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Original Research Article

Effectiveness of private land conservation areas in maintaining natural land cover and biodiversity intactness

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A B S T R A C T

Private land conservation areas (PLCAs) are increasingly looked to for meeting the deficit left by state-owned protected areas in reaching global conservation targets. However, despite the increasing extent and recognition of PLCAs as a complementary conservation strategy, little research has been done to quantify their effectiveness; a critical consideration if they are to be counted towards international biodiversity conservation targets. The long history of PLCAs in South Africa provides an interesting case study to address this knowledge gap. Here, we quantified the effectiveness of South African PLCAs by comparing losses in natural land cover and biodiversity intactness within PLCAs with different levels of protection to that of unprotected control points. Points within PLCAs were matched with unprotected control points to test the prediction that if PLCAs offer effective protection, losses in natural land cover and biodiversity intactness would be significantly lower within their boundaries in comparison to unprotected controls exposed to similar conditions. Consequences of natural land cover loss on biodiversity intactness were thus assessed, thus advancing standard approaches for quantifying effectiveness. Between 1990 and 2013, PLCAs lost significantly less natural land cover (3%) and biodiversity intactness (2%) than matched unprotected areas (6% and 4%, respectively). Of the natural land cover lost within PLCAs, most was converted to cultivated land. Farms can support more species than other land uses (e.g. mines), a likely explanation for why losses in biodiversity intactness were less than losses in natural land cover. Contrary to the predicted pattern, effectiveness did not increase with level of protection; informal PLCAs with no legal protection had comparable natural land cover and biodiversity intactness retention to strictly protected PLCAs, with most losses recorded among PLCAs with moderate protection. This study provides the first national-scale evidence that PLCAs can be an effective mechanism for conserving natural land cover and biodiversity intactness, which is highly relevant given current discussions around their likely long-term biodiversity conservation capacity.
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1. Introduction

The establishment of protected areas, which are mostly state-owned, remains a dominant strategy for biodiversity conservation (Venter et al., 2017). However, there is growing evidence that, in addition to failing to meet international area-based targets (Maron et al., 2018), many state-owned protected areas perform poorly in terms of: (1) representing biodiversity due to their bias towards high elevation and unproductive areas (Joppa and Pfaff, 2009) and (2) protecting biodiversity due to insufficient funding, management and governance problems (Venter et al., 2017). Consequently, there is growing interest in private land conservation areas (PLCAs), as a complementary conservation strategy (Stolton et al., 2014; Nolte et al., 2019). PLCAs are pieces of land predominantly managed for biodiversity conservation, protected with or without formal government recognition, and owned or otherwise secured by individuals, communities, corporations, non-governmental organizations, universities or religious groups (Stolton et al., 2014). PLCAs complement state-owned protected areas by increasing the total area available for biodiversity conservation, biodiversity representation and landscape connectivity (Langholz and Lassoie, 2001; Gallo et al., 2009; De Vos et al., 2019), and also contribute to national and local economies through hunting and ecotourism, and provision of ecosystem services (Stolton et al., 2014; Mitchell et al., 2018). However, comprehensive data on countries' PLCA estates are generally lacking (Bingham et al., 2017; Rissman et al., 2017), making it difficult to quantify their effectiveness in conserving biodiversity (Langholz and Krug, 2004; Bingham et al., 2017). Consequently, despite the long history of conservation on private lands, little is known about their effectiveness as a long-term biodiversity conservation strategy.

Concerns regarding the effectiveness of PLCAs have mainly focused on the fact that they are typically small, hence susceptible to edge effects and likely not appropriate for mega fauna requiring large areas (Langholz and Lassoie, 2001). In addition, diverse motives behind ownership and management of PLCAs may influence their effectiveness.(Farmer et al., 2011; Selinske et al., 2017). For example, in southern Africa, profit-oriented management systems, influenced by expectations of hunters and tourists, may not always align with conservation needs (Langholz and Lassoie, 2001; Clements et al., 2016b), and in Colorado, USA, different motivations were associated with different management actions (Ernst and Wallace, 2008). These uncertainties regarding PLCA effectiveness are a major reason for their exclusion in most national conservation planning and reporting towards international targets (Stolton et al., 2014).

A conservation strategy can be regarded a success or failure through objective measurement of effectiveness (Salafsky et al., 2002). Here, we define effectiveness as how well a strategy (e.g. PLCA) achieves its objectives of maximizing biodiversity conservation based on a particular proxy (Stoll-Kleemann, 2010). Whilst "effectiveness", is a challenging entity to measure (Parrish et al., 2003), there is a genuine need to understand what conservation strategies work, how, and why (Pullin and Knight, 2001). Although imperfect (Scholes and Biggs, 2005), approaches to quantify the effectiveness of protected areas have often involved remote sensing approaches (Gillespie et al., 2008). Proxies such as deforestation (Pfeifer et al., 2012; Bowker et al., 2017), forest fires (Nelson and Chomitz, 2011), natural land cover loss (Ament and Cumming, 2016), and habitat change and fragmentation (Liu et al., 2001) at landscape scales have thus been common. By comparing these proxies between protected and non-protected areas, the effectiveness of a strategy as well as predictions of possible future trajectories of change can be established (Naughton-Treves et al., 2005; Beresford et al., 2013). Changes in natural land cover translate to species diversity and provisioning of ecosystem services, hence natural land cover loss is a major driver of biodiversity loss (Maxwell et al., 2016), thus making it an important proxy to quantify the effectiveness of a conservation strategy (Fischer and Lindenmayer, 2007). Detail is however lost through the common approach of classifying remotely sensed data into a binary variable (e.g., natural or non-natural), given that non-natural land cover types impact biodiversity differently (Scholes and Biggs, 2005). For example, although agriculture and mining might both be non-natural, a protected area that lost natural land cover to agriculture may retain more species than one transformed to a mine (Scholes and Biggs, 2005; Child et al., 2009). There is therefore a need to have a complementary proxy for assessing protected area effectiveness, which accounts for the effect of different land cover changes on biodiversity conservation.

The biodiversity intactness index has been proposed as one measure for assessing the impact of different land uses on a broad range of taxa (Scholes and Biggs, 2005). The index represents the proportion of major taxa (plants, mammals, birds, reptiles, and amphibians) that can persist in an area given different land use/cover scenarios relative to an undisturbed population (Scholes and Biggs, 2005). The index can thus serve as a useful proxy for assessing effectiveness in conservation and protected areas, in the absence of detailed field data that often cannot be compared across scales and regions (Scholes and Biggs, 2005). The index has been proposed as one of the best available methods for capturing the role of biodiversity in supporting earth system functioning under the planetary boundaries framework (Steffen et al., 2015).

In this study we assessed the effectiveness of PLCAs across South Africa using losses of natural land cover and biodiversity intactness between 1990 and 2013. The use of these two proxies in this study not only provides the first national-scale assessment of PLCA effectiveness in preventing natural land cover loss, but also provides understanding of how losses in natural land cover translate to losses in biodiversity. As shown on Table 1, PLCAs in South Africa, are characterised by diverse levels of protection, land use restrictions and incentives (Cadman et al., 2010; Mitchell et al., 2018). The diversity of PLCA types and their long history in South Africa (De Vos et al., 2019), makes the country an interesting case study to understand the role, challenges, opportunities, and effectiveness of PLCAs. If PLCAs are an effective biodiversity conservation strategy (i.e. if they offer significant protection), we expected losses in natural land cover and biodiversity intactness to be significantly lower within their boundaries when compared to unprotected control areas exposed to similar environmental variables. In addition to assessing their overall effectiveness, we tested the hypothesis that legally protected PLCAs would be more effective than informally protected ones, given their stricter land use regulations and higher incentives.

2. Methods

2.1. Study areas

We assessed PLCAs across South Africa (Fig. 1). These included contractual parks, nature reserves, biodiversity agreements, conservancies and conservation areas. Contractual parks and nature reserves are formally protected through the National Environmental Management Protected Areas Act 57 of 2003 (DEA, 2013). Biodiversity agreements are moderately protected through contractual agreements between landowners and the provincial conservation authorities (Cadman et al., 2010). Conservancies and conservation areas are informally protected. They receive their protection from respective landowners, without legally binding contracts. Table 1 shows detailed descriptions of the different PLCA categories, the different policies and legal frameworks under which they are managed and the different incentives and restrictions associated with them (Shumba, 2019).

Data for the PLCAs used in this study were sourced from two quarterly updated databases courtesy of the South African Department of Environmental Affairs (DEA): These are the South African Protected Areas Database and the South African Conservation Areas database (DEA, 2013, 2016). There is a comprehensive record of all formally recognised PLCAs in South Africa (De Vos et al., 2019), but the list is not exhaustive for informal areas. The latter is a gap of global concern as most remain undocumented (Rissman et al., 2017). Additional data on informal conservation areas were thus sourced through provincial conservation bodies, manual digitising and previous studies (Clements et al., 2016a). In total, 5,121 PLCA properties were considered, which included, 127 contractual parks, 4,741 nature reserves, 82 biodiversity agreements, 98 conservancies, and 73 conservation areas (Fig. 1).

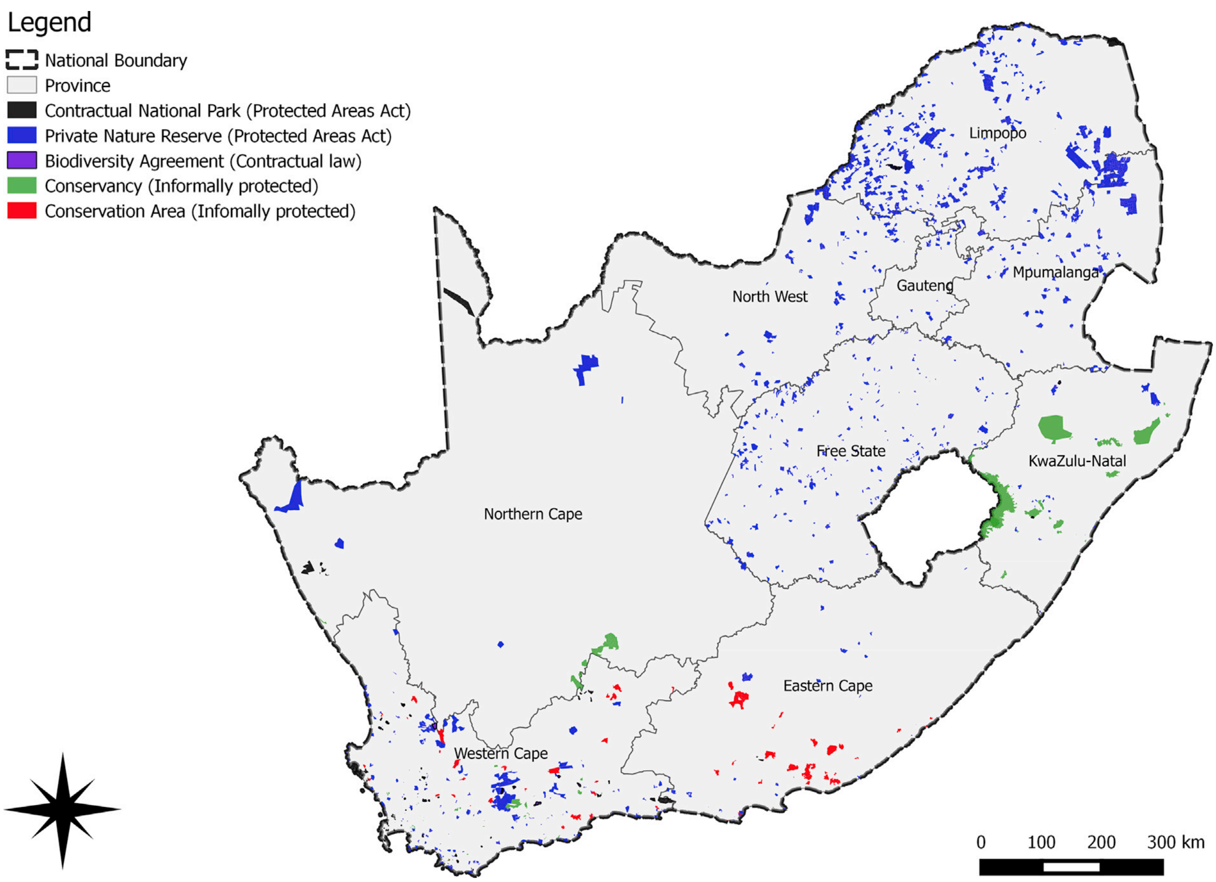

Fig. 1. Private land conservation areas (PLCAs) assessed in this study, classified into the different categories under which they are managed and protected.

Table 1
Description of PLCAs considered in this study and the different legal tools and policies under which they are established and managed, ranked by associated degree of protection, following (Cadman et al., 2010; DEA, 2013, 2016).

Category	Description	Guiding framework	Incentives	Data source(s)
Contractual Park	Established through joint agreements between South African National Parks and the private landowner or community. They are typically small portions of private land within a national park. They are also formed through the state buying land adjacent to a national park and then giving it to a community to manage as contractual park (Magome and Murombedzi, 2003). They are formally declared and protected through the Protected Areas Act, with duration of 30–99 years.	National Environmental Management Protected Areas Act (Act 57 of 2003).	Exclusion from municipality property rates. Reduced tax payments through national tax law. Advanced technical support with habitat and species management. Enhanced recognition and marketing opportunities.	South African Protected Areas Database https://egis.environment.gov.za
Nature Reserve	Formally declared through section 23 of the Protected Areas Act, with strict restrictions on exploitative land uses such as mining, with longevity ranging from 30 to 99 years.			
Biodiversity Agreement	Formed when the provincial conservation body encourages private landowners within highly biodiverse areas or threatened habitats to commit to conservation through contractual agreements. Longevity can be between 5 and 10 years with possibility of extension. These areas are not considered part of South Africa's formal protected area estate, but contracts include a management plan, which gives these areas a medium level of protection (DEA, 2013; Wright et al., 2018). They can also be upgraded to the same protection level as nature reserves through more legally binding long-term contracts	Biodiversity Stewardship program, Biodiversity Act, Contractual laws. The South African National Biodiversity Strategy and Action Plan.	Assistance with management plans and technical support in managing species and habitats from the provincial authority. Assistance with management of fire and invasive species.	South African National Biodiversity Institute http://bgis.sanbi.org
Conservancy	Informal areas dedicated to conservation on a voluntary basis, with mixed land uses including cattle ranching or crop farming being common. They are typically composed of many properties in which adjacent landowners cut down internal fences and manage their properties as one big continuous landscape, with a shared biodiversity conservation vision (DEA, 2013). They have no fixed length of years to be committed.	National Biodiversity economy strategy	Basic extension support with habitat and species management.	South African Conservation Areas Database https://egis.environment.gov.za /Clements (2016a, 2016b)
Conservation Area	Dedicated to conservation without any law influencing their management, with protection only coming from landowners. They are characterised by multiple land uses that include ecotourism, hunting and livestock and crop farming, and do not have specific number of years to be committed.			

2.2. Land cover data

South African national land cover maps for 2013 and 1990 courtesy of the Department of Environmental Affairs (DEA) were used to assess changes in natural land cover among PLCAs in South Africa. See (DEA, 2015a, b), for detailed procedures of how the data sets were created. The land cover maps were derived from Landsat 4, 5 and 8 satellite images, spanning the periods April 2013–March 2014 for the 2013 land cover map, and April 1989–October 1991 for the 1990 map. Using semi-automated modelling procedures, the satellite images were classified into 35 land classes at a 30 m resolution. For the 2013 land cover map, classification accuracy was 88.36%, and because the 1990 map used similar satellite images and classification methodology, a similar accuracy was presumed by the DEA, despite lacking historical reference control points to objectively test its accuracy (DEA, 2015a, b). While large-scale land cover products such as these have inherent limitations that preclude their use in fine-scale studies, they have been shown to be appropriate for national and or regional scale questions regarding natural land cover change (Pfeifer et al., 2012; Ament and Cumming, 2016; Bowker et al., 2017; Nolte et al., 2019). Furthermore, because the two maps here contain the same land cover classes, which were classified using the same method, and with the same resolution they have the advantage of being directly comparable (DEA, 2015b). To investigate natural land cover loss, the 35 land cover classes were reclassified to represent whether a pixel had natural or non-natural land cover. Vegetated pixels were classified as natural while transformed pixels such as with cultivated areas, settlements and mines were classified as non-natural (Shumba, 2019).

2.3. Biodiversity intactness index

We then used the biodiversity intactness index (Scholes and Biggs, 2005) as the second proxy to quantify the effectiveness of PLCAs. The index is a measure of the average proportion of the population of different species and functional groups within the major taxa (plants, mammals, birds, reptiles, and amphibians) that can persist in an area given the land use (moderately used, degraded, cultivated, plantation or urban) and biome (Fynbos, Forest, Savanna, Grassland, Thicket, Nama Karoo and Succulent Karoo), relative to a pristine population within a similar biome, see (Scholes and Biggs, 2005) for detailed descriptions of the different land uses. In this study, pixel-based biodiversity intactness estimates for 1990 and 2013 were thus calculated using the formula

$$BII = \left(\sum_i \sum_j (R_{ij} I_{ijk}\right) \Big/ \sum_i \sum_j R_{ij}) \qquad \text{(Eq. 1)}$$

where R_{ij} is the species richness of taxon i in biome j and I_{ijk} is the population-level impact, i.e. the proportion of a population of taxon i persisting under land use activity k in biome j, relative to an undisturbed pristine population in a similar biome.

Population impacts I_{ijk} were estimated by Scholes and Biggs (2005), through a structured expert interview process in which at least three specialists working on each taxon were interviewed. These experts ranked the effect of each land use on their speciality functional group on a scale of 0–100%, for each functional group within each biome, i.e. 100% if no land use impact (in pristine protected environments) and 0% if a species has no probability existing under a land use (Scholes and Biggs, 2005). This resulted in a matrix of values representing the average abundance of the original group of taxa that can exist under each land use in comparison to an undisturbed pristine protected area. Species richness values per taxa per biome (R_{ij}), compiled from (Le Roux, 2002) and land use classes from the 2013 and 1990 maps reclassified to represent five land uses classes (moderately used, degraded, cultivated, urban and plantation) were then used to calculate respective 1990 and 2013 biodiversity intactness values for sample points, within and outside PLCAs (Shumba, 2019).

2.4. Sampling

A total of 500 random points 100 m apart (to limit spatial autocorrelation) in each PLCA, or the maximum possible within small PLCAs were generated (Shumba, 2019). This resulted in total of 1,123,098 random points inside PLCAs. Outside PLCAs, a total of 1,000,000 random control points were generated for comparisons. These control points were generated 15 km away from PLCAs and state-owned protected areas to counter for spill-over effects (Ament and Cumming, 2016), and were also at least 100 m apart. Covariates and metadata associated with each point were then extracted using the point sampling tool in QGIS 2.8 (QGIS Development Team, 2015). These included, the name of the PLCA, its protection category (contractual park, nature reserve, biodiversity agreement, conservancy or conservation area), size, age (for points inside PLCAs), land cover class in 1990 and 2013, natural land cover classification (1; natural or 0; non-natural) in 1990 and 2013, biodiversity intactness in 1990 and 2013, annual precipitation, distance to town, distance to roads, elevation and slope.

2.5. Data analysis

To ascertain the effect of protection offered by PLCAs by controlling for other factors that might influence losses in natural land cover and biodiversity intactness, sample points inside PLCAs were paired with environmentally similar random unprotected control points outside. A nearest neighbour matching approach was thus used to match points inside PLCAs with control points outside based on similarities in distance to road, distance to town, rainfall, elevation and slope. These variables have been shown to influence losses of natural land cover on state-owned protected areas, and failure to account for their effect can overestimate effectiveness (Andam et al., 2008; Ament and Cumming, 2016; Bowker et al., 2017; Nolte et al., 2019). Because of contextual factors mentioned above, some areas will experience minimum losses in natural land cover or biodiversity intactness for example by being less accessible. However, by using the matching approach, such factors are controlled for resulting in a 1:1 ratio of PLCAs to unprotected points, with which the genuine effect of protection can be established (Andam et al., 2008; Bowker et al., 2017). A 0.5 standard deviation calliper was thus used as the maximum allowable difference between point pairs, which paired respective PLCA and non-protected points with replacement using the MatchIt package in R (Ho et al., 2011; Ament and Cumming, 2016; R Core Team, 2018; Shumba, 2019).

Because our interest was how losses in natural land cover and biodiversity intactness compared between PLCAs and unprotected areas, only points which had natural land cover in the initial year (1990) were considered. Although an increase in natural land cover and biodiversity intactness is a good measure of effectiveness, it was appropriate to only focus on losses given the time period required for a pixel to regain natural land cover and biodiversity intactness and how such gains might be influenced by bush encroachment and invasive species (Bowker et al., 2017).

The effect of protection (1 - PLCAs; 0 - non-protected), on natural land cover loss, a binary response (1 – natural land cover lost; 0 – natural land cover retained), and biodiversity intactness loss (%), was then determined by fitting generalized linear models (GLMs). These GLMs are a family of non-parametric models which consider nonlinear response variables, in this case a Binomial model with logit link for natural land cover loss and a Gaussian model with identity link for biodiversity intactness loss. Points that lost their initial cover both within and outside PLCAs were then assessed to determine the proportional representation of the land uses they were transformed to by 2013.

To test the hypothesis that losses in natural land cover and biodiversity intactness would be less likely among PLCAs with more legal support for conservation, GLMs with natural land cover and biodiversity intactness loss as response variables were fitted with protection category as the explanatory variable. In cases where significance was recorded, Tukey post-hoc tests with Bonferroni correction were used to determine how the specific categories differed. All analysis were done using the lme4 package in R statistical software at a significance level of 0.05 (R Core Team, 2018).

3. Results

To quantify PLCA effectiveness, a total of 937,682 points inside PLCAs (89.9% of points, which had natural land cover in the initial year) were successfully matched with unprotected control points. Of these sample points inside PLCAs that had natural land cover in 1990, 3.06% (SE 0.017%) had lost their natural land cover by 2013, thus retaining approximately 97% of their original natural land cover. In contrast, matched unprotected control points lost approximately double that amount i.e. 6.08% (SE 0.025%). A similar pattern was also observed with biodiversity intactness. Between 1990 and 2013 PLCAs lost 1.97% (SE 0.012%) biodiversity intactness, while unprotected control points lost 3.87% (SE 0.016%). Protection offered by PLCAs thus significantly reduced losses in natural land cover ($p < 0.005$, odds ratio, 0.72) and biodiversity intactness ($p < 0.005$, odds ratio 0.02).

In both PLCAs and matched unprotected areas, a large proportion of the points that lost natural land cover (66.4% and 65.9% respectively) were converted to some form of cultivated land (Fig. 2). Among PLCAs, these cultivated areas comprised of annual crops (38.5%), cultivated areas with irrigation (12.9%), plantation forest (8.7%), subsistence cultivation (3%), commercial orchards (2.4%), and commercial vines (0.9%). Among unprotected areas, settlements and degraded areas were also common outcomes of transformation (11.3% and 15% respectively), along with annual crops (30.6%), subsistence cultivation (19.7%), and plantation forests (10.6%), while irrigated areas (3.2%), orchards (1.3%), and vines (0.4%) were less frequent outcomes (Fig. 2).

There were significant differences in natural land cover loss among the different PLCA categories ($F_{(5,\ 1875363)} = 2002.5$, $p < 0.05$). All pair-wise comparisons were significant ($p < 0.05$) except between contractual parks and conservation areas, and contractual parks and conservancies (Table 2). The greatest losses of natural land cover were recorded among biodiversity agreements, while contractual parks and conservation areas had the least losses (Fig. 3). Nevertheless, all PLCA categories lost significantly less natural land cover than matched unprotected control points (Fig. 3, Table 2).

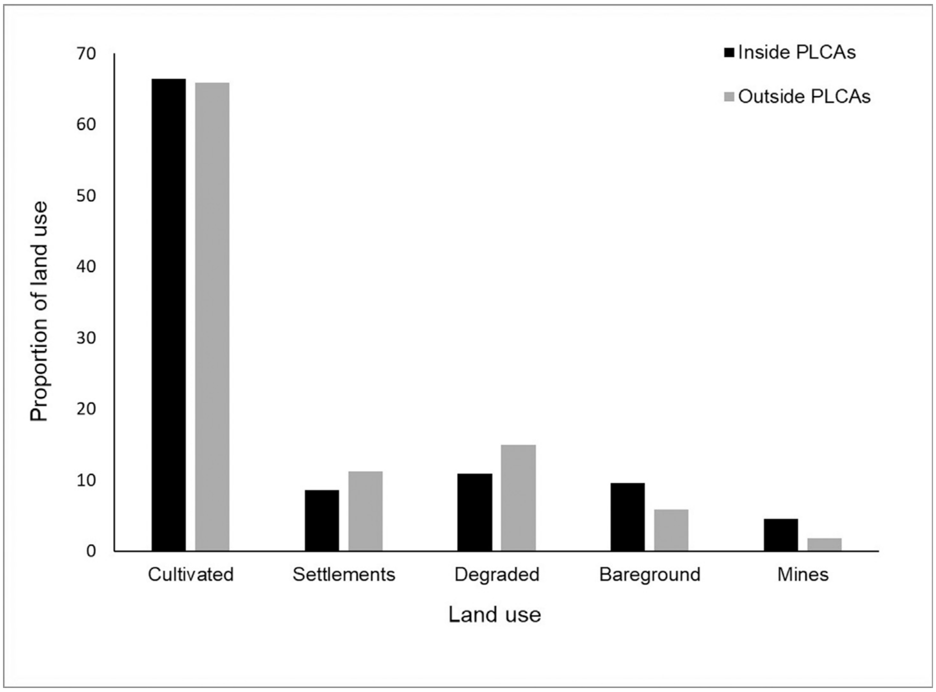

Fig. 2. Proportional distribution of land uses to which points that lost natural land cover were transformed to, inside private land conservation areas (PLCAs) and outside (non-protected areas) from 1990 to 2013.

Table 2
Tukey post-hoc analysis showing results of multiple pairwise comparison of natural land cover loss between different private land conservation areas categories and unprotected control points in South Africa.

Comparison	Difference	Lower	Upper	Bonferroni Adj p	Significance
Conservancy - Biodiversity Agreement	−0.017	−0.025	−0.010	<0.001	***
Conservation Area - Biodiversity Agreement	−0.024	−0.031	−0.016	<0.001	***
Unprotected - Biodiversity Agreement	0.022	0.016	0.029	<0.001	***
Contractual Park- Biodiversity Agreement	−0.024	−0.033	−0.016	<0.001	***
Nature Reserve - Biodiversity Agreement	−0.007	−0.014	−0.001	0.019	*
Conservation Area − Conservancy	−0.006	−0.011	−0.001	0.008	*
Unprotected − Conservancy	0.039	0.036	0.043	<0.001	***
Contractual Park- Conservancy	−0.007	−0.014	0.0001	0.07	ns
Nature Reserve − Conservancy	0.010	0.006	0.014	<0.001	***
Unprotected - Conservation Area	0.046	0.042	0.049	<0.001	***
Contractual Park- Conservation Area	−0.0007	−0.008	0.006	1.00	ns
Nature Reserve - Conservation Area	0.016	0.013	0.02	<0.001	***
Contractual Park- Unprotected	−0.047	−0.05	−0.04	<0.001	***
Nature Reserve − Unprotected	−0.029	−0.03	−0.029	<0.001	***
Nature Reserve - Contractual Park	0.017	0.011	0.023	<0.001	***

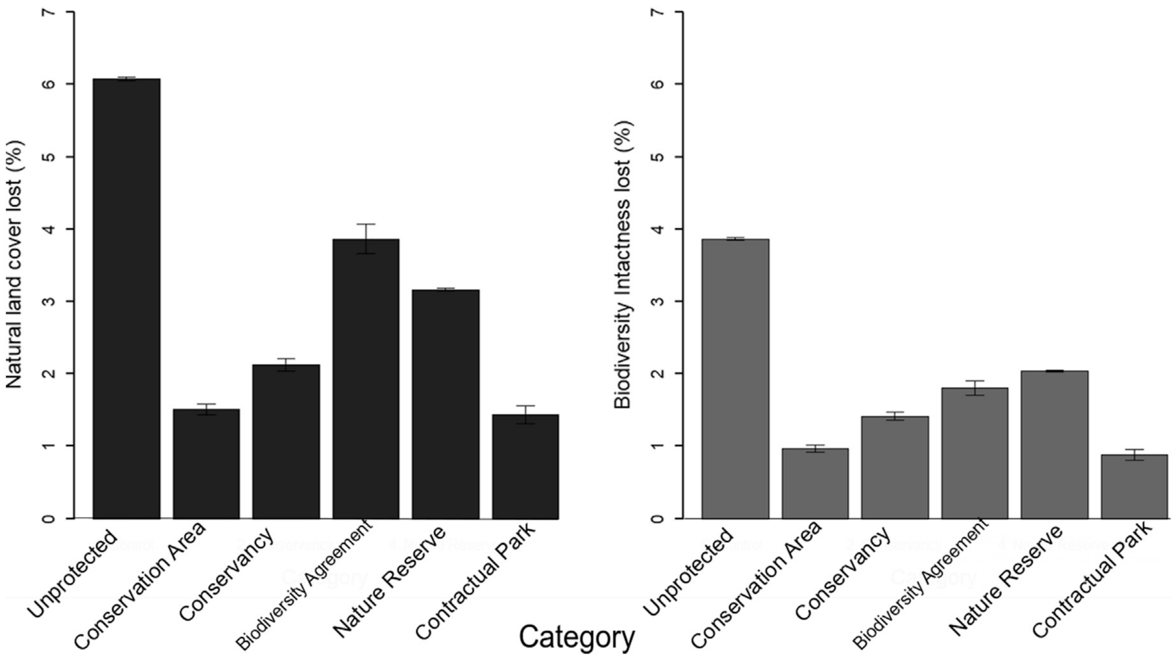

Fig. 3. The percentage of points that lost natural land cover and biodiversity intactness and their respective standard errors of the proportion of points, across different categories of private land conservation areas (PLCAs) and unprotected control areas, arranged in order of increasing legal support for conservation.

Similarly, there were significant differences in biodiversity intactness loss across the different PLCA categories ($F_{(5,\ 1875363)} = 1859.9$, $p < 0.05$) with significant pair-wise comparisons except between conservation areas and contractual parks, biodiversity agreements and nature reserves and between biodiversity agreements and conservancies (Table 3). Most losses in biodiversity intactness were recorded among nature reserves and biodiversity agreements with conservation areas and contractual parks having the least losses (Fig. 3). Likewise, none of the PLCA categories had biodiversity intactness losses comparable to unprotected control areas (Fig. 3).

4. Discussion

Given increased calls for conservation planning to look beyond state-owned protected areas and consider PLCAs (Stolton et al., 2014; Maron et al., 2018; Donald et al., 2019). The main objective of this study was to establish whether South African PLCAs offer effective protection, using two proxies natural land cover and biodiversity intactness. Losses of natural land cover and biodiversity intactness recorded among unprotected areas were almost double those recorded within PLCAs, providing the first national-scale evidence of PLCAs' relative effectiveness. PLCAs lost 3% natural land cover between 1990 and 2013,

Table 3
Tukey post-hoc analysis showing results of multiple pairwise comparison of biodiversity intactness loss between different private land conservation area categories and unprotected control points in South Africa.

Comparison	Difference	Lower	Upper	Bonferroni Adj p	Significance
Conservancy - Biodiversity Agreement	−0.004	−0.009	0.0008	0.28	ns
Conservation Area - Biodiversity Agreement	−0.008	−0.013	−0.004	<0.001	***
Unprotected - Biodiversity Agreement	0.021	0.016	0.025	<0.001	***
Contractual Park- Biodiversity Agreement	0.009	0.0035	0.015	<0.001	***
Nature Reserve - Biodiversity Agreement	−0.002	−0.006	0.002	1	ns
Conservation Area − Conservancy	−0.004	−0.0078	−0.001	0.03	*
Unprotected − Conservancy	0.025	0.02	0.027	<0.001	***
Contractual Park- Conservancy	0.005	0.0007	0.01	0.02	*
Nature Reserve − Conservancy	−0.006	−0.009	−0.004	<0.001	***
Unprotected - Conservation Area	0.03	0.026	0.031	<0.001	***
Contractual Park- Conservation Area	0.0009	−0.004	0.006	1	ns
Nature Reserve - Conservation Area	−0.01	−0.013	0.008	<0.001	***
Contractual Park- Unprotected	0.03	0.03	0.034	<0.001	***
Nature Reserve − Unprotected	0.02	0.018	0.02	<0.001	***
Nature Reserve - Contractual Park	0.01	0.007	0.02	<0.001	***

while South African state-owned protected areas, lost 2% over the period 2000–2009 (Ament and Cumming, 2016). Although not directly related our results indicate comparability in how PLCAs and state-owned protected areas prevent losses in natural land cover and biodiversity (Nolte et al., 2019). With the expanding number of PLCAs around the world and the increasing reliance on them as a conservation tool, evidence of their effectiveness in curbing natural land cover and biodiversity intactness loss in South Africa is thus reassuring.

PLCAs are seen as a useful conservation strategy globally (Stolton et al., 2014; Nolte et al., 2019) because they are self-funded through ecotourism, hunting or mixed land uses, and hence can achieve economic and conservation objectives, which is critical in developing countries where government funding for conservation work is limited (Langholz and Lassoie, 2001). The relevance of these PLCAs to conservation thus depends on financial viability, otherwise known as an 'if it pays it stays' scenario (Pfaff and Robalino, 2012). Consequently, financial and ecological compromises are common among PLCAs. A large proportion of lost natural land cover was converted for cultivation and settlements (Fig. 2), highlighting the mixed land-use strategy of many PLCAs to fund conservation objectives (Child et al., 2013). However, this may negatively impact on PLCA effectiveness, with one study in USA showing that PLCAs were ineffective in protecting natural land cover in comparison to unprotected areas (Fouch et al., 2019). For example, although growing crops might provide extra revenue, it reduces biodiversity intactness, reduces water regulation capacity and increases risk for invasive species (Biggs et al., 2012). Consequently, if biodiversity conservation is to be improved within PLCAs, policies advocating for minimum or no agriculture should be encouraged. One way is to incentivise natural land cover and biodiversity protection by rewarding good stewardship. The notable increase in ecotourism in southern Africa and globally since the 1980s (Langholz and Krug, 2004), and the need to keep PLCAs competitively attractive for tourist markets, may also explain the loss of natural land cover to settlements (e.g., lodges and picnic sites). Such changes in land cover highlight the complexities of conservation in landscapes where financial viability is both a driver of wildlife-based land-uses as well as a potential constraint on their effectiveness in conserving biodiversity (Child et al., 2013; Clements and Cumming, 2017). Policies and regulations should thus assist landowners in achieving their objectives without compromising biodiversity conservation and vice-versa, for example through South Africa's new tax incentive program (Cumming and Daniels, 2014).

This study recognizes that the consequences of natural land cover loss on biodiversity are dependent on what the land transforms to. The finding that 3% natural land cover loss corresponded to 2% loss in biodiversity intactness within PLCAs can thus be explained by cultivation being the land use that predominantly replaced natural land cover. Cultivated areas have been shown to be important for seed eating birds and insects, hence effects of agricultural transformation on biodiversity are tolerable, in comparisons to land transformed to a mine or an urban land use (Scholes and Biggs, 2005; Child et al., 2009). The study thus provides important insights into the consequences of natural land cover loss on biodiversity that are typically overlooked in land cover change studies, which assume all natural cover lost to be having similar consequences.

Among state-owned protected areas, effectiveness has been shown to vary across the International Union for Conservation of Nature categories, with strictly protected areas being more effective (Nagendra, 2008; Bowker et al., 2017). In our study, contrary to this trend, effectiveness of PLCAs did not increase with increasing level of protection (Fig. 3). Notably, informally protected conservation areas and conservancies lost significantly less natural land cover and biodiversity intactness than some formally protected PLCAs, with the highest losses being recorded within biodiversity agreements which are classified by the government as moderately protected (Fig. 3; Table 1). With the Biodiversity Stewardship Program under which biodiversity agreements are established having started in the early 2000s (Wright et al., 2018) and this study covering the period of 1990–2013, it is likely that some areas were proclaimed biodiversity agreements after natural land cover and biodiversity had already been lost, hence their precise contribution in preventing losses in natural land cover and biodiversity intactness can be established in years to come. Biodiversity agreements are established through arrangements between a provincial conservation authority and a landowner within ecologically significant landscapes (Wright et al., 2018). They are set up in an incentive-based system in which the landowner receives help in the form of management advice and management support for fires and invasive species (Table 1) from the provincial conservation body in exchange for the landowner's promise to manage the area at natural or semi-natural conditions (Cadman et al., 2010; Wright et al., 2018). Consequently, when the provincial conservation authority is incapacitated in terms of skilled personnel and funds to provide extension services, biodiversity conservation within biodiversity agreement areas can be compromised (Selinske et al., 2015; Wright et al., 2018). This might explain why biodiversity agreements had the biggest losses in natural land cover and biodiversity intactness, compared to informal conservation areas and conservancies whose effectiveness is not largely dependent on extension services but rather on landowner financial benefits from hunting and ecotourism (Clements et al., 2016a). Consequently, for biodiversity agreements to become more effective, there is need for sufficient funding to ensure consistent provision of extension services and monitoring of landowner's compliance to agreed management plans and land use restrictions. Nevertheless, because biodiversity agreements lost significantly less natural land cover and biodiversity intactness relative to unprotected control points it demonstrates their importance together with other types of PLCAs. Our findings are of broad relevance given the prevalence of both incentive- and market-based PLCA approaches around the world (Capano et al., 2019) and demonstrate the importance of informal PLCAs, as has been observed in India (Bhagwat et al., 2005) and USA (Nolte et al., 2019). Follow up site specific studies are however essential to fully understand future performance of biodiversity agreements and the other PLCAs.

Differences across PLCA categories could also be due to proximity to state-owned national parks, which can be associated with positive spill-over effects (Ament and Cumming, 2016). Positive spill overs occur when proximity to a national park motivates PLCA landowners to maintain natural land cover and biodiversity in their properties, thus boosting their own chances of attracting tourists (Andam et al., 2008; Ament and Cumming, 2016). This might thus explain why contractual parks, which are situated within or adjacent to national parks, had lower natural land cover and biodiversity intactness than nature reserves (Fig. 3) despite both being formally protected through the Protected Areas Act (Table 1). Although our study did not investigate spill-over effects or the influence of distance to other protected areas, it is something future studies can consider, especially using an island biogeography or metapopulation perspective.

In South Africa, the national protected area expansion model places emphasis on establishing PLCAs through the biodiversity stewardship program (Wright et al., 2018). With known biases of where state-owned protected area are located (Joppa and Pfaff, 2009; Venter et al., 2017), considering PLCAs makes sense, since they have been shown to represent habitats under-represented within state protected areas (Gallo et al., 2009; De Vos and Cumming, 2019). In South Africa 79% of the country is privately owned, and with policies and legislation allowing protected areas to be declared on private areas (De Vos et al., 2019), PLCAs form a significant part of the conservation estate, thus significantly complement state-owned protected areas in biodiversity conservation, which this study reinforces (Cadman et al., 2010). We thus recommend the government to support and incentivise not only the formal conservation efforts (contractual parks, nature reserves, and biodiversity agreements) but include the informal one as well (conservation areas and conservancies), which we show here to be equally important.

It is important to note that, given the national-scale focus of this study, PLCA effectiveness was assessed using broad-scale proxies. While such proxies have been commonly used to understand broad-scale effectiveness among protected areas (Pfeifer et al., 2012; Ament and Cumming, 2016; Bowker et al., 2017; Nolte et al., 2019), inherent limitations are acknowledged; notably, the resolution of land cover products and their inability to distinguish bush encroachment and invasive species from natural habitat (DEA, 2015b). Consequently, products that do not use fine-scale resolution, hyperspectral remote sensing data fail to account for such detail, which is a limitation when drawing conclusions. Because the land use maps were also used for the calculation of the biodiversity intactness index, such errors can easily be propagated (Martin et al., 2019). These proxies are however justified given that land cover change is a key driver of biodiversity loss (Maxwell et al., 2016), despite not providing insight into the effectiveness of PLCAs in achieving finer-scale conservation objectives, such as maintaining habitat quality or conserving threatened species. Furthermore, given the diversity of landowners involved in private land conservation, effectiveness should also ideally be considered relative to property-and program-specific objectives, which are likely to be socioeconomic as well as ecological (Selinske et al., 2015). We therefore encourage case-study based approaches to augment these broad-scale findings. Nevertheless, proxies do not have to be flawless to be useful, similar related studies have used such products to understand the effectiveness of protected areas, with implications for policy and management (Scholes and Biggs, 2005; Ament and Cumming, 2016; Bowker et al., 2017).

The study demonstrates that PLCAs, whilst not a panacea for achieving conservation goals, are an effective conservation mechanism. Genuine limitations about PLCAs have been raised, including their typically small sizes, profit oriented management systems, and uncertain tenure arrangements (Langholz and Lassoie, 2001; Clements and Cumming, 2017), which can compromise their effectiveness (Fouch et al., 2019). However, our study demonstrates that PLCAs in South Africa are a conservation mechanism worth recognising, given their comparable effectiveness in conserving natural land cover relative to state-owned protected areas. Our findings suggest emphasis on policies and services that support PLCAs and efforts to incorporate them into national, regional and global conservation action plans should be encouraged (Mitchell et al., 2018). Efforts should also be made to ensure that complete data about where PLCAs are located, when they were established, what they are managed for and by whom are documented and publicly available to enable widespread evaluation of their contribution to biodiversity conservation. The use of fine-scale data, to understand how social, ecological and political factors influence the effectiveness of PLCAs in biodiversity conservation is also encouraged.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gecco.2020.e00935.

Appendix 1. Variables used to match points within Private land conservation areas and unprotected control points, their descriptions and sources

Variable	Type	Description	Source
distance to town	continuous (meters)	Distance to the nearest human settlement	CIESN (2017)CIESIN, 2017
distance to road	continuous (meters)	Distance to major road	Worldwide roads (FAO, 2015)
elevation	continuous (meters)	Height of point above sea level	USGS (2004)
slope	continuous (degrees)	Steepness of a point	USGS (2004)
rainfall	continuous (mm)	Total rainfall received	(Hijmans et al., 2005)Hijmans et al., 2005

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