Quantifying the effects of diverse private protected area management systems on ecosystem properties in a savannah biome, South Africa

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Appendix 1 The mammal species analysed in this study. Although there was only sufficient data, or sufficiently detailed data, to use a core subset of the species in the majority of the analyses, all species were included in at least one analysis.

Common name	Latin name	Feeding guild*
Cheetah	*Acinonyx jubatus*	P
Leopard	*Panthera pardus*	P, B5
Lion	*Panthera leo*	P, B5
Spotted hyena	*Crocuta crocuta*	P, S
Wild dog	*Lycaon pictus*	P
Black rhinoceros	*Diceros bicornis*	G
Blesbuck	*Damaliscus pygargus*	G
Blue wildebeest	*Connochaetes taurinus taurinus*	G
Buffalo	*Synecerus caffer*	MH, G, B5
Bushbuck	*Tragelaphus sylvaticus*	B
Duiker	*Silvicapri grimmia*	B
Eland	*Taurotragus oryx*	SG
Elephant	*Loxodonta africana*	MF, MH, B5
Gemsbuck	*Oryx gazella*	G
Giraffe	*Giraffa camelopardalis*	B
Grysbuck	*Raphicerus melanotis*	B
Hartebeest	*Alcelaphus buselaphus*	G
Hippopotamus	*Hippopotamus amphibius*	MH, G
Impala	*Aepyceros melampus*	MF
Lichtenstein's hartebeest	*Alcelaphus lichtensteinii*	G
Klipspringer	*Oreotragus oreotragus*	B
Kudu	*Tragelaphus strephus*	B
Mountain reedbuck	*Redunca fulvorufula*	G
Nyala	*Tragelaphus angasii*	B
Reedbuck	*Redunca arundinum*	SG
Roan antelope	*Hippotragus equinus*	SG
Sable antelope	*Hippotragus niger*	SG
Tsessebe	*Damaliscus lunatus*	SG
Warthog	*Phacochoerus africanus*	G
Waterbuck	*Kobus ellipsiprymnus*	G
White rhinoceros	*Ceratotherium simum*	MH, G, B5
Zebra	*Equus quagga*	G

*B, browser; B5, so-called big-five species; G, grazer; MF, mixed feeder; MH, megaherbivore; P, predator; S, scavenger; SG, specialist grazer

Appendix 2 Supplementary information on management interviews.

The main set of quantitative and ordinal data requests presented to each conservancy manager were binary. After asking permission to use the ARC-API herbivore and grass biomass datasets, conservancy managers were asked to provide other records relating to hunting, culling, live animal sales, reintroductions and translocations, burning and bush-clearing operations, predator control operations, supplementary feeding operations, breeding camp operations and commercial lodge information. If quantitative records were not available (either inexistent or because of matters of privacy) then managers were asked qualitative questions about the management practice. Usually these answers were 'yes' or 'no' (for example, do you practice

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supplementary feeding? Do you practice predator contraception? Have you established rare species breeding projects?). However, for the burning and bush-clearing variables, questions related to the frequency and extent of the management activity were asked. For the burning policy, these questions were: (1) How many times is the conservancy burnt each year? (2) On average, what area of the conservancy is burnt each time? (3) Is it a point ignition? (4) Do you follow the recommendations of ARC-API? (5) Do you engage in block burning?). For the bush-clearing policy, the questions asked were: (1) Do you practice bush-clearing? (2) How many times per year? (3) Is the bush-clearing done mechanically or by hand? (4) On average, how large are the areas that are opened? Burning and bush-clearing were particularly sensitive subjects for conservancy managers and thus the variables were ranked on a relative scale of intensity to mitigate inaccuracy in detailed descriptions.

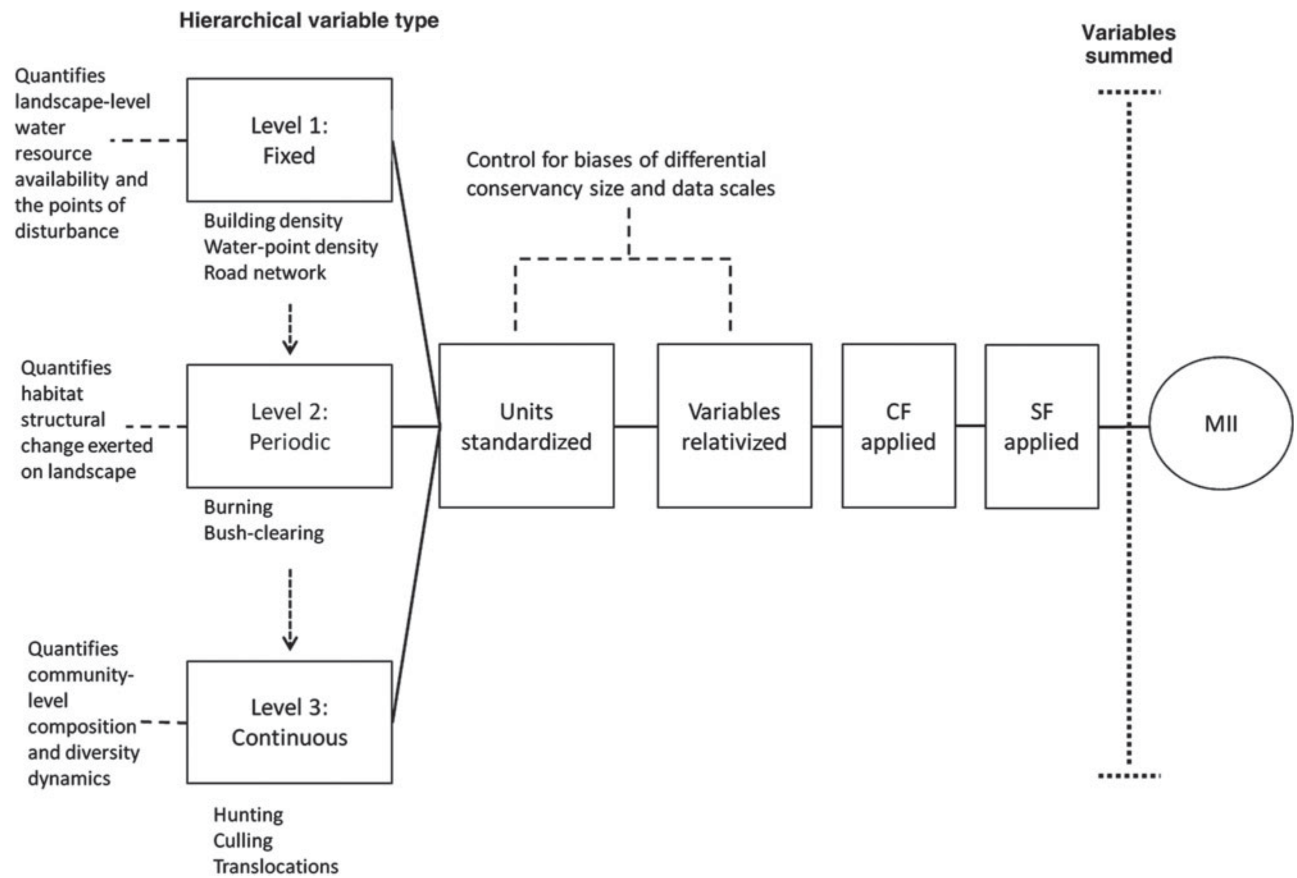
Aside from quantitative and ordinal data extraction, interviews also covered several broad areas relating to management: (1) the property incorporation and fencing history of the conservancy, (2) the philosophical, economic and political underpinning of a chosen management system, (3) the ways in which the conservancy benefited or was benefited from local institutions, commercial development and social groups, and (4) the perceived role of conservancies in conservation and rural rejuvenation. These conversations were also transcribed by hand during the interview. Fact-checking of qualitative data was performed by the ARC-API team who has had over 2 decades of experience in dealing with landowners in this system.

Appendix 3a Supplementary information on the management index.

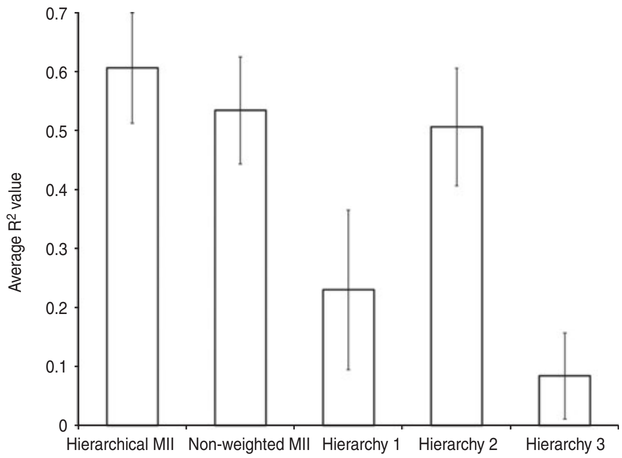
Traditional multivariate approaches were not possible for several reasons: long-term management datasets for many variables are not readily available (primarily because of privacy issues and sometimes inadequate knowledge capture systems) and are often measured differently across conservancies. Consequently, analyses were hampered because of low effective sample sizes and low statistical power. Focusing on individual variables from which to draw comparisons across conservancies would also probably have led to spurious conclusions because, as this study has shown, conservancies employ heterogeneous management policies to achieve very different goals and, by analysing variables sequentially, we could have missed the net effect of management effort. Most univariate correlations were insignificant (see below), which does not preclude the existence of a correlation but demonstrates the difficulties of using aggregated data to infer specific relationships. Instead, the results from this study suggest that a hierarchically integrated index is a significantly better predictor of the ecological effects of management than non-hierarchical or modular predictors, indicating that it may capture some of the emergent effects of interacting management practices. The management intensity index (MII), because it integrates the effects of the overall management syndrome, allows standardized comparisons to be drawn across conservancies. Such indices, through the processes of construction, refinement and application, could become invaluable empirical and rhetorical devices to unite sociologists, conservationist scientists and private protected area managers.

Appendix 3b Univariate regressions (ordinary least squares for continuous data and logistic for ordinal data) showing the relationships between individual management variables and the ecological response variables. Only lodge density (a subset of building density and not used in MII calculations) and the MII show consistent significant correlations with the response variables. All values are correlation coefficients (*r*) and significance is denoted by asterisks (*for $P < 0.05$; ** for $P < 0.01$).

	Stocking rate	Herbivore density	Predator density	Grass biomass	Grass biomass residuals	Community dissimilarity
Management variables						
Artificial water-point density	0.59*	0.32	0.21	0.05	−0.17	0.22
Building density	0.37	0.42	0.01	0.38	0.02	0.17
Road density	0.45	0.43	0.50	−0.08	−0.05	0.61*
Burning practice	0.51	0.49	0.44	0.21	0.39	0.37
Bush-control practice	0.42	0.65*	0.49	0.40	0.35	0.58*
Biomass removal	0.30	0.38	−0.12	0.50	0.10	0.19
Biomass addition	0.19	0.39	0.51	0.54	0.24	−0.36
Species managed (n)	0.27	0.11	0.05	0.21	−0.23	0.28
Lodge density	0.63*	0.70*	0.62*	0.56	−0.21	0.58*
Environmental variables						
Rainfall	0.39	0.30	0.53	0.87**	n/a	0.51
River length	0.13	0.14	0.44	n/a	n/a	0.15
Structural diversity	0.07	0.05	0.12	0.11	0.10	0.24
MII	0.84**	0.73*	0.78**	0.43	−0.70*	0.80**



APPENDIX 4a A schematic diagram of the management intensity index (MII) calculations. By weighting these different management variable types hierarchically we aimed to capture the scale-dependent effects of management practices on ecological variables. The correction factor (CF) is a coefficient to control for the number of variables in each hierarchical level and the scaling factor (SF) weights the hierarchical levels differentially. Fixed variables were converted to units per ha to correct for conservancy size. Burning and bush-clearing data were coded as ordinal variables based on interviews and management reports relating to extent and frequency, because of limited quantitative records. Hunting, culling and translocation data were converted into kg ha^{-1} $year^{-1}$ (positive values for introductions, negative for hunting, culling and live animal sales), and the total number of species manipulated was recorded.



APPENDIX 4b Different constructions of the MII were tested for the trade-off between explanatory power and parsimony. The hierarchically constructed and weighted MII possessed significantly greater explanatory power than a non-hierarchical index or any single variable group alone, although Hierarchy 2 (burning and bush-clearing ordinal variables) also performed well. The hierarchically constructed MII captures significantly more of the variance associated with management than non-weighted or single-hierarchy indices ($R^2 = 0.62 \pm$ SD 0.09 compared to $0.34 \pm$ SD 0.03; ANOVA: $F_{24,25} = 24.3$, $P < 0.01$, n = 25 correlations). Ordinal data on the burning and bush clearing policies of each conservancy (Hierarchy 2) is a better predictor of ecological properties than the hierarchical levels above or below ($R^2 = 0.51 \pm$ SD 0.10 compared to $0.23 \pm$ SD 0.14 and $0.10 \pm$ SD 0.07 respectively).