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Targeting the management of ecosystem services based on social values: Where, what, and how?

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ABSTRACT

Whilst biophysical and economic values are often included in spatial planning for conservation and environmental management, social values are rarely considered. This study demonstrates a method for targeting the management of ecosystem services based on social values within the South Australian Murray-Darling Basin region, Australia. A total of 56 community representatives were interviewed and their values for ecosystem services were elicited and mapped. Spatial indicators of abundance, diversity, rarity, and risk were adapted from ecological science and applied to the mapped social values for ecosystem services. Those areas with the highest social value abundance, diversity, rarity, and risk scores were defined as priority areas for the management of ecosystem services. Four hotspots were located in overlapping areas of high priority for multiple spatial indicators. The ecosystem services contributing to high abundance, diversity, rarity, and risk were identified for management in these focal areas. Community suggestions for managing specific ecosystem services in focal areas were collated and synthesized. The results of this study enable the targeting of management of ecosystem service values in the landscape by identifying where high priority management areas are, specifying what services should be managed, and summarizing how they should be managed. This information can complement biophysical and economic information in systematic landscape planning studies.

1. Introduction

To achieve maximum benefit from investment of limited budgets, environmental management needs to be targeted at specific problems in high priority areas in the landscape (Newburn et al., 2005). Typically, high priority areas for management have been identified by the assessment of environmental values including the spatial distribution of biological (Prendergast et al., 1999; Magurran, 2004), land (Crossman and Bryan, 2009), and water resources (Bryan and Kandulu, 2009). Increasingly, economic values have been also been considered in planning cost-effective and targeted environmental management (Naidoo et al., 2006; Bryan and Crossman, 2008). However, the social values that people attach to the landscape are also important to consider in planning for environmental management (Brown, 2005; McIntyre et al., 2008). Here we adapt a suite of spatial indices from ecological science to social values to better target the management of ecosystem services.

Natural capital assets such as land, water, and biota produce a range of ecosystem services which, when combined with other forms of capital, directly contribute to human well-being (Costanza et al., 1997; Daily, 1997; Millennium Ecosystem Assessment, 2005; Boyd and Banzhaf, 2007; Fisher et al., 2009). The value of ecosystem services has largely been measured in economic terms as a basis for increasing investment in environmental management (Daily et al., 2009). However, ecosystem services encompass the many ways society benefits from nature and hence, the many reasons for which it may be valued by people. The ecosystem services framework (Costanza et al., 1997; de Groot et al., 2002; Millennium Ecosystem Assessment, 2005) provides a useful mechanism for capturing the social values people attribute to the environment (Raymond et al., 2009). Inclusion of social values in spatial planning can increase the benefits of targeted environmental management beyond biophysical and economic values and enhance the engagement of local communities and stakeholders in the planning process (Cowling et al., 2008). There is a need to develop methods for quantifying the spatial distribution of social values as a basis for integration with environmental and economic data to target the management of ecosystem services.

There are many views on the definition and philosophical basis of social values towards the environment (Rokeach, 1973; Brown, 1984; Kellert, 1996; Lockwood, 1999; McIntyre et al., 2008; Fisher et al., 2009). In this study we use the concept of assigned values which are those values that people attach to things such as

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goods, activities, and services (Brown, 1984; Lockwood, 1999). Assigned values incorporate a person's perception of the thing under valuation, their held values and associated preferences, and the context of the valuation (Brown, 1984). We focus on values that people assign to ecosystem services. Values may be assigned heterogeneously by people over the landscape (Norton and Hannon, 1997). In this study, we term these place-based, assigned values for ecosystem services, *social values*. As a corollary, *ecosystem service values* in this study are social values, rather than economic or biophysical values. Further, Relph (1985, p. 27) notes that social values "need not be strong and positive"—they can be also associated with negative experiences (Manzo, 2005). In this study, negative values were interpreted and discussed as *threats* to ecosystem services.

Social values have been mapped to inform the planning and management of conservation areas (Kliskey, 1994; Brown et al., 2004; Raymond and Brown, 2006; Alessa et al., 2008), forestry land (McIntyre et al., 2008), and urban forests and green areas (Tyrväinnen et al., 2007). These studies have developed and applied typologies which measure a broad suite of values including biodiversity and wilderness, life sustaining, therapeutic, learning and knowledge, historical and intrinsic values. Raymond et al. (2009) adapted the Millennium Ecosystem Assessment (2005) ecosystem services typology to identify and map social values (termed *community values*) towards ecosystem services. These studies have found that social values vary in type and abundance (variously measured as a count, magnitude, or intensity score) across the landscape. However, social values mapping studies have typically used a single spatial measure of value abundance (e.g. Brown, 2005; Raymond and Brown, 2006; Alessa et al., 2008; McIntyre et al., 2008; Raymond et al., 2009) to integrate spatially heterogeneous information on multiple value types. New quantitative measures are required to better capture the spatial characteristics of the multiple social values over the landscape.

In ecology, the targeting of conservation and management has been based on ecological values commonly measured by species distributions which also vary in type and abundance over the landscape in a similar way to social values. Objectives used in ecology to target management have moved beyond abundance to capture several other characteristics of ecological value such as species diversity, rarity, and risk (Magurran, 2004; Suter, 2006). Maximizing species diversity is a common management objective in conservation. The aim is to ensure that the greatest number of species is protected (May, 1988; Howard et al., 2000) and that individual abundance is relatively even across all species rather than dominated by a few species (Gaston and Williams, 1993). The objective of rarity aims to ensure that the few remaining examples of uncommon and rare species are conserved thereby maintaining biodiversity (Gaston, 1994). Managing risk is another common objective in ecology (Suter, 2006) where those species with a high likelihood of exposure to a degrading process (e.g. a hazard, threat, or stressor) and having a serious consequence (e.g. extinction) are attributed high risk and hence, are a higher priority for management (Standards Australia, 2006).

Objectives used to target management based on ecological values for species may be directly applicable to social values for ecosystem services. Areas of abundant social values for ecosystem services are a valid management priority as these areas hold greater value for more people. Areas of diverse social values may also be a priority for management as a greater range of social values for ecosystem services can be protected in the same area. Similarly, areas of rare social values may be a priority for management as they are the only representatives of that ecosystem service value occurring in the region. Lastly, areas where social values for ecosystem services are at high risk may also be considered to be a management priority. High risk areas are those assigned both high value (consequence) and high threat (likelihood) to ecosystem services (Standards Australia, 2006).

Quantitative spatial indices have been developed to describe species distributions which operationalize ecological management objectives and enable the spatial targeting of management. These include indices of abundance such as biomass (Tilman and Downing, 1994), evenness (Pielou, 1969), dominance (Simpson, 1949), rarity (Gaston, 1994), richness (Magurran, 2004), and diversity (Shannon and Weaver, 1949). Spatial indices of ecological risk have also been developed to identify management priorities (Mattson and Angermeier, 2007; Walker et al., 2008). These objectives (e.g. abundance, diversity, rarity, and risk) and the associated spatial indices may be adapted to target the management of ecosystem services based on social values.

However, a single measure can never capture the full suite of ecological values (Purvis and Hector, 2000), nor in all likelihood, of social values. The identification of hotspots provides a way to integrate multiple spatial indices into an understanding of management priorities (Gimona and van der Horst, 2007; Crossman and Bryan, 2009). Hotspots are areas of spatial coincidence between management priorities for multiple indices. Hotspots of high priority for multiple spatial indices of social value can enable the identification of focal areas for the management of ecosystem services.

In this study, spatial indices from ecological science were applied to mapped social values for ecosystem services in order to identify priorities for environmental management in the South Australian Murray-Darling Basin. Place-based, assigned values for ecosystem services were elicited from a sample of community members in the study area based upon a modified version of the Millennium Ecosystem Assessment (2005) framework. Interviews were conducted which included a mapping task where participants allocated values to ecosystem services across the study area and suggested management actions to enhance these values. Spatial indices of the abundance, diversity, rarity, and risk of ecosystem service values were calculated using a Geographic Information System (GIS). Areas of high index scores were mapped and overlayed to identify focal areas of high priority for multiple indices (hotspots) and pinpoint *where* ecosystem service values should be managed. Specific ecosystem services contributing to the high priority areas were identified to specify *what* ecosystem services should be managed. Community suggestions for management were then interpreted, synthesized and summarized for each focal area in describing *how* these ecosystem services should be managed. By engaging the community in environmental decision-making, this method can be used to target spatially explicit and ecosystem service-specific environmental management that protects and enhances social values and mitigates threats towards ecosystem services.

2. Methods

2.1. Study area

The South Australian Murray-Darling Basin (SAMDB) Natural Resources Management (NRM) region covers an area of just over 56,000 km^2 at the lower end of the Murray-Darling system (Fig. 1) with a population of around 81,000 people. The region has a Mediterranean to semi-arid climate. The River Murray is the main geographical feature of the region and is the major source of fresh water for South Australia. The region contains many ecologically important wetlands and estuaries including the Ramsar listed lower lakes, Coorong, and Murray mouth. Recent record-low inflows and a history of over-extraction of water for consumptive purposes have critically threatened the riparian ecology of the system.

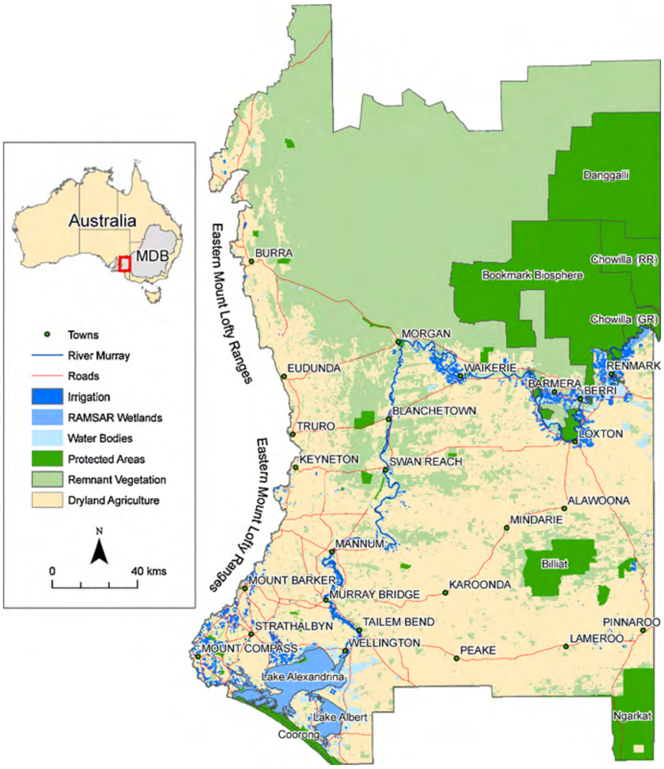

Fig. 1. Location map of the South Australian Murray-Darling Basin Natural Resource Management Board region.

Land use includes dryland agriculture (cereal cropping/grazing), irrigated agriculture (horticulture and pastures), and remnant native vegetation (Fig. 1). In general, land, water, and biotic resources have been heavily impacted by agricultural development, especially in the southern half of the region.

The SAMDB NRM Board (or simply, the *Board*) is a community-based regional agency responsible for environmental management planning in the study area. To achieve widespread and enduring resource condition change, management priorities need to be valued, accepted, and adopted by the community. This study both informs the regional planning process and contributes to community engagement in environmental management.

2.2. Mapping social values for ecosystem services

2.2.1. Interview process

A total of 56 local community members with an interest in regional environmental management were selected by the Board's regional planning team for participation in this study using non-proportional quota sampling (Tashakkori and Teddlie, 2003). Twenty-eight participants were selected from the Board and its four regional advisory groups, and 28 other community members were selected from across the region. Participants came from diverse backgrounds including: primary production; indigenous issues, and; land, water, and biodiversity management. Each participant was interviewed by an experienced ethnographic interviewer with the aim of eliciting what they valued in the environment of the SAMDB region and why they valued it in the context of natural capital and ecosystem services (see Cast et al., 2008 for details).

The first part of the interview involved open-ended questioning and prompting using a natural capital and ecosystem services framework to structure the discussion. The qualitative interview process encouraged participants to think about the values and meanings they assign to different places, and provided participants with a useful introduction to natural capital and ecosystem services. The last part of the interview involved mapping individual assigned values for natural capital assets and ecosystem services in the study area which is the focus of this study (Section 2.2.3).

2.2.2. Natural capital and ecosystem services framework

Natural capital assets in this study were defined by the Board as land, water, biota, and atmosphere. Ecosystem services include provisioning, regulating, cultural, and supporting services (Millennium Ecosystem Assessment, 2005). Whilst recent studies have distinguished between intermediate and final services for more robust valuation and accounting purposes (Boyd and Banzhaf, 2007; Fisher et al., 2009), the full Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005) typology was used as a basis for prompting participants to discuss their range of values towards the environment.

In parallel with the interview process, exploration of coded values revealed that modification of the Millennium Ecosystem Assessment (2005) typology was required to represent the full suite of values expressed by participants (Appendix A) and minimize the forcing of responses into predetermined categories. Using a grounded theory approach (Strauss and Corbin, 1990) a set of institutional, social and economic factors associated with built and social capital valued by participants were added to the Millennium Ecosystem Assessment (2005) typology. These were grouped under a *People* asset and, although they are not ecosystem services, they are referred to for convenience as *People*-related services (Appendix A). Interviews and mapping exercises were recorded and transcribed and values coded based on this modified natural capital and ecosystem services framework (see Cast et al., 2008 for details).

2.2.3. Mapping social values

As a unit of value, participants were allocated 40 green dots to assign to places of positive value (values) and 10 red dots to places of negative value (threats) associated with specific natural capital assets and ecosystem services. Dots were placed on a large scale topographic map of the SAMDB region. Participants could allocate one or more dots to each location as an intensity score reflecting the strength or importance attributed to their identified value/threat. The spatial extent of each value/threat was described by the participant and sketched on a topographic map. The specific natural capital assets and ecosystem services associated with each value/threat were recorded. Finally, participants were asked about factors that could impact upon the values held for each value/threat area and if they could suggest ways that these values could be managed and protected or the threats mitigated.

2.2.4. Spatial indices

The 56 participants identified a total of 879 individual value/threat areas which were digitized in a GIS and converted to a raster GIS layer. Information associated with each value/threat area was entered into a database and linked to the spatial data layers. Loose coupling of Structured Query Language with map algebra in a series of automated GIS macros enabled flexible query, summary, and spatial analysis of the values and threats data. Spatial indices of social value abundance (Raymond et al., 2009), diversity (Shannon and Weaver, 1949; Pielou, 1969), rarity (Magurran, 2004), and risk were calculated using the raster data layers and the associated database using methods summarized below (see Appendix B for details).

The abundance index layer represents the overall magnitude of values calculated by summing the spatially explicit intensity scores of social values for all ecosystem services mapped by participants. Index values are a positive number reflecting the total number of green dots allocated across the landscape by all participants. The diversity index layer was calculated using Shannon's H' index (Shannon and Weaver, 1949). Social values in areas with high diversity scores tend to be assigned evenly across a variety of ecosystem services, rather than dominated by only a few services. Diversity index scores can range from 0 (no diversity) to 3.689 (maximum diversity) (Pielou, 1969). The rarity index layer represents the average relative concentration of social values for ecosystem services. Rarity index values range from 0 (no occurrence of any values) to a positive factor quantifying the number of times the concentration of values was higher than the spatial average over the study area. The risk index layer represents the coincidence of social value and threat and was calculated by multiplying a 0-1 rescaled social value abundance layer (green dots) by a 0-1 rescaled threat abundance layer (summed red dots). Risk index values can range from 0 (either no social values or threats assigned) to 1 (area with highest social value abundance *and* threat abundance).

2.2.5. Identifying management priorities

To protect and enhance social values, a pragmatic approach is needed in identifying *where* the management of ecosystem services needs to be undertaken. We illustrate one way of selecting priority areas for social values for ecosystem services by selecting the highest scoring areas for each index taken at a nominal 5% cut-off. The priority area layers for the four indices were then overlayed in the GIS using a combinatorial Boolean OR function to map the spatial coincidence of priority areas for each unique combination of indices. The outputs identify focal areas that score highly for multiple indices and characterize the objectives for which they are of high priority (e.g. abundant, diverse or rare values, or high risk). The 5% cut-off score could readily be adjusted to reduce or expand the priority areas.

Social values and threats for ecosystem services were summarized for the focal areas using the spatially averaged value and threat abundance scores and compared to the spatially averaged value over the entire study area. Abundant, diverse, rare and at risk values were identified for each focal area to identify *what* ecosystem services need to be managed. Community suggestions for management actions in focal areas were then collated, interpreted, synthesized, and summarized to directly address *how* ecosystem services might be managed to protect and enhance social values in each focal area.

3. Results

3.1. Spatial indices of social values for ecosystem services

The spatial distribution of the social value abundance, diversity, rarity and risk indices for ecosystem services is presented in Fig. 2. Areas of high social value abundance occurred along the River Murray channel, Chowilla floodplain and Coorong, followed by the lower lakes, Billiat Conservation Park and Bookmark Biosphere Reserve. Dryland agricultural areas fringing the River Murray had a low value abundance score. Areas supporting the most diverse ecosystem service values are dominated by remnant vegetation patches on private land in the mixed cropping/grazing land in the Mallee region and in the triangle between Morgan, Burra, and Eudunda (Fig. 2). The Chowilla floodplain, Coorong, Lower Lakes, Bookmark Biosphere, River Murray channel and Billiat Conservation Park also support a diverse range of ecosystem services values. Areas supporting rare social values for ecosystem services include the Noora basin near Loxton, in the Mallee wells area near Pinnaroo, along the River Murray, lower lakes and Coorong, and in the Bookmark Biosphere reserve (Fig. 2). Risk is by far the highest along the River Murray channel and floodplain especially the reaches between Morgan and Mannum townships and Berri and Barmera townships (Fig. 2).

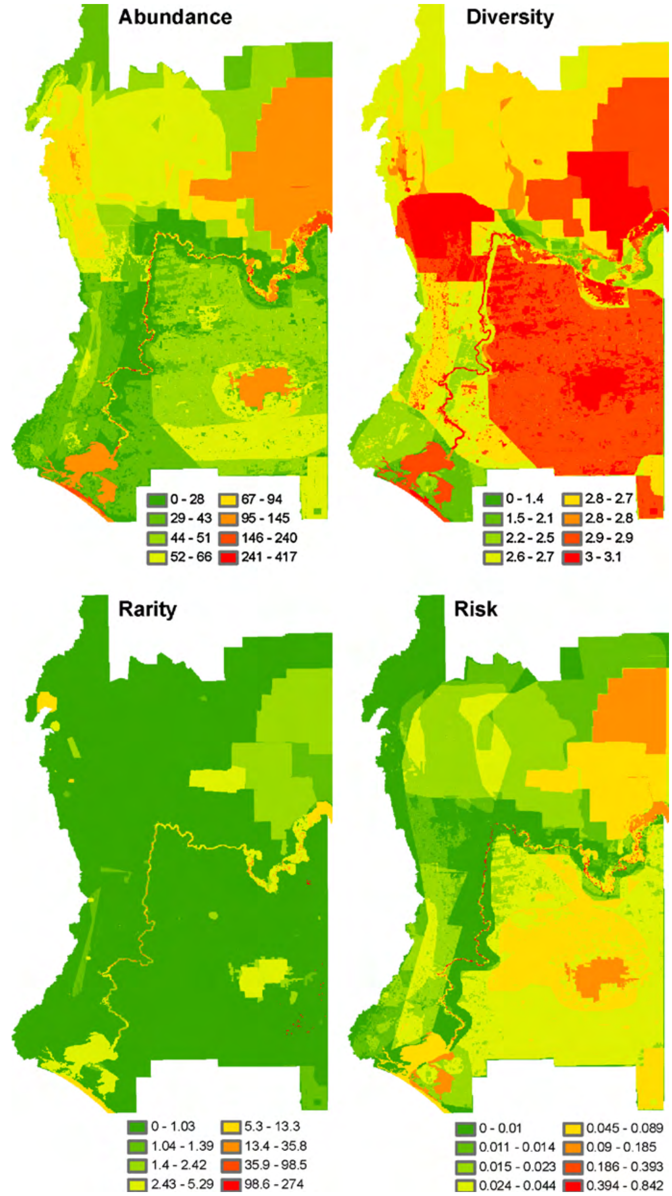

Fig. 2. Indices of social value abundance, diversity, rarity, and risk used to identify high priority areas for management of ecosystem services.

3.2. Abundant and rare social values for ecosystem services

Quantification of the regional abundance and rarity of social values can help identify and target management towards those individual ecosystem services contributing to high index scores across the study area (Fig. 3). Highest mean value abundance was attributed to the *People*-related services of zoning and planning, built environments, and economic viability and employment. This reflects the belief widely held among participants that values relating to people (often referred to as social capital) were central to this landscape (also captured in other frameworks such as the sustainable livelihoods, Scoones, 1998). Food provisioning and bequest, intrinsic and existence values were also highly abundant. The rarest ecosystem service values were provisioning of biochemical resources, disease regulation, energy and other services. Photosynthesis and pollination were not attributed value or threat scores by participants in the mapping exercise.

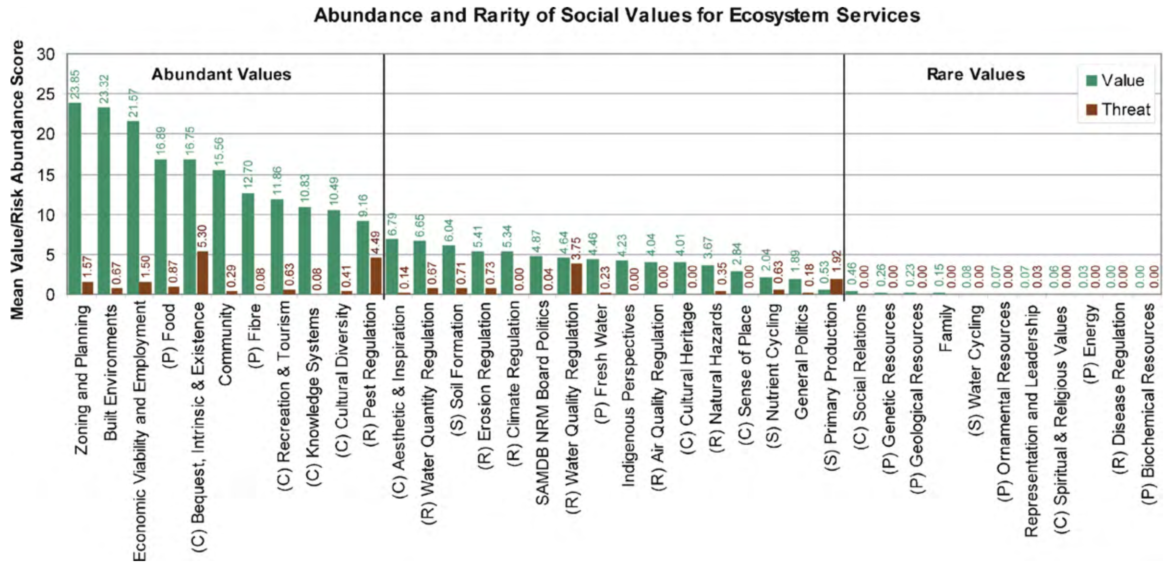

Fig. 3. Spatially averaged social value and threat abundance scores for ecosystem services for the study area illustrating the most regionally abundant and rare social values for ecosystem services.

3.3. High priority management areas and index hotspots

High priority areas were identified as the 5% of the study area (around 285,000 ha) with the highest scores for each index (Fig. 4). Fig. 4 also illustrates the number of indices for which each area has been identified as high priority. Most areas were identified as high priority for a single index only. However, four geographic focal areas can be discriminated that are hotspots of high priority for multiple indices of social value: the Billiat area, Chowilla/Murtho, Lower Lakes and Coorong, and the River Murray (Fig. 5).

Fig. 5 maps combinations of indices for which areas are identified as high priority and these are described in Table 1. The Billiat area is dominated by values of high risk, diversity and rarity. Chowilla/Murtho is dominated by social values of high rarity, risk, and abundance. The Lower Lakes and Coorong is dominated by social values of high rarity and risk. The River Murray

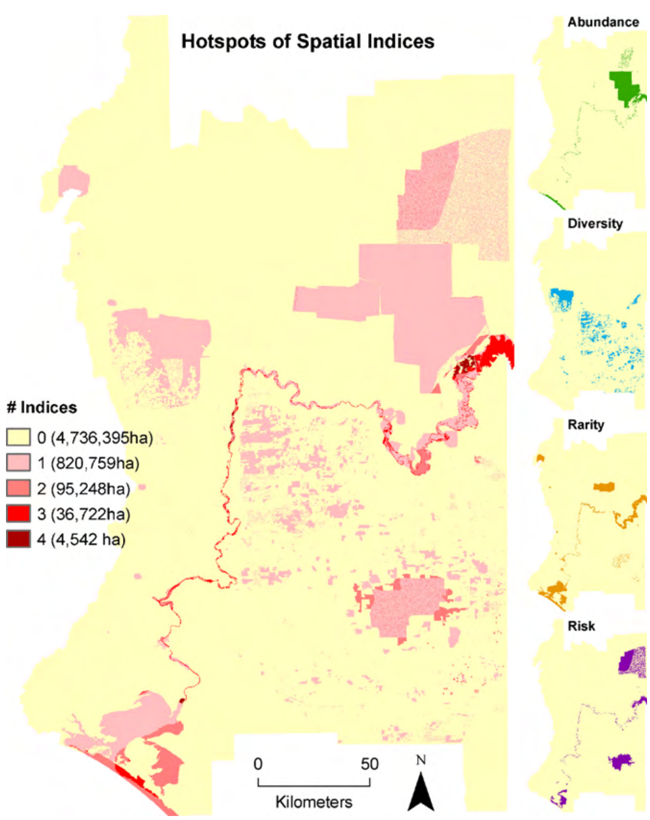

Fig. 4. Smaller maps on the right represent the high priority areas (5% of the study area) for abundance, diversity, rarity, and risk indices. Large map represents management hotspots in the study area according to the number of indices of social values for which areas are identified as high priority.

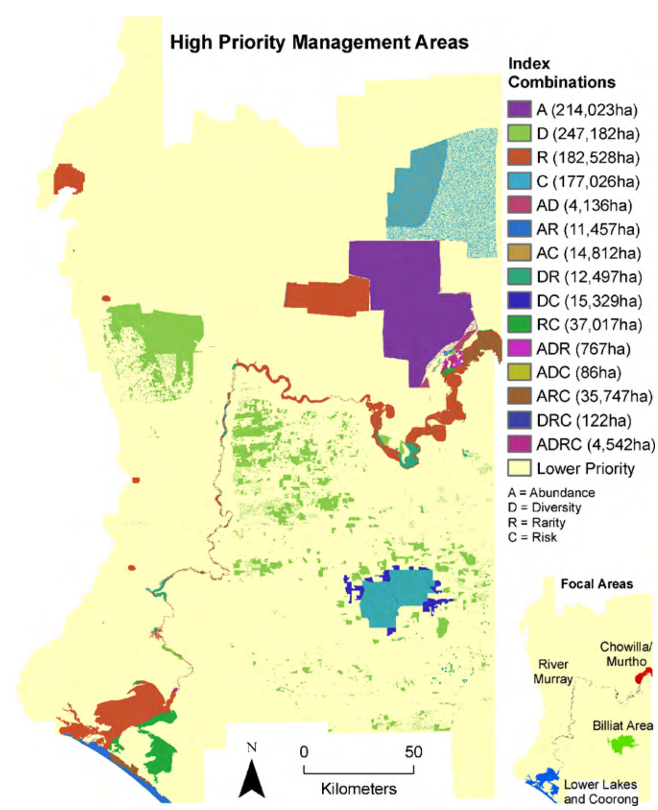

Fig. 5. High priority management areas identified through overlay of the top 5% areas identified for abundance, diversity, rarity, and risk. Most areas have been identified as a priority for only a single index; however, some areas are of high priority for multiple indices.

Table 1
Descriptive statistics for social value indices in focal areas.

	Study area	Billiat Area	Chowilla/Murtho	Lower Lakes and Coorong	River Murray
Area (ha)	5,693,666	74,578	31,078	103,261	17,232
Abundance					
Priority area (ha)	285,570	0	19,667	16,264	17,232
Minimum score	0.0	86.0	11.0	10.0	277.0
Mean score	49.0	116.4	146.4	115.5	333.3
Maximum score	417.0	121.0	417.0	164.0	417.0
Diversity					
Priority area (ha)	284,661	15,377	4642	358	564
Minimum score	0.00	2.94	2.01	1.76	2.77
Mean score	2.76	2.95	2.89	2.77	2.87
Maximum score	3.10	3.01	3.05	2.96	2.96
Rarity					
Priority area (ha)	284,677	9614	28,373	103,189	17,232
Minimum score	0.00	1.80	0.12	1.31	24.71
Mean score	0.70	2.41	6.13	3.81	27.27
Maximum score	273.75	2.53	28.08	8.11	29.94
Risk					
Priority area (ha)	284,681	74,450	20,379	31,121	17,232
Minimum score	0.00	0.09	0.00	0.00	0.36
Mean score	0.02	0.14	0.12	0.09	0.54
Maximum score	0.81	0.16	0.81	0.17	0.81

is dominated by social values of high abundance, rarity, and risk (Table 1).

When comparing focal areas (Table 1), the River Murray has much higher scores for mean ecosystem service value abundance (333.3), rarity (27.27), and risk (0.54) than all other focal areas. Chowilla/Murtho has the second highest scores for abundance (146.4), rarity (6.13), and risk (0.12). The Billiat area has a higher mean diversity score (2.95), followed by Chowilla (2.89), the River Murray (2.87), and Lower Lakes and Coorong (2.77).

3.4. Targeting management of specific ecosystem services

Comparison of the mean social value and threat abundance scores for ecosystem services in each focal area with the same for the study area (Table 2) can inform the interpretation of ecosystem service values in each focal area. Specifically, substantially higher/lower mean social value and threat abundance scores for individual ecosystem services in the focal area compared to the study area overall reflects the over/under representation of these ecosystem service values in the focal areas (Table 2).

Mean value and threat abundance scores can also be used to identify those ecosystem services contributing to high index scores in each area (Table 2). Ecosystem services with higher mean value abundance scores in each focal area contribute most to high abundance index scores. All ecosystem services with moderate mean value abundance scores contribute to a higher diversity score in the focal area. Ecosystem services with a low mean value abundance score in the study area (regionally rare) and high mean value abundance score in the focal area contribute most to a high rarity score in the focal area. Both ecosystem services with high mean value abundance scores and those with high mean threat abundance scores contribute to high risk score in the focal area. Table 3 summarizes the most abundant social values and threats, and the rarest values for specific ecosystem services by focal area.

For each mapped value/threat area, participants also suggested management actions for protecting and enhancing values for, and mitigating threats to, specific natural capital assets and ecosystem services. A summary of management actions is presented in Table 3 that directly addresses specific assets and services in each focal area. For the Billiat area, participants suggested continued preservation of the area and the increased management of pest species and fire. For the other three focal areas, management actions centred around increased environmental flows, more natural flow regimes, and salinity management. The management of places that hold spiritual values was also important in the other three areas. In addition, management actions suggested for the Lower Lakes and Coorong, and the River Murray included the management of development and recreation, and an increase in education and awareness (Table 3).

4. Discussion

4.1. Spatial indices

The spatial indices used in this study, widely applied in ecology, were useful for identifying priority areas in the landscape for managing social values for ecosystem services according to four objectives—abundance, diversity, rarity, and risk. Abundance provides an intuitive measure of the total aggregate social value allocated to each part of the landscape widely applied in social value mapping studies (e.g., Brown, 2005). However, the results of this study suggest that targeting management on the basis of abundance alone can overlook important areas with diverse or rare values, or values at high risk.

The rarity index captures social values for ecosystem services that occur infrequently over the landscape. However, the rarity index is sensitive to both error and nuance in the values expressed by individuals. Simple errors of interpretation or data coding can lead to areas of misallocated value for ecosystem services. Spurious rarity results may also be caused through the idiosyncratic preferences of particular individuals leading to the attribution of value to uncommon ecosystem services. When this occurs to ecosystem services otherwise not allocated value or threat scores (such as pollination or photosynthesis in this study) then the services will have an erroneously high rarity score in that location. Measurement of rarity in ecological science is also sensitive to survey error and sampling bias (Yoccoz et al., 2001). Hence, caution is prudent when interpreting locations of rare ecosystem service values. Qualitative assessment of interview and mapping transcripts proved invaluable for validating the context of rare values in this study.

Table 2
Spatially averaged value/threat abundance scores.

	SAMDB		Billiat area		Chowilla/Murtho		Lower Lakes and Coorong		River Murray	
	Value	Threat	Value	Threat	Value	Threat	Value	Threat	Value	Threat
Assets										
Land	44.00	8.99	45.70	1.94	40.11	5.30	104.48	11.94	94.24	11.91
Surface water	11.80	4.13	6.40	0.74	88.61	5.54	203.30	10.42	269.55	25.23
Ground water	5.62	4.01	8.26	0.74	34.19	1.82	63.92	4.41	109.08	7.57
Biota	42.52	5.88	52.86	1.56	72.09	0.87	135.27	4.56	124.99	10.64
Atmosphere	8.55	3.42	3.76	0.38	11.66	–	18.55	0.16	44.83	–
People	37.45	3.06	30.82	1.00	49.96	3.34	85.01	10.64	207.25	26.12
Ecosystem service types										
Provisioning	31.40	4.41	22.99	0.38	49.64	2.44	77.59	5.42	239.91	19.19
Regulating	26.84	8.96	28.21	2.30	53.18	6.00	142.09	7.92	176.37	22.36
Cultural	35.87	5.40	48.02	1.84	74.85	1.88	171.85	10.42	191.46	8.47
Supporting	14.65	2.01	3.73	0.45	11.19	0.53	41.93	1.01	67.60	0.43
Ecosystem services										
(P) Food	16.89	0.87	7.23	–	28.08	2.09	27.70	3.25	161.78	9.39
(P) Fibre	12.70	0.08	0.54	–	15.41	1.68	7.06	–	108.16	7.22
(P) Genetic resources	0.26	–	6.23	–	–	–	–	–	–	–
(P) Biochemical resources	0.00	–	–	–	–	–	–	–	–	–
(P) Ornamental resources	0.07	–	–	–	1.31	–	–	–	23.00	–
(P) Fresh water	4.46	0.23	5.55	–	38.76	2.01	50.59	2.02	203.56	18.79
(P) Geological resources	0.23	0.00	2.00	–	–	–	0.01	–	0.01	–
(P) Energy	0.03	–	–	–	0.23	–	–	–	4.00	–
(R) Air quality regulation	4.04	0.00	0.54	–	0.06	–	0.00	–	0.05	–
(R) Climate regulation	5.34	0.00	0.63	–	6.96	–	0.13	–	3.09	–
(R) Water quantity regulation	6.65	0.67	–	0.36	46.36	2.39	95.13	6.24	139.07	13.01
(R) Erosion regulation	5.41	0.73	0.41	0.45	0.00	0.20	0.00	0.00	0.37	1.00
(R) Water quality regulation	4.64	3.75	0.24	0.38	25.90	4.97	64.67	6.40	102.18	9.17
(R) Disease regulation	0.00	–	–	–	–	–	–	–	–	–
(R) Pest regulation	9.16	4.49	12.03	1.56	9.77	0.24	2.37	2.52	43.05	0.04
(R) Pollination	–	–	–	–	–	–	–	–	–	–
(R) Natural hazards	3.67	0.35	23.56	1.00	1.05	0.03	0.09	–	8.02	0.00
(C) Cultural diversity	10.49	0.41	18.05	–	12.21	0.24	40.03	4.25	8.61	–
(C) Spiritual and religious values	0.06	–	–	–	4.28	–	14.12	–	5.55	–
(C) Knowledge systems	10.83	0.08	5.59	0.00	5.96	1.24	7.14	3.02	31.91	4.42
(C) Aesthetic and inspiration	6.79	0.14	13.14	1.00	8.56	–	31.76	4.02	39.91	–
(C) Social relations	0.46	–	–	–	6.69	–	12.23	–	19.61	–
(C) Sense of place	2.84	–	2.14	–	–	–	4.65	–	0.03	–
(C) Cultural heritage	4.01	0.00	5.80	–	6.54	–	15.87	0.01	13.02	0.30
(C) Recreation and tourism	11.86	0.63	11.60	1.00	44.59	0.23	101.78	0.00	122.11	4.04
(C) Bequest, intrinsic and existence	16.75	5.30	39.55	1.83	37.55	0.53	61.67	5.42	59.84	2.31
(S) Soil formation	6.04	0.71	0.32	0.45	0.00	0.15	–	–	0.15	0.00
(S) Photosynthesis	–	–	–	–	–	–	–	–	–	–
(S) Primary production	0.53	1.92	–	0.45	3.09	0.21	0.14	0.01	18.99	0.32
(S) Nutrient cycling	2.04	0.63	0.32	0.45	0.28	0.15	–	–	5.00	0.00
(S) Water cycling	0.08	0.00	–	–	0.77	–	5.01	1.00	5.31	–
People-related services										
Built environments	23.32	0.67	6.59	0.00	29.20	2.80	30.85	10.62	115.21	17.56
Zoning and planning	23.85	1.57	28.45	1.00	29.43	0.91	32.58	5.03	50.39	11.52
Economic viability and employment	21.57	1.50	1.08	–	24.39	1.00	25.36	6.61	108.43	6.61
Community	15.56	0.29	0.77	–	8.68	0.27	9.59	3.22	73.47	0.00
Family	0.15	0.00	–	–	0.57	–	8.00	–	10.68	–
General politics	1.89	0.18	0.05	0.00	16.82	1.17	20.07	0.00	82.57	12.02
Indigenous perspectives	4.23	–	1.14	–	6.17	–	16.65	–	1.59	–
SAMDB NRM Board politics	4.87	0.04	4.00	–	3.02	–	4.00	0.37	0.00	–
Representation and leadership	0.07	0.03	–	–	6.00	–	0.23	–	0.58	–

The dark grey shade denotes abundant social values/threats for ecosystem services whilst the light grey shade denotes rare values/threats for ecosystem services.

As a complement to the abundance and rarity indices, the diversity index identifies areas with more even social values spread across multiple ecosystem services. By targeting management in areas of high diversity, multiple ecosystem service values can be protected and enhanced.

The risk index was able to incorporate threats which represent processes, hazards, and stressors that may degrade ecosystem service values. The concept of threat was useful for enabling participants to articulate issues more naturally thought of as degrading processes rather than positive values. The risk index was able to pinpoint areas in the landscape that hold high ecosystem service values for people but were also considered to be subject to high threat to ecosystem services. Similarly, Beier et al. (2008) identified areas in the landscape where ecosystem services were subject to degrading processes but discussed them in terms of vulnerability, rather than risk.

In a similar way as for ecological values (Purvis and Hector, 2000), the results demonstrate that social values for ecosystem services cannot be captured by a single index. It is prudent to identify areas where values are abundant, diverse, rare and at risk if the goal is to manage for multiple objectives at place-specific scales. This is generally the case for regional environmental bodies which

Table 3
Assets, services, and management actions for focal areas.

Focal area	Assets	Ecosystem service values/threats	Management actions
Billiat area *% high priority* Risk 99.8 Diversity 20.6 Rarity 12.9 Abundance 0.0	**Land** Large conservation area **Biota** Diversity of flora and fauna Endangered Mallee fowl	**Abundant values** Bequest, intrinsic and existence (39.55) Zoning and planning (28.45) Natural hazards (23.56) Cultural diversity (18.05) **Abundant threats** Bequest, intrinsic and existence (1.83) Pest regulation (1.56) **Rare values** Genetic resources (6.23) Geological resources (2.00)	• Preserve the natural area • Create larger corridor of habitat • Manage weed incursion • Manage introduced species (goats, pigs, foxes and rabbits) • Manage fire risk through prescribed burning and better roads for fire-fighting
Chowilla/Murtho *% high priority* Rarity 91.3 Risk 65.6 Abundance 63.3 Diversity 14.9	**Water** Wetlands **Biota** Habitat for vulnerable species Red gum forests Wetland areas and backwater streams	**Abundant values** Water quantity regulation (46.36) Recreation and tourism (44.59) Fresh water (38.76) **Abundant threats** Water quality regulation (4.97) Built environments (2.80) Water quantity regulation (2.39) Fresh water (2.01) **Rare values** Social relations (6.69) Representation and leadership (6.00) Spiritual and religious (4.28) Ornamental resources (1.31)	• Preserve wetlands • Build on Water Sharing Plans to preserve red gum forests • Using water allocations to enhance environment flows • Increase salt interception to manage salinity • Protect special places that hold spiritual values for Aboriginal people
Lower Lakes and Coorong *% high priority* Rarity 99.9 Risk 30.1 Abundance 15.8 Diversity 0.3	**Water** Fresh water lakes, wetlands and the Murray Mouth **Biota** Habitat for vulnerable migratory birds and other fauna	**Abundant values** Recreation and tourism (101.78) Water quantity regulation (95.13) Water quality regulation (64.67) **Abundant threats** Built environments (10.62) Water quality regulation (6.40) Water quantity regulation (6.24) Bequest, intrinsic and existence (5.42) **Rare values** Spiritual and religious (14.12) Social relations (12.23) Family (8.00)	• Control development along the Lower Lakes • Acquire more water for environmental flows • Reduce allocations for consumptive use and buy back water licenses • Monitor recreational use • Fulfil Ramsar Treaty obligations • Abandon plans for a weir at Wellington • Protect spiritual values of both Aboriginal and Non-Aboriginal people • Promote the educational value of the system
River Murray *% high priority* Abundance 100.0 Rarity 100.0 Risk 100.0 Diversity 3.3	**Water** Environmental flows Irrigation and other consumptive use **Biota** Vulnerable fish and bird species, and riparian ecosystems	**Abundant values** Fresh water provisioning (203.56) Food (161.78) Water quantity regulation (139.07) Recreation and tourism (122.11) Built environments (115.21) Economic viability and employment (108.43) **Abundant threats** Fresh water (18.79) Built environments (17.56) Water quantity regulation (13.01) Zoning and planning (11.52) **Rare values** Ornamental resources (23.00) Social relations (19.61) Family (10.68) Spiritual and religious (5.55)	• Increase education and awareness—water for the environment is not lost water • Resolve water allocations for the environment vs irrigated agriculture • Control and manage recreational use including camping, canoeing, waterskiing and houseboats • Require best practice from every industry using the River Murray • Reduce the salt loads coming down the river • Reduce the impact of dams, locks and weirs on flows • Allow more natural flooding and drying regimes

have scarce resources to undertake environmental projects. However, there may also be times when it is important to manage for single objectives, as discussed in the ecology literature (May, 1988; Howard et al., 2000; see Fig 5). For example, land managers interested in the protection of cultural and indigenous heritage may have greater interest in those areas identified by the community with 'rare' values than those areas with 'abundant' values. In all cases, a deep understanding of the management context is required to inform priorities.

The focal areas identified as high priority for management based on social values for ecosystem services coincide with ecologically based priority areas for management. Chowilla, the Lower Lakes and Coorong, and the River Murray Channel have been recognized as high priority ecological assets under the Living Murray initiative (Murray-Darling Basin Commission, 2005). The Billiat area has also been recognized as high priority for biodiversity conservation in the Integrated Natural Resource Management Plan for the South Australian Murray-Darling Basin (The Integrated Natural Resource Management Group for the South Australian Murray-Darling Basin Inc., 2003). This agreement may reflect an inherent alignment between social values and management values. Alternatively, it may be a product of the influence of well-known environmental management priorities and policies on social values. More research is needed to understand place-specific differences between scientific priorities and social values for ecosystem services.

4.2. Implications for managing ecosystem services

The science, policy and finance mechanisms are not yet developed sufficiently for integrating natural capital and ecosystem services into decision-making on a large scale (Daily et al., 2009; Carpenter et al., 2009). Most attempts to do this have focussed on the economic valuation of natural capital and ecosystem services for integration into policy and accounting frameworks (Boyd and Banzhaf, 2007). To mainstream the application of natural capital and ecosystem services in society, there is a need to capture a broader range of values for ecosystem services in a way that engages local stakeholders and communities in planning for their management (Cowling et al., 2008). This study provides a complementary way of operationalizing the concept of natural capital and ecosystem services in regional planning for environmental management by identifying high priority areas for management based on multiple indices of social value.

Effective management may be targeted at the specific ecosystem services contributing to high index scores for various management objectives. In focal areas of high priority for abundance or rarity, management needs to be tailored to address the most abundant and most rare ecosystem service values, respectively (noting the caveats associated with rare values). For example, in the Billiat area management may be targeted at the entire park to address the abundant bequest, intrinsic and existence values. Complementary management strategies may focus on rare values such as genetic resources through restoring threatened species habitat (Table 3). For focal areas of high priority for diversity, management should be tailored to protect and enhance the range of ecosystem services valued in the focal area which contribute to this diversity. For example, to manage the diverse set of values within the Chowilla/Murtho focal area participants highlighted the need to build on water sharing plans to preserve red gum forests, use water allocation plans to enhance environmental flows, increase salt interception to manage salinity and protect special places that hold spiritual values for Aboriginal people (Table 3). For focal areas of high priority for risk, management investment should be tailored to directly reduce tensions between ecosystem services with the most abundant values and those with the most abundant threats. For example, in the River Murray focal area the provision of fresh water was identified as the highest value and highest threat. Participants recommended the management of risk to fresh water through the development of water sharing plans that balance the demands of extractive uses and the environment (Table 3). Local knowledge of participants was useful for targeting and tailoring management towards ecosystem services in the high priority focal areas.

Spatial indices of social values for ecosystem services can complement biophysical and economic information in cost-effective planning in environmental management. Indices of social values for ecosystem services including abundance, diversity, rarity and risk now need to be integrated with biophysical and economic criteria into systematic regional planning for environmental management (e.g., Crossman et al., 2007; Bryan and Crossman, 2008). Trade-offs between biophysical, economic, and social values need to be assessed and hotspots of high value for all three types of values need to be identified to inform planning decisions. Consideration of social values can help refine the targeting of areas already identified as high biophysical and economic priority for management investment. Spatial prioritisations that efficiently represent minimum percentage area targets of the full suite of social values for ecosystem services should also be investigated. On the process side, the incorporation of social values can also enhance social learning (Blackstock et al., 2007), increase the likelihood that environmental investment decisions are perceived as holistic and fair (Reed et al., 2008), and increase the quality and durability of decisions (e.g., Fischer, 2000; Plummer and Armitage, 2007). Conversely, failure to consider social values can lead to the disempowerment and alienation of local stakeholders (McIntyre et al., 2008).

The challenge for regional planners is to integrate and institutionalize the consideration of social values together with more traditional biophysical and economic information in planning. Following Ludwig et al. (2001) and Berkes (2004), we reiterate the approach to planning for environmental management where researchers and communities interact to define management problems and identify management priorities. New approaches need to build on established participatory processes including community-based natural resources management (Kellert et al., 2000; Berkes, 2004), participatory action research (Fortmann, 2008), and public participation GIS (Sieber, 2006).

Participatory principles should be reflected in regional planning language—environmental management is more than *doing to* the community (e.g., build capacity and raise awareness). If the goal is to engage local stakeholders and community, regional planning language should reflect the need to *listen to* community values and integrate them with other forms of knowledge and information into environmental decision-making.

5. Conclusion

Previous social values mapping studies have used a single objective in targeting management in areas in the landscape—that of high social value abundance. An extended set of objectives adapted from ecological science was used to identify areas with social values for ecosystem services of high abundance, diversity, rarity, and risk. The application of spatial indices used in ecology to social values for ecosystem services was a very natural fit and proved useful in identifying high priority areas for these management objectives. The indices of abundance, diversity, rarity, and risk have an important role in the spatial targeting of environmental management based on social values. Under limited budgets, management can be targeted towards geographic hotspots of social value and concern for multiple objectives. Ecosystem services can be identified and specifically targeted by management actions suggested by the community. Hence, the results of this study provide a highly targeted approach to the management of ecosystem service values in the landscape by identifying *where* high priority management areas are, specifying *what* ecosystem services should be managed, and summarizing community suggestions on *how* they should be managed. Spatial indices of social value for ecosystem services can augment biophysical and economic information in systematic regional planning environmental management and increase community engagement in environmental management.

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Appendix A. The modified version of the Millennium Ecosystem Assessment (2005) ecosystem services typology used in the assessment of social values and risks in this study

Ecosystem service	Description
Provisioning services	
Food	The vast range of food products derived from plants, animals, and microbes
Fibre	Fibrous materials provided by ecosystems including wood, jute, cotton, hemp, silk, and wool
Genetic resources	The genes and genetic information used for animal and plant breeding and biotechnology
Biochemical resources	The many medicines, biocides, food additives and biological materials derived from ecosystems
Ornamental resources	Animal and plant products used for landscaping and ornaments, such as skins, shells, flowers and whole plants
Fresh water	The supply of potable water to human societies
Geological resources[a]	Mineral resources extracted from the land substrate
Energy[a]	The range of renewable energy sources such as biofuels, wind and solar power
Regulating services	
Air quality regulation	The way in which ecosystems both contribute and reduce pollutants in the atmosphere
Climate regulation	The role of ecosystems in regulating temperature and precipitation at a local scale, and climate at the global scale
Water quantity regulation	The influence of land cover and land use on the timing and magnitude of runoff, flooding, and aquifer recharge
Erosion regulation	The role of vegetative cover in soil retention and the prevention of landslides
Water quality regulation	The filtering qualities of ecosystems, particularly the filtering and decomposition of organic wastes introduced into inland waters and coastal and marine ecosystems and the assimilation and detoxification of compounds through soil and subsoil processes
Disease regulation	The role of ecosystems in regulating the abundance of human pathogens, such as cholera, and disease vectors, such as mosquitoes
Pest regulation	The role of ecosystems in regulating crop and livestock pests and diseases
Pollination	The distribution, abundance, and effectiveness of pollinators regulated by ecosystems
Natural hazards	The role of ecosystems in protection and enhancement of hazards such as flooding, coastal storms, cyclones, and bushfire
Cultural services	
Cultural diversity	The role that ecosystems play in maintaining and enhancing cultural diversity
Spiritual and religious values	The spiritual and religious values associated with ecosystems or their components
Knowledge systems[a]	The role of ecosystems in influencing the types of knowledge systems developed by different cultures, including formal and informal education
Aesthetic and inspiration[a]	The aesthetic and inspirational appeal of ecosystems, as reflected in the support for parks, scenic drives, art, folklore, national symbols, architecture, and advertising
Social relations	The role of ecosystems in maintaining and enhancing social relationships in particular cultures
Sense of place	The connection that people feel with recognized features of the environment, including aspects of the ecosystem
Cultural heritage	The value societies place on the maintenance of either historically important landscapes (cultural landscapes) or culturally significant species
Recreation and tourism	The recreational and tourism characteristics of the natural or cultivated landscapes in a particular area
Bequest, intrinsic and existence[a]	Bequest—satisfaction from preserving a natural environment for future generations Existence—satisfaction from knowing that a site is preserved in a certain condition irrespective of use or potential use Intrinsic—signals that areas have value in and of themselves, independent of any benefit to humans
Supporting services	
Soil formation	The influence of soil fertility and soil formation processes occurring within ecosystems on human well-being
Photosynthesis	The oxygen producing benefits of photosynthetic processes occurring within ecosystems
Primary production	The assimilation or accumulation of energy and nutrients by organisms
Nutrient cycling	The role of ecosystems in cycling nutrients essential for life, including nitrogen and phosphorus
Water cycling	The role of ecosystems in cycling water essential for living organisms
People-related services[a]	
Built environments[a]	Built infrastructure ranging from buildings, schools, roads, weirs, salt interception schemes, etc.
Zoning and planning[a]	Processes and regulation which control land use change and in particular the tension around the development of "lifestyle blocks" or peri-urban development
Economic viability and employment[a]	General economic concerns expressed about financial income and employment security
Family[a]	The importance of family and maintaining family relationships
Community[a]	People's roles in schools, fire-fighting, land stewardship and other activities that form their sense of community
General politics[a]	Institutional and organisational aspects of environmental management in the region
Indigenous perspectives[a]	Conceptualisations of the role Aboriginal people have played in the landscape
SAMDB NRM Board politics[a]	Institutional aspects directly related to the SAMDB NRM Board
Representation and leadership[a]	The role of community representation and leadership

[a] New or modified ecosystem services that emerged from in-depth interviews.

Appendix B. Calculation of the spatial indices of abundance, diversity, rarity, and risk

To describe the spatial database and indices, let J be the full set of 879 value/threat areas as identified by participants, G the subset of 698 value areas, and R the subset of 181 threat areas (where $J = G \cup R$). The spatial extent of each individual value/threat area j is represented by a 2272 column × 3574 row binary raster GIS layer $\mathbf{B}_j$ for $j \in J$. Each layer had a grid cell resolution of 1 ha and n valid grid cells (where $n = 5{,}693{,}666$). In each binary layer, grid cells $\mathbf{B}[x, y]_j$ were given a value of 1 if included in the defined spatial extent of each value/threat area, and 0 otherwise.

In describing the attribute data, each value/threat area j was assigned an intensity score (number of green/red dots) represented by the vector $\mathbf{I}$ with dimension J (879) and elements i_j. Each value/threat area j was associated with multiple specific natural capital assets and ecosystem services represented by the matrix $\mathbf{X}$ with dimension $J \times M$ (where M = the set of 40 ecosystem services described above including *People*-related services). $\mathbf{X}$ has binary elements $x_{j,m}$ where $x_{j,m} = 1$ if value/threat area j is associated with ecosystem service m, and 0 otherwise.

A social value abundance index layer was calculated to enable the targeting of management investment towards those areas valued more highly by more participants. The value abundance layer $\mathbf{A}_G[x, y]$ was calculated by summing the value intensity scores over all value areas G such that:

$$\mathbf{A}_G[x, y] = \sum_{j \in G} \mathbf{B}[x, y]_j i_j \quad (1)$$

Raymond et al. (2009) used a similar process to explore the spatial distribution of social value and threat intensities for individual natural capital assets, ecosystem service types, and *People* asset and

People-related services values separately. In this study we use a single index of value abundance across ecosystem services including *People*-related services.

A social value abundance layer was also calculated for each individual ecosystem service $m \in M$ which forms a key input into the diversity index layer:

$$\mathbf{A}_G[x, y]_m = \sum_{j \in G} \mathbf{B}[x, y]_j i_j x_{j,m} \tag{2}$$

A social value diversity index layer was calculated to enable the targeting of management towards those areas assigned value by the community for many different ecosystem services without being dominated by abundant values for only a few services. The Shannon index (Shannon and Weaver, 1949) which calculates diversity based on the information entropy of the spatial distribution of ecosystem service values. As applied here, a layer describing the relative social value abundance $\mathbf{P}[x, y]_m$ of each ecosystem service m is calculated for $m \in M$:

$$\mathbf{P}[x, y]_m = \frac{\mathbf{A}_G[x, y]_m}{\sum_{m \in M} \mathbf{A}_G[x, y]_m} \tag{3}$$

This was then used to calculate the social value diversity index layer $\mathbf{D}[x, y]$ based on the Shannon index H':

$$\mathbf{D}[x, y] = -\sum_{m \in M} \mathbf{P}[x, y]_m \ln \mathbf{P}[x, y]_m \tag{4}$$

Following the properties of the Shannon index, the minimum value $\mathbf{D}[x, y]_{\min} = 0$ which occurs in areas where social values were attributed to a single ecosystem service. The maximum possible value $\mathbf{D}[x, y]_{\max} = \ln|M| = 3.689$ occurs in areas where all ecosystem services are valued with exactly equal abundance scores (Pielou, 1969).

A social value rarity index layer was calculated to enable the targeting of management investment towards those areas with social values for ecosystem services that occur infrequently over the study area. A partial location quotient layer $\mathbf{Q}[x, y]_m$ was calculated as the basis for the rarity index layer. $\mathbf{Q}[x, y]_m$ is a layer describing the ratio of the value abundance layer to the spatial mean value abundance $\overline{A_G[x, y]_m}$ for each ecosystem service m:

$$\mathbf{Q}[x, y]_m = \mathbf{A}_G[x, y]_m \div \overline{\mathbf{A}_G[x, y]_m} \tag{5}$$

The minimum mean grid cell value for the partial location quotient layers $\mathbf{Q}[x, y]_m = 0$ and the mean value is 1. Grid cells where $\mathbf{Q}[x, y]_m = 0$ have no values attributed for ecosystem service m. Grid cells where $0 < \mathbf{Q}[x, y]_m < 1$ have less than average spatial concentration, cells where $\mathbf{Q}[x, y]_m = 1$ have exactly average spatial concentration, and cells where $\mathbf{Q}[x, y]_m > 1$ have greater than average spatial concentration in social values for ecosystem service m. The rarity index layer $\mathbf{R}[x, y]$ was then calculated by averaging the partial location quotient over all ecosystem services:

$$\mathbf{R}[x, y] = \frac{\sum_{m \in M} \mathbf{Q}[x, y]_m}{|M|} \tag{6}$$

The rarity index layer itself can be interpreted as the average ratio of the place-specific social value abundance to the regional average social value abundance over all ecosystem services. Areas with higher value abundance for those ecosystem services with a higher spatial concentration of values will have a higher rarity index score.

A risk index layer was also calculated to enable targeting of management towards those parts of the study area which display both abundant social values and abundant threats. The risk index layer uses a layer describing the abundance of threats to ecosystem services $\mathbf{A}_R[x, y]$ as identified by the community, calculated as:

$$\mathbf{A}_R[x, y] = \sum_{j \in R} \mathbf{B}[x, y]_j i_j \tag{7}$$

The social value abundance and threat abundance layers were rescaled to values between 0 and 1 using the linear transformation (presented below for value abundance layer only):

$$\mathbf{A}_G[x, y]^* = \frac{\mathbf{A}_G[x, y] - \mathbf{A}_G[x, y]_{\min}}{\mathbf{A}_G[x, y]_{\max} - \mathbf{A}_G[x, y]_{\min}} \tag{8}$$

The rescaled social value and threat abundance layers were multiplied to create the risk index layer $\mathbf{C}[x, y]$ as:

$$\mathbf{C}[x, y] = \mathbf{A}_G[x, y]^* \mathbf{A}_R[x, y] \tag{9}$$

The risk index layer scores range from 0 (no risk) to 1 (maximum risk). Where grid cells have either no values or no threats assigned by the community, $\mathbf{C}[x, y] = 0$. The maximum risk score of $\mathbf{C}[x, y] = 1$ can theoretically occur where grid cells have both the maximum value abundance score $\mathbf{A}_G[x, y]$ and maximum threat abundance score $\mathbf{A}_R[x, y]$.

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