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The influence of biophysical and socio-economic factors on the effectiveness of private land conservation areas in preventing natural land cover loss across South Africa

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ABSTRACT

There is increasing interest in the potential of private land conservation areas (PLCAs) as a complementary biodiversity conservation strategy to state-owned protected areas. However, there is limited understanding of how the diverse social-ecological contexts of PLCAs influence their effectiveness in conserving biodiversity. Here, we investigated how the effectiveness of South African PLCAs in conserving biodiversity varied across social-ecological contexts, using natural land cover as a proxy. Social-ecological contexts were represented by biophysical and legal factors (distance to towns and roads, elevation, slope, terrain ruggedness, rainfall, PLCA size, distance to state-owned national parks, and presence of legal protection) and, for a subset of commercially-operated PLCAs, management factors (adopted business model, and profitability). Biophysical and legal contextual factors had low explanatory power in the best model for the nationwide analysis ($n = 5121$ PLCAs). For a subset of PLCAs ($n = 72$) we found that effectiveness depended on the strategy they adopted to generate an income, as opposed to the amount of income itself. PLCAs that attracted high volumes of visitors to small properties to view charismatic “Big 5” wildlife were less effective in conserving natural land cover than larger, more exclusive “Big 5” PLCAs and those focused on hunting. Overall, site-specific management factors were better at explaining the effectiveness of PLCAs than biophysical factors. Our findings indicate that conservation practitioners and policy makers need to recognise the diverse goals, motivations and management models of PLCAs when considering how to support them in conserving biodiversity. Future studies could explore whether these trends hold for other proxies of biodiversity conservation, beyond land cover change.

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1. Introduction

There is growing recognition of the potential for private land to contribute to global conservation efforts (Drescher and Brenner, 2018; Nolte et al., 2019; Clancy et al., 2020). Private land conservation areas (PLCAs) complement state-owned protected areas by increasing the total area available for biodiversity conservation (Bingham et al., 2017; De Vos and Cumming, 2019), protecting species and habitats in threatened landscapes that are under-represented in state-owned protected areas (Gallo et al., 2009; De Vos and Cumming, 2019; Heringer et al., 2020; Ivanova and Cook, 2020); and increasing the diversity of tenure types and conservation models that protect and manage biodiversity (De Vos and Cumming, 2019; Archibald et al., 2020; Chidakel et al., 2020). Protected areas with different conservation models are likely to respond differently to social-ecological stressors. The conservation model of many PLCAs, particularly in southern Africa and South America, is centred around ecotourism and hunting enterprises (Kirkby et al., 2011; Shanee et al., 2020; Taylor et al., 2020), and PLCAs can contribute to the resilience of conservation networks by adding redundancy and diversity (De Vos and Cumming, 2019; Börner et al., 2020; Clements et al., 2020). Many PLCAs are also established to buffer and link to existing protected areas (Clements et al., 2018; Chidakel et al., 2020), thereby contributing to the overall efficiency of regional and national conservation systems. However, despite increased acknowledgement of the potential role of PLCAs in biodiversity conservation, little is known about how effective they are, or what determines their effectiveness (Bingham et al., 2017). Improving our knowledge of how PLCA effectiveness varies across social-ecological contexts is therefore critical for understanding how PLCAs can best contribute to conservation and how much, and in what contexts, we can rely on them as a sustainable biodiversity conservation strategy.

1.1. Effectiveness of PLCAs in conserving biodiversity

There is reason to be optimistic about the *de jure* effectiveness of PLCAs (i.e., their “on-paper” tenure security). In South Africa, only 6.2% of formally proclaimed PLCAs have been degazetted or downsized in the country’s 83-year history of private land conservation (De Vos et al., 2019), and in Australia only 8 out of 6818 formal multi-party covenants breached contracts (Hardy et al., 2017). In terms of the *de facto* effectiveness of PLCAs (i.e., their “on-the-ground” conservation effectiveness), the evidence is mixed. In a regional study in the United States, privately conserved lands (both formal and informal) contained more agriculture than forest, allowed for more utilitarian use, and were less resilient to climate change than publicly-owned land (Lacher et al., 2019). In contrast, regional Ethiopian and Peruvian studies have shown privately-owned areas (informally protected hunting and ecotourism concessions) to be more effective in preventing forest loss than state-owned areas (Vuohelainen et al., 2012; Young et al., 2020). Similarly, formally protected Ecuadorian private reserves showed comparable management effectiveness to state-managed areas and higher effectiveness than state-created areas of Forest and Protective Vegetation (López-Rodríguez and Rosado, 2017). In South Africa, PLCAs (formal and informal) were shown to be more effective in reducing natural land cover loss than matched unprotected controls (Shumba et al., 2020).

The limited evidence thus suggests that the answer to the question of whether we can rely on PLCAs to conserve biodiversity long term is “it depends” (Palfrey et al., 2020). PLCAs are ultimately, complex social-ecological systems (Clements et al., 2016; Drescher and Brenner, 2018) whose effectiveness (like that of state-owned protected areas) is likely to be influenced by biophysical, social, economic, and political factors (Palomo et al., 2014; Cumming et al., 2015; Geldmann et al., 2018; Nolte et al., 2019). More than state-owned protected areas, PLCA conservation models vary significantly between or even within countries (Gooden, 2019; Palfrey et al., 2020). They include both privately protected areas, which are formally recognised and predominantly managed for biodiversity conservation as well as a diverse array of more informally conserved areas such as other effective area-based conservation measures (OECMs), which may include mixed land uses and management objectives (Clements, 2016; Dudley et al., 2018). Given this diversity, it is less useful to understand if PLCAs in general are effective, but rather to ask when and why they are effective.

1.2. Possible determinants of PLCA effectiveness

Studies that have considered how the effectiveness of protected areas (public and private) may vary across social-ecological contexts have pointed to complex interactions. These occur at multiple scales between biophysical and socio-political contexts, and endogenous factors such as management models, location, ecology, governance systems, and presence of certain species (Pfeifer et al., 2012; Cumming et al., 2015; Bowker et al., 2017; Geldmann et al., 2018). In the United States, non-governmental organizations were more likely to own easements (a type of formal PLCA) nearer to state-owned protected areas, and have a higher conservation status, compared to easements with local government ownership that were located closer to agricultural land and settlements (Baldwin and Leonard, 2015). Proximity to complementary land uses such as state-owned protected areas may thus influence effectiveness of formal and informal PLCAs, as a result of spill-over effects (Ament and Cumming, 2016; Nolte et al., 2019). Landowner motivations and management strategies on formal and informal PLCAs are also highly diverse (Clements et al., 2016; Gooden, 2019), which can both enhance the resilience of multi-tenure conservation systems and increase uncertainty around their effectiveness (De Vos and Cumming, 2019). In southern Africa most PLCAs are self-funded and consequently have to balance conservation and income generation, which sometimes means owners of informal PLCAs have to be flexible in their management strategies to include hunting, ecotourism, crop cultivation, and livestock ranching (Clements et al., 2016; Shumba, 2019). In some areas, financial motivations have been linked to poor ecological management (Cousins et al., 2010; Maciejewski and Kerley, 2014), which has led conservationists and practitioners to question the effectiveness of PLCAs.

While research on the determinants of PLCA effectiveness is limited, the literature on state-owned protected area effectiveness

offers possible insights. Using proxies such as natural land cover loss or changes in Normalized Difference Vegetation Index (NDVI) metrics such as productivity, structure, or phenology, the effectiveness of state-owned protected areas has been found to vary with accessibility, size, age, funding, law enforcement, and community commitment (Pfeifer et al., 2012; Bowker et al., 2017; Geldmann et al., 2018; Schulze et al., 2018). Highly accessible areas (i.e. closer to settlements and roads and with low elevation and gentle slopes) are relatively more vulnerable to natural land cover loss through deforestation and also by being more attractive for infrastructure development and agricultural conversion (Pfeifer et al., 2012; Bowker et al., 2017). Similarly, conservation areas in places where more people live may see enhanced conflicts over land tenure and other land uses (Langholz and Lassoie, 2001; Naughton-Treves et al., 2005; Miteva et al., 2019), with higher human pressure and greater accessibility routinely associated with lower effectiveness (Pfeifer et al., 2012; Bowker et al., 2017). Size has also been shown to have an important impact on the effectiveness of conservation areas. Smaller protected areas are considered to be less effective than larger ones, given their susceptibility to overstocking and edge effects (Langholz and Lassoie, 2001; Schulze et al., 2018). However, contrary to ecological theory suggesting bigger is better, some studies have found small protected areas to be better in biodiversity conservation, with reasons such as decreased detection of threats and high risk of encroachment thought to compromise the effectiveness of bigger areas (Barnes et al., 2016; Geldmann et al., 2018). Among state-owned protected areas, effectiveness has also been shown to vary with International Union for Conservation of Nature (IUCN) management categories, with highly ranked, strictly protected areas being most effective (Nagendra, 2008; Bowker et al., 2017).

1.3. Quantifying effectiveness on private land conservation areas

The existence of PLCAs, whether formal or informal, can only remain relevant if they can protect biodiversity within their boundaries and beyond (Salafsky et al., 2002; Sayer et al., 2017). However, because PLCAs and state protected areas occur at multiple sites and over large areas, systematically quantifying their effectiveness using ground-based biodiversity monitoring methods such as species population trends (Geldmann et al., 2018) has been problematic due to funding and methodological constraints. Consequently, proxies based on remote sensing, such as forest cover loss, natural land cover loss, and habitat fragmentation, have been common in understanding the effectiveness of conservation areas and how different factors influence their effectiveness (Gillespie et al., 2008; Bowker et al., 2017; Fouch et al., 2019; Nolte et al., 2019). Natural land cover change directly influences species abundance and diversity, climate, nutrient cycling, and soil structure, which makes it an important proxy for understanding the effectiveness of conservation strategies (Fischer and Lindenmayer, 2007; Newbold et al., 2016), especially in the absence of fine-scale data (Sayer et al., 2017; Geldmann et al., 2018). However, despite its usefulness and widespread use, inherent limitations exist in the resolution of satellite images and accuracy in mapping, difficulties in distinguishing invasive species from natural vegetation, and problems in linking natural land cover proxies to the status of endangered species, functional integrity and ecosystem function (Fouch et al., 2019; Martin et al., 2019; Shumba, 2019).

1.4. Study system and objectives

We aimed to improve understanding of the social-ecological factors that influence PLCA effectiveness in preventing natural land cover loss using the South African system of PLCAs as a case study. South Africa is an interesting case study given that the country has a long history of conservation on private lands, with over 5000 PLCAs, which are central to the country's conservation strategy (DEA, 2016a) and display considerable diversity in context and degree of protection (Shumba et al., 2020). PLCAs in South Africa include contractual national parks, nature reserves, biodiversity agreements, conservancies, and conservation areas (Shumba et al., 2020). Contractual parks and nature reserves are formally protected through the Protected Areas Act (DEA, 2016b) and are thus officially recognised. In contrast, biodiversity agreements, conservancies and conservation areas are not officially gazetted. They are thus informally protected PLCAs that offer potential conservation benefits through management practices that align with maintaining a certain degree of "wildness" (Child et al., 2019). These informal PLCAs are characterised by diverse business models to fund running costs, ranging from high-end ecotourism to hunting (Clements et al., 2016).

The objectives of this study were thus to determine (1) the degree of natural land cover change over time in South African PLCAs, as a proxy for effectiveness in conserving biodiversity; and (2) how a PLCA's social-ecological context influenced its effectiveness, considering (a) biophysical and legal factors, in a nationwide analysis, and (b) management factors, for a subset of PLCAs. Informed by existing literature on determinants of conservation area effectiveness (see Section 1.2) and data availability, we denote the social-ecological context of a PLCA using ten factors: distance to towns and roads, elevation, slope, terrain ruggedness, rainfall, PLCA size, PLCA distance to state-owned national parks, presence of legal protection and, for a subset of PLCAs, their adopted business models.

2. Methods

2.1. Study area

We considered a total of 5121 properties satisfying the definition of a PLCA as a privately-owned piece of land managed predominantly for biodiversity conservation, protected with or without formal government recognition (Clements et al., 2016; Shumba et al., 2020). We classified all PLCAs as formally or informally protected based on whether they were legally gazetted or not. Formal PLCAs included contractual parks and nature reserves (gazetted under the Protected Areas Act), while biodiversity agreements (established through agreements between a landowner and a provincial conservation authority), conservancies and conservation areas

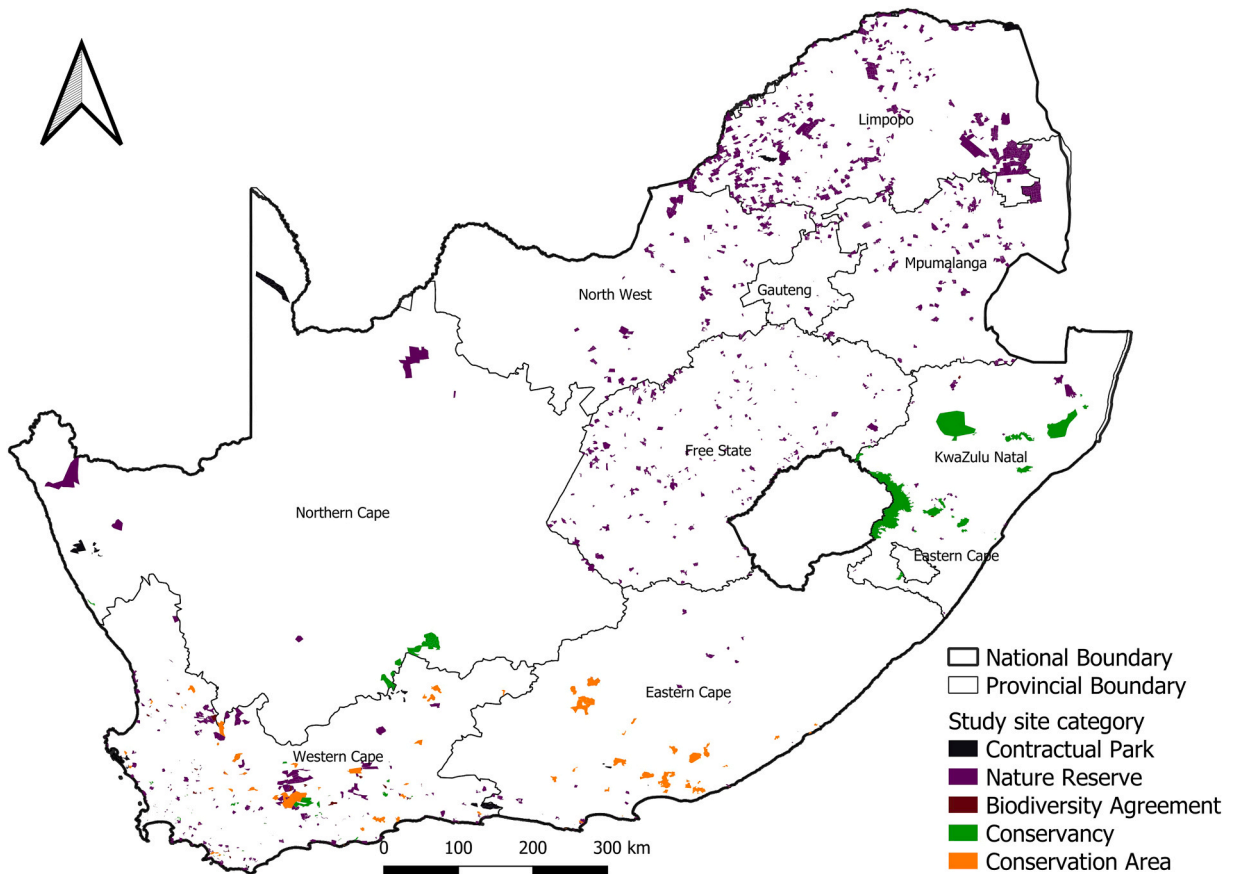


Fig. 1. Map showing private land conservation areas (PLCAs) in South Africa assessed in this study, classified into different categories under which they are managed and protected. Contractual parks and nature reserves constitute formal PLCAs, while biodiversity agreements, conservancies, and conservation areas constitute informal PLCAs.

(established without any agreement) were considered as informal PLCAs (DEA, 2013; Shumba, 2019). See Shumba et al. (2020) for further details on the different types of PLCAs in South Africa, the legal tools under which they are established and managed as well as the incentives and restrictions involved. Spatial data exists for all formally recognised PLCAs in South Africa, together with meta data about their gazettelement dates (age), and ownership, courtesy of the quarterly updated South African Protected Areas Database (DEA, 2013). Such data are not available for biodiversity agreements and conservancies, but are available for some informal areas, collected from previous studies (Clements, 2016; De Vos et al., 2019). Consequently, there is global concern about evaluating the effectiveness of informal areas since for most of them, data about where they are, and when they were established remains unknown (Rissman et al., 2017). The oldest formal PLCA considered in this study was established in 1926, while the youngest was established in 2016. While establishment dates are unknown for biodiversity agreements, it is important to note that they are established through the Biodiversity Stewardship Program, which started in the early 2000s (Shumba, 2019). In total, this study included 127 contractual parks, 4741 nature reserves, 82 biodiversity agreements, 98 conservancies and 72 conservation areas (Fig. 1). Additional analyses were carried out on 72 informal conservation areas, for which management data were available

2.2. Natural land cover change

To address objective 1, the change in natural land cover over time in each PLCA was assessed as a proxy for effectiveness in conserving biodiversity. Natural land cover data were derived from the South African national land cover maps for 1990 and 2013 (DEA, 2015a, 2015b). These maps were created using semi-automated classification of Landsat 4, 5 and 8 satellite images, and had a total of 35 land use classes, a resolution of 30×30 m and a mapping accuracy of 88.36%. We reclassified the 35 classes as either natural or non-natural land cover. Pixels with natural vegetation such as indigenous forests, thickets, woodlands, bushlands, shrublands, and grasslands were reclassified as natural, while transformed pixels including human settlements, mines, cultivated areas, plantations, and degraded bare grounds were reclassified as non-natural (Shumba, 2019; Shumba et al., 2020). See DEA (2015a, 2015b) for detailed descriptions of the methods used to create the land cover products, and detailed descriptions of the different 35 land cover classes. Within each PLCA we calculated the percentage area covered by natural land cover in 1990 and in 2013, to

determine the net change in natural land cover over the 23-year period.

2.3. Determinants of natural land cover change

To address objective 2, we assessed the influence of ten variables on natural land cover change among PLCAs across South Africa, which represent the social-ecological context within which PLCAs exist and are managed. These variables broadly represented biophysical and legal factors including accessibility (distance to town, distance to road, elevation, slope, and terrain ruggedness), climate (rainfall), PLCA characteristics (size, and distance to nearest state-owned national park), and legal protection category (0 – formal; 1 – informal), as well as management factors which were represented by two non-trivial principal components (PCs). We represented continuous variables as raster files, and obtained their corresponding values as averages in each PLCA study site using zonal statistics in QGIS (QGIS Development Team, 2015).

Data for town locations with population sizes $\geq 50,000$ by the year 2000 were obtained from the Global Rural – Urban Mapping project, as vector points (CIESIN, 2017). Using the QGIS `grass, r. grow. dist` command, we then created a proximity to raster layer representing distances from towns with a 30×30 m resolution. The same procedure was used to obtain distances from roads. Data on South African roads, which existed since 1980 were obtained also in vector format, from the worldwide road layer (FAO, 2015). This layer represents major available public domain roads that have existed since 1980. For distance to nearest state-owned national park, we used the geometric centre of state-owned national parks using spatial data obtained from the South African Protected Areas Database (DEA, 2016b). Data on elevation and slope were obtained from the Digital Elevation Model (DEM), Shuttle Radar Topography Mission (SRTM) at 1×1 km resolution (USGS, 2004). Using the DEM layer we calculated the terrain ruggedness index (TRI), in QGIS (QGIS Development Team, 2015). TRI represents a ruggedness value for each pixel in relation to eight neighbouring pixels, with the square root of the sum of squared differences between an elevation pixel and eight neighbouring pixels, giving a quantitative measure for terrain heterogeneity, with a higher ruggedness value indicating high variation (Riley, 1999; Shumba et al., 2018). Precipitation data for South Africa were obtained from worldclim-global climate data (<http://www.worldclim.org/current>). This dataset was compiled from multiple weather stations over the period from 1950 to 2000, with a 1×1 km resolution (Hijmans et al., 2005).

For 72 commercially-operated, informal conservation areas, additional data were available regarding the different business models under which the PLCAs were managed (Clements et al., 2016). These data included biophysical characteristics, as well as management strategies including affordability, available infrastructure, activities, and target market (Table A1). The dimensionality in these business model data was reduced through principal components analysis to two non-trivial PCs, from which four distinct business models (“budget”, “hunting”, “big game day” and “big game stay”), were identified through a cluster analysis (Clements et al., 2016). These PCs have been shown to correlate with PLCA profitability - positively for PC1 and negatively for PC2 (Clements et al., 2016). Budget PLCAs are typically small in size, with no charismatic wildlife species, cheap accommodation facilities, and most revenue coming from unguided ecotourism. Hunting PLCAs are typically large in size and generate most of their revenue from hunting and animal sales. Big game day PLCAs are typically small in size, with low topographic diversity, charismatic species, and intermediately-priced accommodation, making most of their revenue from guided day-visitor ecotourism. Lastly, Big game stay PLCAs have high topographical diversity, support charismatic wildlife species such as lion and elephant, have a limited quantity of expensive accommodation, and generate their revenue from guided overnight ecotourism, game sales and hunting (Clements, 2016; Clements et al., 2016). Table A2 has further descriptions of the business models and their respective means for PC1 and PC2.

2.4. Data analysis

We aimed to determine the best model for explaining natural land cover change across PLCAs and assess how the different explanatory variables influenced changes in natural land cover between 1990 and 2013. Generalized linear models (GLMs) of Gaussian family with Identity link were used. These are a family of non-parametric models appropriate when dealing with non-normal data or nonlinear response variables. These GLMs were executed using the `lme4` package in R Statistical software (Bates et al., 2007; R Core Team, 2018). We standardized all continuous explanatory variables to ensure that they were at a similar scale, with a mean of zero and standard deviation of one and tested them for collinearity, with correlations below 0.70 deemed acceptable. None of the explanatory variables were significantly correlated, hence all were retained for analysis.

Multiple plausible models with different combinations of explanatory variables were run to determine the best set of factors to explain variations in natural land cover change (percentage change between 1990 and 2013), first for PLCAs on a national scale and then on a subset of 72 conservation areas. For the nationwide analysis, accessibility (distance to town, distance to road, elevation, slope, and ruggedness), PLCA characteristics (size and distance to state-owned national park), and climate (rainfall) were used as explanatory variables. For the subset of PLCAs with business model data, PC1 and PC2 were added to the above-mentioned factors, and size and ruggedness were excluded since they were incorporated in the PCs describing PLCA management (Table A1). For both the nationwide and the subset analysis, Akaike Information Criterion corrected (AICc) was used to determine the best models, with the best model being the one with the lowest AICc and highest weight (Burnham and Anderson, 2002). However, for the subset model, to reduce duplication of the national analysis, we grouped the variables based on relatedness, i.e. accessibility (distance to town, distance to road, elevation, and slope), PLCAs characteristics (distance to nearest state-owned national park), climate (rainfall), and management characteristics (PC1 and PC2). Consequently, for the subset model, we ran models with the grouped variables, together with the full and intercept only models, to understand which combination of variables could best explain natural land cover change. We then assessed how well the respective models fitted the observed data and the amount of explained variation using the r-squared value.

Table 1

Top four candidate models and the null model to explain variations in net natural land cover change among private land conservation areas in South Africa based on AICc.

Model parameters ⁺	K	AICc	ΔAICc	w _i	Cum w _i	Rank
town + road + elevation + slope + rainfall + size + ruggedness + category	10	40947.58	0.00	0.66	0.66	1
town + road + elevation + slope + rainfall + size + ruggedness + distnp + category	11	40948.98	1.40	0.33	0.99	2
rainfall + size + ruggedness + distnp	6	40957.64	10.07	0.00	1.00	3
road + elevation + slope + rainfall+size + ruggedness + distnp	9	40958.10	10.52	0.00	1.00	4
Intercept only	2	40979.18	31.60	0.00	1.00	18

⁺town = distance to town, road = distance to road, category = PLCA protection category, and distnp = distance to national park.

The number of model parameters (K), delta AICc (ΔAICc) Akaike weights (w_i) and cumulative AICc weights (Cum w_i) and the null intercept only model are shown.

Table 2

Coefficient of parameters from the best model predicting how different factors influence net natural land cover change on private land conservation areas across South Africa. (* - significant).

	Variable	β	S.E.	T	p
Accessibility	intercept	0.12	0.21	0.59	0.55
	town	0.10	0.23	0.44	0.66
	road	0.17	0.20	0.84	0.40
	elevation	0.59	0.21	2.72	0.007**
	slope	0.12	0.19	0.62	0.53
Climatic	ruggedness	-0.86	0.21	-4.10	< 0.001***
	rainfall	1.03	0.25	4.11	< 0.001***
PLCA characteristics	size	-0.11	0.20	-0.57	0.58
	category	3.57	0.98	3.62	< 0.001***

Table 3

Ranking of candidate models to explain variations in natural land cover change among a subset of 72 commercially operated conservation areas in South Africa based on AICc.

Model parameters ⁺	K	AICc	ΔAICc	w _i	Cum w _i
Management only	4	-103.98	0.00	0.68	0.68
Intercept only	2.	-101.05	2.93	0.16	0.84
PLCA characteristics only	3	-99.36	4.62	0.07	0.91
Climate only	3	-98.98	5.01	0.06	0.96
Accessibility only	6	-97.81	6.17	0.03	0.99
Full model	10	-94.51	9.47	0.01	1.00

⁺Model contents: Management only = PC1, PC2, PLCA characteristics = distance to state-owned national park, Climate = rainfall, Accessibility = distance to town, distance to road, elevation and slope, Full model = all variables, Intercept only = Null model.

The number of model parameters (K), delta AICc (ΔAICc) Akaike weights (w_i) and cumulative AICc weights (Cum w_i) and the null intercept only model are shown.

We then obtained the coefficients of all explanatory variables in the best-fit models to determine their magnitude, direction of effect and significance in influencing respective variations in natural land cover change.

3. Results

3.1. Effectiveness of PLCAs in conserving natural land cover

Net natural land cover change among South African PLCAs in the nationwide analysis ranged from – 99.6% (i.e. almost complete loss of natural land cover) to 99.0% (i.e. almost complete restoration of natural land cover). Mean net natural cover change was 0.3% ± 0.2% SE, indicating a net natural land cover gain of 151.9 km² across the considered national range of PLCAs. Among the subsample of 72 conservation areas for which we had management data (see section 3.2b), natural land cover change ranged from – 6.0 to 78.0%, with the mean being 2.6% ± 1.1% SE, which likewise represented a net natural cover gain.

3.2. Determinants of PLCA effectiveness

a. Nationwide

The best model to explain variation in net natural land cover change among South African PLCAs between 1990 and 2013 included eight of the nine considered social-ecological factors (Table 1). The best model only explained 1% of the total variation (r²

Table 4

Coefficient of parameters from the best model predicting how different factors influenced net natural land cover change across a subset of 72 commercially operated private land conservation areas in South Africa, using two principal components (PCs) representing different management systems (* - significant).

Variable	β	S.E.	T	P
intercept	0.03	0.01	2.38	0.02*
PC1	0.001	0.02	0.03	0.97
PC2	0.05	0.02	2.74	0.01**

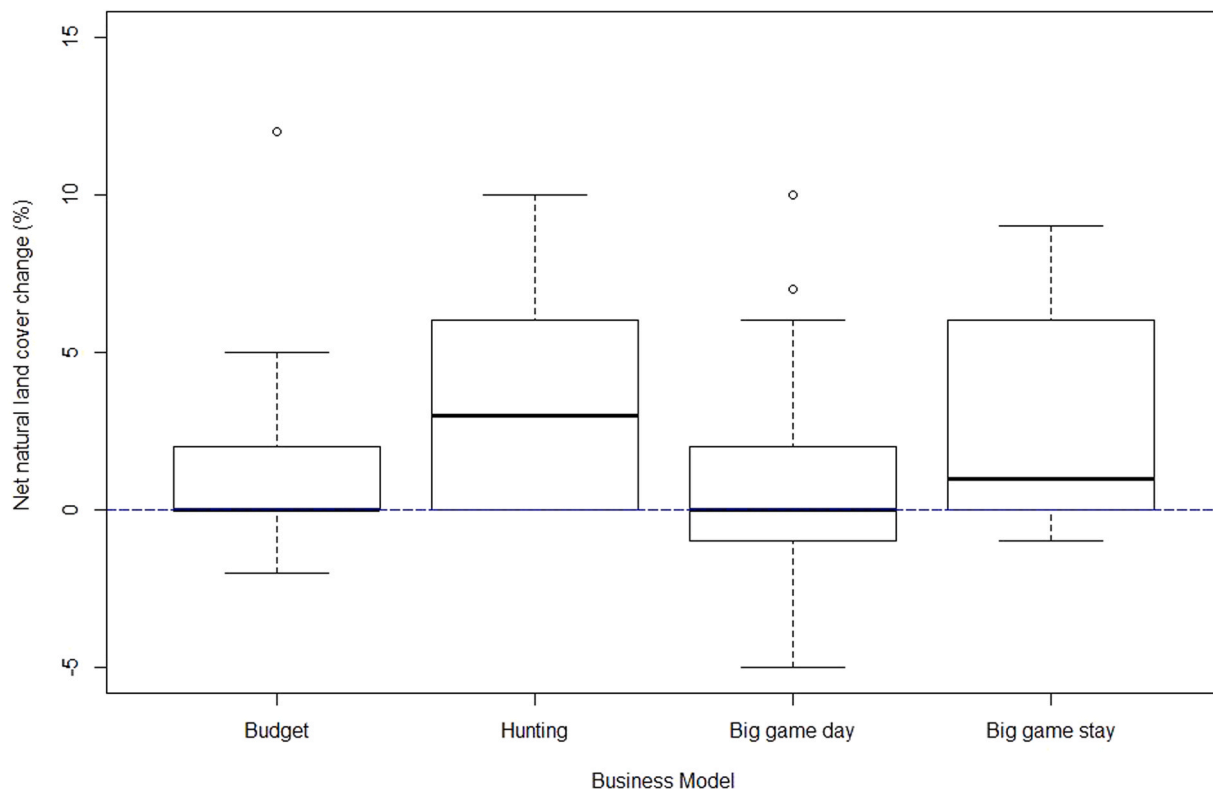


Fig. 2. Box and whisker plot showing differences in net natural land cover change among private land conservation areas under management systems represented by four different business models.

= 0.01). Only four factors in this model were significant i.e. elevation, ruggedness, rainfall and PLCA protection category (Table 2). Losses in natural land cover were greater on PLCAs with lower elevation, lower rainfall, higher ruggedness, and formal protection (Table 2). Nevertheless, both informal and formal PLCAs had a net gain in natural land cover on average ($2.2\% \pm 0.17\%$ SE and $0.2\% \pm 0.19\%$ SE respectively). Despite being insignificant ($p > 0.05$), increased distance to town and roads was associated with higher chances of natural land cover retention. PLCAs with gentle slopes had higher chances of losing natural land cover, while smaller PLCAs had better natural land cover retention than bigger ones (Table 2).

b. Subset of commercially-operated, informally protected PLCAs

For the subset of PLCAs, the best model to explain variation in net natural land cover change included management variables only (Table 3). These management factors explained 22% of the variance in natural land cover change ($r^2 = 0.22$). Of the two PCs representing different PLCA business models, PC2 had a positive and significant influence on net natural land cover change (Table 4). Natural land cover losses were therefore higher on PLCAs that were highly accessible, with more revenue from ecotourism than from hunting, that had more charismatic wildlife species, and higher profitability (Table A1).

We found significant differences in net natural land cover change among the four business models ($F_{(3, 72)} = 2.08$, $p = 0.01$), driven by a significant difference between hunting and big game day PLCAs (Tukey's post hoc $p = 0.02$, Fig. 2). Hunting PLCAs had higher positive change in the natural land cover (average = $9.7\% \pm 0.03\%$ SE) than big game day PLCAs (average = $0.5\% \pm 0.05\%$ SE). Big game stay and budget PLCAs had on average $2.6\% \pm 0.04\%$ SE and $2.2\% \pm 0.06\%$ SE increase in natural land cover, respectively. Overall, all business models had a net positive change in natural land cover on average, although there was high

Table A1

Private land conservation area (PLCA) characteristics captured by two principal components (PCs) representing the business model characteristics across 72 conservation areas (adapted from Clements et al. 2016).

PLCA characteristics	Details	PC1	PC2
Biophysical	Size (ha)	1.07	0.49
	Number “charismatic” game species (mega herbivores and large carnivores)	1.12	-0.53
	Number of “other” game species (equids and bovinds)	0.95	0.54
	Land cover diversity	0.43	-0.07
Accessibility	Elevation range – ruggedness (masl)	0.27	0.69
	Travel time to nearest airport (minutes)	-0.06	0.83
Affordability	Average daily price of visit (South African Rands)	1.17	0.05
Infrastructure	Number of beds available	0.43	-0.38
	Importance of restaurant/catering vs. self-catering facilities	1.09	-0.14
	Importance of overnight vs. day visitor facilities	0.03	0.84
Activities	Importance of guided vs. unguided activities	0.95	-0.53
	Proportion of revenue generated from ecotourism	0.07	-1.16
	Proportion of revenue generated from hunting	-0.04	1.12
	Proportion of revenue generated from game sales	0.38	0.71
	Proportion of revenue generated from farming	-0.48	-0.05
Market	Importance of international vs. national visitors	0.83	0.03

Table A2

Private land conservation area (PLCA) business model descriptions and their respective mean values of principal components (PCs; see Table 1).

Business models	Description	Mean PC1	Mean PC2
Hunting	Characterized by a large size, no charismatic game species, but a high richness of other game species; intermediate ruggedness and accessibility; a low quantity of catered, intermediately-priced accommodation; a large proportion of revenue from hunting, followed by game sales; and the importance of international visitors	0.09 ± 0.11	1.07 ± 0.10
Budget	Characterized by a small size, no charismatic game species and a low richness of other game species; cheap self-catering accommodation; the majority of revenue from unguided ecotourism; and the importance of local, overnight visitors	-0.76 ± 0.06	-0.08 ± 0.06
Big game stay	Characterized by large size; high ruggedness and low accessibility; supporting multiple charismatic (“big”) game species and a high richness of other game species. Expensive catered accommodation was on offer; with a large proportion of revenue generated from guided ecotourism and a smaller proportion from game sales and hunting. Overnight visitors were important. Many big game stay PLCAs were profitable, though there was high variability between properties.	0.64 ± 0.17	0.34 ± 0.15
Big game day	Characterized by small size, low ruggedness; multiple charismatic game species; an intermediate number of other game species and high accessibility. These PLCAs offered intermediately-priced accommodation and activities and a restaurant; and the majority of revenue came from guided ecotourism. Both day and overnight international visitors were important. Big game day PLCAs were significantly more profitable than hunting and budget PLCAs.	0.27 ± 0.11	-0.63 ± 0.04

variability (Fig. 2).

4. Discussion

4.1. Determinants of PLCA effectiveness

Whilst PLCAs in South Africa were effective in retaining or gaining natural land cover on average, their biophysical characteristics alone could explain very little of the considerable variation in effectiveness. In the nationwide analysis of over 5000 PLCAs, rainfall, elevation, ruggedness and PLCA protection category were significant, but generally weak predictors of PLCA effectiveness, as has been the case in other studies (Bowker et al., 2017; Geldmann et al., 2018). By contrast, PLCA management characteristics explained just over a fifth of the variability in effectiveness, with PLCAs adopting “big game stay” or “hunting” business models being associated with more natural land cover gains than “big game day” or “budget” PLCAs. These results have interesting implications for the role of PLCAs in national conservation strategies, and future research on PLCAs.

From a protected area resilience perspective, the low explanatory power of biophysical contextual factors (location, size) may be good news, as it suggests that areas closer to (and therefore ecologically more contiguous with) state-owned protected areas are likely no more effective than areas situated in more diverse, productive landscapes. Several studies have shown that PLCAs contribute to conservation through complementarity and diversity because they are located in less remote, more productive and threatened areas than state-owned protected areas (Gallo et al., 2009; De Vos and Cumming, 2019; Ivanova and Cook, 2020). Our findings thus suggest that PLCAs that are contributing to diversity of areas conserved can be relied upon, despite their location in landscapes with higher human pressure and competing land uses.

A related conclusion is that endogenous factors (represented in our study by different PLCA business models) are more important than exogenous factors (represented by biophysical contextual factors) in predicting PLCA effectiveness. This finding supports

evidence from state protected areas that factors such as management strategies may be important predictors of conservation effectiveness of protected areas (Porter-Bolland et al., 2012; Oldekop et al., 2016; Hargreaves-Allen et al., 2017). Still, many studies on state-owned protected areas have shown that biophysical contextual factors such as elevation, size, and location relative to anthropogenic pressures can explain variation in effectiveness (Muller and Albers, 2004; Bowker et al., 2017; López-Rodríguez and Rosado, 2017). This difference may be explained by the comparatively more homogenous nature of state-owned protected areas in terms of land tenure systems and management strategies compared to PLCAs, with the latter being characterised by diverse strategies such as nature conservation, ecotourism, hunting, and even a degree of crop and livestock farming (Clements et al., 2016; De Vos and Cumming, 2019). Such diversity is important for the long-term contribution of PLCAs to conservation system resilience (De Vos and Cumming, 2019), but also represents challenges for understanding drivers of PLCA success and failures.

While PLCA management strategies influenced effectiveness, profit-to-effectiveness relationships were not straightforward. High-profit, “Big game stay” ecotourism PLCAs and lower-profit hunting PLCAs were more effective than high-profit, “Big game day” ecotourism PLCAs and low-profit, “Budget” nature-tourism PLCAs. These different business models are associated with very different management practices. Big game day PLCAs tend to be smaller, highly accessible to cities, and attract high volumes of day visitors seeking ‘big game’ ecotourism experiences (Clements et al., 2016). Day visitors are attracted by the high richness of charismatic wildlife of these properties (e.g., elephants, lions, giraffe), but supporting these larger mammals in small PLCAs, together with the infrastructure needed to support higher volumes of visitors, can have a negative impact on vegetation (Child et al., 2013). By contrast, big game stay PLCAs, also a highly profitable model, tend to be more effective, likely given their larger size to support large game, lower volumes of high-paying visitors, and higher investment in management of healthy ecosystems (Chidakel et al., 2020). Interestingly, PLCAs generating revenues through hunting were generally effective, which is significant in light of on-going debates around the contribution of hunting to conservation in southern Africa (Lindsey et al., 2016; Parker et al., 2020; Di Minin et al., 2021).

4.2. Implications for management and future research

How multi-scale threats to PLCAs (e.g., local human pressures, national policies, global pandemics) correspond with PLCA management and biophysical characteristics (Clements et al., 2020), and how these threats influence PLCA effectiveness is important for understanding the role of PLCAs in national conservation networks. In particular, it is important for national governments, provincial conservation authorities, and conservation organisations (e.g. those involved in stewardship programmes) to consider how best to support PLCAs that are more vulnerable to natural land cover losses, to ensure that their contribution to biodiversity conservation is sustainable (Selinske et al., 2017). Our results suggest that these “threatened” landscapes or contexts may not be simply those “close to anthropogenic threats” (Porter-Bolland et al., 2012).

The role that business models play in determining conservation effectiveness implies that it is important for conservation practitioners and policy makers to differentiate PLCAs according to their goals, motivations and management models, without eroding profitability. Areas with goals that are compatible with maintaining “wildness” (Child et al., 2019) and where PLCA owners are intrinsically motivated to conserve biodiversity (Selinske et al., 2017) may be better placed to conserve threatened ecosystems than those where profitability is incompatible with maintaining a healthy ecosystem. Such areas (for example, the “big game day” areas) can still play a role in conservation, through, for example, safeguarding rare species that cannot sustain viable populations in altered ecosystems (Child et al., 2013). These areas will not, however, contribute to ecological complementarity, protected area connectivity, and other important landscape-level ecological programmes in the way required by protected areas (Child et al., 2013). In South Africa, plans to establish a voluntary certification scheme for wildlife ranches that recognizes the importance of different PLCA goals, promises to be a useful step in the right direction (DEA, 2019).

We based our assessment of “effectiveness” on the single proxy of natural vegetation change, following other studies on protected area effectiveness (Ament and Cumming, 2016; Bowker et al., 2017; Nolte et al., 2019). This does not capture many other dimensions of biodiversity conservation (e.g. threatened species presence and abundance, ecosystem functional integrity) and other PLCA goals (e.g. ecosystem service provision, contribution to rural economies) (Shumba, 2019). Consequently, our work represents one dimension of PLCAs effectiveness, which can be improved by the direct use of biodiversity data (Sayer et al., 2017; Geldmann et al., 2018). The temporal resolution of our land use maps presents limitations in the amount of detail that can be revealed. Ideally one would need hyperspectral images with a higher temporal resolution to ensure that finer and more recent details about land classes and their dynamics are captured. Nevertheless, previous studies have used products with comparable spatial and temporal resolutions to understand the effectiveness of conservation areas and how different factors influence their effectiveness (Ament and Cumming, 2016; Bowker et al., 2017; Shumba et al., 2020). In their “best practice” guidelines, Mitchell et al. (2018) call for protected area management effectiveness assessments for privately protected areas. A broad diversity of protected area management effectiveness assessment instruments exist that measure the extent to which a protected area is protecting natural and cultural values, and achieving its goals and objectives (Sayer et al., 2017; Mitchell et al., 2018). However, very few of these instruments appear appropriate for capturing the diverse goals of PLCAs (Laffoley et al., 2017; Mitchell et al., 2018; Chidakel et al., 2020). Our findings suggest that developing instruments that can assess the effectiveness of PLCAs in terms of their ability to achieve these goals is critical for understanding how, when and where we can rely on PLCAs in future.

4.3. Conclusions

This study shows that biophysical and legal characteristics of PLCAs are relatively poor predictors of PLCA effectiveness in conserving natural land cover. More variation in natural land cover could be explained by PLCA business models, indicating the

importance of site-specific management factors in influencing the effectiveness of PLCAs. Our results represent an important step forward for context-specific PLCA research, but many unanswered questions remain. Future efforts to understand the conditions under which PLCAs are effective should focus more closely on endogenous (e.g. management) factors, recognizing the diversity of PLCAs. Whilst our study showed that business models and motivations might be one set of endogenous factors to consider, PLCAs also vary in other ways that may have an impact on management practices that affect conservation effectiveness. More work is thus needed to identify these sources of diversity, and how they impact PLCA effectiveness at national, regional and global scales.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

see [Tables A1](#) and [A2](#).

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