Integration of landscape-scale and site-scale metrics for prioritising investments in natural capital

Book · January 2009

3 authors:

Neville D. Crossman
University of Adelaide
134 PUBLICATIONS **4,001** CITATIONS
SEE PROFILE

Brett A. Bryan
Deakin University
187 PUBLICATIONS **4,383** CITATIONS
SEE PROFILE

Darran King
The Commonwealth Scientific and Industrial Research Organisation
44 PUBLICATIONS **998** CITATIONS
SEE PROFILE

Environmental Modelling & Software 26 (2011) 30–37

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

Contribution of site assessment toward prioritising investment in natural capital

Neville D. Crossman[*], Brett A. Bryan, Darran King

CSIRO Sustainable Ecosystems, PMB 2, Glen Osmond, South Australia 5064, Australia

ARTICLE INFO

Article history:
Received 15 December 2009
Received in revised form
19 April 2010
Accepted 28 April 2010
Available online 1 June 2010

Keywords:
Agri-environment schemes
Cost-effective
Analytical hierarchy process
Conservation investment
Stewardship
GIS

ABSTRACT

In prioritising investment in natural capital, site-scale indicators are increasingly used to capture fine-scale variation inherent in complex ecosystems. However, site assessment is costly, has high skill demand, and is time-consuming. We assess the marginal gain associated with including site-scale indicators in metrics typically used by agri-environmental stewardship schemes and payments for ecosystem services. We developed 18 landscape-scale and 14 site-scale indicators to prioritise sites for on-ground works in a real-world conservation auction in South Australia. We used the Analytical Hierarchy Process (AHP) to weight them and multi-attribute utility theory to combine them in quantifying site priority. Bid benefit was calculated as the product of impact of the proposed works and the site priority. Cost-utility analysis was used to rank and select bids with benefits calculated using: i) landscape-scale indicators, and; ii) both landscape- and site-scale indicators. We found that the inclusion of site-scale indicators has limited influence on the ranking and selection of bids for investment when cost of investment is included in the decision-making process. We suggest that, depending on the nature of costs and benefits, and if landholder engagement, information sharing, and trust-building can be achieved in more efficient ways, site assessment may not be necessary. Thereby a significant barrier to the adoption of cost-effective agri-environment schemes and payments for ecosystem services may be eliminated.

1. Introduction

Significant investment is directed at enhancing and restoring natural capital in agricultural landscapes. Market-based agri-environmental stewardship schemes (Stoneham et al., 2003; Connor et al., 2008; Ribaudo et al., 2008) and payments for ecosystem services (Jack et al., 2008; Wünscher et al., 2008) have been used to enhance the cost-effectiveness of investment. Numerous approaches have been used to quantify the multiple intangible benefits of investment in protecting and restoring elements of natural capital (Hajkowicz et al., 2009). Recent attention has focussed on quantifying natural capital benefits at the landscape-scale for prioritising investment (Chan et al., 2006; van der Horst, 2006; Wünscher et al., 2008; Crossman and Bryan, 2009; Wilson et al., 2009). Site-scale indicators have also been widely used to quantify benefits in response to the inability of landscape-scale indicators to adequately represent detailed variation inherent in complex ecosystems (Wainger et al., 2004; Blaschke, 2006; Hein et al., 2006). However, site-scale indicators have a high cost of collection and impose a high skill demand on assessors (Connor et al., 2008; Grantham et al., 2009). This paper examines the relative contribution site-scale indicators make to the natural capital investment decision problem in agri-environment schemes.

Investments in natural capital and ecosystem services can be appropriately prioritised on the basis of cost-effectiveness (Wilson et al., 2007). Quantification of cost in agri-environment schemes is relatively straightforward as this typically comes either from the bid price proposed by the landholder or a standard schedule of payments. However, quantification of the benefits of proposed actions to restore and enhance natural capital and ecosystem services is more complex. Calculating benefits involves the compilation and synthesis of multiple individual indicators representing patterns and processes at both landscape and site scales.

Recent work (Crossman and Bryan, 2006, 2009; Bryan and Crossman, 2008; Dymond et al., 2008; Nelson et al., 2009) has identified the utility of taking a landscape-scale approach to planning for investments in on-ground works that enhance elements of natural capital (e.g. biodiversity, the atmosphere, and stocks of soil and water). This approach typically involves modelling the spatial distribution of various indicators that quantify management priority from the disciplines of landscape ecology and catchment hydrology.

---

[*] Corresponding author. Tel.: +61 8 8303 8663; fax: +61 8 8303 8582.
E-mail address: neville.crossman@csiro.au (N.D. Crossman).

1364-8152/$ – see front matter Crown Copyright © 2010 Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.envsoft.2010.04.022

Many site-scale indicators are also available for prioritising investment in restoring natural capital. The ecological management and restoration sciences are rich with indicators of ecosystem integrity and disturbance. They include local species diversity, terrestrial and aquatic habitat condition and presence and density of invasive species, water-borne nutrient and pathogen loads, ungulate grazing pressure, and soil structure and fertility (Parkes et al., 2003; Magurran, 2004; Dorrough et al., 2007; Oliver et al., 2007).

Several indices have been developed that incorporate site and landscape indicators to quantify the benefits. They include the Environmental Benefits Index for the United States Conservation Reserve Program (Ribaudo et al., 2001), and in Australia, the Biodiversity Benefits Index for the Victorian BushTender Program (Parkes et al., 2003), and the Environmental Benefits Index for the New South Wales Environmental Services Scheme (Grieve and Uebel, 2003).

Many tools for calculating cost-effectiveness are available from the field of economics, operations research, and multiple criteria decision-making (Hajkowicz et al., 2009; Marinoni et al., 2009). Cost-utility analysis enables the prioritisation of investments based on a single cost term and a multi-criteria benefit term (Hughey et al., 2003). Whilst this technique has historically been applied in prioritising health care investments, recent studies have demonstrated its utility in identifying cost-effective environmental investments with multiple intangible benefits (Hajkowicz et al., 2008).

Using cost-utility analysis, we quantified the value added by including site-scale indicators in an agri-environment scheme. We developed 18 landscape-scale and 14 site-scale indicators for a conservation auction in the Adelaide and Mt Lofty Ranges Natural Resource Management Region, South Australia. Our landscape-scale indicators describe management priorities for various natural capital assets including biodiversity, soil, water, and the atmosphere. Our site-scale indicators describe various aspects of the integrity and condition of aquatic habitat and terrestrial remnant vegetation. We used the increasingly popular Analytical Hierarchy Process (AHP; Saaty, 1990; Mahmoud and Garcia, 2000; Hill et al., 2005; Arnette et al., 2010) within a workshop setting with ecologists and decision-makers to weight the relative importance of landscape-scale and site-scale indicators. Landscape- and site-scale indicators were combined to quantify site priority. The priority score was multiplied by the impact of proposed works to calculate a benefit or *utility* score for each bid. Bids were then ranked and selected based on benefit only and cost-utility. The ranking and selection of bids was compared where utility was measured using landscape-scale indicators only, and both landscape- and site-scale indicators. We discuss the implications for cost-effective natural capital investment in agri-environment schemes and payments for ecosystem services.

2. Methods

2.1. Study area

The focus of our study is the Adelaide and Mt Lofty Ranges bioregion in southern Australia. Land use across this hilly, 8500 km^2 landscape is dominated by dryland agriculture (65% of the study area), and includes pockets of conservation (10%), urban development (9%) and high value irrigated horticulture (7%). The ecological character of the study area is typical of a mosaic landscape, with approximately 13% of the original native vegetation remaining, predominantly as small isolated fragments of habitat. The climate is Mediterranean with average annual rainfall ranging from 500 mm in the lowest elevation eastern and western flanks, to over 1000 mm in central and southern parts. Agricultural and urban development have caused a decline in natural capital stocks including biodiversity, water quality, and soils. The Adelaide and Mt Lofty Ranges Natural Resource Management Board (hereafter *the Board*) is responsible for distributing funds for enhancing and restoring natural capital in the region.

2.2. Landscape-scale indicators

We developed a set J of 18 landscape-scale spatial indicators to reflect regional priorities for undertaking on-ground works based on the relative importance of investment in enhancing multiple elements of natural capital. These indicators included flora and fauna species richness, species response to climate change, landscape context, pre-European vegetation remnancy, management of remnant vegetation fragments, protected area representativeness, carbon sequestration, water provision, and soil health and stability (Table 1). Each spatial indicator is represented by a separate GIS raster layer of 1 ha resolution across the entire study area. Each indicator was linearly rescaled in the range 1–5, with 5 the highest priority for investment.

2.3. Site-scale indicators

With the Board we also developed a set K of 14 site-scale indicators designed to be measured in a rapid site assessment by experienced field officers with the aim of balancing detail, accuracy, and repeatability with time efficiency. Site-scale indicators reflected the natural capital benefit of investment in on-ground works that improve the management and protection of remnant native vegetation and aquatic habitat. Site assessment techniques were consistent with other assessment methodologies developed for monitoring the condition of remnant vegetation in the Mt Lofty Ranges (Croft et al., 2005).

Each indicator represented an element of natural capital that cannot be readily measured through remote means such as spatial modelling or remote sensing. The site-scale indicators were grouped into four classes describing various elements of vegetation community composition and structure, vegetation condition, riparian type and condition, and aquatic habitat (Table 2). Each site-scale indicator was scored in the range of 1–5 in the field by experienced field assessor with vales of 5 being the highest priority for investment.

2.4. Structuring and weighting indicators

We developed a goals hierarchy to provide a visual representation and structure for integrating and synthesising all landscape- and site-scale indicators into a single measure of priority for enhancing natural capital. This enabled the Board to quantify the relative importance of each landscape- and site-scale indicator for guiding investment decisions. For example, should investment be prioritised toward locations of greatest species richness, in largest vegetation fragments, in climate zones under-represented in the protected area network, where there is low presence of exotic plants; or in unhealthy riparian zones, or some combination of these and other indicators listed in Tables 1 and 2. The goals hierarchy structures this complex decision-making process into multiple levels by sequentially grouping related indicators. This also enables weights to be quantified representing the relative importance of each element of natural capital.

The AHP was used to derive weights for each element of natural capital in a workshop with three Board ecologists and decision-makers using the Logical Decisions 6.1 software (Smith, 2007). Participants were selected for their expertise in land management and biodiversity conservation, and for their role in distributing funds for enhancing natural capital. The AHP was used to assess the relative importance of indicators using pairwise comparison at all levels. Pairwise comparisons were made at each level of the goals hierarchy beginning with the finest level of disaggregation and ending with the pairwise comparison assessed between site- and landscape-scale indicators. For each pairing, participants were asked to rank importance of one indicator over the other, and by how much. Weights were automatically calculated in Logical Decisions once participants reached consensus on the relative importance of indicators across all pairings. The goals hierarchy, including the global weights for each indicator, is presented in Fig. 1.

2.5. Cost-effective investment

The real-world decision problem in this study was where to invest finite resources under a conservation auction run by the Board over the period 2008–2010 (sensu Latacz-Lohmann and der Hamsvoort, 1997; Stoneham et al., 2003; Connor et al., 2008). A spatial layer was calculated to identify landscape-scale priorities for natural capital investment. This layer was calculated as a weighted sum of all landscape-scale indicator layers using the weights derived in the AHP workshop $\sum_{j\in J} w_j L_j$ where w_j is the weight for each landscape-scale indicator j where $j \in J$ and L_j is the spatial layer describing each indicator. Two high priority areas were identified in the study area for running auction trials. Under the auction, private landholders with rural properties greater than 5 ha in the two priority areas were invited to submit a bid for payment for on-ground works to enhance and restore natural capital on their property.

Field officers employed by the Board visited properties of landholders who expressed interest in the scheme. At these visits the potential options for on-ground works were discussed and the site-scale indicators were scored and entered into a GIS as point-based records. Landscape-scale indicator scores for bids ($n = 44$) were extracted from the spatial data. Natural capital priority scores were calculated for

Table 1
Descriptions of the landscape-scale indicators.

Indicator Name	Description	Methodology source[a]
Biodiversity		
Flora species richness	Total number of native (896 species) and conservation-rated (145 species) flora species predicted using habitat suitability modelling.	Crossman et al. (2009)
Species & climate change	Landscape priorities for vegetation management and restoration for mitigating against flora species range shift impacts driven by a severe 2030 (1.2 degree warming, 15% drying) climate change scenario.	Crossman et al. (2009)
Dispersal distance	Distance from fragments of remnant vegetation using a negative exponential transformation. Locations closer to remnant vegetation have exponentially greater importance.	Crossman et al. (2009)
Fragmentation	Percentage of vegetation cover within fixed 1 km radius circular neighbourhood.	Bryan and Crossman (2008)
Core fragmentation	Percentage of core habitat vegetation cover within fixed 1 km radius circular neighbourhood. Calculated for a 200 m edge distance.	Bryan and Crossman (2008)
Road density	Density of road segments within a fixed circular neighbourhood of 1 km radius.	n.a.
Vegetation remnancy	Percentage of each pre-European vegetation class, soil class and climate zone remaining under remnant vegetation.	Crossman and Bryan (2006)
Vegetation protection	Percentage of each remnant vegetation community, soil class and climate zone formally protected under a conservation agreement.	Crossman and Bryan (2006)
Shape	An index of fragment shape complexity calculated for all contiguous fragments of remnant vegetation. Values closer to 1 indicate lower shape complexity.	Bryan and Crossman (2008)
Area	Total area (ha) of contiguous fragments of remnant vegetation.	Bryan and Crossman (2008)
Atmosphere		
Carbon sequestration	Total carbon sequestered. Modelled using the tree productivity model 3 PG Spatial. Tree parameter set is for Eucalyptus globulus.	Bryan et al. (2007)
Water quality and quantity		
Hillslope erosion	Modelled hillslope erosion using RUSLE, scaled up to sub-catchment level. Three estimates were modelled: erosion under natural (pre vegetation clearance) conditions; erosion under current land use; percentage difference between natural and current conditions.	Wilkinson et al. (2005)
Gully erosion	Proportion of land affected by gully erosion. Higher values indicate higher proportion of the landscape affected by gully erosion.	n.a.
Catchment vegetation cover	Proportion of sub-catchment that is covered by woody vegetation.	n.a.
Environmental flows	Proportion of flow intercepted by farm dams.	n.a.
Aquifer recharge	Groundwater recharge potential. Higher values indicate higher proportion of the landscape with moderate to high recharge potential.	n.a.
Soil		
Soil salinity risk	Risk posed to soil from water table induced salinity.	n.a.
Water erosion risk	Risk posed to soil from surface water erosion.	n.a.

[a] Methods used in this study based on similar methods in other published studies; n.a. denotes unpublished data.

Table 2
Descriptions of the site-scale indicators.

Indicator name	Description
Vegetation	
Conservation status	Conservation status of the mapped vegetation community that contains the site.
Condition	Level of intactness, stability and functionality of remnant vegetation.
Weed invasion	Cover and distribution of common weed species.
Riparian zone	Categorisation of the riparian zone based on intactness and integrity.
Livestock	
Stock damage	Effects of grazing on vegetation, soil stability and riparian habitat.
Stock type	Type of hard-hoofed stock and the level of accessibility to vegetation.
Aquatic habitat condition	
Geomorphology	Indication of the site's potential to support a diverse aquatic community, the rarity of that structure and its risk or capacity to change.
Permanence	Whether the aquatic habitat is permanent or ephemeral.
Channel condition	The rate of active erosion/sedimentation occurring within the reach.
Debris	Presence of snags, logs, or branches.
Abiotic substrate	Type of substrate present within the watercourse.
Organic substrate	Presence of organic substrates in the watercourse.
Macrophytes	Abundance of aquatic plants in the watercourse.
Toxic Inputs	Presence and type of toxic inputs in the watercourse.

each bid i as a weighted sum using the AHP-derived weights based on landscape-scale indicators only $P_i^L = \sum_{j\in J} w_{ij}L_{ij}$, and based on both landscape- and site-scale indicators as $P_i^{L+S} = \sum_{j\in J} w_{ij}L_{ij} + \sum_{k\in K} w_{ik}S_{ik}$.

An additional 'impact' factor was applied that captures the magnitude and efficacy of the proposed on-ground works. The impact I_i for each bid i was scored by field officers in two workshops. Field officers applied their expert local knowledge to subjectively assess potential site-scale improvements to condition and integrity of natural capital. Impact was scored as a percentage where the bid proposing the greatest amount and quality of works was scored as 100% and other bids were scored relative to this (von Winterfeldt and Edwards, 1986). The benefit of each bid i was calculated as the product of impact and priority based on landscape-scale indicators $B_i^L = I_iP_i^L$, and both landscape- and site-scale indicators $B_i^{L+S} = I_iP_i^{L+S}$.

Bids were then ranked and selected for funding until the Board's total budget was reached. The Board provided AUS$ 300,000 for on-ground works and the total value of bids for interested landowners exceeded AUS$ 700,000. Only a subset of bids could be funded. Bids were ranked highest to lowest under four scenarios that examine whether bid ranking with and without site-scale indicators is sensitive to inclusion of cost and changes in weights. The four scenarios are:

1. Comparing the ranking of bids based on benefits only calculated using landscape-scale indicators (i.e. B_i^L), to a ranking based on combined landscape- and site-scale indicators (i.e. B_i^{L+S}).
2. Comparing the ranking of bids based on cost-utility, calculated as the ratio of the cost of the bid to the benefit. Cost of the bid is the price tendered by landowners and is therefore the direct cost to the Board of completing the proposed on-ground works. The cost does not include costs of site assessments and development of landscape-scale indicators. Cost-utility was calculated using landscape-scale indicators (i.e. $U_i^L = c_i/B_i^L$) and using combined landscape- and site-scale indicators (i.e. $U_i^{L+S} = c_i/B_i^{L+S}$). Cost-utility in this scenario was calculated using the actual weights as specified by the Board ecologists and decision-makers during the AHP workshop.
3. Comparing the ranking of bids based on cost-utility with the landscape- and site-scale indicator weights swapped to calculate cost-utility.

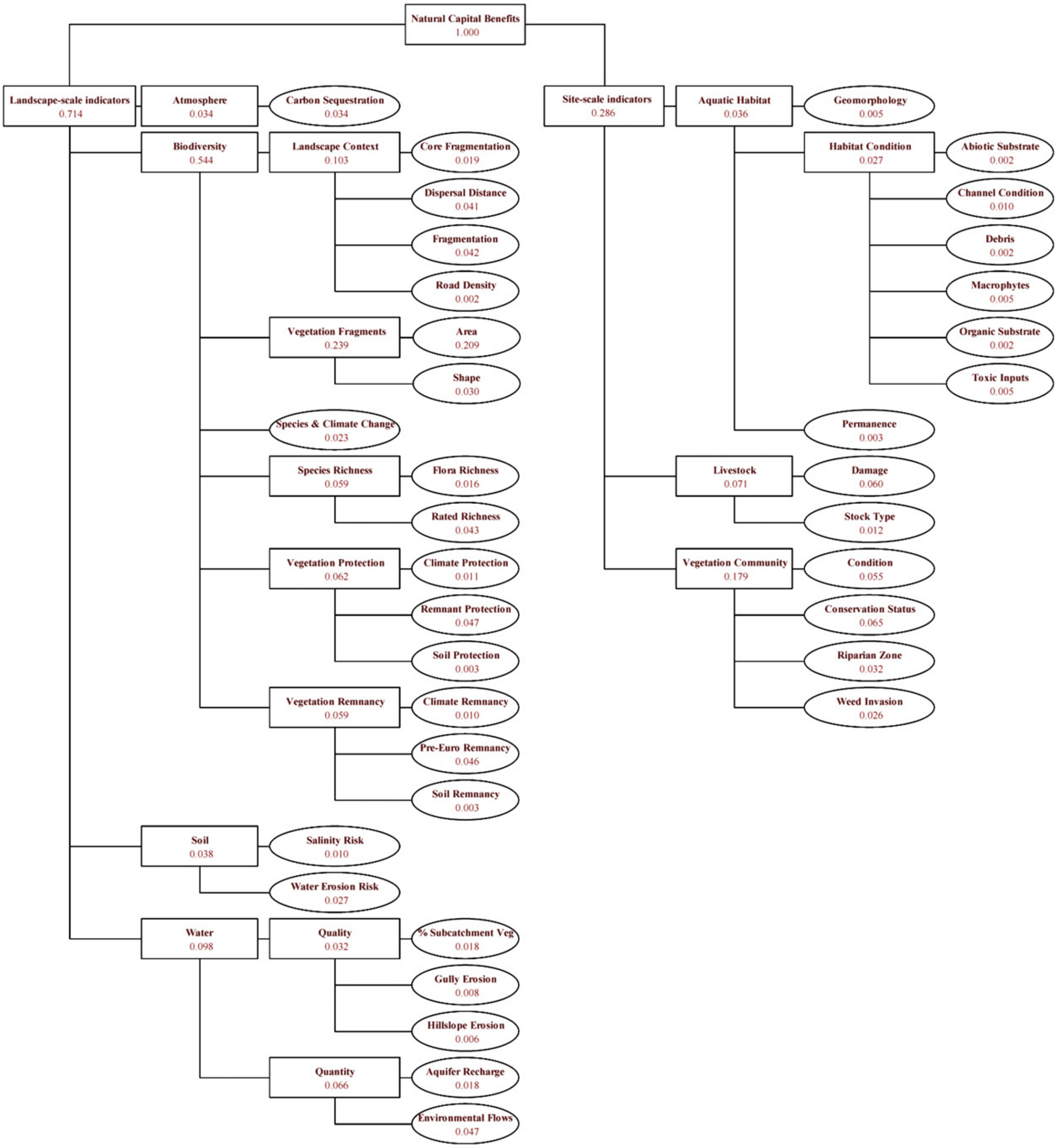

Fig. 1. Hierarchical decision tree for landscape-scale indicators and site-scale indicators. Each oval is an indicator. Global weights are shown.

4. Comparing the ranking of bids based on cost-utility with equal weighting applied to the landscape- and site-scale indicator.

3. Results

Workshop participants considered landscape-scale indicators ($w_L = 0.714$) to be approximately 2.5 times more important than site-scale indicators ($w_S = 0.286$) when prioritising investment. At the landscape-scale, biodiversity was considered to be the most important natural capital asset and was weighted five times higher than the next most important natural capital asset, water (Fig. 1). The area of remnant vegetation fragments was considered the most important individual indicator across the full set, at approximately three times more important than the next most important, being the site-scale indicators of livestock damage and conservation status of the vegetation community.

The map of spatial priorities for enhancing natural capital in the study area is shown in Fig. 2. Highest priority areas coincided with large fragments of remnant vegetation reflecting the influence of the high weighting on the fragment area landscape indicator (Fig. 1). The high priority areas targeted for the auction trials are also shown in Fig. 2 with boundaries following sub-catchments.

Table 3 lists the descriptive statistics of landscape-scale and landscape- plus site-scale natural capital priority, benefit and cost-utility, as well as cost and impact. Table 3 includes the cost-utility statistics for scenarios 2–4. The impact and environmental utility of bids represented by the natural capital priority exhibit relatively little variation. However, cost is widely distributed about the mean, resulting in high variation of cost-utility (Table 3).

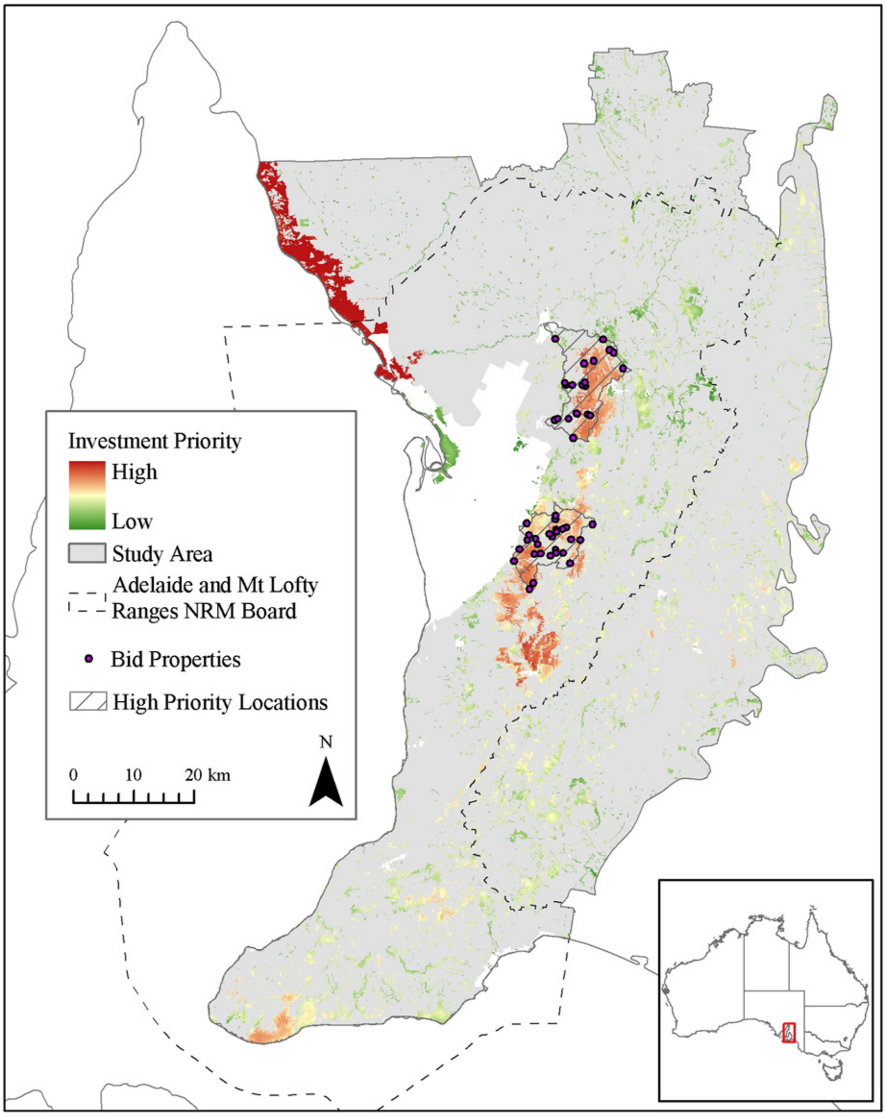

Fig. 2. Spatial priorities for investment in remnant vegetation management and restoration that enhance natural capital. Calculated using landscape-scale indicators.

Fig. 3 shows the change in bid rank and investment selection after inclusion of site-scale indicators when funding is decided based on benefit only (Fig. 3a) and based on cost-utility (Fig. 3b–d). In scenario 1 when bids were ranked based on benefit only (Fig. 3a), the inclusion of site-scale indicators had a significant influence on bid ranking. At one extreme, one property ranked 5th when landscape-scale indicators are considered, but fell to 26th after inclusion of the site-scale indicators. At the other extreme, one property ranked 17th using landscape-scale indicators rose to 3rd after the site-scale indicators were included. However, this influence translated into only a modest effect on bid selection (Fig. 3a). Two bids, selected using landscape-scale indicators, were omitted when site-scale indicators were considered and three bids, not selected using landscape-scale indicators, were included when site-scale indicators were considered.

Table 3
Descriptive statistics of the measures calculated in this study.

Measure	Symbol	Mean	StDev	Min	Max
Impact	I	0.251	0.234	0.001	1.000
Cost	c	\$15,913	\$41,767	\$1200	\$273,900
Natural Capital Priority (Landscape)	P^L	0.255	0.079	0.129	0.381
Natural Capital Priority (Landscape + Site)	P^{L+S}	0.298	0.085	0.134	0.432
Benefit (Landscape)	B^L	0.070	0.072	0.000	0.270
Benefit (Landscape + Site)	B^{L+S}	0.083	0.089	0.000	0.346
Cost-utility (Landscape) – Scenario 2,3,4	U^L	1,830,022	6,315,004	22,769	36,807,276
Cost-utility (Landscape + Site) – Scenario 2	U^{L+S}	1,456,729	4,687,870	22,498	25,454,473
Cost-utility (Landscape + Site) – Scenario 3	U^{L+S}	1,158,939	3,526,000	17,002	17,415,722
Cost-utility (Landscape + Site) – Scenario 4	U^{L+S}	1,284,384	4,000,294	19,745	20,681,409

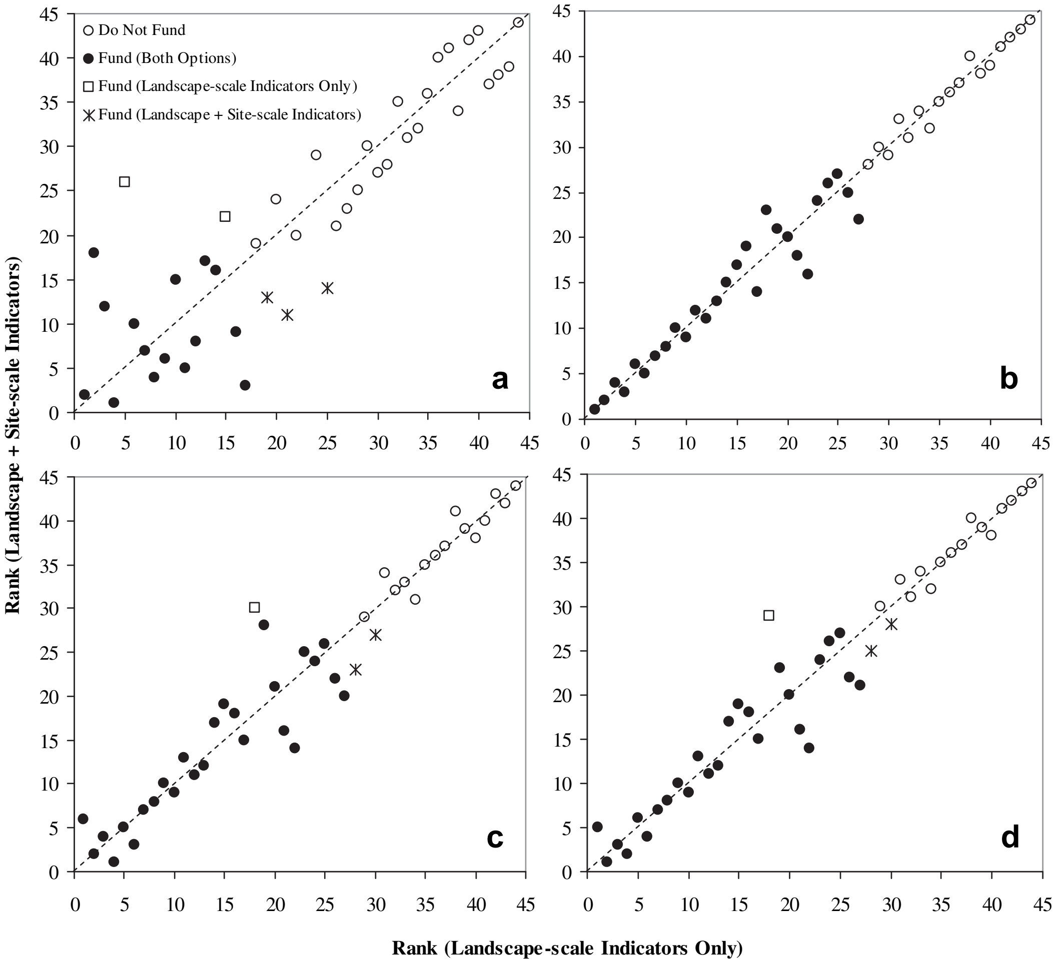

Fig. 3. Rank of properties for landscape-scale indicators only and natural capital benefits rank after inclusion of site-scale indicators: a) Scenario 1 – only benefits used to rank tenders; b) Scenario 2 – benefit-cost ratio used to rank tenders with AHP workshop derived weights that strongly favour landscape indicators; c) Scenario 3 – benefit-cost ratio used to rank tenders with site indicators strongly weighted, and; d). Scenario 4 – benefit-cost ratio used to rank tenders with site and landscape indicators equally weighted. The magnitude of change is represented by the distance a point is from the 45 degree line.

When cost was considered (i.e. scenarios 2–4), the inclusion of site-scale indicators had a very minor influence on the ranking and selection of bids for investment (Fig. 3b–d). In scenario 2, using the Board-specified weights, inclusion of site-scale indicators had a minimal effect on the ranking of bids and did not change the bids selected for funding. In scenario 3, where the site- and landscape-scale weights are reversed, site-scale indicators had more of an effect on ranking due to the higher weighting of site-scale indicators. However, in selecting bids for funding, only one bid dropped out and two others come into contention when site-scale indicators were included. Setting site- and landscape-scale indicator weights equally had an impact similar to scenario 3.

4. Discussion and conclusion

The integration and synthesis of indicators from the two scales is an increasingly popular process for assessing the extent and condition of natural capital assets for prioritising investment in agri-environmental programs (Hajkowicz et al., 2009). Existing agri-environment indices such as the US Environmental Benefit Index and the Victorian Biodiversity Benefits Index are established examples. Our index contributes to the existing set of indices but arguably, based on the Hajkowicz et al. (2009) tabulation, encompasses a greater number of natural capital assets and includes a larger number of indicators.

The inclusion of site-scale indicators had a negligible influence on prioritising investment in on-ground works for protecting and enhancing natural capital in this study. The strongest effect of site-scale indicators occurred when bids were ranked based on benefit alone but even then, the effect on bid selection was not strong. Bid selection was not changed by considering site-scale indicators when cost-utility was used to rank bids based on the Board-specified weights, and only minor changes in funded bids occurred when the relative weighting of site-scale indicators was increased. The findings of this study bring in to question the marginal gain achieved by the more time-consuming and demanding site assessments used to capture fine-scale condition and complexity (Wainger et al., 2004; Blaschke, 2006; Hein et al., 2006).

Bringing cost into the benefit calculation reduces the sensitivity of the decision model to the inclusion of site-scale indicators. Cost becomes the over-riding determinant of which properties receive funding. Similar outcomes were found by Hajkowicz and Collins (2009) who demonstrate that cost provided greater differentiation of which locations received funding in their MCA environmental stewardship program. Wilson et al. (2007) also demonstrate how the inclusion of cost can influence investment priorities considerably within a conservation planning exercise. Babcock et al. (1997) and Ferraro (2003) state that cost has a more significant effect on the cost-effectiveness of environmental investments when: i) budgets are small relative to total cost; ii) cost and benefit are strongly positively correlated, and; iii) cost has a greater variance than benefits. Our case study meets these conditions. Both Bode et al. (2008) and Polasky (2008) postulate that high variability in cost relative to benefit is a common characteristic of environmental investment.

It is important to note that site-scale indicators have considerable value beyond quantifying benefit scores. Their value lies in engaging landholders, sharing knowledge and information, building trust between the funding agencies and the landholder, and providing a baseline for future monitoring of the efficacy of on-ground works. The site visit from a field assessment officer builds rapport with the landowner by providing the first point of contact between the funding body and the recipient. The site visit alone, independent of any detailed effort to collect indicator data, provides an understanding of the likely effectiveness of restoration or management activities, critical to determining the expected impact of proposed actions. Absence of these important processes may increase the chance of moral hazard or other adverse outcomes of agri-environment schemes and payments for ecosystem services. Further important considerations are when site-scale indicators are more highly valued, and therefore highly weighted, by decision-makers or when the natural capital stocks of interest are not readily quantified using landscape modelling and assessment.

Quantifying natural capital for trade under an ecosystem services market (e.g. Gibbons et al., 2009) or to include for conservation planning purposes (e.g. Zerger et al., 2009) will become increasingly common as the concept of ecosystem services becomes more entrenched in policy decision-making. Markets for ecosystem services are led by initiatives such as the Kyoto Protocol's Clean Development Mechanism (CDM), in which projects that reduce emissions in developing countries are able to be traded as certified carbon credits (Basu, 2009). The projects typically centre on carbon sequestration through reforestation. The drive toward on-ground activities that provide multiple natural capital and ecosystem service benefits that can be traded into a market (Ribaudo et al., 2008; Windle and Rolfe, 2008; Palmer and Filoso, 2009), including carbon in programs such as the CDM, arguably require transparent and robust measurements of the commodities being traded.

The problem in market-based approaches is the increase in transaction costs and administrative burden associated with the need for a more robust index quantifying the benefits and hence the commodity traded. Connor et al. (2008) found that auctions of conservation products were more expensive than traditional forms of conservation payment because of the additional effort required by education and extension, including gathering of site-scale information to discriminate between bids. Reducing the effort in collecting site-scale data could save considerably on the transaction costs involved in building indicators for market-based agri-environmental programs. These costs will be program-specific and dependant on the skills and capacity of the organisation implementing the program. We suggest a cost-benefit analysis be completed for market-based programs, that include transaction costs of site-scale data collection and the GIS modelling and analysis to develop the landscape-scale indicators.

This paper demonstrates, however, that the additional effort required to collect site-scale indicators is potentially unnecessary. Rapid calculation of desktop landscape-scale indicators may be sufficient if including cost (i.e. bid price), because cost becomes a significant determinant of ranking for investment. This is a particularly important consideration given the transaction costs associated with the likely substantial increase in market-based conservation and agri-environment schemes. We suggest however, that other more efficient mechanisms may be needed to replace the informal landholder engagement, information sharing, and trust-building roles that site assessment plays.

Acknowledgments

This work was funded under the Department of Agriculture, Fisheries and Forestry National Market-Based Instruments Pilot Program, Round 2 and the CSIRO Water for a Healthy Country Flagship. Staff of the Adelaide and Mt Lofty Ranges NRM Board are kindly thanked for their contribution throughout the project, especially Michael Garrod, John Wood and Martin Weidenbach who contributed valuable input to the AHP workshops. Andrew Reeson, Oswald Marinoni and two anonymous reviewers are thanked for their comments that greatly improved the manuscript.

References

Arnette, A., Zobel, C.D., Bosch, D., Pease, J., 2010. Metcalfe, T. Stakeholder ranking of watershed goals with the vector analytic hierarchy process: effects of participant grouping scenarios. Environ. Model. Software 25 (11), 1459–1469.

Babcock, B.A., Lakshminarayan, P.G., Wu, J.J., Zilberman, D., 1997. Targeting tools for the purchase of environmental amenities. Land Econ. 73, 325–339.

Basu, P., 2009. A green investment. Nature 457, 144–146.

Blaschke, T., 2006. The role of the spatial dimension within the framework of sustainable landscapes and natural capital. Landsc. Urban Plan. 75, 198–226.

Bode, M., Wilson, K.A., Brooks, T.M., Turner, W.R., Mittermeier, R.A., McBride, M.F., Underwood, E.C., Possingham, H.P., 2008. Cost-effective global conservation spending is robust to taxonomic group. Proc. Natl. Acad. Sci. U.S.A. 105, 6498–6501.

Bryan, B.A., Crossman, N.D., King, D., McNeill, J., Wang, E., Barrett, G., Ferris, M.M., Morrison, J.B., Pettit, C., Freudenberger, D., O'Leary, G., Fawcett, J., Meyer, W., 2007. Lower Murray Landscape Futures Dryland Component. Final Report. In: Analysis of Regional Plans and Landscape Futures, vol. 2. Policy and Economic Research Unit, CSIRO Land and Water.

Bryan, B.A., Crossman, N.D., 2008. Systematic landscape planning for multiple objective natural resource management. J. Environ. Manage. 88, 1175–1189.

Chan, K.M.A., Shaw, M.R., Cameron, D.R., Underwood, E.C., Daily, G.C., 2006. Conservation planning for ecosystem services. PLoS Biol. 4, 2138–2152.

Connor, J.D., Ward, J.R., Bryan, B.A., 2008. Exploring the cost effectiveness of land conservation auctions and payment policies. Aust. J. Agric. Resour. Econ. 52, 303–319.

Croft, S., Pedler, J., Milne, T., 2005. Bushland Condition Monitoring Manual: Southern Mount Lofty Ranges. In: Field Guide to Bushland Monitoring, vol. 1. Nature Conservation Society of South Australia.

Crossman, N.D., Bryan, B.A., 2006. Systematic landscape restoration using integer programming. Biol. Conserv. 128, 369–383.

Crossman, N.D., Bryan, B.A., 2009. Identifying cost-effective hotspots for restoring natural capital and enhancing landscape multi-functionality. Ecol. Econ. 68, 654–668.

Crossman, N.D., Bryan, B.A., Cooke, D.A., 2009. An invasive plant and climate change threat index for weed risk management. Ecol. Indicat. doi:10.1016/j.ecolind.2008.10.011.

Dorrough, J., Ash, J.E., Bruce, S., McIntyre, S., 2007. From plant neighbourhood to landscape scales: how grazing modifies native and exotic plant species richness in grassland. Plant Ecol. 191, 186–198.

Dymond, J., Ausseil, A.G., Overton, J.M., 2008. A landscape approach for estimating the conservation value of sites and site-based projects, with examples from New Zealand. Ecol. Econ. 66, 275–281.

Ferraro, P.J., 2003. Assigning priority to environmental policy interventions in a heterogeneous world. J. Policy Anal. Manage. 22, 27–43.

Gibbons, P., Briggs, S.V., Ayers, D., Seddon, J., Doyle, S., Cosier, P., McElhinny, C., Pelly, V., Roberts, K., 2009. An operational method to assess impacts of land clearing on terrestrial biodiversity. Ecol. Indicat. 9, 26–40.

Grantham, H.S., Wilson, K.A., Moilanen, A., Rebelo, T., Possingham, H.P., 2009. Delaying conservation actions for improved knowledge: how long should we wait? Ecol. Lett. 12, 293–301.

Grieve, A., Uebel, K., 2003. The NSW Environmental Services Scheme: Progress Report on Outcome and Experience Developed during Its Implementation. The State of NSW Department of Infrastructure, Planning and Natural Resource, State Forest of NSW and NSW Agriculture, Pennant Hills.

Hajkowicz, S.A., Collins, K., 2009. Measuring the benefits of environmental stewardship in rural landscapes. Landsc. Urban Plan. 93, 93–102.

Hajkowicz, S., Collins, K., Cattaneo, A., 2009. Review of agri-environment indexes and stewardship payments. Environ. Manage. 43, 221–236.

Hajkowicz, S., Spencer, R., Higgins, A., Marinoni, O., 2008. Evaluating water quality investments using cost utility analysis. J. Environ. Manage. 88, 1601–1610.

Hein, L., van Koppen, K., de Groot, R.S., van Ierland, E.C., 2006. Spatial scales, stakeholders and the valuation of ecosystem services. Ecol. Econ. 57, 209–228.

Hill, M.J., Braaten, R., Veitch, S.M., Lees, B.G., Sharma, S., 2005. Multi-criteria decision analysis in spatial decision support: the ASSESS analytic hierarchy process and the role of quantitative methods and spatially explicit analysis. Environ. Model. Software 20, 955–976.

Hughey, K.F.D., Cullen, R., Moran, E., 2003. Integrating economics into priority setting and evaluation in conservation management. Conserv. Biol. 17, 93–103.

Jack, B.K., Kousky, C., Sims, K.R.E., 2008. Designing payments for ecosystem services: Lessons from previous experience with incentive-based mechanisms. Proc. Natl. Acad. Sci. U.S.A. 105, 9465–9470.

Latacz-Lohmann, U., der Hamsvoort, C.V., 1997. Auctioning conservation contracts: a theoretical analysis and an application. Am. J. Agr. Econ 79, 407–418.

Magurran, A.E., 2004. Measuring Biological Diversity. Blackwell Publishing, Australia.

Mahmoud, M.R., Garcia, L.A., 2000. Comparison of different multicriteria evaluation methods for the Red Bluff diversion dam. Environ. Model. Software 15, 471–478.

Marinoni, O., Higgins, A., Hajkowicz, S., Collins, K., 2009. The Multiple Criteria Analysis Tool (MCAT): a new software tool to support environmental investment and portfolio analysis decisions. Environ. Model. Software 24, 153–164.

Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D.R., Chan, K.M.A., Daily, G.C., Goldstein, J., Kareiva, P.M., Lonsdorf, E., Naidoo, R., Ricketts, T.H., Shaw, M.R., 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Front. Ecol. Environ. 7, 4–11.

Oliver, I., Jones, H., Schmoldt, D.L., 2007. Expert panel assessment of attributes for natural variability benchmarks for biodiversity. Austral. Ecol. 32, 453–475.

Palmer, M.A., Filoso, S., 2009. Restoration of ecosystem services for environmental markets. Science 325, 575–576.

Parkes, D., Newell, G., Cheal, D., 2003. Assessing the quality of native vegetation: the ‘habitat hectares’ approach. Ecol. Manage. Rest 4, S29–S38.

Polasky, S., 2008. Why conservation planning needs socioeconomic data. Proc. Natl. Acad. Sci. U.S.A. 105, 6505–6506.

Ribaudo, M.O., Hoag, D.L., Smith, M.E., Heimlich, R., 2001. Environmental indices and the politics of the conservation reserve program. Ecol. Indicat. 1, 11–20.

Ribaudo, M., Hansen, L., Hellerstein, D., Greene, C., 2008. The Use of Markets to Increase Private Investment in Environmental Stewardship. Economic Research Report 64. Economic Research Service, US Department of Agriculture, Washington DC.

Saaty, T.L., 1990. How to make a decision: the analytic hierarchy process. Eur. J. Oper. Res. 48, 9–26.

Smith, G.R., 2007. Logical Decisions for Windows: User’s Manual. Logical Decisions, USA.

Stoneham, G., Chaudhri, V., Ha, A., Strappazzon, L., 2003. Auctions for conservation contracts: an empirical examination of Victoria’s BushTender trial. Aust. J. Agric. Resour. Econ. 47, 477–500.

van der Horst, D., 2006. Spatial cost-benefit thinking in multi-functional forestry; towards a framework for spatial targeting of policy interventions. Ecol. Econ. 59, 171–180.

von Winterfeldt, D., Edwards, W., 1986. Decision Analysis and Behavioural Research. Cambridge University Press, Cambridge.

Wainger, L.A., King, D.M., Cantrell, J.A., Bird, S.L., 2004. Development of indicators to assess economic vulnerabilities to changes in ecosystem services: case study of counties in Maryland, USA. Environ. Manage. 34, 730–747.

Wilkinson, S., Jansen, A., Watts, R., Read, A., Davey, B., November 2005. Techniques for Targeting Erosion Control and Riparian Rehabilitation in the Mount Lofty Ranges. CSIRO Land and Water Client Report.

Wilson, K.A., Carwardine, J., Possingham, H.P., 2009. Setting conservation priorities. Year Ecol. Conserv. Biol. 1162, 237–264.

Wilson, K.A., Underwood, E.C., Morrison, S.A., Klausmeyer, K.R., Murdoch, W.W., Reyers, B., Wardell-Johnson, G., Marquet, P.A., Rundel, P.W., McBride, M.F., Pressey, R.L., Bode, M., Hoekstra, J.M., Andelman, S., Looker, M., Rondinini, C., Kareiva, P., Shaw, M.R., Possingham, H.P., 2007. Conserving biodiversity efficiently: what to do, where, and when. PLoS Biol. 5, 1850–1861.

Windle, J., Rolfe, J., 2008. Exploring the efficiencies of using competitive tenders over fixed price grants to protect biodiversity in Australian rangelands. Land Use Policy 25, 388–398.

Wünscher, T., Engel, S., Wunder, S., 2008. Spatial targeting of payments for environmental services: a tool for boosting conservation benefits. Ecol. Econ. 65, 822–833.

Zerger, A., Gibbons, P., Seddon, J., Briggs, S., Freudenberger, D., 2009. A method for predicting native vegetation condition at regional scales. Landsc. Urban Plan. 91, 65–77.