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Designing a transfrontier conservation landscape for the Maputaland centre of endemism using biodiversity, economic and threat data

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A B S T R A C T

A number of global priority region schemes have been developed, but local assessments are needed to identify priority areas for conservation within these regions. Here, we describe results from a conservation assessment for Maputaland, part of a biodiversity hotspot in southern Africa that is also the focus of the Lubombo Transfrontier Conservation Area (TFCA) initiative between South Africa, Mozambique and Swaziland. The TFCA seeks to establish new state-, private- and communally-managed conservation areas to boost economic development through nature-based tourism and game ranching. The assessment will guide the TFCA process and used a systematic conservation planning approach to design a landscape to conserve 44 landcover types, 53 species and 14 ecological processes. The assessment also included data on modelled risk of agricultural transformation, of which low-risk areas were selected where possible. The current PA systems in the three countries cover 3830 km^2, which represents 21.2% of the region, and meet the representation targets for 46% of the conservation features. The proposed conservation landscape adds 4291 km^2 of new core areas and 480 km^2 of linkages and, if appropriate, could provide potential revenues of US$18.8 million from game ranching, based on modelled large ungulate density, life history and game auction data. We also discuss the benefits of including data on widely distributed, better known conservation features together with less-well studied, range-restricted species and the advantages of using agricultural transformation risk data in conservation assessments.

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1. Introduction

A number of global- and continental-scale priority schemes have been developed during the last decade to identify broad planning regions within which conservation resources are best focussed (Brooks et al., 2006). The next step in this process is to use conservation planning techniques to identify locally important areas within these regions (Margules and Pressey, 2000) but many of these analyses fail to influence activities on the ground (Knight et al., 2008). However, there are a number of ways to increase the social relevance of conservation planning projects, with the most obvious being to involve key stakeholders throughout the process, helping in assessment design and operation (Knight et al., 2007). In addition, projects should be developed within a broader implementation framework that is guided by a model of landscape management (Knight et al., 2006a; Rouget et al., 2006) and should include threat and socio-economic data (Wilson et al., 2005; Naidoo and Ricketts, 2006). These factors help make the process more relevant to decision makers but they can also have a large impact on which areas are selected (e.g. Luck et al., 2004; Stewart and Possingham, 2005). This is why stakeholder input is so important, as it allows the inclusion of relevant biodiversity, threat and socio-economic data (Carwardine et al., 2008). Thus, there is a need for more research on how conservation planning projects can be modified to account for local conditions, so here we describe a project from Maputaland and discuss the factors that influenced its development.

The Maputaland centre of endemism falls within southern Mozambique, north-eastern South Africa and western Swaziland and covers an area of approximately 17,000 km^2 (Fig. 1). Its conservation importance is globally recognised, as it forms part of the Maputaland–Pondoland–Albany biodiversity hotspot and contains the iSimangaliso Wetland Park World Heritage Site, five RAMSAR sites and ten Important Bird Areas (Steenkamp et al., 2004; Smith and Leader-Williams, 2006). A relatively high proportion of the region already has protected area (PA) status, and these PAs are the responsibility of the National Directorate of Conservation Areas in Mozambique, Ezemvelo KwaZulu-Natal Wildlife (EKZNW) and the iSimangaliso Wetland Park Authority in South Africa and the Swaziland National Trust Commission in Swaziland. However, some biodiversity elements remain under-represented in these PAs in relation to their conservation targets (Smith et al., 2006). Moreover, many of the PAs are not large enough to contain viable populations of wide-ranging species, or to conserve important ecological processes.

Maputaland is also home to some of southern Africa's poorest people, who have traditionally relied on harvesting natural resources because the region's nutrient-poor soils are generally unsuitable for agriculture (Soto et al., 2001). However, an increasing human population and the provision of artificial water sources mean that more land is being cleared for farming. Despite this, the region still contains much of its natural vegetation and its low agricultural potential makes nature-based tourism and the sustainable use of natural resources economically competitive. Indeed, there is a thriving ecotourism and game ranching sector in the south of the region (Oldham et al., 2000; Goodman et al., 2002). However, these ventures are generally restricted to privately-owned land, thereby excluding the majority of people, who live on communally-managed land. In response, the governments of Mozambique, South Africa and Swaziland have established the Lubombo Transfrontier Conservation Area (TFCA) initiative, which aims to reduce poverty by building local capacity establishing new conservation projects in four parts of the region (Fig. 1).

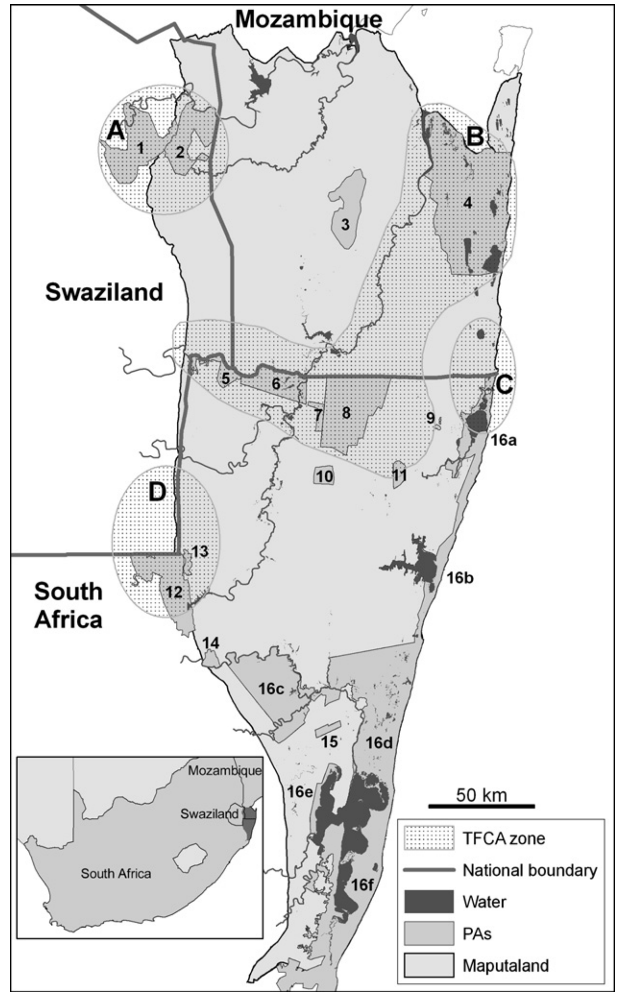

Fig. 1 – Protected areas and Lubombo TFCA zones in Maputaland. TFCA zones are labelled alphabetically and PAs are labelled numerically according to the following system: A = Lubombo-Goba, B = Usuthu-Tembe-Futhi, C = Kosi Bay-Ponta do Ouro, D = Nsubane–Pongola; 1 = Hlane Royal National Park, 2 = Mlawula NR, 3 = Licuati Forest Reserve (FR), 4 = Maputo Special Reserve, 5 = Usuthu Gorge Community Conservation Area (CCA), 6 = Ndumo Game Reserve (GR), 7 = Bhekabantu CCA, 8 = Tembe Elephant Park, 9 = Manguzi FR, 10 = Tshanini CCA, 11 = Sileza NR, 12 = Phongola NR, 13 = Hlatikulu FR, 14 = Ubombo Mountain Reserve, 15 = Makasa Biosphere Reserve, 16 = iSimangaliso Wetland Park, 16a = Kosi Bay, 16b = Lake Sibaya, 16c = Mkhuze GR, 16d = Ozabeni, 16e = False Bay Park, 16f = Eastern Shores.

TFCAs, which are also known as Transboundary Conservation Areas, are relatively large areas that cross the political boundaries between two or more countries, and cover natural ecosystems that include one or more PA. Their main purpose is for the conservation and sustainable use of biological and cultural resources, whilst promoting regional peace, co-operation and socio-economic development (Sandwith et al., 2001). This multiple role means that TFCAs are not selected on conservation value alone and their potential socio-economic impacts have been questioned (Jones, 2005; van Amerom and Buscher, 2005). However, TFCAs are well supported at high political levels, helping to generate much funding for development and conservation projects. For example, the Government of South Africa has spent US$5 million in the Lubombo TFCA since 2004 and the Government of Mozambique is committed to spending US$36 million in three TFCAs, which include the Lubombo TFCA, over the next five years. Much of this funding has been spent on up-grading existing infrastructure and building capacity but future plans include expanding and linking the current PA system with new state-, communally- and privately-owned reserves.

There is, therefore, a need to develop systems to guide this process and ensure the long-term persistence of Maputaland's biodiversity. In response, we have developed the Maputaland conservation planning system (CPS) and used it to undertake a conservation assessment, which is defined as a short-term activity for identifying spatially-explicit priority areas (Knight et al., 2006a). As part of this we: (i) mapped the distributions of a number of important species, landcover types and ecological processes; (ii) set representation targets for each of these conservation features, and; (iii) identified a conservation landscape that met these targets. We adopted a systematic conservation planning approach (Margules and Pressey, 2000) and used Marxan, a widely used software package that can incorporate biodiversity and socio-economic data (Ball and Possingham, 2000). We increased the implementation relevance of the assessment by including data on agricultural and game ranching suitability, so we also describe how these socio-economic datasets were developed.

2. Methods

2.1. Mapping the conservation features

One of the first steps in systematic conservation planning is deciding what elements the final conservation network should conserve and these elements are known as conservation features. For the Maputaland conservation assessment (MCA) we included data on three types of conservation features, which were species, landcover types and ecological processes, and these were selected so that they could be mapped easily and, when in combination, would act as surrogate for biodiversity (Lombard et al., 2003; Cowling et al., 2004). These features were mapped using the ArcView GIS software (ESRI, Redlands, USA) and all the data were converted to a raster format with a resolution of 25 m.

2.2. Landcover types

The landcover type list was adapted from a classification system developed for the South African section of Maputaland (Smith et al., 2006), which divided the region into five ecological zones (Fig. 2). Based on expert opinion, the classification system also split some of the landcover types into biogeographic zones, as it was felt that species assemblages of these types differed across a latitudinal gradient (Smith and Leader-Williams, 2006). The final system consisted of 44 landcover types included in the Maputaland CPS (Table S2). These landcover types were mapped with a resolution of 25 m using Landsat ETM and ASTER satellite scenes. The South African section of the map was ground-truthed as part of a previous study (Smith et al., 2006), which involved recording the actual landcover type at a number of randomly selected points and comparing this with the predicted landcover type. In this study we checked the Mozambican and Swaziland sections by using an additional 80 points that were opportunistically

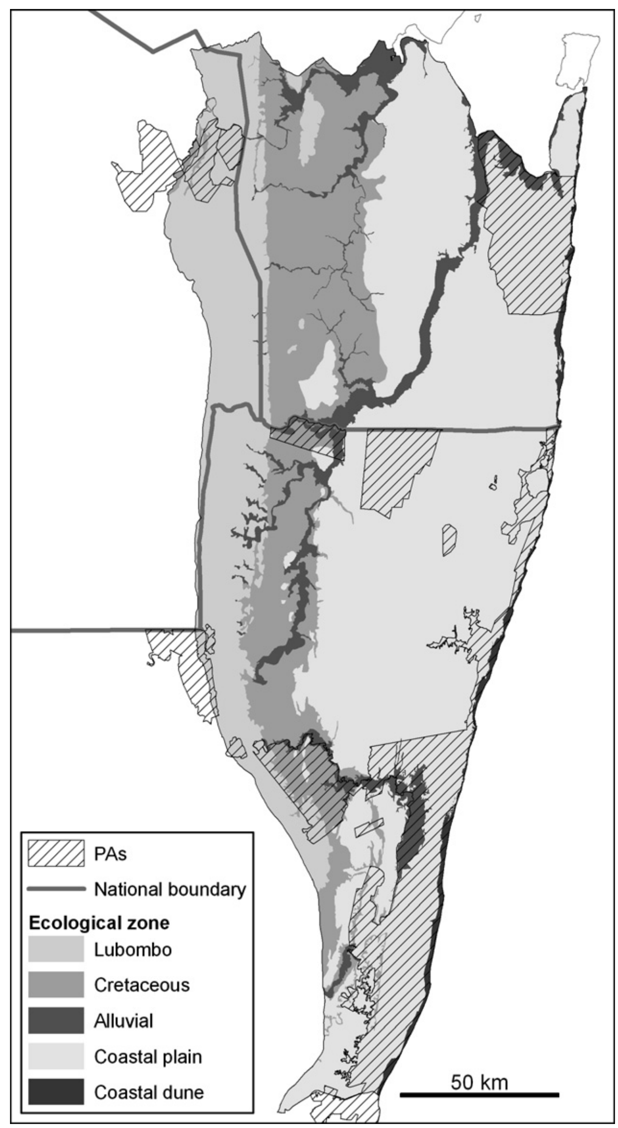

Fig. 2 – Maputaland's ecological zones, based on climate and geology.

collected using a GPS unit. This meant that data on 803 points were collected in total, showing that 86.9% of the South African and 77.5% of the remaining sites were correctly classified.

2.3. Species

We developed a list of vertebrate, invertebrate and plant species to use as conservation features that complemented the landcover data, as we assumed that many species would be automatically conserved by protecting their associated landcover types. Thus, we only included species that fell into one of two categories: (i) species with a limited range within their associated landcover types, and (ii) wide-ranging species that need large patches of habitat that might not be conserved when considering landcover types alone. We also limited our list to those species that were sufficiently well studied to be mapped with some accuracy.

Given the available data, we based all of our species distribution maps on literature reviews and the opinion of senior ecologists and conservation biologists working in the region. We used this information to list the landcover types that were associated with each species and then assumed that the distribution of each species mirrored that of its associated landcover types, unless we had additional information on suitable habitat for these species. These extra data consisted of: (i) distribution rules, so that the maps were modified to exclude areas that were not seen as suitable based on elevation, slope, habitat patch size or distance to the coastline, and; (ii) distribution range polygons drawn by local experts. Where possible, these maps were combined with density estimates derived either from the literature or a previous study on the large herbivores in the region (Easton, 2004). Several large mammal species were extirpated from the region during the last century, but some have since been reintroduced into some of the PAs. There are plans for further reintroductions and so for reintroduced species we mapped the potential and actual distributions, so that the MCA could be used to identify sites for future reintroductions.

2.4. Ecological processes

Three types of ecological processes were identified as conservation features and these were: linkages to maintain connectivity, patches large enough to maintain fire regimes and patches large enough to maintain natural herbivory patterns. This list was developed from expert opinion and was restricted to features that could be represented spatially. One of the linkages could be mapped immediately, whereas the others that could only be mapped using the initial outputs from the MCA. Suitable fire patches were derived from the landcover map and we assumed that meeting the target for elephants would also meet the herbivory target.

2.5. Setting targets for the conservation features

We used a number of techniques for setting targets for the different conservation features (see Supplementary materials), relying on a combination of published information and input from local ecologists and conservation biologists. The landcover type targets were calculated using a method based on habitat specific species-area curves (Desmet and Cowling, 2004), which has been used to set targets for KwaZulu-Natal (KZN) vegetation types (Goodman, 2006). Many of the species targets were based on similar analyses that were undertaken by EKZNW (Goodman, 2006). The remaining species targets were developed according to whether the species is wide-ranging, where it was assumed that Maputaland would support part of a metapopulation, or whether it is restricted to the planning region, so that the population within Maputaland needed to be viable (see Supplementary materials). The ecological process targets were developed through expert review and were either based on maintaining a linkage or conserving a minimum sized patch for maintaining natural fire and herbivory patterns.

2.6. Producing the risk of transformation and potential ranching revenue maps

A logistic regression-based approach that was originally developed to map deforestation risk (Linkie et al., 2004) was used to produce the risk of agricultural transformation map, based on maps showing the spread of agriculture in the South African section of Maputaland between 1987 and 2001. This analysis only used data from South Africa partly because of the availability of satellite images, but also because land-use patterns in Mozambique during that period were probably atypical, being affected by the civil war, which led to mass emigration and then gradual resettlement after the 1992 ceasefire (Nhancale, 2005). The analysis investigated whether patterns of clearance were related to distance from existing agriculture, elevation, slope and agricultural potential (see Supplementary material). The agricultural potential zone map was derived from the ecological zone map (Fig. 2) by merging zones with similar agricultural potential. The map contained three categories: Lubombo; Central, which combined the Cretaceous and Alluvial zones, and; Coastal, which combined the Coastal plain and Coastal dune zone. We used the SPSS statistical software to conduct a logistic regression analysis, selected the best model based on the Akaike's Information Criterion (AIC) values and used it to produce a risk of agricultural transformation map (Linkie et al., 2004). We also validated the approach by testing whether a risk map based on patterns of clearance between 1987 and 1997 was effective at predicting clearance between 1997 and 2001 (see Supplementary material).

The potential ranching revenue map used data on the 10 species that were sold by EKZNW as part of their annual game auction between 2002 and 2006. Other species found in Maputaland are sold or hunted but we felt it was more realistic to restrict our analysis to species with a known market. We used geo-referenced data from 14 annual game counts conducted in Mkhuze Game Reserve, Ndumo Game Reserve and Tembe Elephant Park to estimate the density of each of the 10 species in each of the Maputaland landcover types (Easton, 2004) and then predicted long-term sustainable off-take levels of each species based on the density data (see Supplementary material) and life history information collected from the literature (Table 1). Finally, we calculated the monetary value of each species as the mean price of animals sold at the 2002–06 annual EKZNW game auctions. This allowed us to calculate the

Table 1 – Life history and economic details for large herbivores sold at auction by EKZNW

Common name	Latin name	Inter-birth interval	Litter size	Young/female year	Proportion of females in population	Sustainable off-take of population	Auction cost (US$)
Giraffe	*Giraffa camelopardalis*	19	1	0.63	0.66	0.2	1729
Hippopotamus	*Hippopotamus amphibius*	13	1	0.92	0.5	0.2	4039
Impala	*Aepyceros melampus*	12	1	1	0.66	0.4	75
Kudu	*Tragelaphus strepsiceros*	12	1	1	0.6	0.4	334
Nyala	*Tragelaphus angasi*	9	1	1.33	0.6	0.4	764
White rhinoceros	*Ceratotherium simum*	30	1	0.4	0.5	0.2	20,742
Warthog	*Phacochoerus africanus*	12	3.26	3.26	0.62	0.6	106
Waterbuck	*Kobus ellipsiprymnus*	12	1	1	0.61	0.4	689
Blue wildebeest	*Connochaetes taurinus*	12	1	1	0.6	0.4	240
Burchell's zebra	*Equus quagga burchellii*	13	1	0.92	0.6	0.4	684

Auction cost is based on data from 2002 to 2006 and converted into 2006 US$ values using exchange rate and deflation index data.

potential annual revenue of each landcover type for each species and to sum the result to give a combined potential gross revenue value for each landcover type.

2.7. *Running the conservation assessment*

Once the targets for each conservation feature have been calculated, running Marxan involves: (i) dividing the planning region up into a number of planning units; (ii) calculating the amount of each conservation feature in each planning unit; (iii) assigning a cost value for each planning unit; (iv) setting a boundary length modifier (BLM) value which Marxan uses to determine priority area system fragmentation levels, and; (v) using Marxan to identify priority areas that meet the conservation feature targets whilst minimising costs (Ball and Possingham, 2000). Marxan does not produce one optimal solution to this problem but instead produces a number of near-optimal solutions. Thus, Marxan is run the number of times specified by the user and identifies a collection of planning units (referred to hereafter as a "portfolio") each time. Marxan then identifies the best portfolios, defined as the one with the lowest cost. It also counts the number of times each planning unit appeared in one of the portfolios, and this selection frequency score can be used as a measure of irreplaceability (Ball and Possingham, 2000).

The majority of the planning units used in the MCA were a series of 1 km^2 hexagons apart from the PAs, which were each represented as one planning unit, and a number of hexagons that had to be clipped to accommodate the boundaries of the PA planning units. The amount of each conservation feature in each planning unit was then extracted from the landcover and species distribution maps using the CLUZ ArcView extension (Smith, 2004). The cost of including each planning unit in a portfolio was based on agricultural transformation risk, for reasons that are discussed below. These risk probability values were summed because the units differed in area, so using mean risk would have favoured the selection of larger units because they tend to contain more of each conservation feature.

We designed a conservation landscape for Maputaland, which was defined as the part of the region that contains the existing PAs and any new core areas and linkages needed to meet the landcover and species targets, maintain connectivity and meet the ecological process targets. Marxan could not automatically identify portfolios that met the ecological process or minimum patch size targets, so we had to apply pre- and post-modification of the Marxan outputs to produce the final landscape. This two stage process, which involved developing the landscape and then the core areas within it, is described below.

The first step was to add the North–South linkage running down the western face of the Lubombo Mountains, as maintaining this narrow corridor was set as a target. We then identified planning units that are important for meeting the landcover and species targets by running Marxan 200 times, with each run consisting of two million iterations. Based on trial and error, we used a boundary length modifier value of 2, as this produced portfolios that were neither highly fragmented nor too extensive to be politically unacceptable. We then used the selection frequency map to design the initial conservation landscape by selecting all of the planning units that appeared in at least 75 of the 200 runs. This threshold of 75 was chosen because it identified an area that was expansive enough to meet all of the targets, although it was expected that some of these units would not appear in the final landscape. We also removed any patches of planning units that were smaller than 10 km^2, as these were felt to be too small to be ecologically viable or effectively managed.

We then ran Marxan again to identify the core areas, which were selected to ensure that, when combined with the existing PAs, they met all of the representation targets for the landcover types and species. We used the same set of parameters for this second analysis but restricted it so that only planning units found in the initial conservation landscape could be selected. We then used Marxan's best portfolio output to set the core areas, but any patches of planning units that were smaller than 10 km^2 were removed and some planning units were added to existing core areas to meet any targets that were affected by the removal of these small patches. Finally, we removed any of the planning units that were part of the initial conservation landscape but were not part of the core areas and did not help meet the connectivity targets.

3. Results

3.1. Conservation features

The Maputaland CPS contained data on 111 conservation features, which consisted of 44 landcover types, 53 species and 14 ecological processes (Tables S2–S5). The species consisted of 20 vertebrate, 13 invertebrate and 20 plant species. Eleven of the vertebrate species were selected because they have large potential ranges, while the remaining species were selected because they have a restricted range within their associated landcover types. All of the species were seen as having conservation importance within Maputaland, although not all of them appear in national Red Lists of threatened species. The ecological processes consisted of four linkage conservation features, nine natural fire regime features and one natural herbivory feature (Table S5).

3.2. Risk of agricultural transformation map

The South African section of Maputaland lost 329 km^2 of natural vegetation between 1987 and 2001, which was 6.7% of the total amount of natural vegetation and 15.2% of the unprotected natural vegetation. The risk of agricultural transformation model based on clearance patterns between 1987 and 2001 contained distance to existing agriculture ($p < 0.001$), agricultural potential type ($p = 0.033$) and a combined elevation and slope component ($p = 0.012$) as explanatory factors (Table 2). It predicted that areas that were close to existing agriculture in the Cretaceous or Alluvial zone and on low-lying flat ground were most at risk of transformation. The model was not affected by spatial autocorrelation (Moran's $I = -0.010$, $p > 0.1$) and had an area under the curve value from a receiver operating characteristics (ROC) plot of 0.769, indicating a good model fit. The risk of agricultural transformation map showed that areas in South Africa were most at risk, although the central part of Mozambique and areas around the rivers were also threatened (Fig. 3).

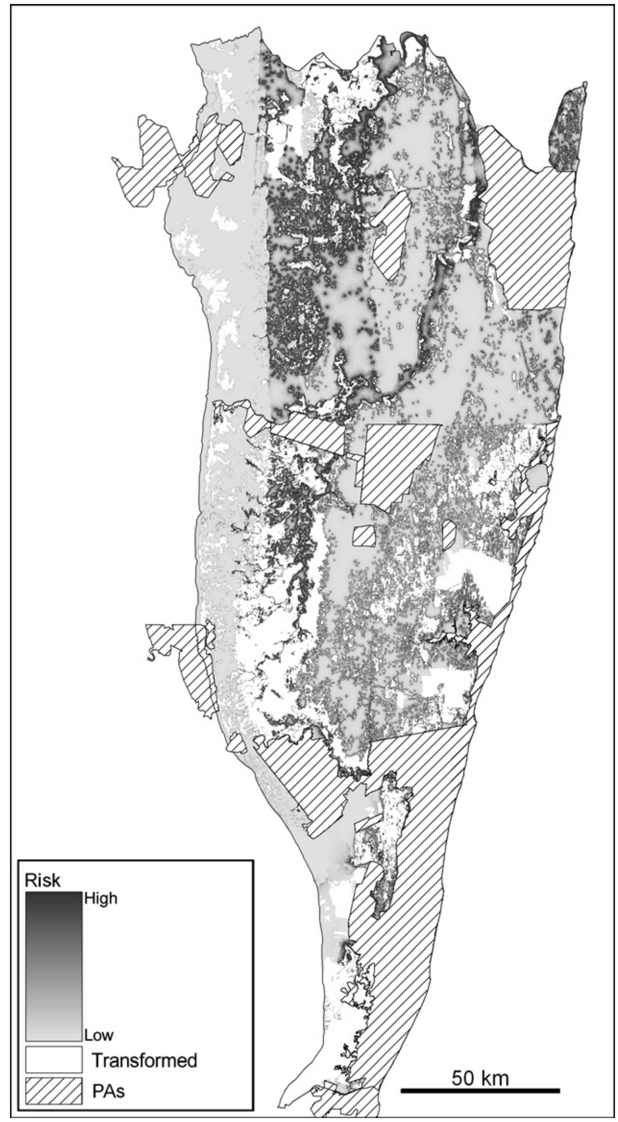

Fig. 3 – Map showing risk of agricultural transformation based on a distance to existing agriculture, ecological zone, elevation and slope.

3.3. Potential game ranching profitability map

The species/landcover type densities ranged between 0.002 white rhinoceros per hectare of sand forest to 0.58 nyala per hectare of floodplain grassland (Table S1). The sustainable harvesting levels of these species ranged between 0.00005 white rhinoceros per hectare of sand forest and 0.313 warthog per hectare of floodplain grassland. The adjusted auction price ranged between US$75 for an impala and US$20,742 for a white rhinoceros (Table 1). Combining these data for each landcover type produced revenue results that ranged from US$0.24 per hectare of Lubombo forest to $143.14 per hectare of floodplain grassland (Fig. 4). The mean revenues per hectare of natural vegetation in the three agricultural potential categories were: US$54.17 for the Lubombo type, US$80.35 for the Central type and US$31.12 for the Coastal type.

Table 2 – Model details for the risk of agricultural transformation analysis where: elevation = principal component analysis band combining slope and elevation; agriculture distance = distance to existing agriculture, and; soil = agricultural potential type

Model	K	ΔAIC	Wi
Agriculture distance + Elevation + Soil	4	0.00	0.8471
Agriculture distance + Soil	3	4.83	0.0756
Agriculture distance + Elevation	3	5.08	0.0668
Agriculture distance	2	8.79	0.0105
Elevation + Soil	3	41.19	0.0000
Soil	2	45.12	0.0000
Elevation	2	45.34	0.0000

K is the number of parameters in the model, ΔAIC is the difference in AIC values between each model with the low-AIC model and Wi is the AIC model weight.

3.4. Current levels of protection

Maputaland contains 16 PAs, of which 2 are in Mozambique, 12 in South Africa and 2 in Swaziland (Fig. 1). This PA system conserves 13.3% of the Mozambique section, 28.9% of the

Fig. 4 – Potential revenue from game ranching.

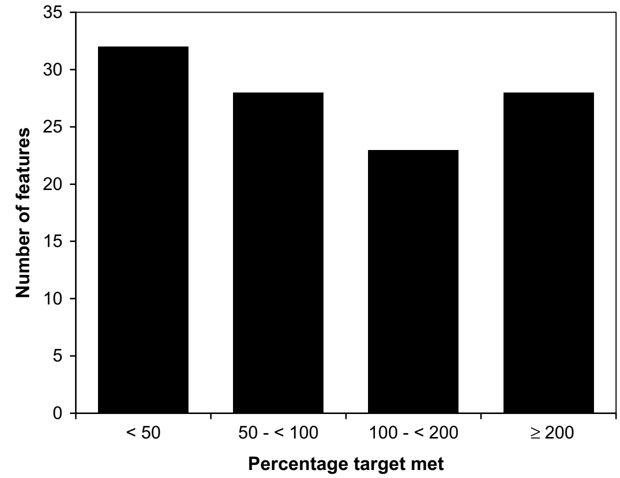

Fig. 5 – Details of representation targets met by the current PA system.

South African section and 13.2% of the Swaziland section of Maputaland, providing a combined protection level of 21.2% of the whole region. This PA system meets the representation targets for 51 of the conservation features and 50% of the targets for another 28 features (Fig. 5, Tables S2–S5). However, four of the landcover and species features are found entirely outside the current PA system (Tables S2–S5).

3.5. *Conservation assessment results*

The initial Marxan analysis identified a number of large patches with high selection frequency scores. These are found in the central part of Mozambique and south of Maputo Special Reserve, south of Ndumo Game Reserve, Tembe Elephant Park and Mkhuze Game Reserve in South Africa, and around the PAs in Swaziland (Figs. 1 and 6). Smaller patches are found neighbouring most of the existing PAs and in isolated areas that contain key plant species. Marxan identified 887 planning units that were selected in each of the 200 runs and 5288 planning units were selected 75 or more and so formed the basis of the initial conservation landscape.

The final conservation landscape contains a number of new core areas that join and extend the existing PA network (Fig. 7). The largest new core areas link the Maputo Special Reserve and Licuati Forest Reserve in Mozambique with PAs in South Africa, but there are other important areas to the south of Mkhuze Game Reserve and the existing PAs in Swaziland. A number of linkages have also been identified that are needed to meet the specified connectivity targets. The combined extent of these new core areas is 4291 km^2 and that of the linkages is 480 km^2, which means that implementing this conservation landscape would increase the land managed for biodiversity from the current 3830 to 8601 km^2. Based on our model, these extra core areas would have the potential to produce US$17,334,098/year of revenue and the linkages would have the potential to produce US$1,466,600/year of revenue from game ranching (Figs. 4 and 7).

4. Discussion

The conservation value of the Maputaland centre of endemism is internationally recognised (Steenkamp et al., 2004) and this is the first study to undertake a conservation assessment for the whole region. In this section we will discuss the results of this conservation assessment and we will also consider broader issues that relate to developing suitable data for a data-poor, biodiversity rich region. We will also discuss how the Maputaland CPS should be developed in the future to ensure its continued used in guiding land-use decisions.

4.1. *The Maputaland conservation assessment*

Maputaland has a relatively high coverage of PAs but the present system only meets 45% of the representation targets, with landcover types in the north of Maputaland and many plant species particularly poorly represented in the PA system. This is why many of the irreplaceable areas within Maputaland are found around Mlawula Nature Reserve and to the west and south of Maputo Special Reserve

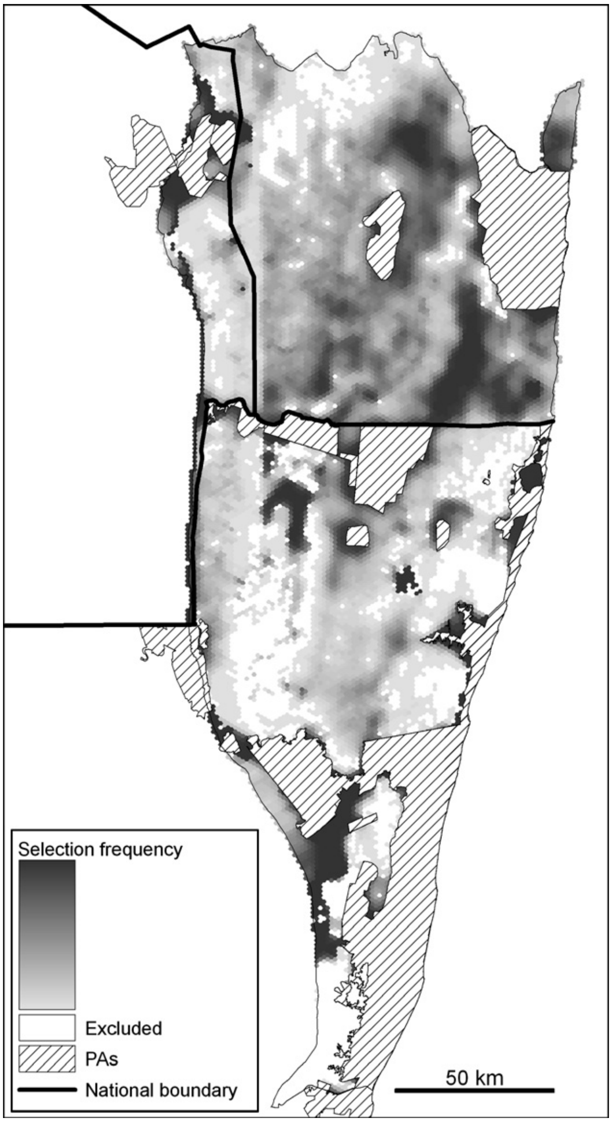

Fig. 6 – Selection frequency based on meeting landcover and species targets.

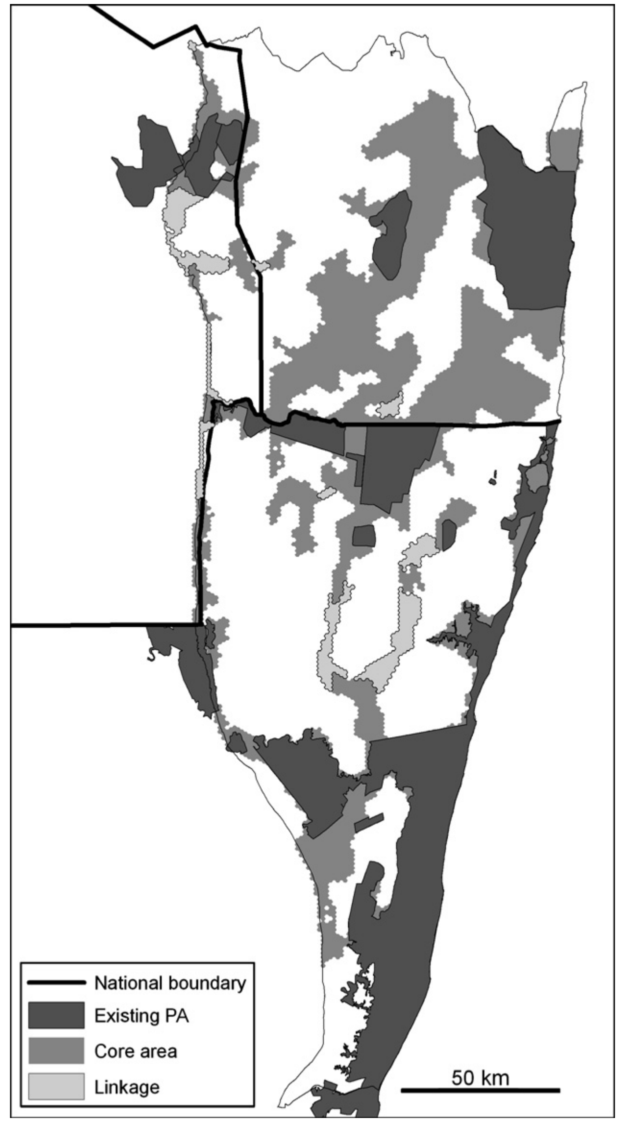

Fig. 7 – Proposed conservation landscape for Maputaland.

(Figs. 1 and 6). Thus, the MCA shows that the biodiversity of the Mozambique and Swaziland sections of Maputaland is relatively less well represented in PAs than the South African section. However, some parts of the South Africa section also have high irreplaceability levels and the most obvious of these is found to the south of Mkhuze Game Reserve (Fig. 6). Additional areas lie to the south of Ndumo Game Reserve and around Tembe Elephant Park, Sileza Nature Reserve and Lake Sibaya.

The results of the MCA also confirm the importance of current TFCA initiatives. All four of the TFCA zones fall within the Maputaland conservation landscape (Figs. 1 and 6) and so there is great scope for the MCA to help refine these TFCA boundaries. The only large core area that is not covered by a TFCA zone is the one to the south of Mkhuze Game Reserve, but this falls within a number of private reserves and so is likely to maintain its conservation value without further intervention. Nevertheless, many parts of the conservation landscape fall outside the boundaries of these existing or proposed conservation initiatives. Thus, it is important for decision makers to recognise that implementing the proposed TFCA will only be part of the process of conserving Maputaland's biodiversity.

Comparing the conservation landscape with the original irreplaceability map shows that a few of the core areas and some of the linkages have relatively low selection frequency scores (Figs. 6 and 7). Therefore, these areas could be swapped with other similar areas without affecting target attainment. It should also be noted that these scores are partly based on connectivity value, so that planning units that neighbour an existing PA generally have a higher value. Thus, establishing new PAs in the future could automatically increase the selection frequency values of any adjoining areas (Smith et al., 2006). Such changes would have particular implications for the position of the proposed landscape linkages, which were selected to join the PAs and core areas and meet the ecological process targets.

4.2. Selecting relevant cost information

Including economic data in conservation assessments ensures the identification of more cost effective PA systems (Stewart and Possingham, 2005) and provides results that are more readily understood and accepted by decision makers (Naidoo et al., 2006). Game ranching is a key industry in the South African section of Maputaland and could be very important throughout the region (Goodman et al., 2002), so it could be argued that the game ranch revenue data should have been included directly in the MCA. For example, the cost of each planning unit could have been set as the inverse of potential game revenue, so that the conservation landscape would have preferentially included land with greater game ranching potential (Easton, 2004).

There were, however, two reasons why we did not use these data directly in the MCA. First, many private reserves in Maputaland combine hunting and photographic safaris to maximise their profits, and we had no data on this other form of nature-based tourism. Moreover, revenue from photographic tourism is more dependent on the spatial pattern of infrastructure, such as roads and lodges, and predicting how this will change in response to proposed developments is difficult. In addition, the profitability of game ranching around Ndumo Game Reserve and Tembe Elephant Park is currently impacted by measures to prevent the spread of foot and mouth disease. Perhaps more importantly, we also had no data on incompatible land-uses, such as commercial agriculture, which tend to be most productive on the rich soil types that also have the highest potential game revenue (Table 3). Thus, we would have needed a much broader range of revenue information to ensure that the MCA was based on more balanced economic data (Naidoo and Ricketts, 2006). Second, the game revenue data were calculated per landcover type and this lack of spatial precision meant that planning units with similar biodiversity would often have had similar cost values in the Marxan analysis. Thus, the planning unit costs would have had little influence on identifying important areas, which is why it is essential to use cost data with a similar spatial resolution to the conservation feature maps (Richardson et al., 2006).

These revenue data could also have been used as part of the target setting process, with landcover types that are suitable for game ranching being given higher targets. However, this would have confused the role of the CPS, which aims to identify areas for ensuring long-term biodiversity persistence, and would have ignored the economic importance of other conservation features and opposing land-uses. Instead, we used the game ranch data to calculate the potential revenue of the conservation landscape, illustrating its economic advantages in a more transparent manner. In doing so, we also highlighted that conserved land can provide economic benefits through game ranching. This suggests that the conservation sector should continue to support and guide the opportunistic development of new private and communally owned game ranches that are managed in ways that maintain their biodiversity value (Knight and Cowling, 2007), whilst focussing their financial resources on those parts of the conservation landscape with less game-ranching potential.

A much more suitable source of cost data was the risk of agricultural transformation map, as it had a number of

Table 3 – Details of the broad landcover types found in Maputaland showing their associated ecological zone, agricultural potential zone and potential revue from game ranching

Landcover type	Ecological zone	Agricultural potential zone	Potential revenue (US$ per ha)
Lubombo aquatic	Lubombo	Lubombo	71.15
Rock faces	Lubombo	Lubombo	0
Lubombo grassland	Lubombo	Lubombo	4.64
Lubombo woodland	Lubombo	Lubombo	66.94
Lubombo thicket	Lubombo	Lubombo	22.73
Lubombo forest	Lubombo	Lubombo	0.24
Acacia woodland	Cretaceous	Central	82.12
Acacia thicket	Cretaceous	Central	71.95
Floodplain grassland	Alluvial	Central	143.14
Reed bed	Alluvial	Central	7.05
Riverine thicket	Alluvial	Central	46.05
Riverine forest and woodland	Alluvial	Central	52.82
Sedge and grass swamp	Coastal plain	Coastal	4.61
Hygrophilous grasslands	Coastal plain	Coastal	16.22
Woody grassland	Coastal plain	Coastal	56.3
Terminalia woodland	Coastal plain	Coastal	23.62
Woodland on red sands	Coastal plain	Coastal	69.71
Sand thicket	Coastal plain	Coastal	62.4
Sand forest	Coastal plain	Coastal	3.99
Inland evergreen forest	Coastal plain	Coastal	3.75
Swamp forest	Coastal plain	Coastal	0
Mangroves	Coastal plain	Coastal	0
Dune thicket	Coastal dune	Coastal	3.75
Dune forest	Coastal dune	Coastal	3.75

advantages. First, it had the same effective spatial resolution as the conservation feature data and provided important information for distinguishing between planning units with similar biodiversity (Richardson et al., 2006). Second, it ensured that the MCA avoided areas, wherever possible, that are likely to be transformed in the near future, so that the proposed landscape is less likely to be affected by future developments (Meir et al., 2004). Third, it can be used to guide the implementation timetable, with the high risk parts of the landscape needing protection first (Linkie et al., 2004; Wilson et al., 2005). Fourth, it provided a measure of financial value, as those areas that are most at risk are threatened because their combination of accessibility and soil quality make them more prized for agriculture (Naidoo et al., 2006). Moreover, this measure of financial value incorporates a range of different aspects and is particularly relevant for communally-managed areas, such as most of Maputaland, where the financial value of land is difficult to measure.

This means that the proposed conservation landscape is both less at risk of transformation and isolation, and less likely to impact on the economic development of people living in the region. Although such an approach could be criticised for ignoring those high risk areas that would benefit most from protection, this problem can be overcome by setting appropriate biodiversity targets and working with landowners to ensure that biodiversity loss outside of the landscape does not impact the region as a whole. Thus, we would recommend the wider use of such data in conservation planning.

4.3. *Distribution data limitations*

Maputaland is known to contain a large number of endemic species and sub-species (Steenkamp et al., 2004) but little is known about their distributions. In addition, many of these species are poorly known, so setting scientifically defensible targets for them is difficult. However, we were able to reduce these problems by including landcover types as conservation features, as these have been studied more recently and could be mapped accurately and cheaply. In addition, the landcover map covered the whole planning region, so was not affected by sampling bias, and the landcover type targets were based on field surveys and so were more defensible than previous assessments based on expert opinion (Smith et al., 2006).

We could also be relatively confident about the wide-ranging species data, as these species have been well studied and their actual or potential distributions could be mapped more accurately. The wealth of published life history and conservation data on these species also aided the target setting process. However, we still felt it was important to include data on the less well known, range-restricted species because the larger species have broader habitat requirements that may make them poor biodiversity surrogates. This is why southern African conservationists commonly identify areas that are important for range-restricted species and then re-introduce or restrict the relevant large mammals where appropriate (Lombard et al., 2001; Hunter et al., 2007). Thus, we included range-restricted species in the MCA, despite the relative uncertainty of the underlying data. In doing so, we helped ensure that the software preferentially selected areas containing both widely distributed species, such as the large mammals, and the remaining range-restricted species. Our work also identified these important species, which should be seen as priorities for future survey work. This is particularly important for some of the invertebrate and reptiles that probably have smaller ranges than were predicted based on our habitat modelling.

4.4. *Future work*

One of the great advantages of the Lubombo TFCA initiative is that it has strong political support at the national and international level (Knight and Cowling, 2007). However, this can create a disjunction if there is insufficient capacity to implement this broad vision at the regional scale. The Maputaland CPS was produced to help overcome this problem but it was not developed as an integral part of the original TFCA initiative. Instead, the CPS project arose from an existing partnership between one UK and one South African institution and had its own external funding. The project involved the Mozambique and Swaziland partners from the outset but the nature of its development meant that these new groups were initially less familiar with the approach and had lower conservation planning capacity levels. This situation is not ideal, as conservation planning is most effective when driven by stakeholder involvement from the beginning (Knight et al., 2006b). However, it is likely that many conservation planning systems will be developed under similar circumstances, with initial developments being led by a small number of project partners.

We would suggest, therefore, that current systematic conservation planning guidelines should be modified to allow for situations where adoption of these techniques occurs at later stages of the project cycle. Based on our experience, we would argue that such *post-hoc* adoption need not have long-term disadvantages if the conservation planning activities are designed to be an ongoing process. This permits further capacity building and mainstreaming, as well as allowing planning systems to remain relevant by incorporating new and refined data. Such an approach is already underway in Maputaland, where we are now working with the Lubombo TFCA authorities to develop a relevant training programme and plan to conduct biennial MCAs that will be incorporated into national and transnational land-use plans.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.biocon.2008.06.010.

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