Journal of Environmental Management 175 (2016) 76–86

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

The contribution of nature to people: Applying concepts of values and properties to rate the management importance of natural elements

Michael J. Smith [a, d, e, *], Christian Wagner [b], Ken J. Wallace [a, c], Amir Pourabdollah [b], Loretta Lewis [a]

[a] Science Division, Department of Parks and Wildlife, Locked Bag 104, Bentley Delivery Centre, WA 6983, Australia
[b] Horizon Digital Economy Institute, IMA & Lab for Uncertainty in Data and Decision Making (LUCID), School of Computer Science, University of Nottingham, Nottingham, United Kingdom
[c] School of Agricultural and Resource Economics, the University of Western Australia, 35 Stirling Hwy, Crawley, WA 6009, Australia
[d] Australian Wildlife Conservancy, PO Box 8070, Subiaco East, WA 6008, Australia
[e] School of Plant Biology, the University of Western Australia, 35 Stirling Hwy, Crawley, WA 6009, Australia

ARTICLE INFO

Article history:
Received 8 June 2015
Received in revised form
10 January 2016
Accepted 5 February 2016
Available online 5 April 2016

Keywords:
System element
Element property
Human value
Natural resource management

ABSTRACT

An important, and yet unresolved question in natural resource management is how best to manage natural elements and their associated values to ensure human wellbeing. Specifically, there is a lack of measurement tools to assess the contribution of nature to people. We present one approach to overcome this global issue and show that the preferred state of any system element, in terms of realising human values, is a function of element properties. Consequently, natural resource managers need to understand the nature of the relationships between element properties and values if they are to successfully manage for human wellbeing. In two case studies of applied planning, we demonstrate how to identify key element properties, quantify their relationships to priority human values, and combine this information to model the contribution of elements to human wellbeing. In one of the two case studies we also compared the modelling outputs with directly elicited stakeholder opinions regarding the importance of the elements for realising the given priority values. The two, largely congruent outputs provide additional support for the approach. The study shows that rating sets of elements on their relative overall value for human wellbeing, or utility, provides critical information for subsequent management decisions and a basis for productive new research. We consider that the described approach is broadly applicable within the domain of natural resource management.

1. Introduction

Given the fundamental connection between human wellbeing and nature (Millennium Ecosystem Assessment, 2005), it is vital that we judiciously manage our natural resources to ensure they continue to satisfy human values and thus wellbeing (Wallace et al., 2016). In response to increasing competition amongst those using natural resources, recent papers have highlighted the need for conservation personnel to better manage conflicts over resource distribution (Redpath et al., 2013; Madden and McQuinn, 2014). At the same time, Mace (2014) has noted the lack of measurement tools to assess the contribution of nature to people. That is, there is a dearth of methods for explicitly and consistently linking human values and wellbeing with the natural biotic and abiotic elements of systems. Yet having this information is crucial to planning the long-term management of natural resources, including the related trade-offs and synergies. Additionally, if decision processes are based on transparent links between system elements and human values, then this should encourage broader understanding and engagement among all stakeholders in land management, thus increasing the likelihood of wise resource use.

To address this methodological gap, we present a method for linking the natural elements to human values in an applied planning and decision context. Specifically, we propose that: (a) the 'state' of any system element is described by its properties, such as size, rarity, species composition (sometimes referred to as attributes or criteria; e.g., Margules and Usher, 1981, Pouwels et al., 2011); (b) these properties may be directly linked to human values; and (c) quantifying this link provides a means for estimating the wellbeing, or utility, that may be derived from any given element or set of elements. If this proposition is sound, then, where the goal is human wellbeing, natural resource managers need to

* Corresponding author. Australian Wildlife Conservancy, PO Box 8070, Subiaco East, WA 6008, Australia.
E-mail addresses: Michael.Smith@australianwildlife.org (M.J. Smith), Christian.Wagner@nottingham.ac.uk (C. Wagner), ken.wallace@uwa.edu.au (K.J. Wallace), Amir.Pourabdollah@nottingham.ac.uk (A. Pourabdollah), Loretta.Lewis@dpaw.wa.gov.au (L. Lewis).

http://dx.doi.org/10.1016/j.jenvman.2016.02.007
0301-4797/

understand and plan to shape system structure and composition accordingly. Such knowledge could also provide a powerful tool for informing debates and decision-making where there are conflicts over resource allocation.

Two lines of evidence support the proposition that human values may be consistently linked to elements through element properties. Firstly, many scientists and resource managers have expounded the importance of properties to the management of natural resources in a more general sense (Armstrong and Bradley, 2012; Keeney, 1992), and a range of element properties – such as size, rarity and intactness – have been routinely applied to quantify some specified or unspecified 'value' when selecting conservation reserves (e.g., Pressey et al., 1994; Scholes and Biggs, 2005; Wilson et al., 2009). This demonstrates that the properties of elements are widely used to calculate conservation 'value'. Often the meaning of the term 'value' is not defined, and as such it is implicit that some form of philosophical-spiritual value (Wallace, 2012), taken here to include the concepts of biodiversity ethics and intrinsic value, is involved.

Secondly, numerous researchers have directly linked specific properties of elements to particular values. For example, properties such as naturalness, accessibility, species richness and vegetation structure have been variously used to score the importance of areas for recreational satisfaction and management (e.g., Horne et al., 2005; Shelby et al., 2005; Pouwels et al., 2011; Edwards et al., 2012; Paracchini et al., 2014). Furthermore, Lindemann-Matthies et al. (2010) produced experimental evidence of a relationship between plant diversity (a property of the studied grassland systems) and peoples aesthetic pleasure (a value). Similarly, other researchers have found relationships between aesthetic pleasure and landscape properties including vegetation and landscape structure (Ribe, 2009; Arnberger and Eder, 2011; Junge et al., 2011; Qiu et al., 2013). In relation to adequate resources value (e.g., food and potable water), the interaction between vegetation structure and water yield and other properties is well-documented (e.g., Hawthorne et al., 2013; Burt et al., 2015), and the relationship between wild food production and the composition (type and number of each type) of biotic elements is uncontroversial. Nevertheless, although many authors have explored some aspects of the interactions among properties and values (e.g., Chapin et al., 2000; Montgomery, 2002; Garcia-Llorente et al., 2011; Schlacher et al., 2014), we have not found an example where multiple properties of elements have been explicitly and consistently linked to a defensible classification of multiple human values and then analysed to drive management priorities (but see Smith et al., 2015a for a qualitative assessment of the relationship between properties and values within a natural resource context).

The above review supports the proposition that linking natural elements to human values via element properties is a sound way to incorporate human values into planning and decision-making. This approach builds on existing concepts (Keeney, 1992; Margules and Usher, 1981); provides an important, novel and broadly applicable tool to assess the contribution of nature to people; and provides a framework within which human wellbeing can be linked directly to management targets. Consequently, we present an approach that draws on expert opinion to quantify the relationships between properties and values (and associated uncertainty), information which can then be used to rate the importance of a given set of elements to specified human values. Because the relationships between properties and values have rarely been quantified in absolute terms, eliciting informed opinions is often the only method for assessing these relationships. By following this approach, planners and managers can better communicate the importance of natural elements to human wellbeing and also use the new information to underpin ensuing planning steps such as risk assessment (Burgman, 2005) and benefit-cost analyses (Robinson, 1993).

The approach described in this paper also aims to capture and preserve the uncertainty inherent in information elicited from multiple people. For the case studies that we use in this paper, we focus on biotic elements, but the approach is equally applicable to abiotic elements and thus to natural resources in general.

2. Methods

2.1. The case study areas

Two case studies from south-western Australia are presented in this paper. In each case, the aim was to assess the importance of individual biotic elements for realising human values, and thus their utility in supporting wellbeing. One case study was conducted in the Lake Bryde Catchment and the other the Buntine-Marchagee catchment (Walshe et al., 2004; who provide a location map). Importantly, some of the properties and values overlapped between the two case studies, providing an opportunity to compare results generated by two expert groups. Both case study catchments were accorded a high management priority by the Western Australian State Government for their significance in terms of their biotic elements and the high risk to these elements due to changes in hydrological processes (Walshe et al., 2004).

The Lake Bryde catchment is about 1400 km^2 in area and is around 300 km south-east of Perth, Australia. The Buntine-Marchagee catchment is around 1810 km^2 in area and around 130 km north-east of Perth. The catchments are used for agriculture (largely wheat and sheep production), with around 25% (Lake Bryde) and 11% (Buntine-Marchagee) remaining as natural vegetation which is mostly managed by the Western Australian State Government Department of Parks and Wildlife (the department). For Lake Bryde, fifteen biotic elements were identified by technical experts and stakeholder representatives. In Buntine-Marchagee, an initial list of biotic elements was identified by departmental project officers, which was then amended by an expert group, resulting in thirty-four elements. Each case study incorporated a one-day workshop with an expert group, followed by email discussions where required.

2.2. Eliciting property-value relationships

Opinions were sought from expert groups to identify a relevant set of element properties and to quantify their relationships with the priority values; for example, how does knowledge-heritage value change with increasing species richness? The approach used for selecting and working with experts will depend on the management context (Reed et al., 2009). For this work, an expert was taken to be someone with skills, experience, education, training, and/or knowledge concerning the issues to be discussed and resolved (adapted from Burgman, 2005). We identified and secured the participation of eight experts for Lake Bryde and seven experts for Buntine-Marchagee who met these criteria.

Importantly, a number of factors may significantly influence the results produced from expert elicitation processes, and these must be managed to ensure useful information is generated. In particular, results can be influenced by framing and anchoring (Luchini and Watson, 2013), over- and under-confidence (Metcalf and Wallace, 2013; Speirs-Bridge et al., 2010), halo effects (Australian Centre for Excellence in Risk Analysis, 2010) and linguistic uncertainty (Burgman, 2005). A number of techniques were employed to manage these issues. Firstly, during initial explanations and training the workshop facilitators avoided any commentary on values, elements or properties that might anchor or frame the responses of experts (Luchini and Watson, 2013; Page et al., 2012). When training participants, examples were based on content that was not relevant to the case at hand, for example, using examples of values and properties unrelated to the biotic elements in the case studies.

We also reduced linguistic uncertainty and alleviated over- and under-confidence by discussing and clearly defining terms. The aim was to bring the expert groups to, as far as practicable, the same understanding of the values classification, biotic elements and, where appropriate, element properties before eliciting opinions. Although mostly operating in an open workshop environment, the actual elicitation of expert opinions was always undertaken as anonymous individuals to reduce "halo" effects (Australian Centre for Excellence in Risk Analysis, 2010) and to maintain expert confidentiality.

Each workshop proceeded with an introductory presentation to explain the planning framework; with an emphasis on the role of elements and element properties in realising human values. A group discussion followed to familiarise experts with the priority values and biotic elements. For Buntine-Marchagee, the values classification (and importance ratings) was taken from the publicly available Buntine-Marchagee Recovery Plan (Department of Environment and Conservation, 2007). The top three priority values for Buntine-Marchagee in order of importance were: ecosystem services, intrinsic/spiritual/philosophical contentment and future options (Department of Environment and Conservation, 2007, see also definitions in Appendix 1). Note, to reduce confusion in this document we use the term *future options*. However, in the Buntine-Marchagee Recovery Plan, future options is labelled *opportunity value* (the terms are interchangeable). Further, we chose to focus on the set of top three values in terms of importance to provide a concise management context. Depending on the circumstances, including guidance from stakeholders, one may choose to focus on a different number of priority values. For Lake Bryde, the values classification was developed with stakeholders based on that outlined in Wallace (2012), and the importance ratings were determined by stakeholders (Wallace et al., 2016). The top three values, in order of priority, from the stakeholder workshop were knowledge-heritage, recreation and future options (defined in Appendix 1).

Once the experts had reached a comparable level of understanding with regards to the planning approach, the facilitators encouraged discussion to identify important element properties, to define them and to set quantified limits (e.g., minimum and maximum species richness expected from any given element of the system). This is a critical step as the properties will become the focus of many subsequent planning steps (e.g., development of management targets, risk assessments, feasibility and benefit-cost assessments). A facilitated practice elicitation using a value and element property relationship unrelated to the case study ensued.

A novel approach developed by Wagner et al. (2015) was used to capture the experts' opinions on the relationships (and associated uncertainty) between the selected element properties and the priority values. For each value-property combination, each expert entered their best estimate into a blank graph (Fig. 1; also refer to Wagner et al., 2015). Each column required only one box to be marked as the best estimate. The experts then filled in the remaining boxes in each column to represent their level of certainty (Fig. 1) with the caveat that there were no blank boxes between the best estimate and the estimates of uncertainty or between two estimates of uncertainty (in a column). The workshops were completed with a group discussion about the approach and future planning activities. In a separate, subsequent stakeholder workshop for Lake Bryde (described below) an additional property, charisma, was identified. Working individually, the Lake Bryde experts quantified the relationship between charisma and the priority values post-workshop using the same approach.

As we demonstrate in the results section, the outputs from the workshops are a series of property-value relationships (Fig. 2) that can be assessed and critiqued by experts and stakeholders alike and incorporated into a range of different planning and decision making approaches. For this paper we demonstrate one application, using

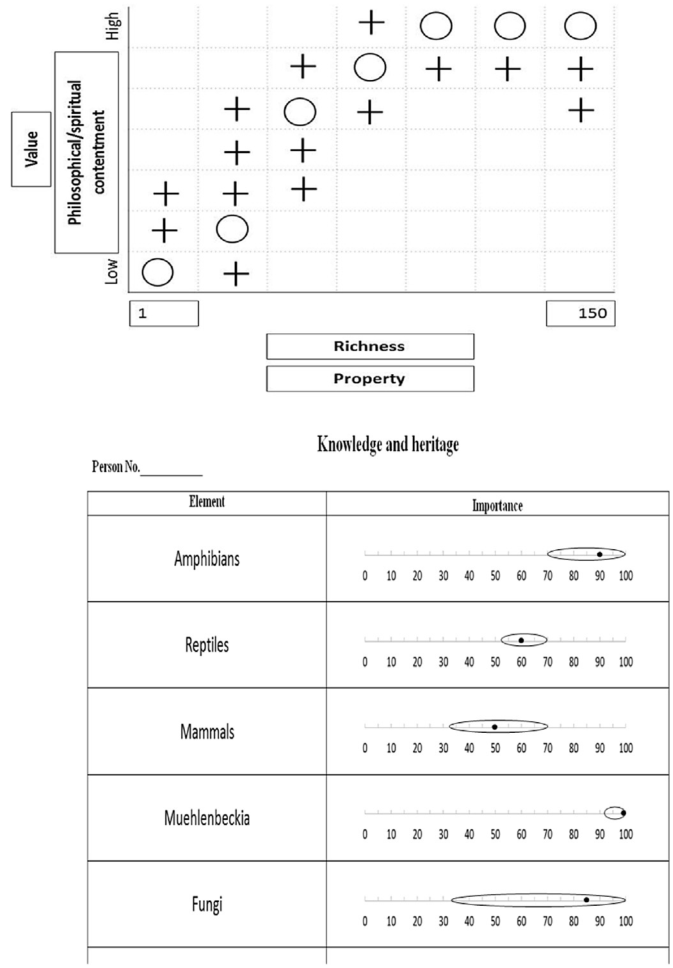

Fig. 1. Example of the graphs used to elicit expert opinion on the relationship between each property and each value (top) and a form used to elicit stakeholder opinions on the value of each element (bottom). For the expert opinion graphs, one property-value combination was estimated per graph. In this completely hypothetical example the expert has entered a circle for their best estimate and crosses to capture their uncertainty. For the stakeholder opinion data sheets, the stakeholder representative draws a best estimate (dot) and then an ellipse to capture their beliefs about the importance of the element to the value (location of the dot and the ellipse on the scale) and their uncertainty (width of the ellipse). The dots and ellipses in this example are purely hypothetical.

the outputs in a Fuzzy Logic Modelling system specifically developed to quantify the relative overall utility of a set of elements (Pourabdollah et al., 2014). The outputs from this system have been used to rate the importance of the system elements for ongoing planning and decision making in the case study catchments.

2.3. Applying the property-value relationships to management

By using the Fuzzy Logic Modelling system designed by Pourabdollah et al. (2014), each property-value relationship generated in the workshop was converted into a series of verbal 'fuzzy' rules (e.g., *IF* Size *IS* Small *AND* Intactness *IS* Low AND … *THEN* Recreation value *IS* Low). This approach is described in detail in Wagner et al. (2015). Once the system has been 'set up' and the rules generated (the detail of which is discussed below), the property scores for each biotic element are entered (e.g., the size, rarity, richness, charisma, visibility and intactness of each element). A combination of published and unpublished literature, departmental data and expert opinions were used to quantify each property score for each element. Each score was entered into the system with an associated range of uncertainty around the best estimate.

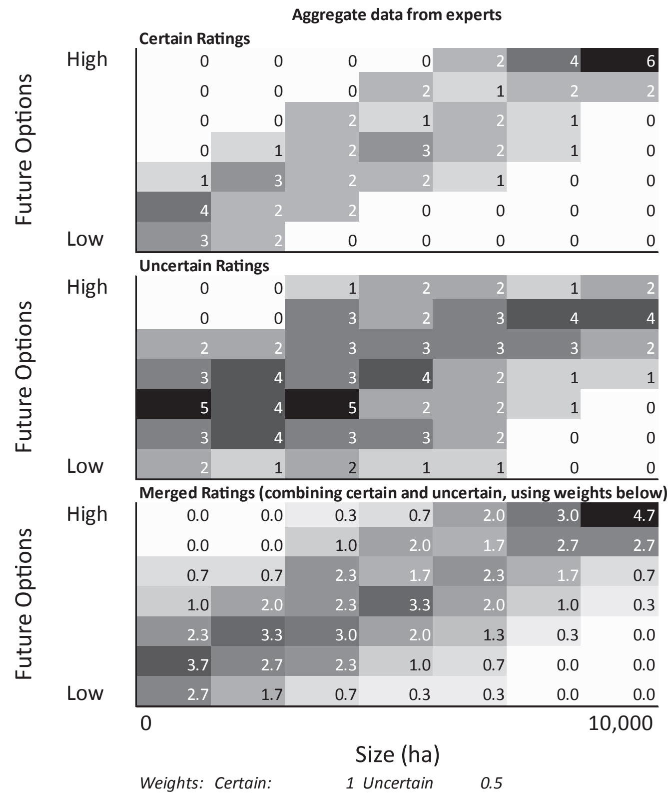

Fig. 2. Example of results generated for each property-value relationship (size and future options in this case). Top graph shows the sum of the expert best estimates ($n = 8$ experts). The graphs are generated in Microsoft Excel™. Within each cell, the number of experts that entered a 'O' into the corresponding box (refer to Fig. 1) are summed. For example, no experts put a 'O' in the top cell in the left most column (column cell order from bottom to top is 3, 4, 1, 0, 0, 0, 0). However, three experts entered a 'O' into the bottom cell in the left most column. The middle graph shows the sum of the expert uncertain estimates (where the number of experts that entered a 'X' into a particular cell (Fig. 1) is summed). The bottom graph, as described in detail in Wagner et al. (2015), is constructed on a cell by cell basis by summing the weighted certain estimate (in our case weighted by '1'; top graph) and the weighted uncertain estimate (in our case weighted by 0.5; middle graph) and dividing that score by the sum of the two weights. The resulting values capture the level of agreement, with higher values representing overall higher certainty/agreement for a given relationship. The shading applied to the table is based on the scores, where higher scores are reflected with darker shades. In the case shown, with eight experts, the highest score possible would be for all eight experts providing a certain response (an "O") to the same cell, resulting in a final score of 5.33 $\left(\frac{(8\times1+0\times0.5)}{1.5} = 5.33\right)$ and shaded black, while a cell which is not considered as a certain or uncertain relationship by any expert would be rated 0 and shaded white. Clearly, these values could be normalised to [0,1] if desired.

The Fuzzy Logic System uses the inference rules to estimate the relative utility of each element (where utility is a score reflecting the capacity of an element or set of elements to provide for a specified human value or set of values). In our case the utility of a given element is a weighted average of the contribution of the element (based on the state of its properties) to each individual priority value, where the weight is the importance of each value as rated by the stakeholders.

Thus, the utility provides an overall estimate of the relative importance of each element in terms of realising the priority human values. Note, for Buntine-Marchagee, faunal elements did not relate to the ecosystem services value (as defined by the stakeholder group) and thus received a weight of zero for that value. Results are provided with surrounding uncertainty reported as spread, the calculation and meaning of which are described by Pourabdollah et al. (2015).

2.4. Comparing model outputs with stakeholder opinions

Finally, to examine the validity of the modelling outputs, for Lake Bryde we directly elicited stakeholder element-value preferences in a workshop. The representatives were asked to directly rate the importance of each element to each priority value. Neither the element properties nor the modelling approach and its outputs for Lake Bryde were discussed during this component of the workshop. Each stakeholder representative was asked to anonymously and individually provide their estimate of the importance of each element to each value without any attempt to assess mediating properties of elements.

In the workshop the facilitators provided a description of, and generated a general discussion about, the human values and the biotic elements to familiarise the stakeholder representative with the values and elements. A facilitated discussion then ensued on the rating process to be employed, which included the presentation of unrelated (to avoid bias) examples. A practice session with a realistic, but hypothetical example was conducted followed by the formal elicitation.

The interval agreement approach (Wagner et al., 2014; Smith et al., 2015b), which we discuss further below, was used to capture and aggregate the representative opinions on the capacity of each element to deliver each value. Each participant was asked to mark a point on a scale (from 0 to 100; Fig. 1) for each element-value combination to indicate their 'best' estimate of the importance of the element to the value and to then draw an ellipse to express their certainty. The application of the 'ellipse' approach is now well documented by Wagner et al. (2014) and Smith et al. (2015b) who provide detailed supplementary material, including a Microsoft Excel™ example, to guide practitioners through the approach. The question asked for each element-value combination was:

> *Over the management period of 20 years, from the perspective of your stakeholder group, how important is the [element] to the [value]?*

In the workshop, the group discussed the question and the process and any issues were clarified. It was also noted that the spatial context of the exercise was limited to the boundary of each element. As noted, participants completed scoring sheets anonymously and individually. Finally, a group discussion was used to encourage the stakeholder representatives to express why/how they discriminated amongst the elements. From this discussion it became apparent that the charisma (Table 1) of individual elements was an important discriminating property for the stakeholder representatives.

The interval agreement approach creates a distribution, a fuzzy set, from the intervals provided by the different stakeholders. To create this distribution, the parts of intervals which are in agreement with (parts of) intervals from other stakeholders are weighted more highly to extract agreement over all intervals. In order to provide summaries of the distribution, their centroid (center of gravity) was calculated and used to estimate the overall utility for each element. All centroids are reported with their spread which provides a basic insight and summary of the uncertainty in the distributions.

3. Results

3.1. Properties

For Lake Bryde, six element properties were identified as important: total natural species richness, rarity, loss (= converse of intactness), size, visibility and charisma. For Buntine-Marchagee, the expert group also identified six properties: total natural species richness, intactness, rarity, size, range limits and visibility. Definitions of all properties are provided in Table 1.

Table 1
Definitions of several important terms and of the properties as defined by experts (Lake Bryde and Buntine-Marchagee) and Stakeholder representatives (Lake Bryde).

Property	Definition
Rarity (in the south-west land division)	The 'unusualness' of the collection of species that characterise the element within the context of the south west land division of Western Australia. Thus, we may consider the rareness of elements at the level of species and sub-species (e.g., Declared Rare Flora, Endangered Fauna); or at the level of an assemblage or community (e.g., Threatened Ecological Community). The maximum rarity of an element is 100% – for example, where there is only one representative of the element persisting. The minimum rarity of an element is 0%. Note that in the case of some elements, it is the particular collection of species that is considered unusual or rare even though some of the species that constitute the element may be quite common. Similarly, a collection of water birds may consist of very common species, but it may be unusual to have that particular gathering of species together in one place and so the element would be rare. In contrast, the collection of frog species in the area may include all common species and may not be a particularly unusual gathering of species and so would be of low rarity.
Size	The total area of occupancy of the species that characterise the element. At some level, occupancy will relate to habitat avoidance. For example, species will typically occupy areas where they feed, reproduce, etc. They may generally try to avoid many areas (e.g., roads, open paddocks, etc.), but may have to traverse such areas to utilise preferred habitats. Birds, for example, may fly between different important habitats, via less preferred areas. Similarly, frogs may rely on habitats in and around water bodies, but on occasion move between habitats. Again, in this example, the areas of occupancy would be the critical habitats and not include the areas the frog moves over to get to an important habitat. In the context of the Lake Bryde NDRC, we therefore think of the important habitats as constituting the area of preferred/required occupancy, but not the areas that are traversed as a means to reaching preferred/required habitat.
Species composition (total species richness)	The total number of natural species that occur within the element. Note that a complete accounting of species richness would include a description of all the types, plus the numbers of each type, in a specified area or element.
Intactness, loss of intactness	Intactness is related to being sound, flawless, entire (adapted from Oxford English Dictionary). The greater the loss the less sound, flawless or entire the element. Scholes and Biggs (2005) describe their comparable biodiversity intactness index as "an indicator of the average abundance of a large and diverse set of organisms in a given geographical area, relative to their reference population". Conceptually, loss is equivalent to, or a subset of, the notion of biotic integrity which is defined by Callicott et al. (1999) as "natural species populations in their historic variety and numbers naturally interacting in naturally structured biotic communities", and includes ecosystem processes. For the Lake Bryde NDRC, the property considered was 'loss' (i.e., loss of intactness), which was thought of in terms of the loss of natural species from an element. Thus, the greater the loss, the less intact. For the Buntine-Marchagee catchment, intactness was thought of in terms of the loss of natural species abundance from the system (where complete loss of abundance results in extinction). Loss of intactness would be expected when the current diversity (species and their abundances) was lower than expected. Intactness therefore, generally relates to the levels of disturbance (i.e. greater disturbance = lower intactness). In some cases, there may be clear evidence, such as the presence of widespread tree death (i.e. dead trunks remain in place), etc. It should be noted that where intactness is high, loss is low, thus the scoring at Lake Bryde is the converse of that at Buntine-Marchagee.
Visibility	Essentially optical visibility can be thought of as a compound property and relates to the ease with which we can see the species that constitute a particular element. So a particularly visible element may mostly include large (size of individuals) sedentary species. Alternatively, less visible elements may include species that are shy, cryptic (mostly hidden from sight – even if they are large), very small, etc. Could be considered as being viewed at optimum time of day for the component species (e.g., birds may be best seen early in the morning, possums at night).
Charisma	Elements are charismatic when they stimulate strong emotional attraction amongst humans. This attraction may stem from a number of sources, including that an element may be iconic, invested with significant symbolic meaning (e.g., national flora and fauna emblems), be 'cute' (e.g., koalas), widely admired for a particular characteristic such as beauty or strength (e.g., birds of paradise, lions), or be otherwise very famous or very popular. Such elements generally have a high public profile or are widely known. This is also really a compound property, but it seems to be an important general discriminator for the stakeholder representatives.
Range limits	A geographic range limit can be thought of as the geographic boundary beyond which a species does not occur. Thus, the limit of the range of a species is the area where individuals are at the "peripheral" or "edge" of their range. For a particular element, the range limit property would be an estimate of the proportion of component species that are near to the edge of their range. An element for which the majority of species are towards the edge of their range would receive a high range limit score (e.g., around 100%) and an element where the majority of species are in their 'core' habitat would receive a low range limit score (e.g., around 0%).

3.2. Expert elicited property-value relationships

Graphs showing the property-value relationships for Lake Bryde and Buntine-Marchagee are provided in Figs. 3 and 4, respectively. These graphs provide a quantitative and rich description of the relationship between each property and each value and consequently, can be used in a range of subsequent planning and decision steps. In general, total natural species richness, size and intactness were thought to be positively related to the priority values. Often, the experts were in strong agreement about the relationships between these properties and the priority values and the levels of uncertainty were also often comparatively low (the interpretation of the graphs is explained in Fig. 2 caption).

Experts strongly agreed with a high level of certainty that loss is negatively related to the different values; particularly with respect to future options and recreation at Lake Bryde. Visibility was seen to be positively related to knowledge-heritage, recreation, and to a lesser degree to the intrinsic/spiritual/philosophical value. It was not seen to have a particularly strong relationship with future options by either expert group. Charisma was thought to relate positively and strongly (with strong agreement and low uncertainty) to the recreation value and positively, but less strongly to the knowledge-heritage value. Charisma was not seen to be particularly important for the future options value. For the experts, rarity related positively, but weakly (and with considerable uncertainty) to knowledge-heritage and intrinsic/spiritual/philosophical value. The experts created a reasonably flat, uncertain relationship between rarity and both recreation and future options values.

3.3. Using the property-value relationships: a fuzzy logic example

The property-value relationships in Figs. 3 and 4 were used to generate a series of linguistic rules for the Fuzzy Logic System of Pourabdollah et al. (2014). Property scores (and associated uncertainty) were entered into the system and element relative utility estimates — i.e., the expected relative contribution to human wellbeing — were generated. Estimates are reported in Fig. 5.

With respect to realising the priority values for Lake Bryde, the highest rated elements (in terms of their current properties) were: the Terrestrial bird, Mallee shrubland, Other woodlands, Fungi and the Salmon gum woodland (Fig. 5). In terms of the priority values, the elements with the least relative utility were the Aquatic invertebrates, Amphibians and the *Melaleuca* shrubland. For the priority values in the Buntine-Marchagee catchment, the highest

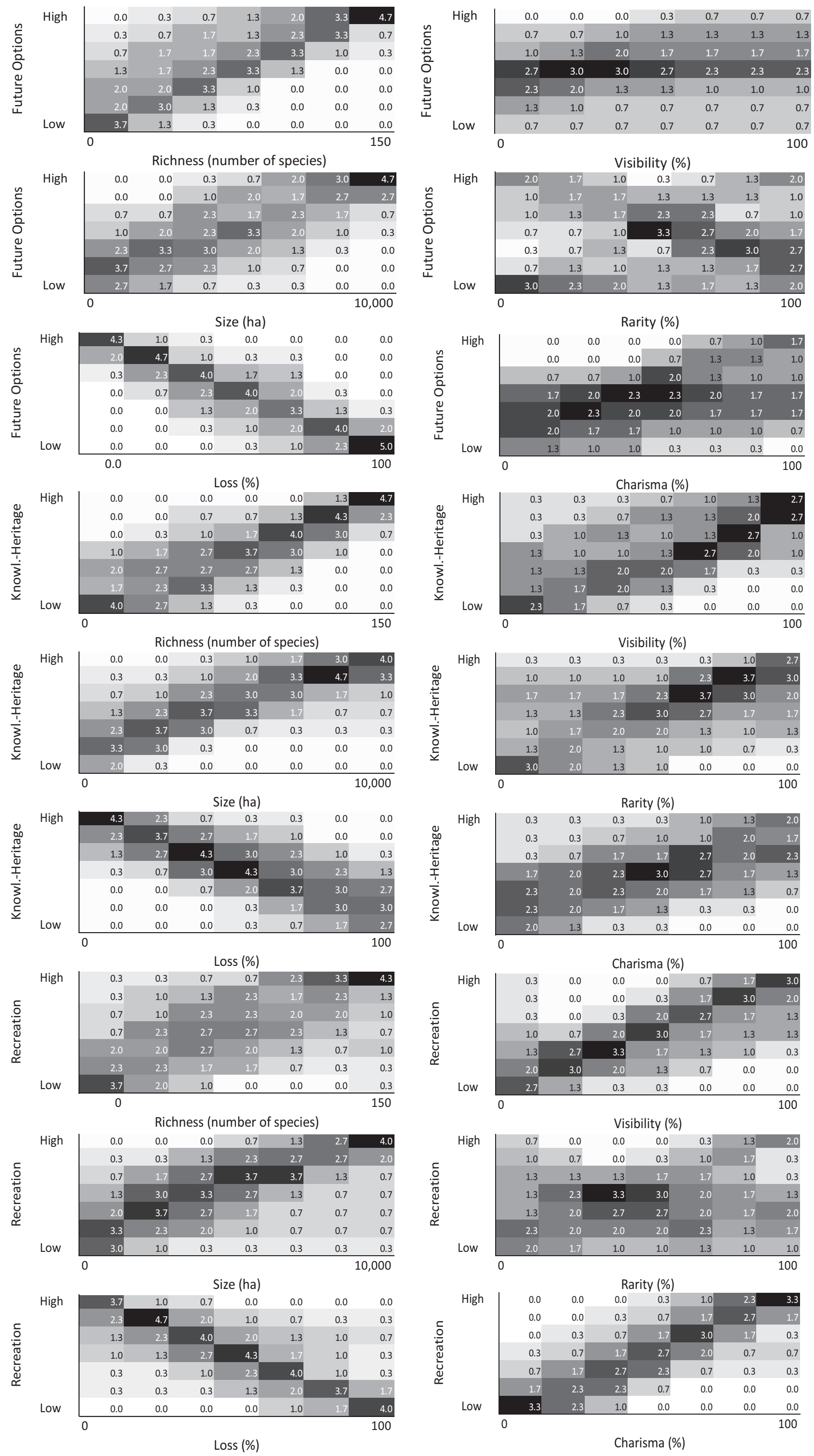

Fig. 3. Graphs showing the expert generated relationships between element properties (x-axis) and priority human values (y-axis) for the Lake Bryde catchment. Note, the graphs incorporate both certain and uncertain estimates (refer to main text) with the uncertain estimates arbitrarily weighted by 0.5.

rated elements were terrestrial vegetation elements (Fig. 5). The lowest rated elements were the Fish, Grassland, Salt River Gum Woodland and Amphibian elements.

3.4. *Assessing the model outputs*

For Lake Bryde, a comparison of the expected utility estimates from the modelling of expert estimates and those generated from stakeholder representatives are reported in Fig. 6. This graph shows that, in general, the model agreed well with stakeholder views. The greatest differences between the two approaches related to the mammal and waterbird elements. The model rated the overall value of the mammal and waterbird elements lower than the stakeholder representatives.

In conclusion, the results indicate that maintaining or, where appropriate and feasible, increasing the species richness, size,

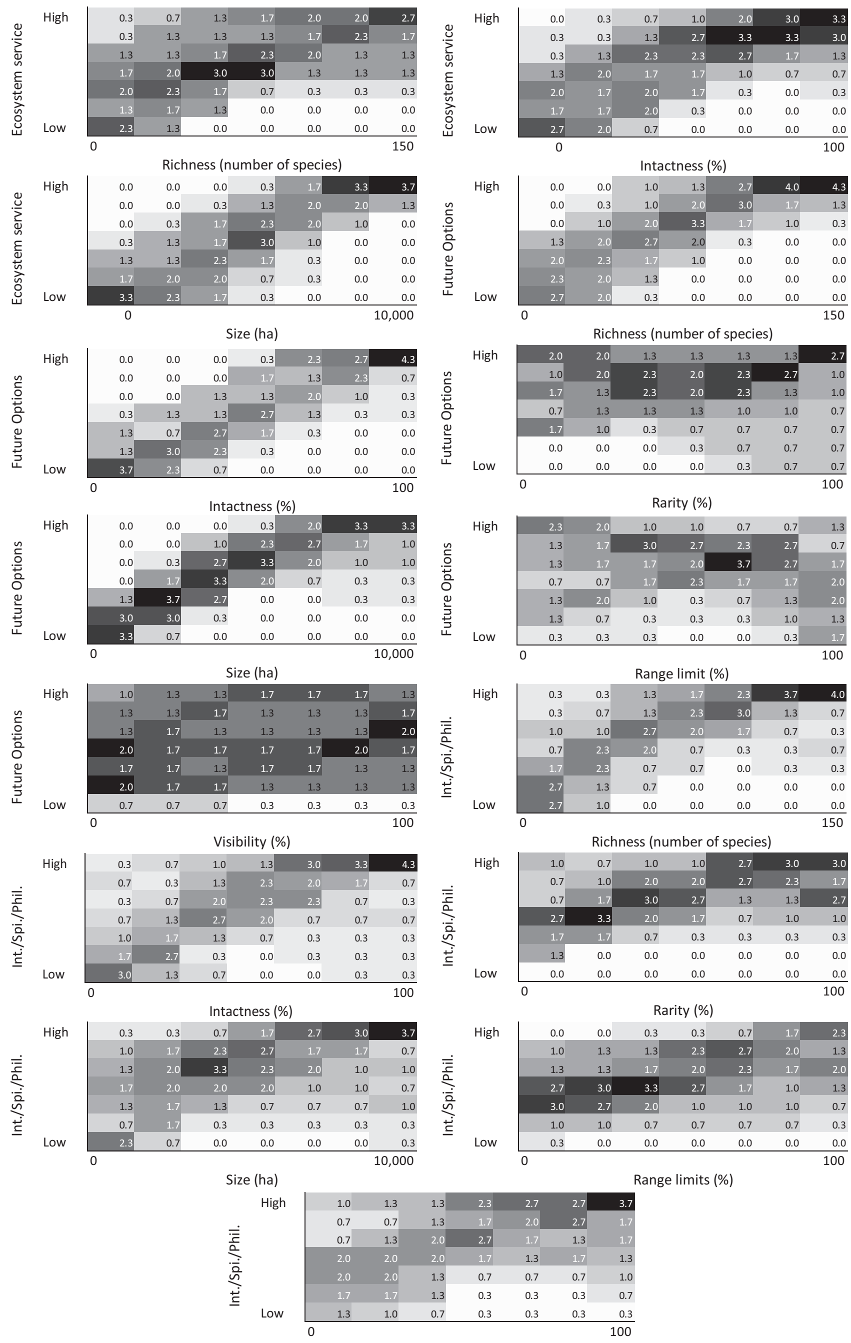

Fig. 4. Graphs showing the expert generated relationships between element properties (x-axis) and priority human values (y-axis) for the Buntine-Marchagee catchment. Note, the graphs incorporate both certain and uncertain estimates (refer to main text) with the uncertain estimates arbitrarily weighted by 0.5.

visibility and charisma of an element will have various positive, incremental benefits in terms of achieving the realisation of human values. Similarly, reducing the levels of loss from an element (or increasing its intactness) will increase its capacity to support human values. Managing element properties with flat relationships to a value are unlikely to significantly improve the flow of benefits from that element in relation to that value.

4. Discussion

The research described in this paper was based on the proposition that the properties of elements may be directly linked to human values, and that quantifying this link provides a method for estimating the wellbeing that people may derive from a given element set. This, in turn, provides a basis for systematically and transparently setting management priorities amongst elements in terms of their utility, and for better informing decisions involving resource conflicts. The results outlined above show that experts were able to identify the properties of elements — such as size and species richness — and quantify property relationships with human values. Applying a set of novel analytical tools, this information was used to calculate the utility of elements in terms of supporting the realisation of priority human values. That is, results from the study support the proposition outlined in the Introduction, particularly points (a), (b) and (c).

Noting that the concept of ‘loss’ used at Lake Bryde is actually the

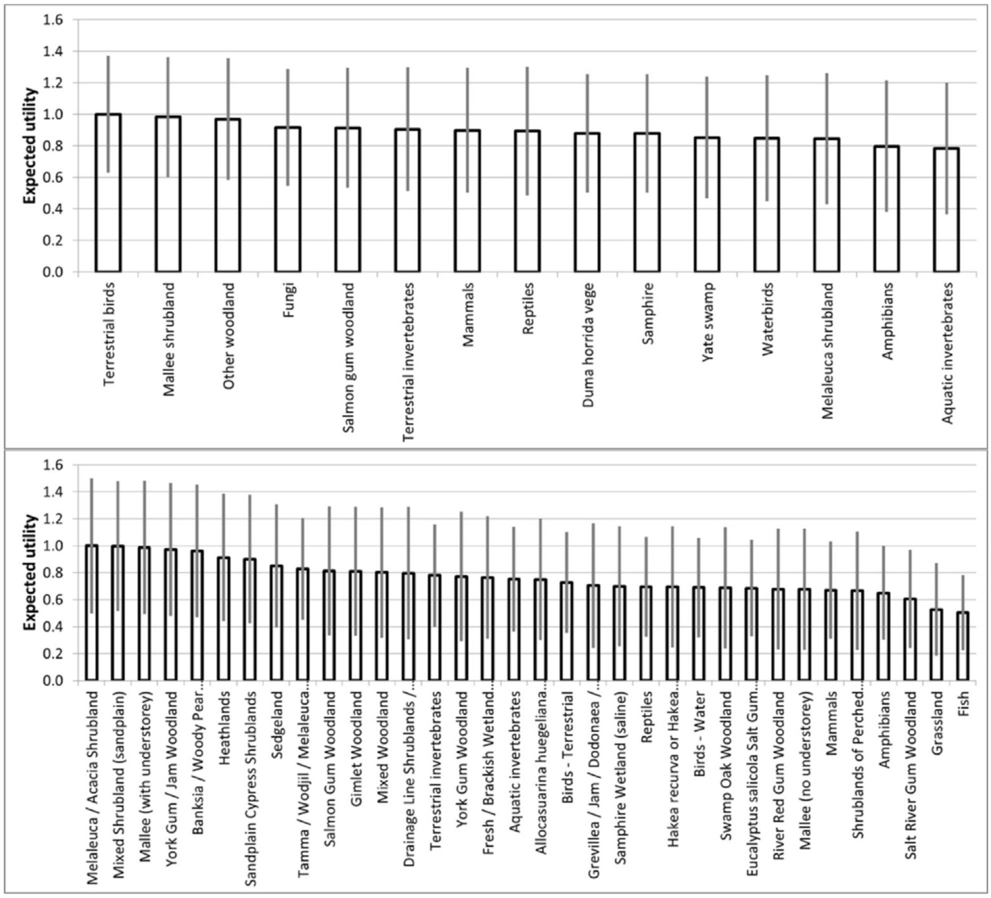

Fig. 5. Estimated overall utility for Lake Bryde elements (top) and the Buntine-Marchagee (bottom) as estimated by the Fuzzy Logic System. Bar height is determined by the centroid utility estimate and grey lines indicate spread — a measure of the variability and shape of the fuzzy set used to generate the utility expectations. The expected utility scale is a unit-less relative score that has been normalised such that the maximum centroid utility is equal to '1.0'.

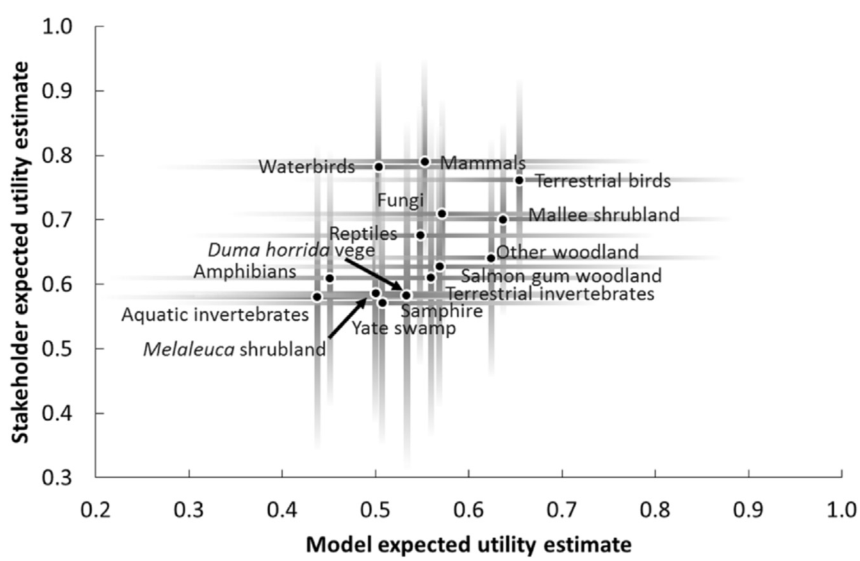

Fig. 6. Expected utility (centroid estimate) for the Lake Bryde biotic elements as estimated from the Fuzzy Logic System (x-axis) and the stakeholder representatives (y-axis). Uncertainty lines indicate spread (a measure of the variability and shape of the fuzzy set used to generate the utility expectations; Pourabdollah et al., 2015). In this case, the expected utility scale is a unit-less relative score that has not been normalised.

converse of 'intactness' at Buntine-Marchagee, then most of the relationships were either strongly (e.g., size and future options value) or weakly (e.g., range limits and intrinsic-spiritual-philosophical value) positive, or were weak without any clear direction, as in the case of rarity and future options value at Lake Bryde. Where an element property is strongly related to a value, then changing that property through management will generally be both more effective and efficient in achieving improved utility than alternative actions. Where a property is not clearly related to a priority value, it would be inefficient to expend management resources trying to change that property. It is interesting to note that while the property of rarity, which is used widely in the conservation literature as an indicator of 'value', is positively related to some values in the case studies (e.g., intrinsic-philosophical-spiritual value at Buntine-Marchagee), the relationship was often quite weak or obscure. Consequently, it is not necessarily safe to assume that properties regularly used in conservation management are always relevant to realising human values; rather, it is essential to understand the nature of the relationships between priority values and the properties of specific elements to manage appropriately. Future research will aim to further clarify the thinking of experts and stakeholders where the relationships between properties and values are very weak, contradictory or unclear.

Overall, the method used was successful in eliciting relationships between element properties and values that could be used to rank the importance of elements based on their relative utility (Fig. 5). This provides an important means of prioritising elements for management action. In one case study we were able to directly elicit stakeholder estimates of the relationships among elements and values. In this instance, the major differences between the modelled and direct stakeholder utility estimates related to two elements (waterbirds and mammals). One explanation for the difference between the two estimates is that the model requires additional properties, or that properties like charisma, which was considered highly important by stakeholders, require greater weighting. Continued dialogue among stakeholder representatives and experts (qualitative information gathering) will be required to 'fine-tune' the modelling. At the same time, it is acknowledged that individual people and groups will vary on how they relate element properties to values, as shown, for example, by the relationships between personal characteristics and preferences in landscape aesthetics (Howley et al., 2012; Kalivoda et al., 2014). Nevertheless, we considered there to be sufficient congruence between modelled and stakeholder representative outputs to apply the results in subsequent catchment planning processes, such as risk and feasibility assessment (e.g., Metcalf and Wallace, 2013; Smith et al., 2015b), and the selection of strategic management actions.

It is emphasised that this formal linking of element properties, utility and values builds on the current use of properties in natural resource management. Already, management targets are often specified in terms of element properties, although the links to any particular human value are often not articulated or even explicitly considered. For example, activities to conserve and restore biotic elements are often based on maintaining or adjusting species composition, possibly by controlling pest species to stop extinction (Baider and Florens, 2011; Fritts and Rodda, 1998) or reintroducing species to an area (Armstrong and Seddon, 2007). Managers regularly attempt to increase the size (a property) of biotic elements (e.g., revegetation to reconnect fragmented vegetation remnants; Hobbs, 1993). Therefore, one key advantage of the approach described here is that it explicitly identifies the properties of elements that generate the opportunity to obtain, maintain, or improve utility. Despite the unavoidable subjective aspects of the method outlined above, it is infinitely preferable to applying element properties in planning without any understanding of how these properties relate to the priority human values driving management.

Turning to the modelling approach used, we chose to use a type-1 Fuzzy Logic System because it allowed us to relate element properties to utility based on linguistic rules, while capturing uncertainty in the variables such as that arising from different levels of agreement (thus implicitly dealing with discord) in a context where multiple sources of information were available (Pourabdollah et al., 2014, 2015; Wagner et al., 2015). The FLSs provided a sound basis to intuitively capture and model the complex relationships between multiple properties and values and provided a crucial level of transparency, interpretability and adaptability. With the modelling approach, sensitivity analyses can also be readily applied (although not reported on here) by interrogating individual property-element-value relationships and by repeating the analysis with individual properties systematically varied and/or removed (Pourabdollah et al., 2014). We are in the process of developing open source software to conduct the analyses described in this paper, but the graphs reported in this paper can be generated in Microsoft Excel™ and can be readily adapted to other modelling environments for a range of planning and decision tasks. In general, deriving the property-value graphs will lead practitioners to a much better understanding of why, how and to what extent, people rate the importance of elements in a management system.

Finally, it is acknowledged that a criticism of the above work will be that it is too subjective, and that the relationships between element properties and human values will vary depending on the interests and other characteristics of experts and stakeholders. But these are existing problems that need to be much better dealt with in management and planning in general. Building on the framework we have outlined, further research may strengthen our understanding of these relationships and diminish, but never remove, their inherent subjectivity. Importantly, the process we have outlined explicitly documents how people view these relationships. This is far preferable to using element properties as a basis for setting management priorities and targets without any understanding of why these properties are important in the first place.

5. Conclusion

The above research was based on the proposition that linking natural elements to human values via element properties is a sound means of quantifying the capacity of elements to provide priority human values. We have demonstrated that this proposition is robust, and that the approach described above provides an important, novel and broadly applicable tool to quantify the relative contribution of nature to people's wellbeing, a critical gap in management processes identified by Mace (2014). Explicitly linking the properties of elements – such as species richness, size and charisma – to human values provides a firm basis for determining the utility of individual elements, both singly and collectively, which in turn provides the basis for establishing management priorities amongst elements. In combination with other planning tools, such as risk assessment, this then enables management actions to be systematically selected and prioritised.

Three key conclusions emerge from the presented work. First, element property-human value relationships can be quantified and used to better understand *why* elements are important and *how* they should be managed to maintain or improve their utility (i.e. on which element properties management should focus). Second, the approach facilitates communication and understanding among a diverse group of stakeholders and experts where views and motivations may differ. Third, the approach provides an important information platform from which to launch subsequent research, planning and management steps in the natural resource domain.

Acknowledgements

We would especially like to acknowledge and thank the stakeholder representatives, experts and departmental staff that provided their time, effort and expertise to ensure the success of the workshops and the post-workshop activities. The authors were funded by the Department of Parks and Wildlife (Western Australia) and by the UK EPSRC's Towards Data-Driven Environmental Policy Design EP/K012479/1, UK NERC's NE/M008401/1 and the RCUK's Horizon Digital Economy Research Hub grant EP/

G065802/1, EP/M02315X/1 grants. Support from the University of Western Australia is also acknowledged.

Appendix 1. Description of the priority human values for the Lake Bryde and Buntine-Marchagee case studies.

Value	Definition and examples
Knowledge-heritage	Biotic elements are widely used for scientific, heritage and educational purposes. For example, particular plants and animals with heritage importance; and maintaining a set of representative, undisturbed soils and their related biota so that we can better understand the changes brought about by various land uses. Other examples include the widespread use of bushland to research natural processes, and as an educational resource by schools.
Future options	*Lake Bryde*: The conservation of biotic elements provides for a range of future opportunities in any of the values described by Wallace et al. (2016). Most obvious is the genetic resource in native plants. Thus opportunity values are those values listed in Wallace et al. (2016) that are not currently realised. They will include maintaining the opportunity for: • Discovery of currently unknown values in our native biota • Retained opportunities to exploit currently known values at some time in the future • Future generations to make their own decisions concerning biotic elements values. *Buntine-Marchagee*: The catchments biotic diversity "provides a range of potential future opportunities. For example, the potential for future use of genetic resources and opportunities for water use and salt harvesting" (Department of Environment and Conservation, 2007).
Recreation	The importance of biotic elements for leisure activities is well known. Includes passive recreation (bird watching, nature photography) and more active recreation which may involve significant construction works (e.g., extensive walk trails). Research links recreation in natural environments to both physical and mental health. There are strong links between recreation and amenity (aesthetic) values.
Ecosystem service values	"Values that contribute to maintaining the catchment and downstream environment. Flood mitigation, nutrient stripping and salt storage are examples of important ecosystem services in the catchment, particularly in relation to managing altered hydrology. This value largely relates to vegetation biotic elements" (Department of Environment and Conservation, 2007).
Intrinsic-spiritual-philosophical contentment	"Biodiversity resources are a strong driver for biodiversity conservation at the State and local level. From the perspective of the catchment community, the local desire to maintain local biodiversity for the strong sense of place it provides and its contribution towards people's spiritual and physical wellbeing were identified as important" (Department of Environment and Conservation, 2007).

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