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Land-cover change in the Kruger to Canyons Biosphere Reserve (1993–2006): A first step towards creating a conservation plan for the subregion

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ABSTRACT

This paper is a first step towards a conservation plan for the Kruger to Canyons Biosphere Reserve (K2C) on the South African Central Lowveld, quantifying the historical land-cover trends (1993–2006). During the analysis period, 36% of the biosphere reserve (BR) underwent land-cover change. Settlement areas increased by 39.7%, mainly in rural areas, becoming denser, particularly along roadways. Human-Impacted Vegetation increased by 6.8% and Intact Vegetation declined by 7.3%, predominantly around settlement areas, which is testament to the interdependency between rural communities and the local environment. However, settlement expansion exceeded the rate of rangeland growth; in the long term, this may raise questions for sustainable resource extraction. Similarly, the block losses of intact vegetation are of concern; issues of fragmentation arise, with knock-on effects for ecosystem functioning. In the economic sector, agriculture increased by 51.9%, while forestry and mining declined by 7.1% and 6.3%, respectively. The future of these three sectors may also have significant repercussions for land-cover change in the BR. The identification of historical drivers, along with the chance that existing trends may continue, will have important implications for biodiversity protection in this landscape. Applied within a conservation-planning framework, these land-cover data, together with economic and biodiversity data, will help reconcile the spatial requirements of socio-economic development with those of conservation.

INTRODUCTION

Land-cover transformation poses one of the greatest threats to global biodiversity[1] and, in light of extensive land-cover change, protected areas (PAs) are often viewed as the 'Noah's Ark' for conservation. However, there has been growing awareness that formal PA systems are failing to protect global biodiversity effectively[2] and additional areas are required to supplement PAs and connect reserve networks. Off-reserve conservation and matrix management has become an imperative.[3] In order to supplement the size of PAs and link PA systems, conservation initiatives have had to look beyond reserve fences, to the actual management of the surrounding landscape to enhance PA function. Yet, given that land-cover transformation may continue unchecked in the unprotected matrix,[4] land-use in this surrounding landscape may not necessarily support conservation objectives.

Many of the current PAs in South Africa that are, in theory, ensuring the persistence of the country's biodiversity, were established for a different purpose (i.e. as scenic tourist destinations), or were either unsuitable for agriculture or located in residual areas under previous governments.[5] The fact that many of the existing PAs were not explicitly created to ensure biodiversity preservation or the long-term maintenance of ecosystem functionality,[5,6] especially under global change scenarios, suggests that the presently limited conservation funds are not being best employed to meet the full suite of national biodiversity objectives. However, action has begun to address the shortcomings of the national PA system (e.g. *The national protected area expansion strategy*[7]), but competing land-uses and development proposals curtail the scope of such conservation initiatives.

Landscape transformation is inevitable with ongoing population growth and socio-economic development, especially as this development has been prioritised by the National Government's electoral mandate[8] until 2014. Given the current Government's emphasis on socio-economic development, conservation has had to evolve in order to be politically acceptable. Conservation decisions cannot occur in isolation any longer; future conservation initiatives must explicitly acknowledge proposed socio-economic development agendas. The challenge now is how to rectify the failings of the current PA system in order to maximise biodiversity protection, whilst addressing the unavoidable land-cover modification that is associated with economic growth. It is here that systematic conservation planning[9] offers significant opportunities.

The central premise of conservation planning is to make informed decisions about the limitations of current PA systems and direct additional conservation action to ensure *enduring* biodiversity protection. Not only do conservation planners need to be aware of how biodiversity features are distributed, but they also require spatially explicit data on current biodiversity threats (i.e. conservation-hostile land-cover and land-uses), as well as data on the rate of land-cover transformation.[10] Biodiversity conservation is more likely to endure if conservation initiatives consider the spatial requirements of other land-use sectors, avoiding, where possible, those areas that will experience a high probability of conversion in the future. Even within land-cover classes, the capacity and attitude of stakeholders (while not assessed in this paper) are crucial to the success of conservation initiatives; enduring conservation goes beyond simply establishing a biophysical template.

This paper is the first step in a much larger conservation planning exercise for the Kruger to Canyons Biosphere Reserve (K2C; http://www.krugertocanyons.com) in the Central Lowveld area of South Africa. Although the area boasts significant spatial investment in conservation, the subregion, particularly

the western part of the biosphere reserve (BR) that is aligned with the north-eastern escarpment bioregion, still remains a priority area for conservation action.[11] Furthermore, the area is impacted by extensive human settlement and economic activity and certain areas, particularly the former homelands of the apartheid regime, have been targeted as priorities for future socio-economic development (i.e. so-called 'Presidential poverty nodes').[12] Thus the choice of land-use options in the K2C is a highly contested and, often, an emotive issue; any conservation initiative that failed to include land-cover and land-use trends would be ineffective. Acknowledging the history of land-use in the BR will help to identify transformation probabilities between land-cover classes and thereby pre-empt the possibility of spatial conflict between conservation and other land-uses in the future.

In this paper, we quantify the land-cover changes that may threaten the BR's biodiversity and address the historical land-cover in the subregion through the creation of status quo land-cover maps. The landscape and the landscape trends are described in-depth and presented as the net land-cover change (1993–2006) of the subregion. We also quantify the spatial nature of the land-cover change in the BR, highlighting areas of dramatic change and suggesting the direction future research and conservation planning decisions should take.

METHODS

Study area

The K2C covers approximately 2.6 million hectares and traverses the Limpopo and Mpumalanga Provinces (Figure 1). It includes the central Kruger National Park (KNP) and a suite of privately owned PAs. In total, just under half of the BR is dedicated to formal biodiversity protection, while agriculture, plantation forestry, mining and settlements dominate in the remaining unprotected land.

The climate is subtropical, with hot, humid conditions and summer rainfall (500 mm – 700 mm per year). Winters are mild and generally frost-free.[13] The K2C includes three biomes: Savannah (northern, western and central areas of the BR), Grassland (the southern limb and isolated patches in the west) and Forest (small isolated patches across the higher elevation areas along the escarpment in the west of the K2C). It encompasses four bioregions: the Lowveld and Central Bushveld predominate (Figure 1), but areas of Mesic Highveld Grassland and the Mopane Bioregion are also present.[14] The diverse vegetation and habitat types have ensured remarkable conservation and tourism opportunities and, owing to the extensive formal PAs, the subregion is an important ecotourism destination.

The K2C was registered with the United Nations Educational, Scientific and Cultural Organization's (UNESCO) Man and the Biosphere Programme in September 2001. It is the largest BR in South Africa and the third largest in the world. As with other BRs, the K2C is divided into three distinct zones: a core zone, a buffer zone and a transition zone.[15] The core zone (approximately 900 000 ha) of formal protected areas is dedicated to the strict protection of biodiversity, while the buffer zone (approximately 480 000 ha) adjoining the core areas, only allows for activities that are compatible with conservation objectives. Beyond this lies the transition zone (approximately 1.1 million ha), wherein land-users must sustainably manage and utilise the area to maintain ongoing ecological functionality. It is within this transition zone that the subregion's mostly rural and rurban (having both urban

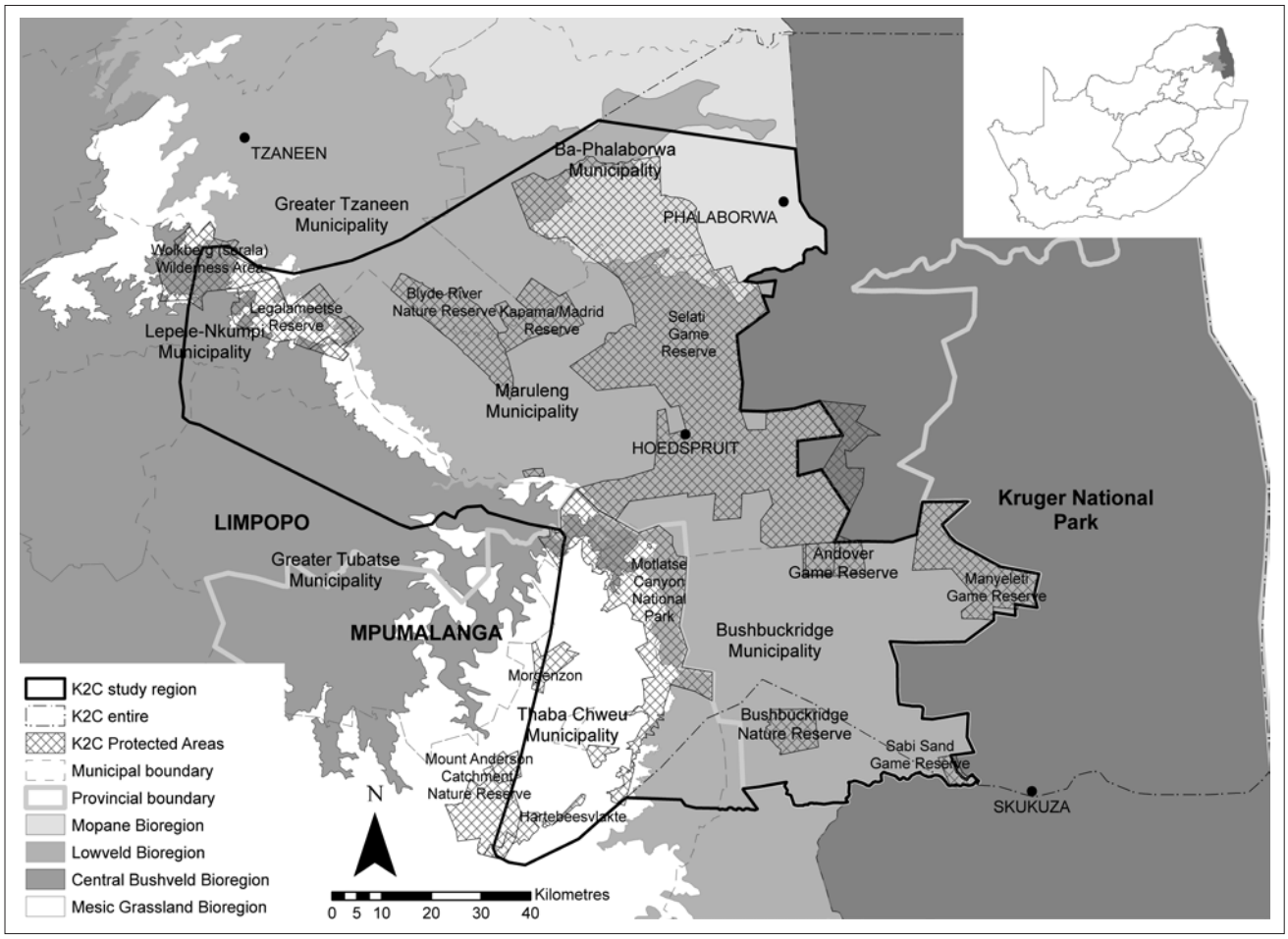

FIGURE 1
Regional location of the Kruger to Canyons Biosphere Reserve (K2C), including protected areas, vegetation bioregions and municipal districts

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TABLE 1
Hierarchical description of land-cover classes used in the land-cover classification procedure

Consolidated land-cover class	Land-cover subclass	Description
Exposed Ground and Rock	Exposed Ground and Rock	• Areas of exposed sand, soil, rock
		• Excludes opencast mines and quarries and fallow agricultural fields
Water	Waterbodies and Rivers	• Open water areas, both artificial and natural areas, and dams and rivers
Intact Natural Vegetation	Intact Woodland	• Intact indigenous plant communities suffering limited / negligible anthropogenic modification
		• Moderately open savannah e g. 'Granite Lowveld' vegetation type[1]
		• Dominated by tall to medium-sized trees with a distinct herbaceous layer
		• Tree species: *Acacia nigrescens*, *A. nilotica*, *A. excuvialis*, *Sclerocarya birrea* subsp. *caffra*, *Combretum apiculatum*, *C. imberbe*, *C. zeyheri*, *Dichrostachys cinerea*, *Peltaphorum africanum*
		• Herbaceous species: *Eragrostis* spp., *Aristeda* spp., *Digitaria erianthra*, *Panicum maximum*
	Intact Thicket and Bushland	• Moderate to dense woodland with a well-developed shrub layer and distinct herbaceous layer, for example, 'Poung Dolomite- and Ohrigstad-Mountain Bushveld' vegetation type[1]
		• Includes bush encroached areas
		• Tree species: *A. caffra*, *A. excuvialis*, *A. erilobola*, *A. tortilis*, *Boscia* spp., *C. apiculatum*, *C. molle*, *C. hereroense*, *Dombeyo* spp., *Euphorbia* spp., *Hippobromus pauciflorus*, *Kirkii wilmsii*, *S. birrea*, *Ziziphus mucronata*
		• Shrub species: *D. cinerea*, *Euclea crispa*, *Grewia* spp., *Ehretia rigida*, *Aloe* spp.
		• Herbaceous species: *Aristeda* spp., *Eragrostis* spp., *Melanis* spp., *Panicum* spp., *Themeda triandra*
Impacted Vegetation	Impacted Woodland	• Human-utilised areas resulting in poor ground cover, reduced vegetation growth and exposed soil patches
	Impacted Thicket and Bushland	• Associated with rural settlement areas and subsistence farming (i.e. communal lands), where land is intensively utilised for livestock grazing and natural resource harvesting
Settlement	Settlement	• Permanent and near-permanent, formal and informal settlement expanses
		• Garden-plots and farm-holds associated with individual houses
		• Building densities range from low to high and include residential small-holding properties
		• Transport-related infrastructure and structures associated with commercial business
Mines	Mines and quarries	• Surface mining and associated operational infrastructure, including that of underground mining operations
Cultivated land	Cultivated land – Sugarcane	• Areas formally cultivated with permanent (i.e. sugarcane, citrus orchards) and temporary (i.e. maize, wheat) crops.
	Cultivated land – Other	• Large formally delineated subsistence fields
	Cultivated land – Fallow	• Fallow lands and areas being prepared for crops
Forest	Forest – Plantation and Indigenous	• Indigenous forest and commercial forest plantations
		• Commercial plantations are dominated by exotic species (*Pinus*, *Eucalyptus*) and are distinguishable from natural forest by the systematic planting pattern
		• Indigenous forest refers primarily to the northern Mistbelt Forest Type[1]
Clearfell	Plantation clearfell	• Residual areas after timber harvesting
		• Dominated by grasses, pioneer species, exotic invader species (e g. *Solanum mauritianus*) and opportunistic seedling recruits of plantation species
Grassland	Grassland	• Natural areas dominated by non-woody plant communities: grasses (Poaceae) and other herbaceous vegetation
Burn Scar	Burn scar	• Recently burnt areas
Cloud Cover	Cloud cover	• Unavoidable cloud cover

Source: Adapted from Thompson[23]

and rural characteristics) population resides (more than 90% of a regional population of more than two million, which, in places, exceeds densities of 300 people/km^2)[16]; poverty and poor economic opportunities have ensured a heavy dependence on the local environment to supplement household income.[17,18,19]

Data sources

Annual status quo land-cover maps were created from Landsat TM images for the period 1993–2006. The pixel resolution of Landsat imagery is fairly coarse (30 m) when compared with other satellite imagery (e.g. SPOT-5: 2.5 m – 10 m, QUICKBIRD: 2.4 m, IKONOS: 1 m – 4 m), as a result of, (1) the large spatial extent of the study region, (2) the temporal extent of the analysis period and the need for annual data and (3) the ultimate purpose of the remote-sensing exercise (i.e. to develop a threat layer for use in a conservation plan). Nevertheless, Landsat imagery was deemed most appropriate for this study because, for prediction purposes, the long-term nature of this dataset is especially valuable. Apart from the analytical benefits of multiple snapshots of the landscape over time, the 13-year analysis period provides an awareness of the change dynamics in this landscape. It incorporates the advent of significant social change in South Africa's recent history (since the 1994 elections) – social change that is likely to have far-reaching consequences for land-cover transformation (e.g. land reform and development proposals in the poverty nodes).[8,12]

For this paper, only the years reflecting the beginning and the end of the analysis period were compared. Winter images were selected to ensure minimal cloud-cover, matching the anniversary of image acquisition as closely as possible to reduce seasonal effects. The raw images were acquired from the Satellite Applications Centre of the Council for Scientific and Industrial Research (http://www.csir.co.za/SAC/). These data were preprocessed by the Remote Sensing Research Unit, at the Meraka Institute (http://www.meraka.org.za), using open source software for high-speed image processing and registration methods.[20]

Land-cover maps were created by a supervised classification method using a maximum likelihood function in which equal prior probabilities were assigned to cover classes. Training sites were based on pre-existing knowledge of the landscape and were selected to best represent each cover type. Classification maps were produced and analysed using geographic information

system (GIS) software packages ArcMap 9.2 [21] and Land Change Modeler for ArcGIS[22]. Changes over the intervening 8 years (for which we have data) were mostly linear, although there was some transient oscillation, and generally reflect the net changes discussed in this paper. All analyses excluded the KNP and adjacent private PAs (now within the KNP fence line) because, as a result of the KNP's permanence and statutory protection, it remains committed to conservation, regardless of any land-cover changes occurring within its borders. Any land-cover changes that do occur within the KNP's borders are unlikely to be the result of extensive human activity, but rather a result of more natural drivers. Thus the inclusion of this area into a land-use 'threat layer' is unnecessary.

Cover classes reflect broad land-cover types specific to the development of a threat layer for conservation planning purposes (i.e. generic conservation priority cover types and land-use threats across the BR, Table 1). The classification structure is hierarchical to a degree, but fine-scale vegetation types were not mapped. Where possible, the naming conventions of the National Land-cover (NLC) classification scheme were followed.[23]

Although 'land-cover' and 'land-use' are related, the terms cannot be used interchangeably. Land-cover refers to the features that cover the earth's surface, whilst land-use involves the human utilisation of a specific land-cover or landscape unit.[23,24] While there can only be one land-cover associated with a specific point at a particular time, a particular land-cover can have multiple land-uses. The classification scheme proposed here reflects land-cover, indicating those major cover types that are specific to the development of both a priority layer and threat layer for the BR. Similarly, the map legend differs from the land-cover classification scheme, in that it presents the land-cover classification in a hierarchical manner, indicating the main cover types applicable to the study objectives (conservation plan) and specific to the scale of the study region[24] (BR scale).

Data analyses

The accuracy assessment of the classification maps was a three-stage process. Stage 1 involved ground-truthing, in which we compared classified maps with the national land-cover maps (1994 and 2000) and original satellite images for major discrepancies (e.g. forest within wetland areas). Although it is unlikely that any remotely sensed land-cover map (including the NLC maps) is a perfect description of reality,[25] this step served to improve the initial supervised classification. If unlikely classifications existed, those pixels were re-examined and adjusted if necessary.

Stage 2 ground-truthing made use of historical aerial photographs, as well as site visits and GPS points for more recent images, while Stage 3 involved post-classification expert refinements of classified images that were based on the outcomes of Stages 1 and 2. For each year, the agreement between classified maps and the real-world was assessed using Cohen's Kappa statistic (K) for classification accuracy[26]; K was calculated on a class-level basis, as well as at the landscape level using the combined class-level ground-truth points (GTPs, Table 2). The number of GTPs per class were initially area-proportional, but subsequently depended on the classification difficulty and potential for spectral confusion between specific cover classes (e.g. Settlement versus Impacted Vegetation, owing to the scarce ground cover and exposed areas in both classes). The strength of classification agreement can be interpreted using accepted benchmarks[27] (Table 3), but, for the purpose of this study, $K > 0.75$ was deemed satisfactory.

Analysis years were classified independently, as were the classes within analysis years, to avoid compounding classification errors through the time series. This, together with the high Kappa values, enhanced the confidence that can be placed in the status quo maps and the overall change analysis.

TABLE 2
Class-level and landscape-level classification accuracy of status quo land-cover maps (1993 and 2006)

Class	1993	2006	Points per class
Settlement	0 867	0 854	250
Impacted Vegetation	0 868	0.772	250
Intact Woodland	0 871	0 834	250
Intact Thicket and Bushland	0 808	0 869	250
Grassland	0 916	0 911	100
Forest	0 906	0 942	200
Clearfell	0 846	0 978	100
Cultivated land	0 900	0 800	150
Mines	0 974	0 968	100
Water	0 907	0 964	70
Landscape total	0 802	0.782	1720

TABLE 3
Interpretation of Cohen's Kappa statistic

Kappa statistic	Interpretation Strength of agreement
< 0	Poor
0 0–0.20	Slight
0 21–0.40	Fair
0.41–0 60	Moderate
0 61–0 80	Substantial
0 81–1 0	Almost perfect

We quantified the net change in land-cover classes between 1993 and 2006 as the percentage change relative to the original 1993 extent. The change is expressed spatially, highlighting areas of transitions between particular cover classes, as well as areas of persistence over the analysis period.

The accuracy assessment of the extent of change compared class-specific classification errors to the magnitude of the changes that were observed. Should the classification error be greater than the observed change, the change reported may be an artefact of pixel misclassification, rather than a genuine change in the landscape. The formula for calculating the classification error was: (1 - the observed agreement of GTPs and status quo maps) × 100.

The formula we proposed above for assessing the extent of change, only considers agreement between GTPs and the corresponding cover class and is expressed as a percentage. In contrast, Cohen's Kappa considers agreement (true positive and true negative predictions), Type I errors of commission (false positives), as well as Type II errors of omission (false negatives), through the use of a confusion matrix and is expressed as a value between $0 \leq K \leq 1$.

RESULTS

Classification method

Given that class-level Kappa statistics indicated a 'substantial' to 'near perfect' agreement with the real world (Table 3), the portrayal of the K2C landscape by the status quo maps was viewed with confidence. Similarly, as the classification error was less than the observed change (Table 4), class-level changes were deemed valid. However, the range of classification errors (0.2% – 5.2%) suggested a differential rate of misclassification across cover types. This range was a function of the class-level classification difficulty and the potential overlap between the spectral signatures that defined each cover-type. Cover-types that displayed within-class heterogeneity, and those that had the potential to share similar characteristics (e.g. Intact Woodland and Intact Thicket and Bushland; Settlement and Impacted Vegetation), suffered a degree of spectral 'confusion' in certain areas. This resulted in a relatively higher incidence of pixel misclassification, as reported by the higher classification errors (e.g. those within the Impacted Vegetation and Intact Vegetation classes, as well as within Settlement areas). Classes with more homogenous cover and distinctive spectral signatures

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displayed less misclassification and, as a result, produced lower classification errors across the class expanse (e.g. Mines and Water).

General land-cover changes

Overall, 36% of the subregion underwent a transition from one cover class to another between 1993 and 2006, regardless of the directional nature of that transition (Figure 2). Spatially, land-cover change dominated in areas of significant anthropogenic activity, that is, in the densely populated rural communities, as well as in the agricultural hubs (e.g. around Hoedspruit). The plantations in the southern limb were also inherently dynamic. The combination of afforestation-harvesting and burn cycles resulted in spatio-temporal inconsistencies in felling across the forestry areas and ensured that these plantations had a fragmented 'persistence' status. In addition, the 2000–2002 construction of the Inyaka Dam immediately west of the plantation area in Bushbuckridge Municipality (Figure 4) further contributed to the change observed at this plantation–settlement interface. The construction of this dam increased the amount of standing water in the BR by 37.1% over 13 years (Table 4).

The protection offered by the private reserves in the central BR contributed considerably to the persistence of the intact vegetation in the subregion, particularly the Woodland-cover class. However, across the escarpment area in the west, topography, and resultant inaccessibility of certain areas, may also have played a role in ensuring the persistence of the Intact Thicket and Bushland cover.

Changes in priority conservation classes: Intact Natural Vegetation

A significant proportion of the BR is dedicated to the 'priority conservation classes' (Figures 3 and 4) – the Intact Natural Vegetation cover classes: Intact Thicket and Bushland (predominating across the escarpment area, where it is interspersed with grassland patches) and Intact Woodland (predominating in the central area).

Between 1993 and 2006, these priority conservation classes declined by a collective 7.3% (an area greater than 460 km^2, Table 4), or 6.5% when natural grasslands were combined into this category, and suffered both 'block' losses (large areas of conversion) and smaller-scale fragmentation to other cover classes. Block losses occurred at the base of the escarpment in the Maruleng Municipality and, most dramatically, on the outskirts of the Bushbuckridge Municipality, extending outwards towards the adjacent privately owned PAs. In this south-central part of the BR, it was the Intact Woodland cover class that underwent the majority of the conversion, changing to a human-impacted version of the original intact vegetation. The Intact Thicket and Bushland class also suffered significant block losses, in the area adjacent to the Bushbuckridge Nature Reserve.

Although there was an overall decline in the expanse of Intact Vegetation within the BR, class-level changes within the combined Intact Vegetation provided interesting results. Across the K2C, Intact Woodland declined by 27.2%, a significant loss of more than 1100 km^2, while Intact Thicket and Bushland increased by 30.2% (approximately 670 km^2). These changes suggested that there were transitional changes within the Intact Vegetation classes (i.e. changes between Intact Woodland and Intact Thicket and Bushland), most likely a result of bush encroachment. Yet, in terms of conservation planning principles, if change is inevitable, changes between intact vegetation classes are preferred over the conversion to other land-cover types, as the resultant cover remains within the 'priority conservation' category.

Changes in Settlement and Impacted Vegetation classes

Over the 13 years, settlement areas increased by 39.7% (more than 180 km^2, Table 4), mainly in the rural areas (Figures 3 and 4), at the base of the escarpment in eastern Maruleng and, especially, across Bushbuckridge. Not only have settlement areas increased in size, but individual settlements have become denser, suggesting a more intensive utilisation of the settlement-space by the (growing) local population. In both municipalities, pre-existing settlement areas expanded outwards, often linking smaller settlement areas and forming areas of near-continuous settlement expanse. This pattern was especially true for areas along transport routes. In Bushbuckridge, a railway line bisects the municipality east to west and village expansion followed this route. However, the smaller, more remote villages in the east also increased, becoming less isolated or developing indistinct village boundaries.

Human-Impacted Vegetation increased from the original 1993 expanse by more than 6.8% (an area greater than 120 km^2) as a result of rural settlement increases (Table 4), suggesting a dependency of the rural communities on the adjacent communal lands.[18,28] Almost all conversion to this cover type has occurred in and around settlement areas, expanding towards the private reserves.

Cultivated land

Agriculture in the BR is dominated by commercial farms, the majority of which occur in the central portion, adjacent to Hoedspruit (Figure 4). Other commercial agricultural areas are found along the Ga-Selati River at the interface of the Maruleng – Lepele-Nkumpi – Greater Tzaneen Municipalities and, to a lesser degree, along the Klaserie and Motlatse Rivers. In these areas, the retention of crops during the winter increased by 51.9% in 2006, while fallow areas doubled, resulting in a combined increase of 86% in formal cultivation (Table 4). This value does not reflect changes in subsistence cultivation in the communal rangelands; changes in informal farm-holdings and garden-plots were associated with the human-impacted natural vegetation around settlement areas.

TABLE 4
Percentage change per cover class including class-level classification error for 1993 and 2006

Class	2006 change relative to original 1993 extent (%)	Observed agreement (%) with GTPs		Classification error (%)	
		1993	2006	1993	2006
Urban	+ 39.7	97 2	96.8	2.78	3.13
Impacted Vegetation	+ 6.8	97 0	95.0	2.98	4.99
Intact Woodland	- 27.2	97.1	96.3	2.87	3.63
Intact Thicket and Bushland	+ 30 2	97 5	96.9	2.47	3.07
Combined Intact Vegetation	- 7 3	95 8	94.7	4.12	5.24
Grassland	- 3.7	99 0	99.0	0.92	0.93
Forest	- 2 0 (entire); - 7.1 (southern limb)	98 2	98.9	1.71	1.09
Clearfell	+ 23.7	98.4	99.2	1.58	0.76
Cultivated land	+ 51 9 (with crop); + 86.0 (total)	95 8	96.9	4.14	3.06
Mines	- 6 3	99.7	99.6	0.27	0.33
Water	+ 37.1	99 3	99.7	0.67	0.28

The plus and minus signs respectively indicate an increase or decline in a particular cover.
GTPs, ground-truth points.

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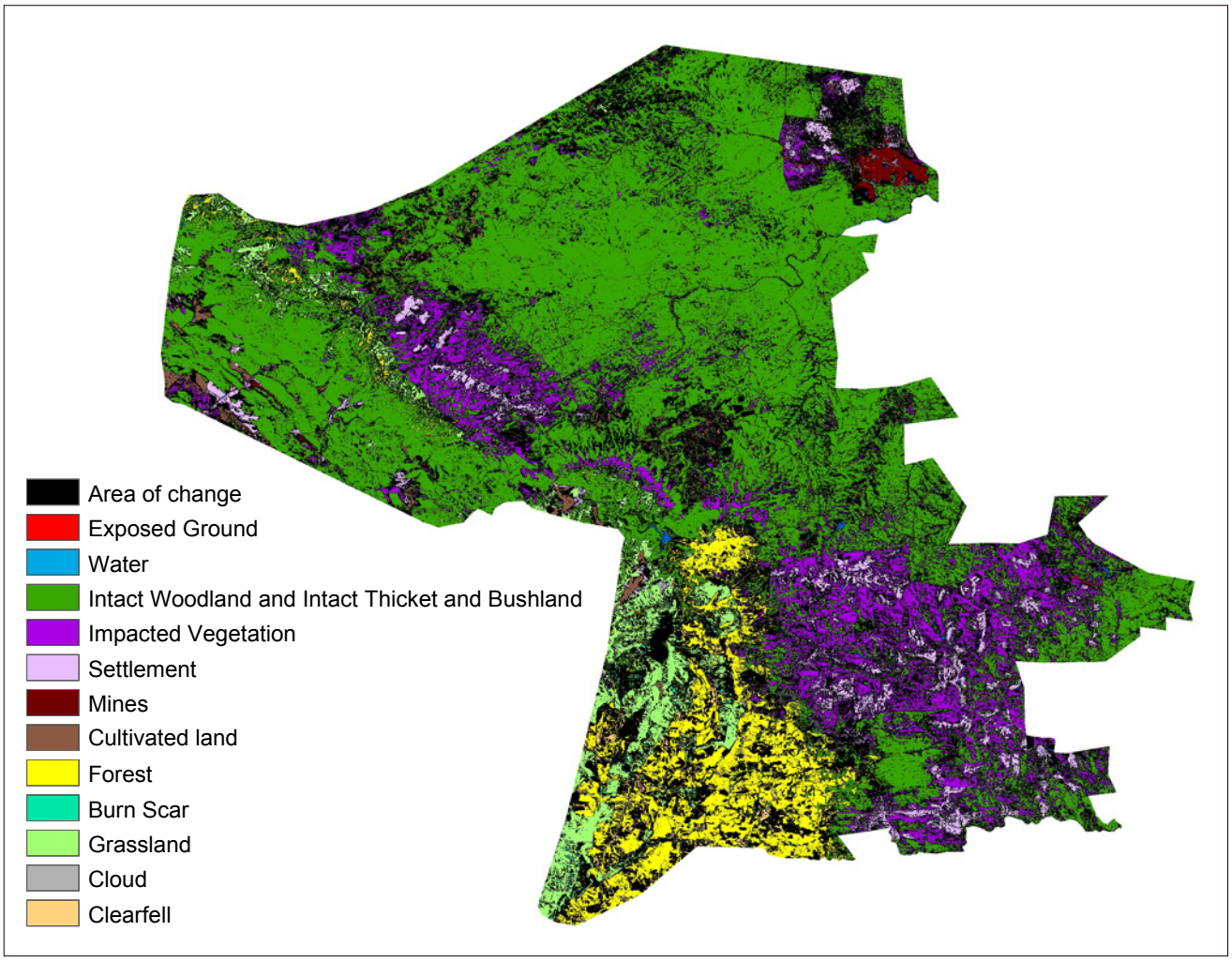

Areas in black have undergone a transformation to another class. These changes exclude any transitions between the Intact Woodland and the Intact Thicket and Bushland classes. For the purpose of this map, these two classes were combined into a single Intact Vegetation class – regardless of the transitions between the two, they remain a priority class for conservation planning.

FIGURE 2
Net persistence of land-cover classes in the Kruger to Canyons Biosphere Reserve from 1993 to 2006

Mining

The K2C includes the largest opencast mine in southern Africa – the Palabora mine in the north of the BR (Figures 3 and 4). There are also smaller mines elsewhere in the BR, but none of which approach the size of Palabora. The Mines class decreased by 6.3% of the original 1993 expanse (more than 5 km^2) across the subregion (Table 4), suggesting that the surface mine expanse has remained fairly consistent for the study period; consistency of this form is typical of established mining operations.

Plantations and indigenous forests

There was a 2% decline in the original 1993 extent of forests across the subregion. The southern limb includes an extensive portion of Mpumalanga's commercial forestry plantations (mostly pines and eucalypts), as well as patches of indigenous forest. In this southern limb, the Forest class declined by 7.1% (Table 4), while Clearfells increased by 23.7%.

DISCUSSION

The K2C is a region of varied and sometimes seemingly antagonistic land-uses, with the KNP, primary production sectors and poor rural communities juxtaposed across the landscape. Yet it is the combination of these land-uses and associated values that has ensured that the subregion has achieved its BR status. The essence of the BR concept is an enduring human–environment relationship,[15] a departure from the traditional 'fortress conservation'[29] views, which were, until recently and are often still, held by many PAs. Hence, land-cover change in this BR is actually expected. Rather than preventing human usage of the landscape, BRs recognise that conservation initiatives may be a means of enhancing local livelihoods[30] and, thereby, a means of facilitating the sustainable use of resources. The K2C mission statement reflects the overarching Man and Biosphere theme, highlighting biodiversity conservation, whilst ensuring that the development needs of other stakeholders in the subregion are met (see http://www.Kruger2Canyons.com). As such, preferential conservation initiatives in the BR are those that incorporate some form of socio-economic benefit for the wider BR community; especially given the current 'Presidential poverty node' status of two of the region's local municipalities, Bushbuckridge and Maruleng.[12]

The K2C is a coupled social-ecological system, that is, an ecological system intrinsically linked to many different socio-economic elements of the landscape.[31,32] The majority of the people in these communities rely heavily on the natural resource economy[19] that is provided by their immediate environment, both as a supplement to household income and a 'safety net' in times of increased hardship.[18,33]

Change in settlement and the rural cultural landscape

Land-cover change predominates in the areas adjoining the dense rural settlements and a broad footprint of change propagates outwards from the village districts (Figure 2).

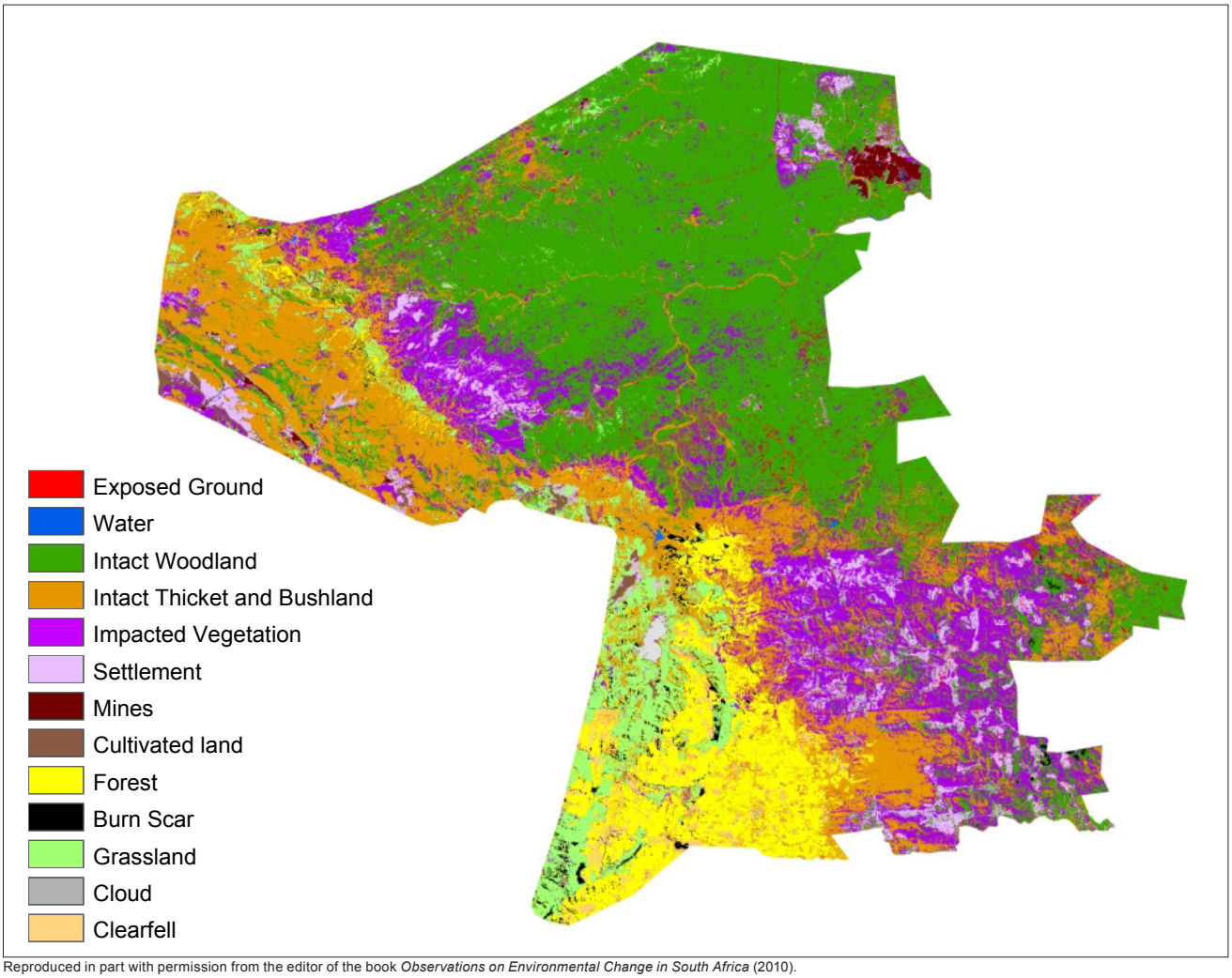

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FIGURE 3
Status quo land-cover map for the Kruger to Canyons Biosphere Reserve (1993)

The former apartheid homelands, with their history of forced settlement, and the more recent influx of foreign refugees into the subregion,[16,34] have produced high human population densities and entrenched poverty.[28,33] The activities of these high densities of impoverished people constitute a primary driver of landscape change observed during the analysis period. In these rural areas, individual villages have expanded and become denser and smaller settlement areas are being near-amalgamated into neighbouring settlements. In particular, settlement expansion tracks transport routes (Figures 3 and 4). In addition, transfers of water to Bushbuckridge from Inyaka Dam may fuel future socio-economic development in the area[35,36] and, as a result, this may have as yet unseen effects on the growth of the regional settlement expanse and, ultimately, land-cover change in the area.

With the expansion of settlement areas, there is a concomitant effect on the surrounding natural environment and the footprint of human impact associated with each village radiates outwards, depleting environmental resources. An analysis of land-cover change (1974–1997)[32] in three villages within Bushbuckridge, also revealed extensive growth of human settlements and an associated decrease in woodland cover. However, the long-term spatial footprint and usage intensity of the communal areas is dynamic[32] and linked to the regional economic climate, local population size, site-specific poverty circumstances and the ecological condition of the environment being utilised. As such, these communal areas pulse with the regional socio-economic conditions and may alter in times of stress.

While expansion of settlement and rangeland are intrinsically linked, the rate of settlement expansion exceeded the rate of rangeland growth during the analysis period. This observation suggests that the spatial limits imposed on the communal areas by surrounding land-uses (i.e. existing village and PA distribution) may prevent the equivalent spatial expansion of rangeland in response to settlement increases. Should this trajectory continue, settlements will continue to erode communal areas, potentially resulting in an unsustainable use of the natural resource base.

In terms of conservation planning priorities, a significant proportion of the Intact Woodland and Intact Bushland loss occurred around these dense settlement expanses (Figures 3 and 4). Here, large areas of this intact vegetation were transformed to an intensively utilised cover type (e.g. around the Bushbuckridge Nature Reserve). Intact Vegetation suffered losses throughout the BR, but from a conservation planning perspective, it is these block losses (as opposed to smaller-scale fragmentation) that are most concerning. Block losses affect coarse-scale structural and functional connectivity and composition,[37,38] potentially undermining conservation possibilities and long-term landscape functioning.

However, change in the study region is not only driven by dense populations of the rural poor. The literature cautions against the assumption of a single, linear change driver (i.e. the expanding rural landscape).[32,39] Drivers of change are likely to be distributed differentially (spatially, temporally, compositionally) across the BR. The industrial sector, the diverse management strategies of

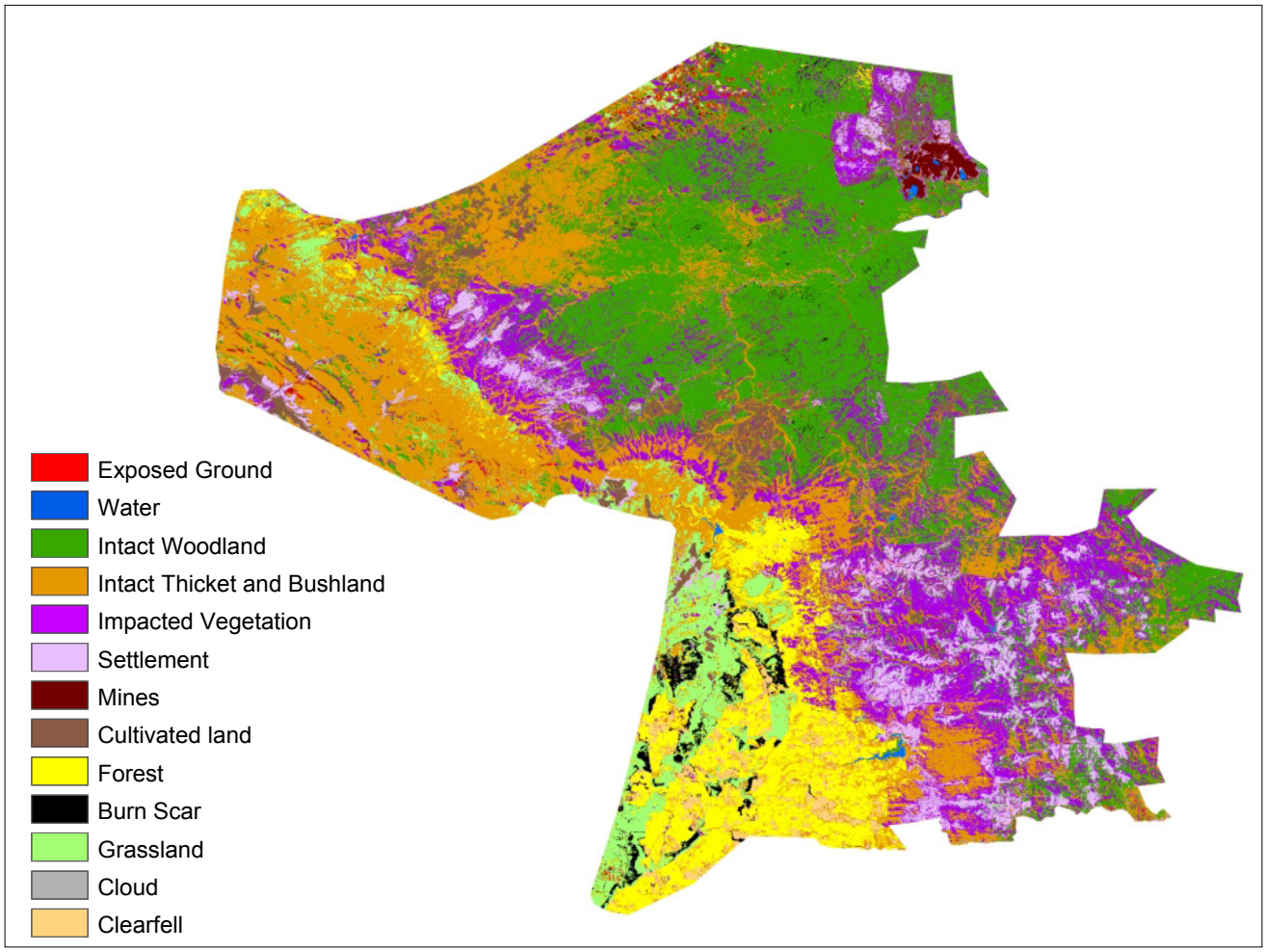

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FIGURE 4
Status quo land-cover map for the Kruger to Canyons Biosphere Reserve (2006)

individual private PAs and the inherent heterogeneity of African savannahs are also responsible for variation in land-cover observed in the BR. For example, the intensive management of the local landscape[40] within private PAs, may resemble areas within communal land, due to the addition of artificial water points,[41] mowing and bush-clearing (Figures 3 and 4). The presence of these bare areas in PAs is detected as land-cover change, as sharply defined as that within intensively utilised communal areas, raises the question of whether all PAs should automatically be considered as 'Intact' and, unequivocally, included in biodiversity planning studies. However, in terms of this study, and in relation to general conservation planning principles[9] (regardless of any ongoing change in the PAs), these PAs will be regarded as a regional conservation commitment, provided that their 'protected' status is maintained.

Change in the core industrial sectors

Commercial agriculture and plantation forestry practices drive considerable change in this landscape (Figure 2), particularly in the Hoedspruit area (agriculture) and in the southern limb of the K2C (forestry). These two sectors are inherently dynamic (agriculture more than forestry) due to the replanting–harvesting cycle.

Plantation forestry is a significant driver of the formal economy in the BR, particularly in the southern limb, where the extensive Komatiland plantations extend beyond the K2C borders. Given the vast expanse of these commercial plantations, any future changes in related land-cover should have implications for biodiversity conservation in the subregion. However, potential changes in this plantation expanse may be positive – as in the proposed transfer of 15 600 ha of the consolidated Limpopo–Mpumalanga forests to the Blyde River Canyon National Park.[42] After rehabilitation, a portion of these in the Sand River catchment will be used to link the smaller Blyde Reserve with the KNP,[43] effectively enhancing overall connectivity in the BR.

Formal agriculture has increased considerably in the BR during the analysis period. This finding is corroborated by provincial agricultural census trends for the 1993–2002 period.[44] In the 13-year study period, the area contained within the large, formal fields (under crop or fallow, commercial or subsistence) has increased substantially. Crop agriculture in the subregion is distinctively seasonal, but was less so in 2006, when more crops endured through the winter. This pattern may reflect either a change in the method of irrigation since 1993, or increased investment in field crops in the region.[44] Future agricultural developments, such as the biofuel development planned for Hoedspruit, may be important for the BR, with significant implications for future land-cover change.[45]

Although mining occupies a relatively small portion of the total available land-surface in the BR (less than 5%), environmental consequences of mining are often locally severe. At this time it seems likely that operations at Palabora mine may continue for at least 20 years, but its eventual closure may have significant repercussions for the regional social-ecological system (i.e. the generation of 'new-poverty'[46] within the mine-employed community after mine closure). Reliance on the rural resource economy may therefore increase, with negative effects on settlement–communal land relationships and regional land-cover change.

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RECOMMENDATIONS AND CONCLUSION

Land-cover change reflects both the status of economic development and the landscape character and condition[47] and will vary with future socio-ecological circumstances. The identification of historical drivers and the possibility that existing trends will continue into the future may have important implications for biodiversity protection in the K2C. In this paper, we have quantified land-cover changes in this landscape, while speculating as to the drivers of this change, yet the long-term transition probabilities between cover classes still need to be determined in a realistic context. Directing conservation action at areas that will remain intact and secure from future transformation, ensures the best use of limited conservation resources, and promotes enduring biodiversity protection.

In terms of application within a conservation planning framework, land-cover data provide an essential 'threat' layer and a spatial basis to determine the potential land-cover conversion risk of important biodiversity features. Yet land-cover data are but one of the required layers of a conservation plan. Economic cost surface data and biodiversity data are also required for a conservation plan, which needs to integrate a wide range of data sets to be effective. Land-cover data implemented within this framework provide a systematic process that addresses the spatial requirements of both conservation and other stakeholders, attempting to reconcile conservation land-use with other land-uses in the BR.

Given the lag between the accumulation of historical land-cover data and the development and, ultimately, the implementation of the conservation plan,[48] it is critical that the methodology employed allows for additional land-cover data sets to be added to the time-series. The raw satellite data are readily available, the procedure used to translate raw images to usable land-cover data sets is clearly defined and, as a result, repeat procedures are feasible and easily achieved. Although this land-cover data set was created for use within a conservation planning framework, these data have multiple applications for PA managers (e.g. in regard to management decisions), community conservation and sustainable resource-use initiatives (e.g. in relation to issues of sustainable harvesting), land-use planners (e.g. regarding settlement growth and associated service delivery) and researchers alike. We hope that these data, and the subsequent studies that develop from their use, will make a valuable contribution to the stakeholders present in the subregion.

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