




A multi-criterion approach for prioritizing areas in urban ecosystems for active restoration following invasive plant control

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Abstract

Resources for biodiversity conservation and invasive plant management are limited, and restoring invaded vegetation is labour-intensive and expensive. Managers must prioritize their actions to achieve their goals efficiently and effectively. They must distinguish between areas that require only the removal of invasive alien plants (“passive restoration”) from those that require additional restoration measures (“active restoration”). This study used a multi-criterion approach (Analytical Hierarchy Process) to develop a framework for identifying areas that require active restoration, and then to prioritize these areas for active restoration. The South African city of Cape Town is used as a test case to illustrate the utility of the framework. Framework criteria selected in determining the need for active restoration included: dominant alien species invading the area, density of invasion, duration of invasion, indigenous vegetation cover, adjacent land use, level of disturbance, size of the area, aspect, soil texture, soil depth and erodibility, slope and vegetation type. In deciding which areas to prioritize for active restoration, factors such as vegetation conservation status, selection in a regional conservation plan and connectivity function were assessed. Importance in ecosystem functioning (by providing a diversity of habitats and soil conservation) and the delivery of ecosystem service benefits were also considered. The resulting framework provides an objective tool for prioritizing sites for active restoration.

Keywords Active restoration · Analytical Hierarchy Process · Biological invasions · Ecosystem services · Invasive alien plants · Urban ecosystems · Urban invasions

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Introduction

Many invasive alien plants (IAPs) have negative impacts on biodiversity and ecosystem functioning (Mack et al. 2000). Managing IAPs and restoring invaded ecosystems can potentially lead to an increase in the delivery of ecosystem goods and services and a recovery of native biodiversity (Tongway and Ludwig 2012). Resources for alien plant management and restoration are, however, limited (Crossman and Bryan 2006) and managers must prioritize actions to achieve their goals efficiently and effectively (Aronson et al. 2007; Rew et al. 2007; Skurski 2012; Van Wilgen et al. 2012a). Restoration actions are considered unsuccessful and a waste of resources when re-invasion of the same species or other weedy species (“secondary invasions”) occurs (Hilderbrand et al. 2005; Holmes et al. 2008; Le Maitre et al. 2011). It is therefore important to distinguish between areas that require only the control or removal of IAPs (“passive restoration”) and those that require additional restoration measures (“active restoration”). Active restoration measures can include re-introducing key

species by seed or propagated material after clearing IAPs, and in extreme cases soil stabilization, landscaping and engineering (Allen 1995; Holmes and Richardson 1999; Holmes et al. 2000). Protocols for distinguishing when to apply either of the restoration types are lacking.

Numerous studies have sought to prioritize areas and species for IAP management, but most of these fail to consider the role of restoration actions and the prioritization of these actions (Holmes and Richardson 1999; Van Wilgen et al. 2007; Roura-Pascual et al. 2009; Forsyth et al. 2011). Where restoration has been prioritized or included in IAP management studies, it has generally focused on a single factor or a limited group of factors (Esler et al. 2008). For example economic factors that determine restoration priorities are sometimes included, but overall restoration goals are not established (Beechie et al. 2008; Tongway and Ludwig 2012; Richardson and Gaertner 2013). Capturing the relative importance of biodiversity or ecosystem services should be included as benefits to be gained through restoration, as this may justify expensive active restoration interventions (Gaertner et al. 2012; Crookes et al. 2013).

Especially in urban ecosystems, managing invasive alien species is complex and often controversial (Van Wilgen 2012; Dickie et al. 2013; Gaertner et al. 2016, 2017). The challenge in prioritizing areas for active restoration is to weigh up factors relating to biodiversity conservation against those relating to other diverse benefits to society. A decision-support method is required that satisfies specific needs. This methodology should: (1) incorporate different views; (2) be transparent, flexible and adjustable; (3) incorporate a spatial approach; and (4) use data from different sources and scales. Multi-Criteria Analysis (MCA), and more specifically Analytical Hierarchical Process—AHP (Saaty 1990), satisfies all four criteria and is explored in detail below. The AHP gives a problem a hierarchical structure and identifies criteria for achieving a pre-determined goal. Criteria are compared in a pair-wise fashion in developing numerical weights, and are ranked according to their relative importance in achieving the established goal.

Incorporate different views

The process starts by defining the problem and agreeing on a goal, and then divides the problem into different levels of criteria and sub-criteria that are required to meet the goal, thereby constructing a framework (Arroyo et al. 2015). The AHP can effectively incorporate different stakeholder views and support a large number of alternative options which can be compared during decision making (Malczewski 1999; Herath 2004; Forsyth et al. 2011; Orsi et al. 2011).

Transparent, flexible and adjustable

As new data become available and understanding improves, rankings and weightings can be adjusted and criteria can be added or removed. Following this approach can make the prioritization process defensible in that the method of deriving priorities is participatory and transparent (Forsyth 2013). It has also been found to be a flexible way of prioritizing areas for invasive species management (Nielsen and Fei 2015).

Incorporate a spatial approach

Decisions concerning restoration and conservation actions are spatially oriented (Rouget et al. 2003), and Le Maitre et al. (2011) propose using spatial mapping for prioritizing areas for restoration, which can in turn be used in motivating funding allocations. This makes the identification of restoration priorities more credible (Rouget et al. 2003). An MCA can be used in conjunction with a geographic information system (GIS) and georeferenced data (Cadenasso and Pickett 2008; Orsi and Geneletti 2010). Indicators for criteria or sub-criteria can be mapped and combined using GIS; these can then be presented as a prioritization map. The use of GIS in restoration planning is more efficient than manual mapping and can combine data at a landscape scale, using large data sets from many sources (Lee et al. 2002).

Use data from different sources and scales

Outcomes of IAPs management are usually not available and managers need to rely on personal knowledge and experience to make decisions (Parker-Allie et al. 2004). There have been recent efforts to collate restoration data, such as for forest restoration (Crouzeilles et al. 2016) but the results and outcomes are of limited value (Suding 2011). Often restoration data are focussed on specific ecosystems or previous land-uses (Trujillo-Miranda et al. 2018). An MCA approach was chosen to ensure that personal expertise on restoration that is not reflected in publication and reports is included in decision making (Parker-Allie et al. 2004).

This study aimed to inform management practices by determining how best to prioritize active restoration efforts following removal of IAPs, based on the experience and knowledge of experts in the fields of restoration and invasion ecology. We developed a tool for: (1) identifying areas requiring active restoration; and (2) prioritizing such areas for funding. Frameworks were developed using the AHP and their utility is illustrated in a case study in city of Cape Town, South Africa. In elucidating the methodology for Cape Town, we provide the foundation for a decision-making tool for prioritizing areas for active restoration which should be generally applicable to urban centres in different geographic regions and across a range of spatial scales.

Methods

Study area

The city of Cape Town (hereafter “Cape Town”) at the southwestern tip of Africa is located in a global biodiversity hotspot, the Cape Floristic Region (CFR). Many locally endemic and threatened species and six locally endemic vegetation types occur within the city borders (Holmes et al. 2012a). Fynbos and renosterveld shrubland are the dominant vegetation types in CFR; both vegetation types are fire-adapted. It is vital to maintain fire regimes for healthy ecological functioning and IAP management (Van Wilgen et al. 2012b), but fire poses a risk to people and infrastructure in an urban environment which makes prescribed burning more challenging than in rural areas.

Cape Town is home to varied landscapes and cultures, and is a major economic centre with a rapidly increasing human population. Urban expansion, agriculture and IAPs are key threats to the loss of habitat and native biodiversity (Rebello et al. 2011), and have negative impacts on a variety of ecosystem services, including water supply, soil retention and recreation. Cape Town has a long history of species introductions and management of invasive alien species, but despite their negative impacts, some species provide benefits to people, e.g. pines are planted for timber and wattles are used as firewood (Potgieter et al. 2018). Conflicts relating to their management can arise due to the different stakeholder interests; this greatly complicates invasive species management (Gaertner et al. 2016, 2017). The city’s fine-scale systematic spatial conservation plan (Biodiversity Network; Holmes et al. 2012a, 2012b) strives to meet local and national biodiversity conservation targets. The city is committed to conserving, managing and restoring priority areas (Local Biodiversity Strategy and Action Plan 2016–2026, Strategic Objective 2).

Approach to developing frameworks

Facilitated stakeholder workshops were held with the goal of developing two frameworks: (1) for the identification of sites requiring active restoration; and (2) for prioritizing those sites for restoration. Stakeholders were identified and selected from various conservation departments that research, plan and implement restoration.

To meet these goals, firstly ecological factors known to influence restoration potential for terrestrial sites were selected and secondly, factors considered important when prioritizing and selecting areas for active restoration were identified (Fig. 1).

Stakeholders selected the factors that would achieve the above-mentioned goal according to the AHP method. This involved the selection of three different levels of factors in

the hierarchy. The first level is comprised of broad factors, termed criteria. The second level (sub-criteria) are more detailed sub-divisions of the broader criteria. The third level is comprised of “categories”, which are the measurable units of the sub-criteria. Categories were decided upon at the stakeholder workshop, after agreeing on the data to be used to evaluate criteria and sub-criteria. As an example, ‘Density of Alien Invasion’, a sub-criteria of the criterion ‘History of Invasion’, is divided into density categories of <25%, 25–75% and >75% cover.

These overall framework criteria, sub-criteria and categories were then compared to each other using a pairwise approach. This involved a facilitated deliberation exercise whereby weightings for each of the criteria and sub-criteria were established to denote their relative importance. Super Decisions Software (version 2.4.0) was used to facilitate pairwise comparisons by ranking and assigning weightings. Inconsistent judgements were identified using a consistency ratio (measured with a consistency index-CI) given by the software: where the consistency ratio exceeded the generally accepted 0.1 limit, weightings were re-evaluated by stakeholders and adjusted during the workshop until the ratio was below 0.1.

Each workshop was attended by 11 participants and five participants attended both workshops. Stakeholders were chosen to represent restoration ecology researchers that inform practice and policy and managers from various conservation departments that plan and implement restoration. Most stakeholders had experience with the social implications of IAP control and restoration, either through their research or planning and implementation of IAP control. All stakeholders were involved in setting the goal, developing the overall frameworks, and selecting criteria and sub-criteria, and all stakeholders did pairwise comparisons for the framework’s criteria, sub-criteria and their categories. Experts that could not attend the workshops were asked to compare and rank criteria, relating to landscape and soil (aspect, nutrient retention ability, soil depth, slope and soil erodibility) and ecosystem services. Two researchers in the field of restoration ecology (focussing on soil aspects) and a soil scientist ranked soil criteria. A researcher working on invasion ecology and an ecosystem services expert and a top-level manager in the City of Cape Town’s Invasive Species Unit ranked ecosystem services. Final weightings developed by stakeholders were assigned to spatial data layers identified to represent criteria and sub-criteria.

For the prioritization framework, ecosystem service provision and social considerations were also deliberated and are discussed below.

Ecosystem service provision

Urban areas can be characterized by conflicting land use, more so in cases where urban areas overlap with regions of

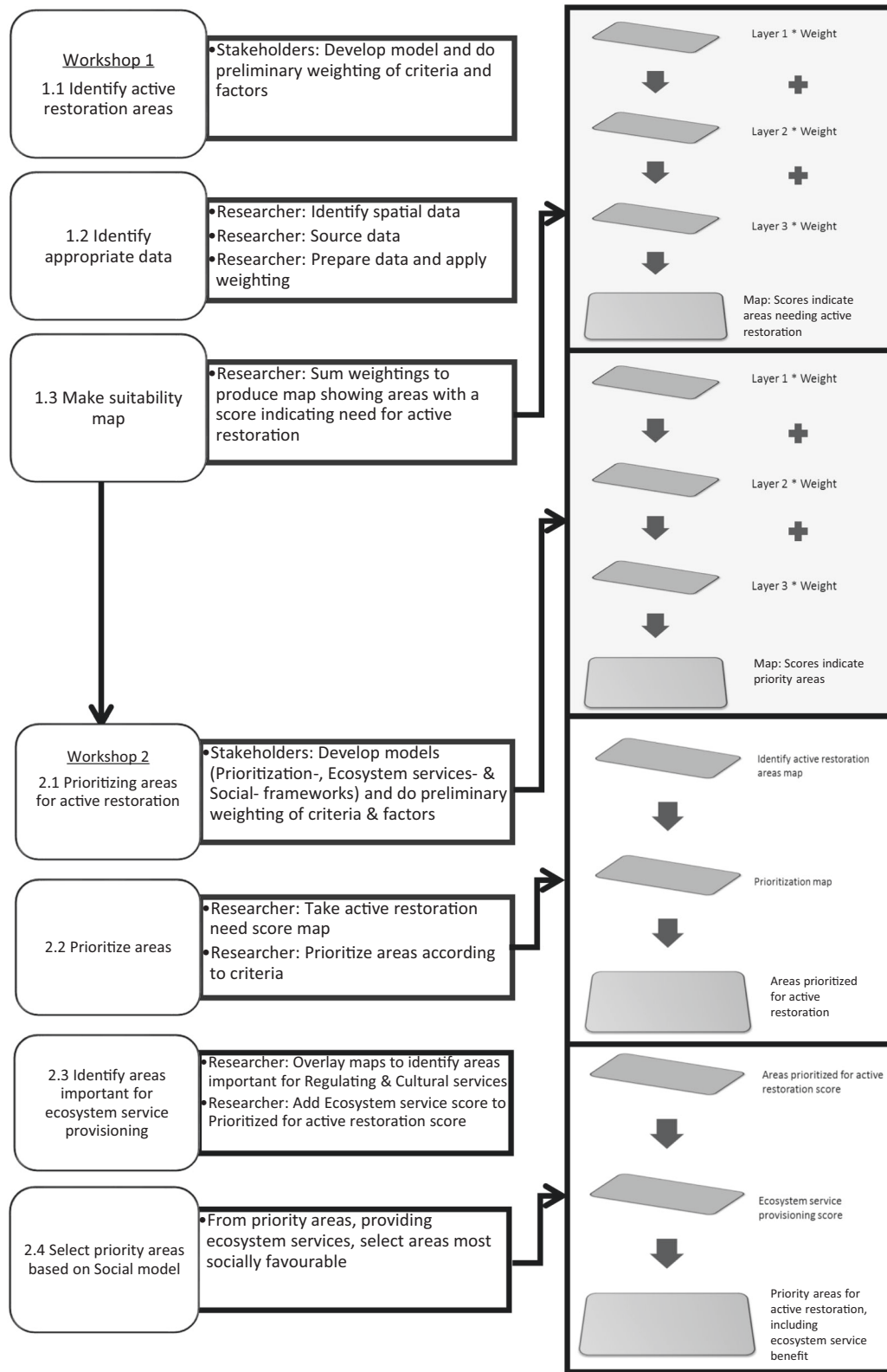


Fig. 1 Logical work sequence illustrating the framework development process, from the input of two workshops and spatial analysis to produce an overall product for prioritizing areas for active restoration as outcome. These steps follow on after the key stakeholders have

been identified. Each step in the process is explained by indicating the roles of the stakeholders and researcher developing the framework. Spatial analysis is conceptually illustrated in the right hand column

high biodiversity (O'Farrell et al. 2012). Natural vegetation is important for conserving biodiversity but also supports ecosystem functions and their associated ecosystem services (O'Farrell et al. 2012). When vegetation can be restored to the benefit of society, projects are more likely to gain general support and to be funded (Newman 2008). An important assumption of this framework is that natural, non-invaded areas provide the best sites for optimal ecosystem service (Cadenasso and Pickett 2008). It is recognized that invaded and other non-natural remnants can also provide a level of ecosystem service provision (O'Farrell et al. 2012), but our framework did not include this in the analysis.

Ecosystem services were used as indicators in deciding the gross benefit that a restored, functioning ecosystem could potentially provide. This in turn can be used to prioritize areas for active restoration, where areas providing a bundle of ecosystem services can receive preference for restoration above an area providing a single service or lower service output. Data on areas that are important for various ecosystem service provisioning were obtained from O'Farrell et al. (2012). These data layers were developed using a rapid ecosystem service assessment for Cape Town to spatially identify which ecosystems and land uses are important for provisioning, regulatory and cultural ecosystem services.

Social considerations

It was recognized that certain social aspects would be relevant in restoration prioritization for an urban setting. Social criteria and sub-criteria were discussed, decided upon and weighed through pairwise comparison by stakeholders.

Applying frameworks in Cape Town

The decision-making framework was applied to spatial data using Analysis Tools in ArcMap (ESRI, version 10.2). Each criterion and sub-criterion was assigned to the spatial data layer that best represents the criterion, e.g. vegetation type is represented by the map of remnants of indigenous vegetation within the boundaries of Cape Town and the percentage of the vegetation type remaining by the National Ecosystem Threat Status map (Van Niekerk 2012). Using this spatial approach, one can identify small patches with relatively homogeneous characteristics. It should be noted that some of the currently available data are at a coarse, national resolution.

Planning units were created by dividing city areas into small sub-catchments as described by Maherry et al. (2013). Although the size of these sub-catchments varied, we restricted the minimum size to 25 m² which is considered a practical unit for restoration planning, i.e. to establish small nodes of restored vegetation to act as seed sources (P.M. Holmes, personal observation). Sub-catchments were intersected with the indigenous vegetation remnant map to

create polygons with relatively homogenous slopes that were small enough to be appropriate for on-the-ground planning of active restoration. Sub-criteria consisted of continuous or categorical data. Continuous data were multiplied by the weighting of the sub-criteria, while categories had to be further compared pairwise to assign relative weightings. Each category was then multiplied by the category's relative weighting.

'Need for active restoration' framework

The aim of this framework is to create a map that represents the likelihood that a unit requires active restoration. The attribute value of each criterion and sub-criterion was added to the attribute table of the corresponding planning units' map. All spatial layers were combined by summing the weightings together and the resulting score ranged between 0 and 1. Higher values indicated a greater need for active restoration whereas lower values meant that passive restoration may still be possible or that very little active restoration is required. This resulted in a map indicating areas possibly requiring active restoration in Cape Town.

'Prioritizing' areas for active restoration

The aim of this framework was to create a map illustrating the priority of units for active restoration. In a first step the same units as were used in the 'Need for active restoration' framework were used to combine spatial layers of the 'Prioritizing' framework by adding the attribute value of each criterion and sub-criterion (as identified in the second workshop) to the corresponding planning unit's attribute table. 'Prioritizing' criteria and sub-criteria weightings were summed; values indicate the relative priority score of a unit for restoration (range: 0–1, with 1 representing the highest priority).

Two priority maps were produced. Firstly, a 'Prioritizing' map, considering only the 'Prioritizing' framework criteria and sub-criteria (ranging between 0 and 1) was derived, the second map involved combining (by summing) the 'Prioritizing' scores with the 'Need for active restoration' scores (ranging between 0 and 1). The sum of the two scores denotes the 'Active Restoration Priority' (range between 0 and 2).

Ecosystem service provision

'Ecosystem service provision' values were determined by assigning values for each ecosystem service to the planning units. 'Ecosystem service provision' criteria values were assigned their weightings and summed to provide a score indicating how important an area is in terms of providing a gross benefit of 'Ecosystem service provision' (ranging between 0 and 1). The 'Ecosystem service provision' score

Table 1 Framework of the model used to identify areas needing active restoration for Cape Town, South Africa

Criteria and sub-criteria	Relative weighting (%)	
	Level-1 criteria	Level-2 sub-criteria
Invasive alien species	27	
Invasion history	25	
Density of invasion		55
Duration of invasion/no. fire cycles		45
Remaining indigenous vegetation	20	
Landscape	11	
Soil depth		37
Erodibility		27
Aspect		24
Nutrient retention		12
Vegetation type	10	
Local influences	7	
Disturbance		78
Patch size		15
Adjacent land use		7

Criteria and sub-criteria identified at a stakeholder workshop are listed. Level-1 criteria are shown in bold; the relative weightings (%) indicate the importance of these criteria compared to other Level-1 criteria. Level-2 sub-criteria are sub-categories of Level-1 criteria; their relative weightings (%) indicate their relative importance compared to each other

was then summed with the ‘Need for active restoration’ and the ‘Prioritizing’ to restore these areas to indicate the ‘Overall priority’.

Sensitivity analysis

To test the sensitivity of the results, the results from the ‘Overall priority’ model were ranked from greatest need (largest score) to least need (smallest score) and the top two units were selected. Next, the score of each model was ranked from largest to smallest and again, the two top units were selected.

The values of the two highest weighted variables (one each from Level-1 criteria and Level-2 sub-criteria) in each model were changed (‘Need for active restoration’, ‘Ecosystem service provision’ score and ‘Prioritizing’) in turn (ranging from 0 to 1). After each change in the weight, that rank of the unit was noted. The result gave an absolute value for a variables’ change in weighting that will change the rank of units.

Goals and selected ranking criteria

‘Need for active restoration’ framework

The agreed goal was: *To identify characteristics of invaded natural sites that require active restoration to meet ecosystem biodiversity and/or ecosystem functioning targets.* Six criteria and nine sub-criteria were identified to achieve

this goal. Weightings for the ‘Need for active restoration’ framework are presented in Table 1. Table S1 in Supplementary Material gives weightings of criteria, sub-criteria and their categories that were compared and weighed by experts. All criteria and sub-criteria are presented and discussed in detail in Supplementary Appendix 1.

‘Prioritizing’ areas for active restoration

The goal for prioritizing areas for active restoration was: *To improve resilience of the Biodiversity Network (ecologically and socially) through an appropriate level of restoration (i.e. restore ecosystem structure and functioning, composition and biodiversity, ecosystem services or revegetate with indigenous species).* The criteria and sub-criteria that were identified to achieve the above-mentioned goal are presented in Table 2, along with their relative weightings as decided upon by stakeholders. Table S2 in Supplementary Material gives the weightings of sub-criteria and categories that were compared and weighed by experts.

Ecosystem service provision

Ecosystem services and their weightings are listed in Table 3. Regulating services include critical infiltration areas, flood mitigation zones, coastal protection, groundwater recharge areas, groundwater yield and groundwater quality (O’Farrell et al. 2012). Cultural services considered to be most important were heritage, tourism and education.

Social criteria

Social criteria considered important in prioritizing remnants for active restoration (Table 4) include: the legal status of remnants (i.e. whether they are legally declared as a protected area) and the ability to maintain the gains (i.e. the attitude of the community).

Results

Applying the approach to Cape Town

The major woody invasive plants in the (semi)natural vegetation within the boundaries of Cape Town are species of *Acacia* (wattles), *Eucalyptus* (gums), *Hakea* (hakeas) and *Pinus* (pines) (Richardson et al. 1996; Gaertner et al. 2016). Distribution of main woody invasive species is shown in Fig. 2. Gums were given the highest relative weighting in terms of impacting ecosystems and reducing natural vegetation recovery (65%), although these species cover a small area (c. 3%) and are usually restricted to riparian areas (Holmes et al. 2008; Van Wilgen 2012). Wattles carry the

Table 2 Framework of the model to prioritize areas for active restoration in Cape Town, South Africa

Criteria and sub-criteria	Relative weighting (%)		
	Level-1 criteria	Level-2 sub-criteria	Level-3 sub-criteria
Conservation status	48		
% of vegetation type remaining		59	
CBA rank		41	
Ecosystem functioning	38		
Habitat diversity		64	
Erosion		36	
Slope			65
Soil erodibility			35
Physical attributes of connectivity	14		
Width		36	
Adjacent habitat the same		34	
Distance to uninvaded habitat		30	

Criteria and sub-criteria identified at an expert workshop are listed. Level-1 criteria are shown in bold; the relative weightings (%) indicate the importance of these criteria compared to other Level-1 criteria. Level-2 sub-criteria are sub-categories of Level-1 criteria; their relative weightings (%) indicate their relative importance compared to each other. Level-3 sub-criteria are sub-categories of Level-2 sub-criteria and their relative weightings (%) indicate their relative importance at that level

second largest weighting in terms of species effects on ecosystem recovery (28%) and also cover the largest part of invaded areas in the Biodiversity Network (31% of the area). Pines and hakeas cover about 10% of invaded area and had the lowest relative weighting (7%) among woody invasive species. Areas containing mixtures of species were given the weighting of the species with the highest score. Areas invaded by gums and wattles will have the highest need for active restoration according to the framework because their post-invasion areas are more vulnerable to poor vegetation recovery.

Wattle invasions cover the largest area and impact greatly on vegetation recovery but these areas are less important in providing ecosystem services; they were hence given the lowest average ‘Ecosystem service provision’ score, followed by areas invaded by hakeas, pines and gums. Restoring areas invaded by gum, hakea and pine will give the highest benefits in terms of gross ecosystem-service provisions as these species generally invade mountainous and some riparian habitats which are associated with the delivery of many ecosystem services in Cape Town (especially water-related ecosystem services). Even though invasions of gum, hakea and pine (and pines in particular) threaten water-related ecosystem services, they also provide positive ecosystem services in some cases, such as where gums provide nectar for commercial honey bees and

Table 3 Results of ‘Ecosystem service provision’ framework and their relative weightings (%) as scored by experts during a workshop, which were used to develop a framework for prioritizing areas in need of active restoration in Cape Town, South Africa

Criteria and sub-criteria	Relative weighting (%)		
	Level-1 criteria	Level-2 sub-criteria	Level-3 sub-criteria
Regulating	55		
Critical infiltration		34	
Flood mitigation		34	
Coastal protection		23	
Groundwater		10	
Groundwater quality			50
Groundwater recharge			28
Groundwater yield			22
Cultural	45		
Education		65	
Culture		35	
Tourism			60
Heritage			40

Level-1 criteria are in bold with the relative weighting (%) indicating their relative importance compared to other Level-1 criteria. Level-2 sub-criteria are sub-categories of Level-1 criteria and their relative weightings (%) indicate their relative importance compared to each other. Level-3 sub-criteria are sub-categories of Level-2 sub-criteria and their relative weightings (%) indicate their relative importance at that level

Table 4 Social criteria and sub-criteria that are important to consider when selecting areas to actively restore

Criteria and sub-criteria	Relative weighting (%)	
	Level-1 criteria	Level-2 sub-criteria
Legal status	83	
Protected: in perpetuity		72
Protected: not in perpetuity		17
Conservation area		11
Ability to maintain gain	17	
Community attitude		63
Current level of community engagement		37

The Social framework and their relative weightings (%) as scored by experts during a workshop, which were used to develop a framework for prioritizing areas in need of active restoration in Cape Town, South Africa. Level-1 criteria are in bold with the relative weighting (%) indicating its importance compared to other Level 1 criteria. Level-2 sub-criteria are sub-categories of Level 1 and their relative weightings (%) indicate their relative importance compared to each other in Level-2 criteria

provide shade. However, by law all listed invasive trees need to be cleared from waterways where they are most likely to have negative impacts on water resources (Allsopp and Cherry 2004; DEA 2015).

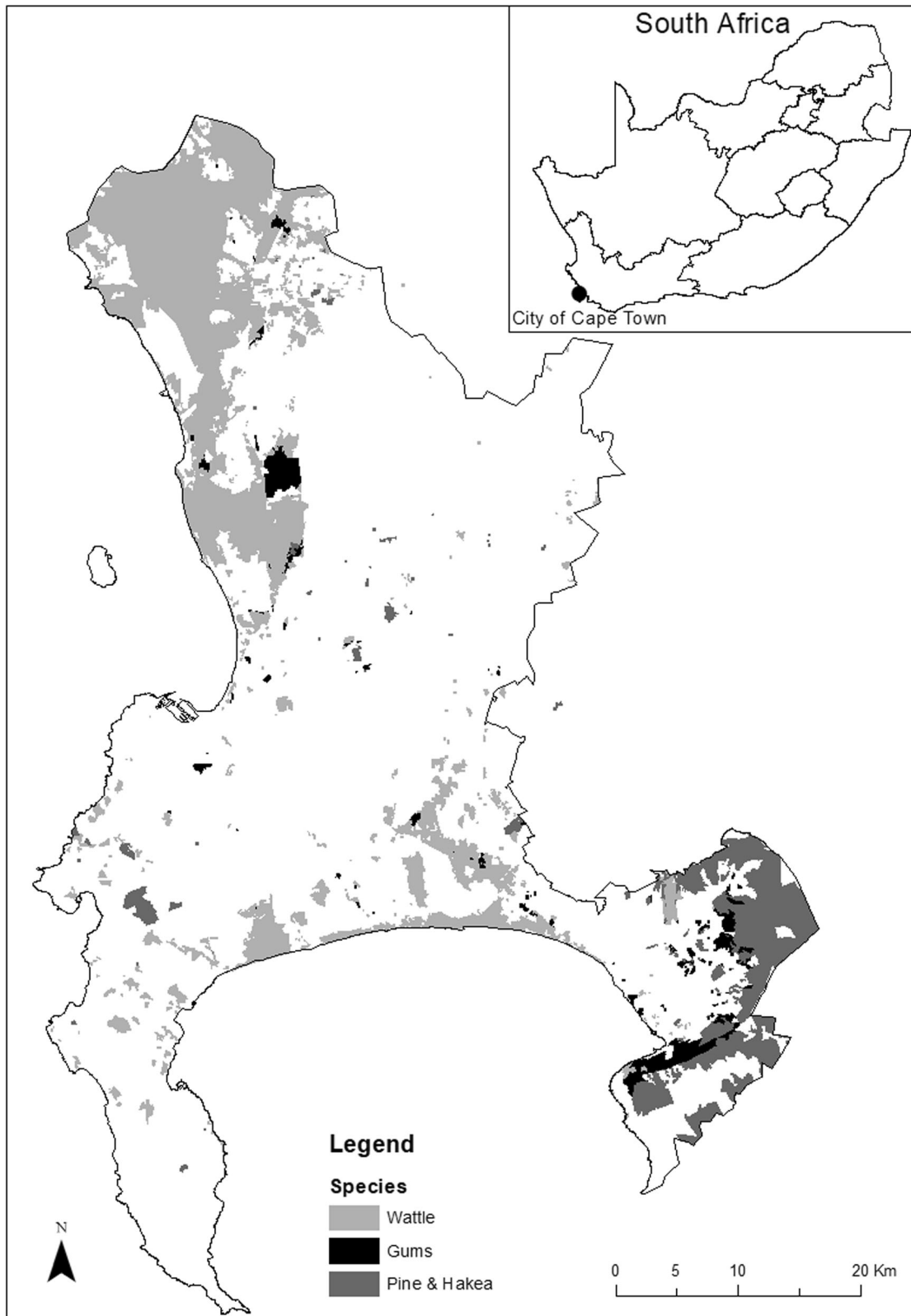


Fig. 2 Distribution of dominant invasive species in the Biodiversity Network. Biodiversity network represents areas of remaining vegetation within the City of Cape Town

Density of invasion varied between 0% (uninvaded) and 97% invasion. Densely invaded areas are few according to current data. Uninvaded areas (<25% cover and 10% weight), occupy about 72% of the Biodiversity Network area, and invaded areas occupy 28%, of which 4% is densely invaded and the remainder cover between 25 and 75%. The 4% portion will mostly be targeted for active restoration and priority for restoration will depend on ecological 'Prioritizing' criteria.

The Biodiversity Network habitat condition map was used as a proxy for the remaining native vegetation. Most remaining vegetation is classified as being high (11% weighting) to medium (23% weighting) quality habitat, indicating good sources of propagules for vegetation recovery once invasive alien species have been cleared. Most poor habitat quality sites (66% weighting) are those isolated within an urban matrix, not formally protected or managed. Poor quality sites will need the most active restoration (Figs. 3 and 4).

Lowland fynbos is typically found on deep sands, whereas mountainous areas have steep slopes and shallower soils: the former was allocated a higher priority for active restoration. The steep and shallow soils do, however, not coincide with the most erodible soil, based on their *k*-values. The most erodible soils are soils in the lower lying areas, having less need for active restoration based on soil depth and slope criteria.

Vegetation remnants with the highest 'Ecosystem service provision' scores (Fig. 5) are situated around the mountainous areas of the Cape Peninsula and to the far east of the city boundaries within critical infiltration areas, flood mitigation zones and close to the city's heritage sites (criteria with highest weightings). When looking at the distribution of scores across the 'Ecosystem service provision' map (Fig. 5), 'Prioritizing' (Fig. 6), and 'Overall priority' map (Fig. 7), they show the same pattern of highest scores being focussed in the periphery of the city where large conservation areas are situated.

Sensitivity analysis

'Need for active restoration' framework

Variables with the highest weightings were 'Species' and 'Density of invasion'. Changing the weightings of 'Density of invasion' or the weightings of 'Species' did not change the rank of units. This indicates a robust framework in terms of criteria having the biggest influence in the model.

'Prioritizing' framework

The highest weighted variables for 'Prioritizing' areas for active restoration were the 'Conservation status' and

'Percentage of remaining vegetation'. Changing 'Conservation status' and 'Percentage of remaining vegetation' did not change the rank of the units. This means the model is robust, even when considering Level-1 criteria.

'Ecosystem service provision' framework

The highest weighted variables for the 'Ecosystem service provisioning' framework were 'Education' and 'Regulating services'. Changing 'Education' did not change the rank of the units. 'Regulating services' had to be increased by 5% to change the rank of units (ranks changed from when weightings were >0.6). At weightings <0.6 ranks did not change. The 'Ecosystem service provision' model is therefore robust at Level-2 sub-criteria, but the Level-1 criteria will induce bigger changes in model results when weightings are changed, as illustrated with changing 'Regulating service's' weighting.

Discussion

Utility of the presented approach

This study introduces a novel application of AHP into restoration prioritization by applying it to areas degraded by IAP.

Active restoration is much more resource intensive than passive restoration. In some cases, however, expensive active restoration interventions may be justified to increase native biodiversity, ecosystem services or social benefits. The framework developed here can identify areas where such interventions should be considered. Another application of the framework could be to identify and restore areas with the lowest need for active restoration first, and concurrently restoring those high priority areas needing active restoration, justified by their conservation status and/or ecosystem service provisioning. The AHP method adds the scores of multiple ecosystem services, thus motivating the allocation of resources for restoration not for a single service, but with the aim of selecting areas that provide either a 'bundle' of services or one or two important services (Bennett and Balvanera 2007; Trabucchi et al. 2012). The method provides a holistic, multi-benefit approach whereby restoration of remnants is prioritized based on ecosystem services provision, conservation status and habitat condition.

The frameworks developed in this study are intended to be used as tools for invasive species-control planners and biodiversity managers enabling them to improve restoration outcomes by identifying and prioritizing areas for active restoration. By applying these frameworks, limited IAP control resources can be more efficiently allocated. The

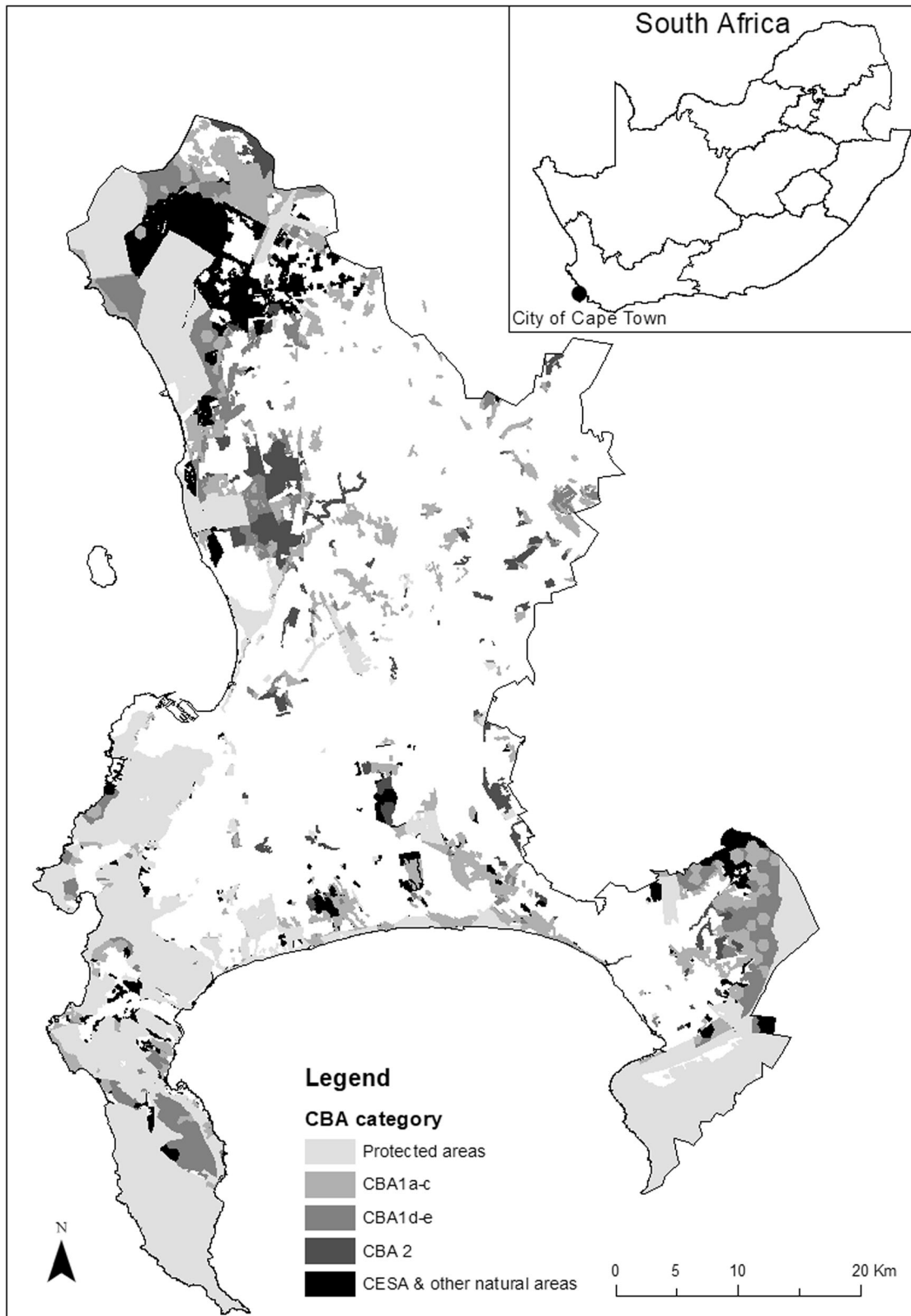


Fig. 3 CBA category of vegetation remnants, taken from the Biodiversity Network. Biodiversity Network represent areas of remaining vegetation within City of Cape Town

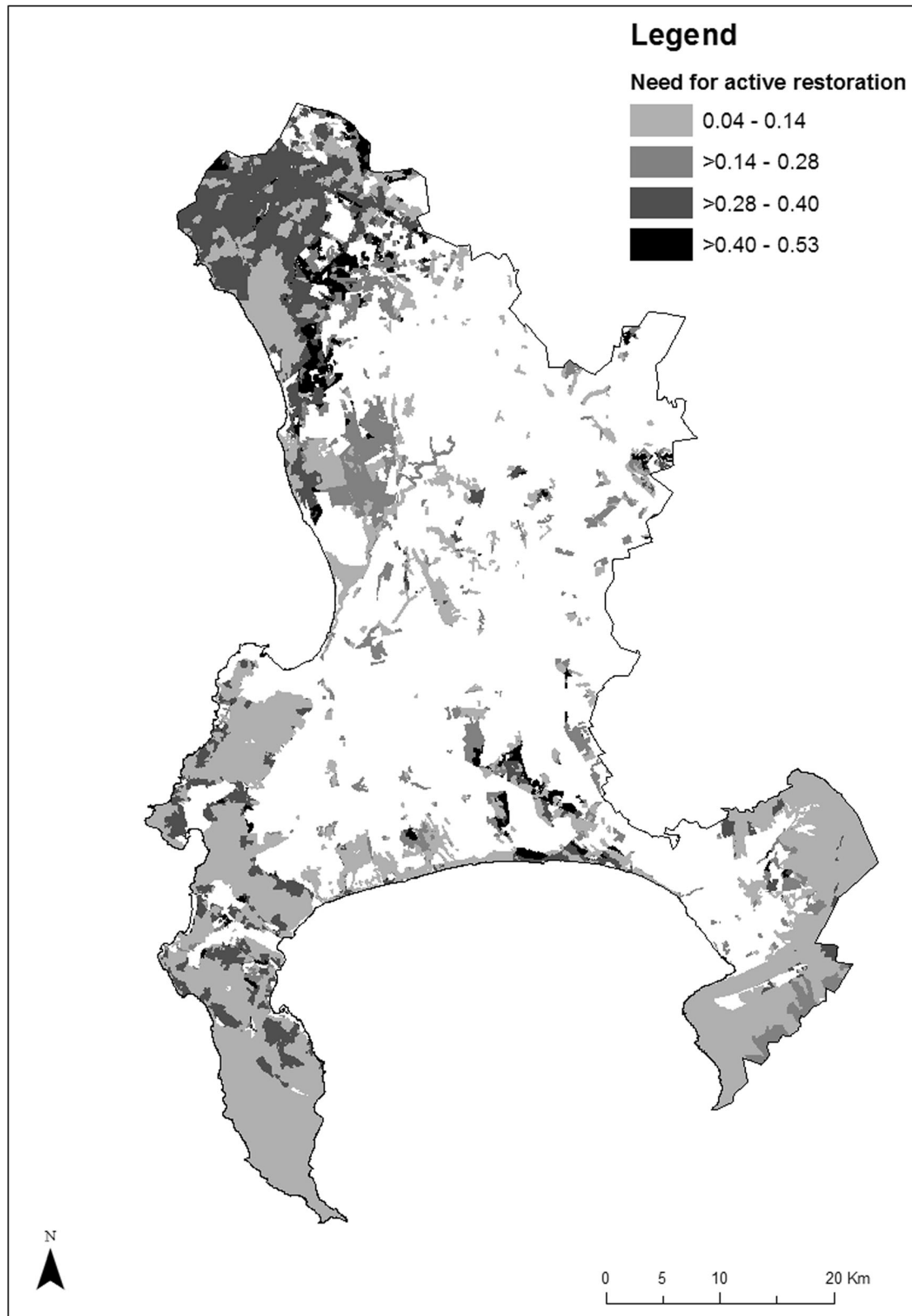


Fig. 4 'Need for active restoration' score in Cape Town, based on criteria and sub-criteria, combined by their relative weightings. Higher values indicate a greater need for active restoration

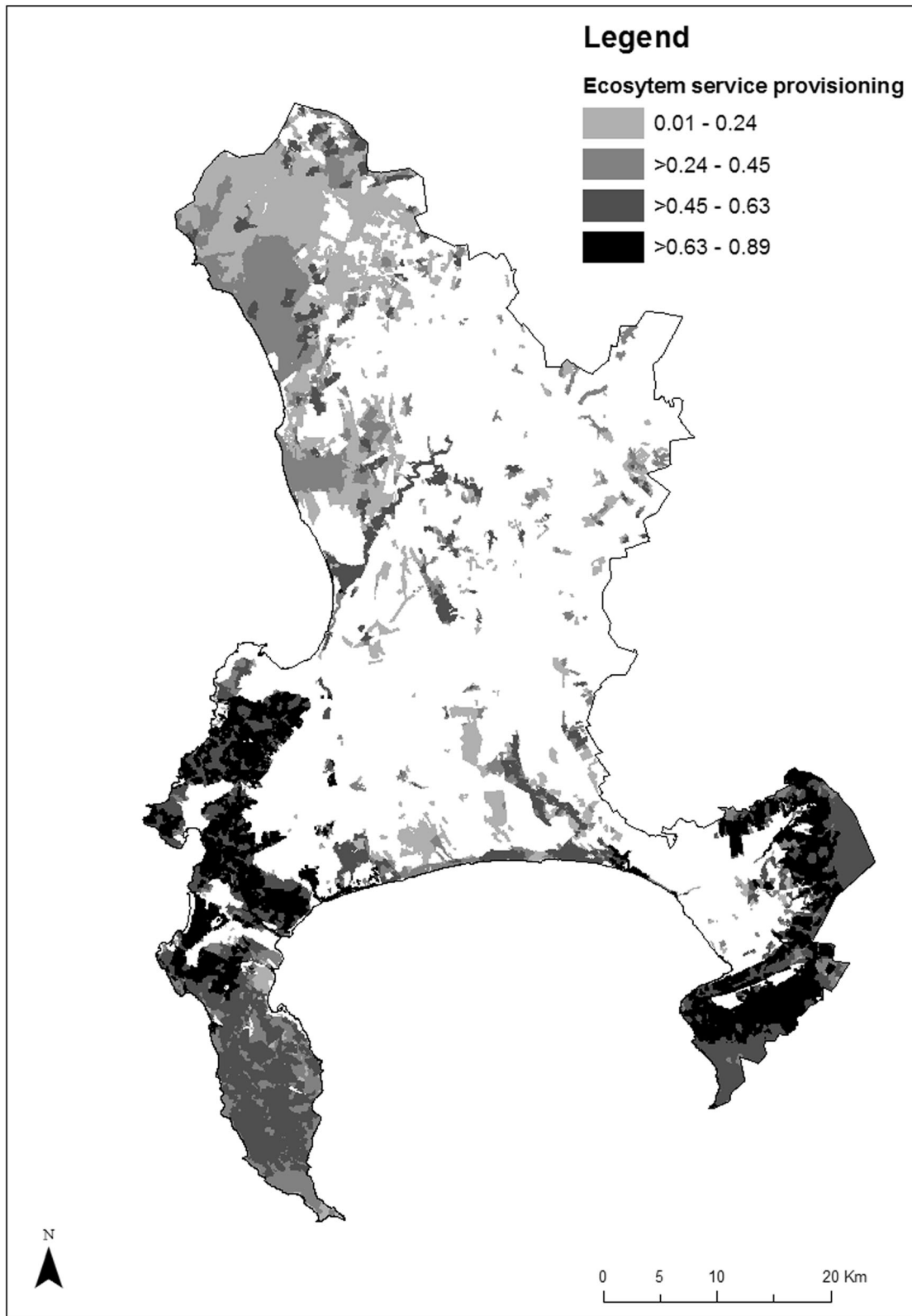


Fig. 5 Score of natural remnants, according to their importance in providing ecosystem services (ecosystem services weightings combined for remnants)

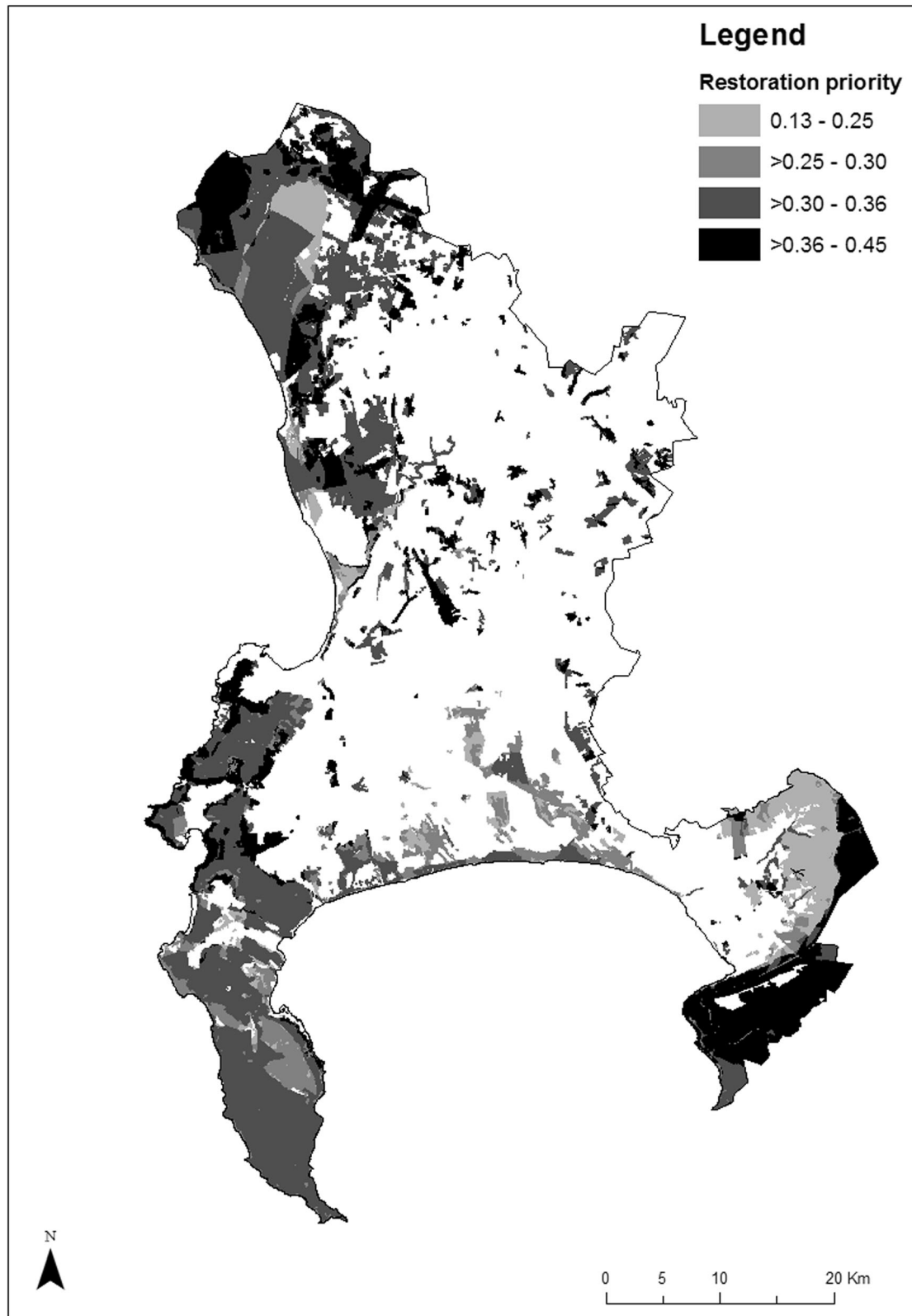


Fig. 6 'Prioritizing' score of remnants, calculated by 'Prioritizing' criteria, not considering active restoration need

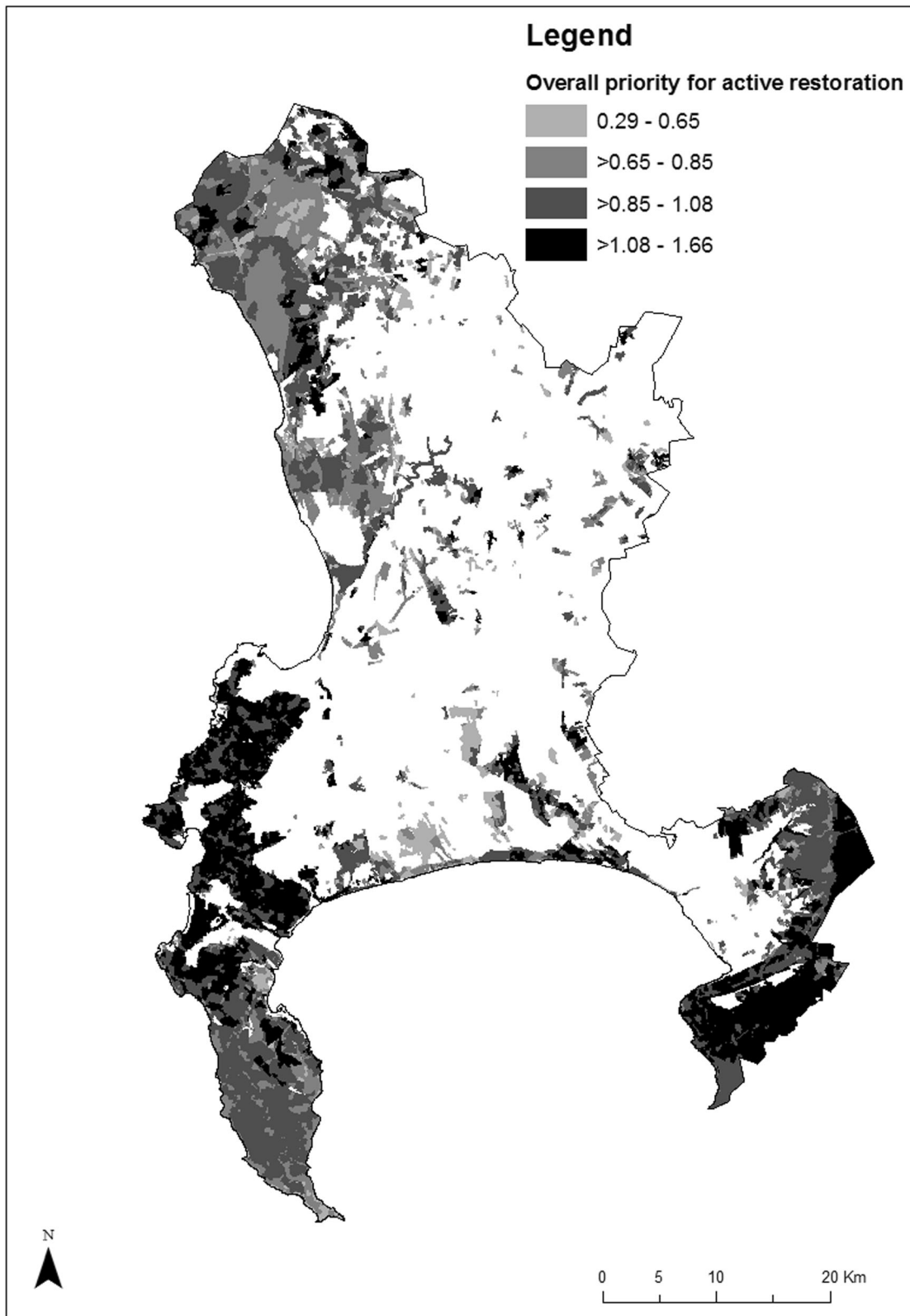


Fig. 7 'Overall priority'- sum of 'Ecosystems service provision'-, 'Prioritizing'- and 'Need for active restoration'-score (includes current invasion status)

prioritization framework and methodology has been recently presented to managers Cape Town reserves and received positive response for future utilization in prioritization restoration areas (Biodiversity Management Branch personal communication).

Analytical Hierarchy Process, a key component of the frameworks, provides a transparent and flexible way to structure and weigh criteria to reflect their importance. AHP, as applied in this study, relied on experts (managers, planners and scientists) to select and weigh criteria to identify and prioritize areas for restoration, as done in other studies (Newman 2008; De Feo and De Gisi 2010; Delgado-Galván et al. 2014). Weightings typically differ depending on the stakeholders involved. A team comprising researchers, conservation managers and decision-makers who plan and implement restoration were invited to ensure a diversity of perspectives. There is some level of subjectivity involved in the selection and weighing procedure (Arroyo et al. 2015) but the method is set out clearly in the framework, making decisions defensible and justifiable (De Lange et al. 2012). Comparing criteria and sub-criteria enables relative comparison without considering the absolute units of criteria (Ishizaka and Labib 2009). Additionally, dividing a problem into different components (in this case criteria) and doing pairwise comparisons is easy and comes naturally to decision makers (Arroyo et al. 2015).

The use of GIS in restoration planning is efficient at a city scale and can integrate data at a landscape scale, thus allowing datasets from many sources to be combined (Lee et al. 2002). Sources of data can be qualitative or quantitative, and can be collected from different geographical scales using different methods (Brown et al. 1998; Beechie et al. 2008; Consorte Widis et al. 2015). More resources should be spent on developing spatially accurate data sets for criteria with the highest weightings to ensure that the method is applied effectively and accurately. Spatial data on levels of disturbance are not available even though a decision rule could be developed to some extent from National Land Cover Data for South Africa (https://egis.environment.gov.za/national_land_cover_data_sa; Details of source data are listed in Tables S3–S5 in Supplementary Appendix 1). However, this information would be of more value to consider at a site scale when investigating which areas within a site to restore.

Some restoration prioritization studies use more species-specific data and complex analysis techniques and are scale specific, for example studies that focus on landscape connectivity (Tambosi and Metzger 2013; Volk et al. 2018). Area prioritization algorithms such as those used for systematic conservation planning have been used for restoration prioritization but were not applicable in this study

(Zafra-Calvo et al. 2010), since Cape Town's systematic conservation plan (the Biodiversity Network) was included as a criterion in the model. Advances have been made to make optimization techniques used in operation research more accessible to landscape planners but such programs were nonetheless considered too complex for application by the intended users of the prioritization protocol developed in this study (Ager and Mezharich 2014; Rappaport et al. 2015). Our approach is effective in that it combines data from a variety of sources and scales in a relatively straight forward way, making the approach suitable for land managers who do not have access to more data and analytically complex prioritization methods.

Although the value of the frameworks is constrained by lack of some data features, both frameworks can be updated with new data as this becomes available. A strength of the approach is its flexibility—the weightings of services can be changed as demands and values change. These frameworks can thus be adapted for use in areas other than in the case study presented in this paper. Furthermore, the weightings and rankings can apply in areas with similar ecological and socio-economical characteristics (De Lange et al. 2012). The frameworks can also be modified by adding or removing criteria depending on the nature and dynamics of ecosystems that need restoration. As an example: in nutrient-poor environments such as fynbos, legacy effects from IAPs in the form of increased nutrients often lead to poor vegetation recovery (Yelenik et al. 2004; Marchante et al. 2008). This weighting may decrease when applying the framework to less nutrient-poor ecosystems. Model results can be confirmed by ground-truthing areas with high priority for active restoration scores, to determine the degree of congruence among spatial data, model results and realities (Consorte Widis et al. 2015). Ground-truthing results can potentially lead to the refinement of the model and also provide justification to adjust model weightings (Consorte Widis et al. 2015). Future models will also benefit from improved post-clearing monitoring and reporting results from restoration efforts, both active and passive (Wortley et al. 2013; Zhang et al. 2018).

The presented frameworks focussed on 'Need for active restoration', 'Prioritizing' and 'Ecosystem service provision'. These criteria are useful for making defensible decisions for allocating funding towards restoration in cities, and they also identify new priority areas where restoration projects need to be initiated. Social criteria were not applied to the framework spatially, but can be applied to a final list of prioritized fragments or protected areas to refine the selection process. Both the protective status of a site and the level of community support towards a restoration project should determine the ultimate success and sustainability of outcomes.

Learning from the application of the frameworks to Cape Town

Areas in need of restoration were prioritized for management according to the restoration goals for Cape Town. Different areas were selected based on different combinations of goals (there may be some overlap among selected areas). As an example looking at the vegetation types: considering ‘Need for active restoration’ and the ‘Prioritizing’ factors, Lowland Fynbos, Renosterveld, Sandstone and Strandveld are ranked the highest but when also considering the ‘Ecosystem service provision’, Forest, Mid-slope- and Sandstone Fynbos are ranked highest. This shows that setting a clear goal at the onset of management planning can impact the management decisions and subsequent outcomes.

When looking at the ‘Need for active restoration’ score (Fig. 4), the maximum score reached was 0.53. In general, it was expected that some areas would have scores closer to the maximum (1.00). The low score is probably due to the overall low densities of IAPs.

The ‘Ecosystem service provisioning’ scores provided further motivation to conserve natural vegetation remnants, and to restore invaded and degraded vegetation to an ecologically functional state. Ecosystem service provisioning is important in an urban context, and is gaining favour restoration world-wide (Wainwright et al. 2018). Developing countries which have biodiversity hotspots and where these are experiencing intense land use conversion pressures can prioritize restoration in ecosystem service hotspots to ensure that funds are applied efficiently, to provide the most benefit to society. Currently, certain regulatory and cultural services have been mapped, but as other ecosystem services become important, they can be added to the framework.

Limitations

Fine-scale data collected by managers were only available for formally protected areas (complete for 2013), while data on alien plant distribution for the rest of the city had to be gleaned from a national data set (Kotzé et al. 2010) and a basic city-scale survey from 2009. From this is clear that limitations to data used during decision making should be acknowledged when assessing outcomes.

Analytical Hierarchy Process assumes independence among alternatives and criteria (Ishizaka and Labib 2009). Alternatives in this case are not strictly independent as there are clear dependencies among the selected ecological criteria. The Analytical Network Process (ANP), a more general form of AHP, can be used to solve this problem, but this approach requires many complex considerations for decision-makers (Ishizaka and Labib 2009). During the workshops, criteria and sub-criteria were also weighted,

without considering the effects that criteria might have on one another.

Priorities for future work

Research should focus on monitoring areas that have been both actively and passively restored to assess which assumptions and predictions hold true, and what adjustments need to be made to this prioritization framework (Nilsson et al. 2016). However, we believe that the two frameworks presented here provide us with a clear and transparent approach for establishing restoration priorities, and enable us to consider and integrate multiple aspects relating to conservation and restoration, namely: biodiversity, ecosystem functioning, ecosystem services, and social and political issues, into decision making.

Conclusion

AHP was successfully applied to develop a framework to firstly identify areas for active restoration after IAP clearing and secondly to prioritize areas for active restoration. The utility of the framework was illustrated using Cape Town as a case study. The method draws in the experience of experts that is not always reflected in the scientific literature. The framework provides a transparent and flexible method for aiding decision making and can be used as a tool for focussing restoration efforts.

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Compliance with ethical standards

Conflict of Interest The authors declare that they have no conflict of interest.

References

- Ager A, Mezרח P (2014) Accelerated restoration: new landscape tools to prioritize projects and analyze tradeoffs. *Science Findings* 159. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, p 6
- Allsopp MH, Cherry M (2004) An assessment of the impact on the bee and agricultural industries in the Western Cape of the clearing of certain Eucalyptus species using questionnaire survey data. National Government of the Republic of South Africa, Department of Water Affairs, Internal Final Report, Pretoria (South Africa), p 58
- Allen, EB, Roundy, BA, McArthur, ED, Haley, JS (1995) Restoration ecology: limits and possibilities in arid and semiarid lands. In

- Proceedings of the Wildland Shrub and Arid Land Restoration Symposium, Roundy, BA, McArthur, ED, pp 7–15
- Aranson J, Milton SJ, Blignaut JN (eds) (2007) Restoring natural capital: science, business, and practice. Society for Ecological Restoration International. Island Press, Washington, DC
- Arroyo P, Tommelein ID, Ballard G (2015) Comparing AHP and CBA as decision methods to resolve the choosing problem in detailed design. *J Constr Eng Manag* 141:401–4063. [https://doi.org/10.1061/\(ASCE\)CO.1943-7862.0000915](https://doi.org/10.1061/(ASCE)CO.1943-7862.0000915)
- Beechie T, Pess G, Roni P, Giannico G (2008) Setting river restoration priorities: a review of approaches and a general protocol for identifying and prioritizing actions. *N Am J Fish Manag* 28:891–905
- Bennett EM, Balvanera P (2007) The future of production systems in a globalized world. *Front Ecol Environ* 5:191–198. [https://doi.org/10.1890/1540-9295\(2007\)5\[191:TFOPSI\]2.0.CO;2](https://doi.org/10.1890/1540-9295(2007)5[191:TFOPSI]2.0.CO;2)
- Brown NJ, Swetnam RD, Treweek JR et al. (1998) Issues in GIS development: adapting to research and policy-needs for management of wet grasslands in an Environmentally Sensitive Area. *Int J Geogr Inform Sci* 12:465–478. <https://doi.org/10.1080/136588198241752>
- Cadenasso ML, Pickett STA (2008) Urban principles for ecological landscape design and maintenance: scientific fundamentals. *Cities Environ* 1:4
- Consorte Widis D, BenDor TK, Deegan M (2015) Prioritizing wetland restoration sites: a review and application to a large-scale coastal restoration program. *Ecol Restor* 33:358–377
- Crookes DJ, Blignaut JN, de Wit MP, Esler KJ, Le Maitre DC, Milton SJ, Mitchell SA, Cloete J, de Abreu P, Fourie (nee Vlok) H, Gull K, Marx D, Mugido W, Ndhlovu T, Nowell M, Pauw M, Rebelo A (2013) System dynamic modelling to assess economic viability and risk trade-offs for ecological restoration in South Africa. *J Environ Manag* 120:138–147. <https://doi.org/10.1016/j.jenvman.2013.02.001>
- Crossman ND, Bryan BA (2006) Systematic landscape restoration using integer programming. *Biol Conserv* 128:369–383. <https://doi.org/10.1016/j.biocon.2005.10.004>
- Crouzeilles R, Curran M, Ferreira MS, Lindenmayer DB, Grelle C, Benayas JMR (2016) A global meta-analysis on the ecological drivers of forest restoration success. *Nat Commun* 7:11666
- DEA (2015) Guidelines for monitoring, control and eradication plans as required by Section 76 of the National Environmental Management: Biodiversity Act, 2004 (Act No. 10 of 2004) (NEM: BA) for species listed as invasive in terms of Section 70 of this Act. Department of Environmental Affairs, Pretoria. http://www.environment.gov.za/sites/default/files/legislations/nemba_invasive-species_controlguideline.pdf. Accessed 7 May 2016
- De Feo G, De Gisi S (2010) Using an innovative criteria weighting tool for stakeholders involvement to rank MSW facility sites with the AHP. *Waste Manag* 30:2370–2382. <https://doi.org/10.1016/j.wasman.2010.04.010>
- De Lange W, Stafford W, Forsyth G, Le Maitre D (2012) Incorporating stakeholder preferences in the selection of technologies for using invasive alien plants as a bio-energy feedstock: applying the analytical hierarchy process. *J Environ Manag* 99:76–83
- Delgado-Galván X, Izquierdo J, Benítez J, Pérez-García R (2014) Joint stakeholder decision-making on the management of the Silao–Romita aquifer using AHP. *Environ Model Softw* 51:310–322
- Dickie IA, Bennett BM, Burrows LE, Nuñez MA, Peltzer DA, Porté A, Richardson DM, Rejmánek M, Rundel PW, van Wilgen BW (2013) Conflicting values: ecosystem services and invasive tree management. *Biol Invasions* 16:705–719. <https://doi.org/10.1007/s10530-013-0609-6>
- Esler KJ, Holmes PM, Richardson DM, Witkowski ETF (2008) Riparian vegetation management in landscapes invaded by alien plants: insights from South Africa. *S Afr J Bot* 74:397–400. <https://doi.org/10.1016/j.sajb.2008.01.168>
- Forsyth GG (2013) Prioritising target plant species for early detection and rapid response in the Cape Metropol (No. CSIR/NRE/ECOS/ER/2013/0039/B). CSIR Natural Resources and the Environment, Stellenbosch
- Forsyth GG, O'Farrell PJ, Le Maitre DC (2011) Prioritising quaternary catchments for invasive alien plant control within the Working for Water Free State Region (No. CSIR/NRE/ECO/ER/2011/0039/B). CSIR Natural Resources and the Environment, Stellenbosch
- Gaertner M, Nottebrock H, Privett SDJ, Richardson DM (2012) Plant invasions, restoration, and economics: perspectives from South African fynbos. *Perspect Plant Ecol Evol Syst* 14:341–353. <https://doi.org/10.1016/j.ppees.2012.05.001>
- Gaertner M, Larson BMH, Irlich UM, Holmes PM, Stafford L, van Wilgen BW, Richardson DM (2016) Managing invasive species in cities: a framework from Cape Town, South Africa. *Landsc Urb Plan* 151:1–9
- Gaertner M, Novoa A, Fried J, Richardson DM (2017) Managing invasive species in cities: a decision support framework applied to Cape Town. *Biol Invasions* 19:3707–3723. <https://doi.org/10.1007/s10530-017-1587-x>
- Herath G (2004) Incorporating community objectives in improved wetland management: the use of the analytic hierarchy process. *J Environ Manag* 70:263–273. <https://doi.org/10.1016/j.jenvman.2003.12.011>
- Hilderbrand RH, Watts AC, Randle AM (2005) The myths of restoration ecology. *Ecol Soc* 10:19
- Holmes PM, Esler KJ, Richardson DM, Witkowski ETF (2008) Guidelines for improved management of riparian zones invaded by alien plants in South Africa. *S Afr J Bot* 74:538–552
- Holmes PM, Rebelo AG, Dorse C, Wood J (2012a) Can Cape Town's unique biodiversity be saved? Balancing conservation imperatives and development needs. *Ecol Soc* 17:28
- Holmes PM, Richardson DM (1999) Protocols for restoration based on recruitment dynamics, community structure, and ecosystem function: perspectives from South African fynbos. *Restor Ecol* 7:215–230
- Holmes PM, Stipinovich A, Purvis A (2012b) City of Cape Town's Biodiversity Network. Environmental Resource Management Department (EDRM), City of Cape Town
- Holmes PM, Richardson DM, Wilgen BW, Gelderblom C (2000) Recovery of South African fynbos vegetation following alien woody plant clearing and fire: implications for restoration. *Austral Ecology* 25(6):631–639
- Ishizaka A, Labib A (2009) Analytic hierarchy process and expert choice: benefits and limitations. *OR. Insight* 22:201–220
- Kotzé I, Beukes H, Van den Berg E, Newby T (2010) National invasive alien plant survey. Agricultural Research Council, Institute for Soil, Climate and Water, Report No. GW/A/2010/21
- Lee JT, Bailey N, Thompson S (2002) Using geographical information systems to identify and target sites for creation and restoration of native woodlands: a case study of the Chiltern Hills, UK. *J Environ Manag* 64:25–34
- Le Maitre DC, Gaertner M, Marchante E, Ens E, Holmes PM, Pauchard A, O'Farrell PJ, Rogers AM, Blanchard R, Blignaut J (2011) Impacts of invasive Australian acacias: implications for management and restoration. *Divers Distrib* 17:1015–1029
- Mack RN, Simberloff D, Mark Lonsdale W, Evans H, Clout M, Bazzaz FA (2000) Biotic Invasions: causes, epidemiology, global consequences, and control. *Ecol Appl* 10:689–710. [https://doi.org/10.1890/1051-0761\(2000\)010\[0689:BICEGC\]2.0.CO;2](https://doi.org/10.1890/1051-0761(2000)010[0689:BICEGC]2.0.CO;2)
- Maherry AM, Horan MJC, Smith-Adao LB, van Deventer H, Nel JL, Schulze RE, Kunz RP (2013) Delineating river network quinary catchments for South Africa and allocating associated daily

- hydrological information: Report to the Water Research Commission (No. 2020/1/12). Water Research Commission, Pretoria, South Africa
- Malczewski J (1999) GIS and Multicriteria Decision Analysis. Wiley, Chichester, UK
- Marchante E, Kjølter A, Struwe S, Freitas H (2008) Short- and long-term impacts of *Acacia longifolia* invasion on the belowground processes of a Mediterranean coastal dune ecosystem. *Appl Soil Ecol* 40:210–217. <https://doi.org/10.1016/j.apsoil.2008.04.004>
- Newman A (2008) Inclusive planning of urban nature. *Ecol Restor* 26:229–234
- Nielsen AM, Fei S (2015) Assessing the flexibility of the Analytic Hierarchy Process for prioritization of invasive plant management. *NeoBiota* 27:25
- Nilsson C, Aradottir AL, Hagen D, Halldórsson G, Høegh K, Mitchell RJ, Raulund-Rasmussen K, Svavarsdóttir K, Tolvanen A, Wilson SD (2016) Evaluating the process of ecological restoration. *Ecol Soc* 21:41. <https://doi.org/10.5751/ES-08289-210141>
- O'Farrell PJ, Anderson PML, Le Maitre DC, Holmes PM (2012) Insights and opportunities offered by a rapid ecosystem service assessment in promoting a conservation agenda in an urban biodiversity hotspot. *Ecol Soc* 17:27
- Orsi F, Geneletti D (2010) Identifying priority areas for Forest Landscape Restoration in Chiapas (Mexico): an operational approach combining ecological and socioeconomic criteria. *Landsc Urb Plan* 94:20–30. <https://doi.org/10.1016/j.landurbplan.2009.07.014>
- Orsi F, Geneletti D, Newton AC (2011) Towards a common set of criteria and indicators to identify forest restoration priorities: an expert panel-based approach. *Ecol Indic* 11:337–347. <https://doi.org/10.1016/j.ecolind.2010.06.001>
- Parker-Allie F, Richardson DM, Holmes PM (2004) The effects of past management practices for invasive alien plant control on subsequent recovery of fynbos on the Cape Peninsula. *S Afr J Bot* 70:804–815
- Potgieter LJ, Gaertner M, O'Farrell PJ, Richardson DM (2018) Perceptions of impact: invasive alien plants in the urban environment. *J Environ Manag*, in press. <https://doi.org/10.1016/j.jenvman.2018.05.080>
- Rappaport DI, Tambosi LR, Metzger JP (2015) A landscape triage approach: combining spatial and temporal dynamics to prioritize restoration and conservation. *J Appl Ecol* 52:590–601
- Rebello AG, Holmes PM, Dorse C, Wood J (2011) Cape Town: averting a biodiversity megadisaster? *S Afr J Bot* 77:20–35
- Rew LJ, Lehnhoff EA, Maxwell BD (2007) Non-indigenous species management using a population prioritization framework. *Can J Plant Sci* 87:1029–1036. <https://doi.org/10.4141/CJPS07121>
- Richardson DM, Gaertner M (2013) Plant invasions as builders and shapers of novel ecosystems. In: Hobbs RJ, Higgs ES, Hall CM (eds) *Novel ecosystems: intervening in the New Ecological World Order*. Wiley Chichester, UK, pp 102–114
- Richardson DM, Van Wilgen BW, Higgins SI, Trinder-Smith TH, Cowling RM, McKell DH (1996) Current and future threats to plant biodiversity on the Cape Peninsula, South Africa. *Biodivers Conserv* 5:607–647. <https://doi.org/10.1007/BF00137612>
- Rouget M, Richardson DM, Cowling RM, Lloyd JW, Lombard AT (2003) Current patterns of habitat transformation and future threats to biodiversity in terrestrial ecosystems of the Cape Floristic Region, South Africa. *Biol Conserv* 112:63–85. [https://doi.org/10.1016/S0006-3207\(02\)00395-6](https://doi.org/10.1016/S0006-3207(02)00395-6)
- Roura-Pascual N, Richardson DM, Krug RM, Brown A, Chapman RA, Forsyth GG, Le Maitre DC, Robertson MP, Stafford L, Van Wilgen BW (2009) Ecology and management of alien plant invasions in South African fynbos: accommodating key complexities in objective decision making. *Biol Conserv* 142:1595–1604
- Skurski TC (2012) Quantifying non-native plant impacts: *Centaurea stoebe* L. (spotted knapweed) and *Bromus tectorum* L. (downy brome) in sagebrush-grasslands of the greater Yellowstone ecosystem. Montana State University, Bozeman
- Suding KN (2011) Toward an era of restoration in ecology: successes, failures, and opportunities ahead. *Ann Rev Ecol Evol Syst* 42:465–487. <https://doi.org/10.1146/annurev-ecolsys-102710-145115>
- Tambosi LR, Metzger JP (2013) A framework for setting local restoration priorities based on landscape context. *Nat Conserv* 11:152–157
- Saaty TL (1990) How to make a decision: The analytic hierarchy process. *European Journal of Operational Research* 48(1):9–26
- Tongway DJ, Ludwig JA (2012) Planning and implementing successful landscape-scale restoration. In: Van Andel J, Aronson J (eds) *Restoration Ecology*. Wiley, Chichester UK, pp 30–42
- Trabucchi M, Ntshotsho P, O'Farrell PJ, Comín FA (2012) Ecosystem service trends in basin-scale restoration initiatives: a review. *J Environ Manag* 111:18–23. <https://doi.org/10.1016/j.jenvman.2012.06.040>
- Trujillo-Miranda AL, Toledo-Aceves T, López-Barrera F, Gerez-Fernández P (2018) Active versus passive restoration: recovery of cloud forest structure, diversity and soil condition in abandoned pastures. *Ecol Eng* 117:50–61
- Van Niekerk D (2012) National Biodiversity Assessment 2011: an assessment of South Africa's biodiversity and ecosystems. Synthesis Report. South African National Biodiversity Institute, Pretoria
- Van Wilgen BW, Nel J, Rouget M (2007) Invasive alien plants and South African rivers: a proposed approach to the prioritization of control operations. *Freshw Biol* 52:711–723
- Van Wilgen BW (2012) Evidence, perceptions, and trade-offs associated with invasive alien plant control in the Table Mountain National Park, South Africa. *Ecol Soc* 17:23
- Van Wilgen BW, Forsyth GG, Le Maitre DC, Wannenburg A, Kotzé JDF, van den Berg E, Henderson L (2012a) An assessment of the effectiveness of a large, national-scale invasive alien plant control strategy in South Africa. *Biol Conserv* 148:28–38. <https://doi.org/10.1016/j.biocon.2011.12.035>
- Van Wilgen BW, Forsyth GG, Prins P (2012b) The management of fire-adapted ecosystems in an urban setting: the case of Table Mountain National Park, South Africa. *Ecol Soc* 17:8. <https://doi.org/10.5751/ES-04526-170108>
- Volk XK, Gattringer JP, Otte A, Harvolk-Schöning S (2018) Connectivity analysis as a tool for assessing restoration success. *Landsc Ecol* 33:371–387
- Wainwright CE, Staples TL, Charles LS, Flanagan TC, Lai HR, Loy X, Reynolds VA, Mayfield MM (2018) Links between community ecology theory and ecological restoration are on the rise. *J Appl Ecol* 55:570–581
- Wortley L, Hero JM, Howes M (2013) Evaluating ecological restoration success: a review of the literature. *Restor Ecol* 21:537–543
- Yelenik SG, Stock WD, Richardson DM (2004) Ecosystem level impacts of invasive *Acacia saligna* in the South African fynbos. *Restor Ecol* 12:44–51
- Zafra-Calvo N, Cerro R, Fuller T, Lobo JM, Rodríguez MÁ, Sarkar S (2010) Prioritizing areas for conservation and vegetation restoration in post-agricultural landscapes: a Biosphere Reserve plan for Bioko, Equatorial Guinea *Biol Conserv* 143:787–794
- Zhang YS, Cioffi WR, Cope R, Daleo P, Heywood E, Hoyt C, Smith CS, Silliman BR (2018) A global synthesis reveals gaps in coastal habitat restoration research. *Sustainability* 10:1040