doi: 10.1111/j.1442-8903.2010.00513.x

BioPrEP – a regional, process-based approach for assessment of land with high conservation value for Bush Heritage Australia

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Summary A framework is presented for terrestrial conservation assessment that has been developed for Bush Heritage, an Australian non-profit organisation that manages land of outstanding conservation value through acquisition or working in partnership with other landowners. The framework is called Biodiversity Prediction using Ecological Processes and comprises seven conservation goals, with a set of candidate criteria and indicators for each goal. Particular emphasis is given to criteria that relate to habitat quality in addition to the more conventional focus on land quantity. The MCAS-S graphic user interface is used to help analyse the indicators and visualise the results in a transparent way that assists the decision-making process. The interface also allows indicators to be weighted differently, which among other things, allows analyses to reflect inter-regional differences in what represents high quality land. The framework was tested in a case study region (the Woodland region of south-eastern Australia), and the results reveal land that is potentially a priority for conservation investments. While the framework and case study results are indicative, and further analyses are required before they can be considered operational, the approach has potential application to other organisations in the private conservation sector.

Key words: *conservation land assessment, ecological processes, habitat quality, metabolic theory of ecology, private conservation.*

Introduction

Bush Heritage has the organisational mission of owning and managing (directly or in partnership) 1% of Australia by 2025 and in so doing conserve 'land, water and wildlife of high conservation value' (HCV). But, how can HCV be usefully defined to guide the organisation's investments? Here, we consider HCV in terms of habitat quality defined by measures of biological and ecological productivity at a land system scale (*sensu* Christian & Stewart 1953). Note that the term 'land' is used here in reference to whole terrestrial ecosystems, including their aquatic components.

Historically, protected areas have tended to be biased away from more productive land of high value for human production systems, especially agriculture, pastoralism and forestry (Pringle 1995; Pressey *et al.* 2002). While this bias in the protected areas network (PAN) is recognised, opportunities for its expansion on to more productive land are limited for a variety of reasons including land costs and availability (McDonald-Madden *et al.* 2008). Limited opportunities means prioritisation of resources to achieve the best possible conservation outcomes is important (Possingham *et al.* 2001). Private conservation organisations can play an important complementary role in addressing this gap given their non-government status, organisational flexibility and capacity to develop innovative land management partnerships.

Since the 1990s, the comprehensiveness, adequacy and representativeness criteria (CAR; Commonwealth of Australia 1997) have been used by the states, territories and the Commonwealth to underpin more systematic conservation planning (Bryan 2002; NRMMC 2004). Application of the CAR approach has involved a focus on target species, their habitat and ecosystems usually defined in terms of dominant vegetation types. However, despite long-standing recognition of its importance (Margules & Pressey 2000), measures of habitat quality and related ecological processes are not usually considered. Nonetheless, it is increasingly recognised that, along with the CAR criteria, consideration must also be given to ecosystem functions and the ecological processes that both generate and sustain biodiversity assets (Pressey *et al.* 2003; Soulé *et al.* 2004; Mackey 2007; Klein *et al.* 2009).

In response to the above issues, Bush Heritage has developed an approach to land assessment for conservation that endeavours to explicitly consider some key ecological processes that relate to habitat quality. The approach builds upon established conservation criteria, including the CAR criteria, but gives priority to identifying land with high habitat quality defined in terms of biological and ecological productivity at the land system scale. The framework is called Biodiversity

Prediction using Ecological Processes (BioPrEP), and comprises a set of seven biodiversity conservation goals, along with candidate criteria and indicators. The purpose of BioPrEP is to enable Bush Heritage to have a more systematic, transparent and scientifically based approach to its conservation investments, and to identify land that better meets its organisational mission and complements the existing national reserve system (NRS) (Commonwealth of Australia 2005).

This paper: (i) reviews ecological theory relevant to measuring habitat quality defined in terms of biological and ecological productivity at the landscape scale; (ii) details the main elements of the framework and the procedure developed for its application and then (iii) presents indicative analyses from one of the priority regions identified for Bush Heritage conservation investments.

Conceptual Framework

Quality *cf.* quantity

Systematic conservation planning has drawn substantially upon island biogeography theory (MacArthur & Wilson 1967). Diamond (1975) operationalised this theory by proposing some geometric principles for designing reserves that focus on 'size' and 'spatial configuration'; all other factors being equal, 'more is better'. From this perspective, the quantity and overall spatial configuration of land that is added to the PAN becomes the paramount consideration. 'Spatial configuration' refers to the geographical location of reserves in relation to each other. Let us call this Diamond-based approach the 'quantity principle'. It is problematic for Bush Heritage to base its land assessment approach on the quantity principle alone because its activities are built around a relatively small total area of land. The CAR criteria provide helpful additional considerations by focussing attention on the representation in PANs of species and ecological types. Furthermore, the 'adequacy' criterion opens the door for considering, among other things, measures related to habitat quality.

Ecological theory has developed in recent decades in a direction that helps inform consideration of how measures of habitat quality can be incorporated into the conservation assessment of land. Specifically, a body of ecological theory has emerged which explicitly accounts for the relationships between habitat productivity and various aspects of biodiversity such as species richness, functional diversity, population abundance and persistence. Of particular relevance are: (i) the metabolic theory of ecology (Brown *et al.* 2004; Rooney *et al.* 2006; McCann 2007); (ii) habitat source/sink theory (Pulliam 1988) and (iii) the dynamic habitat templet theory of Southwood (1988). These theories provide the basis for developing additional conservation criteria that complement those related more closely to the quantity principle.

Theoretical underpinnings of habitat quality

The metabolic theory of ecology (Brown *et al.* 2004) provides a cross scale synthesis of a number of theories related to species–energy relationships [species-area theory (Preston 1962); species-energy theory (Wright 1983); macro-ecology theory (Brown & Maurer 1989) and food web theory (Boudreau *et al.* 1991)]. At the heart of this theory is the concept of metabolic rate – the rate at which organisms take up, transform and expend energy and materials. Brown and colleagues have developed a quantitative theory for how metabolic rate varies with body size and temperature. Metabolic theory predicts how metabolic rate, by setting the rates of resource uptake from the environment, along with body size, influences resource allocation to survival, growth and reproduction. Energy fluxes and stores consequently control ecological processes at all levels of organisation from individuals to the biosphere. Resource availability (or habitat productivity) can be considered in terms of gross primary productivity (GPP) and the subsequent supply of vegetation-based habitat resources (food, shelter and nesting) (Berry & Mackey 2007; Berry *et al.* 2007).

The relevance to habitat quality of theories relating species metabolism to energy and resource availability can be appreciated when viewed in light of two additional concepts, namely: source/sink habitat theory (Pulliam 1988) and habitat templet theory (Southwood 1988). Source/sink theory is based on the proposition that for many species a large portion of their populations occurs in 'sink' habitat where reproduction is insufficient to balance mortality. Where populations persist in such habitats, it is because they are maintained by immigration from more productive 'source' habitat locations. Note that this is consistent with niche theory (Hutchinson 1958) where, within the envelope of permissible habitat conditions, there is an optimal subset for a species.

Habitat templet theory considers the ecological and evolutionary implications of space/time variability in the productivity of habitat resources and complements source/sink theory because it suggests that what constitutes a source habitat can vary from ecosystem to ecosystem and from species to species. Theoretically, a given potential habitat volume can be specified within the space defined by: (i) overall habitat productivity; (ii) the temporal stability of the habitat resources and (iii) the stress or most resource-poor conditions that species would encounter. The third axis was originally interpreted to reflect physiological stresses separate from trophic energy resources. However, here we consider it in terms of resource-poor conditions. Different 'habitat productivity regimes' can be identified within this three-dimensional volume, each best suited to assemblages of species with differing life history strategies (Mackey *et al.* 2008a).

Consistent with both the source/sink and habitat templet theories, Stafford-Smith and Morton (1990) identified in arid Australia two distinctive food chains that occupy the intrinsically high and low productivity habitat regimes occurring in these landscapes. The high productivity regimes are associated with sites where water and nutrients are more plentiful, and support a diverse and abundant herbivorous and granivorous mammalian fauna. In the low productivity regimes, rates of perennial plant growth are slower and a detritivore-based food chain dominates. In Australia's forest and woodland ecosystems, source habitats tend to correspond with landscape positions that have deep, well watered and nutrient-rich soils and substrates – most typically: lower hill slopes; valley bottom flats and alluvial flood plains.

In summary, there is now a strong theoretical basis for incorporating into systematic conservation planning goals and criteria that reflect habitat quality; along with consideration of the area, spatial configuration and representation of habitat and ecological types. A focus on habitat quality promotes a richer interpretation of a 'more is better' approach. However, what constitutes high quality habitat will vary between bioregions. Among other things, the ecological processes that generate and sustain habitat resources, together with the associated biotic-interactions, change depending on environmental conditions and the life history characteristics of the regional pool of available species. Therefore, rather than one generic set of criteria and indicators, different measures may be needed to assess habitat quality in different bioregions.

The BioPrEP land assessment framework

Bush Heritage has decided to focus on five priority regions (clusters of IBRA – Interim Biogeographic Regionalisation of Australia – bioregions; Thackway & Cresswell 1995) as determined by national biodiversity conservation priorities, the location of existing conservation investments (especially reserves) and the location of key partners (especially the corporate pastoral and indigenous sectors). The BioPrEP framework allows for operating sub-regionally in identifying and assessing priority landscapes and has three components: (i) an interpretation of the Bush Heritage mission statement; (ii) seven biodiversity conservation goals (Table 1) and (iii) for each goal, a set of candidate criteria and indicators (Table 2). Land that rates highly against the criteria will therefore be given priority consideration for conservation investments.

The choice of criteria and indicators relies on expert judgment, and will vary with the bioregional context (as noted above) and the availability of data. Given the absence of systematic inventories of biota and ecosystem process rates at representative sites, the inability to map key indicators across extensive landscapes, and the lack of experience in application of habitat quality-related conservation goals, deferring to professional judgement in the selection of criteria and indicators is unavoidable. Neither is the choice fixed, as new criteria and indicators will become available over time as ecological knowledge, new technologies and changing circumstances dictate. The principle of parsimony suggests that the smallest set of criteria and indicators possible be used; implying it is better to focus on high level, integrative indices for which data are

Table 1. Description of the seven goals that comprise the basis of the BioPrep framework

Goal	Description
1. Capture viable source areas	Across all of Australia's biomes, 'source areas' for threatened and declining species have been lost or are under-represented in the PAN (Pringle 1995; Pressey *et al.* 2002; Pringle *et al.* 2003). These are often 'run-on' sites that receive lateral water flow or ground water discharge and are more biological productive
2. Protect the areas with highest remaining functional integrity	The degree to which ecological function[1] has been degraded (e.g. through the loss of framework species (*sensu* Tongway *et al.* 1997), soil loss, or intrusion of weeds and feral animals), the greater the need for restoration/rehabilitation, along with the associated costs and risks of failure. Given their organisational capacities, Bush Heritage's conservation investments are more effectively directed to land that is in better condition and requires less ecological restoration
3. Improve the level of protection of the least protected ecological types	Because Bush Heritage aims to complement public and other private conservation efforts via a partnership business model, it is also appropriate for their investments to be focused on land systems that are currently poorly conserved through other efforts
4. Protect functionally viable populations of significant species or assemblages and their (biophysical) habitat	Application of this goal requires identifying land that has extant viable populations of significant species; as distinct from populations in degraded habitats that are highly disturbed and require extensive restoration investments or that are otherwise marginal or sub-optimal for the species. A 'significant' species or assemblage is defined here as those that are (1) formally listed as threatened under State or Commonwealth legislation, (2) considered functionally important, (3) endemic, (4) phylogenically novel or (5) otherwise recognised as important for cultural or economical reasons
5. Contribute to mitigating current and future threats to Australian biodiversity	Addressing this goal will give priority to land which is in good condition and not currently being degraded or under active threats, but where it is anticipated that future land use or environmental change will introduce threats to biodiversity. By being proactive, Bush Heritage can contribute to safeguarding, in a cost effective way, land systems likely to be vulnerable to future damage
6. Spread investments across bioregional gradients	There are at least two reasons to reflect regional-scale diversity in the investment strategy: (1) as a standard risk reduction strategy by investing in a range of areas that are likely to respond differently to the same meso-scale event and (2) to hedge the potential enormous impact of human-forced rapid climate change as it is currently impossible to predict with sufficient certainty future climate at a bioregional scale
7. Optimise spatial configuration of protected habitat	This goal provides for consideration of the quantity and area-based design principles of Diamond (1975) whereby, all other factors being equal, preference is given to the largest and most spatially contiguous extant habitat, and land that will add to, buffer, or link existing conservation areas

[1]Ecological function comprises two elements: (1) the ecosystem functions species perform such as seed and spore dispersal, pollination, regulation of prey species, increasing rates of biomass decomposition and nutrient turnover, nutrient conservation and micro-topography and (2) the condition of the stocks and flows of water, nutrients and energy that sustain ecosystem productivity and also buffer the ecosystem against the vagaries of climate and disturbance.

Table 2. Summary of the candidate criteria and indicators identified for each of the seven conservation goals

Conservation goal	Candidate criteria	Candidate indicators
1. Capture source areas	1.1. Locations that have the highest and most reliable levels of productivity for a given ecosystem type	Average, seasonal and inter-annual variability in gross primary productivity (GPP) of the vegetation cover for woody and herbaceous plants Landform unit defined by topographic attributes and substrate Fertile soils Rain Use Efficiency (RUE) index
2. Protect the areas with highest remaining functional integrity	2.1. Site Leakiness	Landscape Function Analysis
	2.2. Catchment Integrity	River Disturbance Index Nutrient Imbalance Index
	2.3. Integrity of Vegetation Cover	VAST classification of vegetation condition Degree of land clearing and fragmentation in a given land system
	2.4. Community Integrity	Compositional integrity Compositional nestedness Invasive plant importance indices Dominance of highly interactive feral and native animal species
3. Improve the level of protection of the least protected ecological types	3.1. Level of the ecological type's representation within existing PAN	Area of remnant relative to the original distribution of an ecological type Replication across the geographical range of an ecological type Irreplaceability Minimum area to maintain viability of ecosystem processes
4. Protect functionally viable populations of significant species or assemblages and their (biophysical) habitat	4.1. Viable populations of significant species assemblages and habitats	Known or predicted presence of species Assessment of population viability
5. Contribute to mitigating current and future threats to Australian biodiversity.	5.1. Locations not yet, but potentially subject to intensification or expansion of grazing or agriculture	Land use capability evaluation
	5.2 Fire, drought or climate change refugia	Long unburnt areas Permanent or semi-permanent mesic areas The distribution of phylogenetically ancient species The distribution of ecologically sensitive species
6. Spread investments across Bioregional gradients	6.1. Regional and subregional representation	Distribution with respect to IBRA region
7. Optimise size and spatial configuration of protected habitat	7.1. Spatial coherence of conservation habitat	Patch size (ha) Fragmentation statistics Adjacency to existing conservation land

widely available (Bailey *et al.* 2004; see Nix 1976, 1982; for Australian evidence). Further discussion on the selection of the criteria and indicators is presented in Mackey *et al.* (2008b,c) which are available on request.

Case Study

Methods

The Woodland region of south-eastern Australia (Fig. 1) was selected for the case study analyses to test the proposed framework and investigate issues concerning selection of candidate criteria and estimation of indicator values. The major considerations in the selection of criteria and indicators were: (i) the availability of data with which to calculate the indicators; (ii) the principle of parsimony such that the smallest set of criteria and indicators is used and (iii) Bush Heritage's investment decision-making process which uses the information generated by the BioPrEP framework. Application of an indicator requires that it can be measured on a landscape-wide basis, which means spatially distributed data values must be available. Despite the enhanced capacity that GIS (Geographic Information Systems), environmental modelling and remote sensing provide for spatial analysis, serious data gaps remain and this will likely remain the case for many decades yet. Therefore, many theoretically useful indicators will remain out of reach for conservation land assessment for some time. The principle of parsimony is readily justified simply in terms of efficiency, but there are also statistical reasons to consider the fewest variables possible.

Decision-support tool

To aid in these preliminary investigations into applying the BioPrEP framework, a transparent, easy-to-use graphical user interface called MCAS-S (Bureau of Rural Sciences 2007) has been adopted as a decision-support tool. MCAS-S (Multi-Criteria Analysis Shell for Spatial Decision Support) has the advantage of intuitively and easily enabling technically unskilled senior

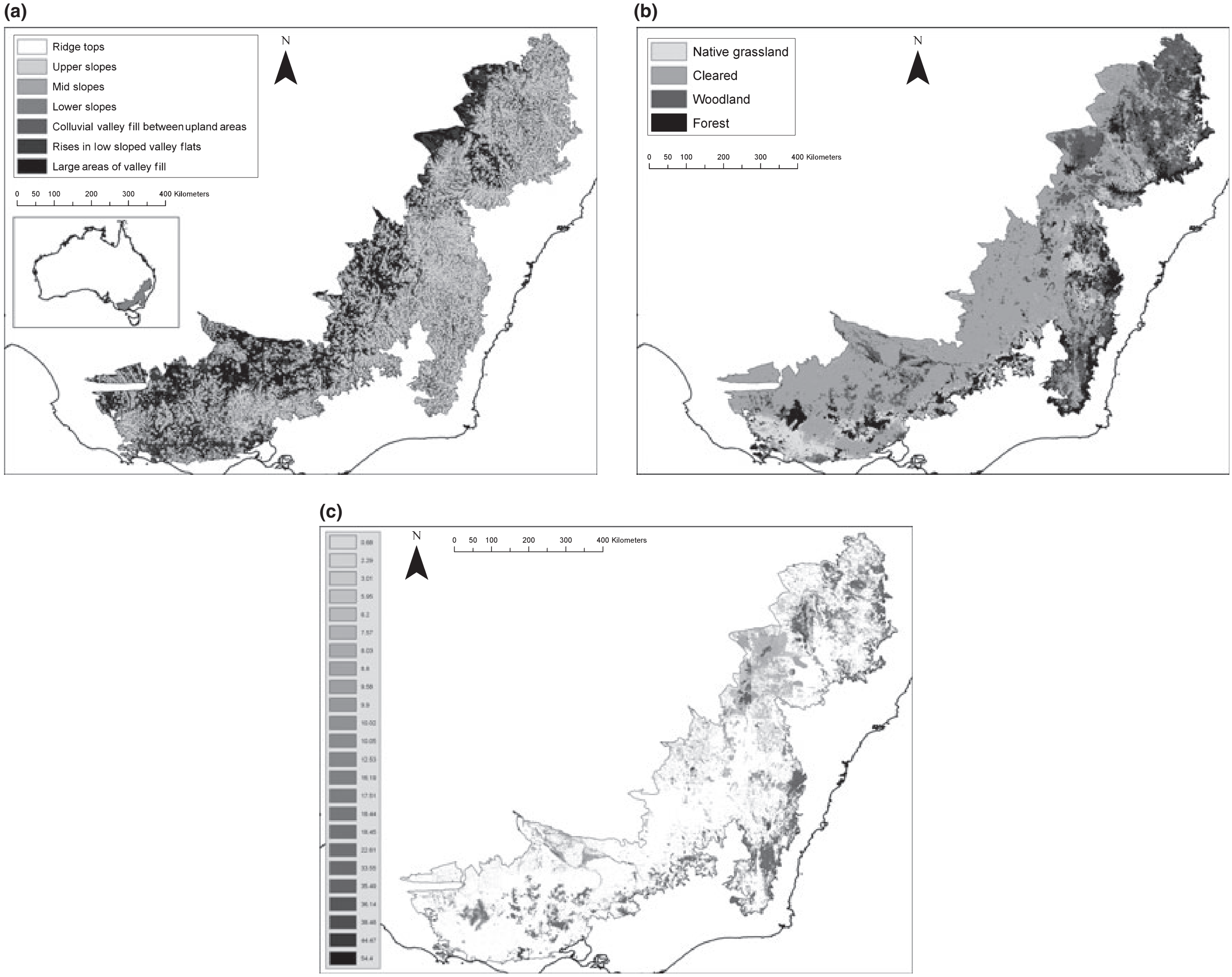

Figure 1. Input data layers for goals 1, 2 and 3 from ArcMAP into MCAS-S for the Woodlands region of south-eastern Australia respectively: (a) landform units with categories below lower slope position being indicators of source areas; (b) the distribution of high quality grassy woodland [defined by the level and seasonality of gross primary productivity (GPP)] and (c) percentage of the continental area of each National Vegetation Information System (NVIS) major vegetation groups found within the National Reserve System (NRS).

managers to interrogate land assessment data and explore conservation investment options. In this way, senior managers can gain more first hand experience with the BioPrEP framework and the implications of the information derived from its application for their investment decisions. MCAS-S assumes the user has already generated the necessary indicator values using a GIS such as ArcMAP (ESRI 2006).

Spatial unit of analysis

The Woodlands region encompasses largely temperate climatic regimes and is dominated by erosional land systems. This region is also primarily freehold/public land, and has experienced extensive native vegetation clearing and habitat fragmentation. Sub-catchments were selected as an ecologically appropriate and useful spatial unit of analysis (SUoA). However, the choice of the SUoA varies with bioregion. For example, the Gulf Plains bioregion in northern Queensland encompasses tropical climatic regimes, is dominated by depositional land systems and is primarily leasehold and Indigenous land, with native vegetation cover relatively intact. In that region, pastoral leases might be a more appropriate SUoA.

Selection of indicators

When applying BioPrEP in a given region, the user must first decide on the most appropriate criteria for each of the seven goals. Then, the most appropriate indicator must be selected for each chosen criterion. Here, we selected criteria and indicators based on: (i) the ecological characteristics of the bioregion and (ii) the continental availability of source data. The appropriateness of an indicator will vary depending on the region's particular ecological conditions and land use history. While we focused on continentally available data, future bioregional evaluations can and should draw upon finer resolution data where available.

The data layers used to calculate the indicator variables are listed in Table 3. Indicators were selected from the candidate set based on expert knowledge about both the indicators and the ecological conditions of the case study region. Table 3 also details sources for the data and the methods used to generate the spatially distributed estimates of the indicator values. The data layers were generated at a grid cell resolution of 250 m, commensurate with the scale of the available remotely sensed data and continental digital elevation model.

Analytical steps

The reporting function of MCAS-S provides the user with the ability to assess and rank spatial units according to a set of user-defined indicator values. We developed a sequential approach to assessing land in relation to the seven conservation goals (Table 4). Goal 6 (*Spread investments across bioregional gradients*) was given effect by separately analysing each of the bioregions found with the case study region. The indicators for goals 1 (*Source areas*), 2 (*Functional integrity*) and 3 (*Least protected*) were applied simultaneously using the MCAS-S three-way comparison function to map 'Areas of Interest' (AoI) from the spatial coincidence of the highest values for the three indicators (Fig. 1).

The reporting function in MCAS-S was then used to overlay the sub-catchment boundaries on the AoI and tabulate descriptive statistics and display maps which identified the spatial units with the highest rankings. Goal 7 (*Optimise spatial configuration of protected habitat*) was given effect by identifying spatial units that had the largest, contiguous extent of land with highest indicator values. Goals 4 (*Functionally viable populations*) and 5 (*Mitigate threats*) were not considered here due to time and resource constraints and their application remains a task for ongoing research.

The rationale behind this sequence (Table 4) came from considering how the information will be used in the decision-making process. Application of a criterion acts as a filter which removes land from

Table 3. Summary of the data layers used to calculate the indicator variables. For data sources and methods see footnotes and also Mackey *et al.* (2008a)

Indicator variable	Source data
Landform unit† (used for Goal 1: Capture Source Areas)	A Digital Elevation Model (DEM) Terrain attributes classification algorithm
Vegetation Productivity Response including: GPP of the non-growth season and % turgor of GPP. (used for – Goal 2: Protect the areas with highest remaining functional integrity)	MODIS monthly Normalized Difference Vegetation Index (NDVI) data GPP modelling algorithm Mean monthly radiation data
National Vegetation Information System‡ (NVIS) (used for – Goal 3: Improve the level of protection of the least protected ecological types)	Vegetation mapping from State agencies
CAPAD (Conservation and Protected Areas Database) protected areas in the National Reserve System (used for – Goal 3: Improve the level of protection of the least protected ecological types)	State and Commonwealth Land Administration and conservation authorities
IBRA§ (Used for Goal 6: Spread investments across bioregional gradients)	Land system, land use history, land cover data and vegetation classification data from state agencies (assembled by the Commonwealth)
Sub-catchment boundaries¶ (reporting framework in Woodlands region)	Digital terrain analysis calculated from a DEM

†See Summerell (2005) and Hutchinson *et al.* (2001) for DEM and terrain classification methods respectively. ‡See ESCAVI (2003). §See Thackway and Cresswell (1995). ¶Sub-catchment boundaries were provided by J. Stein (ANU, pers. comm.). For details see Stein (2006).

Table 4. Sequential steps used in MCAS-S to apply the goals, criteria and indicators in the Woodlands case study region

Step	Description	Woodlands
1	Apply criterion for goal 6 (Spread investments across bioregional gradients)	Nine IBRA bioregions
2	Apply criteria for goals 1 (Capture source areas), 2 (Protect the areas with highest remaining functional integrity) and 3 (Improve the level of protection of the least protected ecological types) using preferred indicators; ('Areas of Interest')	Landform unit as the indicator of criterion 1.1; High quality grassy woodland (defined by the level and seasonality of GPP) as the indicator of criterion 2.4; NVIS major vegetation groups as the target for indicator 3.1
3	Apply criterion for goal 7 (Optimise spatial configuration of protected habitat)	Sub-catchments as the spatial units of analysis
4	Apply criteria for goal 4 (Significant species and assemblages)	N/A
5	Apply criteria for goal 5 (Mitigating threats)	N/A

Goals 4 and 5 have not been included in this case study, but will be incorporated in the final framework. IBRA, Interim Biogeographic Regionalisation of Australia.

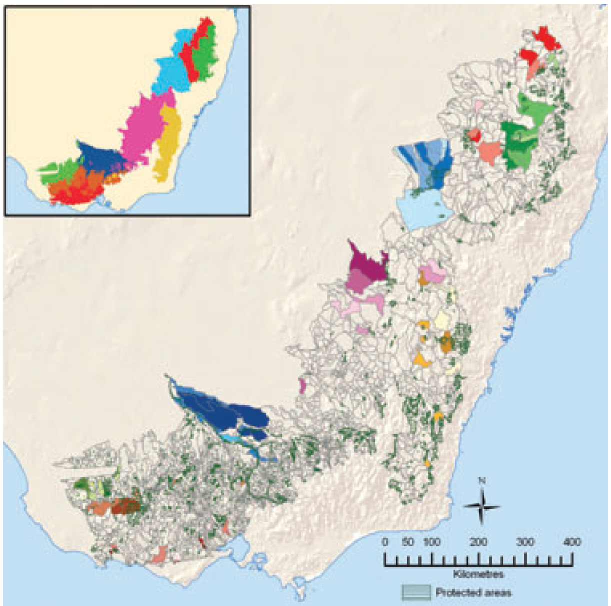

Figure 2. Location of the top 10 sub-catchments that posses the highest areas of interest (AoI) ranking stratified by IBRA Bioregion in the Woodlands region. Note each colour represents a different IBRA Bioregion with the darker shade indicating higher ranking.

subsequent consideration. It makes sense to apply goal 6 sequentially ahead of others as it reflects broader scale considerations. Goals 1, 2 and 3 are best considered jointly as there will often be trade-offs and it may not prove possible to find locations that have maximum values for all three (e.g. the source areas may not have the highest functional integrity).

Results

The key result was a ranking of spatial units that had the highest values for the selected indicators, presented in the form of tables and maps ranking the SUoA (i.e. sub-catchments) according to the calculated extent of AoI stratified by bioregion (Fig. 2).

The Woodlands region contained a total of 655 799 ha of AoI (1.8% of total area) spread across all nine bioregions (or part bioregions), with the majority (81.5%) in the Brigalow Belt South and Riverina (southern half) bioregions. With the exception of the Victorian Volcanic Plains (where there is only a relatively small amount of native forest and woodland), the balance was evenly shared between the remaining bioregions (Table 5).

This clustering of AoI was further evident at the sub-bioregion scale with 88.9% of the total AoI occurring in the highest ranked one or two sub-bioregions (representing 16 of the 55 sub-bioregions in the Woodlands region) (Table 5). These 16 sub-bioregions have been selected as candidates for future pro-active property assessment under Bush Heritage's draft Woodlands strategic plan.

Within the Woodlands region, sub-catchments on average had an area of about 20 000 ha. Sub-catchments as small as one grid cell, representing a very short stream link between tributary confluences, were not integrated with downstream catchment units. This gave a total of 4328 sub-catchments in the Woodlands region (Fig. 2). Although the majority of the AoI (94.2%) was contained in the 798 sub-catchments >10 000 ha (Fig. 3), sub-catchment size and total AoI per sub-catchment were independent variables indicating that the selection of AoI was based on criteria of habitat quality rather than land quantity. Figure 4 shows the lack of correlation between sub-catchment size and AoI per sub-catchment in the Woodlands region.

Discussion and Conclusions

Application of the BioPrEP framework will mean that investment decisions are informed by an explicit and systematic set of ecological considerations. Bush Heritage can use this framework as a risk

Table 5. Summary of results of AoI analysis for the Woodlands region by IBRA bioregions and sub-bioregions

IBRA bioregion	'Areas of Interest' (ha)	% Total AOI	Total bioregion area (ha)	% AOI/ bioregion	Sub-bioregions with AOI majority	% AOI in top sub-bioregions
Brigalow Belt South	374 598	57.1	5 264 581	7.1	Pilliga Outwash; Pilliga	87.1
Riverina (southern half)	159 977	24.4	3 824 136	4.2	Murray Sands; Victorian Riverina	100.0
NSW South Western Slopes	24 764	3.8	8 757 351	0.3	Lower Slopes; Upper Slopes	100.0
Nandewar	21 240	3.2	2 703 362	0.8	Peel, Nandewar	98.2
Murray Darling Depression	20 505	3.1	2 282 494	0.9	Wimmera	99.7
New England Tablelands	18 241	2.8	3 001 065	0.6	Eastern Nandewars; Moredun Volcanics	36.1
Victorian Midlands	16 772	2.6	3 478 745	0.5	Dundas Tablelands; Goldfields	78.5
South-eastern Highlands	15 806	2.4	4 572 614	0.3	Crookwell; Monaro	43.4
Victorian Volcanic Plain	3896	0.6	2 351 711	0.2	Victorian Volcanic Plain	100.0
	655 799	100.0	36 236 059	1.8		88.9

AoI, area of interest; IBRA, Interim Biogeographic Regionalisation of Australia.

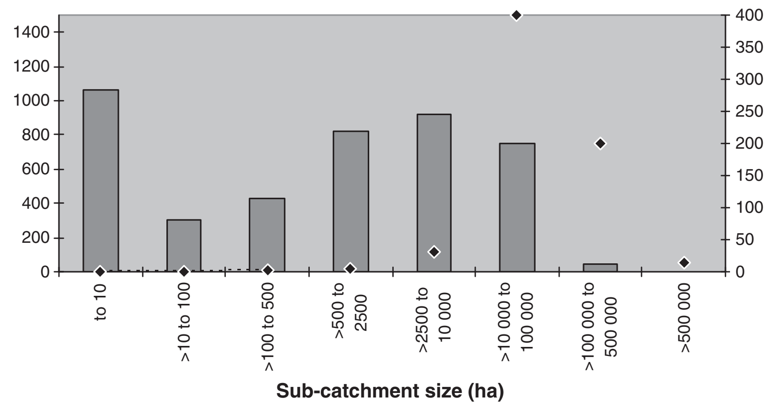

Figure 3. Distribution of the areas of interest (AoI) within the 4328 sub-catchments in the Woodlands region by size of sub-catchment. The bars indicate the number of spatial units of analysis (SUoA) within each class of sub-catchment size, and the diamonds indicate the extent of the AoI (thousands of ha) within each class of sub-catchment.

management tool to maximise the chance that investments proposals are likely to contribute to its mission before significant investment is made. The framework creates a context within which to demonstrate rigour and transparency around the property selection process and helps contribute to the scientific basis of Bush Heritage's operations. Application of the BioPrEP framework should also give Bush Heritage supporters and investors more confidence in what has been achieved to date in the absence of such a tool and what is aimed for in the future.

Because sub-catchments were the SUoA, and the properties here are orders of magnitude smaller and largely freehold, it is possible only to identify which sub-catchments are likely to support larger properties with more AoI. Whilst these rankings help contextualise individual leases and sub-catchments in terms of priority for conservation investment, they cannot and should not dictate the final decision. Ultimately, information to inform a particular land acquisition must be based on consideration of other factors and information including: (i) property availability; (ii) price and (iii) variables that affect long-term management costs such as physical infrastructure, isolation and degree of degradation. Implementation of the BioPrEP framework will therefore include a field component that complements and validates the computer-based assessments (e.g. Purdie *et al.* 1986). Also, there may never be spatially distributed source data available to apply particular indicators on a landscape-wide basis. However, if considered of sufficient importance, it may be possible to assess them at a property-level through site visits and focused surveys. Regarding further development of goal 5 (*Mitigate threats*), the work by Pressey *et al.* (2000) in NSW, that identified agricultural land suitability as a surrogate for threat of disruption, warrants further consideration as an indicator.

Practically, final decisions about conservation investments reflect time-dependent social and economic considerations as much as biophysical factors. Alternative scenarios need to be considered, where social and economic criteria are explicitly traded off with the conservation goals in each particular instance, to identify efficient and effective outcomes for a particular financial investment. However, before sophisticated, optimisation-based planning approaches are pursued, more research and development is needed into both: (i) the selection, application and interpretation of ecologically appropriate and parsimonious sets of criteria and indicators and (ii) how these can be integrated into a more comprehensive decision-support framework. A range of computer-based decision-support tools are now available to assist decision makers in systematic conservation planning, for example, the Marxan family of software (Possingham *et al.* 2000). It is recommended that organisations such as Bush Heritage work towards utilising such planning tools. However, this will require, amongst other things, the development of targets for the criteria presented here (Table 2), and we recommend that organisations first gain experience in integrating the BioPrEP framework into their current decision-making processes.

The BioPrEP framework is designed to be flexible so that it can accommodate Australia's landscape diversity and varying regional characteristics, the availability of new information, and changing land use and environmental conditions, including climate change impacts. And while the seven goals remain constant, there are choices to be made in terms of the most appropriate set of criteria and indicators. These choices require informed judgment that are best made for each region by

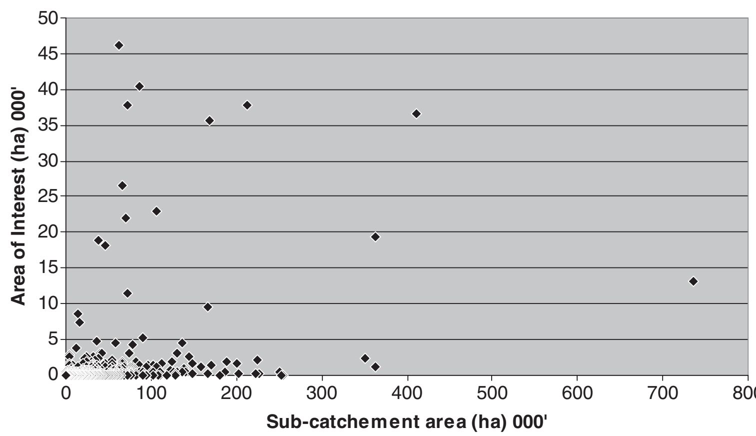

Figure 4. Relationship between sub-catchment size and areas of interest (AoI) per sub-catchment in the Woodlands region.

panels of experts with knowledge of local ecological characteristics and land use conditions. Once parameterised, MCAS-S has proven to be a useful and appropriate decision-support tool for Bush Heritage in arriving at conservation investment decisions. While the framework and case study results are indicative, and further analyses are required before they can be considered operational, the approach has potential application to other organisations in the private conservation sector.

Acknowledgements

The remotely sensed data used for the GPP-based indicators were produced from research funded by ARC Linkage grant LP0455163. We are grateful to the following individuals and organisation for their generous assistance with this project: Dr Rob Lesslie for facilitating access to MCAS-S and for assisting in the fine tuning of MCAS-S functions to the needs of our project; Dr Janet Stein and Prof. Michael Hutchinson for providing access to the water sub-catchment boundaries and the digital elevation model; Gregory Summerell from NSW Department of Primary Industry for providing the code to calculate landform units and technical assistance in operationalising the code on ANU computers; Richard MacNeill from Bush Heritage for sharing his GIS expertise and for his assistance in obtaining key spatial data sets and Dr Jim Radford also from Bush Heritage for comments on the manuscript.

References

Bailey S. A., Horner-Devine M. C., Luck G. *et al.* (2004) Primary productivity and species richness: relationships among functional guilds, residency groups and vagility classes at multiple spatial scales. *Ecography* **27**, 207–217.

Berry S. and Mackey B. (2007) Habitat productivity, connectivity and bird conservation in Australia. *The State of Australia's Birds 2007 Supplement to Wingspan* **17**, 26–28.

Berry S., Mackey B. and Brown T. (2007) Potential applications of remotely sensed vegetation greenness to habitat analysis and the conservation of dispersive fauna. *Pacific Conservation Biology* **13**, 120–127.

Boudreau P. R., Dickie L. M. and Kerr S. R. (1991) Body-size spectra of production and biomass as system-level indicators of ecological dynamics. *Journal of Theoretical Biology* **152**, 329–339.

Brown J. H. and Maurer B. A. (1989) Macroecology: the division of food and space among species on continents. *Science* **241**, 1145–1150.

Brown J. H., Gillooly J. F., Allen A. P., Savage V. M. and West G. B. (2004) Towards a metabolic theory of ecology. *Ecology* **85**, 1771–1789.

Bryan B. A. (2002) Reserve selection for nature conservation in South Australia: past, present and future. *Australian Geographical Studies* **40**, 196–209.

Bureau of Rural Sciences (2007) *Multi-Criteria Analysis Shell for Spatial Decision Support*. Version 2 User Guide and CD. [Cited 21 February 2010.] Available from URL: http://adl.brs.gov.au/mcass/index.html.

Christian C. S. and Stewart G. A. (1953) *General Report on Survey of Katherine-Darwin Region, 1946*. Land Research Series 1. Commonwealth Scientific and Industrial Research Organisation, Canberra.

Commonwealth of Australia (1997) *Nationally Agreed Criteria for the Establishment of a Comprehensive, Adequate and Representative Reserve System for Forests in Australia*. A Report by the Joint ANZECC/MCFFA National Forest Policy Statement Implementation Sub-committee. Australian and New Zealand Environment and Conservation Council. ISBN: 0 642 26670 0. [Cited 21 February 2010.] Available from URL: http://www.daff.gov.au/__data/assets/pdf_file/0003/49493/nat_nac.pdf.

Commonwealth of Australia (2005) *Direction for the National Reserve System – A Partnership Approach*. Commonwealth of Australia, Canberra.

Diamond J. M. (1975) The island dilemma: lessons of modern biogeographic studies for the design of natural reserves. *Biological Conservation* **7**, 129–146.

ESCAVI (2003) *Australian Vegetation Attribute Manual, Version 6.0. Executive Steering Committee for Australian Vegetation Information*. Department of Environment and Heritage, Canberra.

ESRI (2006) *What is ArcGIS 9.2?* Printed in the United States of America. 126 pp. [Cited 21 February 2010.] Available from URL: http://www.esri.com.

Hutchinson G. E. (1958) Concluding remarks. *Cold Spring Harbor Symposia on Quantitative Biology* **22**, 415–427.

Hutchinson M. F., Stein J. A. and Stein J. (2001) *Upgrade of the 9 Second Australian Digital Elevation Model*. A Joint Project of CRES and AUSLIG. [Cited 21 February 2010.] Available from URL: http://fennerschool.anu.edu.au/publications/software/dem/index.php#6.

Klein C., Wilson K., Watts M. *et al.* (2009) Incorporating ecological and evolutionary processes into continental scale conservation planning. *Ecological Applications* **19**, 206–217.

MacArthur R. H. and Wilson E. O. (1967) *The Theory of Island Biogeography*. Princeton University Press, Princeton, NJ.

Mackey B. (2007) Climate change, connectivity and biodiversity conservation; lessons from Australia. In: *Protected Areas: Buffering Nature Against Climate Change. A Symposium on Building and Managing the Terrestrial Protected Area System to Best Enable Australia's Biodiversity to Adapt to Climate Change* (eds M. Taylor and P. Figgis) pp. 90–96. WWF Australia and the IUCN World Protected Areas Commission. [Cited 21 February 2010.] Available from URL: http://www.wwf.org.au/publications/cc-report/.

Mackey B., Berry S. and Brown T. (2008a) Reconciling approaches to biogeographic regionalization: a systematic and generic framework examined with a case study of the Australian continent. *Journal of Biogeography* **35**, 213–229.

Mackey B., Gilmore S., Pringle H., Foreman P., van Bommel L. and Haseler M. (2008b) *BioPrEP – an Approach to Conservation Land Assessment for Bush Heritage Australia, Part I. Conceptual Framework*. Unpublished Report, Bush Heritage Australia, Melbourne.

Mackey B., van Bommel L., Gilmore S., Foreman P. and Berry S. (2008c) *BioPrEP – an Approach to Conservation Land Assessment for Bush Heritage Australia, Part II. Case Study Results*. Unpublished Report, Bush Heritage Australia, Melbourne.

Margules C. R. and Pressey R. L. (2000) Systematic conservation planning. *Nature* **405**, 243–253.

McCann K. (2007) Protecting biostructure. *Nature* **446**, 29.

McDonald-Madden E., Bode M., Game E. T., Grantham H. and Possingham H. P. (2008) The need for speed: informed land acquisitions for conservation in a dynamic property market. *Ecology Letters* **11**, 1169–1177.

Nix H. A. (1976) *Environmental Control of Breeding, Post-Breeding Dispersal and Migration of Birds in the Australian Region*. 16th International Ornithological Congress, Australian Academy of Science, Canberra.

Nix H. A. (1982) Environmental determinants of biogeography and evolution in *Terra Australis*. In: *Evolution of the Flora and Fauna of Arid Australia* (eds W. R. Barker and P. J. M. Greenslade) pp. 47–66. Peacock Publishing, Frewville, South Australia.

NRMMC (2004) *Directions for the National Reserve System – A Partnership Approach*. Prepared by the National Reserve System Taskforce of the NRM Ministerial Council's Land, Water and Biodiversity Committee. [Cited 21 February 2010.] Available from URL: http://www.environment.gov.au/parks/publications/nrs/directions.html.

Possingham H. P., Ball I. R. and Andelman S. (2000) Mathematical methods for identifying representative reserve networks. In: *Quantitative Methods for Conservation Biology* (eds S. Ferson and M. Burgman) pp. 291–306. Springer, New York.

Possingham H. P., Andelman S. J., Noon B. R., Trombulak S. and Pulliam H. R. (2001) Making smart conservation decisions. In: *Research Priorities for Conservation Biology* (eds G. Orians and M. Soule. Covelo) pp. 225–244. Island Press, Washington.

Pressey R. L., Hager T. C., Ryan K. M. *et al.* (2000) Using abiotic data for conservation assessments over extensive regions: quantitative methods applied across New South Wales, Australia. *Biological Conservation* **96**, 55–82.

Pressey R. L., Whish G. L., Barrett T. W. and Watts M. E. (2002) Effectiveness of protected areas in north-eastern New South Wales: recent trends in six measures. *Biological Conservation* **106**, 57–69.

Pressey R. L., Cowling R. M. and Rouget M. (2003) Formulating conservation targets for biodiversity pattern and process in the Cape Floristic Region, South Africa. *Biological Conservation* **112**, 99–127.

Preston F. W. (1962) The canonical distribution of commonness and rarity: Part I. *Ecology* **43**, 185–215.

Pringle H. J. R. (1995) Pastoralism, nature conservation and ecological sustainability in Western Australia's southern shrubland rangelands. *International Journal of Sustainable Development and World Ecology* **2**, 26–44.

Pringle H. J. R., Tinley K. L., Brandis T., Hopkins A. J. M., Lewis M. and Taylor L. (2003) The Gascoyne-Murchison Strategy: a people-centred approach to conservation in arid Australia. In: *Rangelands in the New Millenium. Proceedings of the Seventh International Rangelands Congress* (eds N. Allsop, A. R. Palmer, S. J. Milton, K. P. Kirkman, G. I. H. Kerley, C. R. Hurt and C. J. Brown) pp. 213–223. Document Transformation Technologies, Durban, South Africa.

Pulliam H. R. (1988) Sources, sinks, and population regulation. *The American Naturalist* **132**, 652–661.

Purdie R. W., Blick R. and Bolton M. P. (1986) Selection of a conservation reserve network in the Mulga biogeographic region of south-western Queensland. Australia. *Biological Conservation* **38**, 369–384.

Rooney N., McCann K., Geliner G. and Moore J. C. (2006) Structural asymmetry and the stability of diverse food webs. *Nature* **442**, 265–269.

Soulé M. E., Mackey B. G., Recher H. F. *et al.* (2004) The role of connectivity in Australian conservation. *Pacific Conservation Biology* **10**, 266–279.

Southwood T. R. E. (1988) Tactics, strategies and templets. *Oikos* **52**, 3–18.

Stafford-Smith D. M. and Morton S. R. (1990) A framework for the ecology of arid Australia. *Journal of Arid Environment* **18**, 255–278.

Stein J. L. (2006) *A Continental Landscape Framework for River and Stream Conservation*. PhD thesis, Centre for Resource and Environmental Studies, Australian National University, Canberra.

Summerell G. K. (2005) Predicting channel incision of low relief landforms. In: *MODSIM Annual Conference* (eds A. Zerger and R. M. Argent) pp. 1465–1470. Modelling and Simulation Society of Australia and New Zealand Inc, Melbourne.

Thackway R. and Cresswell I. D. (1995) *An Interim Biogeographic Regionalisation for Australia: A Framework for Setting Priorities in the National Reserves System Cooperative Program, Version 4.0*. Australian Nature Conservation Agency, Canberra.

Tongway D., Hindley N., Ludwig J., Kearns A. and Barnett G. (1997) Early indicators of ecosystem rehabilitation on selected mine sites. *Proceedings of the 22nd Annual Minerals Council of Australia Environmental Workshop*, Adelaide, 12–17 October 1997 pp. 494–505. Minerals Council of Australia, Canberra.

Wright D. H. (1983) Species-energy theory – an extension of species-area theory. *Oikos* **41**, 496–506.

