esa ECOSPHERE

The relevance of socioeconomic interactions for the resilience of protected area networks

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Citation: Maciejewski, K., and G. S. Cumming. 2015. The relevance of socioeconomic interactions for the resilience of protected area networks. Ecosphere 6(9):145. http://dx.doi.org/10.1890/ES15-00022.1

Abstract. Ecological theory suggests that intermediate connectivity between protected areas will increase their resilience by facilitating dispersal, recolonisation, and genetic mixing. Conversely, over-connectivity may make areas less resilient to contagious perturbations such as pathogen outbreaks. In a similar manner, socioeconomic connectivity should enhance the spread of effective management strategies and the sharing of scarce resources, but over-connectivity carries the risks associated with one-size-fits-all strategies. We used network analysis to examine the topology of management collaborations and related exchanges of information and equipment in two protected area networks in South Africa using the Eastern and Western Cape Provinces as study sites. National protected areas displayed the highest degree of centrality in the Western Cape, while provincial protected areas occupied the central role in the Eastern Cape. Managers in the Western Cape were more concerned about establishing ecological connectivity between protected areas whereas tourism emerged as an important driver in the Eastern Cape protected area network. Our results support the argument that both location and network membership are important for the socioeconomic resilience of protected areas. As with ecological corridors, deliberate fostering of particular socioeconomic corridors may make the protected areas more resilient to perturbations.

Key words: conservation; governance; network analysis; social-ecological systems; spatial proximity.

Received 14 January 2015; accepted 18 March 2015; **published** 14 September 2015. Corresponding Editor: M. Cadenasso.

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Introduction

National parks and nature reserves have been a cornerstone in the conservation of species and natural areas for many years (Bengtsson et al. 2003). Systematic conservation planning remains focused on the biophysical elements of protected areas, including such questions as where new areas should be placed to conserve the largest number of species and the ways in which organisms may move between protected areas via habitat corridors or stepping stones (Bodin et al. 2006, Fischer et al. 2009). In Africa, however, with its increasing human population, growing cities, and agricultural expansion, space for new parks and corridors is becoming limiting (McKinney 2002) and existing protected areas are increasingly being expected to justify their existence through their contributions to economies and ecosystem service provision. At the same time, land use and land cover change are reducing ecological connections between protected areas and making them less resilient to species loss by reducing the potential for immigration. From a conservation perspective, these trends imply that increasingly active human management and manipulation (e.g., fire management, species translocations to enhance genetic diversity, invasive species control, restoration) of protected areas and their surrounding landscapes will be necessary if protected areas are to continue to meet conservation goals.

Protected areas are social-ecological systems that include a suite of actors (e.g., managers, tourists, and surrounding communities) who interact with one another and with ecosystems in a shared environment (Cumming et al. 2015). Socioeconomic interactions between protected area managers such as exchanging information, sharing knowledge, management strategies and tourism are important for protected areas. These interactions provide opportunities for learning, improved management, monitoring, assessment of regional trends, persistence through periods of hardship (e.g., controlling disease outbreaks or managing under drought conditions), and the generation of income. For example, most populations of the white rhinoceros in southern Africa trace their origins to a re-stocking program that translocated animals from a growing population in Hluhluwe Game Reserve in Kwazulu-Natal (Tomlinson 1977). Socioeconomic interactions can thus play a vital role in protected area resilience (i.e., the capacity of a protected area to absorb disturbance and reorganize while undergoing change so as to retain its function, structure, identity and feedbacks [Walker et al. 2004]). In this context there is a strong parallel between ecological corridors, which contribute directly to ecological resilience, and socioeconomic interactions and networks, which contribute directly to socioeconomic resilience and indirectly to ecological resilience through their effects on the actions of managers, tourists, and local human communities.

Different protected areas may have different rules, laws, policies, and management (Cumming et al. 2006). For example, strong contrasts exist between the management structures associated with national protected areas and those associated with privately owned protected areas. Private protected areas are "land parcels of any size that are predominately managed for biodiversity conservation, protected with or without formal government recognition and owned or secured by individuals, communities, corporations, or NGOs" (Mitchell 2005). Formal connections may already exist between protected areas, as in the case of national protected areas that are managed by a single government agency. However, informal networks often develop in management contexts through exchanges of information and resources (Goss and Cumming 2013), and these interactions may be more frequent and more meaningful than simply being members of the same organization.

If socioeconomic connectivity influences protected area resilience, then it is important that we understand how these interactions are formed and which factors dominate their development. Two competing hypotheses may explain how socioeconomic interactions develop. The first proposes that socioeconomic interactions should be most frequent and/or most intense between protected areas that belong to the same organization and are regulated by the same institutions, because they share management structures and a common identity. If correct, this hypothesis would imply that the socioeconomic interactions between protected areas are most strongly driven by the organization to which it belongs. This phenomenon, known as homophily, is frequently found in political networks where actors with similar characteristics are more likely to form network ties than actors with different characteristics (Gerber et al. 2013). The second hypothesis proposes that socioeconomic interactions should be most frequent and/or most intense between protected areas that are near to one another in geographic space, because interactions are dominated by contact frequencies and shared problems rather than by organizational membership. Several studies have found that sustainable cooperation is more likely when interactions occur with immediate neighbors rather than with any other individuals in the community (Nowak and May 1992, Nowak et al. 1994, 2006). In 2009, Bodin and Crona found an increasing number of different types of actors within close proximity interacting with one another, resulting in many positive benefits. Spatial proximity between actors is considered crucial for them to gain knowledge, information, and access to new innovations and technologies (Feldman 1994, Cooke 2001, Belaire et al. 2011), although in this age of digital communication it remains unclear whether and how the benefits of spatial proximity compare to the benefits of shared organizational membership. Spatial proximity also establishes ecological connectivity between protected areas which facilitates gene flow, maintains demographic links, reduces pressure on ecosystems and contributes to building resilience against climate change (Jones et al. 2009).

We used two adjacent South African provinces to test these two contrasting hypotheses. South Africa offers an interesting case study because it contains many protected areas that range in levels of governance or tenure type. The South African government manages 20 national protected areas throughout South Africa. These areas are regulated by South African National Parks (SANParks). Provincial protected areas, by contrast, are independently managed within the 9 provinces. In addition, numerous private protected areas are found throughout the country. Private areas are usually managed and owned by individuals or private organizations. For this study, we focused on the Western and Eastern Cape provinces of South Africa to explore different socioeconomic connections and their role in the resilience of social-ecological systems. We employed a social network analysis approach, which focuses on the structure of the interactions and the ways in which this structure affects the performance of the system (Janssen et al. 2006).

Network analysis is based on graph theory and statistics (Janssen et al. 2006) and focuses on how a collection of units interacts together as a single system (Meyers et al. 2005, Proulx et al. 2005). A network consists of nodes and links that can be used to represent the relations between components (Janssen et al. 2006). In this study, the nodes represent protected areas and the links represent interactions that exist between them. Links can be directed or undirected. The nature of the relations could either be social, ecological, or a combination of the two (Janssen et al. 2006).

The application of network analysis to data depends of the commonality of network properties between diverse systems. Measures such as network size (number of entities incorporated into the analysis) or network connectivity (measure of network connectivity) may be used (Barabási 2009). The level of connectivity is the density of the links within the network i.e., the number of links divided by the maximum possible number of links (Janssen et al. 2006). Reachability is the accessibility of all the nodes in the network (Janssen et al. 2006). Higher-density networks are more resilient to the removal of links. To quantify reachability, network diameter can be used which is the minimum path length connecting any pair of nodes in the network (Wasserman and Faust 1994). By analyzing the network structure of the network systems, inferences can be made about how the system functions.

Nodes may form communities within the network, which consist of highly connected nodes with few links to other nodes (Pons and Latapy 2005, Wong et al. 2006). The community structure of a network can be calculated by measuring the modularity of the network, which is the number of edges falling within a group minus the expected number of an equivalent network with edges placed at random (Newman 2006). A positive modularity value indicates good community division within a network, which can be useful in understanding the behavior of the system (Newman 2006). Using network analysis, we can explore the resilience of protected area networks to the loss of protected areas or interactions between protected areas by examining the effect of removing individual nodes or links on the overall functioning of the network. This will determine how spatial resilience of a protected area influences resilience of the protected area network and help us identify nodes that are particularly important for overall network connectivity. The concept of centrality can be used as it assesses the influencing capacity of each node (Wasserman and Faust 1994).

Methods

Study area and data collection

We compared the Western (129405 km^2) and Eastern Cape Provinces (169936 km^2) of South Africa, which contained several hundred protected areas managed by various institutions and organizations. National protected areas, regulated by South African National Parks (SANParks) are found in both provinces, five in the Western Cape and three in the Eastern Cape (Fig. 1). The provincial protected areas in the Western Cape are managed by Cape Nature and governed by the Western Cape Nature Conservation Board Act 15 of 1998. The Eastern Cape consists of provincial protected areas managed and governed by Eastern Cape Parks and Tourism Agency (Fig. 1). There are also a large number of private protected areas found in both prov-

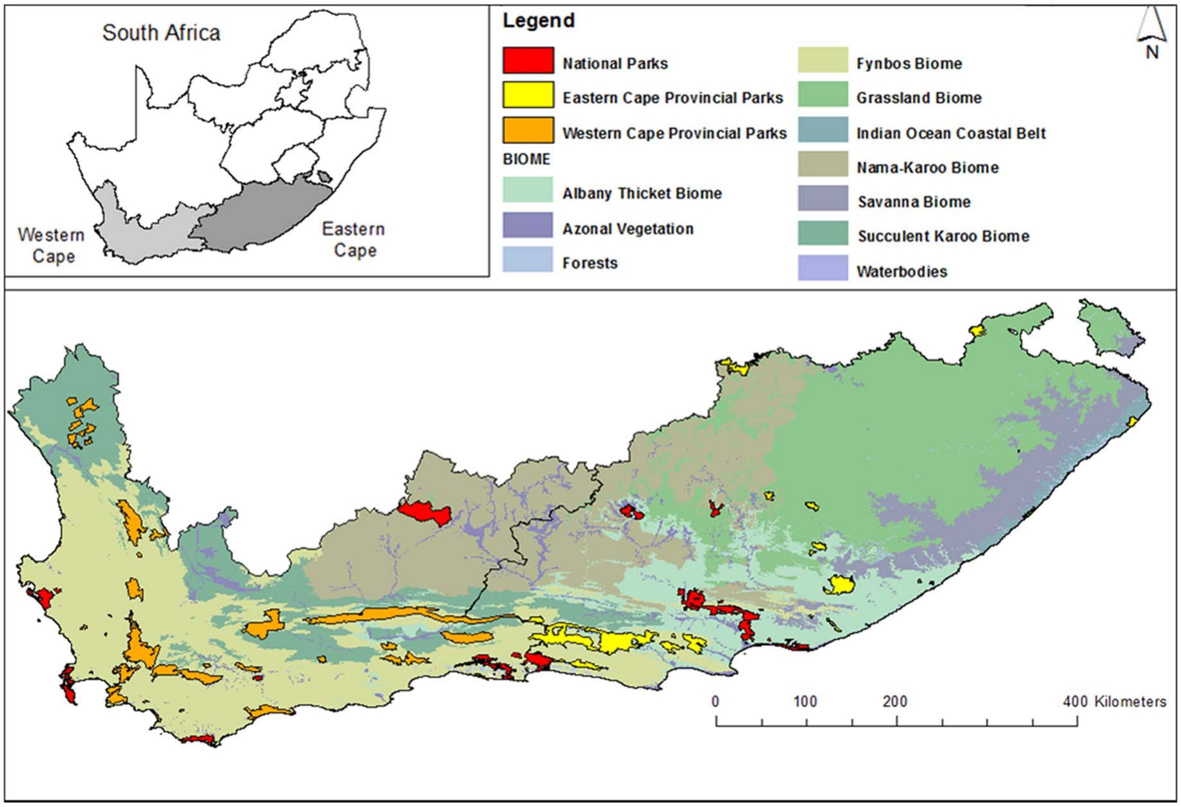

Fig. 1. Statutory protected areas (national and provincial protected areas) used as case studies in analyzing the protected area network of the Western and Eastern Cape Provinces in South Africa.

inces, usually owned and managed privately.

The study sites were visited between 2013 and 2014 and interviews were conducted with managers to identify existing socioeconomic interactions between protected areas. Interaction was defined as including exchanging ideas, sharing equipment, trading in wildlife, engaging in discussions with regard to management, education, tourism, research, and forming collaborations with managers from surrounding protected areas. During the interviews managers identified factors that influenced these interactions and how they differed across organizational levels.

Network description

Interactions between protected areas were used to construct a protected area network for each province, using the package igraph 0.5.5-3 (Csardi and Nepusz 2006) in the R statistical computing environment version 2.14.1 (R Development Core Team 2011). All network visualizations were generated using Gephi 0.8, an open-source software package for graph and network analysis (Bastian et al. 2011).

Network analysis, which is based on graph theory and statistics (Janssen et al. 2006) focuses on how a collection of units interacts as a single system (Meyers et al. 2005, Proulx et al. 2005). The protected areas from which managers were interviewed (source) and the lists that they provided of connected protected areas (targets) represented the nodes of the protected area network. We looked up to two steps (nodes) away from the provincial and national protected areas, resulting in a total of 127 and 48 nodes for the Western and Eastern Cape respectively. In the Western Cape, this network included 10 national, 46 provincial, and 71 private protected areas. The EC PAN included 7 national, 19 provincial, 16 private protected areas, and 6 protected areas that belonged to other organizations including Cape Nature, KZN Wildlife, and Free State Provincial Parks. The edges (links, vertices) of the protected area network consisted of directed linkages between source and target protected areas. The nodes were sized according to each node's eigenvector centrality, which assigns relative scores to all nodes in the network based on the principle that connections to high-scoring nodes contribute more to the score of the node in question. Nodes with a high centrality therefore receive flows and are in a position to control flows (Borgatti 2005).

We divided the number of interactions by the maximum possible number of interactions within the protected area network to determine the level of connectivity or density of the interactions (Janssen et al. 2006). Modularity of the network was calculated using the Walktrap community logarithm to detect community structure in the protected area network (Pons and Latapy 2005). Spearman's correlation coefficient was used to determine the role that organizational level of protected area played in the establishment of linkages. This non-parametric statistical test gave us an indication whether protected areas were more likely to establish interactions with protected areas belonging to the same organization by measuring the statistical dependence between the source and target protected areas.

We calculated the ratio of the number of bidirected edges to the total number of edges to determine edge reciprocity or the tendency of adjacent nodes to form mutual connections (Wasserman and Faust 1994). The significance of this ratio was determined by a comparison to 100 random networks to assess if reciprocity occurred more or less than expected, using the Erdös-Rényi algorithm (Erdös and Rényi 1959), which preserves the number of nodes and edges in the real network while randomly modifying edge locations.

Spatial location of protected area networks

To determine the role that spatial proximity plays in the establishment of the protected area networks we measured the geographic distance between the centroids of all protected areas in the networks using the spDist function in the R package sp 1.0-11 (Pebesma et al. 2012). A two-sample t test was used to compare the distance between all connected and non-connected protected areas and determine whether a difference existed. Significance was allocated where $p < 0.05$.

To further investigate the role that spatial location plays in a protected area network we looked at biome coverage of individual protected areas to determine whether ecological similarity existed between connected protected areas. Biome coverage was calculated as a proportion of biomes covered by the protected areas in relation to the total available biomes in each province to determine the degree of preference for biome type. Selectivity for each biome was assessed using Jacob's selection index (Jacobs 1974),

$$D = \frac{r - p}{r + p - 2rp}$$

where r is the proportion of total area of biomes covered by protected areas in each province and p is the proportional availability of biome in each province. The resulting values ranged between -1 (maximum avoidance) and $+1$ (maximum preference; Jacobs 1974).

Differences between relative availability and utilization of each biome were further assessed by calculating 95% confidence intervals for the proportional utilization of each biome. The normal approximation interval binomial interval was used (Brown et al. 2001)

$$p \pm z_{1-\alpha/z}\sqrt{\frac{p(1-p)}{n}}$$

where p is proportional of usage, n is sample size, α is desired confidence, $z_{1-\alpha/2}$ is the z value for desired level of confidence, and $z_{1-\alpha/2} = 1.96$ for 95% confidence. This reflected a conservative approach to interpreting the data where p is close to 1 or 0; n should be larger to maintain a good approximation (Neu et al. 1974). The preference or avoidance of each biome may be considered to be significant if the confidence interval does not overlap the relative availability.

Interactions between protected areas

During interviews managers indicated from a list of potential socioeconomic and ecological factors how they interacted with surrounding national, provincial, and private protected areas. This information was used to identify the most important factors responsible for connecting

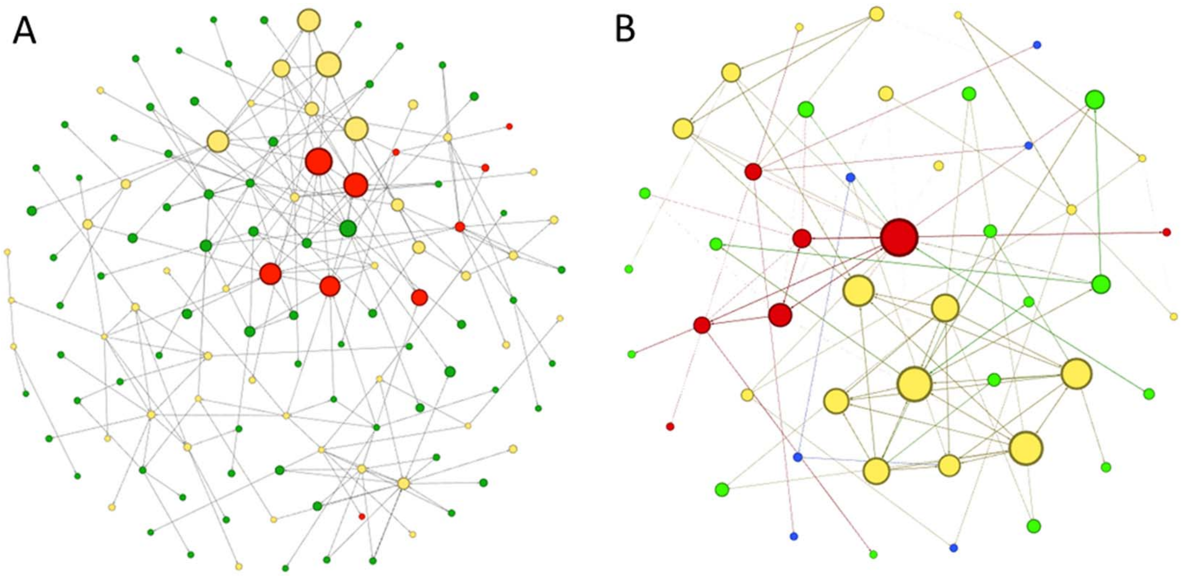

Fig. 2. Protected area network visualization of the (A) Western Cape and (B) Eastern Cape Province of South Africa formed from (A) 127 protected areas and 241 interactions and (B) 48 protected areas and 119 interactions. Node colors represent scale of governance: national protected areas are red, provincial protected areas are yellow, private protected areas green, and other protected areas colored blue. Node size indicates the eigenvector centrality of each node with the most connected nodes appearing as the largest nodes.

protected areas in this protected area network using a Wilcoxon matched paired tests to determine degree of significance between various data. To determine the means by which these socioeconomic interactions take place, managers ranked four options (phone, e-mail, social networking, and face-to-face) from 1 (least relevant) to 5 (most relevant). To determine the most important interacting factors and the role that spatial proximity plays in the establishment of these interactions, managers were provided with a list of potential factors and asked to rank these from 1 (strongly disagree) to 5 (strongly agree). An analysis of covariance was used to determine degree of significance and a weighted average calculation was used to analyze these five-point Likert scales using the following equation:

$$\frac{(a \times 1) + (b \times 1) + (c \times 1) + (d \times 4) + (e \times 5)}{(a + b + c + d + e)}$$

where $a = 1$ (strongly disagree) and $e = 5$ (strongly agree; Clasen and Dormody 1994). Composite scales were created by combining the scales 1 and 2 (strongly disagree and disagree) and 4 and 5 (agree and strongly agree) to calculate the Cronbach α scores (Nunnaly 1978).

Results

Network description

The Western Cape Protected Area Network (WC PAN) consisted of a total of 127 protected areas (nodes) with 241 pairs of unweighted directed interactions (edges; Fig. 2A). The Eastern Cape Protected Area Network (EC PAN) was a considerably smaller network, with 48 protected areas and only 119 pair of interactions (Fig. 2B).

The average eigenvector centrality for the WC PAN was significantly lower (mean ± SD, 0.14 ± 0.21; $t = 4.42$, df $= 173$, F ratio $= 1.64$, $p < 0.05$) than the EC PAN (0.31 ± 0.27). National protected areas in the Western Cape displayed an average eigenvector centrality of 0.41 (± 0.39), which was significantly higher ($t = 2.63$, df $= 54$, F ratio $= 2.62$, $p < 0.05$) than that of the provincial protected areas (0.16 ± 0.24). In the Eastern Cape the opposite occurred, with the provincial protected areas displaying higher centrality values (0.42 ± 0.21) than national protected areas (0.39 ± 0.32). The centrality of provincial areas in the

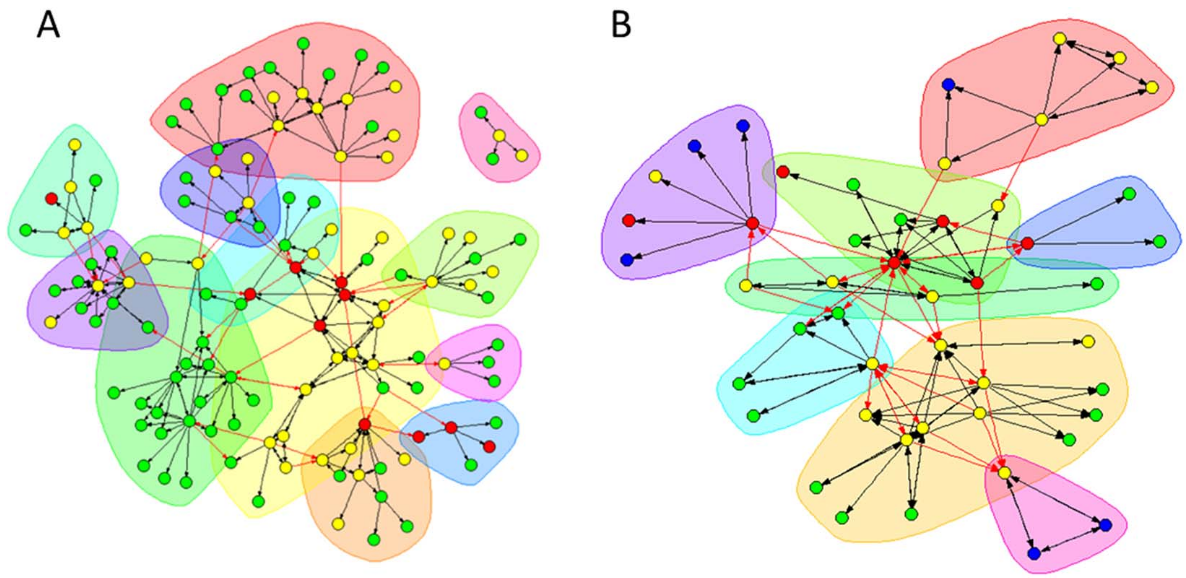

Fig. 3. Protected area network visualization of the (A) Western Cape and (B) Eastern Cape Province of South Africa formed consisting of (A) modularity value of 0.69 with 12 communities and (B) modularity value of 0.53 with 8 communities. Node colors represent scale of governance: national protected areas are red, provincial protected areas are yellow, private protected areas green, and other protected areas colored blue. All edges between the different communities are painted red.

EC PAN was also significantly higher than in the WC PAN ($t = -3.64$, df = 63, F ratio = 1.69, $p < 0.05$). Private protected areas were on the periphery of both protected area networks with an average centrality value of 0.17 (±0.11) for the EC PAN and 0.08 (±0.08) for the WC PAN (Fig. 2).

The WC PAN had a modularity value of 0.69 and consisted of 12 communities ranging in size from 4 to 22 nodes (Fig. 3A). The EC PAN had a modularity value of 0.53, with only 8 communities of 3–13 nodes (Fig. 3B). Compared to equivalent randomly generated networks, both protected area networks had smaller diameters (WC = 10, EC = 9) and smaller largest components than expected (WC = 22, EC = 13). Diameter is related to the largest community size (Minor and Urban 2007) so we examined the ratio of diameter to the size of the largest community and found this ratio (0.45) as well as density (0.15) was smaller than expected in the WC PAN and larger in the EC PAN (ratio = 0.69, density = 0.53). The average path lengths in both protected area networks were smaller than expected (EC and WC PANs, 3.44 and 4.23, respectively). Transitivity and reciprocity values were higher than expected in both the EC (transitivity = 0.26, reciprocity = 0.48) and WC PAN (transitivity = 0.21, reciprocity = 0.38).

Spatial location of protected area networks

A significant difference was found in the distance between connected and non-connected protected areas in the EC PAN (C = 135.66 ± 140.84 km, NC = 322.54 ± 247.81 km, $t = 8.02$, df = 1243, F ratio = 3.096, $p < 0.05$) and in the WC PAN (C = 76.67 ± 90.09 km, NC = 231.98 ± 149.74 km, $t = -23.62$, $p < 0.05$, df = 299). Protected areas in both networks were therefore more likely to establish connections with surrounding protected areas in close proximity.

In the WCPAN, there was no significant difference ($t = 1.08$, df = 240, p value = 0.28, cor = 0.10) between the dominant biomes covered between connected protected areas, suggesting connected protected areas may be ecologically similar. In the Western Cape, the PAN includes significantly more of the fynbos biome than expected by chance (76.8%, 8006 km^2; $D = +0.5$, $p < 0.05$, $n_{NP} = 5$, $n_{PP} = 37$; Fig. 4A). Fynbos covers just over half of the Western Cape (51%, 66207 km^2) but is considered to be of high

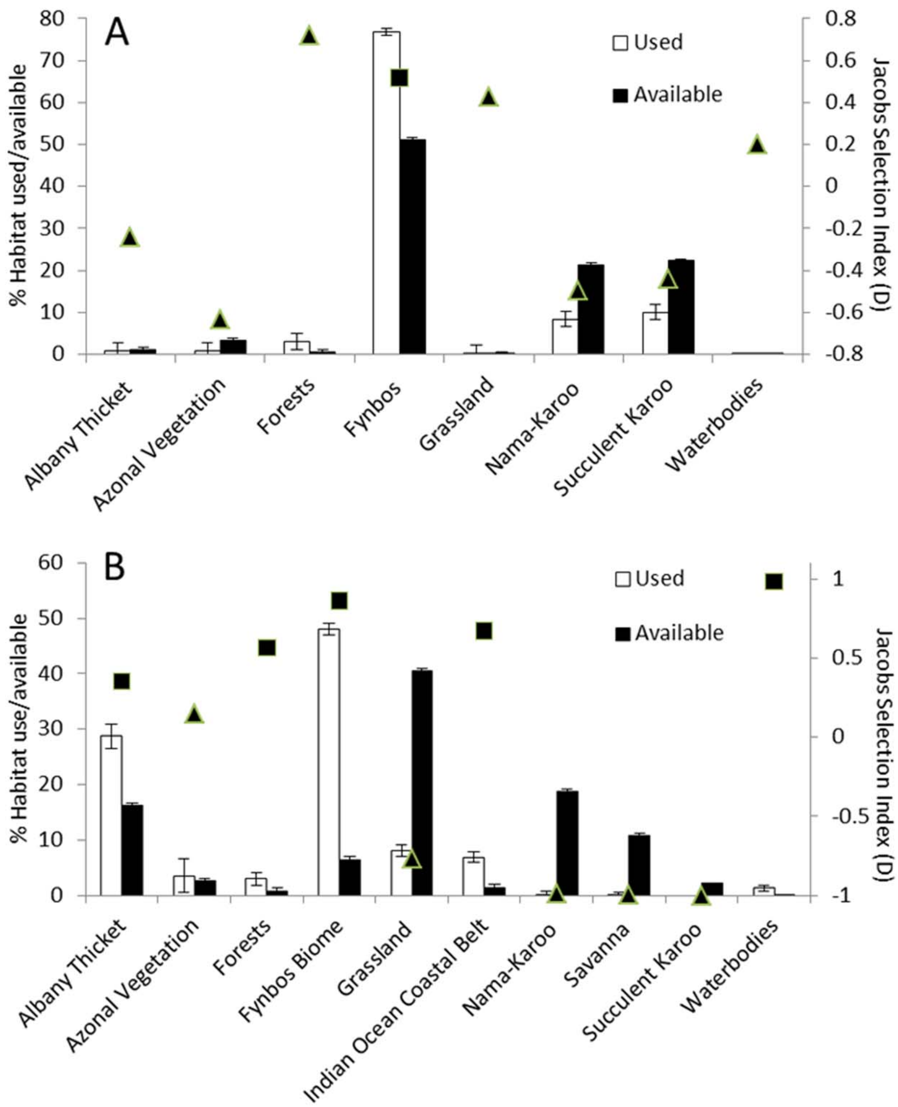

Fig. 4. Proportional availability and representation of biomes in the protected area network of the (A) Western Cape and (B) Eastern Cape Province of South Africa, showing 95% confidence intervals. Jacob's index values (black triangles and squares) indicate preference ($D > 0$) and avoidance ($D < 0$). Preference/avoidance was considered to be significant (black squares) if the confidence interval did not overlap with the mean relative availability.

conservation priority because of its high endemicity and biodiversity. It is also the dominant vegetation type in high-lying catchment areas that are protected for water provisioning. The WC PAN also included forest biomes disproportionally ($D = +0.72$; Fig. 4A). The forest biome only covered 0.5% (653 km^2) of the study area; 48% of the biome was in the protected area network (311 km^2; Fig. 4A). The grassland biome was also largely represented in the WC PAN ($D = +0.42$), which again is a factor of a small available proportion in the Western Cape (0.1%, 148 km^2) and 20% (29 km^2) being utilized within the protected area network (Fig. 4A). The Albany thicket, Azonal vegetation, Nama-karoo, and Succulent karoo were largely unrepresented in the WC PAN with Jacobs Selection Index values of −0.2, −0.6, −0.4, and −0.5, respectively (Fig.

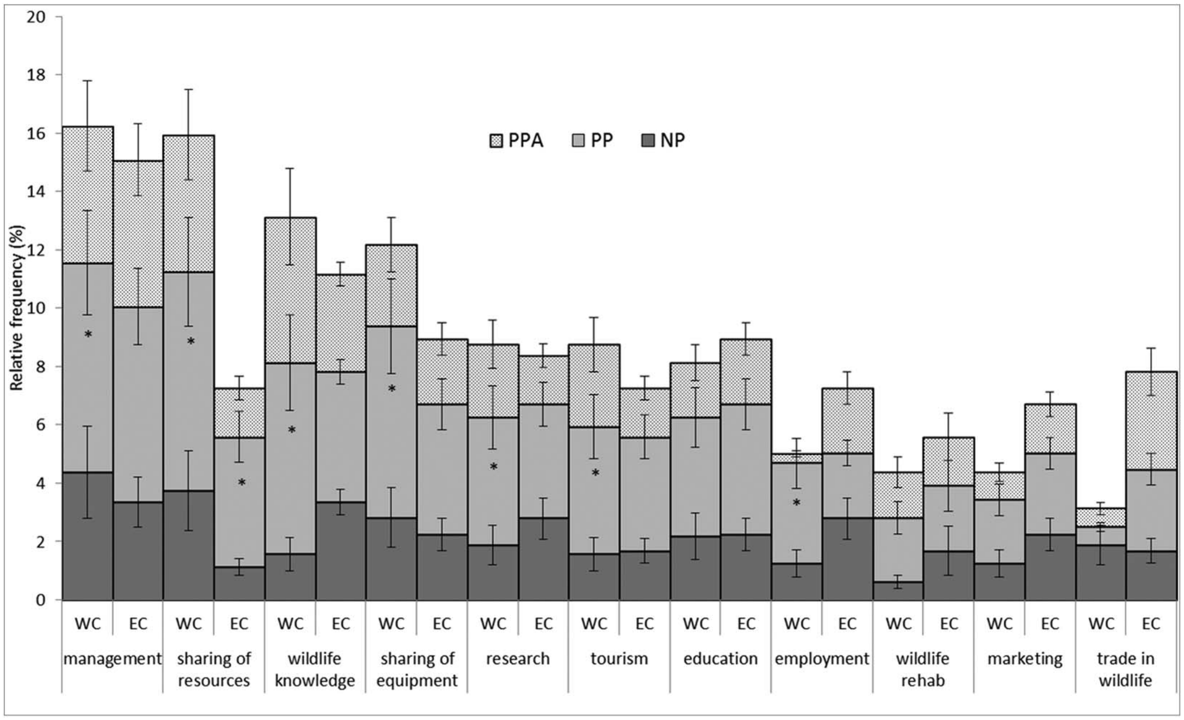

Fig. 5. Factors that play an important role in the establishment of linkages across in the Western Cape (WC) and Eastern Cape (EC) protected area network according to statutory managers and how this differs across different levels of organization comparing national (NP) to provincial (PP) and private protected areas (PPA). Vertical bars denote 95% confidence intervals where the asterisk indicates significance where $p < 0.05$.

4A).

In the EC PAN, a significant difference ($t = 3.88$, df = 110, $p < 0.05$, cor = 0.347) was found in the type of biomes covered by connected protected areas, suggesting connected protected areas were not ecologically similar. The EC PAN was largely comprised of the fynbos biome (48% of total biomes, 2670 km^2, $D = +0.86$, $p < 0.05$, $n_{NP} = 1$, $n_{PP} = 4$). Only 6.5% (11041km^2) of the Eastern Cape consisted of fynbos of which 24% were found in protected areas (Fig. 4B). The Albany thicket was also largely represented in the EC PAN (28.8%, 1598 km^2, $D = +0.35$, $p < 0.05$, $n_{NP} = 3$, $n_{PP} = 7$), which covered 16% (27500 km^2) of the Eastern Cape (Fig. 4B). Waterbodies only made up 0.13% (23 km^2) of the Eastern Cape but 1.36% (75 km^2, $D = +0.98$, $p < 0.05$, $n_{NP} = 1$, $n_{PP} = 4$) was found in the EC PAN (Fig. 4B). The EC PAN also included the Indian Ocean coastal belt ($D = +0.67$, $p < 0.05$, $n_{PP} = 4$) as well as the forest biome ($D = +0.56$, $p < 0.05$, $n_{NP} = 1$, $n_{PP} = 9$; Fig. 4B).

Interactions between protected areas

A total of 33 and 19 surveys were conducted with statutory protected area managers in the Western Cape and Eastern Cape respectively which resulted in a 100% response rate. Across all protected areas, management was the most important driving factor behind the establishment of linkages between surrounding protected areas in the WC PAN (16.25 ± 2.88%, $n = 52$) and EC PAN (15.08 ± 1.98%, $n = 27$; Fig. 5). In the WC PAN, this was closely followed by sharing of resources (15.95 ± 2.83%, $n = 51$), exchanging wildlife information (13.3 ± 0.55%, $n = 42$), and sharing of equipment (12.19 ± 2.16%, $n = 39$; Fig. 5). In the EC PAN, sharing wildlife knowledge (11.73 ± 1.54%, $n = 21$) was ranked as the second most important factor followed by the drive to share equipment with surrounding protected areas (9.50 ± 0.95%, $n = 17$; Fig. 5). The two protected areas networks showed a significant difference in the role that trading in wildlife plays in the establishment of linkages between protected areas. Eight percent ($n = 15$) of managers in the EC ranked wildlife trade as being important whereas only 3% ($n = 3$) of the WC managers selected it (Fig. 5).

When we analyzed the representation of the different levels of organizations within each network we found significant differences emerging across the protected area networks. In the WC PAN, provincial protected areas were significantly preferred above national protected areas for factors related to employment ($W = 719$, $p < 0.05$, df = 66, $n = 34$), management ($W = 425$, $p < 0.05$), exchanging wildlife knowledge ($W = 850$, $p < 0.05$, df = 66, $n = 34$), sharing of resources ($W = 771$, $p < 0.05$), tourism ($W = 731$, $p < 0.05$, df = 66, $n = 34$), sharing equipment ($W = 782$, $p < 0.05$), and research ($W = 741$, $p < 0.05$, df = 66, $n = 34$; Fig. 5). In the EC PAN, provincial protected areas were significantly preferred above national protected areas for management ($W = 80$, $p < 0.05$, df = 15) and sharing of resources ($W = 72$, $p < 0.05$, df = 15; Fig. 5). When we compared the difference in the representation of organizations we found that national and provincial protected areas played a larger role in the exchange of resources in the Western Cape than in the Eastern Cape. National protected areas played a larger role in the EC PAN than in the WC PAN in the exchange of wildlife knowledge and employment (Fig. 5). The opposite was true among provincial protected areas for the exchange of wildlife knowledge, for which there was a higher representation in the Western Cape than in the Eastern Cape (Fig. 5). Provincial protected areas were largely responsible for the trade in wildlife in the Eastern Cape (Fig. 5).

No significant difference was found between Western and Eastern Cape respondents in communicating with surrounding protected areas and so these data were grouped together. Email was the preferred form of communication (mean weighted value = 2.5), followed closely by telephone (mean weighted value of 2.3). Managers were more likely to communicate with provincial protected areas than national and private protected areas, whether using telephone ($W_{NP} = 957$, $W_{PPA} = 1620$, $p < 0.05$), email ($W_{NP} = 967$, $W_{PPA} = 1676$, $p < 0.0$), or paying actual visits ($W_{NP} = 860$, $W_{PPA} = 1676$, $p < 0.05$) to managers from surrounding protected areas.

The Cronbach's α score for the composite scales for managers' opinions of various factors and the role that spatial proximity plays between protected areas was above 0.7, indicating the scale was reliable (Nunnaly 1978). Managers from the Eastern and Western Cape had different opinions about the establishment of interactions between protected areas, but none of these differences was significant. Tourism (3.6 $\pm$ 1.7) emerged as the most important socioeconomic factor according to managers from the EC PAN, followed closely by establishing ecological connectivity (3.5 $\pm$ 1.3). Ecological connectivity was ranked as the main factor by the Western Cape managers (4.15 $\pm$ 1.2). Having a professional relationship with managers and the management of fire were also seen as important factors in the EC PAN (PR = 3.38 $\pm$ 4.12, FM = 3.18 $\pm$ 1.37) and WC PAN (PR = 4.12 $\pm$ 0.89, FM = 4.09 $\pm$ 1.2).

The Western Cape managers strongly felt that having protected areas in close proximity played an important role in controlling the spread of invasive species (3.45 $\pm$ 1.45) and facilitating the collaboration of management (3.24 $\pm$ 1.58), tourism (2.70 $\pm$ 1.61) and marketing (2.03 $\pm$ 1.33; Fig. 5). In the Eastern Cape, managers felt that having protected areas in close proximity played an important role in facilitating tourism (3.06 $\pm$ 1.22) as well as management collaboration (2.87 $\pm$ 1.30). This was followed closely by the control of wildlife diseases (2.73 $\pm$ 1.58) and competition with surrounding protected areas for tourists (2.67 $\pm$ 1.45).

Discussion

Our results provide clear support, from two comparable but distinct regions, for the hypothesis that socioeconomic interactions are more intense between protected areas that are near to one another in geographic space than they are between protected areas that belong to the same organization. In other words, just as would be expected for ecological connectivity, geographic proximity matters more than organizational membership in the formation of socioeconomic interactions.

Socioeconomic interactions play an important role in protected area networks and therefore the resilience of these social-ecological systems largely relies on achieving a better understanding of how these interactions are formed and which factors dominate their development. Both protected area networks had shorter diameters than expected. This may be beneficial to the spread of information as it is possible to move through the network in just a few steps (Janssen et al. 2006). A small network diameter also signifies high reachability within the system, which increases the ability of a system to respond to changes, and encourages the union of different social actors (Janssen et al. 2006). In the Eastern Cape, we saw a denser network, in which different organizations are more tightly connected, than expected whereas the WC PAN had a lower density compared to the random networks. In a system with high density and high reachability as found in the EC PAN, all possible links are included and each node is a neighbor of each node (Janssen et al. 2006). This suggests managers in the EC PAN are exposed to more and more diverse information, which spreads more quickly throughout the network (Hanneman and Riddle 2005). In contrast, the WC PAN had a lower density with high reachability, representing a simple network in which the minimum number of links is used to connect all the nodes, and they can be reached within two steps (Janssen et al. 2006).

The transitivity or clustering coefficients of both protected area networks were considerably higher and were associated with higher levels of reciprocity, than in comparable random networks. High clustering coefficients are characteristic of a small world network, which indicates the presence of redundant pathways that should confer resilience to random patch removal or disturbance (Minor and Urban 2007).

The higher levels of centrality observed in the EC PAN indicate the presence of structures that may facilitate coordination and control (Janssen et al. 2006). The performance of a highly central network is strongly dependent on the existence of few hubs (key actors in the network). These key actors represented different levels of organizations in the two protected area networks. In the Eastern Cape, provincial protected areas played a significantly central role whereas national protected areas emerged as the central actors in the WC PAN. This suggests that provincial and national protected areas play important roles in the resilience of the EC and WC PANs respectively. The central actors are in a position to share information of value for other, less central actors (Berardo and Scholz 2010). Private protected areas displayed low centrality and had a minimal influence on both protected area networks.

Centralized networks are highly vulnerable to exploitation, incompetence, and error if the central actors fail (Berardo and Scholz 2010). Fortunately, the interactions in these protected area networks were largely based on sharing management information, wildlife knowledge, and equipment. These are all examples of informal networks (Goss and Cumming 2013). In the EC PAN, managers strongly rely on provincial protected areas for management advice and sharing resources. When it came to trading in wildlife, however, national protected areas played a more important role. This emerged as the distinguishing feature between the EC and WC PANs. Protected areas in the Eastern Cape stock high numbers of game, not only due to the suitable habitat available for the management of these species but also in an attempt to attract tourists (Sims-Castley et al. 2005). Managers in the Eastern Cape placed high emphasis on the importance of tourism and were aware that spatial proximity between protected areas may facilitate management as well as lead to competition for tourists. The EC PAN covered a variety of habitat types whereas the fynbos biome (allied to higher elevations) emerged as the dominant habitat type in the WC PAN.

In the Western Cape, even though national protected areas play a very central role in the network, managers strongly rely on provincial protected areas with regards to most socioeconomic aspects. This suggests that provincial protected areas play an important connecting role between national and private protected areas in the WC PAN. The connectivity of the WC PAN could therefore be increased if provincial protected areas were to more deliberately adopt a scale-crossing broker role (i.e., by linking otherwise disconnected social actor groups across different scales [Ernstson et al. 2010]).

Managers in the WC PAN were more concerned about establishing ecological connectivity between protected areas and the potential spread of invasive species. This may be correlated with the strong preference found for the fynbos biome in the WC PAN. Not only has the fynbos region been recognized for its global importance as a center of endemism, but also it is highly vulnerable to poor fire management and alien invasive trees and shrubs (Richardson et al. 1996, Van Wilgen 2009). Groups of species including the pines (*Pinus* species), wattles (*Acacia* and *Paraserianthes* species), hakeas (*Hakea* species), and gums (*Eucalyptus* species) are invasive and of major ecological significance in the fynbos biome (Van Wilgen 2009). Protected area managers are therefore strongly driven to protect this rich floral kingdom and the resilience of protected areas relies heavily on connectivity. Spatial proximity between protected areas also plays an important role in the management of fire according to Western Cape statutory managers.

The roles that different organizations or tenure types play in a protected area network are heavily dependent on the spatial arrangement of protected areas. Interactions do not appear to rely on protected areas belonging to the same organization, suggesting that innovations and learning spread locally between nearby social-ecological systems rather than through institutional connections. Spatial proximity between protected areas plays an important role in facilitating socioeconomic interactions, in the same sense as geographic proximity ensures ecological connectivity. These results challenge the popular notion that in an age of advanced communications technology, learning spreads through networks independently of scale or location (McPherson et al. 2001) and the closely related assumption that spatial position doesn't matter because of modern means of communication (Brown and Duguid 2002). Spatial proximity plays an important role in connecting protected areas, even though modern means of communication are utilized in establishing these socioeconomic interactions.

It is intriguing that spatial proximity and informal relationships appear to have a larger influence on protected area management than institutional structures. These results suggest spatial location of protected areas may therefore both influence and be influenced by the resilience of surrounding protected areas (Cumming et al. 2010). Management decisions made in a single protected area may therefore affect the resilience of surrounding protected areas even if formal connections do not exist. Our analysis shows unequivocally that protected area managers are more inclined to form socioeconomic interactions with managers from nearby protected areas, regardless of organizational governance. Strong parallels therefore exist between ecological and socioeconomic interactions, which both play an important role in fostering the ability of the protected area network to deal with perturbations. Establishing management collaborations is thus important not only for the socioeconomic resilience of protected areas, but also for effective ecological management and the conservation of biodiversity.

Acknowledgments

This research was supported by the DST/NRF Centre of Excellence at the Percy FitzPatrick Institute of African Ornithology, a CPRR grant to G. S. Cumming from the National Research Foundation of South Africa, and a James S. McDonnell Foundation complexity scholar award to G. S. Cumming.

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