaang	Moxoso Modikele	21.249442 -23.366618

Table 8. LB allocations/applications not yet operational retained within 10 km radii of 4 RAD villages in Scenario 6

District	Village Radius	Name	Coordinates (Decimal Degrees)
KD	Ngwatle	Molapong Syndicate	21.101804 -23.621303

3.2.9 Scenario 7 – loss of WMAs KD5/11

Scenario 7 is a future wherein KD5 and KD11 WMAs are entirely lost to cattlepost expansion. This scenario was created by populating the extents of both WMAs with simulated KraalsNF clusters, following the minimum 6 km proximity spacing rule for the allocated borehole locations. Figure 22 shows the only change in landscape variables modeled (KraalsNF) between Scenario 1 and Scenario 7.

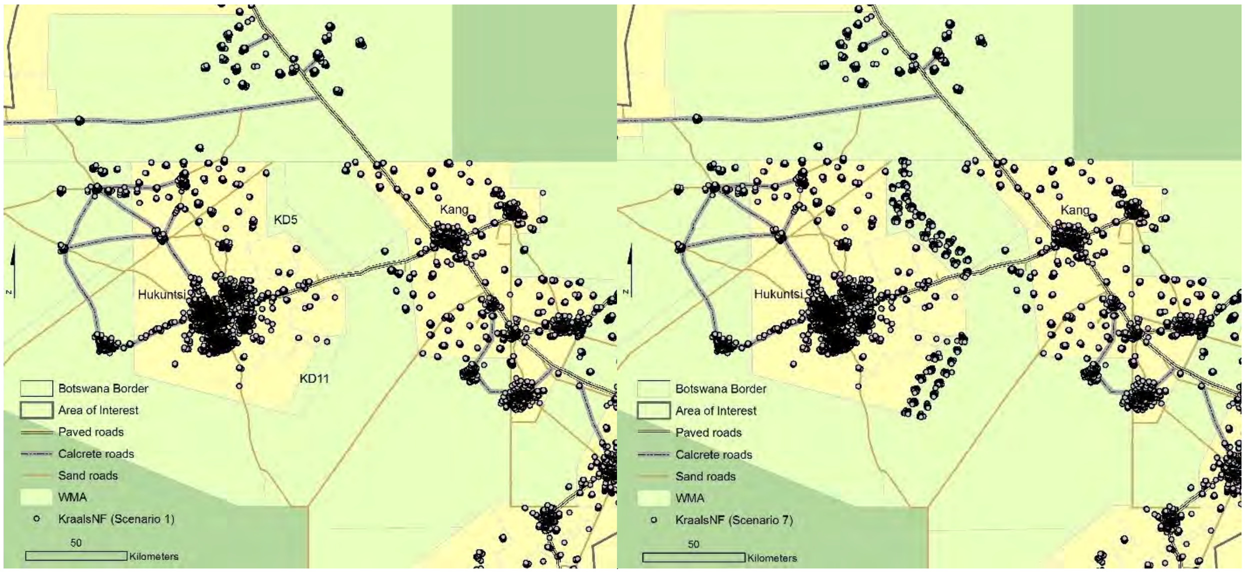


Figure 22 Extent of Kraals NF in Scenario 1 (left panel) VS Scenario 7 (right panel). The right panel shows the full occupation of KD5/11 with simulated cattleposts (KraalsNF).

3.2.10 Scenario 8 – wildlife-friendly fence removed

Scenario 8 is simply to predict what can happen if the 31.5 km length of wildlife-friendly fencing along the Kang-Hukuntsi highway bisecting the central corridor is removed to allow uninhibited free-ranging wildlife movements over the roadway once again. That is the only change from Scenario 1 landscape variables, illustrated in Figure 23.

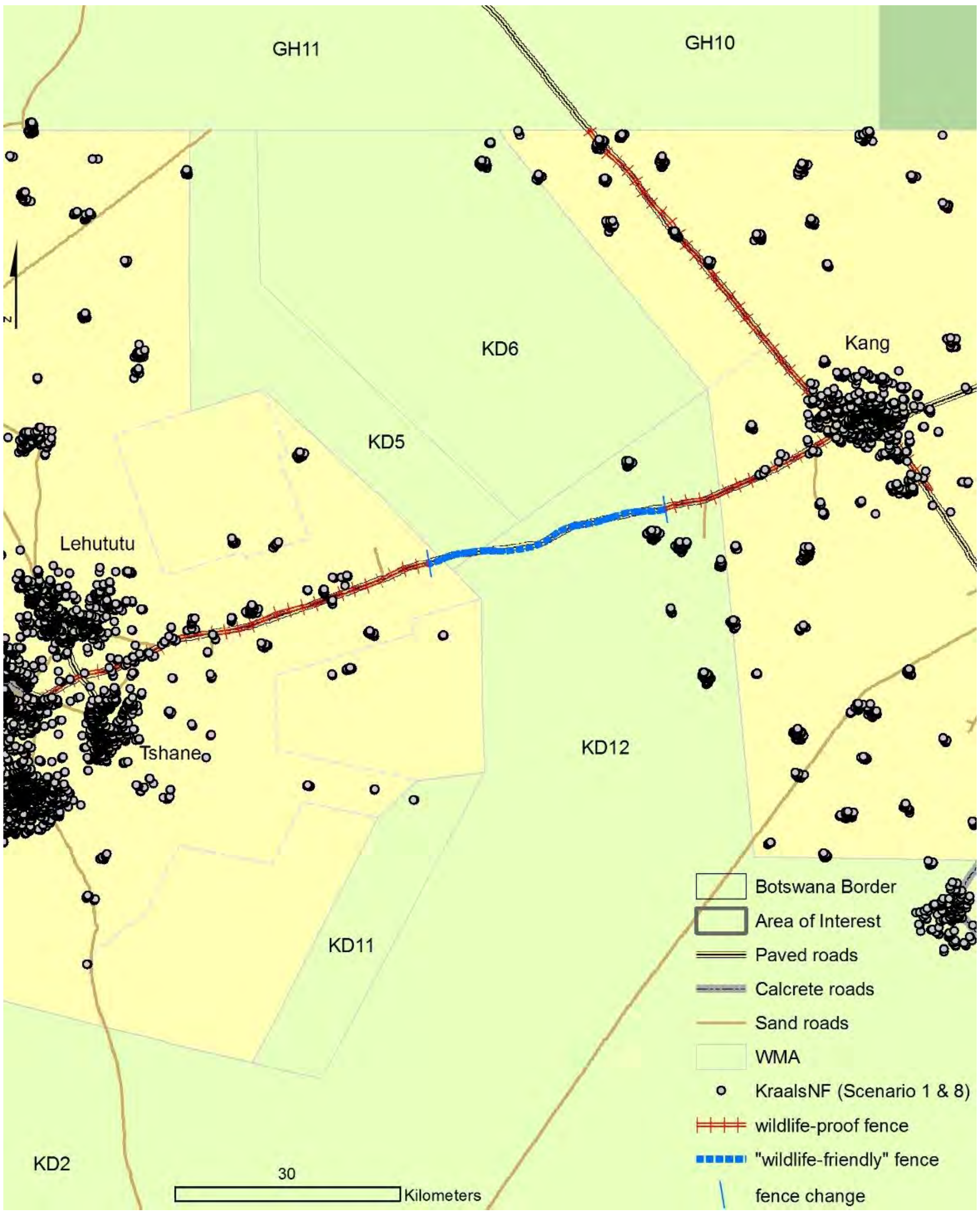


Figure 23 The location of the 31.5 km 'wildlife-friendly' fence (blue) spanning both sides of the Kang-Hukuntsi highway. It was removed in Scenario 8, differentiating that model from Scenario 1. Road types, main towns, and established present time KraalsNF are illustrated for reference.

3.2.11 Scenario 9 – southern GH11 cattlepost encroachment removed

Scenario 9 is the deactivation/removal of an established informal settlement and a mis-allocated and established cattlepost inside the gazetted southern GH11 WMA. Their specific locations are provided in Table 9 and illustrated in Figure 24. Besides removal of these two KraalsNF clusters, all other landscape variables remained identical in the Scenario 9 model as the Scenario 1 model.

Table 9. Informal settlement and cattlepost in operation requiring relocation/compensation to achieve Scenario 9

District	Name	Coordinates (Decimal Degrees)
GH	Ranyane	21.144 -23.141
GH	Xamaqa Syndicate	21.676 -23.262

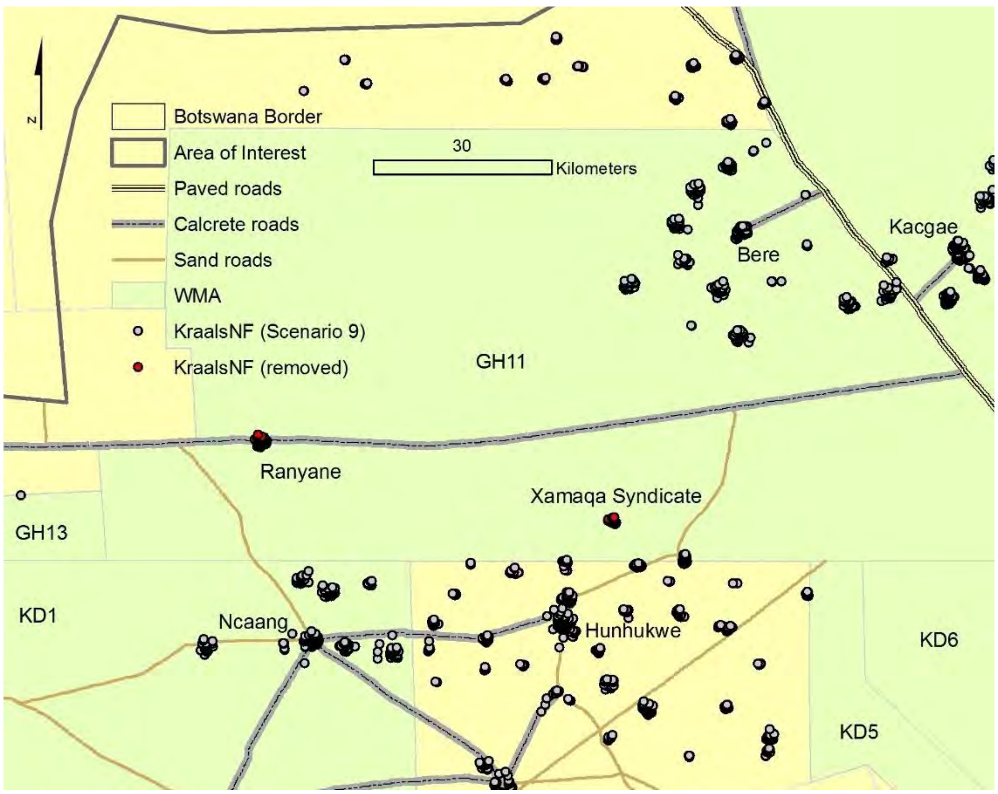


Figure 24 Two KraalsNF clusters (red, labeled Ranyane/Xamaqa Syndicate) removed from the Scenario 1 KraalsNF layer to create the Scenario 9 model.

3.2.12 Scenario 10 – KD6/12 cattlepost encroachment removed

Scenario 10 is the deactivation/removal/relocation of two cattleposts in KD6 WMA and six cattleposts in KD12 WMA. These locations are inside ungazetted WMA boundaries, not associated with any RAD development zones. Their specific locations are provided in Table 10 and illustrated in Figure 25. There are additional waterpoints within KD LB database located in these same areas of KD6/12 which appear to be only at the application stage or allocated but not yet developed. These are listed in Table 11 and illustrated in Figure 25. **Removal of these KraalsNF at waterpoint locations listed in Tables10/11 are the only change in landscape variables from Scenario 1**.

Table 10. Cattleposts in operation requiring relocation/compensation to achieve Scenario 10

WMA	Name	Coordinates (Decimal Degrees)
KD6	Mogobewamoraba Syndicate	22.324988 -23.363079
KD6	Tlhokwane Brothers	22.322706 -23.356993
KD12	Monnaesi & Group	22.498774 -23.717127
KD12	Nelson Lekutlane	22.524022 -23.803570
KD12	Tgii-xu-yane	22.559968 -23.818119
KD12	Magowe and Sons Syndicate	22.605329 -23.843367
KD12	Herbert Magowe	22.551877 -23.892992
KD12	Naka la tlou Syndicate	22.589408 -23.975155

Table 11. LB allocations/applications not yet operational requiring relocation to achieve Scenario 10

WMA	Name	Coordinates (Decimal Degrees)
KD6	Boikago Syndicate	22.404795 -23.479133
KD12	Moathodi Raditsebe	22.537549 -23.724355
KD12	Xoogke Syndicate	22.586999 -23.709139
KD12	Samuel Rantoane	22.593085 -23.760111
KD12	Khonema Syndicate	22.619712 -24.015729
KD12	Osetselemang Motokwane	22.611344 -24.068983
KD12	Keitumetse Komoki	22.602975 -24.149624
KD12	drilled point	22.606018 -24.195271
KD12	point	22.548200 -23.673383

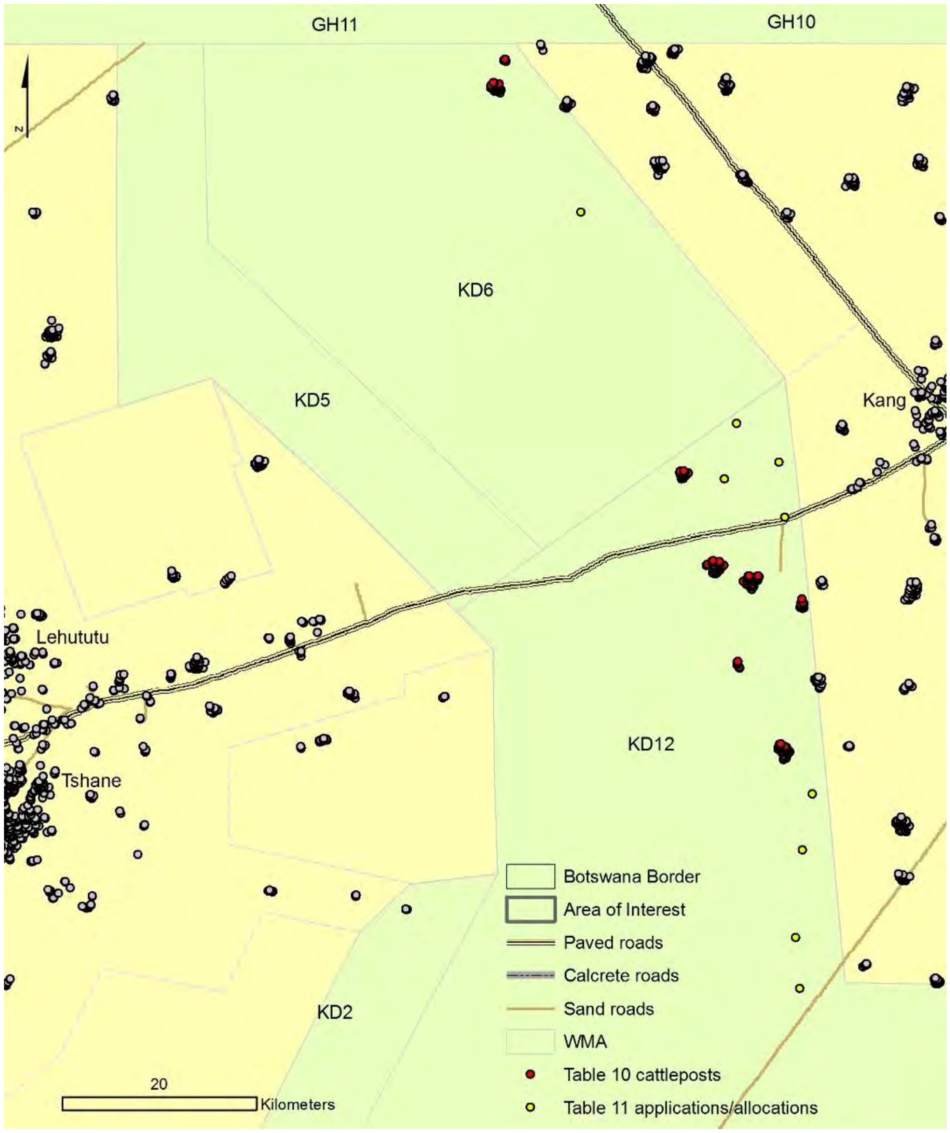


Figure 25 Locations of both established cattleposts in KD6/12 removed from the model (Table 10, red) and waterpoint allocations/applications in KD6/12 from KD LB database removed from the model (Table 11, yellow) to achieve Scenario 10. KraalsNF (grey) remaining for Scenario 10 after the removals are illustrated.

3.2.13 Scenario 11 – cumulative planned developments (business-as-usual trajectory)

Scenario 11 presents the future landscape wherein all planned, intended, and known lobbied developments go forward with no effort to change course or mitigate land use planning in this ecosystem to accommodate wildlife landscape connectivity needs. It is a cumulative combination of all the elements of Scenarios 2, 3, 4 and 7. It also includes a proposal for a new ranch layout along the Kang-Hukuntsi highway completely bisecting the present central corridor (Kgalagadi LB pers comm). The extent of the most relevant anthropogenic variables in Scenario 11 are shown in Figures 26 and 27.

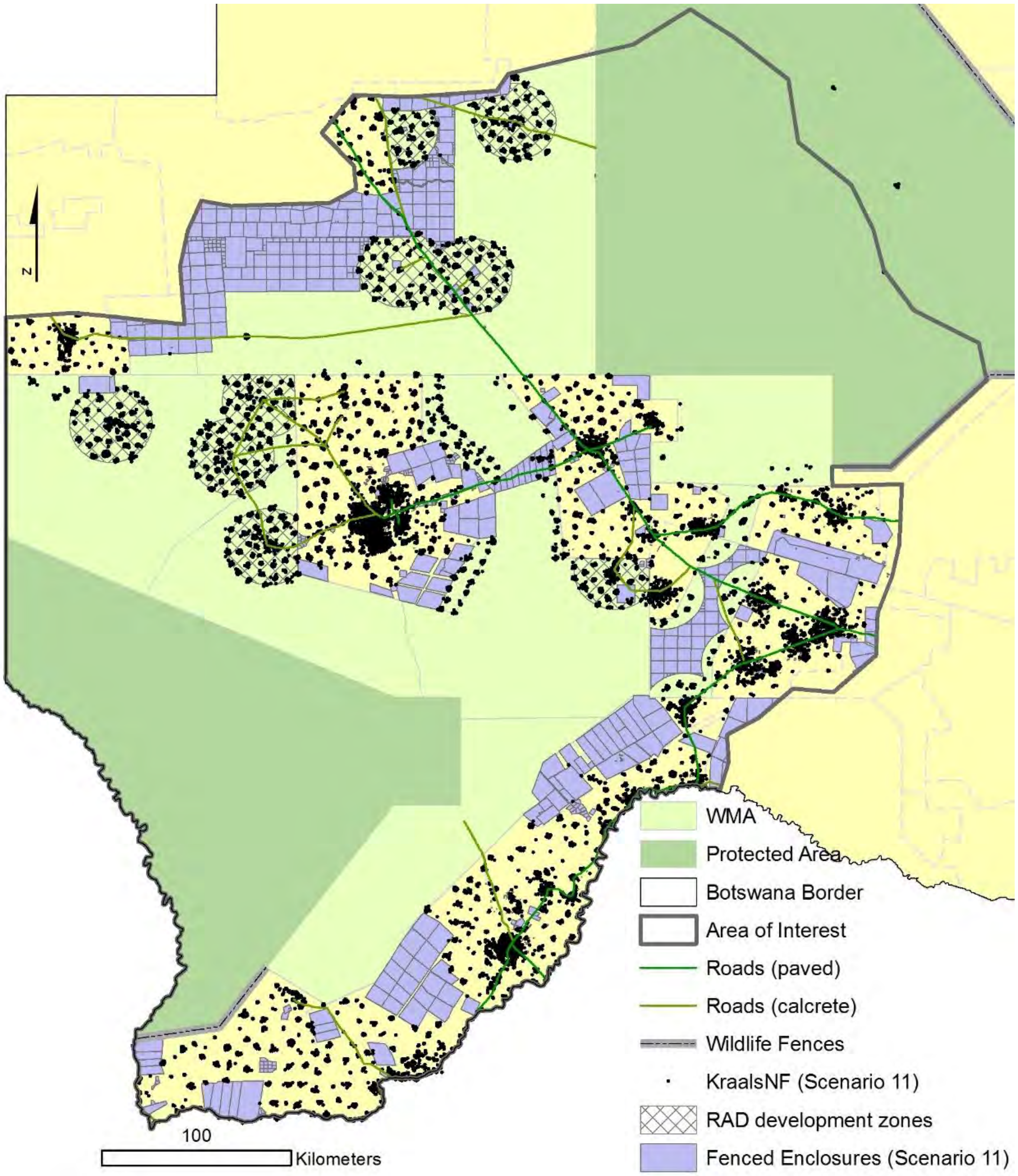


Figure 26 Scenario 11 extent of model variables KraalsNF, fenced enclosures, roads and wildlife fence at the AOI scale.

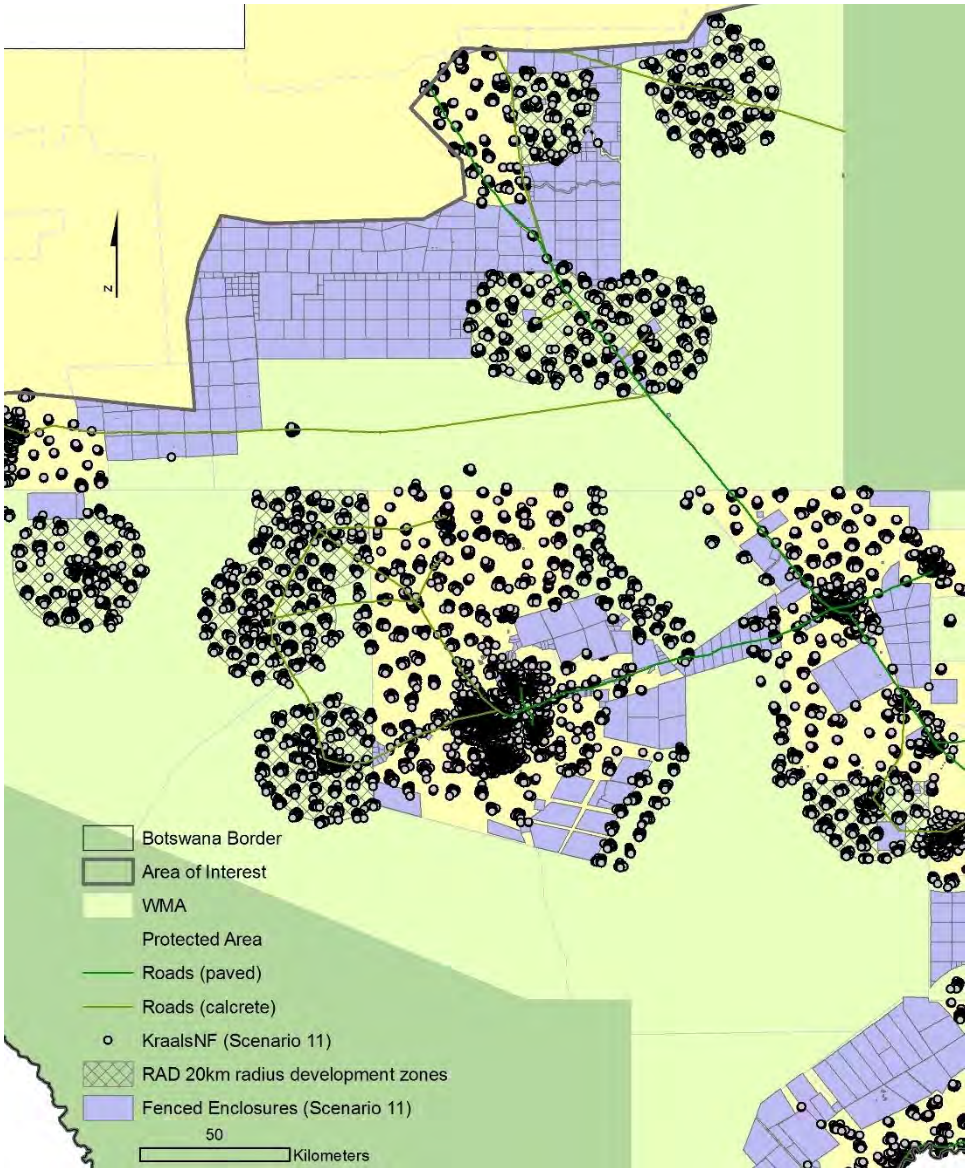


Figure 27 Scenario 11 extent of model variables KraalsNF, fenced enclosures and roads at the corridors scale.

As mentioned in Section 3.2.5 (Scenario 3 description), this Scenario 11 model may in fact be an optimistic picture because it assumes, for example, adherence by Land Boards to their own proximity and land use rules regarding borehole allocations (which appear not to have been strictly adhered to in the past). It also assumes the A2 Trans-Kalahari Transportation Corridor in Ghanzi District continues to remain fence-free allowing unimpeded wildlife movements over the highway (and potential future railway). Furthermore, there may be, or are even likely to be, future agricultural, infrastructural and mining developments in the landscape that we were not informed of and were therefore unmodeled. Thus, the true "business-as-usual" future on the ground may in fact be quite a bit worse for wildlife and landscape connectivity than appears in this Scenario 11 model predictions.

3.2.14 Scenario 12 – alternative development path 1 (combination Scenarios 2, mitigated 3, 6, 8)

Scenario 12 presents a mitigative alternative to Scenario 11. The key changes are adopting alternative RAD development zones and alternative expansion zones as per Scenario 6 (i.e. 10 km radius encroachment permitted into sensitive core/corridor area) and deactivating the wildlife-friendly fence as per Scenario 8. Additional differences are KD5/11 WMAs are maintained rather than encroached, and any ranch development along the Kang-Hukuntsi highway is withheld. Scenario 12 assumes allocated/application waterpoint locations in Scenario 3 are developed, with the exception of those which need to be mitigated to accommodate the Scenario 6 alternative RAD development zones (see Tables 5-6 and 7-8). The most relevant anthropogenic variables in Scenario 12 are shown in Figures 28. Most visible are the changes to the RAD development zones and implementation of alternative expansion zones compared to Scenario 11, while the removal of the fence is not visible.

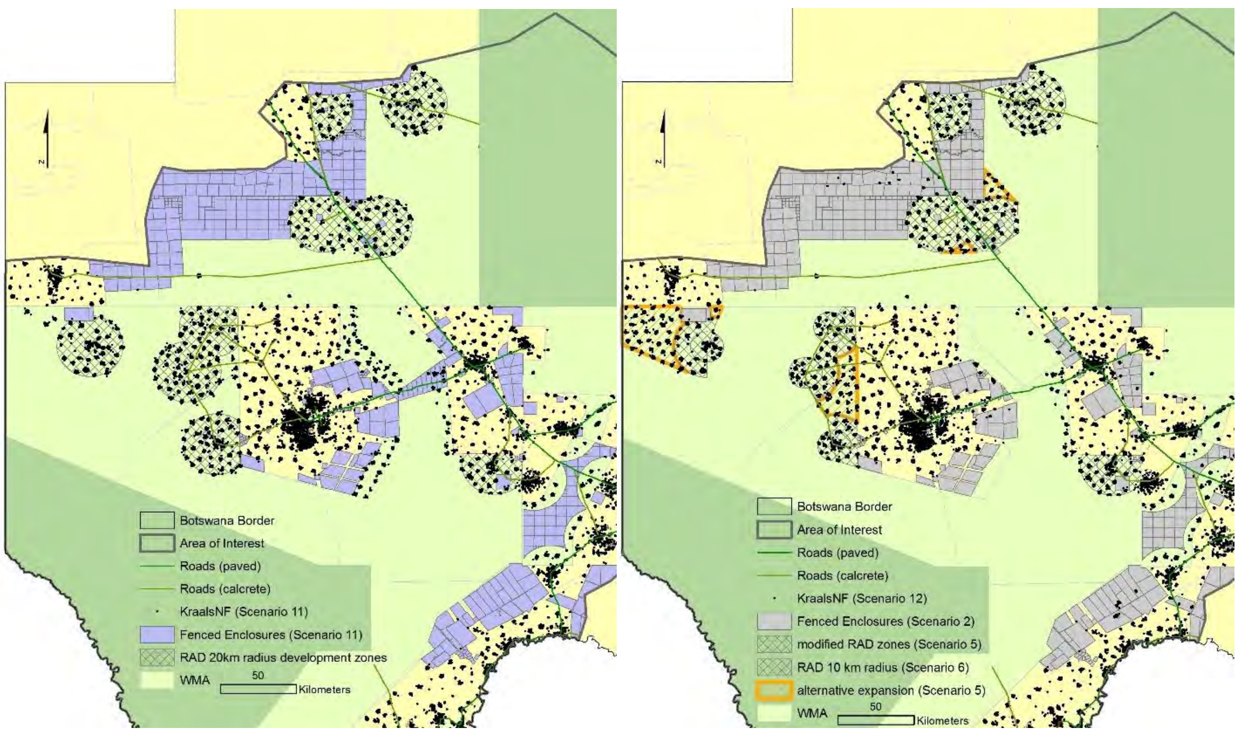


Figure 28 Key model variables for Scenario 11 (left panel) business-as-usual future compared to mitigative Scenario 12 (right panel). Alternative expansion areas are highlighted in orange. Notice also the change of select RAD full 20km radii to 10km radii (i.e. Scenario 6), removal of KraalsNF encroachment into KD5/11, and loss of ranch layout straddling the Kang-Hukuntsi highway.

3.2.15 Scenario 13 – alternative development path 2 (combination Scenarios 2, mitigated 3, 5, 8, 9, 10)

Scenario 13 is an incremental level of mitigation effort more than Scenario 12. The key differences are: a) adopting the alternative RAD development zones proposed in Scenario 5 instead of 6, and b) relocation of cattleposts established inside WMA boundaries not associated with RAD communities (Scenarios 9, 10). Plus the additional alternative expansion polygon in the east of KD12 south of Inalegolo.

Scenario 13 strives towards optimization of the Kalahari landscape to improve wildlife connectivity at the minimal effort/cost/compromise to agriculture. It still accommodates most planned agricultural expansion and includes proposed least-risk areas for future expansion (i.e. alternative expansion polygons of Scenarios 5/6). Scenario 13 additionally proposes a large (979 km^2) alternative expansion polygon in the east of KD12 south of Inalegolo (Figure 29, Box 4) which could potentially accommodate those cattleposts removed from southern GH11, KD6, and KD12 (Scenarios 9, 10), that is, to make those deactivations more politically feasible by providing alternative areas for expansion.

Scenario 13 goes a subtle step further by removing individual kraals spilling over WMA boundaries, but only in key corridor areas. This includes those individual kraals spilling over from KD3 into southern GH11 from cattleposts just at the border, and similarly all kraals encroaching into KD5 from KD3, into KD6 from KD7, and into KD12 from KD13. Table 12 lists those locations where spillover occurs presently; in the Scenario 13 model all spillover from future simulated cattleposts (KraalsNF clusters) into the WMA side was similarly removed. In both present and simulated cases, only kraals on the WMA-side of the boundary were removed, while those on the CGA side of the cattlepost were left alone. Scenario 13 therefore provides a picture of how the wildlife landscape could look like if WMA boundaries were respected. Once again, however, we did not apply the stricter criterion stated in the Land Management Policy (Kgalagadi Land Board 2006) - namely no waterpoints within $\leq$ 4 km of unfenced WMA boundaries - due to the high number of locations already presently violating this policy and therefore assumed political unlikelihood of their relocation.

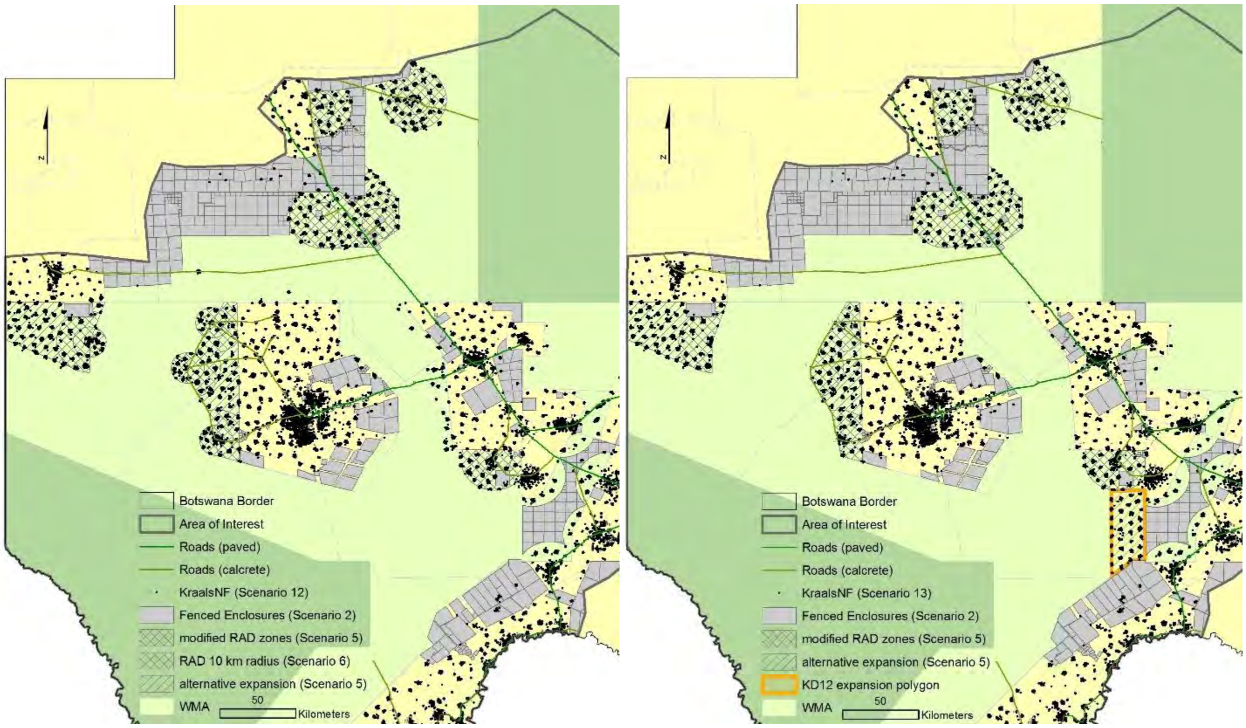


Figure 29 Key model variables for Scenario 12 (left panel) compared to Scenario 13 (right panel). The additional alternative expansion polygon proposed in Scenario 13 excising eastern KD12 is highlighted in orange. Notice also adoption of the modified RAD zones (i.e. Scenario 5 vs 6), and removal of cattleposts encroached into southern GH11 and KD6/12 WMAs.

Box 4. – Spatial description of additional agricultural expansion area as potential off-set for waterpoint allocations, applications, and cattleposts in operation requiring relocating listed in Tables 8-10 necessary to achieve Scenario 13 (refer also Figure 17).

<ins>KD12</ins> – A proposed alternative agricultural expansion area is similar to, but not as aggressive as, that proposed in the Review of the National Land Use Map (Department of Lands 2009). The polygon is approximately a vertical rectangle located SE of Inalegolo and SW of Kokong, excising the farthest eastern extent of WMA KD12. The western border of the proposed polygon lies perfectly north-south (180 deg) at exactly 20 km west of the KD12-SO2/1 boundary (22.854 East longitude). The eastern border is the KD12-SO2/1 boundary. The southern border aligns with the KD12-KD20 boundary. The northern border lies east-west (90 deg) touching the 20 km southern extent of Inalegolo's RAD development radius. This leaves a small wedge of contested land in KD12 encroached by SO1 inhabitants (Kokong village) laying between the northern border of the polygon, Inalegolo 20 km radius extent, and KD12-SO1 boundary.

Table 12. Cattleposts in operation on or near WMA boundaries with kraals spilling over into the WMAs. Kraals inside WMAs were removed for Scenario 13.

LU boundary	Name	Coordinates (Decimal Degrees)
KD3 - GH11	Alphonse Molefele	21.606336 -23.323696
KD3 - GH11	Tjawane Syndicate	21.784531 -23.321906
KD7 - KD6	Nelsen Lekutlane	22.387941 -23.373216
KD13 - KD12	Xola Syndicate	22.623812 -23.913278
KD13 - KD12	Bagapanyana Syndicate	22.628345 -23.920665

3.2.16 Scenario 14 – alternative development path 3 (combination Scenarios 13, enhanced 5)

Scenario 14 represents one incremental but potentially necessary step further than Scenario 13. **Scenario 14 requires further trimming/modification to the southern extents of Bere and Kacgae 20 km radii development zones** (see Box 5, Figures 30,31). In this scenario those villages adopt a nearly 50:50 livestock:wildlife compromise, similar to the four KD1/2 RAD villages in Scenario 5. **To offset the loss, additional alternative expansion areas are proposed in northern GH10** (see Box 6, Figures 30,31)**. The rezoned GH11 ranch block layout also loses the very southern row of ranch blocks** (see Box 5, Figures 30,31).

These changes in Scenario 14 are of course additive to the changes described in Scenario 5 and Scenario 13. Please refer to Scenarios 5, 8-10, and 13 descriptions, in addition to the following specific to 14, in order to understand the total mitigations involved for Scenario 14.

Box 5. – Spatial descriptions of modifications to Bere and Kacgae 20 km radius development zones and to rezoned GH11 ranch block layout.

> Bere/Kacgae – the southern extent of both Bere and Kacgae development circles is a horizontal boundary at -22.8665 decimal degrees South. No waterpoint allocations or kraals develop to the south of this boundary.
>
> Rezoned GH11 ranch block layout – The most southerly row of ranch blocks in GH LB proposed ranch block layout for the rezoned area of GH11 is removed. This row comprises six large blocks approximately 6.5 km deep (see Figure 31). The new southern boundary (latitude -22.8665) of the modified GH11 rezoned ranch block layout coincides with the adjacent southern extent of the modified Bere/Kacgae development zones. Essentially, no agricultural footprint is permitted to develop in GH10/11 WMAs south of latitude -22.8665.

Box 6. – Spatial description of additional alternative agricultural expansion areas to off-set the grazing land relinquished from 20 km radius development circles of Bere and Kacgae (refer also Figures 20,31).

<u>GH10</u> – The first alternative agricultural expansion area is to the west of New Xade. It is bound at its southern extent by a horizontal line coinciding with the southern extent of the New Xade 20 km development radius (-22.3025 South latitude). This southern boundary of the alternative expansion polygon intersects the eastern extent of the rezoned GH10 ranch blocks. The eastern extent of rezoned ranches thus forms the western boundary of the expansion polygon. It is bound to the north by the existing TGLP Ghanzi ranches, and in the east by the 20 km radius circumference of the New Xade development zone (see Figures 30 and 31).

The second alternative agricultural expansion area is to the north of New Xade. It is bound at its eastern extent by a vertical line coinciding with the eastern extent of the New Xade 20 km development radius (22.6105 East longitude). This eastern extent intersects in the north with the GH3/GH10 boundary. The GH3/GH10 boundary thus forms the northern extent of the expansion polygon, while the TGLP Ghanzi ranches and 20 km radius circumference of the New Xade development zone demarcate the western and southern boundaries of the expansion polygon respectively (see Figures 30 and 31).

Figure 30 Key model variables for Scenario 13 (left panel) compared to Scenario 14 (right panel). The additional alternative expansion polygons proposed in Scenario 14 are highlighted in orange. Notice also relinquishment of the southern row of ranch blocks in the GH11 rezoned layout as well as southern extents of RAD 20km zones from Bere/Kacgae.

Table 13. Cattleposts in operation (or newly developing) that require relocation/compensation to achieve Scenario 14 (this list is in addition to those encompassed cumulatively by Scenarios 5, 9-10, 13)

WMA	RAD circle	Name	Coordinates (Decimal Degrees)
GH11	Bere	Boineelo Syndicate	21.703335 -22.906681
GH11	Bere	Annah Xlauku shift	21.789932 -22.868631
GH11	Bere	T Kangatsuru shift / Menatshe Syndicate	21.837166 -22.911929
GH11	Bere	Gustel Heinz	21.797804 -22.967036
GH11	Bere	Xaxen Syndicate	21.919826 -22.897497
GH11	Bere	Malatso Syndicate	21.867344 -22.978845
GH11	Kacgae	Xhee Syndicate / KCQ_15	22.035288 -22.930298
GH11	Kacgae	Richard & Sons Syndicate / KCQ_16a	22.094331 -22.921114
GH10	Kacgae	Kgothu Syndicate	22.100892 -22.868631

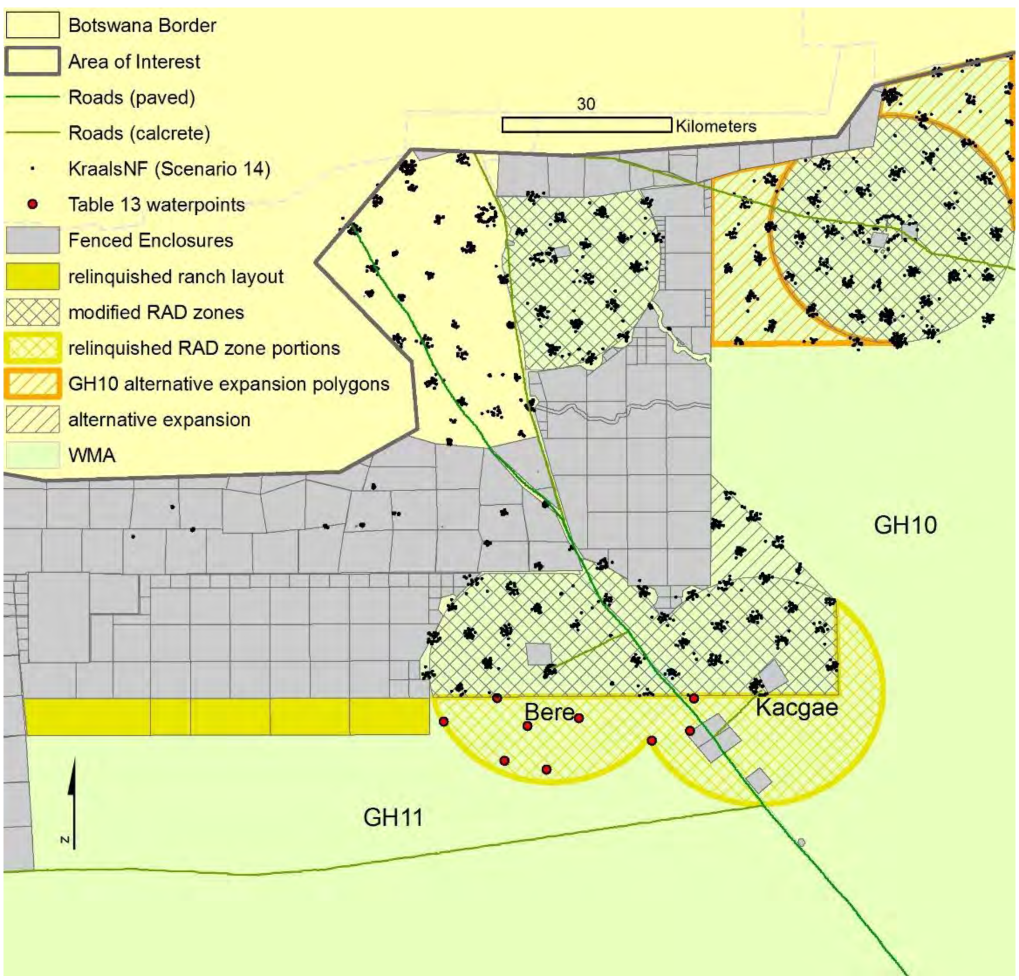


Figure 31 Changes from Scenario 13 to Scenario 14: removal southerly row of undeveloped (GH LB proposed) ranch blocks in GH11 rezoned ranch layout, new limit of Bere and Kacgae modified RAD development zones and location of waterpoint allocations requiring relocation within retained WMAs - offset by additional expansion polygons in the northeast around the unmodified New Xade RAD zone.

The total area of the partial 20 km radius development zones encroaching into sensitive wildlife corridors and relinquished from 6 RAD villages (Zutshwa, Ngwatle, Ncaang, Ukwi, Bere, Kacgae) to achieve Scenario 14 = 3531.13 km².

The total area of alternative (conservation-sensitive) agricultural expansion polygons proposed in Scenario 14 = 3555.60 km².

Thus, the total area of alternative expansion polygons to offset the portions of 20 km radius development circles relinquished for wildlife conservation in Scenario 14 is approximately equal.

The total number of cattleposts and allocated (undeveloped) waterpoint locations requiring relocation to achieve Scenario 14 includes the sum of those within relinquished portions of RAD development zones in Scenario 5 (43 waterpoints), those encroached into WMAs in Scenarios 9 and 10 (19 waterpoints) and those in the additional relinquished area of Bere/Kacage development zones here proposed in Scenario 14 (9 waterpoints; see Table 13). These sum to 71. The total alternative expansion polygons proposed for Scenario 14 comparatively provide space for 98 allocations, respecting the minimal 6 km proximity spacing rule between new allocations within the polygon areas and those adjacent.

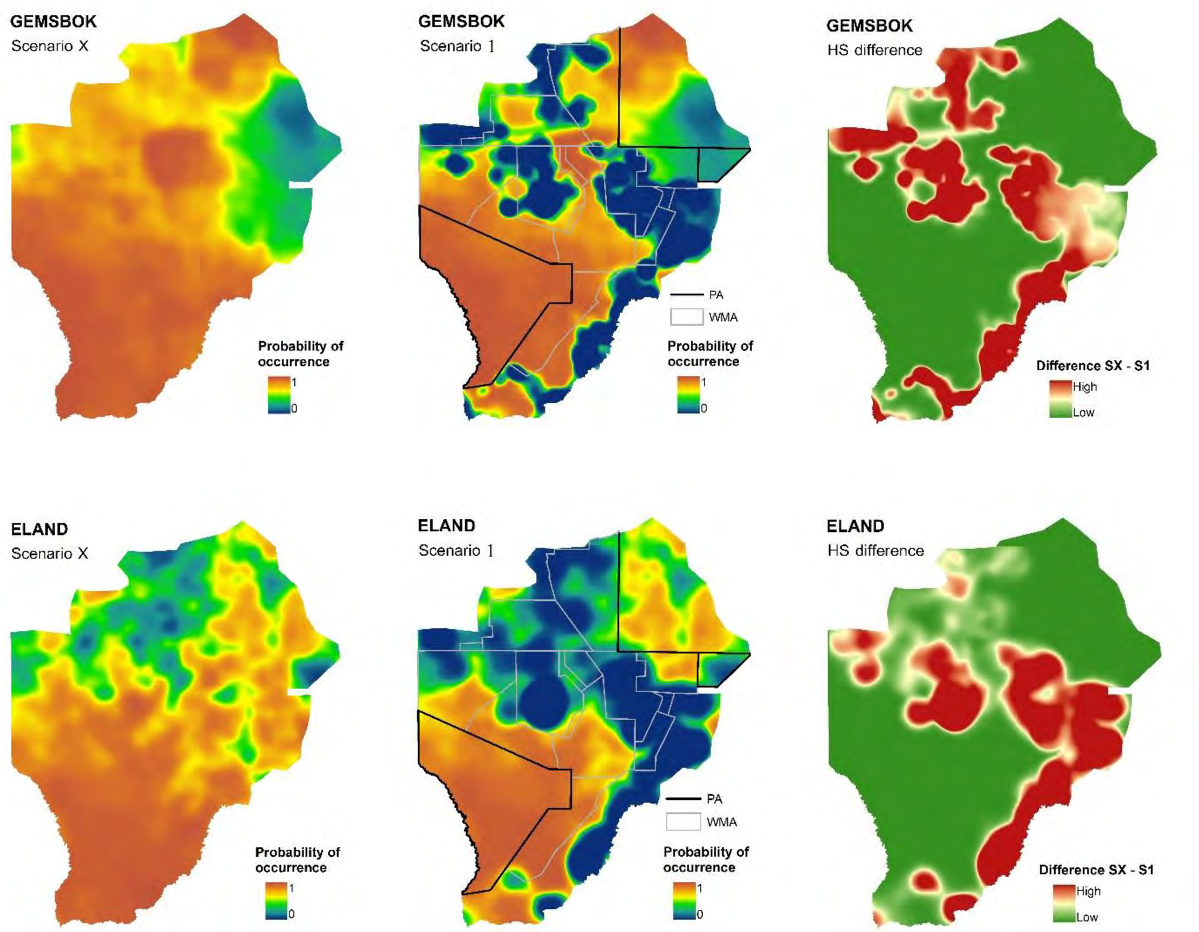
In summary, **to achieve Scenario 14 outcomes requires: gazettement of and no waterpoint encroachment into WMAs KD5/11, relocation of cattlepost encroachment in KD6/12 and southern GH11 WMAs to alternative development zones (Scenarios 9,10), modification to select RAD community 20 km radius development zones offsetting future expansion of RAD waterpoints to alternative development zones (Scenario 5 plus additional expansion polygons discussed in Scenarios 13/14), removal of bottom row of fenced ranch layout in GH11 rezonings (Figure 30), removal of the Kang-Hukuntsi wildlife-friendly fence (Scenario 8) and prohibiting any future obstructive fencing along the Trans-Kalahari Transportation Corridor in southern GH10/GH11 WMAs.**

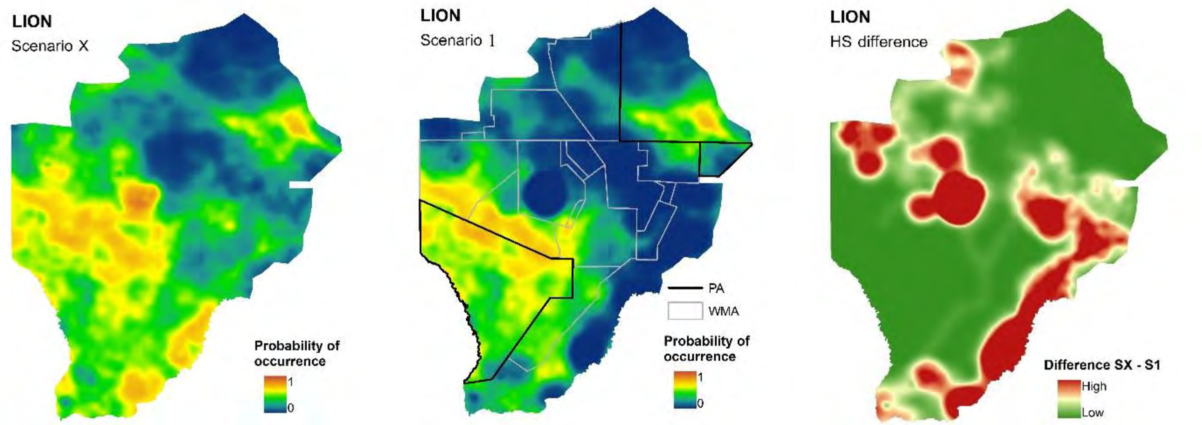
4 RESULTS and DISCUSSION

4.1 Habitat Suitability comparisons between Scenarios

4.1.1 Historical changes

4.1.1.1 Habitat Suitability change from Scenario X (historical pre-settlement) to Scenario 1 (present time) for three disturbance-sensitive species



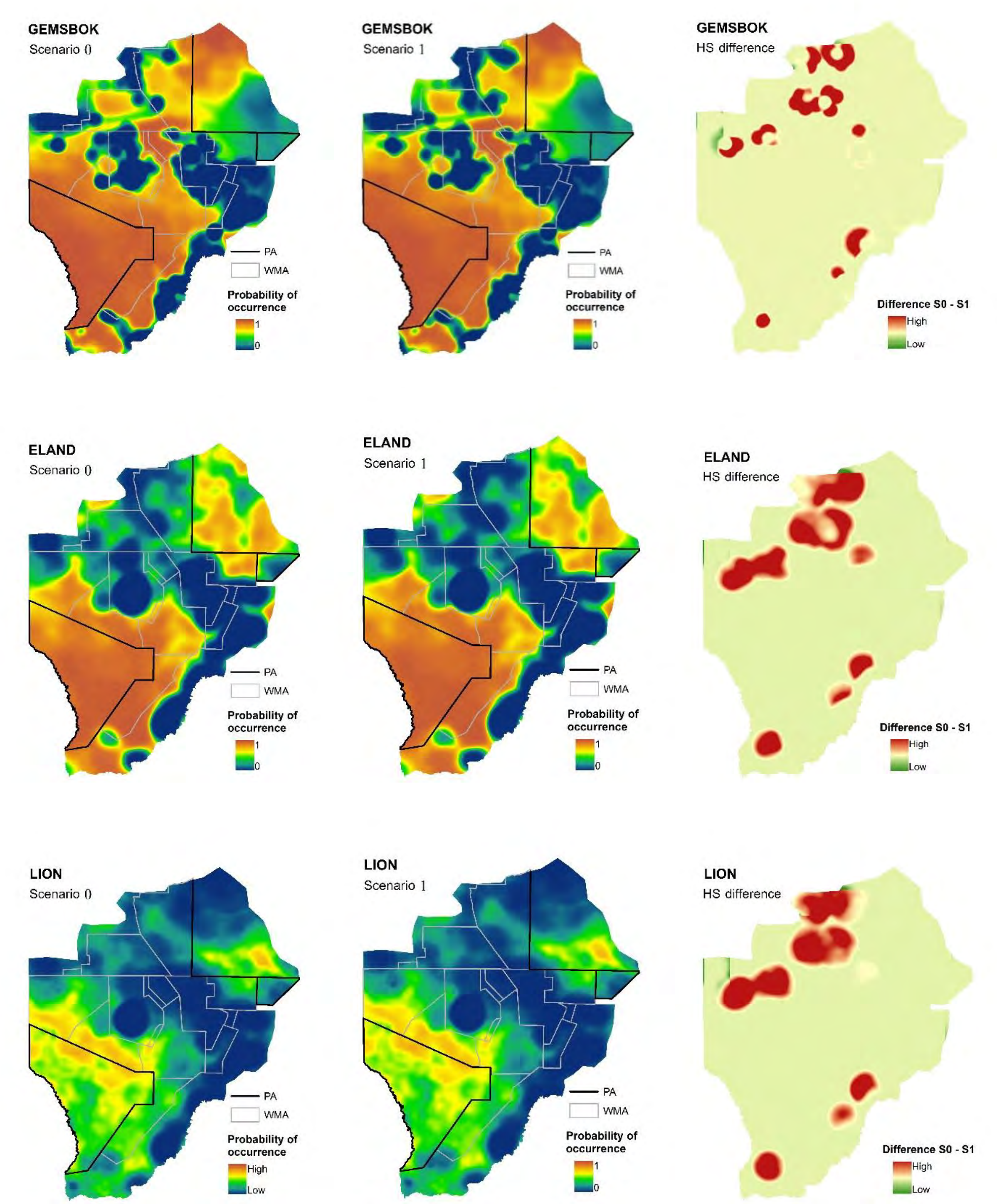


The three most disturbance-sensitive Kalahari wildlife species have experienced an average estimated 45% loss of habitat suitability across the AOI due to human land use cumulating to the present time (Table 14). This comparison highlights the already substantially encroached and shrunken area available to wildlife in the Kalahari due to settlement and human-livestock expansion, largely facilitated by borehole technology proliferating waterpoints. The spatial pattern of habitat loss encroaching from the general southeast, northwest, and from an 'island' in the middle of the AOI (Matsheng villages) - most visible in the "HS difference" maps in the right panel above – has spared two potential corridors of limited habitat loss coinciding with WMA linkages between KTP and CKGR.

Table 14. Percent loss of habitat suitability from Scenario X (historical pre-settlement) to Scenario 1 (present time)

Species	Habitat Suitability Loss from SX to S1
Gemsbok	-42.32%
Eland	-48.49%
Lion	-43.36%

4.1.1.2 Habitat Suitability change from Scenario 0 (- 10 years present) to Scenario 1 (present time) for three disturbance-sensitive species



The habitat suitability loss from the time of wildlife track data collection approximately 10 years ago until present highlights areas of recent rapid encroachment. This habitat loss is occurring primarily as a result of waterpoint-cattlepost proliferation, most prominently within the RAD 20 km radius development zones and most dramatically in Ghanzi District. Due to the geography of RAD village locations, expansion of waterpoints in their development zones disproportionately threatens to shrink habitat suitability at the corridor pinchpoints and render them unviable for disturbance-sensitive wildlife species' connectivity.

Table 15. Percent loss of habitat suitability from Scenario 0 (-10 years present) to Scenario 1 (present time)

Species	Habitat Suitability Loss from S0 to S1
Gemsbok	-2.69%
Eland	-1.78%
Lion	-1.81%

4.1.2 Future changes

Scenario	Sum Suitability	Percent Change
s1	9085297	
s2	7949985	-12.50
s3	8113515	-10.70
s4	8623278	-5.09
s5	8759803	-3.58
s6	8698468	-4.26
s7	8880514	-2.25
s9	9109080	0.26
s10	9158168	0.80
s11	6844875	-24.66
s12	7139548	-21.42
s13	7250479	-20.20
s14	7280750	-19.86

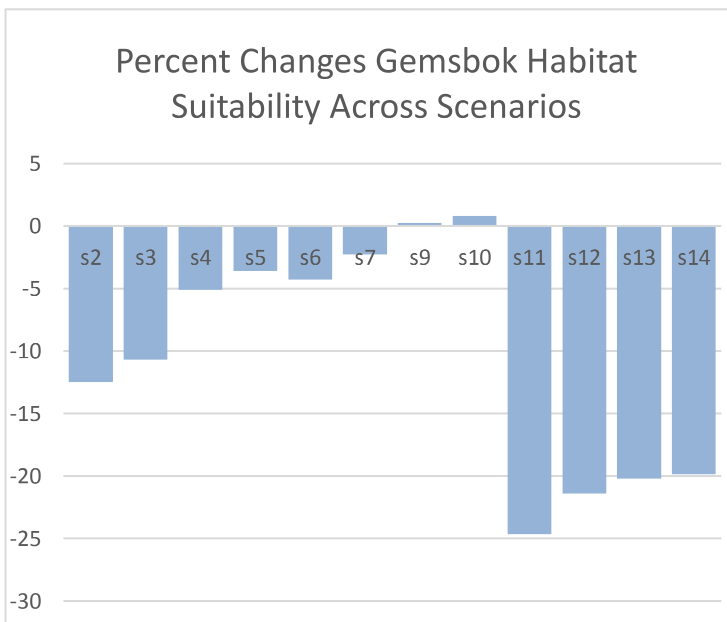


Table 16 and Figure 32 Quantification of habitat suitability change across all future scenarios compared to present time Scenario 1 for gemsbok measured from sums of suitability value across all cells in the HS models.

Scenario	Sum Suitability	Percent Change
s1	7839536	
s2	7520182	-4.07
s3	7129882	-9.05
s4	7454645	-4.91
s5	7623524	-2.76
s6	7547888	-3.72
s7	7708854	-1.67
s9	7855303	0.20
s10	7911021	0.91
s11	6580350	-16.06
s12	6766750	-13.68
s13	6831345	-12.86
s14	6852705	-12.59

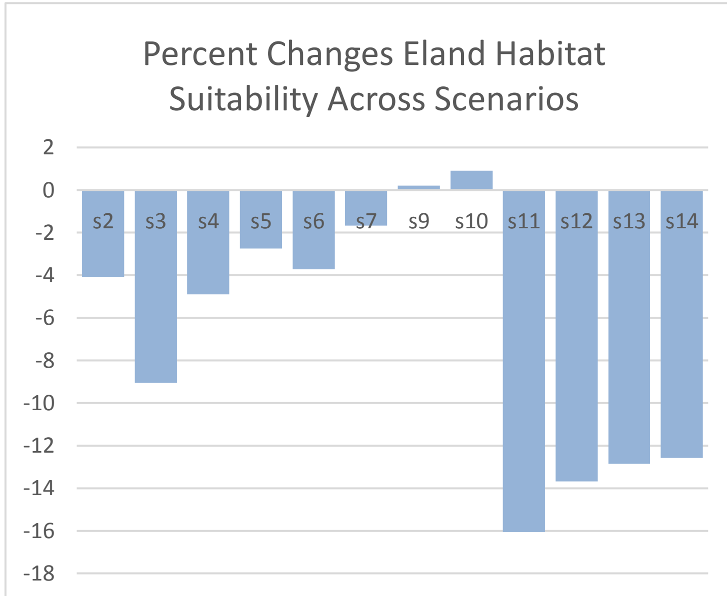


Table 17 and Figure 33 Quantification of habitat suitability change across all future scenarios compared to present time Scenario 1 for eland measured from sums of suitability value across all cells in the HS models.

Scenario	Sum Suitability	Percent Change
s1	4270221	
s2	3919954	-8.20
s3	3888727	-8.93
s4	4001770	-6.29
s5	4104990	-3.87
s6	4046250	-5.24
s7	4226606	-1.02
s9	4278026	0.18
s10	4291055	0.49
s11	3443778	-19.35
s12	3544600	-16.99
s13	3601085	-15.67
s14	3612690	-15.40

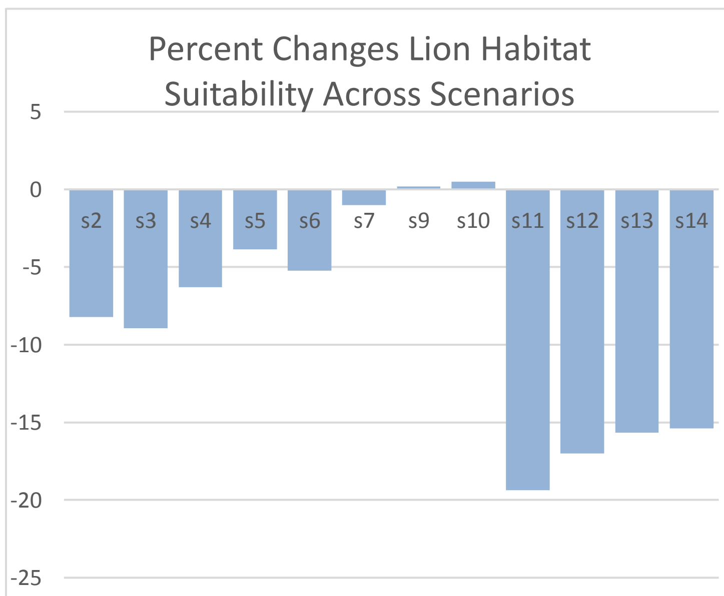
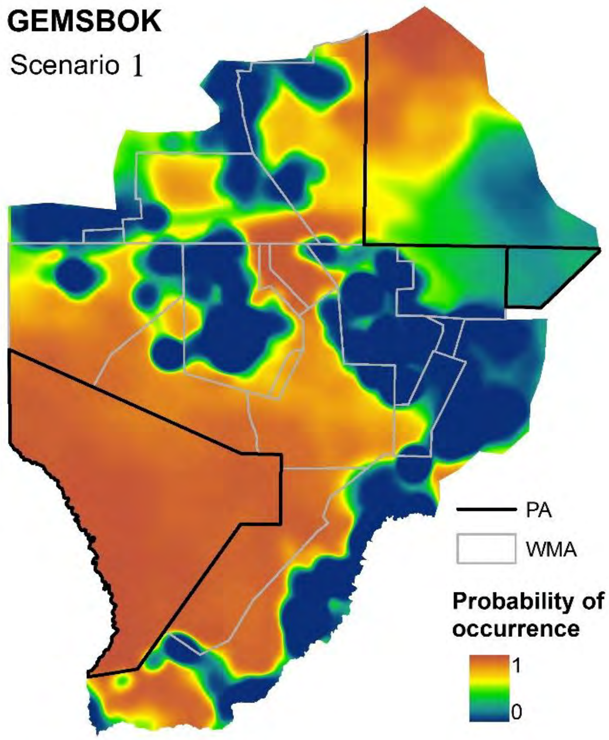


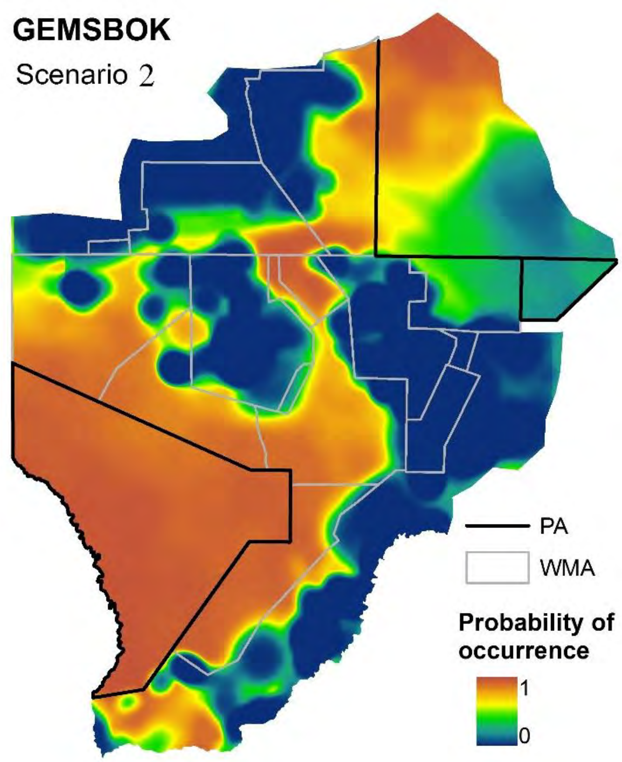
Table 18 and Figure 34 Quantification of habitat suitability change across all future scenarios compared to present time Scenario 1 for lion measured from sums of suitability value across all cells in the HS models.

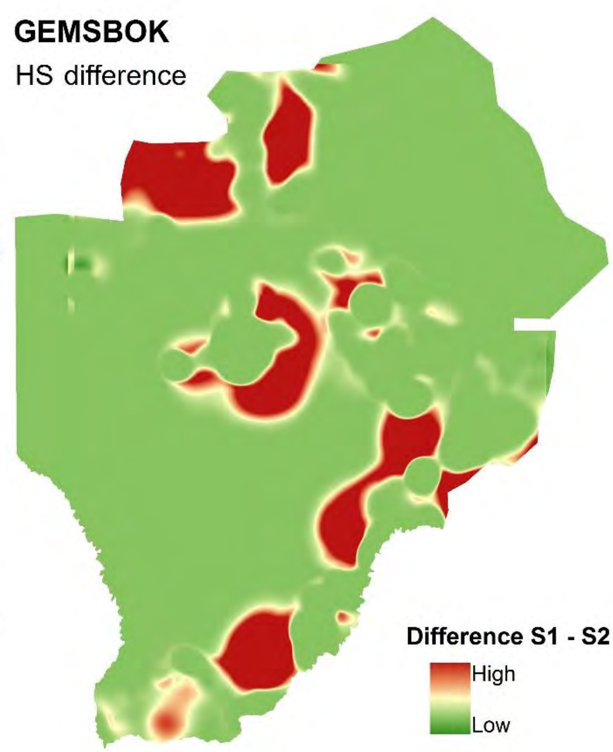
With the exception of few isolated cattlepost relocations examined in 9-10 which result in modest habitat gains (but disproportionate importance to connectivity shown in Section 4.2), habitat loss occurs across all future scenarios. The pattern of habitat loss is similar across scenarios for all three disturbance-sensitive species, with slight variation. For example, bringing all zoned and planned fenced livestock operations online (Scenario 2) will remove slightly more gemsbok habitat (-12.5%) than will all allocated and applied for boreholes developing as cattleposts (Scenario 3) (-10.7%). The reverse is true for eland and lion, i.e. Scenario 3 will affect more habitat than Scenario 2.

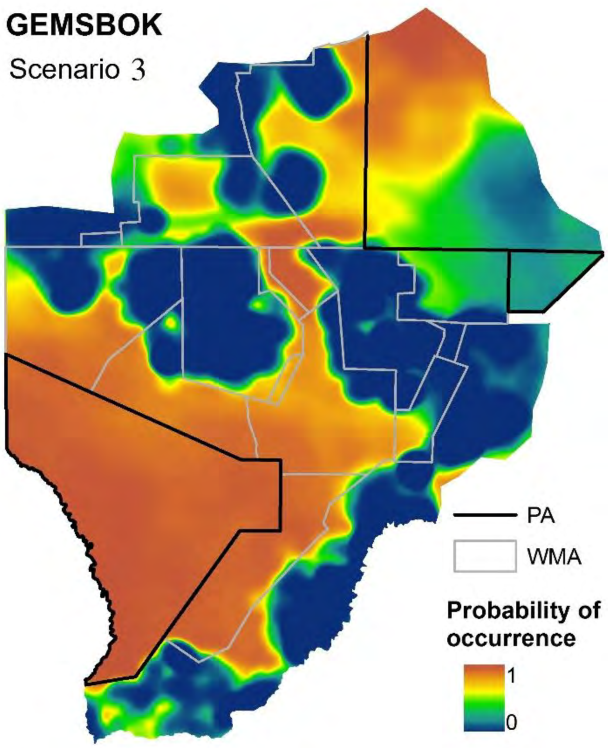
The most substantial levels of habitat loss occur over future scenarios encompassing realistic cumulative developments already planned and in consideration (Scenario 11) as well as proposed alternative development paths (Scenarios 12-14). The habitat loss quantified here as HS model suitability values across all cells in the AOI thus represents not necessarily only human-livestock expansion into pristine habitats, but also intensification in areas with less than perfect suitability. The future increase of human-livestock footprint in the AOI is taken for granted given human population growth and demand for land. Scenario 11 represents future habitat loss only for what is already allocated, planned, and under consideration. Proposed alternative development paths (s12-14) are iterative attempts to salvage landscape connectivity while accommodating this increased human-livestock pressure. In Scenarios 12-14 we proposed nearly equivalent area for future agricultural expansion as those planned areas encroaching into sensitive wildlife corridors that were relinquished. Considering this balance, the fact that total habitat loss declines incrementally from s11-14 reflects how human-livestock activity becomes more concentrated and organized in Scenarios 12-14 rather than haphazardly encroaching into high value wildlife habitats in the current trajectory (Scenario 11). While the reductions in habitat loss over s12-14 compared to s11 are modest, connectivity improves disproportionately as shown in Section 4.2.

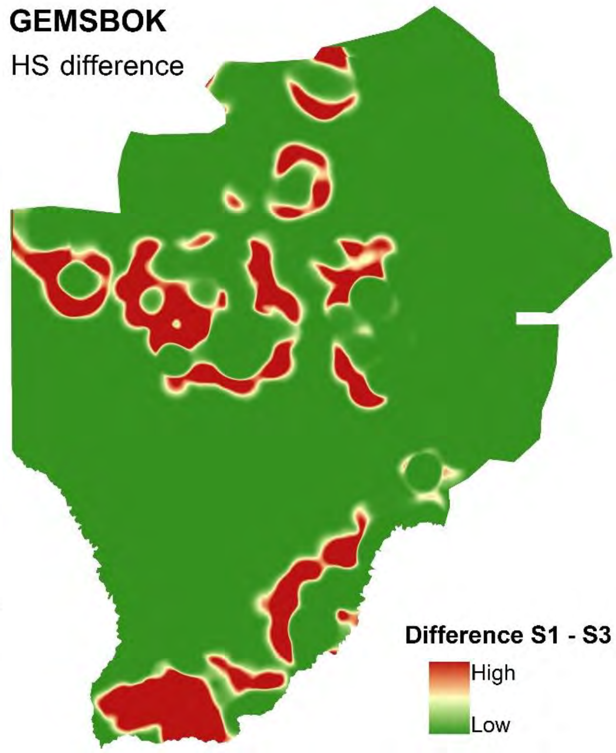
4.1.2.1 Habitat Suitability change from Scenario 1 (present time) to future Scenarios 2-10 (planned and optional changes in isolation) for Gemsbok

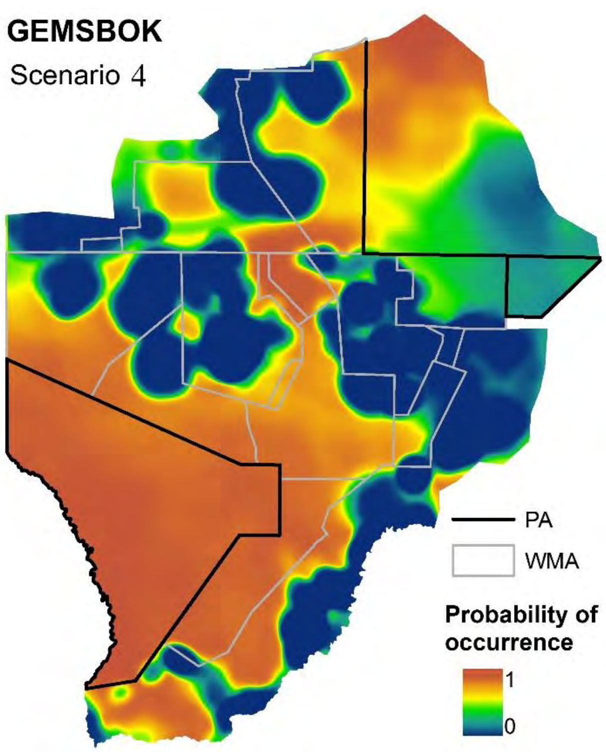


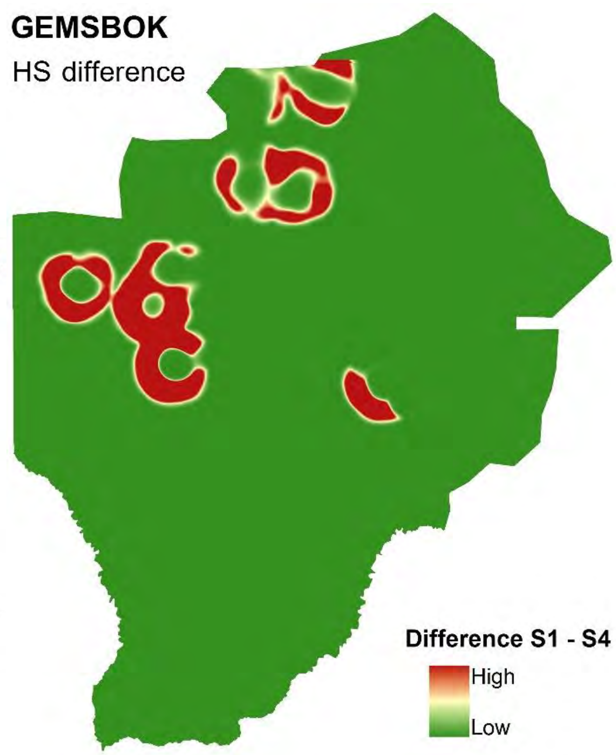


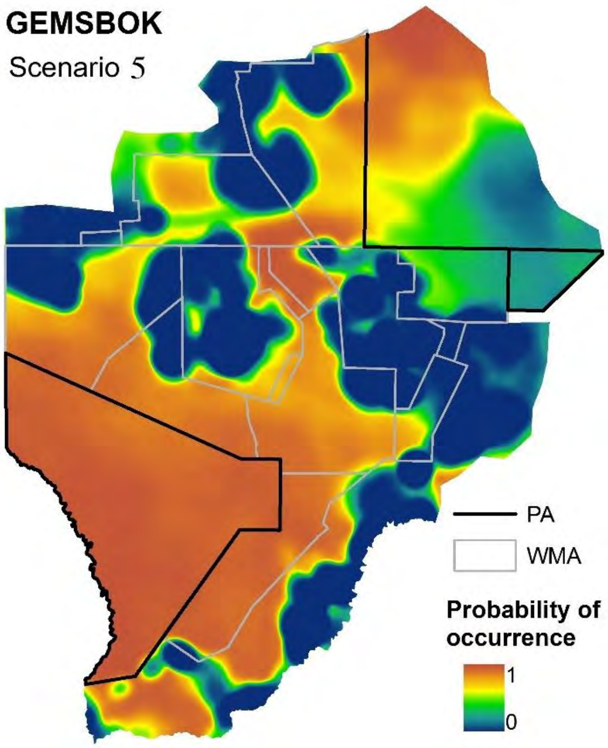


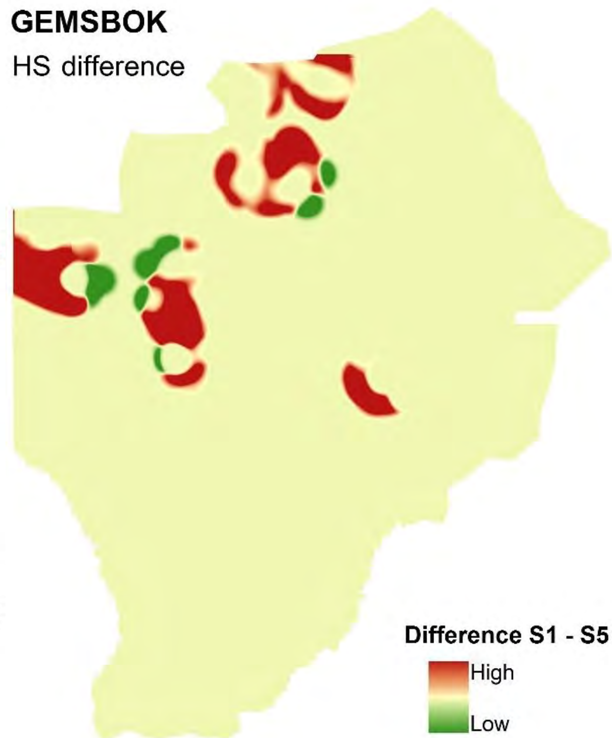

GEMSBOK
Scenario 3
PA
WMA
Probability of occurrence
1
0

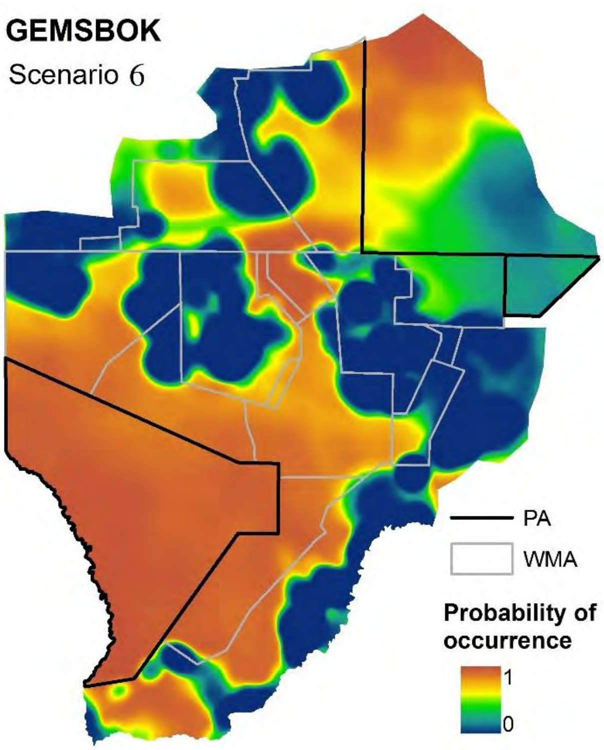

GEMSBOK
HS difference
Difference S1 - S3
High
Low

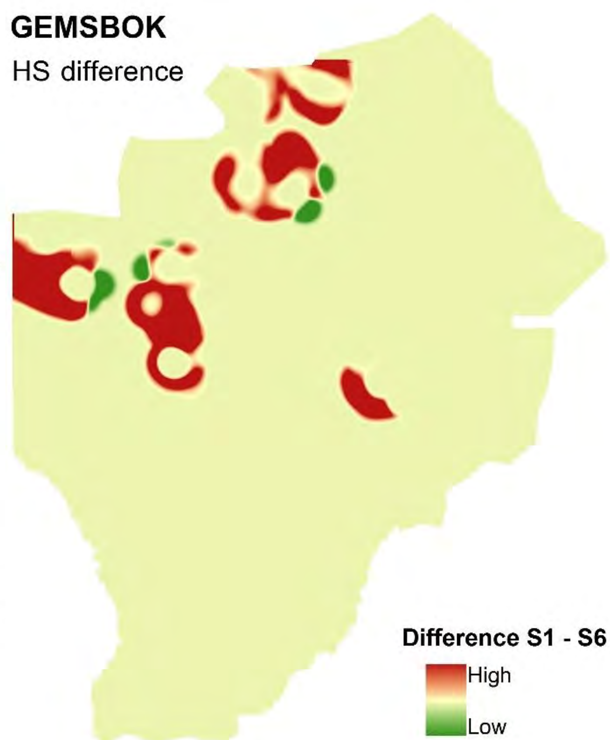

GEMSBOK
Scenario 4
PA
WMA
Probability of occurrence
1
0

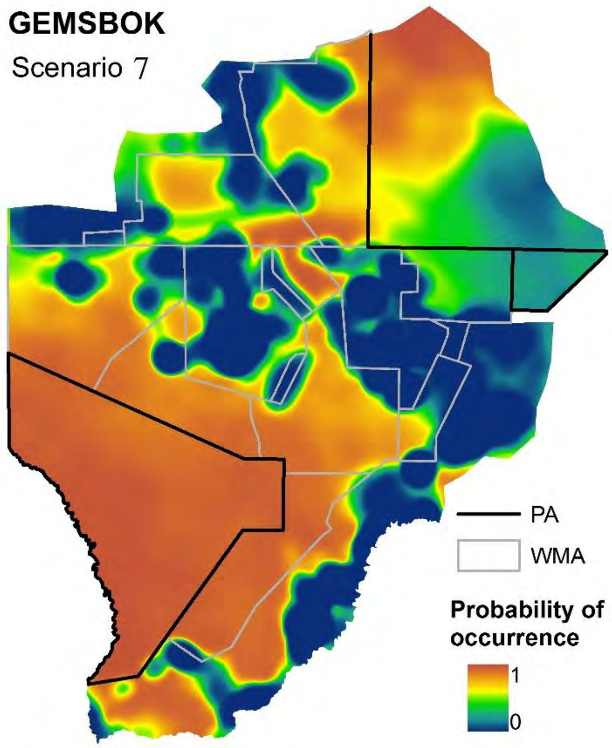

GEMSBOK
HS difference
Difference S1 - S4
High
Low

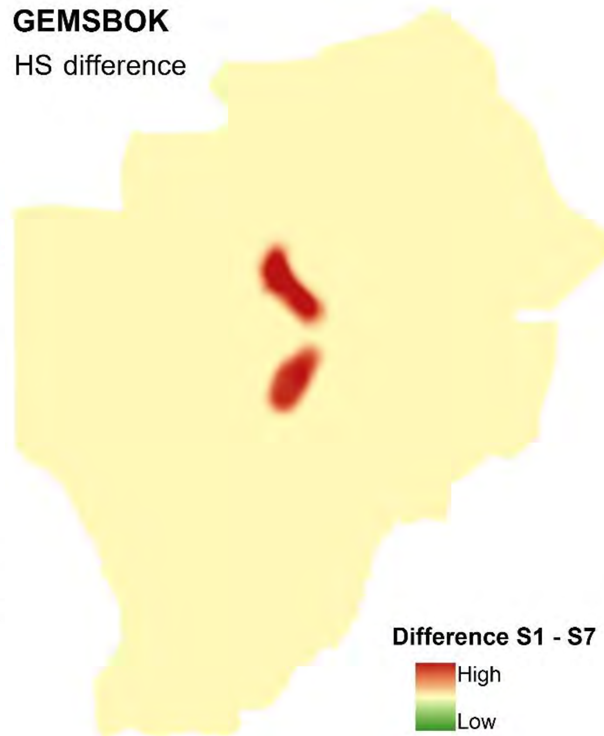

GEMSBOK
Scenario 5
PA
WMA
Probability of occurrence
1
0

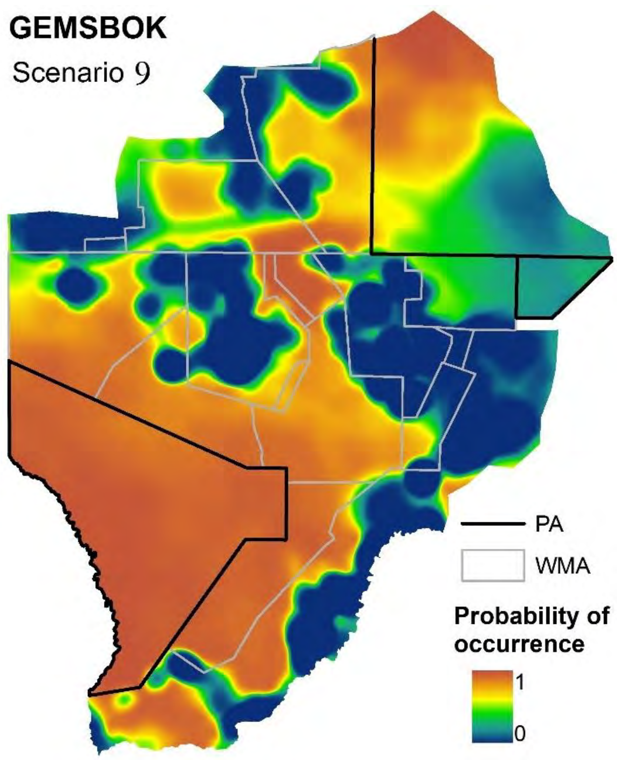

GEMSBOK
HS difference
Difference S1 - S5
High
Low

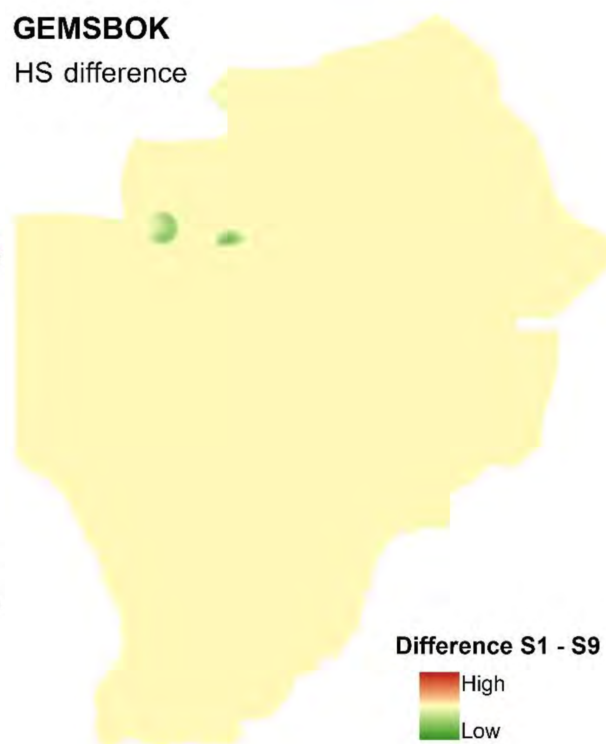

GEMSBOK
Scenario 6
PA
WMA
Probability of occurrence
1
0

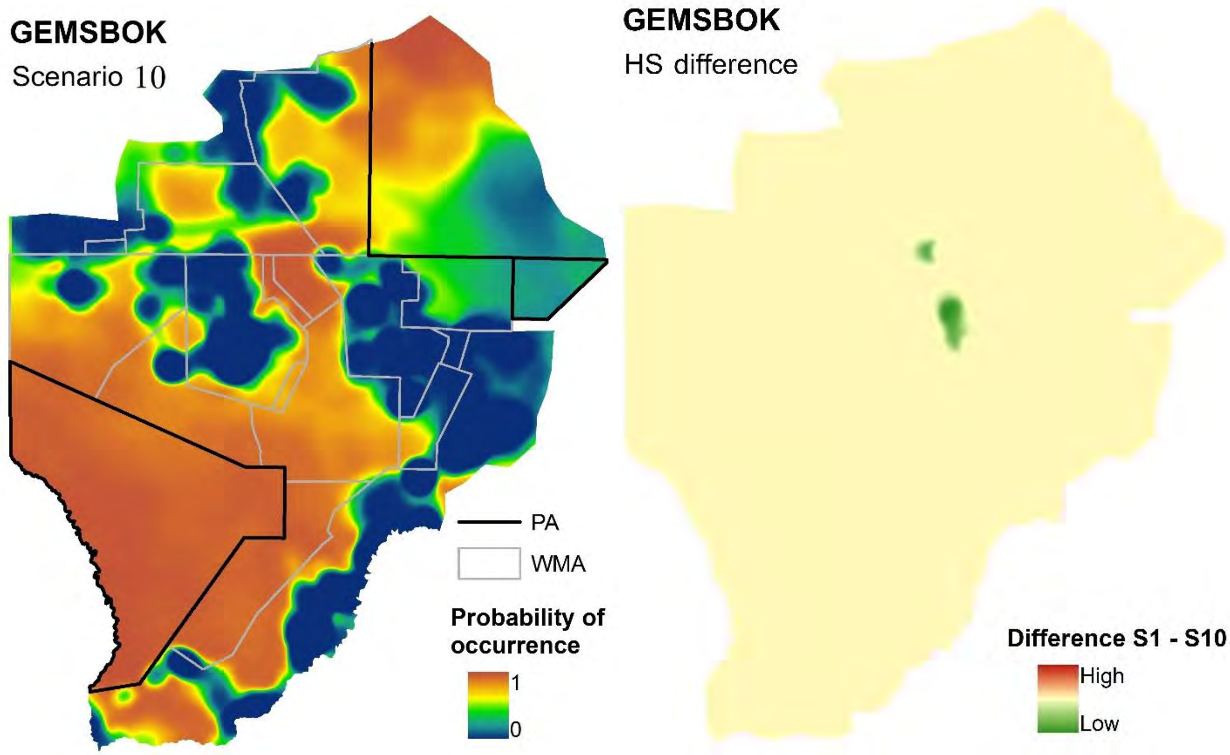

GEMSBOK
HS difference
Difference S1 - S6
High
Low


GEMSBOK
Scenario 7
PA
WMA
Probability of occurrence
1
0


GEMSBOK
HS difference
Difference S1 - S7
High
Low


GEMSBOK
Scenario 9
PA
WMA
Probability of occurrence
1
0


GEMSBOK
HS difference
Difference S1 - S9
High
Low



Scenarios 2-3 draw attention to the spatial pattern of fenced and non-fenced livestock encroachment threatening corridor pinchpoints and overall landscape fragmentation from planned and already zoned/allocated future developments. Planned fenced operations (Scenario 2) will cause disproportionate habitat loss within the central corridor, while cattlepost expansion (Scenario 3) heavily impacts the western corridor.

Scenario 4 illustrates the serious threat of RAD 20 km radius development zones to landscape connectivity, in the western corridor particularly.

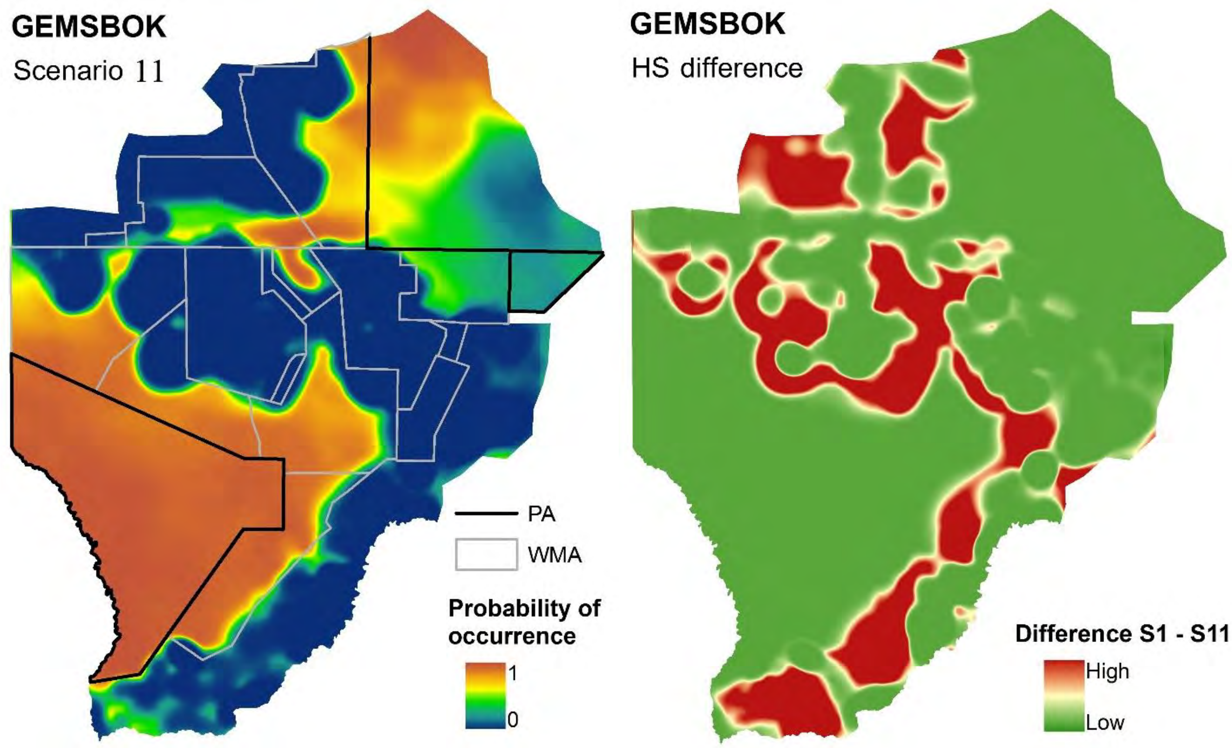
Scenarios 5-6 (two alternative RAD development zone options) show the gain in habitat (green in the HS difference maps) primarily within the western corridor pinchpoint due to rollback of waterpoint allocations (specific locations described in Section 3.2.7) in relation to habitat loss from the retained portions of RAD development zones plus alternative areas for expansion.

Scenario 7 shows the disproportionate habitat loss caused by allocating waterpoints within the relatively narrow buffer WMAs KD5 and KD11.

Scenario 8 is omitted from this section as the change in status of the Kang-Hukuntsi wildlife-friendly fence does not affect the HS models in which fences were excluded. Fences were rather modelled for resistant kernel and factorial least cost path connectivity reported in Section 4.2 below.

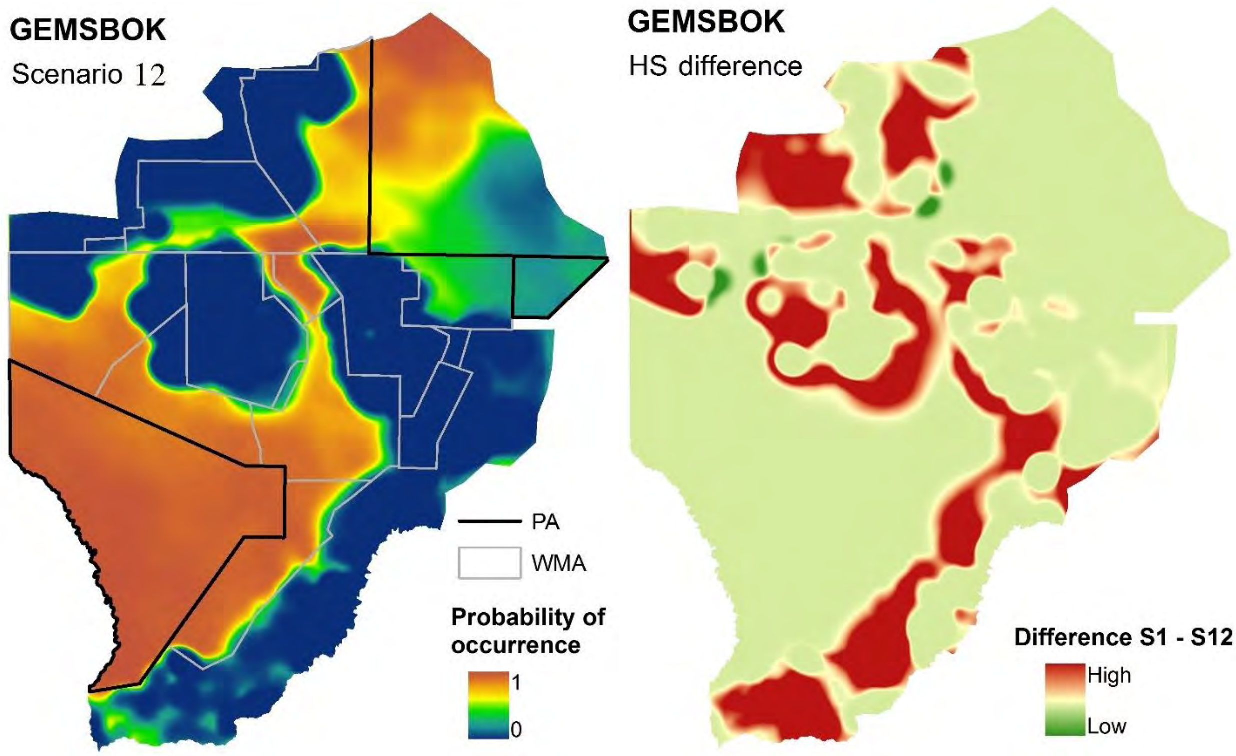
Scenarios 9-10 show the disproportionate gain in habitat suitability to the western and central corridors respectively when a limited number of specific cattleposts encroaching exceptionally far into high suitability habitats within WMAs are removed (refer Sections 3.2.11/12). Notice in Scenario 9 how removal of only two problematic locations encroaching into southern GH11 WMA regains a thread of high probability gemsbok habitat linking the western corridor.

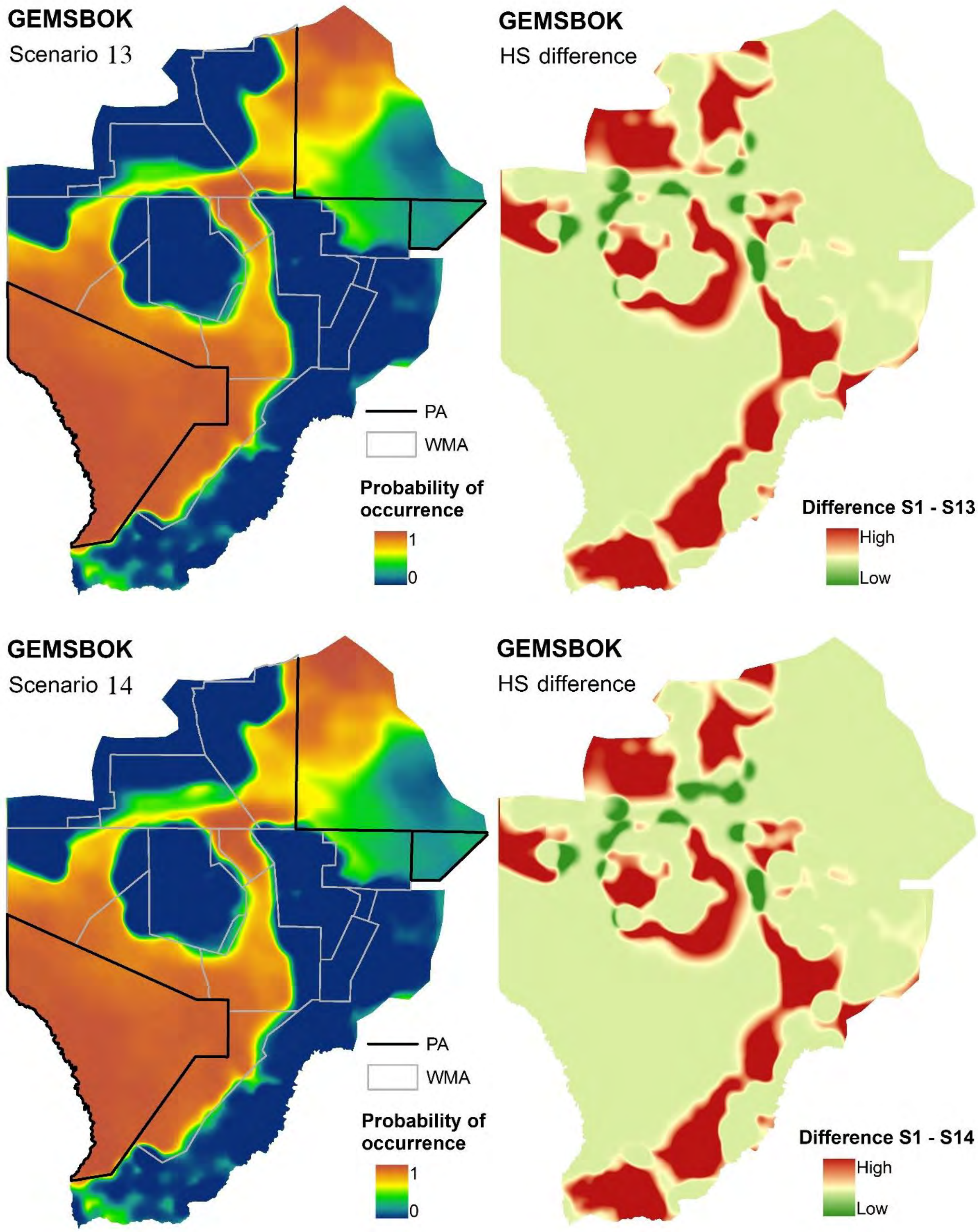
4.1.2.2 Habitat Suitability change from Scenario 1 (present time) to future Scenario 11 (cumulative planned development) for Gemsbok



Scenario 11 once again is the current development trajectory. It is the cumulative human-livestock developments which are known and probable to occur in the near future unless alternatives are urgently considered. It includes not only planned zones for agricultural expansion (e.g. GH/SO WMA rezonings (Scenario 2), RAD development zones (Scenario 4), and other allocated/applied for waterpoints in the AOI), but also changes to key areas which have been proposed and/or lobbied (i.e. loss of KD5/11 WMAs (Scenario 7), row of new ranches along the Kang-Hukuntsi highway). As illustrated in the above HS and difference maps, these cumulative changes result in a 36-kilometre gap of zero value habitat suitability within the central corridor. In the western corridor, extremely flimsy threads of only low-moderate habitat suitability are predicted to remain, with almost non-existent pinchpoints of habitat between Ukwi-Ngwatle, and Ranyane-Ncaang. The HS difference map illustrates the future loss along almost every frontier as human-livestock expansion occurs in nearly every direction from currently settled areas.

4.1.2.3 Habitat Suitability change from Scenario 1 (present time) to future Scenarios 12-14 (alternative development paths) for Gemsbok





Scenarios 12-14 once again offer alternative futures to the current trajectory (Scenario 11) with spatially and precisely targeted mitigations to the human-livestock disturbance landscape. Mitigation effort incrementally increases from Scenario 12 to 14.

Compared to Scenario 11, Scenario 12 salvages habitat in the lower western corridor by way of limiting RAD development zones into the corridor to 10 km from village centres instead of 20km. An almost non-existent pinchpoint of low probability habitat remains between Ranyane and Ncaang, however, and higher suitability habitat is discontinuous throughout the length of the western corridor. High probability habitat is reduced to a narrow thread through the central corridor in KD12.

Scenario 13 shows substantial visible improvement to habitat suitability and potential connectivity, bolstering the central corridor and restoring a connection of high probability habitat through the western corridor.

Scenario 14 shows the gain in habitat around the critical confluence/divergence of western and central corridors in GH11 and GH10 WMAs south of Bere and Kacgae.

Comparing HS and difference maps of Scenario 11 with Scenarios 12-14, one can visualize the minimal impact that the various alternative expansion polygons (which both offset restoration and accommodate future agricultural expansion) cause to the habitat suitability surface. These maps largely validate the substantial area we proposed for future agricultural expansion in causing minimal loss to core wildlife areas while attempting to salvage sensitive corridors.

Scenarios 12-14 incur high levels of habitat loss within the AOI overall compared to present time (Tables 16-18/Figures 32-34). Although these scenarios minimize loss to core wildlife areas while simultaneously bolstering corridors for enhanced connectivity, land use must intensify inside designated zones, which contributes to the relatively high levels of habitat suitability loss relative to Scenario 1. Erratic encroachment into high value habitats are reduced while spatial utilization is optimized within allowable zones with boundaries that are strictly adhered to. Thus, overall habitat loss in the AOI is an incomplete assessment of the value of these scenarios to achieving the goal of landscape connectivity. The trade-off between overall habitat loss and enhanced connectivity can only be quantitatively appreciated when the habitat suitability changes of the present section are viewed in light of the connectivity changes in the following section.

Core areas remain relatively stable throughout the scenarios. Loss is most extreme in the full 20 km radius RAD development zones (Scenarios 4, 11).

4.2 Wildlife Landscape Connectivity Models – Resistant Kernel and Factorial Least Cost Paths

Scenario	Sum Kernel	Percent Change
s1	679485773	
s2	602583475	-11.32
s3	628998199	-7.43
s4	648799143	-4.52
s5	685482724	0.88
s6	679467363	0.00
s7	664459715	-2.21
s8	696344491	2.48
s9	691006847	1.70
s10	695566840	2.37
s11	543083264	-20.07
s12	552790290	-18.65
s13	579976670	-14.64
s14	573103390	-15.66

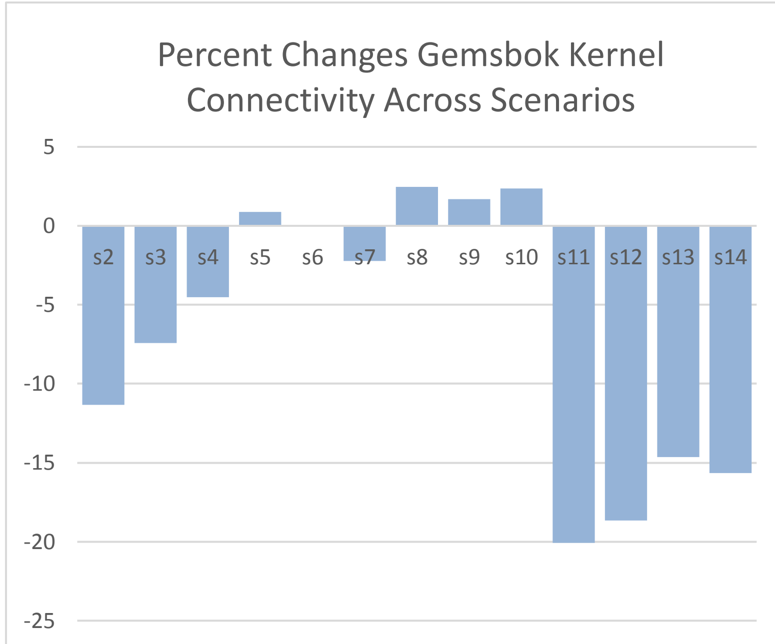


Table 19 and Figure 35 Quantification of total connectivity change between each scenario and the present time baseline (Scenario 1) for gemsbok measured as the difference in sum of kernel surfaces.

Scenario	Sum Path	Percent Change
s1	77162672	
s2	57226917	-25.84
s3	58850227	-23.73
s4	64741024	-16.10
s5	76102019	-1.37
s6	76276114	-1.15
s7	69349269	-10.13
s8	87414125	13.29
s9	83103813	7.70
s10	82412511	6.80
s11	39346172	-49.01
s12	43225352	-43.98
s13	46582866	-39.63
s14	51463612	-33.31

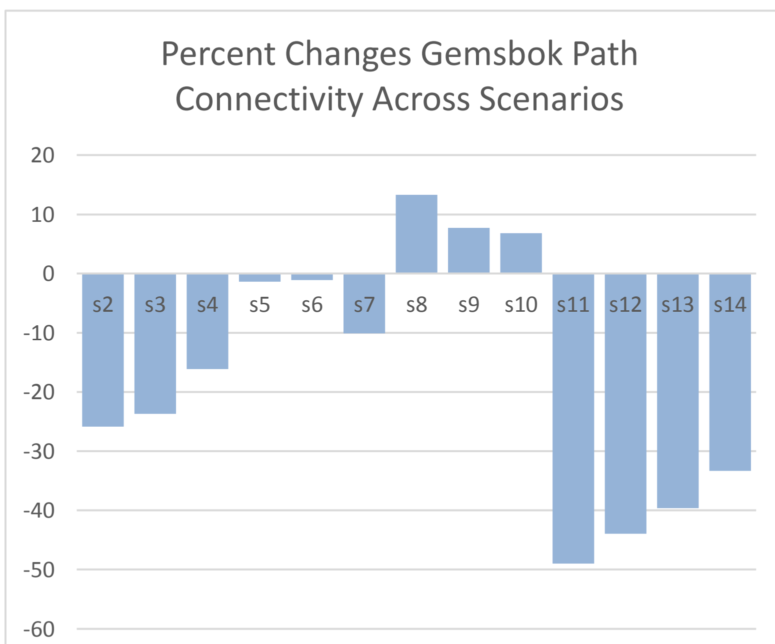


Table 20 and Figure 36 Quantification of total connectivity change between each scenario and the present time baseline (Scenario 1) for gemsbok measured as the difference in sum of path surfaces.

Scenario	Sum Path	Percent Change
s1	188833984	
s2	118381623	-37.31
s11	56858113	-69.89
s12	63545674	-66.35
s13	75025554	-60.27
s14	71414200	-62.18

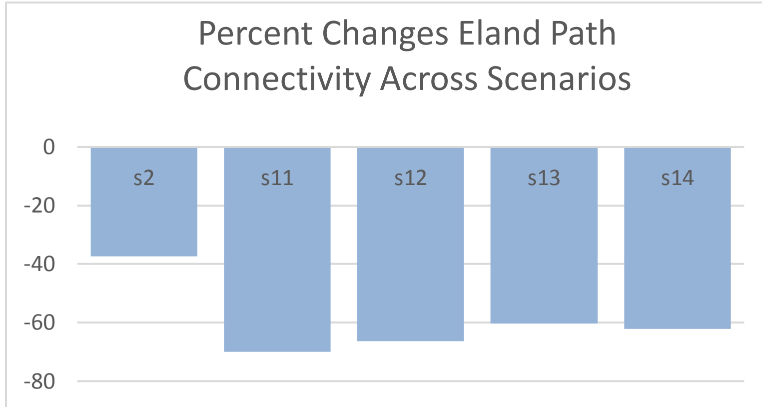


Table 21 and Figure 37 Quantification of total connectivity change between each scenario and the present time baseline (Scenario 1) for eland measured as the difference in sum of path surfaces.

Scenario	Sum Path	Percent Change
s1	105707509	
s2	79477209	-24.81
s11	56324134	-46.72
s12	63186416	-40.23
s13	63755087	-39.69
s14	74818801	-29.22

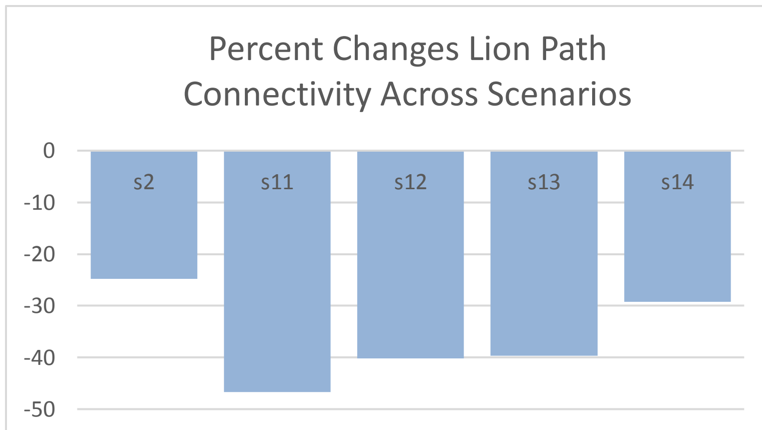
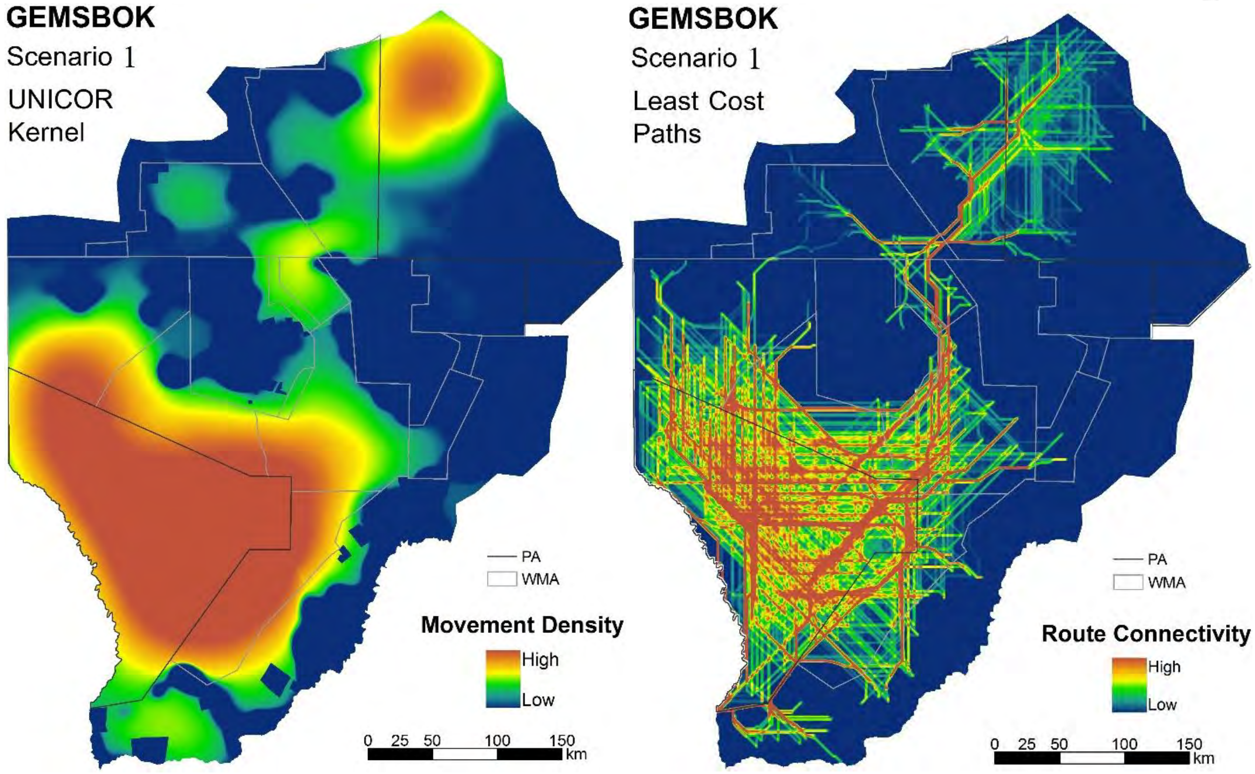


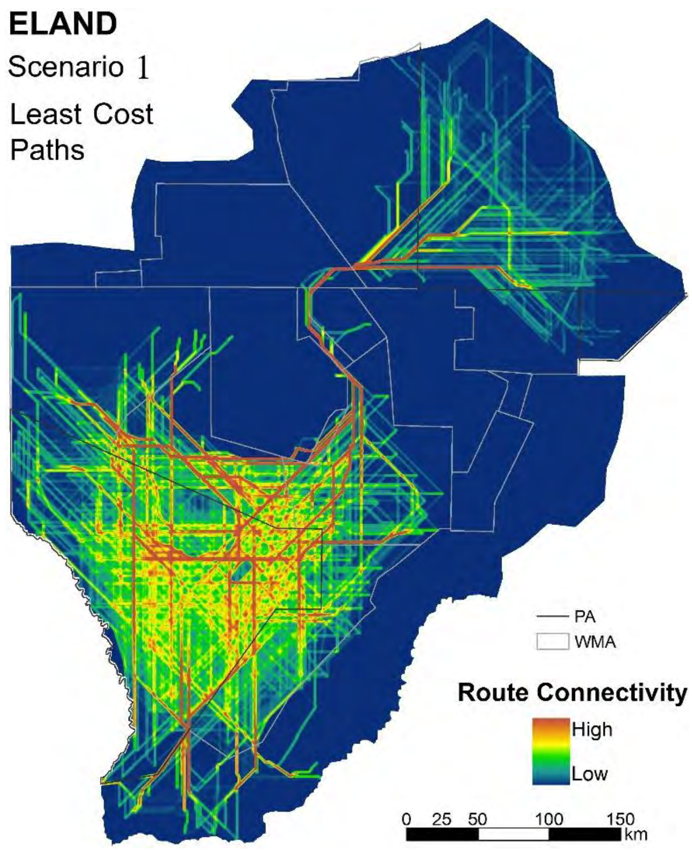
Table 22 and Figure 38 Quantification of total connectivity change between each scenario and the present time baseline (Scenario 1) for lion measured as the difference in sum of path surfaces.

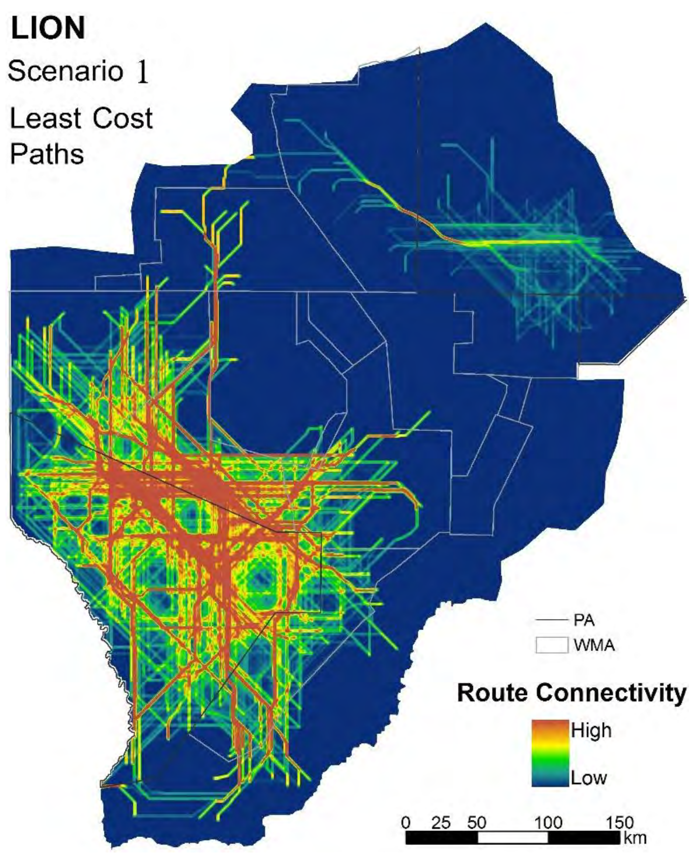
4.2.1 Scenario 1 – present time



Two population cores are indicated by the kernel connectivity modelling: a main core centered upon KTP and adjacent WMAs (KD1,2,12,15), and a second core in CKGR.

Gemsbok cores are linked strongly through the central corridor with relatively high movement density in northern KD6/southern GH11. A nearly isolated subpopulation exists in northwestern GH11 as connection through the western corridor appears tenuous. Connectivity through the western corridor appears most vulnerable at the pinchpoint between Ranyane and Ncaang RAD cattlepost expansion, and between Bere RAD cattleposts and that inside GH11 WMA encroached beyond the KD3-GH11 boundary north of Hunhukwe. While gemsbok occur in southern SO2, the potential eastern corridor (SO2-KW6-KW2) is predicted unviable.

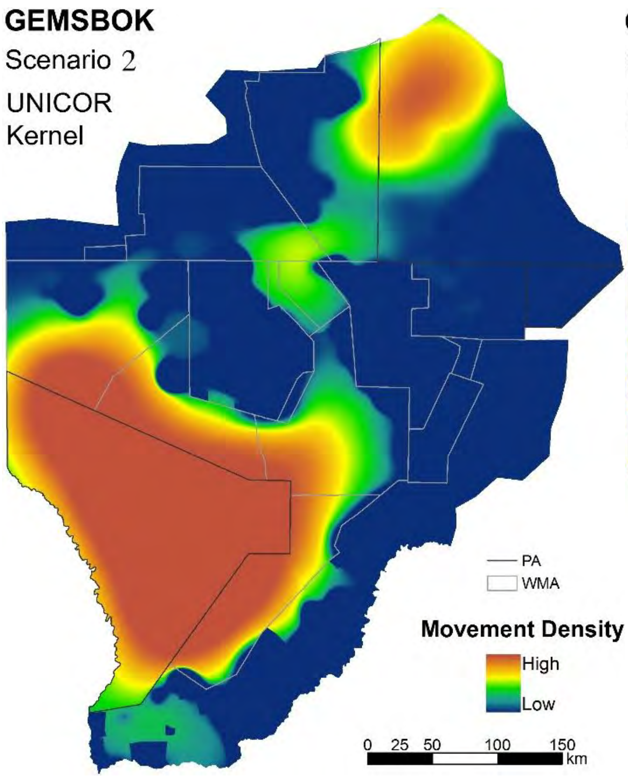

ELAND
Scenario 1
Least Cost
Paths
PA
WMA
Route Connectivity
High
Low
0 25 50 100 150
km

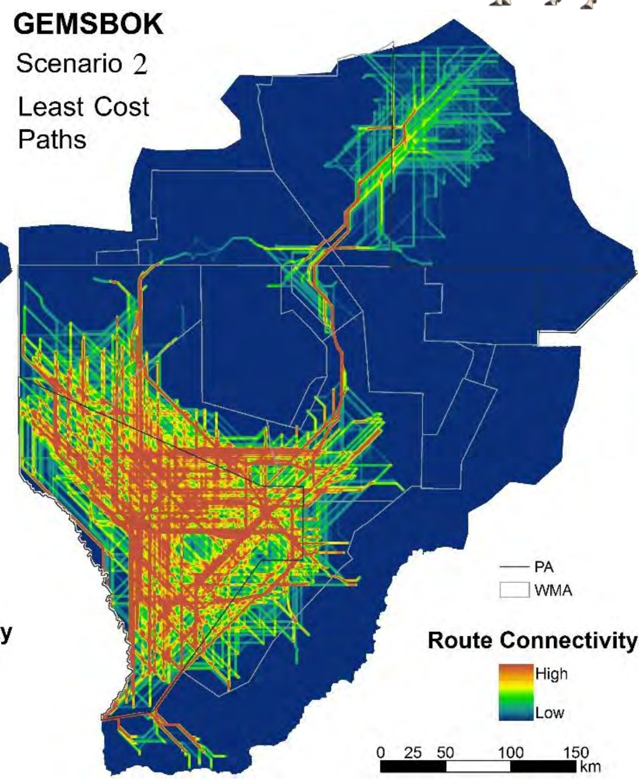

LION
Scenario 1
Least Cost
Paths
PA
WMA
Route Connectivity
High
Low
0 25 50 100 150
km

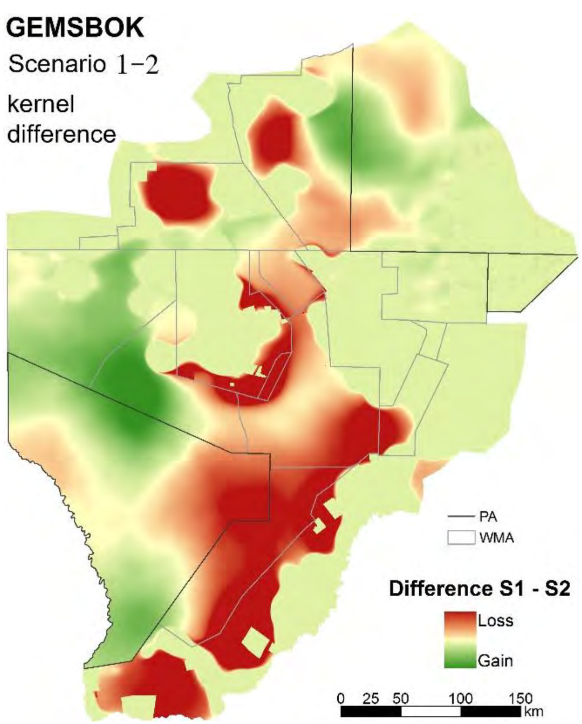
Least cost path connectivity modeling for eland predicted a connection through the central corridor distinctly via KD5, not KD6. This is relevant as KD5 may tend to be ignored as a WMA.

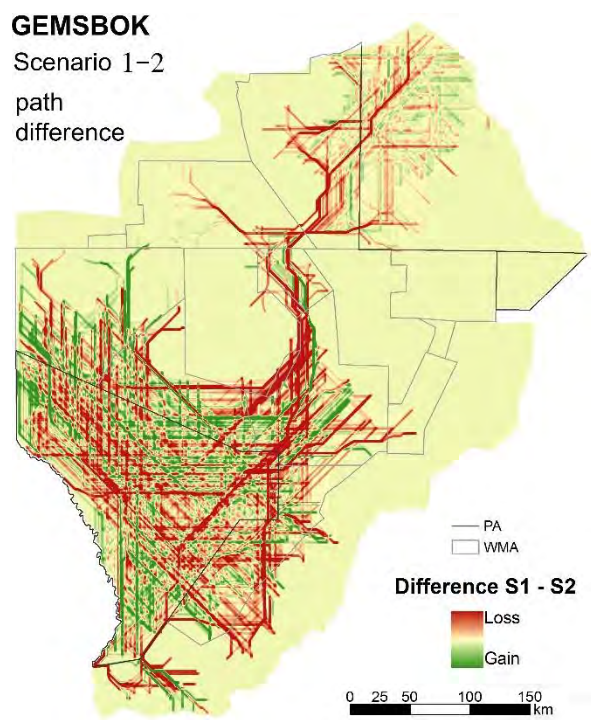
Lion are predicted to hold a tenuous linkage through the Okwa valley to northern GH11. This was an unexpected finding. This connection was assumed to be untenable due to the intensity of cattleposts and fencing activity in GH9 CGA separating GH10 from GH11. Notably, however, this model prediction is corroborated with field observations including lion at the far western extent of Okwa valley in GH10 and along the Trans-Kalahari highway nearby (Figure 11). Unfortunately, this discovery came too late in the Phase 2 processes to model future scenarios that accommodate a suitable buffer along the molapo tributary in northern GH11 which feeds into the Okwa valley all the way through GH9, thus linking GH10 to GH11. This option is very much worth exploring by land planning to enhance landscape connectivity, especially considering the Okwa valley would have historically been a major facilitative movement corridor for wildlife in the SW-NE direction along the rainfall gradient, linking the Schwelle to northern CKGR and beyond. This is evidenced by wildebeest radio collared movements 30 years ago (Bonifica 1992). Anecdotal observations also point to continued attempts by large antelope herds to move up the Okwa valley from GH10, including an eland herd crossing the Trans-Kalahari highway from west to east numbering several hundred strong (G. Neo-Mahupeleng pers comm). Notably, Ghanzi LB have proposed a modest buffer along the Okwa valley in the rezoned GH10 ranch layout. Perhaps this could be extended through GH9. However, development of the rezoned GH11 ranch layout as per Scenario 2 may render this connection finally unviable, even with a continual buffer, unless that buffer is substantially large (i.e. on the scale of ranch width within those blocks). If there is interest in building a mitigative corridor connecting GH10 to GH11 through the Okwa then we can provide further spatial guidance on request.

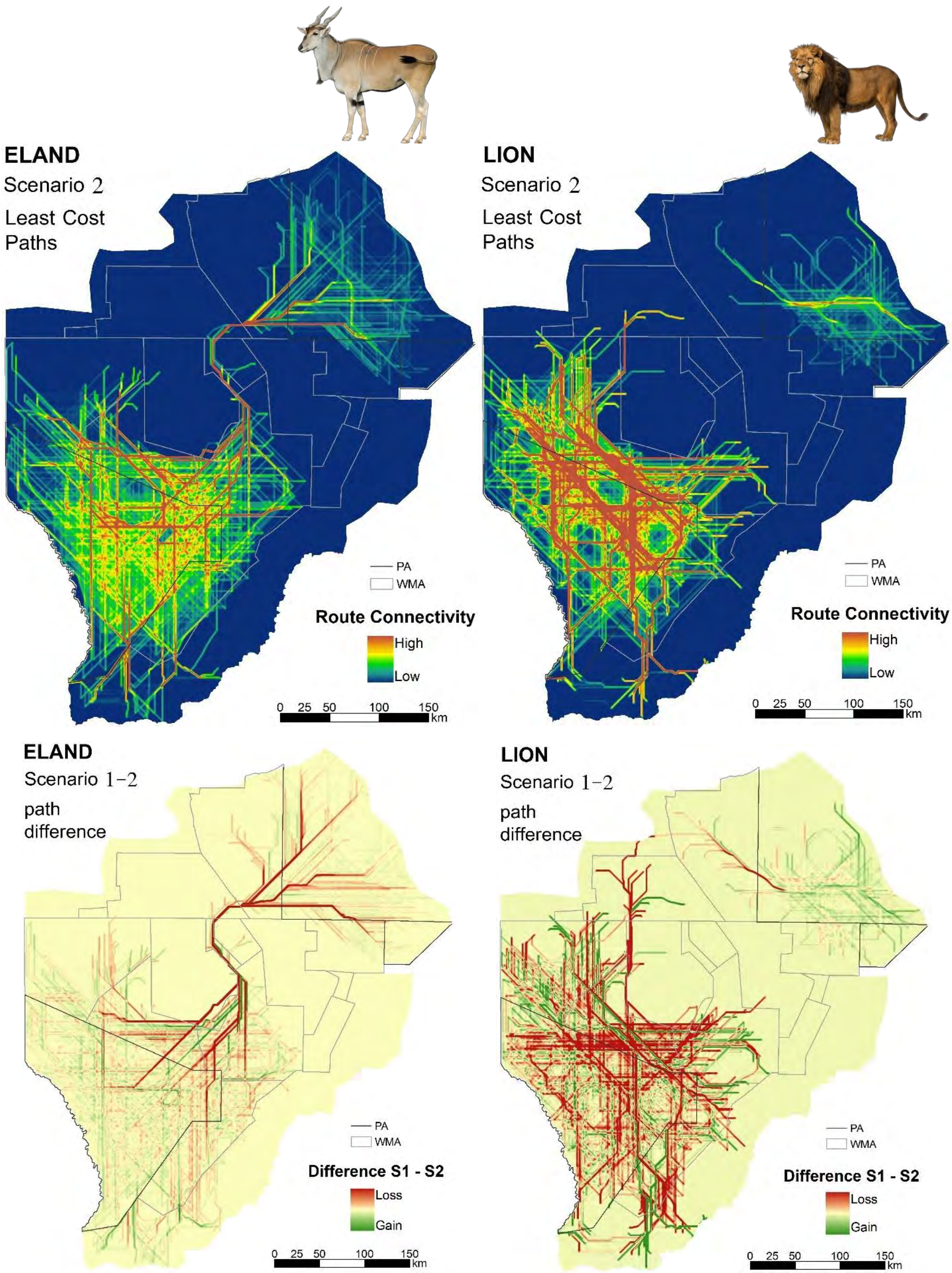
4.2.2 Scenario 2 – all designated and planned ranches fenced and operational







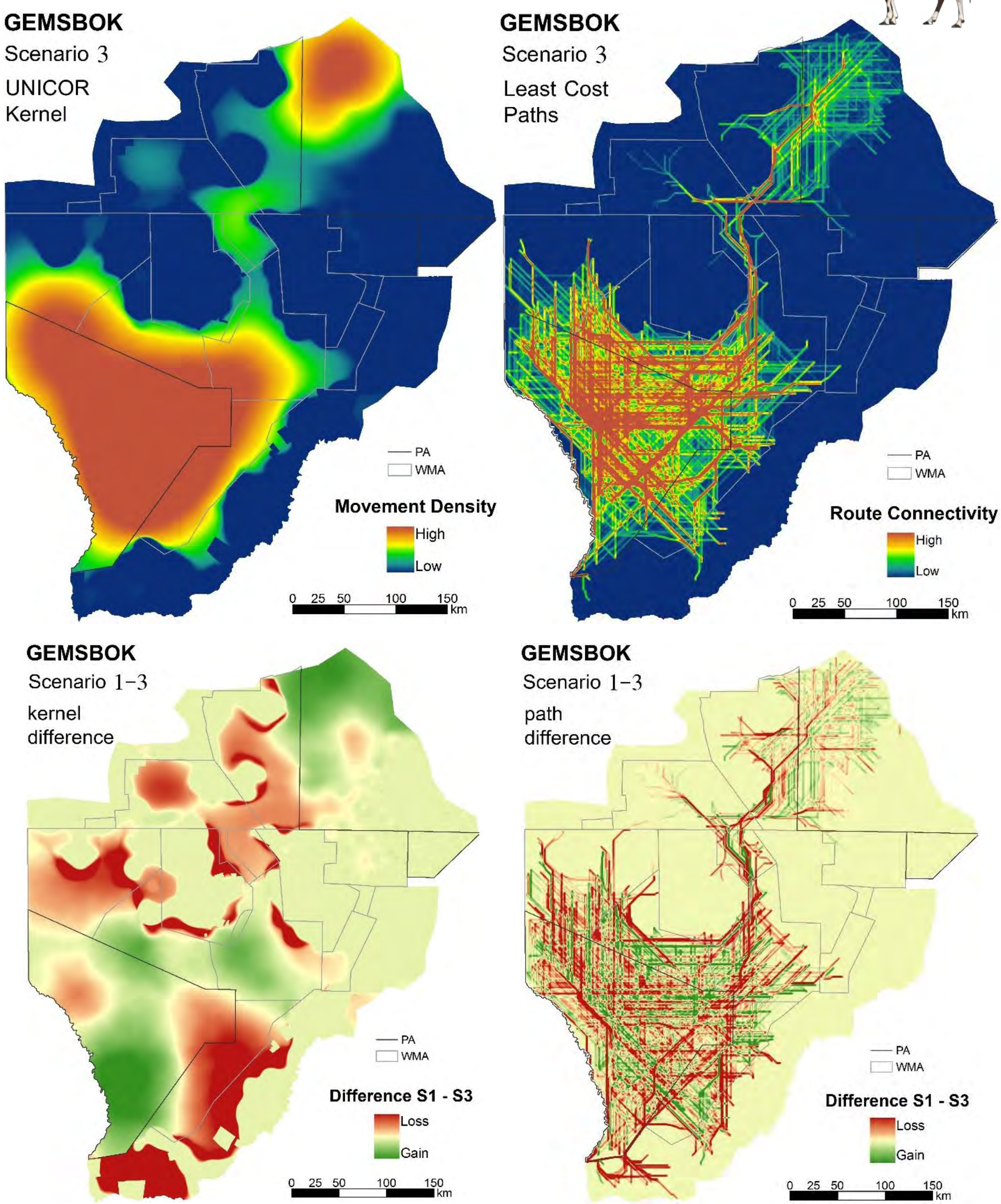




ELAND
Scenario 2
Least Cost Paths
PA
WMA
Route Connectivity
High
Low
0 25 50 100 150 km
LION
Scenario 2
Least Cost Paths
PA
WMA
Route Connectivity
High
Low
0 25 50 100 150 km
ELAND
Scenario 1-2
path difference
PA
WMA
Difference S1 - S2
Loss
Gain
0 25 50 100 150 km
LION
Scenario 1-2
path difference
PA
WMA
Difference S1 - S2
Loss
Gain
0 25 50 100 150 km

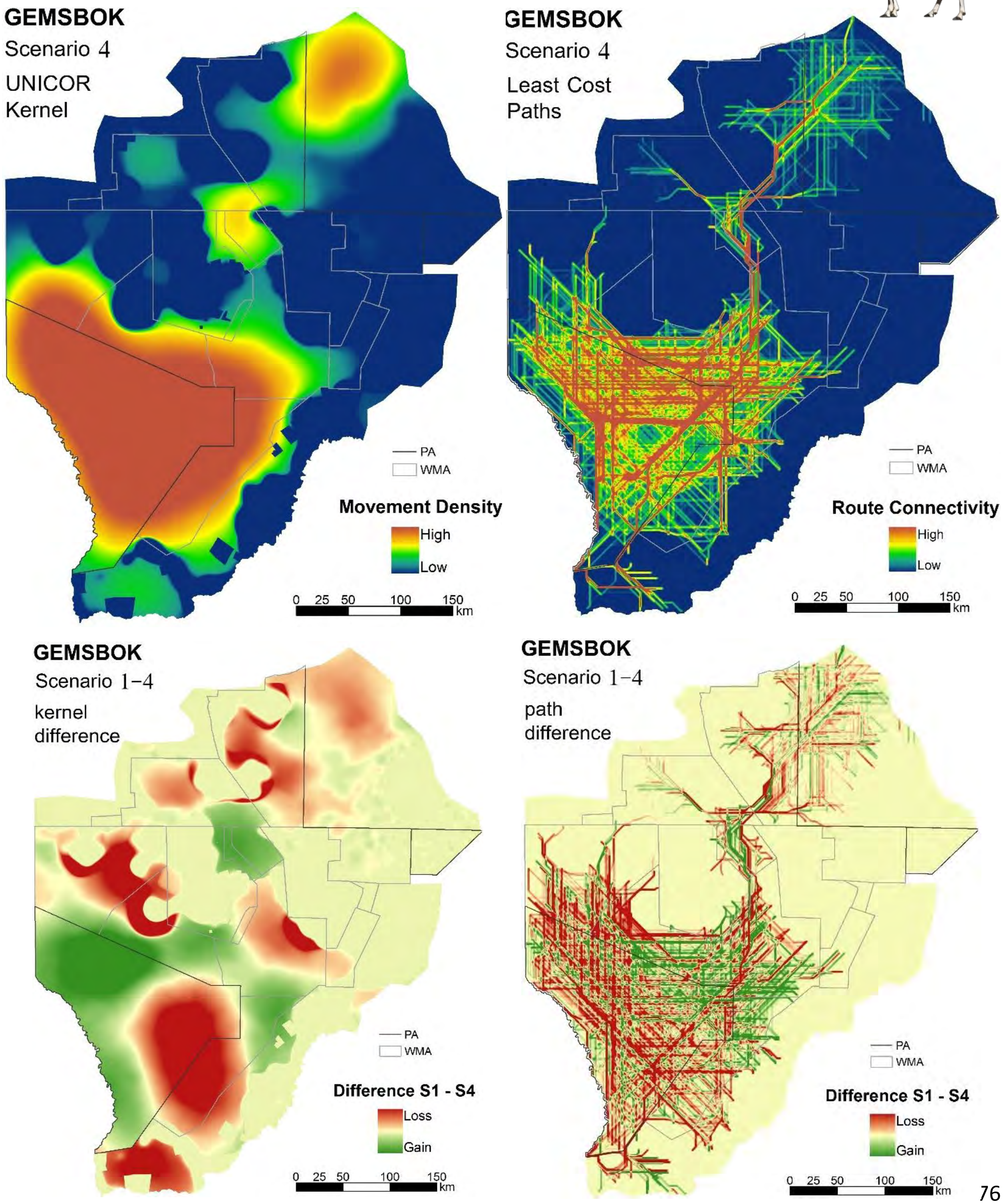
In Scenario 2 wildlife disappear from rezoned portions of WMAs: northern GH11, western GH10, and SO2. The frontier shrinks markedly to the east and south of KTP, as it does to the east and south of KD3. Areas of no wildlife movement creep into KD15 and KD12 and characterize KD11 as a result of encroachment up to its border. While the area straddling northern KD6/southern GH11 remains relatively strong for gemsbok, the connection south of the wildlife-friendly fence in KD12 is weakened. Lion connection through northern GH11 to the Okwa valley is lost due to the GH10/11 rezoned ranch layouts. Gemsbok experience -11.32% and -25.84% changes to kernel and path connectivity respectively throughout the landscape, eland path connectivity decreases -37.31%, and lion -24.81%.

4.2.3 Scenario 3 – all allocated and applied for boreholes developed into cattleposts



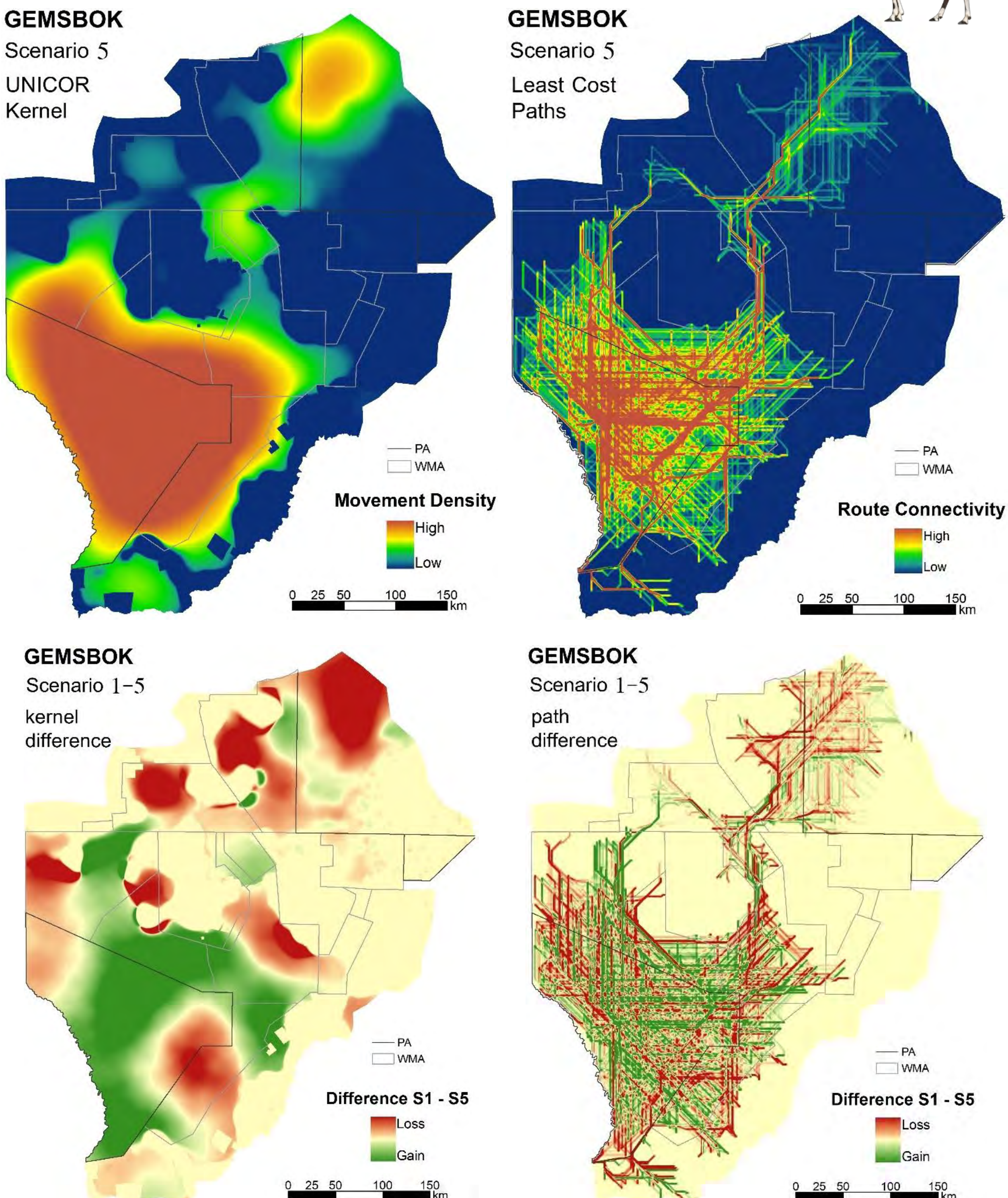
In Scenario 3, cattlepost expansion, much of it associated with 20 km radius RAD development zones, reduces connectivity broadly across areas in between KTP and CKGR including both corridors. Waterpoints coming online within Ukwi, Ncaang and Ngwatle RAD zones render the western corridor unviable for gemsbok. The subpopulation in NW GH11 becomes further isolated. Gemsbok experience a loss of -7.43% and -23.73% to kernel and path connectivity respectively throughout the landscape.

4.2.4 Scenario 4 – RAD 20 km radius zones developed



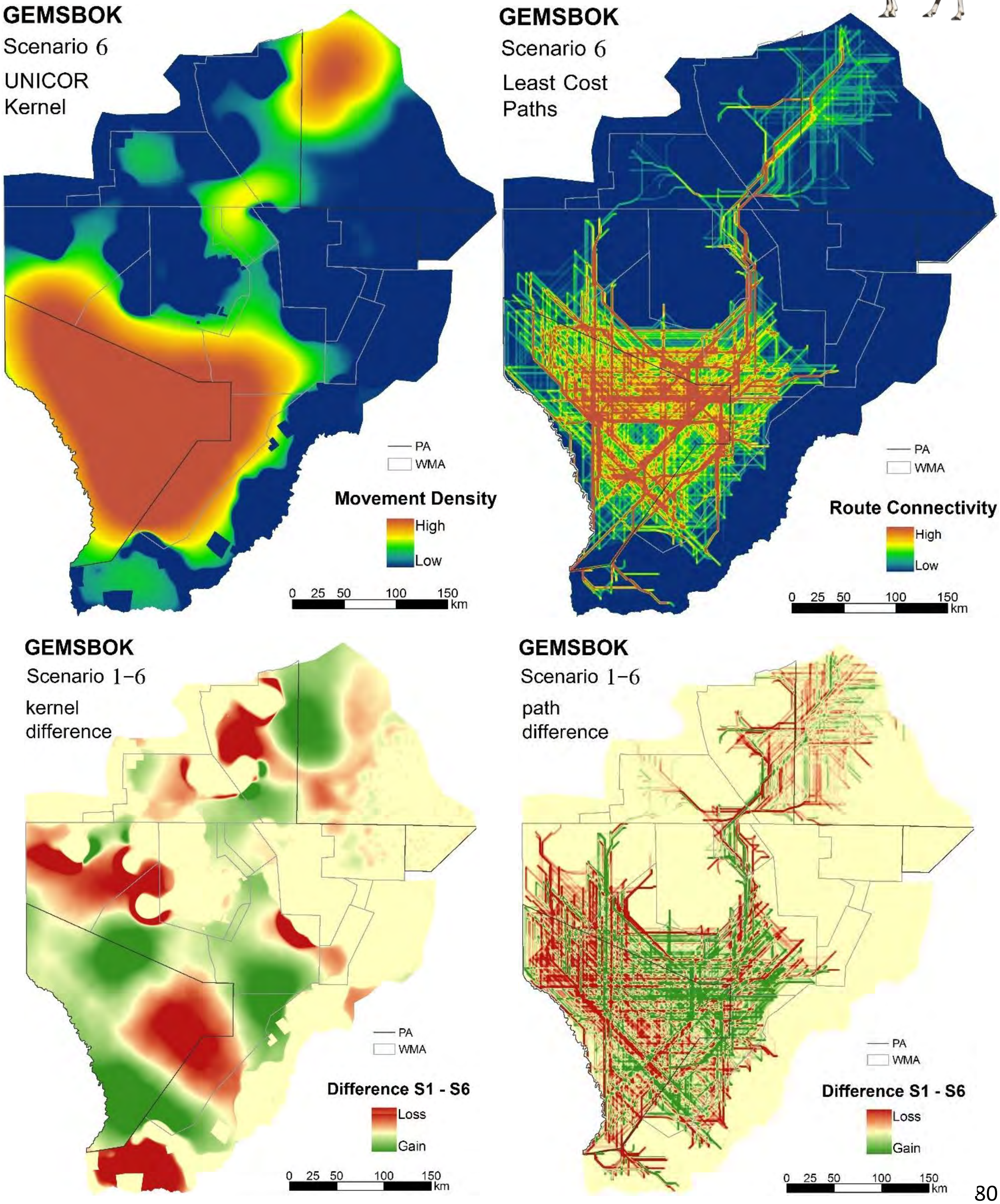
The western corridor is impacted the hardest in Scenario 4. Wildlife access into northern KD1 becomes severely restricted in the narrowed spaces between RAD development zones. Disturbance-sensitive wildlife cannot get through pinchpoint between Ncaang RAD cattleposts and Ranyane. Wildlife core areas are impacted more deeply, especially KD1 and KD2. Gemsbok experience a loss of -4.52% and -16.10% to kernel and path connectivity respectively throughout the landscape.

4.2.5 Scenario 5 – alternative RAD zones and expansion polygons



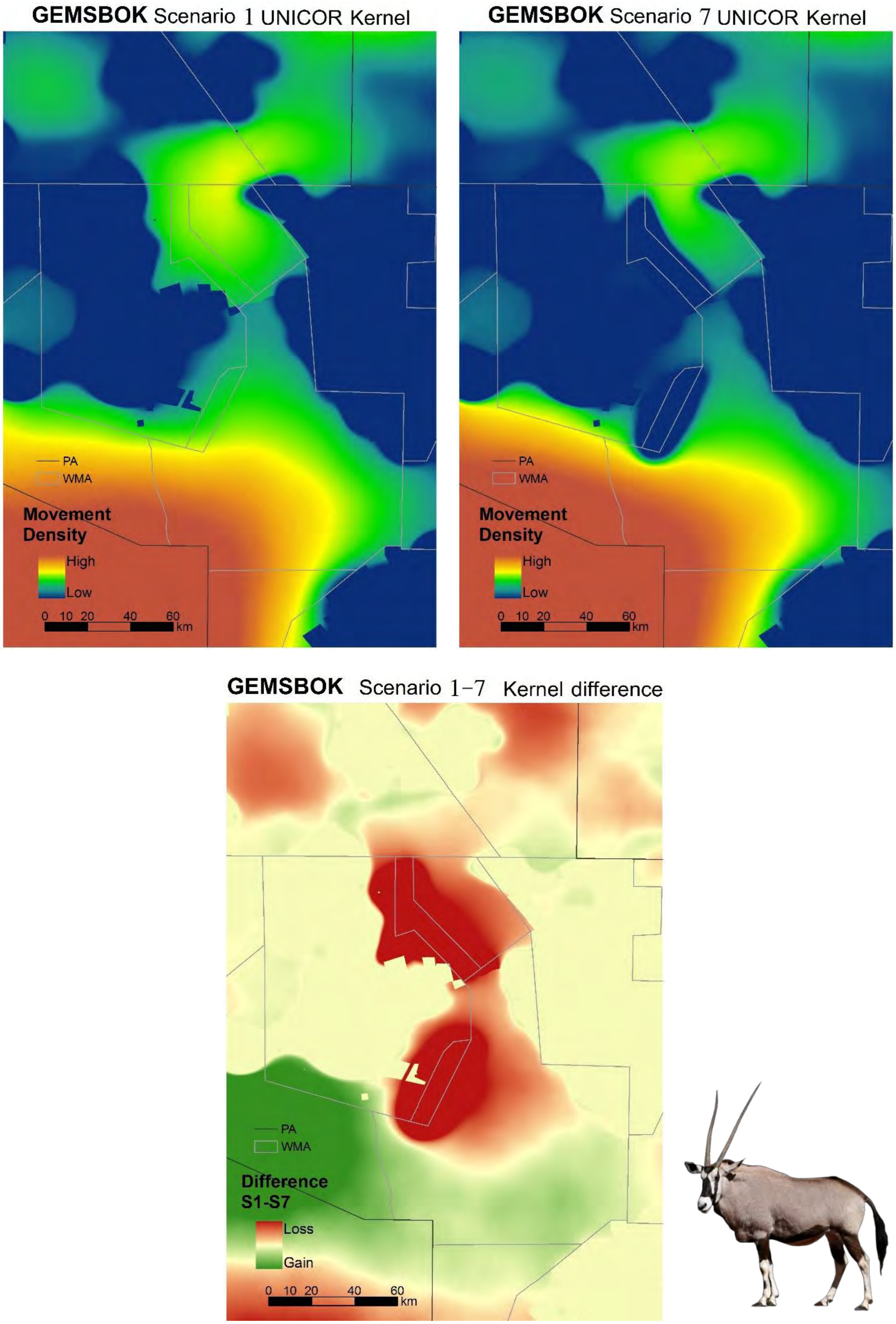
Shifting RAD cattlepost expansion from the wildlife-sensitive side of key communities to alternative expansion areas instead salvages northern KD1 and connectivity through the western corridor for gemsbok. Compared to the present time landscape, gemsbok kernel connectivity throughout the landscape increases slightly (0.88%) while path connectivity reduces slightly (-1.37%).

4.2.6 Scenario 6 – 2nd alternative RAD zones and expansion polygons

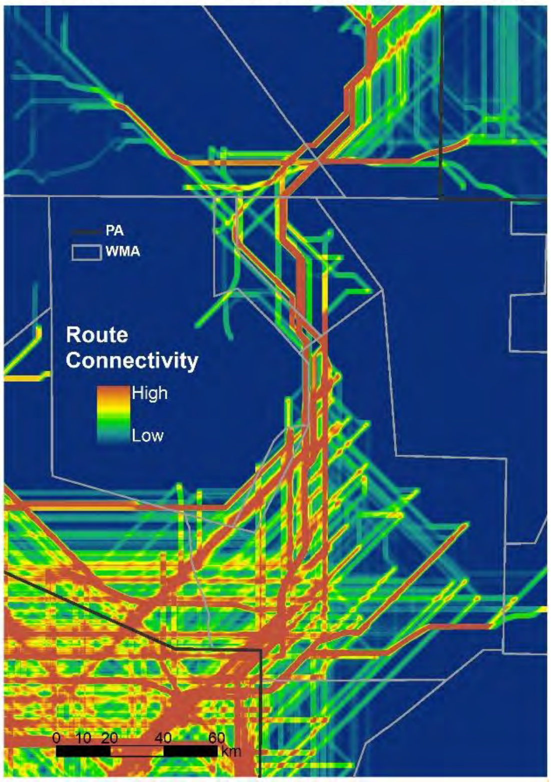


Compared to Scenario 5, movement becomes more restricted into northern KD1. However, gemsbok models predict an at least tenuous connection remains through the western corridor when RAD communities limit their expansion into their wildlife-sensitive side to a 10-km limit. Compared to the present time landscape, gemsbok kernel connectivity throughout the landscape stays neutral (0.0% change) while path connectivity reduces slightly (-1.15%).

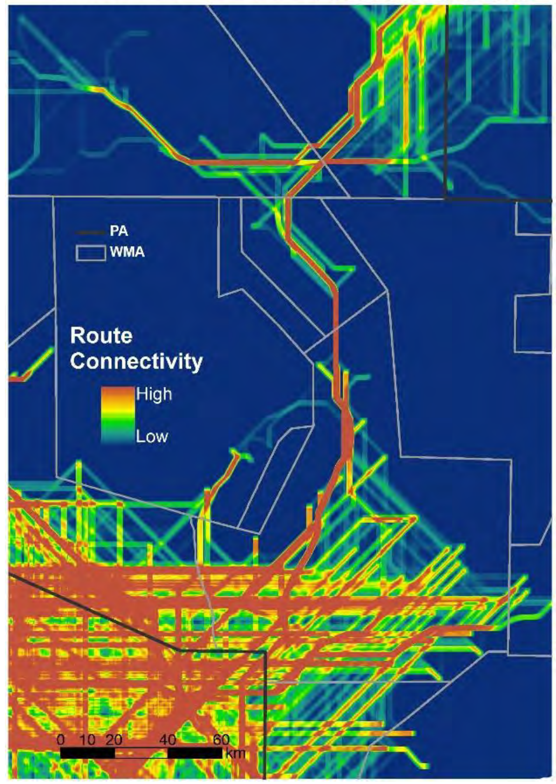
4.2.7 Scenario 7 – loss of WMAs KD5/11



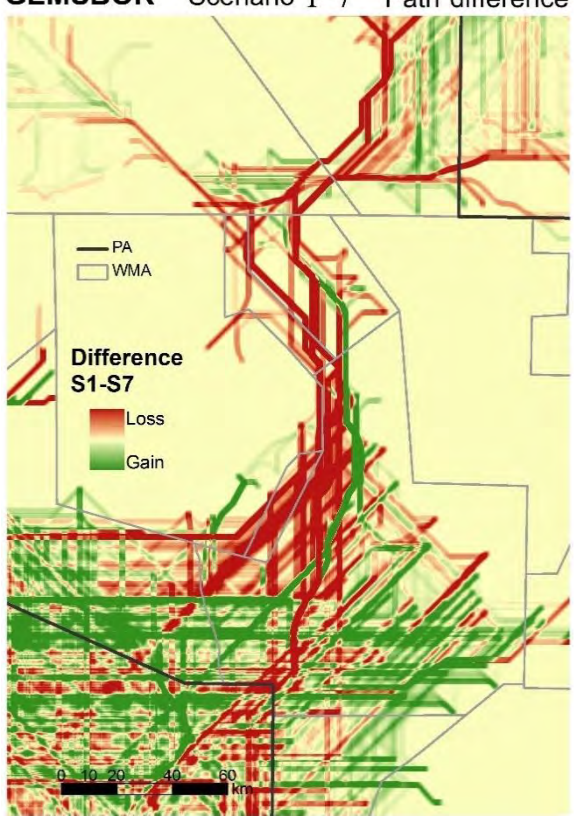
GEMSBOK Scenario 1 Least Cost Paths



GEMSBOK Scenario 7 Least Cost Paths

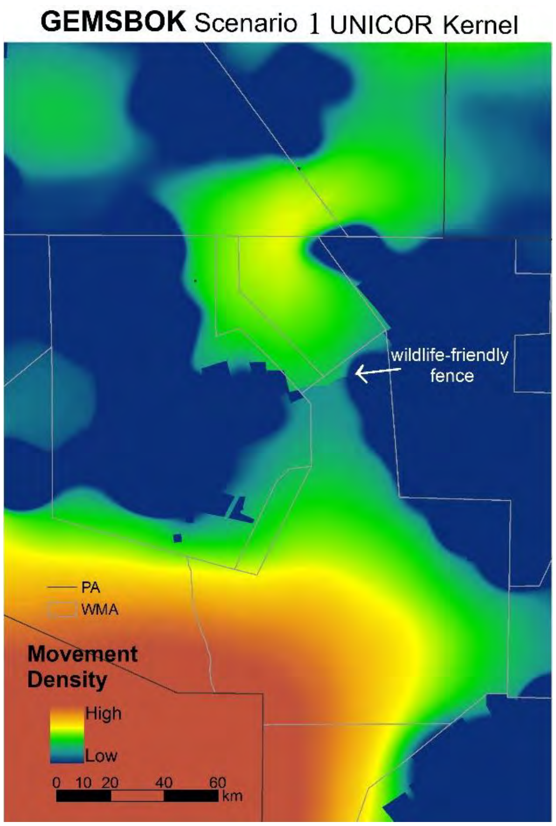


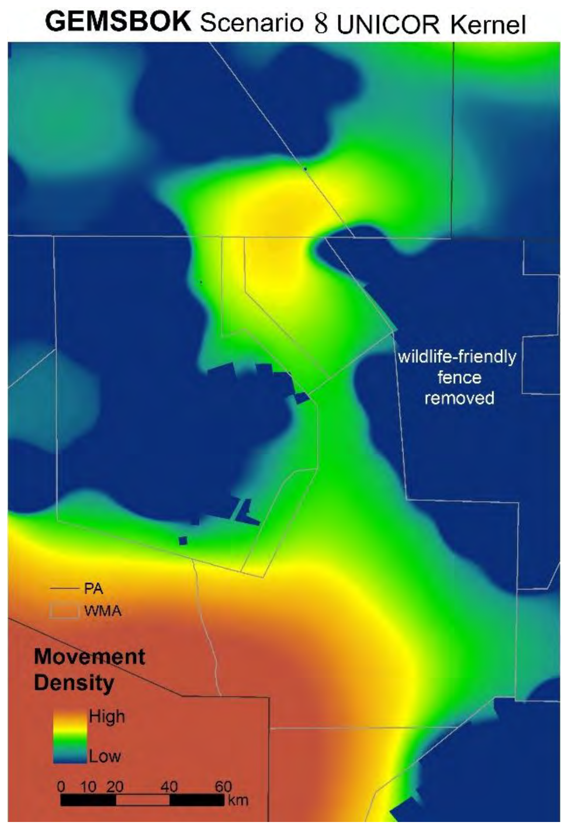
GEMSBOK Scenario 1-7 Path difference

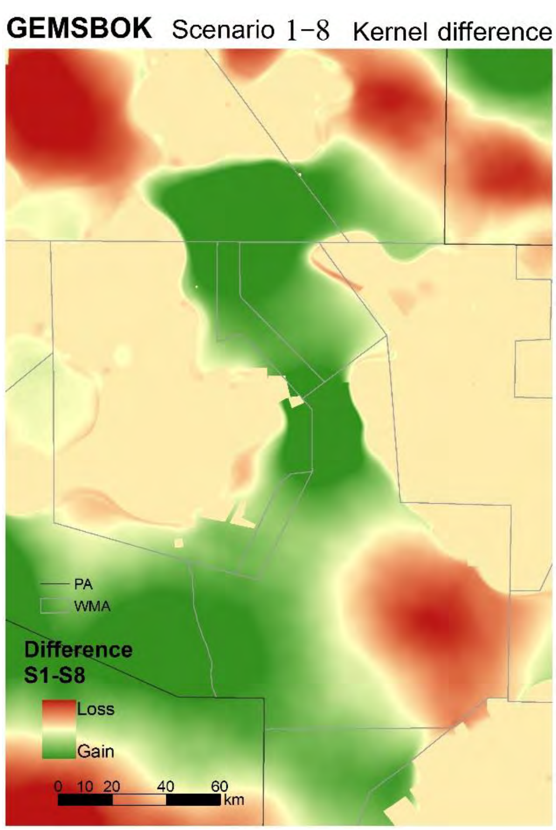


Loss of relatively narrow WMAs KD5 and KD11 heavily impacts the central corridor. The present time strong gemsbok connection through the central corridor is squeezed to a tenuous remaining connection. Eland, although unmodeled for Scenario 7, would loose connectivity through the central corridor as Scenario 1 predicts use of KD5 rather than KD6. The viability of KD6 as a stand-alone WMA capable of supporting a hunting quota for Mahumo Trust is doubtful after the loss of KD5. Compared to present time gemsbok models predict a loss of -2.21% and -10.13% to kernel and path connectivity respectively throughout the landscape following conversion of KD5/11 to agriculture. This scenario illustrates how small, and perhaps easily neglected, WMAs KD5, KD11, and GH13 are critical pieces to larger WMAs they buffer and to the maintenance of functioning wildlife corridors.

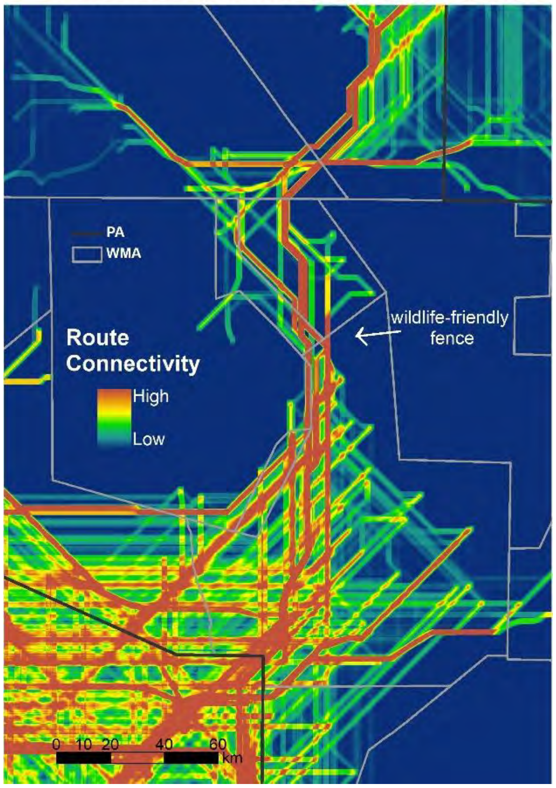
4.2.8 Scenario 8 – wildlife-friendly fence removed



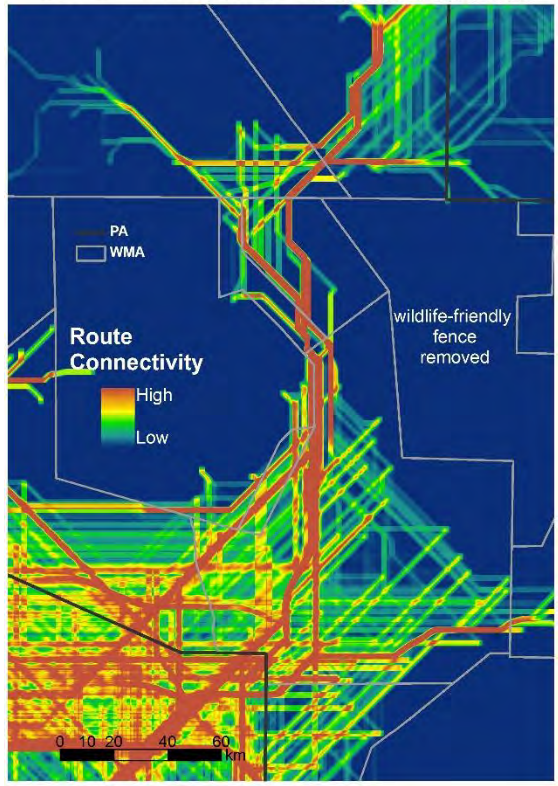




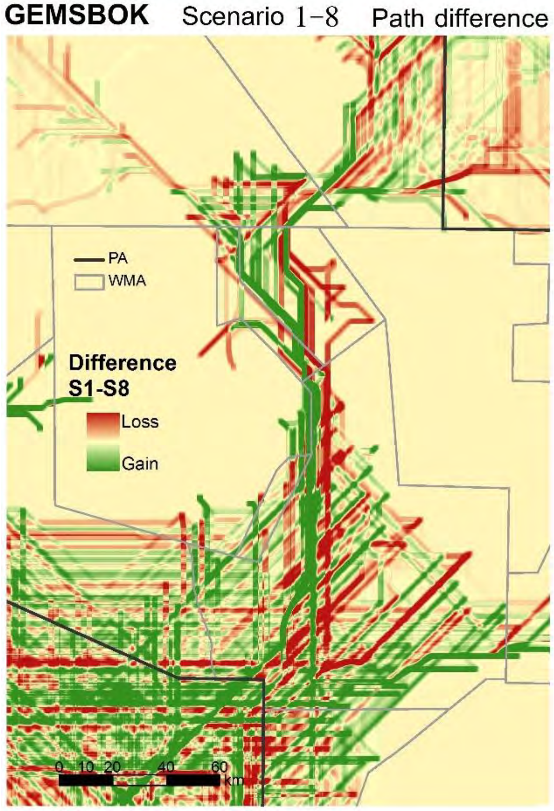
GEMSBOK Scenario 1 Least Cost Paths



GEMSBOK Scenario 8 Least Cost Paths

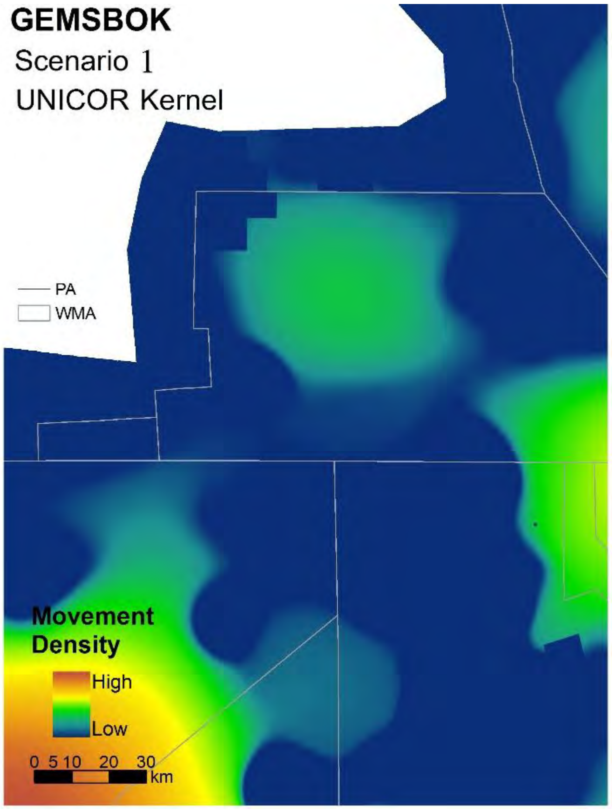


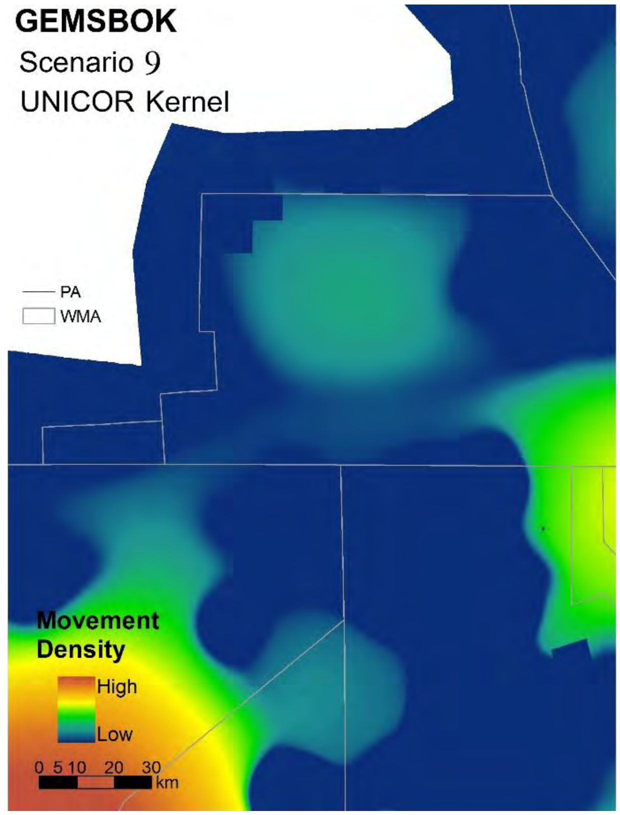
GEMSBOK Scenario 1–8 Path difference

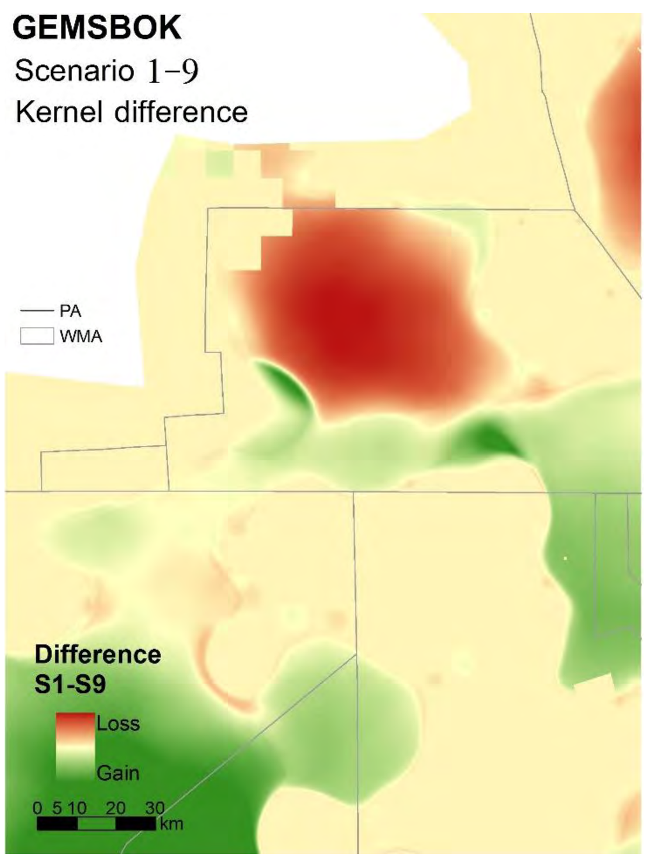


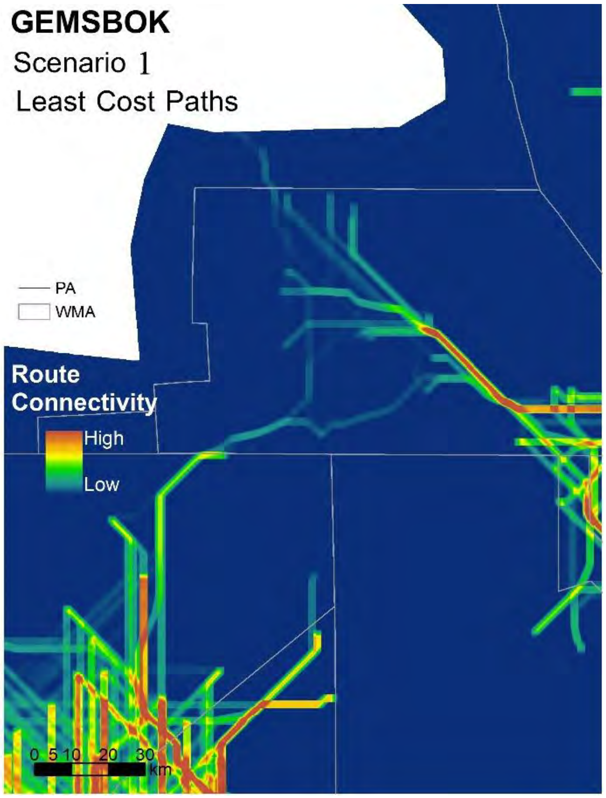
Scenario 8 models the substantial gains to wildlife movement and landscape connectivity following the simple removal of the present wildlife-friendly fence along the Kang-Hukuntsi highway where it bisects the WMA space. Gemsbok show 2.48% and 13.29% improvements to kernel and path connectivity respectively at the AOI scale after the wildlife-friendly fence is removed. Improvements for other unmodeled species such as wildebeest, which have higher movement resistance at this fence (Table 24 Section 4.5.4.2.1), is likely to be even greater than for gemsbok.

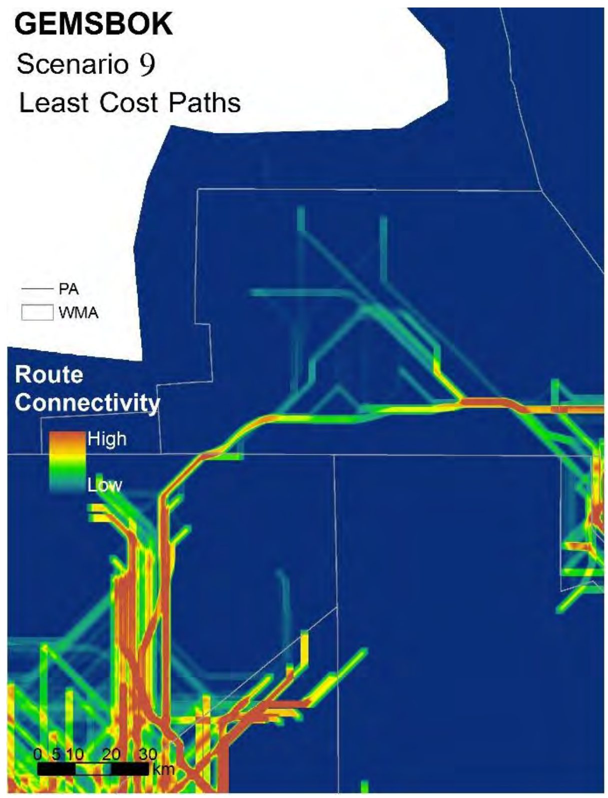
4.2.9 Scenario 9 – southern GH11 cattlepost encroachment removed

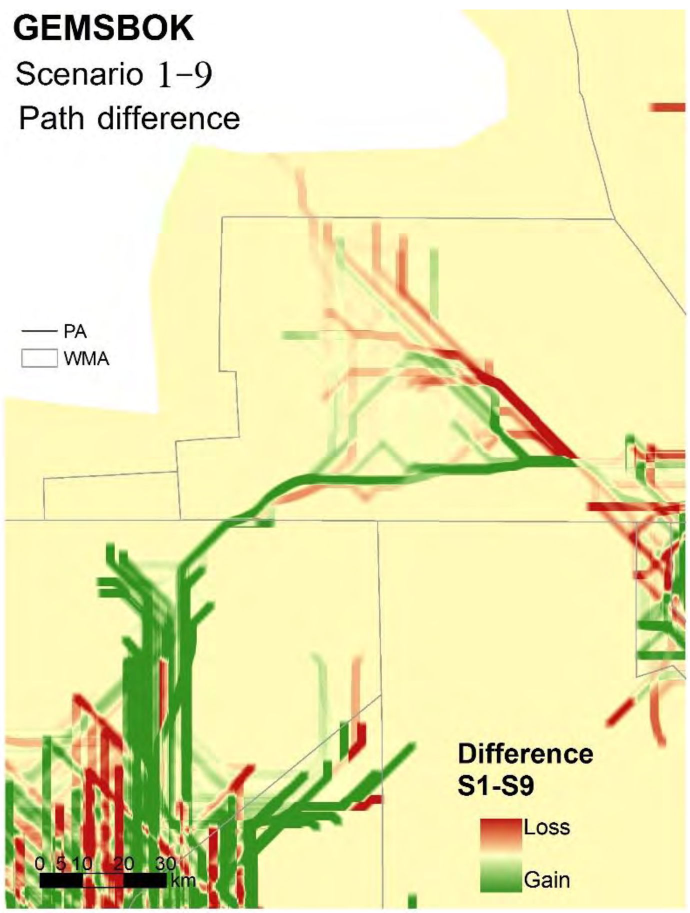






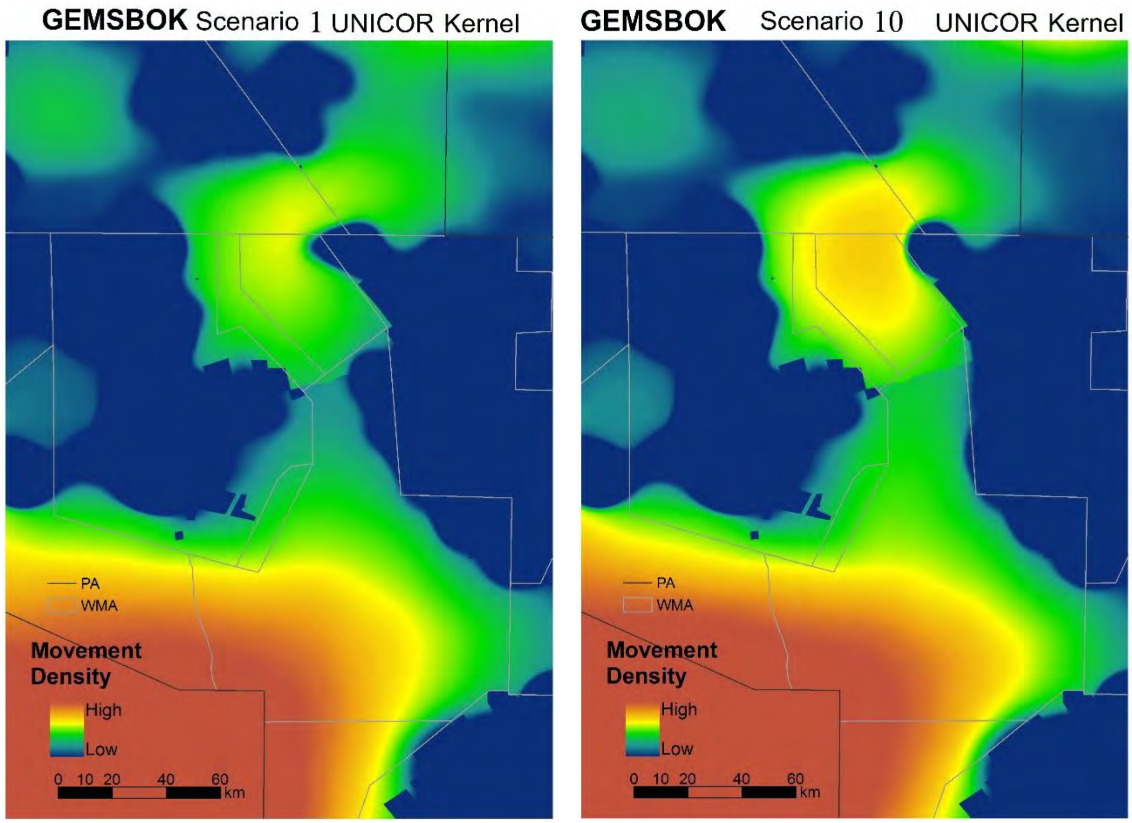

GEMSBOK
Scenario 1
Least Cost Paths
PA
WMA
Route Connectivity
High
Low
0 5 10 20 30
km

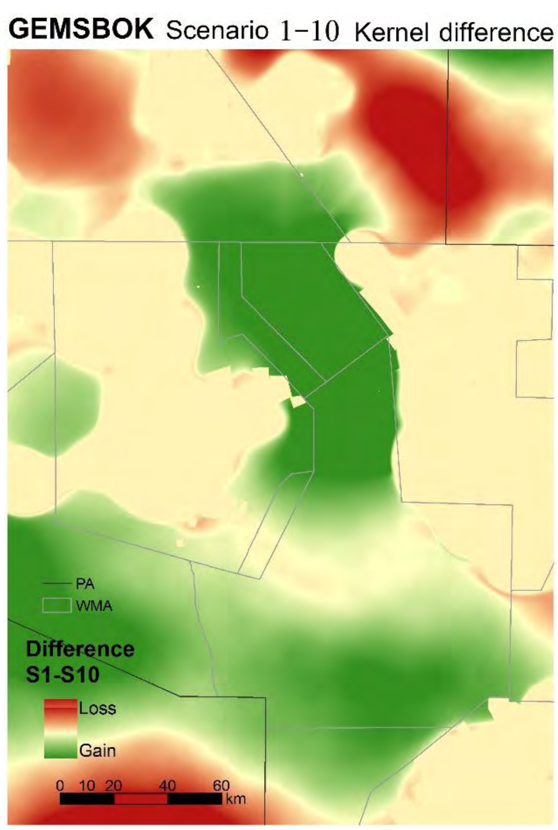

GEMSBOK
Scenario 9
Least Cost Paths
PA
WMA
Route Connectivity
High
Low
0 5 10 20 30
km

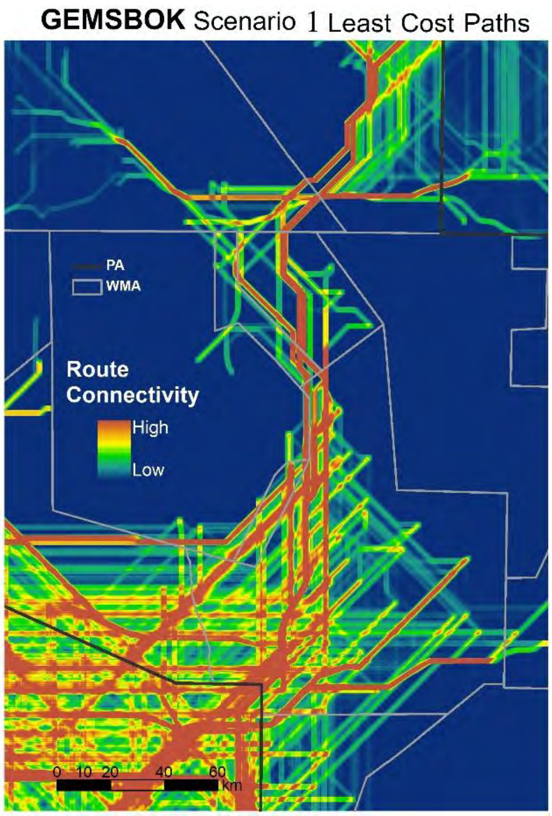

GEMSBOK
Scenario 1-9
Path difference
PA
WMA
Difference S1-S9
Loss
Gain
0 5 10 20 30
km

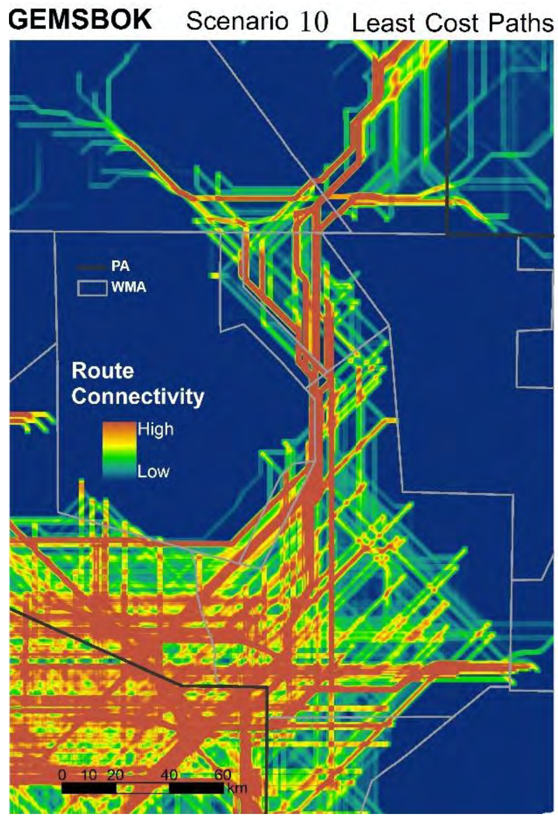
Scenario 9 illustrates the disproportionate improvement to landscape connectivity following removal of 2 problematic locations in southern GH11 WMA: Ranyane informal settlement and Xamaqa Syndicate. Removal of these results in a modest improvement to gemsbok habitat suitability at the landscape scale (0.26%) and a relatively disproportionate improvement to kernel and path connectivity (1.7 and 7.7% respectively). Route connectivity through the western corridor improves visibly after this intervention.

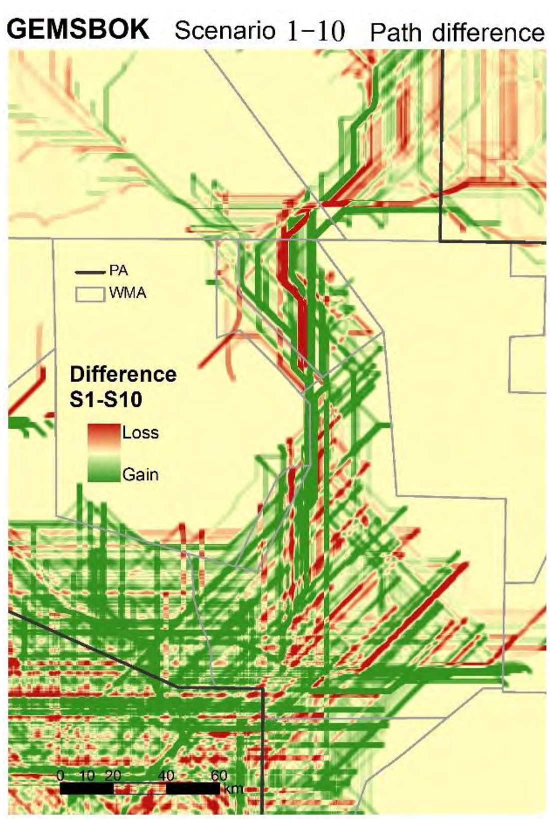
4.2.10 Scenario 10 – KD6/12 cattlepost encroachment removed





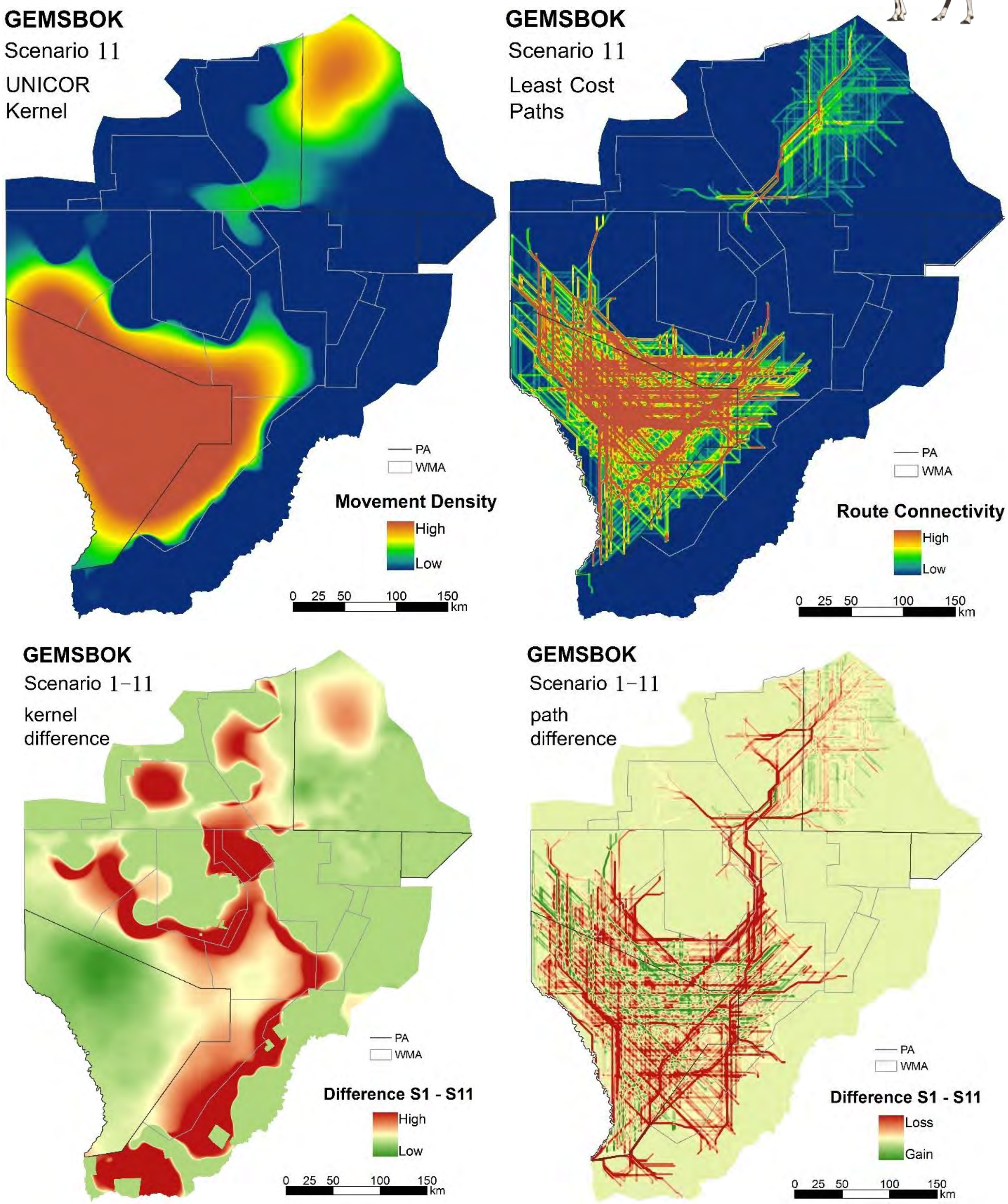

GEMSBOK Scenario 1 Least Cost Paths
PA
WMA
Route Connectivity
High
Low
0 10 20 40 60 km

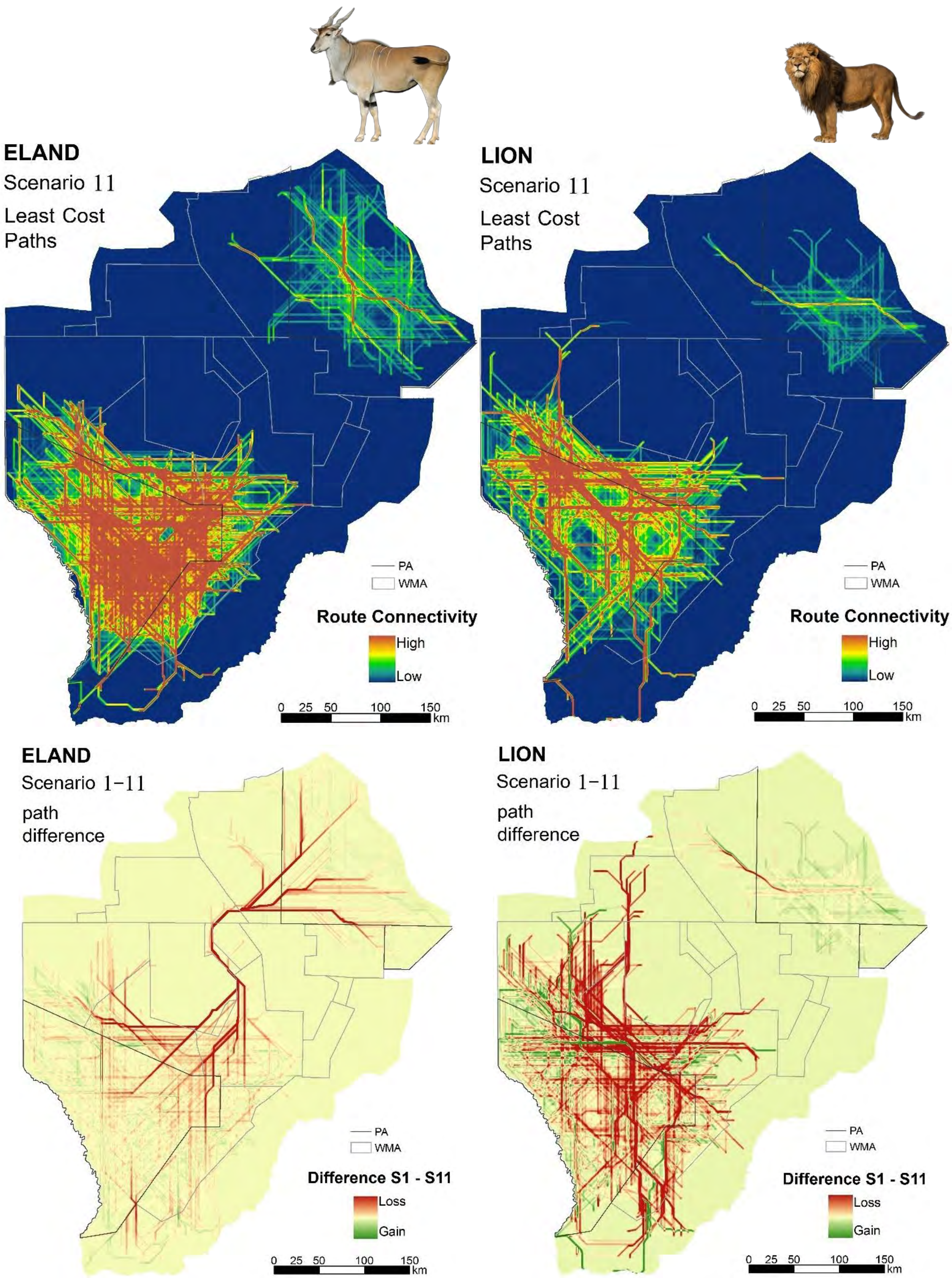

GEMSBOK Scenario 10 Least Cost Paths
PA
WMA
Route Connectivity
High
Low
0 10 20 40 60 km


GEMSBOK Scenario 1-10 Path difference
PA
WMA
Difference S1-S10
Loss
Gain
0 10 20 40 60 km

Scenario 10 illustrates the gain to the central corridor following relocation of cattleposts encroached inside the WMAs comprising the central corridor. The improvement is visible and quantified as 2.37% and 6.8% to gemsbok kernel and path connectivity respectively, across the whole landscape.

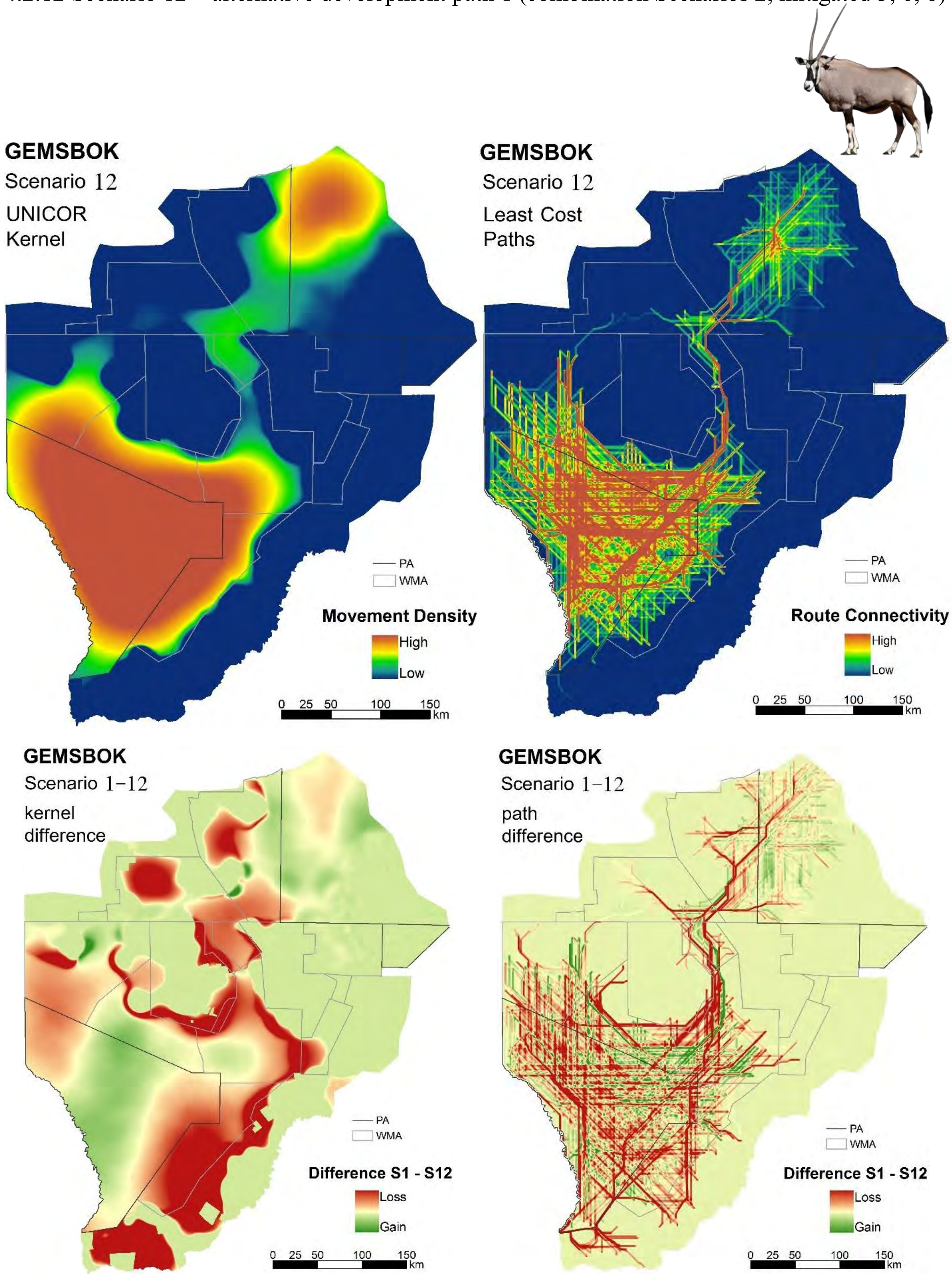
4.2.11 Scenario 11 – cumulative planned developments (business-as-usual trajectory)

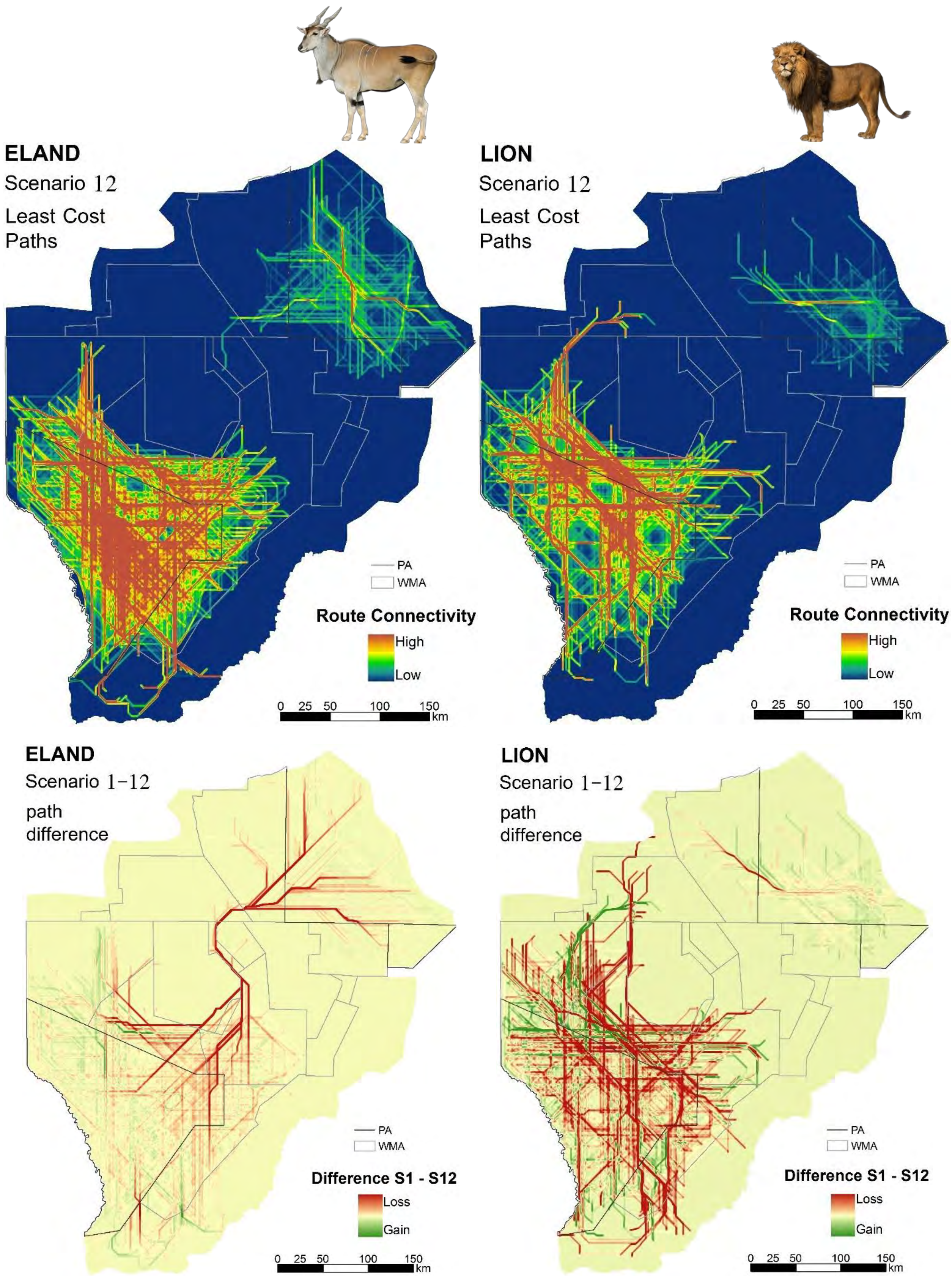



ELAND
Scenario 11
Least Cost Paths
PA
WMA
Route Connectivity
High
Low
0 25 50 100 150 km
LION
Scenario 11
Least Cost Paths
PA
WMA
Route Connectivity
High
Low
0 25 50 100 150 km
ELAND
Scenario 1-11
path difference
PA
WMA
Difference S1 - S11
Loss
Gain
0 25 50 100 150 km
LION
Scenario 1-11
path difference
PA
WMA
Difference S1 - S11
Loss
Gain
0 25 50 100 150 km

Without any land use planning effort to alter the current trajectory of agricultural expansion in the Kalahari ecosystem, Scenario 11 predicts a future landscape broken into two from the perspective of wildlife. Populations loose access to areas in between the PAs and shrink back to two cores. Shrunken WMAs adjacent to PAs remain viable (GH10, KD1,2,12,15), while those in between (GH11,13, KD6,5) likely collapse into irrelevance in terms of wildlife use. Connectivity models predict a nearly 50% loss to overall path connectivity for gemsbok (Table 20/Figure 36) and lion (Table 22/Figure 38) and 70% loss for eland (Table 21/Figure 37) compared to the present-day landscape.

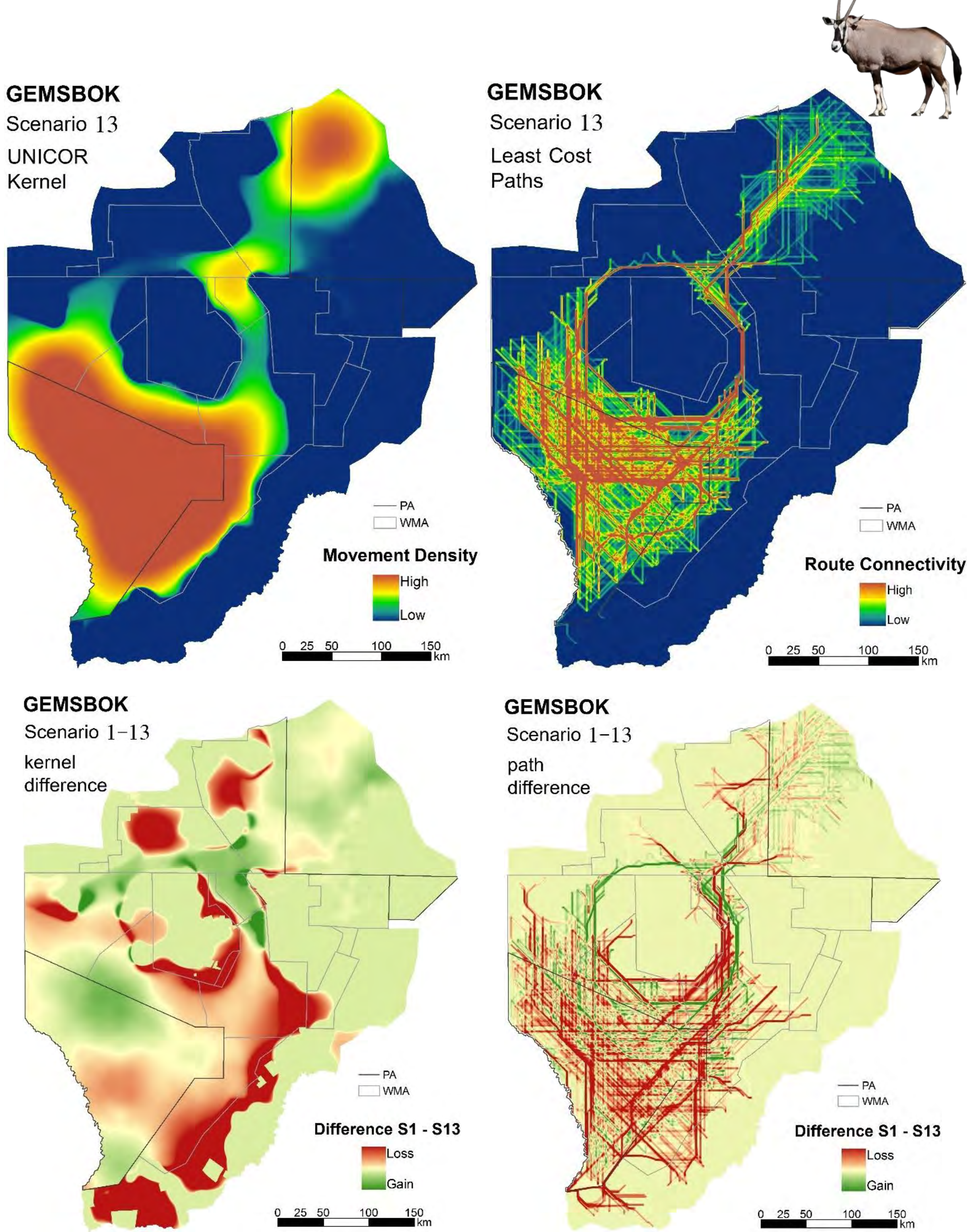
4.2.12 Scenario 12 – alternative development path 1 (combination Scenarios 2, mitigated 3, 6, 8)

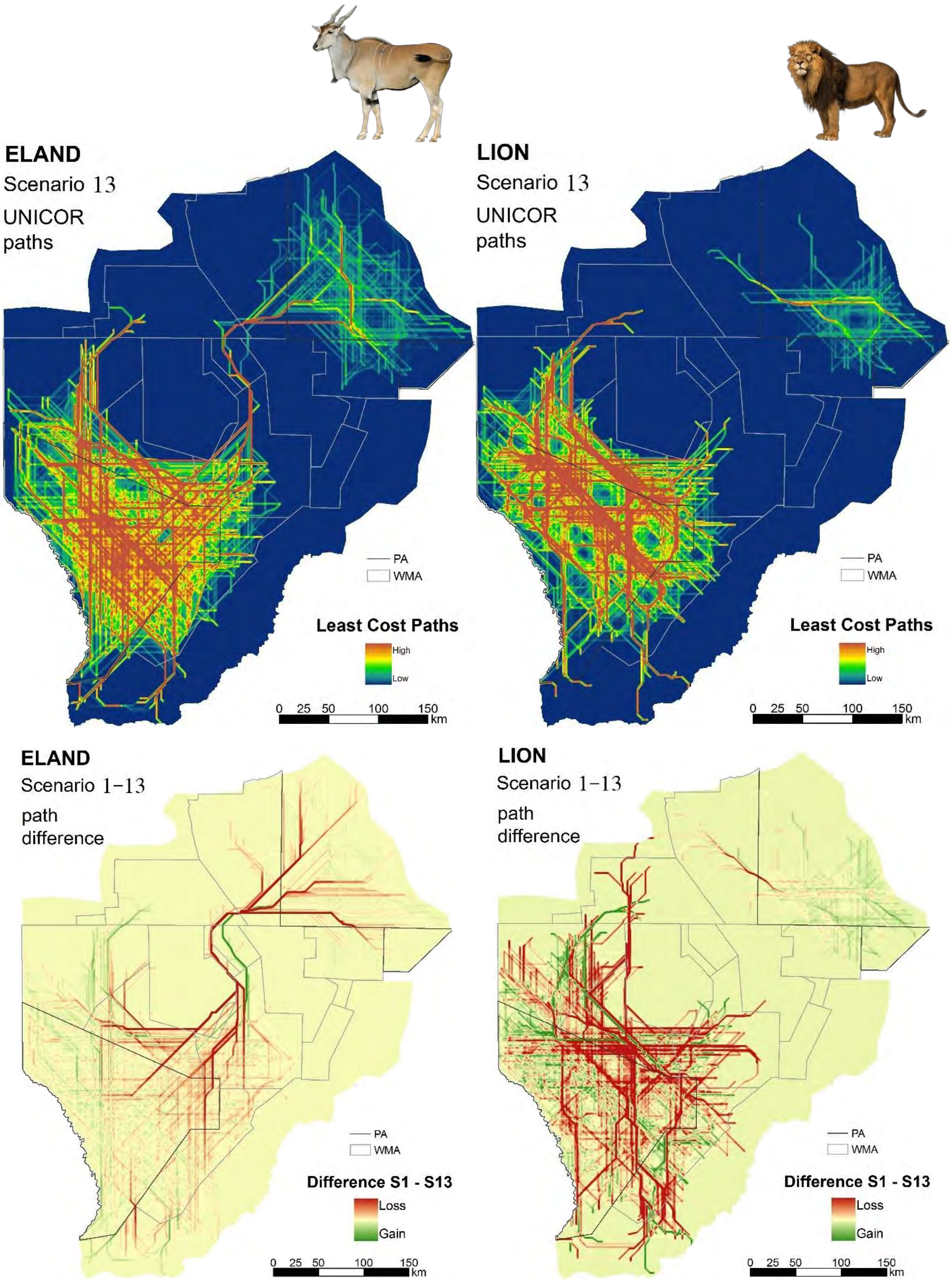



ELAND
Scenario 12
Least Cost
Paths
LION
Scenario 12
Least Cost
Paths
PA
WMA
Route Connectivity
High
Low
0 25 50 100 150
km
ELAND
Scenario 1-12
path
difference
LION
Scenario 1-12
path
difference
Difference S1 - S12
Loss
Gain

Modest mitigative effort for the western corridor (implementing Scenario 6) and eastern corridor (implementing Scenario 8) represented in Scenario 12 salvages tenuous connections for gemsbok. No connection is regained for either eland or lion.

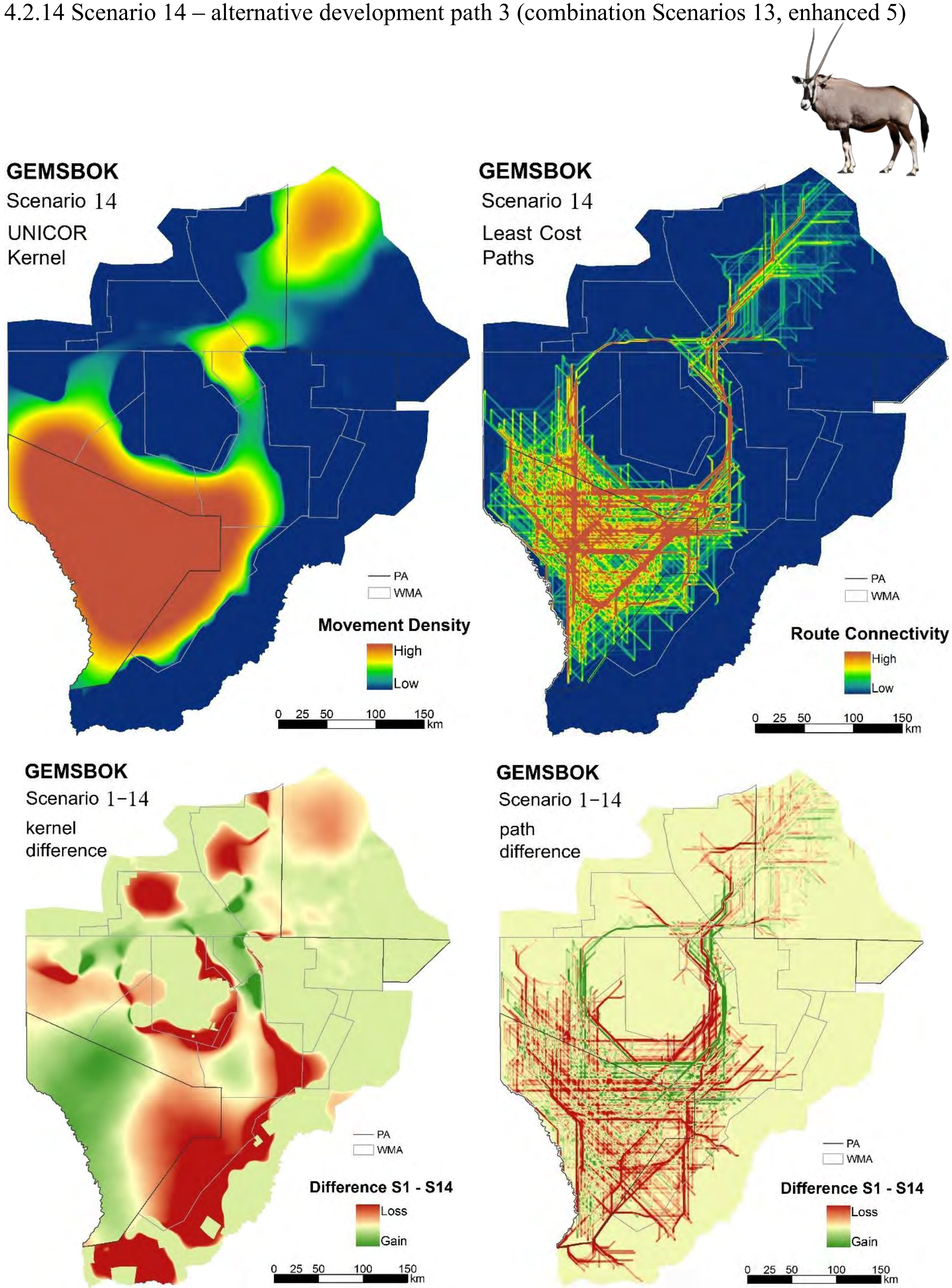
4.2.13 Scenario 13 – alternative development path 2 (combination Scenarios 2, mitigated 3, 5, 8, 9, 10)

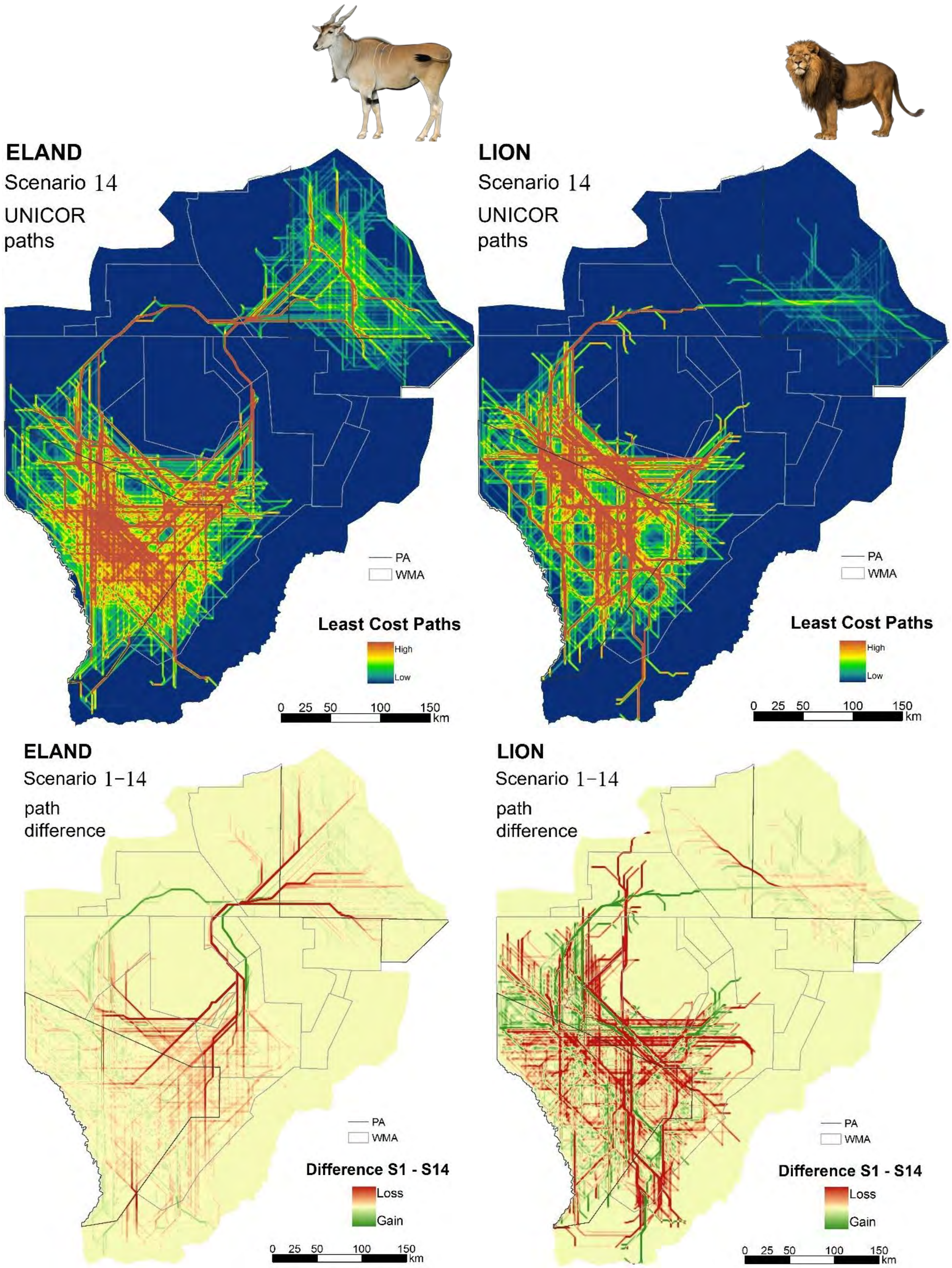



ELAND
Scenario 13
UNICOR
paths
PA
WMA
Least Cost Paths
High
Low
0 25 50 100 150
km
LION
Scenario 13
UNICOR
paths
PA
WMA
Least Cost Paths
High
Low
0 25 50 100 150
km
ELAND
Scenario 1–13
path
difference
PA
WMA
Difference S1 - S13
Loss
Gain
0 25 50 100 150
km
LION
Scenario 1–13
path
difference
PA
WMA
Difference S1 - S13
Loss
Gain
0 25 50 100 150
km

The incremental addition of mitigative Scenarios 5 (instead of 6), 9 and 10 bring substantial visible improvements to the gemsbok connectivity landscape through both western and central corridors in Scenario 13 compared to Scenario 12. Eland are predicted to regain connectivity through the central corridor via KD6.

4.2.14 Scenario 14 – alternative development path 3 (combination Scenarios 13, enhanced 5)



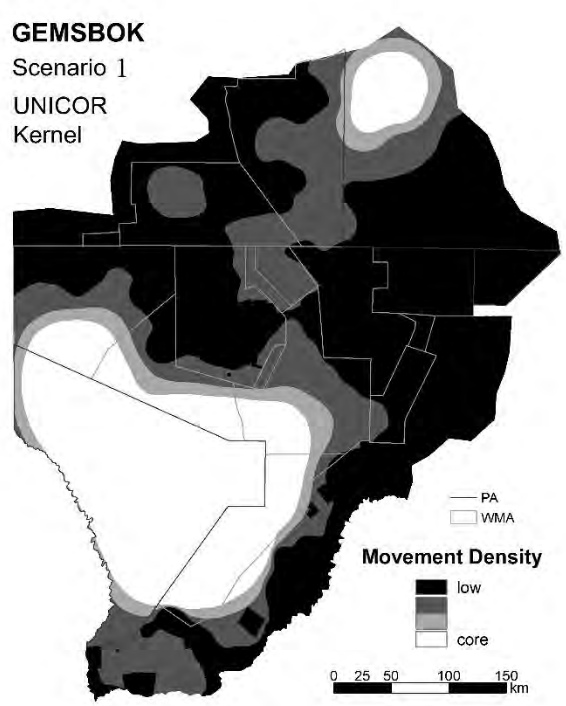

ELAND
Scenario 14
UNICOR
paths
PA
WMA
Least Cost Paths
High
Low
0 25 50 100 150 km
LION
Scenario 14
UNICOR
paths
PA
WMA
Least Cost Paths
High
Low
0 25 50 100 150 km
ELAND
Scenario 1−14
path
difference
PA
WMA
Difference S1 - S14
Loss
Gain
0 25 50 100 150 km
LION
Scenario 1−14
path
difference
PA
WMA
Difference S1 - S14
Loss
Gain
0 25 50 100 150 km

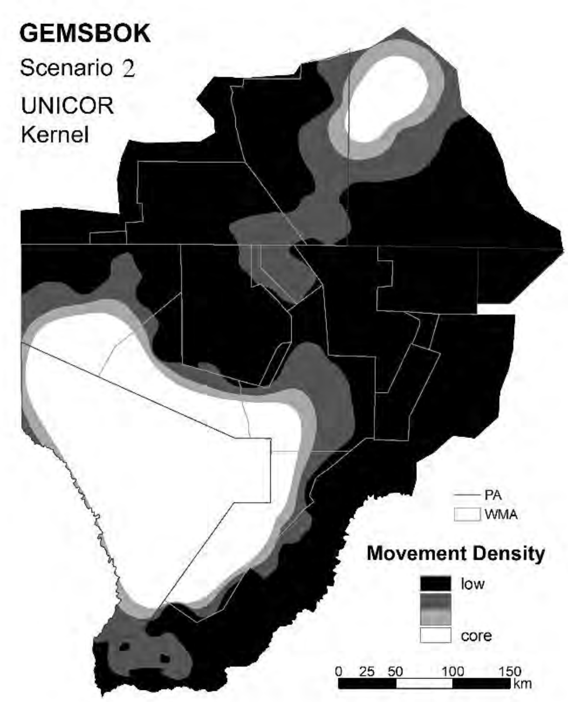
Further incremental mitigation to the southern extents of Bere/Kacgae RAD development zones plus slight reduction to the new ranch blocks in rezoned northern GH11 bolsters the connectivity landscape from Scenario 13 to 14, especially the most important singular pinchpoint south of Kacgae which links both western and central corridors. Consequently, eland and lion gain connection through a strengthened western corridor. The improvement to landscape connectivity compared to the present time is most readily visualized in the kernel and path difference maps. Scenario 14 represents the minimum mitigation necessary to recover landscape connectivity for the complete Kalahari free-ranging wildlife community.

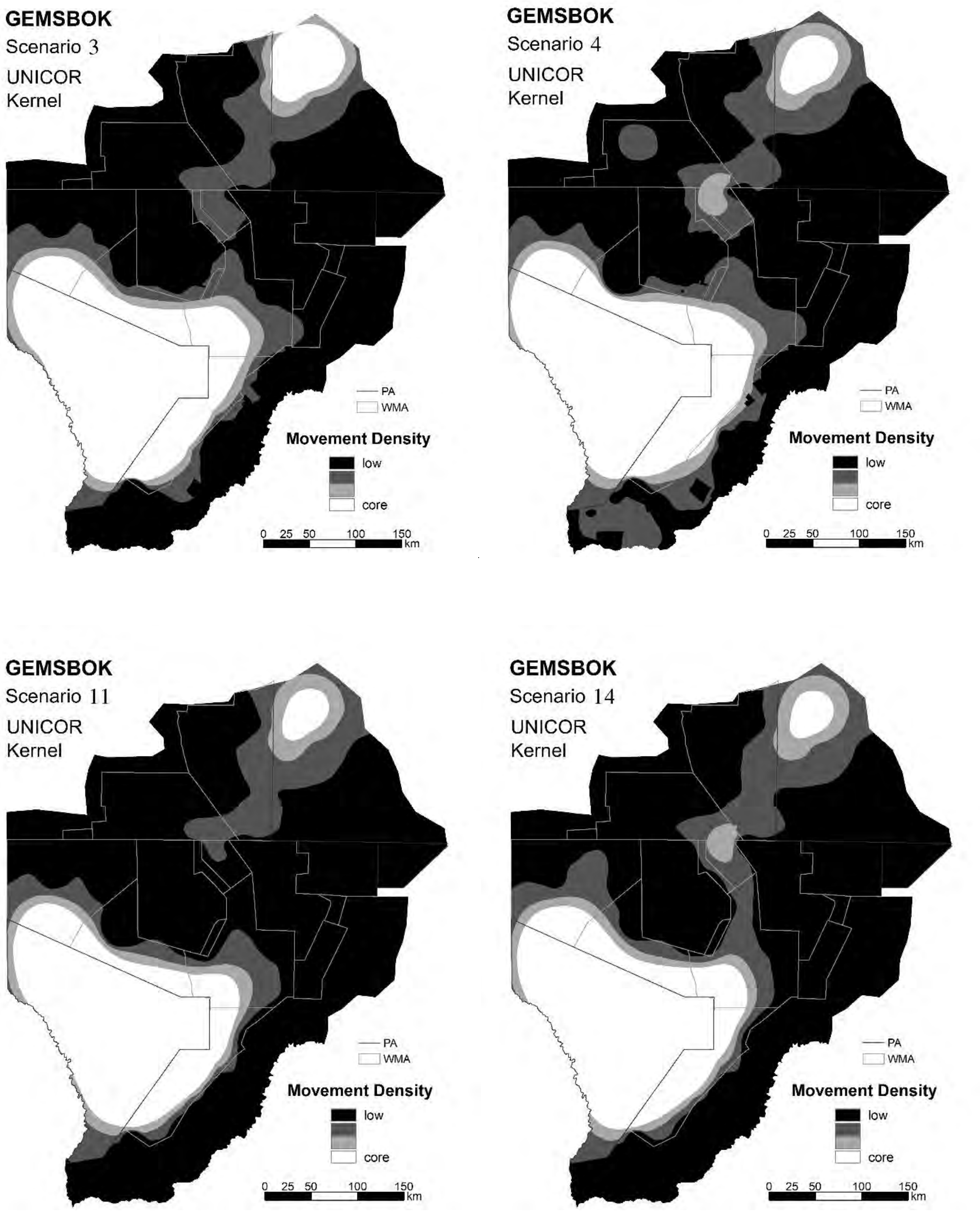
4.3 Corridors VS Cores

The focus of the KWLCA was landscape connectivity facilitating wildlife movement corridors. However, any discussion about connectivity and corridors is somewhat incomplete without reference to the cores that are being connected. Here we restrict comment to the main core (KTP, KD1/2/12/15) of the Kalahari landscape only, and not the secondary core (CKGR, GH10, KW2) which was modeled without wildlife locational data from inside CKGR and is therefore less reliable.

The impact of different scenarios on the main Kgalagadi core can be productively illustrated for comparison using standardized quantitative categories of gemsbok kernel movement from the UNICOR kernel analysis outputs. Gemsbok is the best illustrative example of the three species because of its relatively high and uniform density in undisturbed core areas. These maps are provided below for select scenarios 1,2,3,4,11,14. This limited selection is provided based on the greatest dissimilarity between scenarios.







Across the range of landscape change modeled in the scenarios the main Kgalagadi core held up remarkably, its extent impacted only by minor degrees. The greatest contraction appears to be predicted by all fenced ranches developing (Scenario 2) and planned and allocated waterpoints (cattleposts) coming online (Scenario 3), particularly in the southeast KD15 WMA portion of the core. The combination of these is reflected in both Scenarios 11 and 14. Also noticeable is the enlarged dent imposed by the future development of Zutshwa's RAD 20km radius zone in the central northern extent of the core (Scenario 4, also reflected in Scenario 11). This results from Zutshwa being located closer to the KTP boundary than other communities, Khawa at the southern end of the KTP excepted. With respect to the conserving the core, it is here that mitigating a future scenario of proliferation of RAD cattleposts to the full 20 km radius extent may be most relevant where the core overlaps KD2 WMA is exceptionally important wildlife estate outside the strictly protected KTP (Keeping et al. 2018).

There is a subtle but noticeable difference in the extent of the core along its entire northern margin in KD1/2/12 WMAs between the business as usual trajectory of agricultural encroachment (Scenario 11) and the mitigative Scenario 14. However, this is relatively minor in comparison to the differences between these scenarios measured in terms of landscape connectivity between the cores. Overall, the KWLCA shows that planned and imminent agricultural expansion stands to negatively impact landscape connectivity to a much greater extent than it does the cores. The alternative development paths represent targeted landscape design to mitigate such damage to connectivity. Scenario 14 succeeds at doing so, while also maintaining the Kgalagadi core.

4.4 Detailed Corridor Pinchpoint Maps

To assist land planners, detailed maps are provided at three vulnerable pinchpoints for connectivity in the landscape: the A2 Trans-Kalahari highway pinchpoint (confluence of both western and central corridors), Kang-Hukuntsi highway pinchpoint (central corridor), and Ncojane ranches-Ncaang pinchpoint (western corridor). Land use layers and least cost paths are displayed from Scenario 14. Kraals requiring relocation from Scenario 1 (present time) land use to Scenario 14 are indicated in the map. The least cost paths displayed are only relevant to the Scenario 14 landscape of course, not the Scenario 1 land use. Overall, we draw attention to the necessary gap between cattleposts nearest the WMAs and where disturbance-sensitive wildlife chose to move. Generally, wildlife are squeezed to the centers of the corridor WMAs by the disturbance attenuating either side from the kraals locations.

Figures 39-41 highlight the convergent singular pinchpoint linking disturbance-sensitive wildlife between KTP and CKGR. This arguably most critical pinchpoint in the landscape (as it encompasses movement through both western and central corridors) is where wildlife cross the A2 Trans-Kalahari highway at a safe distance from the KD-GH boundary (Palamakoloi) in the south, and Lone Tree government camp in the north. Western and central corridors merge (or conversely bifurcate) in southern GH11 west of the A2, and once joined form a single artery of least disturbed habitat linking the two great Kalahari parks. In 2014 the highest movement activity for gembok and eland across the A2 highway was detected in the vicinity of a cellular tower 7.25 km south of Lokalane, also associated with an old borrow pit utilized by wildlife as a mineral lick a mere 3 km east of the cellular tower in GH10 (Keeping et al. 2015). The importance of minimizing future disturbance at these locations and throughout the pinchpoint and maintaining its fence-free condition is stressed.

Figures 42-44 highlight the pinchpoint of the western corridor between Ncaang and the TGLP Ncojane ranches. Scenario 14 assumes that the informal settlement of Ranyane is entirely relocated. The most critical pinchpoint of wildlife movement activity coincides with the intersectional vicinity of the sand road leading from Ncaang northwest to the Ncojane ranches with the KD-GH boundary cutline. We provide a caution interpreting these maps. They only show the least cost paths component for the restorative Scenario 14 for the 3 most disturbance-sensitive wildlife species which underwent modelling. None of 3 most disturbance-sensitive species least cost path modeling showed use of GH13 WMA in Scenario 14. However, as but one example of what is not shown in these maps among other wildlife species, GH13 is core wet season wildebeest range (Bonifica 1992, DWNP 2000, Phase 1 report pg. 48 and Section 3.1.3.4) and will predictably remain so into the future projected by Scenario 14.

Figures 45-46 highlight the pinchpoint of the central corridor which is where wildlife cross the Kang-Hukuntsi highway. The hotspot for movement is predicted to be approximately in the middle of the WMA space. Sampling in 2016 and 2018 revealed concentrated movements rather shifted westwards around the KD5/6 boundary and a large pan just off the highway in KD5, due to cattlepost encroachment into the east of KD12 (Keeping et al. *in review*). This shift is accommodated by the still undeveloped ranches bounding the west of the pinchpoint. Intensifed development along the KD5-KD3 and KD12-KD3 border in the future necessitates the relocation of cattleposts occupying eastern KD12 to recover connectivity for the most disturbance-sensitive antelope species. Scenario 14 failed to recover lion connectivity through the central corridor so only gemsbok and eland least cost paths are displayed in detail.

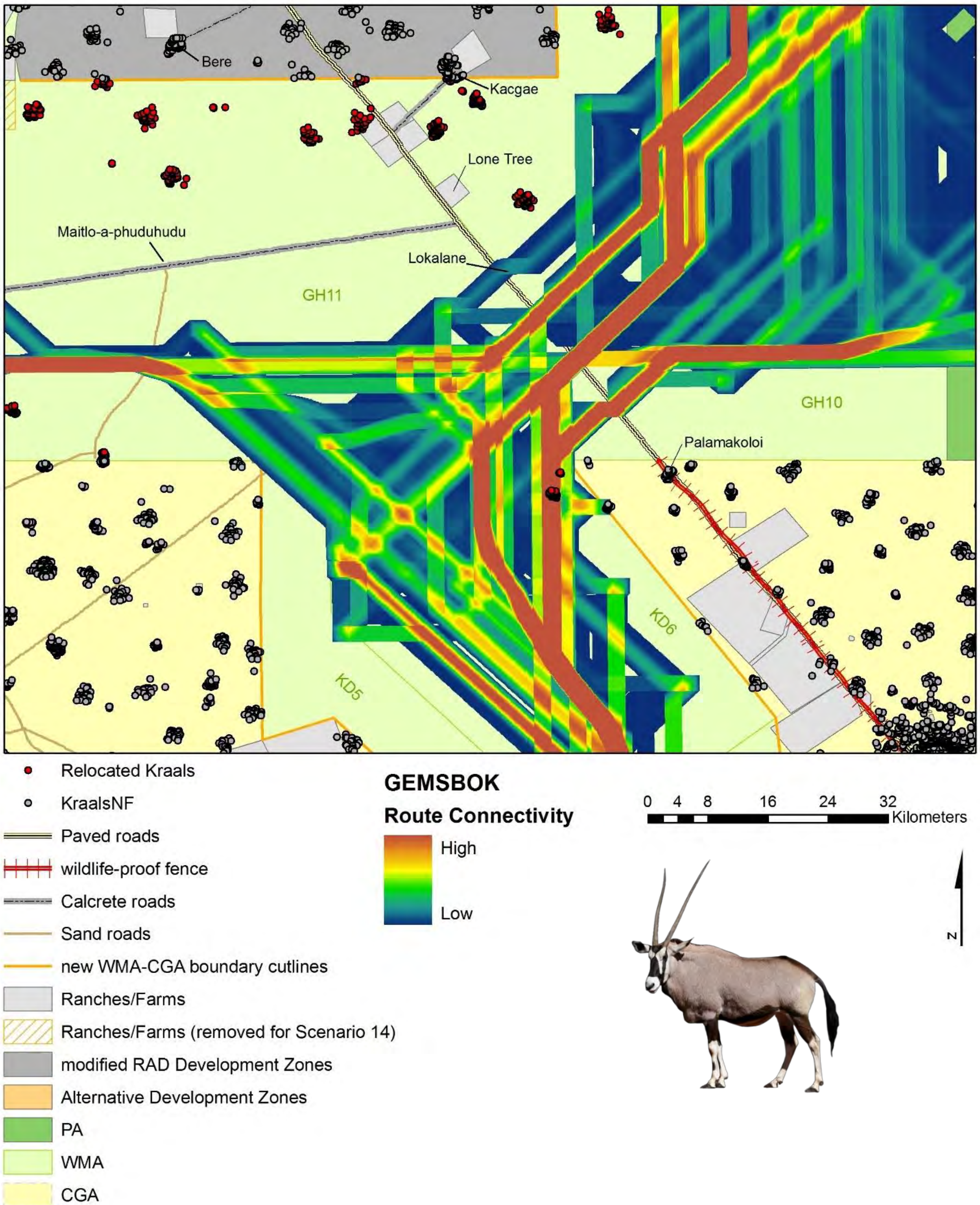


Figure 39 Scenario 14 gemsbok least cost paths in relation to land use showing detail at the AOI's singular connective pinchpoint for wildlife which crosses the A2 Trans-Kalahari highway. Kraals requiring relocation to achieve Scenario 14 are shown.

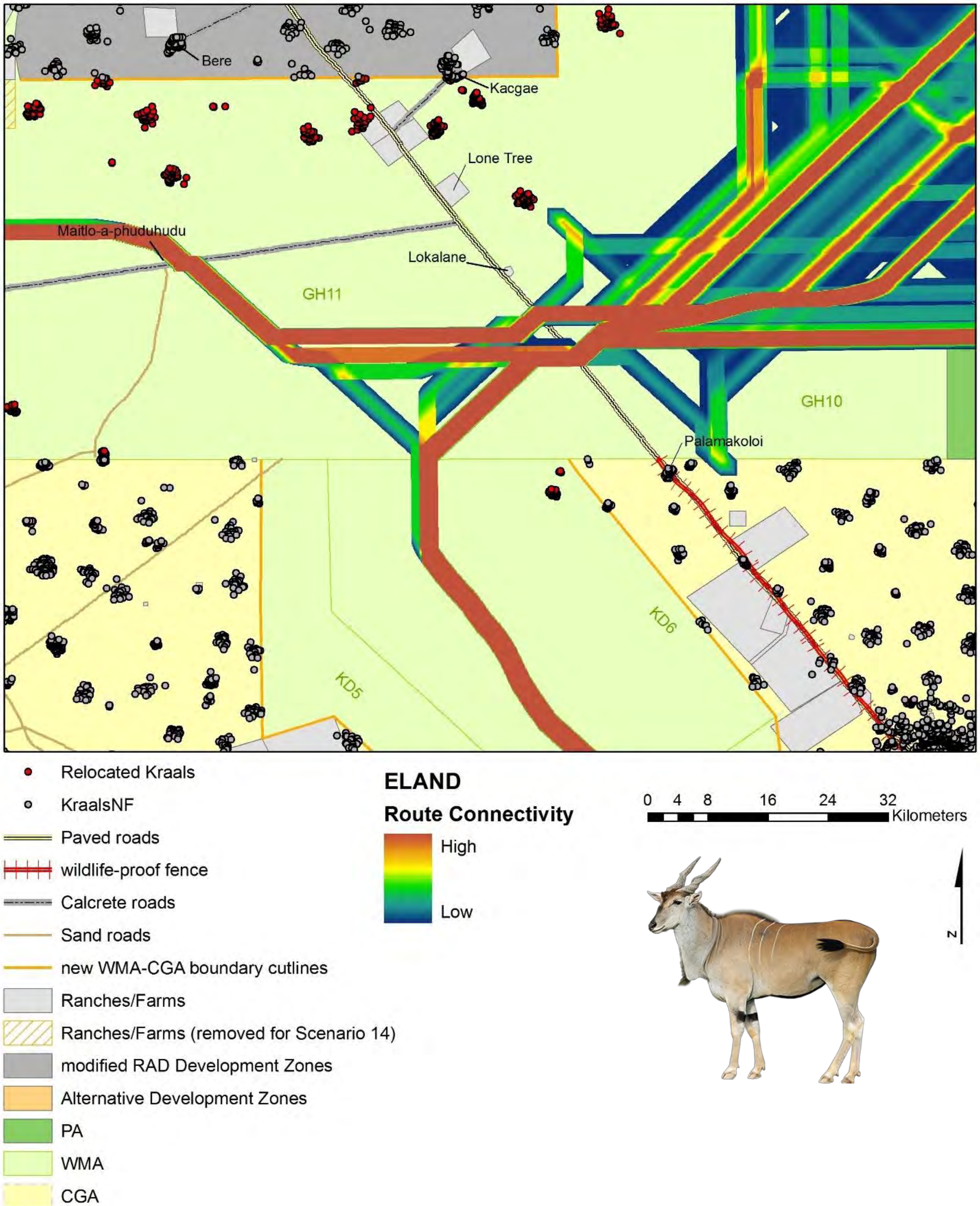


Figure 40 Scenario 14 eland least cost paths in relation to land use showing detail at the AOI's singular connective pinchpoint for wildlife which crosses the A2 Trans-Kalahari highway. Kraals requiring relocation to achieve Scenario 14 are shown.

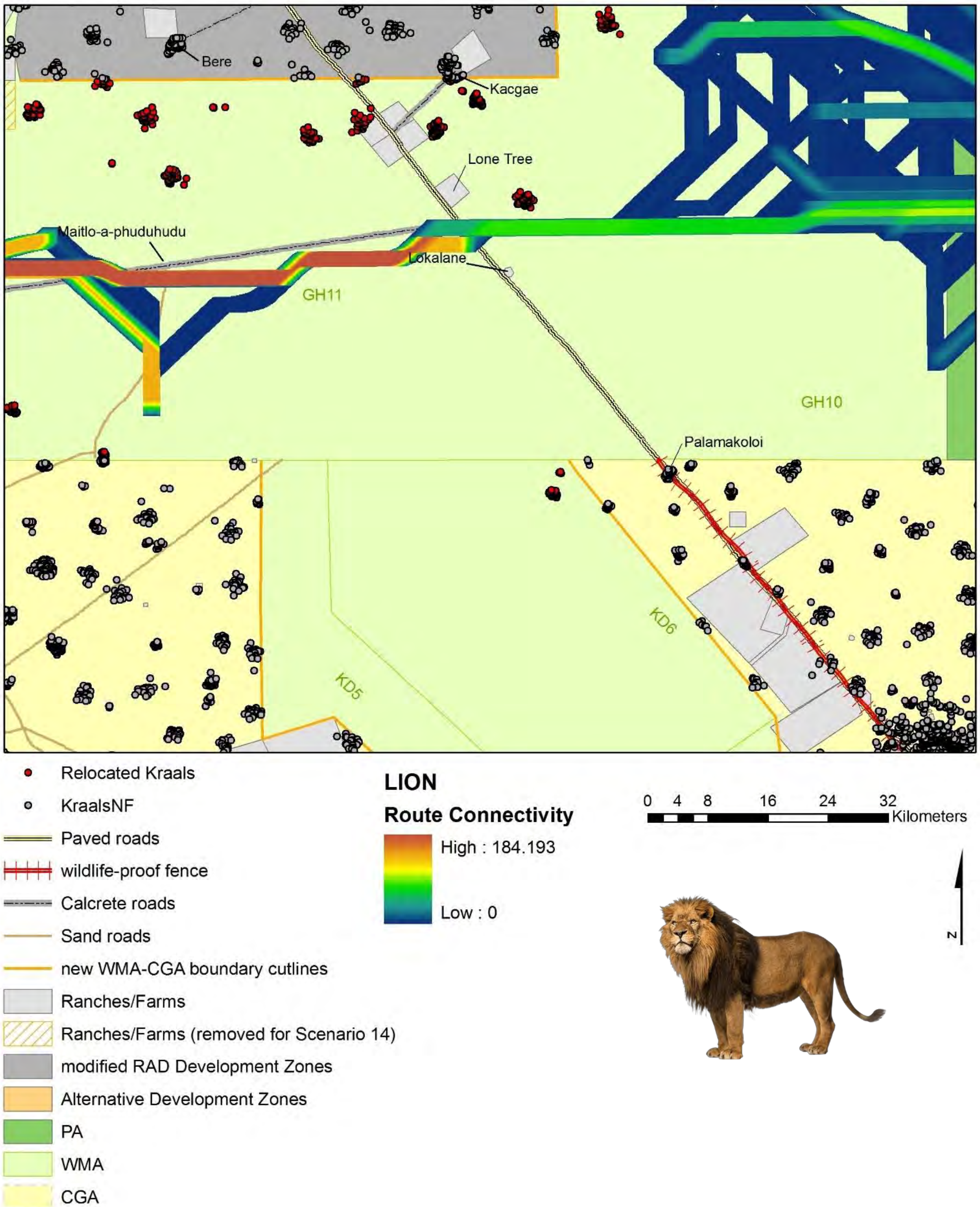


Figure 41 Scenario 14 lion least cost paths in relation to land use showing detail at the AOI's singular connective pinchpoint for wildlife which crosses the A2 Trans-Kalahari highway. Kraals requiring relocation to achieve Scenario 14 are shown.

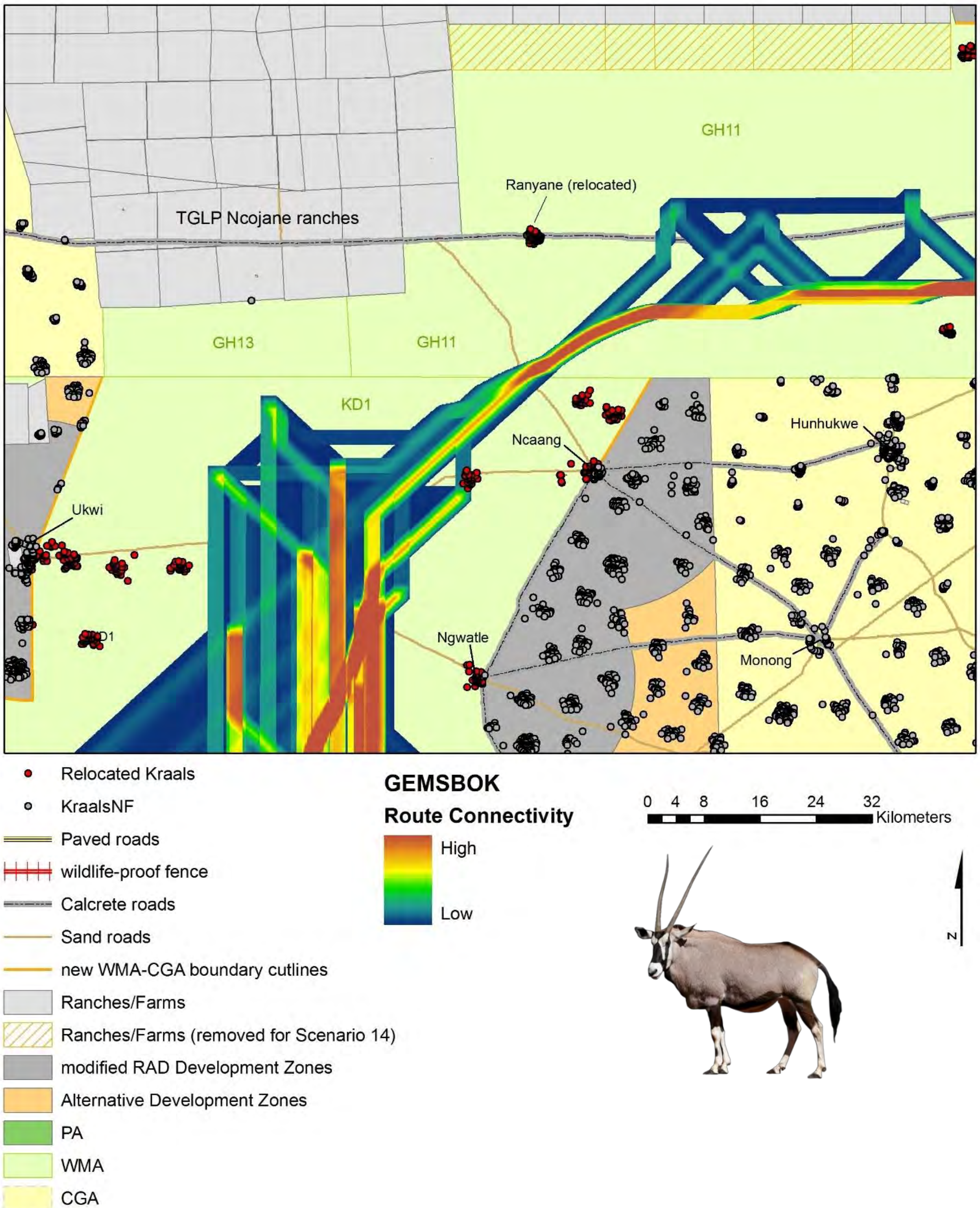


Figure 42 Scenario 14 gemsbok least cost paths in relation to land use showing detail at the pinchpoint of the western corridor between Ncaang and the TGLP Ncojane ranches. Kraals (including Ranyane informal settlement) requiring relocation to achieve Scenario 14 are shown.

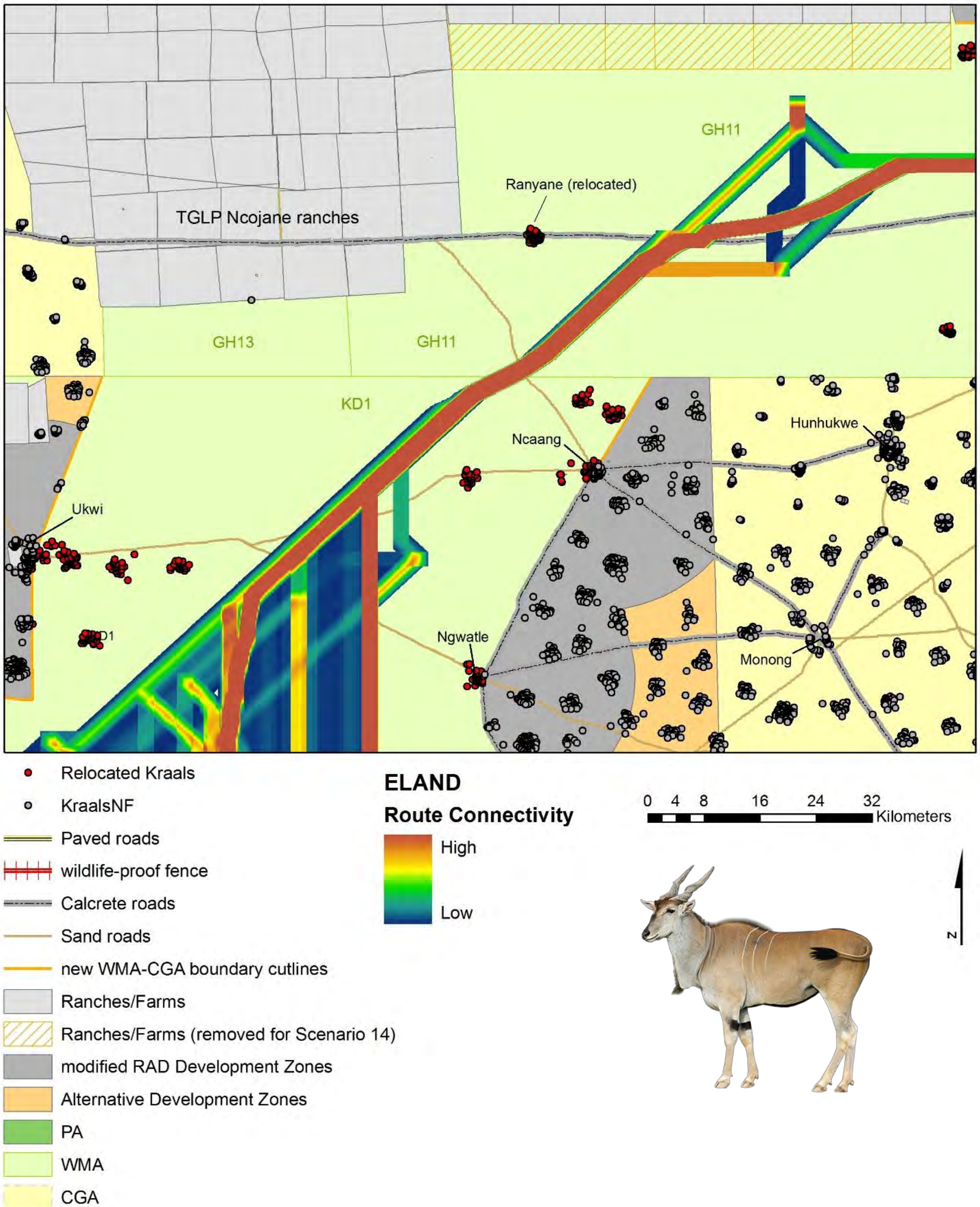


Figure 43 Scenario 14 eland least cost paths in relation to land use showing detail at the pinchpoint of the western corridor between Ncaang and the TGLP Ncojane ranches. Kraals (including Ranyane informal settlement) requiring relocation to achieve Scenario 14 are shown.

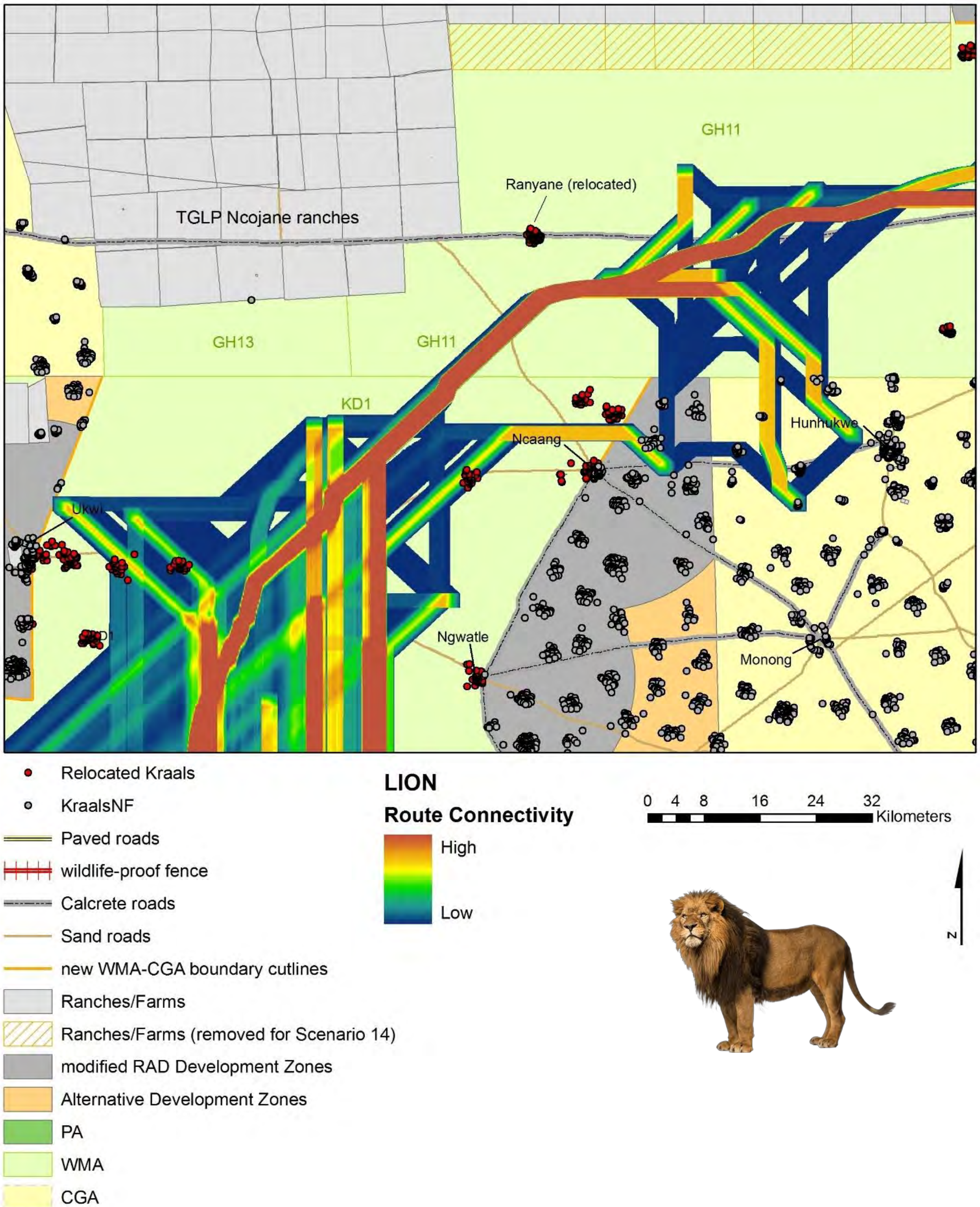


Figure 44 Scenario 14 lion least cost paths in relation to land use showing detail at the pinchpoint of the western corridor between Ncaang and the TGLP Ncojane ranches. Kraals (including Ranyane informal settlement) requiring relocation to achieve Scenario 14 are shown.

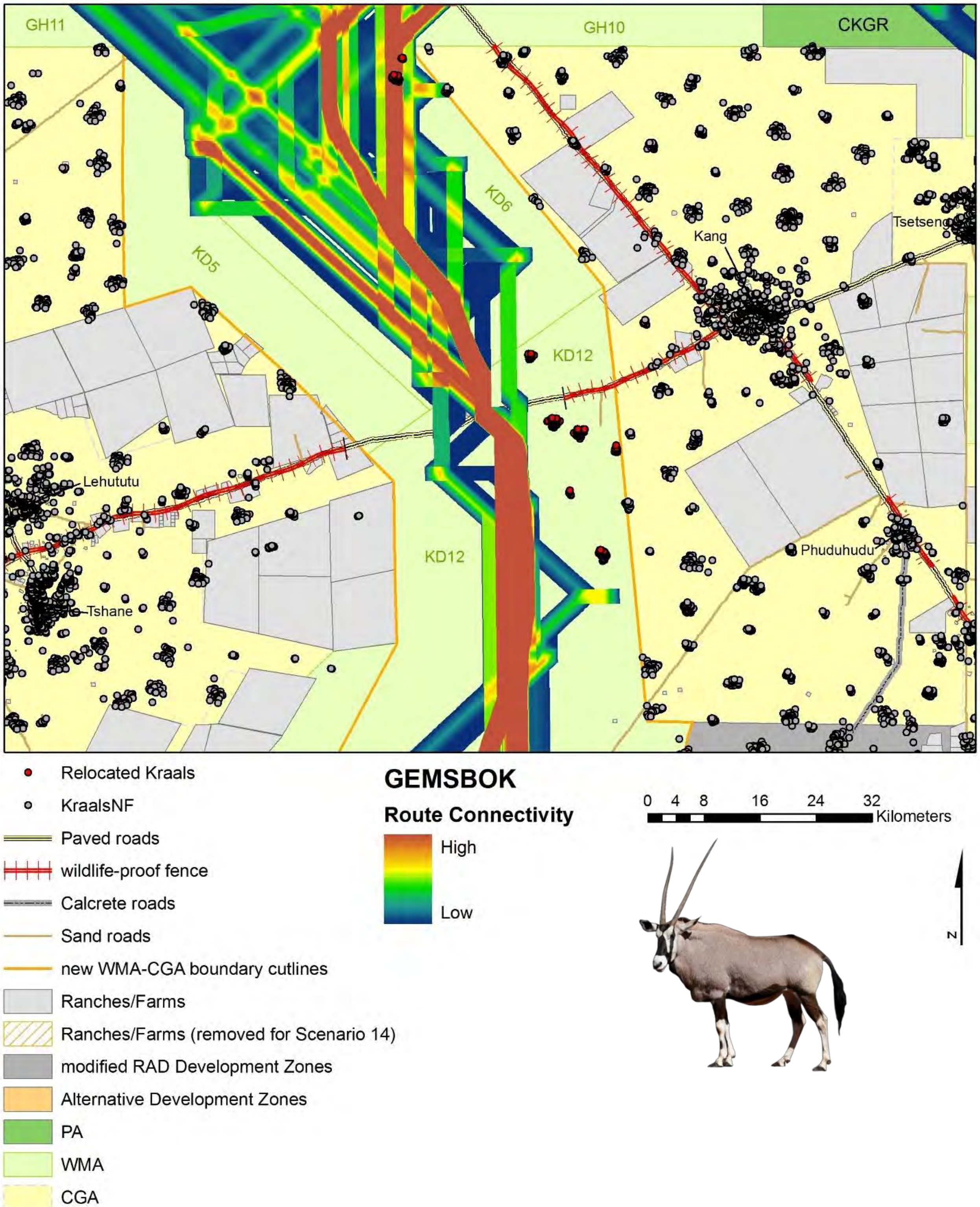


Figure 45 Scenario 14 gemsbok least cost paths in relation to land use showing detail at the pinchpoint of the central corridor where wildlife cross the Kang-Hukuntsi highway. Kraals requiring relocation to achieve Scenario 14 are shown and the wildlife-friendly fence is removed.

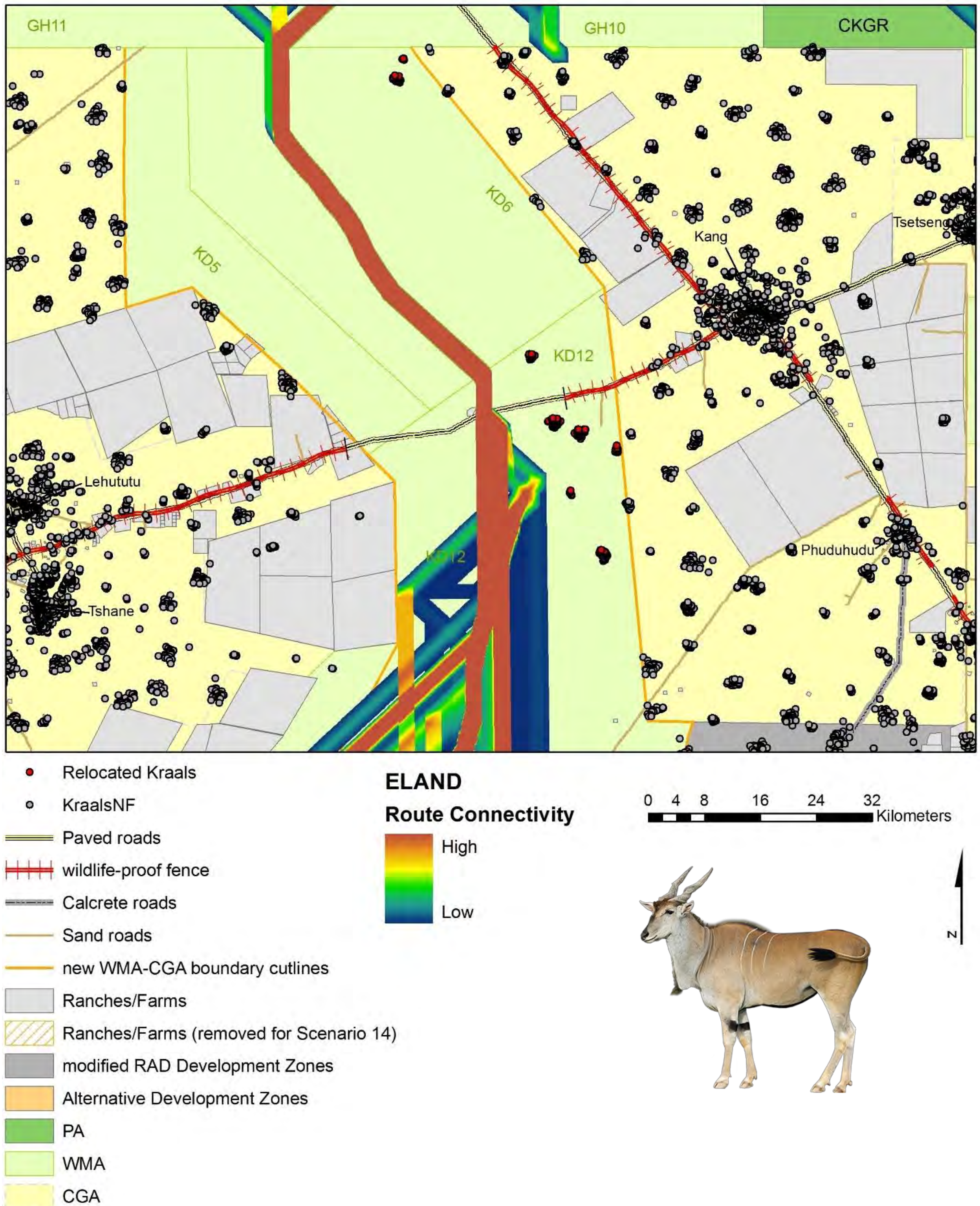


Figure 46 Scenario 14 eland least cost paths in relation to land use showing detail at the pinchpoint of the central corridor where wildlife cross the Kang-Hukuntsi highway. Kraals requiring relocation to achieve Scenario 14 are shown and the wildlife-friendly fence is removed.

4.5 Synthesis and Recommendations

4.5.1 Threats to Connectivity

The analysis has revealed the key threats to Kalahari landscape connectivity at the land planning level. In short, functional and absolute loss of WMAs, through agricultural encroachment and rezoning is the quintessential threat. Specific threats under land planning control in relation to the three recognized primary wildlife corridors are summarized here:

Eastern Corridor (SO2-KW6)-

- Unviable connection for the 3 most disturbance-sensitive species, although facilitates substantial movements of less disturbance sensitive species such as hartebeest (Keeping et al. 2015, 2017).
- Recent rezoning of SO2 with accompanying ranch layout and planned cattlepost expansion zones around bordering communities will certainly close this corridor for the remaining large antelope species.

Central Corridor-

- Continued and/or increased fencing along the Kang-Hukuntsi highway. Maintaining or upgrading the 'wildlife-friendly' fence as proposed by Roads Department.
- Loss of WMAs KD5/11 to agricultural encroachment.
- Further encroachment of cattleposts in WMAs KD6/12.
- Development of ranches along the Kang-Hukuntsi highway.

Western Corridor-

- Continued presence of Ranyane, even if reduced from informal settlement to cattlepost, near the middle of the western corridor. Continued presence of Xamaqa Syndicate, as a large established cattlepost well inside the southern GH11 boundary north of Hunhukwe in the corridor.
- Numerous waterpoint applications inside the gazetted GH13 and southwestern GH11 WMAs inside the corridor.
- Proliferating cattleposts inside RAD community 20km radius development zones which will squeeze wildlife habitat past minimal threshold width for corridor function particularly between Ncaang-Ranyane, Ukwi-Ngwatle, and Bere-Hunhukwe.
- Rezoned ranch layout intruding too far south into the corridor in GH11 WMA.

Combined (joined) Central and Western Corridors (through GH11/10)-

- TransKalahari Transportation Corridor fencing, including any fencing proposals for either highway or railway.
- Proliferating cattleposts out to the 20-km radius extent south of Bere and Kacgae squeezing wildlife habitat past minimal threshold width for corridor function between those two RAD development zones and the GH-KD boundary.

- Numerous waterpoint applications inside the gazetted southern GH10/11 WMAs inside the corridor.

4.5.2 Recommendations to salvage and sustain Connectivity

The minimal mitigative effort necessary to salvage and sustain landscape connectivity for the free-ranging Kalahari wildlife community and therefore achieve KGDEP Component Goal #3 requires:

1. Kang-Hukuntsi 'wildlife-friendly' fence deactivation/removal.
2. Gazettement of and no further waterpoint encroachment into WMAs, including KD5/11.
3. Withholding development of the most southerly row of ranches in the rezoned GH11 layout (i.e. maintaining that area as WMA).
4. Modification of select RAD community 20-km radius development zones around Zutshwa, Ngwatle, Ukwi, Ncaang, Bere, Kacgae as per Scenarios 5 and 14, and implementing the prescribed alternative development zones to accommodate future expansion offset from the selected reduced RAD development zones.
5. Deactivation/relocation of Ranyane and select cattlepost encroachment into southern GH11, KD6 and KD12 WMAs to alternative development zones as per Scenarios 9, 10 and 14.

Implementing any of the above mitigations will help improve landscape connectivity. Implementing all of them (Scenario 14) is predicted to restore wildlife population connectivity through two landscape corridors – both central and western. Implementing all of them together, as per Scenario 14 is, as the scenario modeling shows, the minimal action necessary to restore landscape connectivity for the full suite of Kalahari wildlife species.

Together with the above, the following is also necessary to maintain landscape connectivity:

6. Resist any and all future fencing proposals along transportation routes that bisect wildlife corridors, namely the Trans-Kalahari between Palamakoloi and Bere-Kacgae, and the Kang-Hukuntsi highway where it passes through KD5/6/12 WMAs. As the KWLCA shows, despite good intentions even the 'wildlife-friendly' fence poses a formidable barrier to large grazing antelope movements. Enhance interpretive signage along highways that bisect wildlife corridors (A2 TransKalahari and Kang-Hukuntsi) to affect motorist behavior and raise awareness and appreciation of Botswana's free-ranging wildlife landscape.

In addition to the above listed, the following is also recommended:

7. Implement firebreaks/cutlines or at least visible 4x4 tracks along WMA-CGA boundaries as defined in Section 4.5.3.1. Enhance anti-poaching effort along these long cattlepost frontier interfaces.
8. Gazette all WMAs and facilitate development of land use management plans for each.
9. Expand the Green Preserve and associated wilderness trail concept to include the central corridor in addition to the western corridor. Encourage a diversification of natural resource economies for RAD communities in WMAs, not one option vs another (i.e.

hunting vs photographic tourism). Facilitate rather than hinder private/NGO partnerships with communities and investment in community development and various natural resource-based economic projects (including tourism). Provide latitude for creative solutions in marginal areas with unique constraints rather than one-size-fits-all policy, and restrict BTO or other government interference in community-private sector partnerships.
10. Diligently vet and mitigate future proposals of agricultural expansion that threaten WMA integrity, particularly at the pinchpoints of landscape connectivity described in Section 4.4. This includes individual waterpoint applications. Scenario 14 is the limit of such encroachment at these vulnerable pinchpoints.

Many of the points in this numbered list are elaborated in the remaining sections and subsections below.

4.5.3 Implementation of Scenario(s)

If wildlife population connectivity on the ground is to become realized in accordance with the selected scenario chosen by Botswana decision-makers and land planners, then it will be crucial for implementing bodies to follow the Scenario Descriptions (Section 3.2), especially in regards to relocation/reallocation of cattleposts/waterpoints identified in the tables. Land boards will need to be strict in following their own policies and respecting WMA boundaries demarcating wildlife corridors, and not entertain applications for boreholes therein. Within Ghanzi District especially there are numerous applications inside WMAs but outside RAD development zones and situated within critical pinchpoints of wildlife corridors including SW of Ranyane, and north of Palamakoloi. Table 23 provides a list of these locations which were vetted from all scenarios and if allocated and permitted to be established, would certainly undermine or negate the wildlife connectivity landscape. Figure 47 illustrates these locations.

Table 23. Uncertain status waterpoint allocations/applications in LB databases vetted/excluded from all scenarios and of particular concern for spatial conflict inside wildlife corridors

WMA	Name	Coordinates (Decimal Degrees)
GH11	Robert P. Dithobolo	22.422401 -23.318428
GH11	Ipotje	22.364562 -23.280222
GH11	Tebogo	22.135710 -23.162244
GH11	Makanyane	22.062758 -23.057846
GH11	Kutlwano Syndicate	21.940750 -23.067909
GH11	K Maragaole shift	21.865282 -23.010050
GH11	Batlhahune BH 537	21.859085 -23.088440
GH11	Gakebitswe M. Thiite	21.848577 -23.180915
GH11	RO23	21.852115 -23.161104
GH11	Kadikgetha	21.707270 -23.283662
GH11	Kgobutse Gorosho	21.753809 -22.964179
GH11	Isaiah W. Kelefhile	21.712498 -22.958598

GH11	Benjamin K. Molemisi	21.316866	-23.145010
GH11	BH No. 9296 (Bakgatle Kgafela)	21.240305	-23.141876
GH11	Moshoeshoe	21.416881	-22.962350
GH11	Esther	21.332495	-22.916985
GH11	Tuelo	21.081920	-22.916893
GH11	Keikanyemang Motumise	21.097014	-22.948758
GH11	Kaongwa	21.032961	-23.233927
GH11	M. S. Hendrik	21.054154	-23.170350
GH11	Chwihaba	20.989383	-23.172738
GH11	Tirisano	21.003113	-23.165873
GH13	Seboneganawa	20.778936	-23.291170
GH13	T. R. Ditirelo	20.677054	-23.289047
GH13	Mahube Syndicate	20.601703	-23.274720
GH13	Mahube Syndicate II	20.594274	-23.285333
GH13	Rhumba	20.599050	-23.294884
KD12	proposed point	22.786887	-24.441681

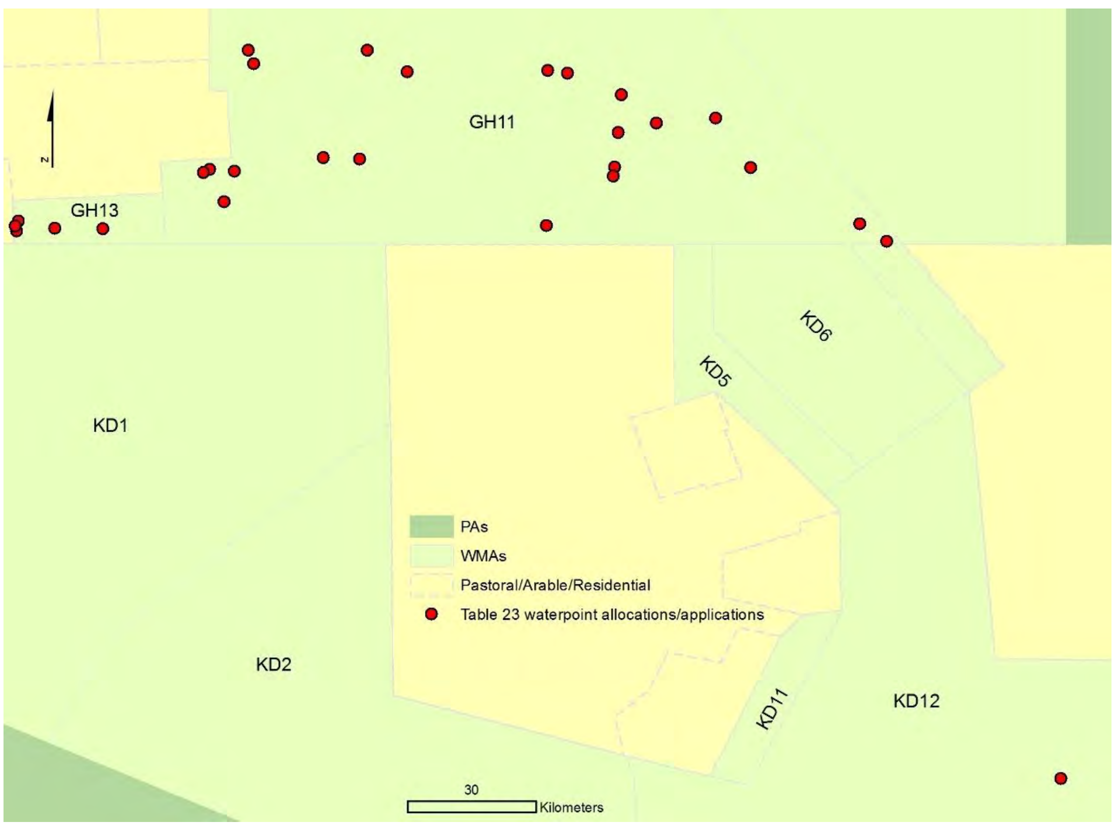


Figure 47 Uncertain allocation/application waterpoint locations (Table 23, red) inside WMAs from LB databases which were vetted from all scenarios and problematic for wildlife landscape connectivity if approved and developed.

4.5.3.1 WMA gazettement and land use boundary demarcations

To maximize the probability of success in rescuing connectivity and realizing a future alternative sustainable development scenario Botswana may choose to aim for, all presently ungazetted Kalahari WMAs comprising core and corridor areas should be gazetted urgently. In doing so, this should facilitate the sequential enhancement of these areas as conservation zones and capacity of RAD communities to derive conservation-related economic benefits from these areas, for example via CBNRM-controlled utilization and tourism development.

Gazetted WMAs should also make it easier for Land Boards to adhere to their waterpoint allocation policies, both for future allocations and in relocating existing allocations that have spatially violated those policies. Studying the distribution of waterpoint allocations encroaching into WMAs (excluding RAD development zones), it appears that past errors may have been made by LBs simply because the CGA-WMA boundaries are visibly nonexistent in the field. The worst encroachment occurs into eastern KD6 and KD12 where no demarcation of WMA boundaries exists, and therefore the true location of those boundaries in the field may be called into question during the allocation process.

A recommendation to remove ambiguity and prevent misallocations inside WMAs in the future is to create new cutlines (or at least 2-spoor 4x4 tracks) on the CGA-WMA boundaries where no such visible demarcations currently exist. This should enhance the practical ease for LBs in adhering to their policies during field allocation processes, and in adhering to the aimed scenario overall. We recommend these new linear features be created specifically for the CGA-WMA boundaries including KD3–KD5, KD3–KD2, KD7-KD6, KD13–KD12, KD10–KD11 (see Figure 48). Additionally and similarly, these new field demarcations should be created to define the boundaries for the alternative expansion polygons and modified RAD development zones with their adjacent WMAs, where no such roads currently exist (e.g. southeast of Zutshwa, Ukwi, north of Ncaang, Bere and Kacgae, as well as Inalegolo's and New Xade's 20 km extent circumferences; see Figure 48).

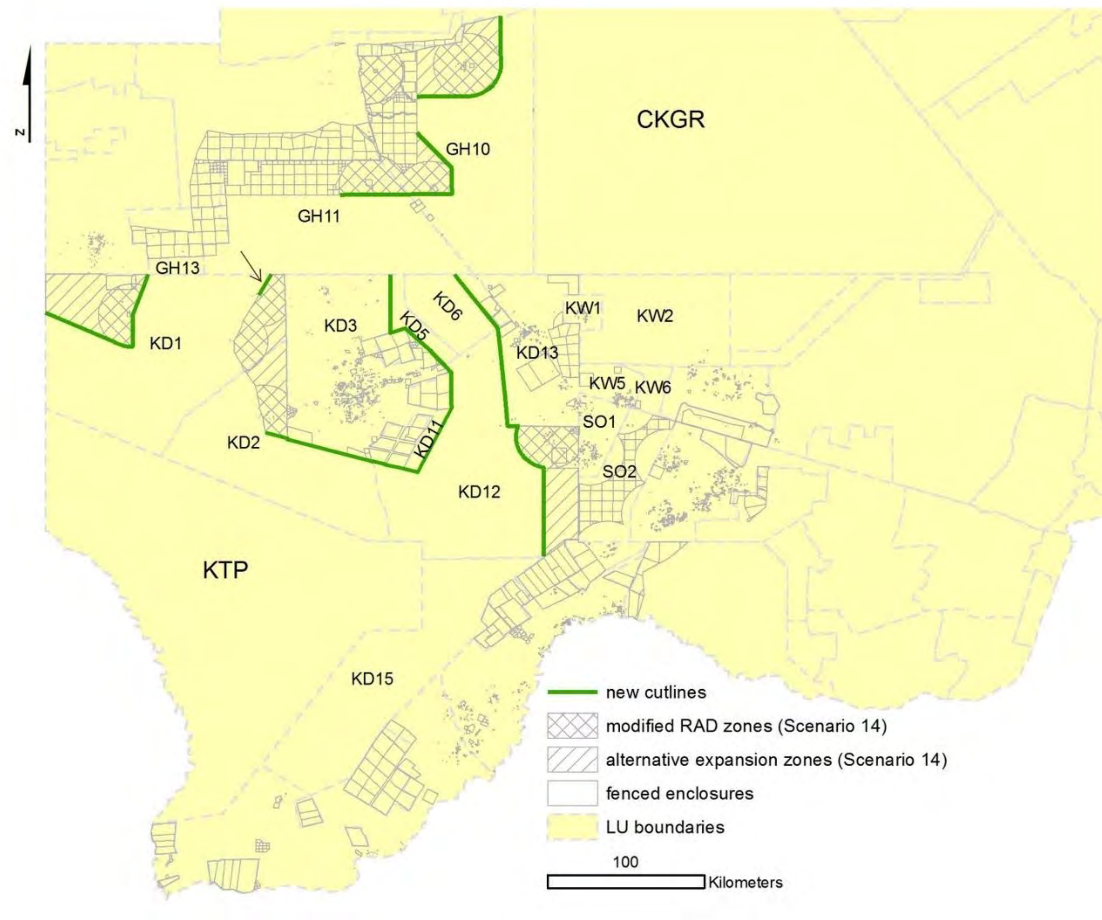


Figure 48 Proposed new cutlines on the CGA-WMA boundaries in relation to Scenario 14 land use zonation. We propose these demarcated limits of human-livestock encroachment on the ground would assist practically towards achievement of the desired future scenario.

A second advantage to these strategically located roads is that they could be utilized to track activity and improve anti-poaching efforts along the vast CGA-WMA interface across which the majority of poaching in the Kalahari occurs (see Section 4.5.4.3). The poaching activity along this extensive cattlepost-WMA frontier appears to proximally shape the occurrence probability distributions of disturbance-sensitive wildlife species, thus influencing the success or failure of corridor functionality. Land planning for the limits of waterpoint encroachment are the ultimate determinant of wildlife distributions and connectivity; poaching from those source points may be the strongest proximate determinant (see Section 4.5.4.3).

4.5.4 Impediments to implementation of mitigative Scenario(s)

Once again, details in Scenario Descriptions (Section 3.2) will need to be followed carefully through implementation if landscape connectivity and wildlife outcomes predicted in the desired scenario are to be realized on the ground. We selectively highlight some of the challenges to implementing the recommended mitigative measures below.

4.5.4.1 Land Board waterpoint allocations

The single greatest quantifiable development threat to connectivity is waterpoint allocations encroaching into WMAs, particularly the present RAD development zonation policy. Each District Land Board is "the legal custodian of the land and takes overall responsibility for allocation and use of boreholes" (KLB 2006). Inability of land boards to adhere to modified zonation specified in scenario descriptions, to reallocate approved points and applications to the alternative zones, and to relocate the specified problematic cattleposts established inside WMA to alternative zones, might prove to be the major impediment to implementation.

4.5.4.1.1 RAD development zones in WMAs

A policy to proliferate cattleposts within 20-kilometre radii of RAD villages located inside of WMAs is being pursued by Botswana's Government and enacted by both Ghanzi and Kgalagadi Land Boards, it appears, on a principle of fairness in comparison to villages located outside of WMAs, i.e. due to the perceived non-equivalent or inadequate value of CBNRM-based economic activities for those RAD villages. This is occurring both in gazetted (Ghanzi District) and ungazetted (Kgalagadi District) WMAs. The present configuration of those 20-km radius development circles, we have shown, is a major threat to wildlife population connectivity between KTP and CKGR.

Although the development of RAD cattleposts within these circular zones is at early stages, the situation on the ground is rapidly changing (see Section 4.1.1.2). Numerous already allocated but undeveloped waterpoints and applications exist within these zones in LB spatial databases. The number of allocations/applications on the corridor-sensitive side of select RAD villages can be appreciated in the description of Scenario 5 with Tables 5-6 (Section 3.2.7). Continuing to pursue the present policy to occupy the full 20 km radii will not only compromise the western wildlife corridor as connectivity models clearly demonstrate (Scenarios 4, and 11 Sections 4.2.4, 4.2.11), but additionally, we here briefly suggest, worsen the prospect for future economic development and poverty alleviation for the intended RAD beneficiaries. Adjusting the existing policy to align with a mitigative scenario (particularly Scenario 5 encompassed in Scenarios 13-14) will not only rescue wildlife population connectivity, but also potentially enhance livelihood prospects for RAD communities relative to the present trajectory. Here we take a speculative departure beyond conservation science to question the social-economic validity of the policy to proliferate cattleposts in WMAs out to 20 kilometres around all Kalahari RAD communities.

The present development trajectory will predictably produce a future glimpsed as Scenarios 4 and 11 wherein 20 km RAD zones are completely occupied by cattleposts and the western corridor is squeezed into irrelevance. Notably our modelled scenarios constrained future waterpoint locations within the 20 km radius limit. However, this may be over-optimistic given evidence that even at this early stage of development RAD allocations have already exceeded the 20-km limit. It is important to understand that the attenuating impact of those farthest cattleposts along frontier extends far beyond the 20 km radii. High occurrence probability gemsbok habitat does not begin to appear until approximately 6.5 – 8 km beyond the last cattleposts, and eland at least 10 km or greater. Published research like Phuthego and Chanda (2004) underestimates the present richness of traditional ecological knowledge (TEK) in Kalahari RAD communities, and the dependence of people, particularly the poorest, upon traditional resource use within foot or donkey access of settlements. Heinz (1979, 1971) by contrast provides a better glimpse of the depth of TEK, but still scratches the surface. It seems wholly underappreciated and overlooked by Botswana's government. Where once people had access to natural resources to feed and heal themselves, the future trajectory predicted by 20 km RAD development zones is easily compared to present day communities situated inside CGAs where a sea of cattleposts and livestock overgrazing has transformed vegetation to great distance beyond their centres. Effectively, RAD communities will lose access to resources perhaps critical to food security, as well as practice, transmittance and preservation of TEK.

A second problem is that communal grazing areas have very low tourism value. On a continent where any randomly drawn coordinates are likely to land one in proximity to pastoral livestock, such areas are commonplace and therefore uninteresting. Conversely, the Kalahari WMAs, beyond the human-livestock sphere of disturbance, possess high and unrealized tourism value. Maintaining minimal distance between RAD villages and their high value tourism areas is more likely to facilitate future benefits to such communities. Zutshwa in KD2 WMA is perhaps the best Kalahari example highlighting a de facto 50:50 development zone compromise - i.e. the west of the village remains essentially cattlepost-free. As a direct consequence, at no other community can wildlife be regularly seen in such close proximity, Zutshwa has benefitted from non-hunting tourism more than any other, and a mere 20 km from the village occurs a pan ("Name") surrounded by a parkland of exceptional scenic beauty and high wildlife value. Future tourism potential remains huge and unrealized. A comparable situation exists for Ngwatle community in the case of "Masetleng" pan and its nearby "Western woodlands". These high value tourism assets will be made irrelevant if the present RAD development zone trajectory continues to be pursued. The full circle development zones around RAD communities precludes tourism development by mutual exclusion of wildlife and wildlife-based livelihoods. It will constrain communities still unique and full of potential to a predictable single-track livestock-only economic future at the expense of the environment and diversified, resilient economies.

A further tragedy is that this unimaginative policy may already be failing to uplift the intended beneficiaries, and instead of poverty eradication, ultimately drive its opposite. Safeguards are in place to ensure RADs receive waterpoint rights via District Councils vetting the RAD status of applicants. However, RADs lack capital resources to develop those waterpoints LBs allocate them. Instead, recent cases can be pointed to whereby successful cattlemen from outside RAD communities arrive to make non-contractual deals "under the tree" with RAD awardees of new waterpoints. They fund the borehole drilling and equipping in exchange for grazing. With time more cattle and family members arrive in what effectively amounts to a subtle takeover whereby the intended impoverished RAD beneficiaries of waterpoint allocations are displaced. Although perhaps well-intended, the net result of this policy may be reinforcing the continued bottom-rung economic status of RADs, if not exacerbating inequality and extreme poverty into the future (Chanda *et al*. 2003).

We suggest that the assumption that RAD development zone policy will lead to improved long-term well-being of the affected communities requires re-evaluation. The present policy represents a near complete relinquishment of RAD communities to capture natural resource related benefits in the future. Even present commercial safari hunting operations are starting to be impacted by the expansion of cattleposts in 20-km radius development zones, which, at their full extent, will substantially eat into the core of WMAs. The proposed alternative development paths involving a 50:50 'compromise' between livestock and wildlife among select RAD communities salvages connectivity to bolster wildlife populations over the ecosystem whole in addition to maintaining the aforementioned communities' proximity to their functional WMAs to derive benefits from that ecosystem enhancement. But moreover, the proposed alternative expansion polygons of Scenario 14 offer an equivalent grazing area to that relinquished from the RAD development zones encroaching into sensitive wildlife space. Thus, communities 'sacrificing' one half of their circular development zones need not experience a net loss of grazing area. "Compromise" and "sacrifice" may therefore be inappropriate phrasing; "optimize" and "diversify" more relevant. Psychologically, the 50:50 semicircle development zone strikes a straightforward and equivalent balance between livestock and wildlife among RAD communities closely linked to their WMAs. It may be made even more politically palatable if they have equivalent opportunities to develop livestock in the alternative expansion polygons. No net loss; rather long-term gain.

We have strategically and minimally proposed adjustments to RAD development zones for key villages encroaching into critical corridor areas only, carefully and incrementally in order to salvage whole ecosystem landscape connectivity. However, the advantages that communities could gain by balancing livestock and wildlife zones at the community land use level may be considered by other RAD communities (Inalegolo) whose 20 km radius zone does not compromise wildlife cores and landscape connectivity. They may likewise choose to diversify their economies away from single-track livestock development mutually exclusive of multi-faceted wildlife and related benefits including: tourism, both hunting and non-hunting (wilderness, photographic, traditional cultural), food security for the poorest segment, preservation of traditional knowledge and cultural practices, etc.

4.5.4.2 Fences

The only changes to fences in the landscape considered in scenarios were those associated with fenced enclosures (i.e. ranches, farms), plus the limited extent wildlife-friendly fence in between Kang and Hukuntsi. Besides the wildlife-friendly fence, scenarios did not entertain changes to present time fences along transportation routes, or protected area boundaries. It is an essentially redundant exercise to model the impact of any future game-proof fencing because the result is highly predictable without the assistance of computation: fences stop large antelope movement, and therefore fragment landscapes and populations either side of the fence. That is indeed precisely the intended purpose of a fence, although the target is often livestock rather than free-ranging Kalahari antelopes. Even high-jumping antelopes considered capable of negotiating the typical 140 cm high fencing along highways can run into trouble sometimes (Figure 49).

Figure 49 Kudu entangled to death along highway fencing near Hukuntsi.

For as long as the possibility of increased fencing in the Kalahari landscape continues, fences will remain a potential overshadowing threat to connectivity for iconic large antelopes. Such a simple piece of infrastructure inflicts disproportionate devastation to Kalahari wildlife (Child 1972, Owens and Owens 1983, Parry 1987, Williamson and Mbano 1988, Spinage 1992, Albertson 1997,1998, Thouless 1998). Ghanzi District has resisted erecting any fencing along the A2 Trans-Kalahari Transportation Corridor (TKTC) from the KD-GH District boundary at Palamakoloi northward throughout the length of GH10/11 WMAs to Mamuno junction. This is laudable landscape planning which must continue.

In the interest of wildlife landscape connectivity, fencing should be absolutely minimized in the Kalahari ecosystem to the necessary ranch blocks and limited stretches of highway in high-density livestock areas. Proposals to fence, for example, CGA-WMA boundaries ought not be entertained. For one, fences do not and will not stop people and cattle venturing into WMAs. Secondly, less disturbance-sensitive large antelope species such as hartebeest, wildebeest, kudu and springbok continue to utilize habitats in and move through CGAs of low-moderate cattlepost density as evidenced by track surveys and reflected in HS maps in Phase 1 report (Sections 3.1 and 3.2). More extensive fencing in the Kalahari will predictably equate to greater large antelope movement fragmentation and more direct mortality.

Although Ghanzi District has laudably resisted until present time, the most critical pinchpoint of landscape connectivity in the AOI may be threatened by future fencing proposals related to TKTC upgrades, particularly the planned Trans-Kalahari railway. This pinchpoint is the singular connection (see Section 4.4, Figures 39-41) through which disturbance-sensitive wildlife are likely to move between CKGR and KTP and containing all flow before bifurcating into west and central corridors. This main artery for disturbance-sensitive wildlife means all movement must pass over the A2 Trans-Kalahari highway between the KD-GH District boundary (demarcating the corridor south extent) and the expanding cattlepost areas south of Bere/Kacgae villages (indicating the corridor north extent). From the perspective of disturbance-sensitive antelopes the pinchpoint narrows moreso because of the attenuating influence of cattleposts both in the south around Palamakoloi and recently expanding within the Kacgae 20 km radius development zone. In 2014, large antelope movements through this corridor pinchpoint and across the highway occurred on the order of 52 movements per day (Keeping et al. 2015). Together with the unfenced section of highway through SO1/2 in the AOI further south, an estimated 30,000 large antelope movements over the TKTC might be expected annually (Keeping et al. 2015).

Continuous fencing along the TKTC would straightforwardly fragment the Kalahari landscape for free-ranging large antelopes into two pieces. Landscape connectivity would be conclusively negated. Fencing arguments related to a future railway appear flimsy, such a fence serving to protect untended livestock from train collisions, not to protect the train itself nor safety of its passengers, and certainly not wildlife (Keeping et al. 2015). It is essential for land planners to remain diligent to keep wildlife corridors fence-free.

4.5.4.2.1 The ‘wildlife-friendly’ fence

The simple removal of the present wildlife-friendly fence erected across the central corridor resulted in 2.5% and 13.3% improvement to gemsbok kernel and path movement connectivity through the entire landscape (Section 4.2.8). Scenario 11 included full game-proof fencing which subsequently resulted in complete fragmentation. Alternative development Scenarios 12-14 all include the no fence option in which the present wildlife-friendly fence is deactivated/removed so that wildlife can move unobstructed over the Kang-Hukuntsi highway once again.

While gemsbok was the only species to undergo connectivity modeling isolating the impact of the wildlife-friendly fence, unpublished field data (Keeping et al. *in review*) show that other less disturbance-sensitive large antelope species also stand to have population connectivity substantially improved following the deactivation/removal of the wildlife-friendly fence. Combining data from the two brief periods (November 2016, April 2018) we sampled the wildlife-friendly fence and adjacent control transect each once produced a remarkable 751 track observations of large wildlife herbivore and carnivore species. Of this sum, 555 (74%) track interceptions occurred on the control transect, while 123 (16%) successful crossings of the wildlife-friendly fence were documented, and 73 (10%) unsuccessful crossing attempts or 'deflections' were noted (Table 24). The pinchpoint of the central corridor is thus highly active for large antelope movements.

Table 24. Categorical summary of track observations along the wildlife-friendly fence in relation to control transect from both November 2016 and April 2018 sampling periods

		Wildlife-friendly fence					
	Control transect	Successful crossings	Unsuccessful crossings (deflections)	Permeability Rate (% successful crossings of attempted crossings)	Physical impact causing damage	Injury / Mortality*	Separation from young
Hartebeest	215	88	44	67%	1	—	5
Gemsbok	152	6	17	26%	6	1/1*	—
Wildebeest	41	0	12	0%	—	—	—
Kudu	95	22	0	100%	—	—	—
Ostrich	25	0	0	—	—	—	—
Springbok	4	0	0	—	—	—	—
Brown hyaena	13	0	0	—	—	—	—
Cheetah	2	2	0	100%	—	—	—
Leopard	8	4	0	100%	—	—	—
Lion	0	1	0	100%	—	—	—

Both the ratio of successful:unsuccessful wildlife-friendly fence crossings, and the discrepancy between observations along the control transect vs the wildlife-friendly fence, are informative. Gemsbok showed the most disparate counts, with nearly 7 times as many observations at the control transect as the fence. Large antelope species show differential ability to negotiate the fence. It appears permeable to kudu, a minor filter for hartebeest although especially problematic for their young, a major filter for gemsbok, and a nearly impermeable barrier for wildebeest. Eleven years prior to fence erection, DWNP (2000) concluded “Wildebeest cross the Trans-Kalahari highway and Kang-Hukuntsi road hence fencing them can result in a negative impact on the wildebeest population”, and in light of wildebeest sensitivity recommended “Kang-Hukuntsi road should [also] not be fenced.”

Hardly a decade old, the wildlife-friendly fence has already fell into disrepair, to an extent that the Roads Department in Kang has proposed in its budgets to replace it with a taller wildlife-proof fence (O. Mothobi *pers comm*). Clearly, the main cause of damage is wildlife impacts. Most wildlife movement occurs after dark, and interpretation of track sequences clearly showed animals frightened by traffic careening towards the fence and either not seeing it at all or only attempting to break last minute when in immediate proximity with it (Box 7). Thus, whilst the fence alone causes difficulties for wildlife, the combination of fence with the highway appears to exacerbate fence damage along with injuries and mortalities as frightened animals run blindly at the fence rather than selecting suitable points to cross it. Six out of seven events damaging the fence were instigated by traffic frightening animals and causing them to run towards it. The single exception was a gemsbok that walked into the fence and struggled to free itself after it became entangled in the wires (Figure 37). As these wildlife-caused damages accumulate over time, they facilitate increased permeability. Since the 'wildlife-friendly' fence is presently in an intermediate state of decay, disrupted movements, injuries and mortalities were presumably greater when the fence was new.

Box 7. Sample of wildlife behavioral interactions with wildlife-friendly fence along Kang - Hukuntsi highway bisecting the central corridor as reconstructed from track and sign evidence by Master Trackers and indicating disrupted connectivity.

Gemsbok:

- *A large bull gemsbok tried to escape from the highway right-of-way southward, impacting the fence and deflecting. From there it walked 17 m west, turned around and walked 93 m east, then galloped at a right angle from the highway, impacting the fence again and bending two metal fence posts, before deflecting back towards the road. It then walked 651 m eastwards before finding a damaged section of fence where two remaining wires were on the ground. It stepped one foot over the wires, then deflected back toward the road. It continued walking eastwards in the highway corridor for 248 m. At this point it became frightened by a vehicle causing it to gallop fast towards the fence. It was pre-dawn but getting light enough for the gemsbok to see the fence wires. It jumped at an oblique angle, contacting a metal fence post and bending it. While in mid-flight, the top barbed wires scraped its underside and legs leaving grey hair along 21 barbs (273 cm between the first and 21st barb) and blood between the 20th and 21st barb. The impact caused the gemsbok to flip forward and land upside down on the other side of the fence, it's long horns both deeply gouging the sand as it landed on its back. It stood up and walked off to the south, slowly and in a manner as though injured.*

- *A gemsbok approached the fence and road from the south at a walk. It became entangled in the fence wires, bent a metal fence post during the struggle (Fig. 50), then ran back south, failing to cross the fence.*

- *A large bull gemsbok was startled by traffic and ran south from the highway towards the fence. Head down, it smashed into a sturdy stabilizing fence post, breaking its neck as its body flipped over the wires onto the other side of the fence (Fig. 51).*

Hartebeest:

- *A hartebeest was frightened by a vehicle and sped in a gallop towards the fence at an oblique angle. It attempted to brake and deflect just before contact at a particularly high point (98 cm), bent a metal fence post, left hair on the top barbs as it went over, and whilst airborne spun 180 degrees, landing on its side with horn digging into the sand (Fig. 52). It recovered and continued southwards.*

- *A mother hartebeest and small calf attempted to cross the fence heading south. They became separated when the calf jumped a damaged section of fence and the mother remained inside the right-of-way. Panicked, they both ran westwards on either side of the fence. The calf hit the fence as it ran, trying to rejoin its mother. After 69 m, the calf squeezed through the bottom and middle wires rejoining its mother inside the right-of-way, and they changed direction, running together eastwards. After 111 m, they turned westwards again, running, scared. After 54 m, they doubled back eastwards. They slowed and walked 234 m inside the right-of-way while the mother searched for places to cross the fence with her young, deflecting each time. The mother eventually jumped the fence (78 cm); we did not follow up if/how the calf joined her.*

Wildebeest:

- *Three wildebeest approached from the south, encountered the fence, then walked back the way they came. Days later the same 3 wildebeest approached the same spot. HL and NK offered, "They tried on many days to cross here, but just stopped to look at the fence because they know they can't jump." After deflecting again they meandered westwards, paralleling the fence some distance away from it, often hidden in trees and shrubs. After 1.9 km they timidly approached the fence together, stopping some distance to examine it. One of the three approached within 1.5 m. They deflected back into the trees at a slow walk, continuing westwards. 215 metres on a hartebeest joined the group and they continued together walking westwards another 1.1 km. At this point they passed the end of the 'wildlife-friendly' fence where it ties into the wildlife-proof fence and continued walking steadily westwards now trapped to the south by the tall fence. HL and NK commented, "Because of this fence, they will kill [poach] these three wildebeest and hartebeest in Hukuntsi."*

Figure 50 Master Tracker Horekwe "Karoha" Langwane indicating where a gemsbok contacted the wildlife-friendly fence, bending the metal fence post and damaging the top wire, failing to cross and returning the direction it came.

Figure 51 Remains of a gemsbok killed upon impact with a stabilizing fence post along the wildlife-friendly fence.

Figure 52 Master Tracker Njoxlau Kashe showing where a hartebeest contacted the wildlife-friendly fence at a fast gallop, bending a metal fence post and falling turned 180 degrees on the other side.

The wildlife-friendly fence was erected to limit livestock access to the highway and thus reduce vehicle collisions. Wildlife responses to the fence suggest there is no easy design solution to allow unhindered wildlife passage, whilst maintaining its barrier property for livestock. It is believed that fencing roadways in western Botswana reduces collisions with livestock. However, just as the Roads Department's assumption that improving roads reduces accident rates is invalid (Archer et al. 2005), so too does the excluding livestock with fences assumption need to be scrutinized. As wildlife-caused damages to the wildlife-friendly fence accrue, it becomes more permeable to livestock. However, even if maintained, the fence is not a barrier to livestock. During our survey, young cattle were observed jumping an undamaged section of fence. Furthermore, cattle, donkeys and horses can be observed in numbers throughout the entire 108 km length of Kang-Hukuntsi highway right-of-way between the fencelines, i.e. not only the wildlife-friendly fence but also the full wildlife-proof fence fails to keep the highway livestock-free. This pattern is observable throughout western Botswana wherever fencing as been erected along roads. One problem appears to be the gated accesses to cattleposts off the highway, whereby gates are left open or removed, perhaps even purposefully to allow cattle grazing throughout the highway right-of-way when grazing is depleted outside of the fences. Thus, in some cases fences might be doing the opposite of what they were intended to do, exacerbating the problem by concentrating livestock inside the highway right-of-ways (Keeping et al. 2015).

Although well-intentioned, the wildlife-friendly fence fails to achieve its intended dual purpose of facilitating wildlife movement and restricting livestock. A valid argument supporting its continuance seems to be lacking, other than psychological amelioration for motorists. We suggest that its deactivation/removal as per the alternative development scenarios is an easily implementable low cost/conflict mitigation action that will deliver disproportionate enhancement of free-ranging Kalahari antelope connectivity through the central corridor. Ideally, all fencing materials be removed as even downed wires pose an entanglement hazard to wildlife. Cattle grids could be installed over the highway at both tie-ins with the wildlife-proof fence (consistent with the design used at other wildlife corridor areas along the Trans-Kalahari highway) to limit livestock movement into the high-fence right-of-way. This could be done in combination with enhanced signage that educates motorists and encourages safer driver behavior (Figure 40). Although in practice all fence types fail to keep Kalahari highways livestock-free, there is even less reason to fence sections that bisect WMAs which have the least livestock numbers and pose the least risk of collisions.

Figure 53 Example signage to affect motorist behavior where unfenced highways bisect major wildlife corridors. British Columbia, Canada.

4.5.4.3 Poaching

The WMA-CGA cattlepost frontier within the AOI is > 2,000 km long. It is along this vast frontier that most poaching activity occurs. Incentive to push land boards for waterpoint applications as far as possible into WMAs appears not only to be motivated by access to pristine grazing, but also access to wildlife and avoidance of law enforcement.

Researchers have noted the large gap between the extent of livestock influence from cattleposts and where wildlife, particularly gemsbok and eland, begin to occur (Verlinden et al. 1998, Bergstrom and Skarpe 1999, Senyatso 2011) resulting in an “empty savannah’ phenomenon (Perkins 2018). Some speculate this pattern is a consequence not of livestock influence (e.g. overgrazing, disturbance avoidance), but unregulated hunting (Senyatso 2011, Verlinden et al. 1998). If this is true, then poaching must be a remarkably consistent phenomena emanating from virtually every cattlepost in the Kalahari with approximately equivalent intensity. Only that would explain the astonishingly strong p-values relating gemsbok and eland to kraals density. Having been quantified from thousands of gemsbok and eland observations in relation to thousands of kraals, each sampled across the broad extent of the AOI over a decade, indicates just how incredibly consistent and predictable the spatial patterns are. It means anti-poaching efforts are ineffectual to influence wildlife distributions at the landscape scale. It also means the patterns are highly unlikely to change in the future.

If it is indeed ultimately human behaviour that determines the most predictable pattern of wildlife distribution in the Kalahari landscape, one would like to believe that it could, potentially, be malleable. We therefore suggest the possibility of enhancing wildlife landscape connectivity by strategically focussing anti-poaching efforts at those cattleposts influencing the extents of the most vulnerable corridor pinchpoints (see Section 4.4). Anti-poaching effort presently appears focussed on RAD communities in relation to the vast WMA-cattlepost frontier where the majority of poaching happens. Increased anti-poaching effort utilizing the proposed cutlines or two-spoor trails marking the WMA-CGA boundaries (see Section 4.5.3.1) could also potentially assist and enhance wildlife population connectivity.

We stress, however, that spatial details pertaining to land planning described for each Scenario in Section 3.2 - down to the individual waterpoint location - need to be followed if the outcome anticipated as modeled by that scenario is to be achieved. The KWLCA has thoroughly demonstrated that the location of waterpoints-cattleposts-kraals is what overwhelmingly determines gemsbok and eland occurrence and that this encroachment is what shrinks cores, narrows corridors and isolates populations, regardless of whatsoever proximal mechanism(s) (such as poaching). Only through informed land planning that accommodates predictable human behavior (i.e. traditional cattlepost culture) can core areas and corridors be conserved. To believe that enhanced anti-poaching efficacy could revitalize wildlife areas alone without the accompanying land use planning, or that wildlife corridors can function with cattleposts within them so long as they are intensively enforced - is pure fantasy.

4.5.5 KWLCA scenarios in relation to existing land use plans

Regarding harmonization of the Botswana National Spatial Plan (MLWS 2018) and KWLCA, there are two key takeaways:

1. WMA boundaries in the western corridor do not change across scenarios and are consistent with those presented in the NSP, with a couple minor exceptions. WMA boundaries not only remain essentially constant across all scenarios in the western corridor, but at the AOI scale also. Thus, land use type polygons are largely harmonized between the NSP and the scenarios in the KWLCA. The limited exceptions are: a) the removal of the most southerly row of ranches from the proposed layout for rezoned GH11 in Scenario 14, b) the alternative expansion areas proposed in the scenarios which represent functional losses to specifically targeted areas of select WMAs, culminating in their greatest extent in Scenario 14, and c) the notable deviation by government from the NSP in the imminent ranch layout planned for rezoned SO2 WMA, this deviation accepted in the KWLCA. The NSP proposed to re-designate SO2 and KW6 as WMAs to restore the eastern corridor linking KTP to Khutse, as highlighted by Keeping (2015, 2017), but already plans have advanced in Southern and Kweneng Districts to relinquish WMAs.

2. The Green Preserve concept will fail to be achieved by simply mapping WMA land use boundaries. This is because polygon-based land use planning that has been done to date, and exemplified by the NSP, ignores agricultural encroachment into WMAs. As the KWLCA shows, this unacknowledged encroachment renders large areas inside WMA boundaries dead zones of unsuitable habitat for wildlife. These zones of cattlepost encroachment into WMAs instead function like CGAs from the perspective of wildlife. Thus, the only way to achieve the conservation goals engendered by a Green Preserve concept is to recognize that land use polygon boundaries are too coarse-grained and illusionary compared to reality on the ground. Instead, land planning must now explicitly acknowledge human land use at the cattlepost (kraal) scale and implement mitigations at this scale as defined in the KWLCA. This is especially relevant to the huge areas of WMA affected by RAD development zones, in addition to other haphazard encroachment deviating from LB waterpoint spatial allocation policy. It is now necessary for land planners to incorporate fine-scale planning in the form of individual waterpoint locations, as defined in the KWLCA scenarios. In other words, if presentations of the Green Preserve concept made simply as WMA land use polygon boundaries are to be taken seriously, that is expected to achieve their conservation goals, then LB policies for waterpoint allocations and RAD development zones need to reconcile with a stricter recognition of WMA land use than at present.

4.5.5.1 Recommended revision to the NSP Green Preserve and associated wilderness trail(s)

The KWLCA predicts that when planned ranch layouts are implemented (Scenario 2) no eland or lion connectivity will remain through the western corridor, and gemsbok will hold only a most tenuous connection - arguably not a “Green Preserve”. At present time the central corridor is more important to gemsbok than is the western corridor. Additionally, limited track sampling indicates notable activity for other species at the pinchpoint of the central corridor across the ‘wildlife-friendly’ fence of the Kang-Hukuntsi highway (see Table 24, Section 4.5.4.2.1). Yet the Green Preserve proposal in the NSP refers to the western corridor only, ignoring the central corridor entirely.

To align with the new knowledge and land use planning guidance brought forth by the KWLCA, we propose a geographic broadening of the Green Preserve concept to encompass the central corridor in addition to the western corridor. The NSP appears to have underestimated the importance of the central corridor which under future mitigative scenarios assumes comparable importance to landscape connectivity as the more popularized western corridor. Each are important to overall landscape connectivity that works to prevent confinement and decline of free-ranging Kalahari wildlife populations into the future.

In addition to including the central corridor into the Green Preserve, we propose an accompanying second wilderness trail through it (Figures 54,55). Each wilderness trail would trace the wildest central thread through their respective corridors. They would interlink pans, providing numerous options for scenic wilderness camp sites. The two wilderness trails would provide connection through both available access points to the KTP (Kaa gate and Mabua gate) instead of Kaa gate only proposed in the NSP (Mabua gate is the busier of the two). The two wilderness trails would strategically link tourism ground traffic from CKGR and northern tourism areas with KTP/Mabuasehube, potentially facilitating more involvement of Maun-based operators in the south. Currently ground linkages between these areas are both indirect and uninteresting. There is further potential for a 3rd wilderness trail linkage through GH10 down the Okwa valley to the CKGR boundary and Xade gate. If implemented this would complete an ideal wilderness trail routing between Two Rivers and Matswere gate in northeast CKGR, fulfilling the majority distance component of the NSP vision for a wilderness trail traversing the full length of Botswana within the Green Preserve along the rainfall gradient between Two Rivers and Kasane.

KD5/6 are relatively small WMAs dependent on connectivity with adjacent WMAs via the central corridor to remain viable for wildlife and therefore viable for continued natural resource based economic benefits to neighbouring communities’ CBO Mahumo Trust (e.g. KD6 hunting quota). A motivating argument for urgent implementation of the wilderness trails is that it will invigorate beleaguered CBOs and give less endowed WMAs (such as KD5/6) a foothold in CBNRM and the non-consumptive natural resources economy as an alternative to livestock encroachment. This has been shown with success with Zutshwa community in KD2. It is recommended that government, including parastatals (e.g. BTO) would best step back and allow NGO/private sector experts to finalize the exact physical wilderness trails routes, campsite locations, associated signage and infrastructure, and the operation and management of the trails in collaboration with the participating communities linked to WMAs KD1/5/6/12, GH10/11/13.

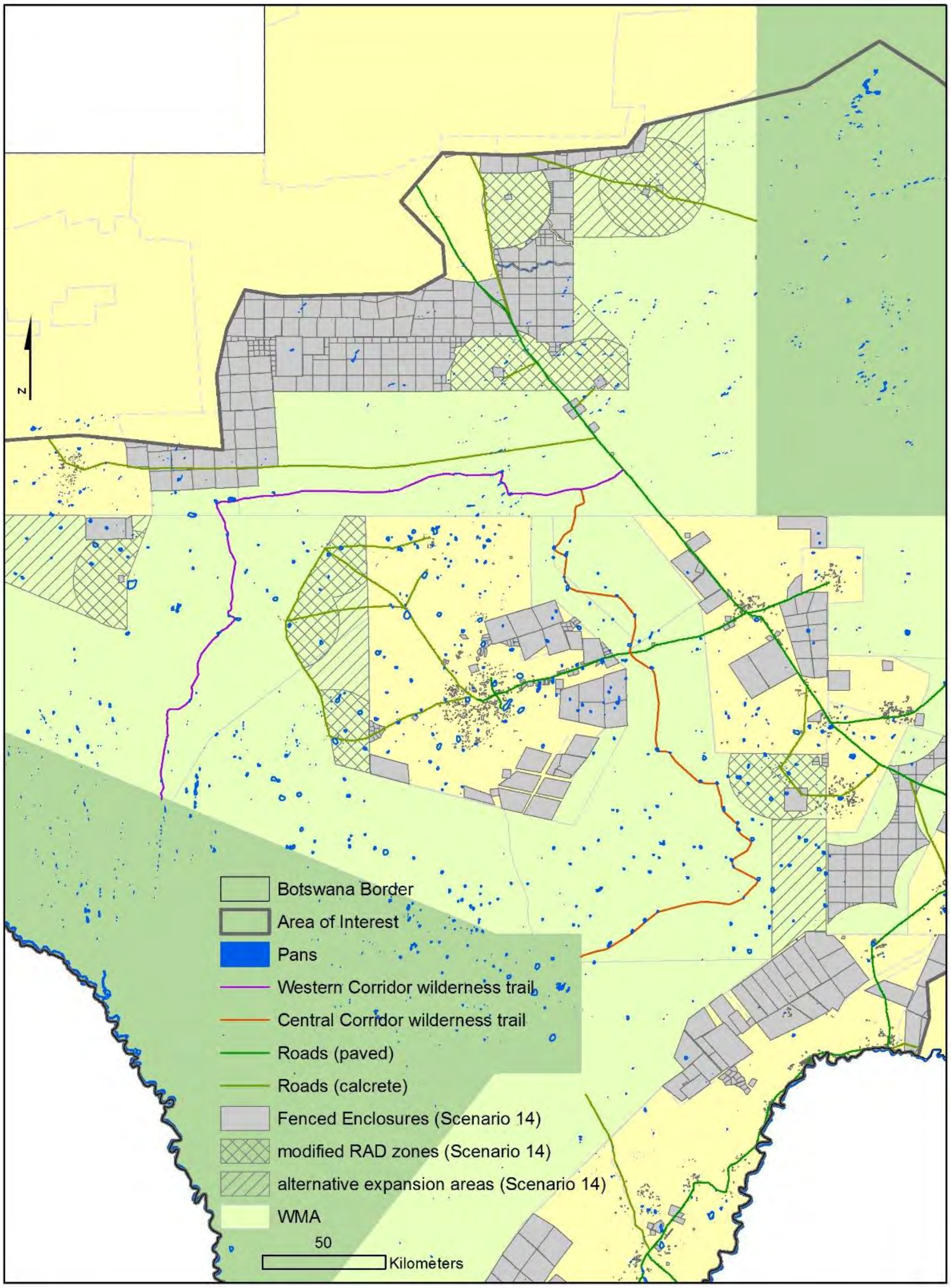


Figure 54 New wilderness trail routes through each of western and central corridors comprising a broadened Green Preserve concept. Land use demarcations for Scenario 14 are indicated.

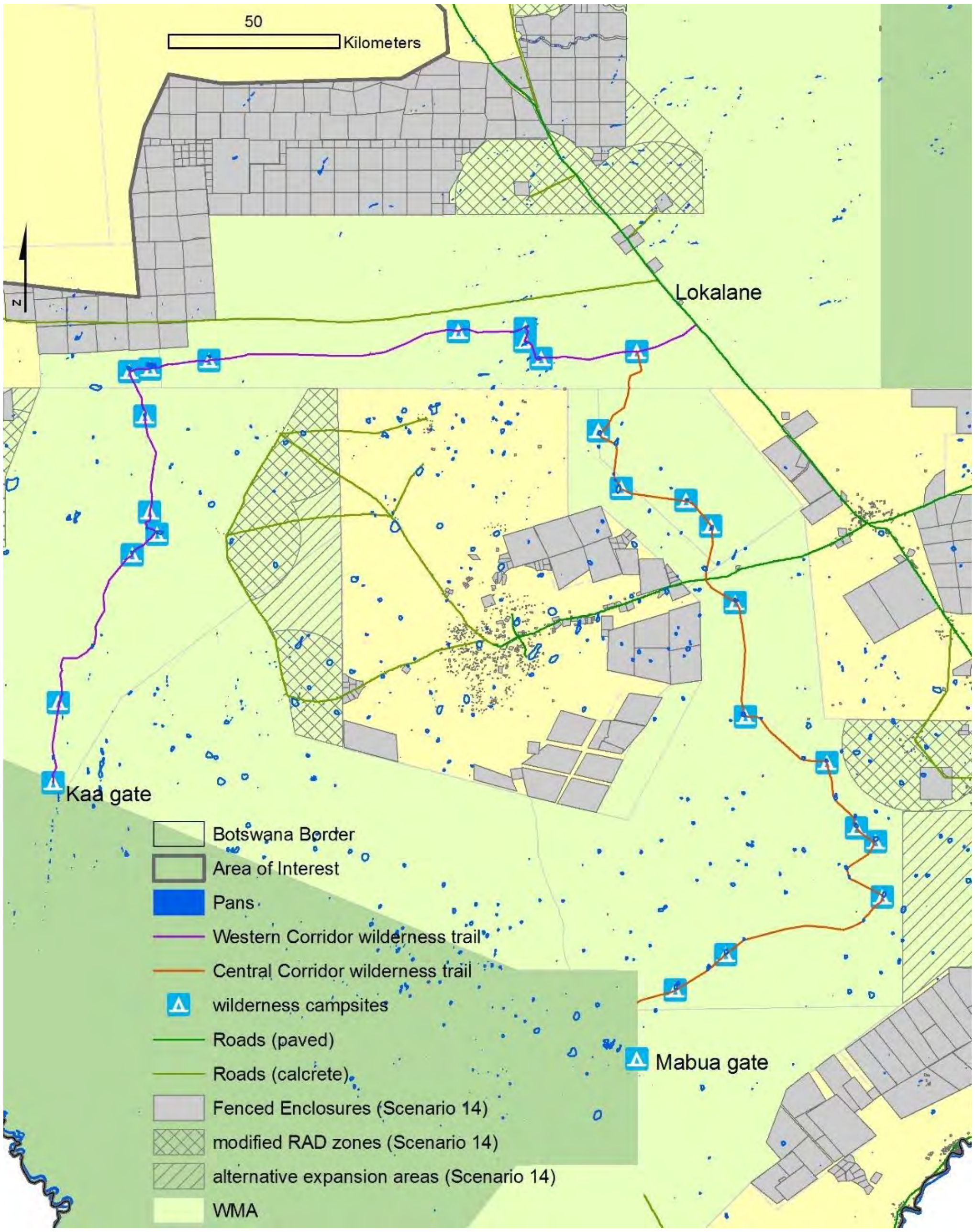


Figure 55 Zoomed new wilderness trail routes through each of western and central corridors comprising a broadened Green Preserve concept. Access points at the KTP are indicated as well as the intersection with the Trans-Kalahari highway near Lokalane. Proposed wilderness campsite locations along the trails are indicated. Land use demarcations for Scenario 14 are indicated.

4.5.6 Conclusion

We set out to definitively, quantitatively answer the question: What are the limits to agricultural encroachment in this landscape which maintains population connectivity between protected area cores for the three most disturbance-sensitive wildlife species and therefore presumably the complete free-ranging wildlife community in Botswana's Kalahari? More simply stated, "How much agricultural encroachment into the Kalahari is too much?"

The answer, in simplest terms, is that in some locations agricultural encroachment has already exceeded thresholds for safeguarding minimal corridor widths, and what is planned but not yet implemented is definitely too much. Pastoral encroachment in Botswana's free-ranging Kalahari wildlife landscape has thus arrived at a critical threshold. As we quantitatively demonstrate in this report, population connectivity between the two great protected areas (KTP and CKGR) among the most conservation-sensitive wildlife species is imminently threatened by both planned livestock expansion and even that which is already approved and allocated but not yet implemented. Without changing course, we show how the landscape will be fragmented into two isolated pieces with respect to the most disturbance-sensitive wildlife species. Land use planning thus finds itself at a decisive crossroads in determining the future of the Kalahari ecosystem.

The present KWLCA was conducted precisely to assist land use planners, and Botswana's government more broadly, in decision-making to achieve a balanced trade-off between development and conservation in the Kalahari ecosystem. We combined the highest quality and most extensive existing wildlife occurrence database with the best existing science to generate quantitative predictions of past, present and future landscape outcomes regarding habitat quality and population connectivity for key sensitive wildlife species so that decision-makers are clearly informed about the consequences of land use policies and can therefore choose which actions to take to achieve a sustainable future for the Kalahari ecosystem.

Generating these scenario predications involved manipulating the high-resolution anthropogenic landscape according to specific land use changes. We provided detailed descriptions of each scenario in Section 3.2 so that land planners have all the spatial information they need to implement and realize any given scenario. We applied two wildlife movement-based connectivity modelling approaches (resistant kernel and factorial least cost paths) to each scenario to predict and quantify changes to the connectivity landscape. Resistance surfaces formed the foundation of these connectivity models, and these were derived from the occurrence probability (HS) models of Phase 1. Of three species selected for Phase 2 connectivity modelling the two antelopes (gemsbok, eland) had the highest performing models among the complete mammalian wildlife community (32 species), largely due to their exceedingly high spatial predictability in relation to the density of human-livestock disturbance (i.e. kraals). As future scenario land use changes mainly involve permutations of kraals distribution and density, the Phase 2 models, therefore, offer powerful predictions. In addition to the effects of kraals, roads and fences were included in the resistance surfaces based on empirical data regarding their barrier and filter effects on movement of these focal species in this ecosystem.

We first offered a look into the past, showing that the three most disturbance-sensitive wildlife species have experienced an estimated average 45% loss of habitat suitability across the AOI since pre-settlement to present time. We produced 13 future scenarios, discriminated and categorized in an attempt to provide the most useful information to land planners. The first nine scenarios examined land use changes in isolation. This allowed us, for example, to pinpoint the disproportionate quantitative gains to the wildlife landscape from relatively modest interventions like deactivating the undesirable encroachment inside southern GH11 WMA (7.7% improvement to overall landscape least cost path connectivity for gemsbok) and "low-hanging fruit" such as removing the deteriorated wildlife-friendly fence (13.3% improvement to overall landscape least cost path connectivity for gemsbok). Isolated elements were combined to produce realistic cumulative development trajectories among the final 4 scenarios (i.e. encompassing all concurrent changes expected to happen throughout the landscape).

Scenario 11 simulates the current business-as-usual trajectory including all known changes coming to the landscape, be they already allocated, planned or intended. Scenarios 12-14 are alternative development pathways to Scenario 11 that incrementally optimize the core and connectivity landscape with the least possible mitigative effort and compromise to planned agricultural expansion, thus balancing agricultural ambitions with the needs of free-ranging wildlife. Contrasting with the haphazard encroachment into some sensitive wildlife areas characterizing Scenario 11, in the alternative development scenarios selected planned agricultural expansion (e.g. partial relinquishment of select RAD 20km radius expansion zones), and few disproportionately damaging cattleposts at the corridor pinchpoints, are strategically reallocated to areas less important for wildlife. These areas of the landscape where agricultural expansion could occur with minimal negative impact on corridors and core areas were identified as 'alternative development zones (or polygons)'. Notably, in the final iteration (Scenario 14), the total alternative area proposed for agricultural expansion equates to that necessarily mitigated to rescue the wildlife landscape.

Modeling of the present time landscape predicted all three disturbance-sensitive species currently maintain at least tenuous population connectivity between the two PAs. The lion least cost path model generated a surprising prediction of connection not through the least-disturbed area of southern GH10/11 but along the Okwa valley through GH9 CGA. This discovery unfortunately came too late in the analyses to explore mitigative options for the rezoned GH10/11 ranch layouts. Such mitigation would, however, be worth pursuing, and if there is interest we could provide further spatial guidance than supplied in this report.

Scenario 11 reveals a prescient warning of proceeding along the business-as-usual development trajectory that has to date not taken into consideration the landscape needs of the exceptional Kalahari wildlife resource. This current course leads to an average 20% loss of habitat suitability for 3 most disturbance-sensitive species, and average 55% loss in path connectivity throughout the ecosystem. It closes all corridors, fragmenting and isolating populations, generating a Kalahari landscape no longer connected. Notably, the future landscape might become much worse for wildlife than modeled in Scenario 11. This is because only the agricultural encroachment which is known to be planned during the time of consultation with LBs and government departments (during late 2021) is included in Scenario 11. Moreover, LB databases of waterpoints were vetted for applications inside WMAs (beyond RAD development zones), while in practice some of these may be developed in the future.

Encouragingly, the alternative development scenarios with least-cost trade-offs provide predictions that avert this unfavorable trajectory if implemented. Landscape connectivity improves iteratively from Scenario 12 to 14. Scenario 14 is the final mitigative iteration and only one that restores connectivity for all 3 disturbance-sensitive species through two functioning corridor habitat linkages between KTP and CKGR. It therefore defines the minimal mitigative effort necessary to achieve KGDEP Component Goal 3. **To achieve this requires: gazettement of and no waterpoint encroachment into WMAs (including KD5/11), relocation of cattlepost encroachment in KD6/12 and southern GH11 WMAs to alternative development zones, modification to select RAD community 20 km radius development zones offsetting future expansion of RAD waterpoints to alternative development zones, removal of the Kang-Hukuntsi wildlife-friendly fence and prohibiting any future obstructive fencing along this stretch of highway and the Trans-Kalahari Transportation Corridor in southern GH10/GH11 WMAs.**

Rapid landscape transformation is unfolding as a result of RAD policy that encourages cattlepost proliferation within 20-kilometre radii of communities inside WMAs. The crucial point is recognition of the far-reaching spatial impacts of livestock development on conservation-sensitive wildlife. Scenario modelling clearly shows that these development circles as planned exceed the limits of encroachment tolerable for a functioning western corridor. They also undermine the most critical area of landscape connectivity south of Bere and Kacgae villages where western and central corridors converge into a single vulnerable linkage for wildlife between KTP and CKGR. Scenarios therefore necessarily presented spatial modifications to the RAD policy, specific to village. However, areas relinquished for conservation are offset by alternative expansion zones away from sensitive wildlife cores and corridors. Not only are the modifications shown to salvage wildlife connectivity, we suggest they may in fact enhance the future economies of those RAD communities situated in the most sensitive wildlife areas by balancing livestock development on the one hand with the multitude of wildlife and ecosystem-related benefits on the other.

The alternative development paths (Scenarios 12-14) require mitigation both to a limited number of cattleposts already established, and a larger number of waterpoints in application and allocated but presently undeveloped. It is imperative that mitigative details (e.g. specific waterpoint locations) provided in the scenario descriptions (Section 3.2) are followed to achieve a desired scenario approximating the simulated predictions.

The alternative development paths (Scenarios 12-14) incur substantial levels of loss in both habitat suitability (see Tables 16-18, Section 4.1.2) and connectivity (see Tables 19-22, Section 4.2), although less than the business-as-usual (Scenario 11) trajectory. We strived to find the least cost/effort mitigation necessary to salvage connectivity through Scenarios 12-14, so it is important to realize that these future scenarios accept in large part the planned future agricultural development in this landscape as a perhaps politically unavoidable reality. It is the spatial fine-tuning of exactly where agricultural encroachment occurs, down to the individual waterpoint allocation level around which kraals cluster, that the analysis has defined as the necessarily minimal mitigation to bring about the desired landscape connectivity outcomes. Restoration could get much more ambitious beyond that presented in the alternative development path Scenarios 12-14, but our view is that this is not politically feasible in the current climate. Thus was stuck as minimally and conservatively selective as possible in the mitigation modeling – which is indeed the reason it took three iterations (Scenarios 12-14) to achieve predictive connectivity for all 3 most disturbance-sensitive wildlife species. To render the necessary mitigative interventions defined by Scenario 14 more as implementable as possible, we have identified and defined specific locations of WMAs as sacrificial alternative development areas – that are less risk to the wildlife landscape than the areas of expansion currently planned (e.g. select RAD 20km radii). This alternative development areas increase iteratively in proportion to mitigation required, building towards an optimized landscape striking a balance between agriculture and wildlife to accommodate and maximize both within the counter limits placed by each upon the other.

4.5.6.1 Not only the three most disturbance-sensitive species

Three most disturbance-sensitive species were selected as umbrella representatives for the complete free-ranging Kalahari wildlife community. The track locational data show clearly, reflected in the HS maps, that movements through western and central corridors at present time are especially relevant for other large antelopes including wildebeest and hartebeest. The last severe reduction in Kalahari landscape connectivity occurred when wildlife lost access northeast of CKGR to Makgadikgadi pans and beyond. That caused catastrophic die-offs (Child 1972, Owens and Owens 1983, Parry 1987, Williamson and Mbano 1988, Spinage 1992, Thouless 1998) from which wildebeest and hartebeest have never recovered. This ratcheting down the landscape causing die-offs and forcing the ecosystem to alternative stable-states is foreboding for present landscape planning which will imminently decide whether the remaining free-ranging Kalahari landscape, housed entirely within Botswana's borders, will remain or be split into two.

Presently, data indicate that the central corridor is a highly active conduit for hartebeest and wildebeest (see Table 24). Then in the western corridor, the pinchpoint around GH13, southwestern GH11, and northern KD1 comprises the hotspot of wildebeest wet season range to which they continue to exhibit fidelity over 30 years after the landmark Bonifica (1992) radio-collar study. The planned proliferation of cattleposts within 20km radii of RAD communities Ncaang, Ngwatle, and Ukwi in particular, plus the rezoned area of GH11 WMA to ranch expansion, added the numerous waterpoint applications with GH LB database within this critical area of gazetted southwestern GH11/13 (which were vetted from Scenario 11; see Table 23), will cumulatively predictably compromise this seemingly forgotten and beleaguered critical wet season wildebeest range, and squeeze movement options between here and the protected areas to a threshold of irrelevance. Thus, the no change to land use planning future modeled as Scenario 11 which closes the landscape for three most disturbance sensitive species, probably represents a closing of the landscape for large free-ranging Kalahari grazers comprehensively.

4.5.6.2 Consequences of failing to rescue wildlife population connectivity through landscape planning

The KWLCA set out to provide the best attainable and most scientifically sound spatial guidance for Botswana's land planners so to make possible the achievement of landscape connectivity for free-ranging Kalahari wildlife and therefore balance the increasing conflict between agricultural expansion and wildlife spatial needs as per KGDEP Component Goal #3.

Political failure to follow though is a possibility.

The precise consequences of failure are difficult to predict. The general trajectory, however, is predictable with high probability, informed both by basic theoretical fundamentals of conservation biology, the application of state-of-the-art modeling and our present knowledge of Kalahari wildlife ecology. That predictable trajectory is downward: diminished population sizes, contraction of range towards the protected areas, loss of functional WMAs (i.e. empty of wildlife and therefore irrelevant) and subsequent loss of the tangible and intangible benefits to local communities and Botswana overall. Exactly how much worse and how quickly is complex beyond the scope of the KWLCA. Past experiences are instructive: when the Kuke veterinary cordon fence was erected it roughly halved the country with respect to Kalahari wildlife movements and consequently, within a short span of years, collapsed hartebeest and wildebeest populations by perhaps 90% (Spinage 1992, Thouless 1998) from which they have never recovered. What will halving the remaining free-ranging Kalahari landscape do? How quickly will species slip to extinction when it is added the bleak climate change outlook of extensive drying in southern Africa over the next 80 years and their confined inability to move to survive and adapt as they once did up and down the drought corridor over past periods of climatic change (Perkins 2019)? Granting wildlife populations their necessary minimal spatial requirements to maintain connectivity across the Kalahari landscape (exemplified by Scenario 14) is thus a land use planning strategy of climate change mitigation and adaptation. KTP and CKGR are large compared to other global protected areas, but insufficient in relation to the seasonal resources utilized by exceptionally mobile Kalahari wildlife. Increased artificial waterpoints might only marginally ameliorate the population damage caused by dual blows of connectivity loss and drought. The mechanism of drought-induced die-offs among Kalahari wildlife is probably more food than moisture related. Will Botswana afford to feed wildlife in beleaguered Kalahari protected areas in addition to maintaining water provision? Will it afford to transport animals among isolated habitats to manage genetics of small populations? At such point will the scraps of former free-ranging wildlife glory kept supplemented and artificially bred be genuinely conceived as “wild”-life anymore?

Batswana now have at their disposal the knowledge to make an informed choice about the desired future trajectory at this timely crossroads for the Kalahari ecosystem.

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