A framework for systematic conservation planning and management of Mediterranean landscapes

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Abstract

Active and dynamic management of biodiversity is of utmost importance in the face of climate change and increasing human pressures on nature. Current approaches for site selection of protected areas often assume that both conservation features and management actions are fixed in space and time. However, this approach should be revised to allow for spatiotemporal shifts of biodiversity features, threats and management options. Our aim here was to demonstrate a novel approach for systematic conservation planning at a fine scale that incorporates dynamic ecological processes (e.g., succession), biodiversity targets and management costs. We used the new 'Marxan with Zones' decision support tool to spatially redistribute the major vegetation types within a privately-owned nature park in Israel and facilitate the achievement of multiple conservation targets for minimum cost. The park is located in the Mediterranean climate region of the eastern Mediterranean Basin, one of Earth's richest biodiversity hotspots. This small park alone (450 ha) holds 660 species of native plants and six vegetation types. The region has been subject to manifold human pressures such as grazing, clearing and fire for millennia and is currently threatened by a range of modern human-related activities (e.g., invasive alien species and fire). By spatially redistributing the six vegetation types under three scenarios, representing different conservation objectives (No change; Evenness of structural formations; Early succession stages) within three budget frameworks, we identified a set of near-optimal conservation strategies that can be enacted over time. The current spatial distribution of vegetation types and the cost of changing one vegetation type into another via management actions had a major impact on the spatial prioritization outcomes and management recommendations. Notably, an advanced successional stage (dense Mediterranean garrigue) tended to dominate a large portion of the landscape when the available budgets were low because it is a cheap vegetation type to maintain. The approach presented here can be further applied to spatially prioritize conservation goals in a phase of shifting environments and climates, allowing conservation planning at multiple spatial scales.

Keywords

Conservation planning; decision support tools; Local scale management; Marxan; Mediterranean ecosystems; succession.

Introduction

The growth in the number of systematic conservation planning tools and approaches and their use by both government and nongovernment organisations (NGOs) is changing the way conservation is currently being conducted around the world (Groves et al. 2002; Pressey et al. 2007; Moilanen et al. 2009). However, there is still an important gap between conservation science and conservation practice (e.g., Arlettaz et al., 2010; Gibbons et al. 2011). By guiding practitioners and policy makers to identify management objectives that incorporate biological, social and economic factors within one decision making framework, systematic conservation planning can help to both clarify goals and plan strategically (Joseph et al. 2009; Watson et al. 2011a). Spatial decision support tools (e.g., Marxan; Ball and Possingham, 2000; Possingham et al. 2000; Zonation; Moilanen, 2007) are now frequently used to guide management actions and locations that simultaneously meet conservation targets while minimizing social and economic costs (Wilson et al. 2006; Carwardine et al. 2008; Kark et al., 2009). Their use is increasing accountability and transparency in the planning process and leading to more economically efficient conservation outcomes on the ground (Knight et al. 2006; Pressey and Bottrill, 2009; Joseph et al. 2011).

One major limitation to systematic conservation planning is the assumption that biotic and abiotic conditions are static in space and in time. Increasing attention is now being given to include dynamic changes and shifts of species and ecosystems into conservation planning in the face of ongoing (and often increasing) land use and rapid, human-forced climate change (Meir et al., 2004; Pressey et al. 2007; Drechsler et al., 2009; Heller and Zavaleta 2009; Possingham et al., 2009; Watson et al. 2009). While in forest management planning dynamic optimization models with habitat conservation objectives have been in use since the 1990s (e.g., Bevers et al.

1997; Hof et al. 2002; Öhman et al. 2011), these models were mostly solved with linear integer programming methods, which are not used in reserve site selection models (such as Marxan).

A range of conservation actions have been proposed as outcomes of the planning process, including the relocation of species (McDonald-Madden et al., 2010), protecting altitudinal gradients (Watson et al. 2011b), adding protected areas, and creating large scale corridors that allow shifts in species ranges due to environmental changes (Hannah et al. 2007). However, these actions are planned at regional and global scales (e.g., Ricketts et al., 2005; Drechsler et al., 2009; Hoffmann et al., 2010; Lourival et al., 2011), and there is less work demonstrating the use of a dynamic approach in systematic conservation planning and prioritization of actions at the local scale (but see Toth et al., 2011). At regional scales various types of spatial components are identified as surrogates for key processes (e.g., riverine corridors, upland-lowland gradients, macroclimatic gradients; Rouget et al., 2003). At more local scales participatory or incentive-based instruments are often applied and optimization approaches are rarely used. In addition, processes such as changing human land uses and natural successional change dynamics in space or in time should be taken into account in dynamic conservation planning (Pressey et al., 2007). The bias towards conservation planning at regional and global scale is unfortunate as many conservation decisions occur at the local level (a reserve or park) and local conservation efforts will benefit from effective strategic planning processes (Hockings et al. 2000; Possingham et al. 2006; Boyd et al. 2008).

The Mediterranean Basin, one of Earth's richest biodiversity hotspots (Myers et al., 2000), has been subject to multiple human pressures such as grazing, clearing and fire for millennia (Naveh and Dan, 1973) and is currently threatened by a range of human activities (Kark et al., 2009). Very few systematic conservation plans have been developed for the

Mediterranean Basin, which is partly due to its complexity and diversity, ranging over many different countries, cultures and conservation agendas (Kark et al., 2009), and partly due to the huge population and economic pressures in this region. Most of the region is human dominated with multiple land uses and relatively little room for allocation of new single-use reserves and land purchase for conservation. Thus, the traditional conservation planning approach has not been widely applied in this region. Furthermore, the long history of human disturbances in the area has led to diverse landscape mosaics and high biodiversity (Naveh and Whittaker, 1980; Perevolotsky and Seligman, 1998; Bar Massada et al., 2009). The traditional agro- pastoral disturbance regime based on clearing and grazing has been abandoned in many places during the last few decades due to socio-economic changes (Perevolotsky and Seligman, 1998). Nowadays, conservation management in these regions is complicated mainly because the end target or the reference state for conservation is subjective and hard to define (Perevolotsky 2005). The concept of pristine ecosystem or undisturbed climax as the desired state of the ecosystem to set as the conservation goal has little meaning in this region, and the role of professional planning defining active management schemes becomes very important.

The aim of our study was to develop and apply a new approach of conservation planning for successional landscapes at the local scale. We used a novel spatially-explicit decision support tool, Marxan with Zones (Watts et al., 2009), to spatially relocate and redistribute the major vegetation features within a privately-owned nature park in Israel to allow for maximum achievement of multiple targets with minimum cost. In many Mediterranean ecosystems, including the Eastern Mediterranean, it has been shown that the succession process is one of the most important dynamic ecological processes shaping the ecosystem structure (Drechsler et al., 2009). One of the final stages of the succession process in Mediterranean landscapes leads to an increase in the cover of the woody vegetation (Bar Massada et al., 2009; Koniak and Noy-Meir, 2009). This in return leads to decline in overall plant richness, and potentially increases fire risk to human infrastructures (Naveh and Whittaker, 1980; Perevolotsky and Seligman, 1998). Reducing threats to biodiversity is costly and needs to be done continuously. Therefore, a challenge for Mediterranean conservation managers is to decide whether, where and how to effectively intervene in the natural succession process and its dynamics. We illustrate an approach to solving the management challenge of meeting conservation targets within 30 years while minimising costs. We believe this represents one of the first attempts to utilize a spatially explicit systematic conservation planning approach to identify management priorities at the local scale while at the same time considering the underlying dynamics of the system (McBride et al., 2010; Wilson et al., 2011).

Methods

Study area

The study was conducted in Ramat Hanadiv, a privately owned Nature Park established by the descendants of the Baron Edmond Benjamin de Rothschild, operated for the benefit of the general public by the Rothschild Foundation (Yad Hanadiv). The site covers approximately 450 hectares (1,125 acres) on a plateau at the southern tip of the Carmel mountain range in NW Israel (Fig. 1; the average area of nature reserves is about 6.7 km^2, and the median area of nature reserves in Israel is less than 1 km^2). The most common shrubs in the park are *Phillyrea latifolia*, *Pistacia lentiscus*, *Calycotome villosa* and the dwarf shrub *Sarcopoterium spinosum* (Koniak and Noy-Meir, 2009). There are also conifer groves in the park planted in the 1970's, mostly the species *Pinus Brutia*, *Pinus Pinea* and *Cupressus sempervirens* (Osem et al., 2011). The park is perhaps the most researched and managed open space in Israel (e.g., Hadar et al., 1999; Koniak and Noy-Meir, 2009; Osem et al., 2011), with over 25 years of intensive research and dozens of fine spatial resolution data layers that were specifically surveyed and mapped within this park.

The Nature Park management seeks to conserve and nurture diverse habitats to support rich and attractive biodiversity (660 plant species; Liat Hadar, personal communication). In order to achieve these goals, various management operations have been carried out in the Park since its early years (late 1980s), including the introduction of cattle and goat grazing, manual shrub clearing, fencing to protect rare plant species and reintroduction and re-stocking of endangered animals.

Our goal was to provide a scientific basis for effective management activities applied in the park. Following a large fire in 1980, many studies have been carried out in the Park, enriching existing knowledge in diverse fields (including soils, avifauna, botany, zoology, grazing, etc., e.g., Ben David & Farkash,1983; Cohen, 1987). As the foundation of scientific knowledge expanded, an approach based on adaptive management supported by monitoring and research was developed (Holling 1978; Walters 1986; Perevolotsky, 2001). Research and evaluation of the ecological effects of the management activities was undertaken on several taxonomic groups (e.g., Hadar et al. 1999). In the eastern Mediterranean context, Ramat Hanadiv is a unique case of a natural area that is actively managed, intensively studied and detailed on all levels. As such, it can serve as an example of nature conservation and management of Mediterranean ecosystems in Israel and the region. We demonstrate a stakeholder engagement process for identifying conservation objectives (sensu Nicholson & Possingham 2006) and targets (sensu Sanderson 2006), using realistic working definitions of benefits and costs.

Spatial analysis

Our conservation planning process used eight steps (Table 1), allowing dynamic ecological and management processes to be included, as explained below.

Step 1: Define objectives

To optimally allocate resources among management projects, it is essential to clearly state the highest priority objectives (Possingham et al. 2001; Sanderson 2006). In February 2010, we conducted a survey of the Ramat Hanadiv Park professional staff (10 people), in order to prioritize the main conservation objectives in the park. All park staff members were asked to fill a questionnaire and rank management objectives according to their relative importance. Overall, plant structural diversity was ranked as the most important objective, being a basic component of the ecosystem, both ecologically as vegetation serves as a habitat for other taxa, environmentally as it modifies the climate and the soil, aesthetically as it is the major factor defining how a landscape is perceived, and functionally as it enables several land uses and inhibits others. This objective, which received the highest ranking (with a large majority over all other objectives), maximization of overall plant structural diversity, was therefore chosen as the focal objective in our paper.

Step 2: List biodiversity assets

The biodiversity assets are defined as the components of biodiversity that we wish to manage. In this case, the biodiversity assets are structural vegetation formations that occur in the Nature Park that need to be created, maintained or improved through management. The six major structural plant forms identified within the park: Low Open (sparse shrub cover), Medium Sparse garrigue (medium-sized shrubs, partial cover), Medium Dense garrigue (medium-sized shrubs, complete cover), Tall Dense maquis (stands of oak trees on favourite habitat), Trees Sparse (thinned planted groves) and Trees Dense (planted grove). A more comprehensive definition for each of these vegetation types is provided in Table 2.

Step 3: Spatially map assets

The next step was to spatially map the present distribution of assets in the park and where they could potentially exist under optimum management actions. In the context of Marxan, planning units are the parcels of land or water that are compared to one another in site selection analyses. Here the planning units were defined as100 m^2 grid cells resulting in 43,998 units. We selected 100 m^2 because of the spatial heterogeneity within the park and the availability of high spatial resolution data. The present distribution of the vegetation forms was derived from GIS layers created through automated segmentation of remotely sensed height and cover maps derived from LiDAR imagery (Bar Massada et al., 2012; Fig. 1). The potential distribution of the vegetation formations was defined by experts (Ramat Hanadiv research team, based on former knowledge using soil, lithology, topography and micro-climate considerations, as well as modelling of vegetation succession; Konyak and Noy-Meir, 2009; Fig. 2). The archaeological sites, an agricultural field and the memorial gardens within the borders of Ramat Hanadiv Park were excluded from the scenarios run by Marxan with Zones.

Step 4: Set targets

For the fourth step of target setting, we asked experts to define targets to be met within the park for each of the assets. The assets (vegetation structural formations) are not constant in space or time. For example, an area of the park that is now “Low open” may change to “Medium sparse” due to successional processes within 20 years if the land is not managed with fire, clearing or grazing. Therefore, the managers were asked to define the target amount of area for each of the vegetation structural formations based on their opinion about the optimal area not the current area.

For the purpose of illustration of the method, we examined three scenarios. Each of the scenarios is described in detail, including the percentage of each asset (Table 2).

Scenario 1: No change (i.e. preserving current amount of each asset). In this scenario each asset will maintain its current proportions within 30 years.

Scenario 2: Evenness of structural formations - in this scenario, we set equal area targets for all assets, thus maximizing landscape diversity (as in Richards et al., 1999).

Scenario 3: Early succession stages - in this scenario, high area targets are set for the assets that represent early succession stages such as “Low open” at the expense of ‘Medium Sparse’ and ‘Medium Dense’ that represent the medium and late succession stages. This scenario leads to "opening" the landscape, favouring open patches, dominated by herbaceous vegetation that tend to disappear as the Mediterranean maquis becomes more dense (Hadar et al., 1999). Early succession stages of Mediterranean vegetation also favour higher species richness and high primary productivity areas, as more annual species are able to thrive there (Osem et al., 2002).

Step 5: List management actions

The next step was to identify the specific management actions needed to ensure that the assets will occur in the future or needed to transition from one vegetation community to the other. A matrix of all transitions between assets (e.g., from ‘Low Open’ to ‘Medium Sparse’, to maintain ‘Trees Sparse’ as ‘Trees Sparse’, etc.) was created at the spatial scale of the planning unit size (i.e. 100 m^2). For each transition, we identified the full sets of actions required over a period of 30 years. The following actions were defined: ‘Do nothing’, ‘Controlled fire’, ‘Light grazing’, 'Moderate grazing', 'Intensive grazing', 'Tree clearing', 'Tree planting', 'Tree clearing and grazing', 'Thinning', 'Goat exclusion', 'Shrub removal', 'Tilling' etc. Experts were required to clearly describe a precise intensity and duration of management for each action.

Step 6: Estimate costs

The cost of each set of management actions for every transition between the vegetation types was estimated for the entire 30 year period. The total cost of the sequence of treatments is calculated for each transition (shown in Table 3). Costs included all future outlays; whereas, past outlays were not considered.

Step 7: Choose set of actions

We employed a new multiple land use zoning tool that is based on a version of the popular decision-support tool Marxan (Possingham et al. 2000). Marxan is an area selection algorithm that aims to identify planning units that are important for protection given their cost-effective contribution to achieving biodiversity targets (Ball and Possingham, 2000). To achieve this, Marxan aims to minimize the following objective formula:

$$\sum_{Sites} Cost + BLM \sum_{Sites} Boundary + \sum_{ConValue} CFPF \times Penalty \qquad (1)$$

where the *Cost* is some measure of the cost of the sites within the reserve system, *Boundary* is the length of the boundary surrounding the reserve system, the constant *BLM* is the boundary length multiplier which determines the importance given to the boundary length relative to the cost of the reserve system, and the last term is a penalty given for not adequately representing a conservation feature in the reserve system (for the formal formulation see Watts et al., 2009).

However, the original version of Marxan is limited to certain conservation applications as it was unable to consider more than one type of management intervention at a time (i.e. it has one static cost, usually the cost of making any planning unit a protected area). One of the common outputs of a Marxan exercise is a binary map, presenting the set of planning units that were selected to be include within a protected areas network. Commonly in practice, managers need to choose among more than one management intervention (e.g., which activities to allow within a protected area – fishing, diving, and boating), and, thus, often use zoning (i.e. designating permitted uses of land) to spatially and temporally designates areas for specific purposes (McCook et al. 2010). Marxan has recently been revised and can now optimize among an increased number of land-use zones (e.g., ranging from full protection to forest production and forest clearing), this new tool is called Marxan with Zones (Watts et al. 2009). We overcome the problems associated with planning schemes that assume the distribution of vegetation types as being static in space and in time by acknowledging the dynamic nature of the ecosystem (e.g., vegetation succession) in this study and incorporate it in the zoning costs. In our application of Marxan with Zones, a specific zone was equivalent to a specific vegetation type to be created or maintained using a defined set of management actions.

Each Marxan with Zones run had 1,000,000 iterations, and we repeated the runs for each scenario 100 time to find the selection frequency. While integer programming can guarantee an optimal solution to a problem, it has two major drawbacks: it may fail to solve extremely large problems, and, for practical reasons (such as data uncertainty) as well as political reasons finding a single best solution is not that useful (Ball et al., 2009). As Marxan does not find a single optimal solution, each Marxan run provides a slightly different near-optimal solution (this range of solutions enables decision makers to negotiate and make choices). We used the metric ‘‘selection frequency’’ to analyse the results of the runs within each scenario. Selection frequency is the number of times each planning unit is selected for a particular zone (action) in good solutions to the overall problem (McDonnell et al., 2002; Leslie et al., 2003). Planning units that are selected above a certain threshold-percentage of runs for a specific zone are considered to be important for achieving targets for that zone. We used a threshold of 90% to indicate a very high probability for a specific planning unit to be managed as that zone (i.e., set of management actions; Kark et al., 2009). The solution that best achieves the objective function (e.g., zones targets and cost) is termed as the "best solution". It should be used as an example for the possible distribution of zones, and not as the prescriptive guide for management, due to uncertainty in data, the existence of additional important factors not considered, and the existence of numerous appropriate solutions. In addition we used the best solution to evaluate whether the targets were achieved and what was their overall cost. We chose not to consider spatial diversity and fragmentation of the vegetation in our zoning targets as this would further complicate the Marxan runs. To present the degree of uncertainty involved in the selection of planning units to different zones in each of the runs, we calculated the classification uncertainty as common in remote sensing studies (Eastman, 2009):

$$\text{Classification uncertainty} = \left(1 - \frac{max - \frac{sum}{n}}{1 - \frac{1}{n}}\right) * 100 \qquad (2)$$

Where:

max = the maximum set membership for a planning unit (the highest frequency it was selected for a specific zone)

sum = the sum of the membership values for a planning unit (100 as there were 100 runs)

n = the number of zones considered (6)

Planning units that were always assigned to the same zone will have low uncertainty (i.e. high confidence) score (0), where as planning units that were equally assigned to each of the six zones, will have a high uncertainty (i.e. low confidence) score (100). The frequency (summed solutions) in which a certain planning unit was selected for a specific zone (i.e. future vegetation type) and not to alternative zones can also be interpreted as certainty for assigning that planning unit for that zoning.

Step 8: Explore the effects of budget limitation:

The park managers had set an annual budget of 2.1 million Israeli New Shekels (NIS) (approximately $630,000). Nonetheless, they haven't decided how to allocate it among different conservation goals of the park. Therefore, in order to explore the effects of different budget limitation on managing the vegetation structure, three options were explored, by setting an upper cost limit within Marxan with Zones:

A) No budget limitations - assuming the budget would increase if it would be found necessary to achieve the park managers' goals;

B) Full budget – assuming that the entire annual budget of the nature park (2.1 million NIS) would be dedicated only to the management of the vegetation structures;

C) Partial budget – assuming that only a third of the annual budget (700,000 NIS) would be dedicated to the goals regarding the vegetation structure, and that the rest would be used for other important goals.

These budget options were applied for the three different scenario suggested in step 4. It was assumed that the overall budget is adjusted to potential changes in management costs, such that management costs can effectively assumed to be constant. Within our Marxan runs, park managers were limited to spending only the amount of the annual budget each year.

Results

The conservation objective that received the highest rank based on the responses of the park member's questionnaire was 'maximising overall plant structural diversity'. It was ranked as the most important objective by seven of the ten park members.

Based on the management actions listed by the park managers as needed to transform from any one vegetation type to any other, we calculated the cost matrix (Table 3). Supplementary Tables 1-6 detail how Table 3 was calculated, listing the management actions and their relative costs and annual frequencies. Different actions are needed for the different transitions; e.g., for maintaining a present plantation as a plantation, removal of dead trees and fire prevention actions are needed, as well as new plantings if the aim is to achieve a high density plantation. For the 'Low Open' and 'Medium' vegetation types, the cheapest vegetation formation to transition into was 'Medium Dense'. For the 'Tall Dense' and for the two Trees formations, the cheapest transition was to remain the same formation as present. Out of all possible combinations, the cheapest vegetation formation to transform into was 'Medium Dense' (average value of 2,920 NIS/0.1 ha over 30 years), and the most expensive was ‘Low Open’ (average value of 22,080 NIS/0.1 ha over 30 years). The most expensive vegetation formations to transform from (i.e. to change to another type) were 'Medium Sparse' and ‘Medium Dense’ (average values of 15,660 and 14,830 NIS/0.1 ha over 30 years, respectively).

We present the best solution next to the present current distribution of the structural vegetation formations (Fig. 3). The summed solutions map for each of the zones shows how often a specific planning unit was selected for each of the six zones. The summed solutions maps are summarized in the uncertainty map, where the zoning uncertainty was calculated for each of the planning units (Fig. 3).

With no budget limitations, most of the zoning targets were achieved within each of the three scenarios (± 3%, except for three of the six vegetation types in scenario two; Table 4). Out of the three scenarios, the most expensive one was scenario three, in which the objective to prefer early succession stages (Table 4). Within the first scenario (No change), all zoning targets were achieved (± 3%), however certainty in the zoning of planning units was high just for two classes: that of ‘Medium Dense’ and ‘Tall Dense’. The zoning of ‘Tall Dense’ patches in the best solution offered to keep them in their present location, as this is the cheapest option for this zone (Table 3). High certainty areas for the ‘Medium Dense’ zone were located in areas where the present vegetation is either ‘Medium Sparse’ or ‘Medium Dense’; the transformation cost from both these vegetation types into ‘Medium Dense’, is the cheapest option (Table 3). The highest uncertainty was found for the ‘Low Open’ vegetation class (Fig. 3), probably due to high cost of the management actions required to achieve this zone (Table 3) as well as its small target area in this scenario. The areas with the greatest zoning uncertainty and patchiness were those that are at present with planted trees. The costs of transforming between these two zones (‘Trees Dense’ and ‘Trees Sparse’) are quite similar, and therefore a planning unit could be zoned for either of these at a similar probability. The spatial pattern of the zoning of the two tree classes was similar in all scenarios.

In the second scenario (Evenness of structural formations), the target for ‘Medium Dense’ was not achieved. The reason for not meeting the targets may be due to limitations in current proportions of vegetation types and their ability to transition to the desired vegetation types within 30 years, given the penalty factors that were used. Generally, the vegetation type of ‘Medium Dense’ remained with the same percent cover as in the present distribution (~31%), whereas the two tree classes increased in their area from 7% to 10% but did not reach the intended 16% cover (Table 4). Certainty in the zoning of classes was high (> 90%) for the classes of ‘Low Open’ and ‘Tall Dense’, and relatively high (> 50%) for ‘Medium Dense’ (Fig. 4). Within the third scenario (Early successional stages), all targets were achieved (± 3%; Table 4). Certainty in the zoning of classes was high (> 90%) for the classes of ‘Low Open’, ‘Medium Dense’ and ‘Tall Dense’ (Fig. 5).

Overall, the uncertainty was lowest in the first scenario (No change), and highest in the third scenario (Early succession). In the best solutions of all three scenarios, many areas of the park appear to be very patchy having high fragmentation of the six zones, with less patchiness in the western area of the park, where the zoning uncertainty was lower (Fig. 3, 4 and 5). Patchiness can be reduced by changing the values of the zone boundary cost matrix (a zone boundary cost matrix represents the relationship between zones to calculate boundary length costs for our network of planning units; Watts et al., 2008; results not shown). As the planning units in this study are quite small in size, management in the field would be facilitated by having larger compact zones.

When the full budget of the park (2.1 million NIS per year) was available for managing the structural formation of vegetation, the targets of the first and second scenarios (No change and Evenness) were mostly achieved (± 3%, except for the 'Medium Dense' zone in the Scenario 2), however the third scenario (Early succession) was affected as it was the most expensive scenario (2.6 Million NIS/year) and three of its six targets were not achieved (Table 4). When only a partial budget was available (700 thousands NIS per year) the targets were not achieved in any of the scenarios (as this budget was below the yearly average obtained when no budget limitations were imposed; Table 4). The main trend under increased budget limitation was as an increase in the spatial representation of the ‘Medium Dense’ zone in the three scenarios (Table 4), being the cheapest zone to transform into (Table 3). The two ‘Trees’ classes were the least affected by changes in the available budgets, as for them the cheapest option was to remain the same (Table 3).

Discussion

Systematic conservation planning has been widely used in the past two decades to prioritize conservation areas, but is almost always based on the past or current distribution of biodiversity features. With ongoing natural and human-caused environmental changes, it is clear that conservation planning must include ecosystem dynamics and changes in future distributions of species and other biodiversity features (Smith et al. 2001a; Rouget et al. 2003; Meir et al., 2004; Pressey et al., 2007). Here, we have demonstrated that ecosystem dynamics can be incorporated into systematic conservation planning using site selection models (see also Drechsler et al., 2009). In our case, we modelled vegetation succession dynamics from open grasslands to dense garrigue and maquis at the local scale. A similar approach may be applied to ecosystem changes resulting from climate change, land use change and other factors.

While climate change is generally expected to alter environmental conditions, and modify the habitat ranges of species (e.g., Fitzpatrick and Hargrove, 2009), we do not expect major changes in vegetation types within the study area due to climate change, for several reasons: (1) while summer temperatures in Israel were found to be increasing, no significant trend was found in the annual average temperature in Israel (Saaroni et al., 2003); (2) due to the naturally high inter-annual variability of rainfall in semi-arid areas and mediterranean areas, no significant trends in rainfall were observed in most of Israel (Morin, 2011) and vegetation may be adjusted to this natural climatic variability; (3) it is estimated that annual rainfall will decrease over Israel between 4-27% by 2100 (Golan-Angelko and Bar-Or, 2008), however as the study site is not near the transition zone to the desert, its climate will remain mediterranean.

In order to include management options in the conservation planning, we used a modified approach to the basic systematic conservation planning steps originally proposed by Margules and Pressey (2000), altering them to incorporate successional processes (Possingham et al., 2009). A first important step in this approach was to identify the key dynamic processes in the system that can be managed given a realistic spatial scale, time scale and budget framework in the focal system. This can be done with the use of expert opinion. The second step is to identify and spatially map both the present and future (projected) states of the dynamic study system with and without management intervention. In our case this included mapping of the present and potential areas of coverage of each of the structural vegetation formations, which represented different states. The following stage includes defining the management actions required in order to shift among states of the system and their costs. Pre-determined areas with desired uses (for which a single state is required) can be locked in (Watts et al. 2008). Different states can be spatially redistributed to allow for more effective solutions. This can be done, for example, by determining the degree of patchiness or buffer zones desired (Watts et al., 2008; Klein et al., 2010; Wilson et al., 2010). Next, multiple scenarios can be compared given different goals for each of the states (for example in our case we changed the proportion of the total area required for each structural vegetation formation state and rerun the scenarios). Finally, results are evaluated against the available budget, time frame and original targets.

The approach we have outlined has important outcomes beyond the incorporation of dynamic threats and responses within a planning framework. While protected areas are traditionally perceived as the major biodiversity conservation strategy, recent studies attempt a more realistic approach to conservation planning, and incorporate multiple land uses and unprotected areas (e.g., agricultural production and urban landscapes) to achieve conservation goals (e.g., Klein et al., 2010; Wilson et al., 2010; Douglass et al. 2011). We have shown that this type of spatial management plan can be applied at the local scale, using detailed biodiversity, management and cost data within a long-term ecological research station in Israel. A similar zoning approach can be easily adapted in other Mediterranean ecosystems, using the knowledge and transition matrices developed in this case study, and adjusting the costs to those of other countries. While we used expert knowledge to estimate the future distribution of vegetation formations, this can also be achieved using modelling approaches (e.g., Smith et al., 2001b) where no expert opinion is available, or when analysing over large areas in space and at various time steps.

Mediterranean ecosystems are characterized by their heterogeneity and as being a dynamic mosaic of vegetation formations (Perevolotsky, 2005). Shaped over millennia by human disturbances such as cutting, grazing and burning, the Mediterranean landscape is a composed of a mosaic of patches at varying regeneration stages of woody vegetation. Model simulations and field data demonstrate that highly disturbed vegetation is dominated by herbaceous plants whereas under no disturbance tall woody plants dominate (Koniak and Noy-Meir, 2009). While base ecological data exists, the zoning (spatial allocation of desired land use/management option) of the key structural vegetation formations allowed us to propose alternate management options for park managers that address dynamic succession processes in this system.

In this study we focused on three scenarios representing different proportions of six structural vegetation types, using the revised formulation of Marxan, termed ‘‘Marxan with Zones’’ (Watts et al. 2009). Most previous applications of Marxan assume that biodiversity features are fixed in space and apply have been applied to spatially allocate the conservation status or management of a planning unit. A novelty of this study is that biodiversity features were treated as the zones, i.e. in our scenarios the zoning (i.e. management) is the type of vegetation, whose spatial location and distribution is subject to natural processes (succession) as well as human manipulation through actions such as planting, clearing, grazing, burning, weeding etc. Because the entire study area is managed as a nature park and because the park is rather small (~ 450 ha) manipulation of the landscape is feasible and some (cattle and goat grazing) has already been applied.

The results of the Marxan runs were highly dependent on the costs and on the present distribution of the structural vegetation types. We used a classification uncertainty metric, which measures to what degree was a planning unit assigned to a specific zone from all the possible zones. Mapping this metric enables the park managers to visually grasp in which areas the results of the algorithm are quite robust, and in which areas other considerations (e.g., landscaping) can or should be used, as based on the costs various management options are relevant there. While linear integer programming may enable to find a single best solution, the approach applied in Marxan acknowledges uncertainties resulting from the input data layers as well as from the model assumptions, and instead of offering a single solution, provides the decision makers with a range of possible solutions from which they can choose (Ball et al., 2009; Linke et al., 2011). New systematic planning tools available allow us today, better than before, to plan systematically at small scales in changing systems and provide management advice considering both ecological processes and economic factors. We believe that this approach may contribute to the efficiency of conservation planning in other systems, areas and spatial scales.

Acknowledgements

We thank Matt Watts for his help with Marxan with Zones and the Ramat Hanadiv Park staff for their assistance and Carissa Klein for comments on the manuscript. Hugh Possingham was supported by an ARC Federation Fellowship.

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Tables

Table 1: The steps used in the dynamic conservation planning process

Step	Action	Description
1	Define objectives	Define overall goals for the park management.
2	List biodiversity assets	Identify the assets of interest; in this case the vegetation formations.
3	Spatially map assets	Map the current and potential distribution of assets.
4	Set targets	Identify the conservation targets for each of the biodiversity assets.
5	List management actions	Identify the set of feasible management actions that can achieve the desired objectives.
6	Estimate cost	Calculate the costs for each management action.
7	Choose set of management actions	Combine information on costs to rank projects according to benefits per unit dollar, using Marxan with Zones.
8	Explore the effects of budget limitation	Compare the effects of different budget limitations on the conservation targets.

Table 2: The present distribution and targets set for each of the six vegetation structural formations for each scenario: (1) no change – maintaining the present proportions of vegetation formations; (2) evenness of structural formations – each formation will have the same proportion in the park (or will cover the same area size); (3) early succession stages – favouring low vegetation cover and herbaceous vegetation:

Assets	Description	Current area (ha)	Scenario 1: No change (%)	Scenario 2: Evenness (%)	Scenario 3: Early succession (%)
Low open	Open habitats that are mostly covered with herbaceous vegetation (<0.5m) with sparse scrub (<33% cover) within them	11.0	2.6	16.7	32.6
Medium sparse	Mediterranean garrigue comprised of woody vegetation which is of medium height (<2.5m) with low vegetation cover (<33%)	162.4	38.0	16.7	22.3
Medium dense	Mediterranean garrigue comprised of woody vegetation which is of medium height (<2.5m) with vegetation cover greater than 33%	136.1	31.8	16.7	17.4
Tall dense	Mediterranean maquis comprised of woody vegetation whose height is between 2.5-5m and the vegetation cover is greater than 33%	55.6	13.0	16.7	13.0
Trees sparse	A planted forest where the trees' height is above 5m and the vegetation cover is low (<33%)	31.5	7.4	16.7	7.4
Trees dense	A planted forest where the trees' height is above 5m and the cover of the species is greater than 33%	31.3	7.3	16.7	7.3
Total		427.9	100.0	100.0	100.0

Table 3: The cost in New Israel Shekel (NIS; US $1 =~ 3.5 NIS) for maintaining or changing each structural vegetation formation (see Figure 1) to any of the other vegetation formation, over a period of 30 years, within an area of 0.1 ha

		From (present condition)					
		Low Open	Medium Sparse	Medium Dense	Tall Dense	Trees Sparse	Trees Dense
To (future condition)	Low Open	9,500	49,000	41,500	25,000	3,500	4,000
	Medium Sparse	2,750	12,000	14,000	4,500	5,000	5,500
	Medium Dense	2,000	1,000	1,500	4,500	4,000	4,500
	Tall Dense	4,750	4,750	4,750	250	4,000	4,750
	Trees Sparse	11,500	11,750	11,750	9,750	250	2,250
	Trees Dense	11,500	15,500	15,500	11,750	2,250	2,250

Table 4: The achieved distribution of the six zones in the best solution of each scenario under three budget limitations: no budget limitations, full budget (2.1 million NIS per year) and partial budget (700 thousand NIS per year). The three scenarios are: (1) no change – maintaining the present proportions of vegetation formations; (2) evenness of structural formations – each formation will have the same proportion; (3) early succession stages – favoring low vegetation cover and herbaceous vegetation. Detailed scenario definitions in Table 1. All columns sum up to 100%. The budget spent is the bottom row is in Millions of New Israeli Shekel per year.

Structural vegetation formation	Scenario 1: No change (%)				Scenario 2: Evenness of structural formations (%)				Scenario 3: Early succession stages (%)			
	Target	Best Solution			Target	Best Solution			Target	Best Solution		
		No budget limitations	Full budget	Partial budget		No budget limitations	Full budget	Partial budget		No budget limitations	Full budget	Partial budget
Low open	2.6	2.6	2.6	2.5	16.7	16.6	16.6	3.4	32.6	32.3	26.5	4.1
Medium sparse	38.0	37.6	37.6	25.9	16.7	16.5	16.5	16.5	22.3	22.1	22.0	22.0
Medium dense	31.8	34.3	34.8	48.1	16.7	31.5	31.7	46.0	17.4	20.6	27.6	52.0
Tall dense	13.0	11.1	10.5	8.9	16.7	15.0	14.6	13.6	13.0	10.4	9.4	7.4
Trees sparse	7.4	7.2	7.2	7.3	16.7	10.3	10.2	10.2	7.4	7.3	7.2	7.2
Trees dense	7.3	7.3	7.3	7.3	16.7	10.1	10.4	10.4	7.3	7.3	7.3	7.3
Budget spent		1.0	1.0	0.7		1.6	1.6	0.7		2.6	2.1	0.7

Figure legend

Figure 1: Location of Ramat Hanadiv Park within Israel (A); the present distribution of vegetation types (B) and a 2009 orthophoto of the study area (C). Representative photos of the six vegetation types: Low Open (D), Medium Sparse (E), Medium Dense (F), Tall Dense (G), Trees Sparse (H), Trees Dense (I).

Figure 2: The potential distribution of the six vegetation types as identified in this study (the current distribution area is also a potential distribution area).

Figure 3: Results for scenario 1 (as present). The current distribution can be compared with the best solution within the Marxan runs. The uncertainty map expresses whether in different runs a planning unit was assigned to different zones or to the same zone (i.e. high certainty). The six grey scale maps present how often was a planning unit chosen for a specific zone.

Figure 4: Results for scenario 2 (evenness). The current distribution can be compared with the best solution within the Marxan runs. The uncertainty map expresses whether in different runs a planning unit was assigned to different zones or to the same zone (i.e., high certainty). The six grey scale maps present how often was a planning unit chosen for a specific zone.

Figure 5: Results for scenario 3 (opening up). The current distribution can be compared with the best solution within the Marxan runs. The uncertainty map expresses whether in different runs a planning unit was assigned to different zones or to the same zone (i.e., high certainty). The six grey scale maps present how often was a planning unit chosen for a specific zone.

Figure 1

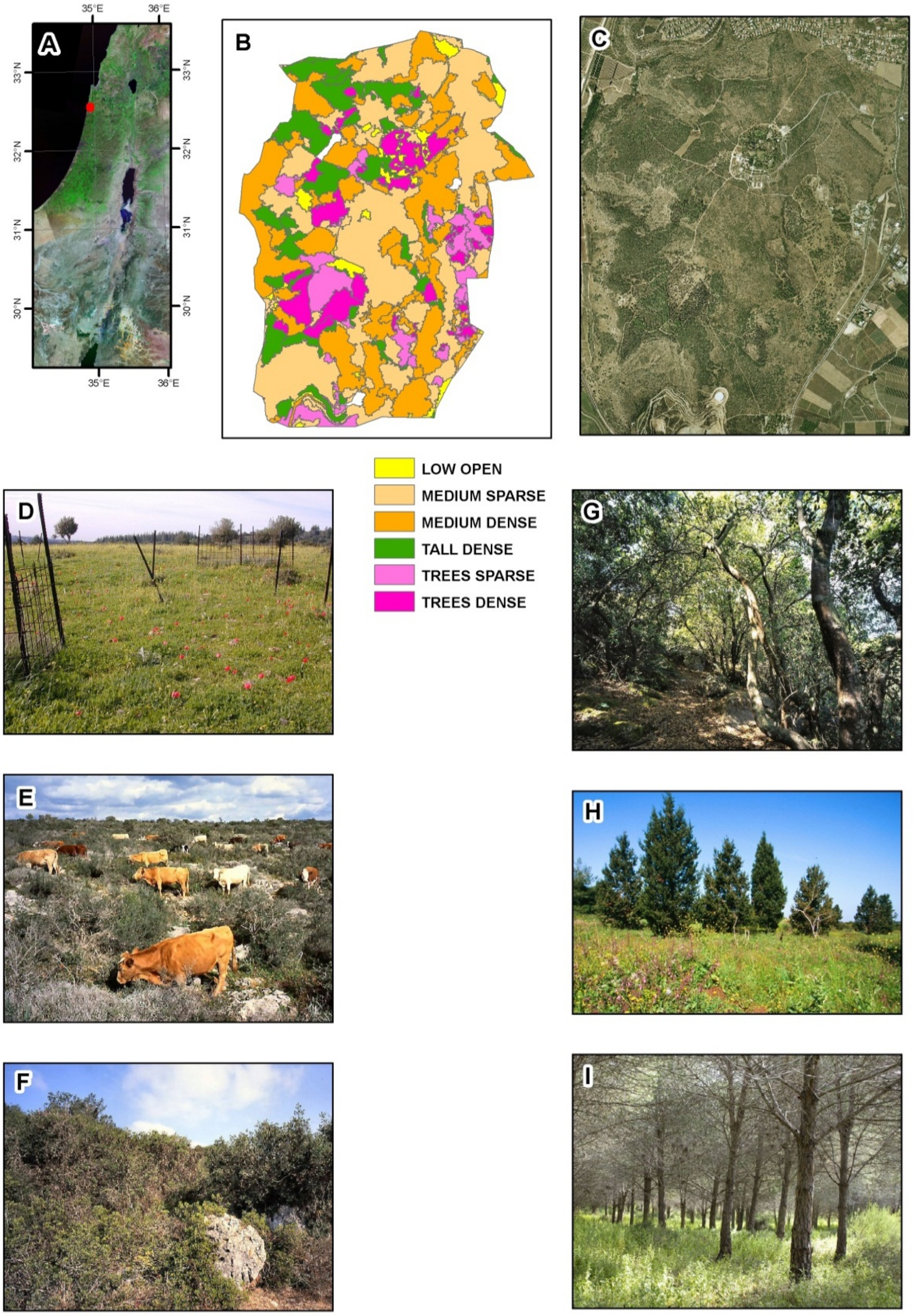

A
35°E
36°E
33°N
32°N
31°N
30°N
B
C
LOW OPEN
MEDIUM SPARSE
MEDIUM DENSE
TALL DENSE
TREES SPARSE
TREES DENSE
D
E
F
G
H
I

Figure 2

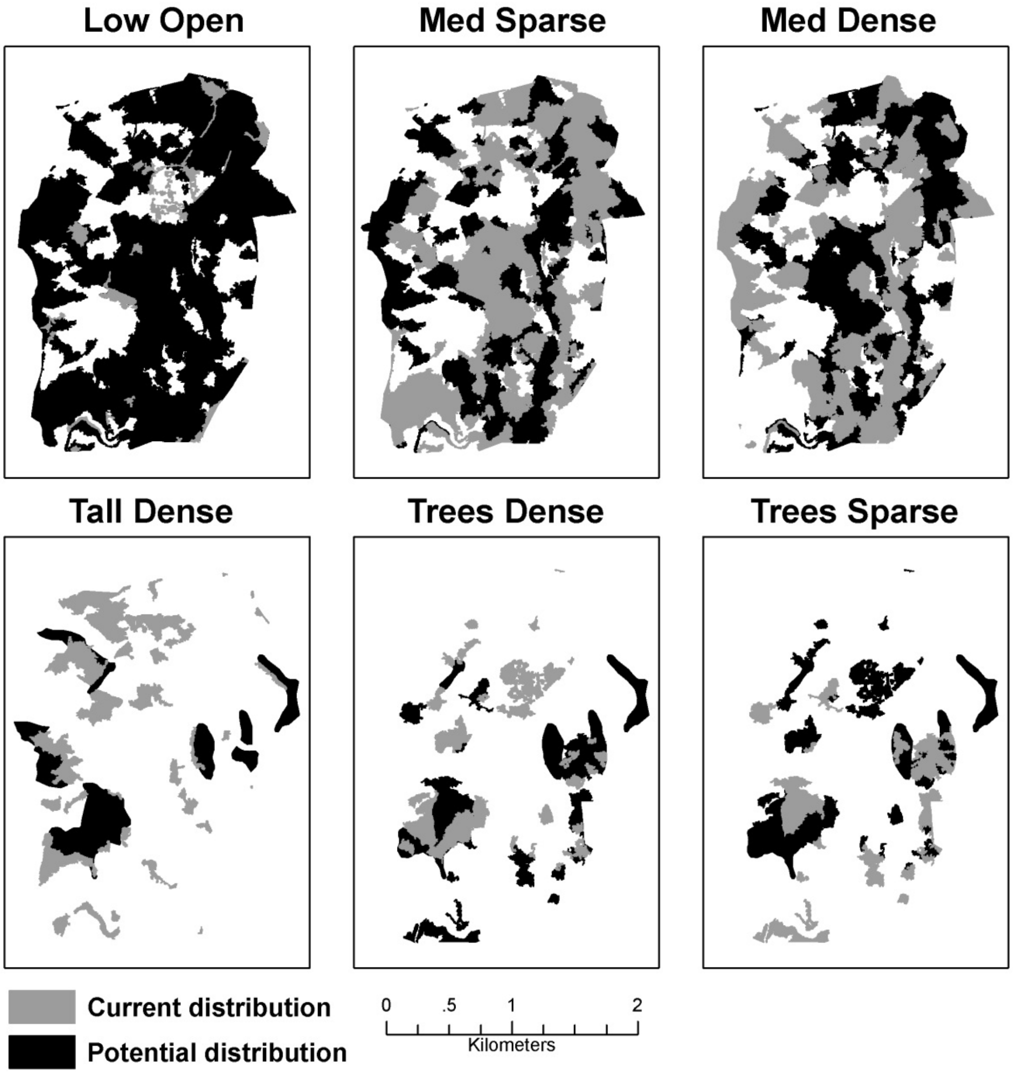
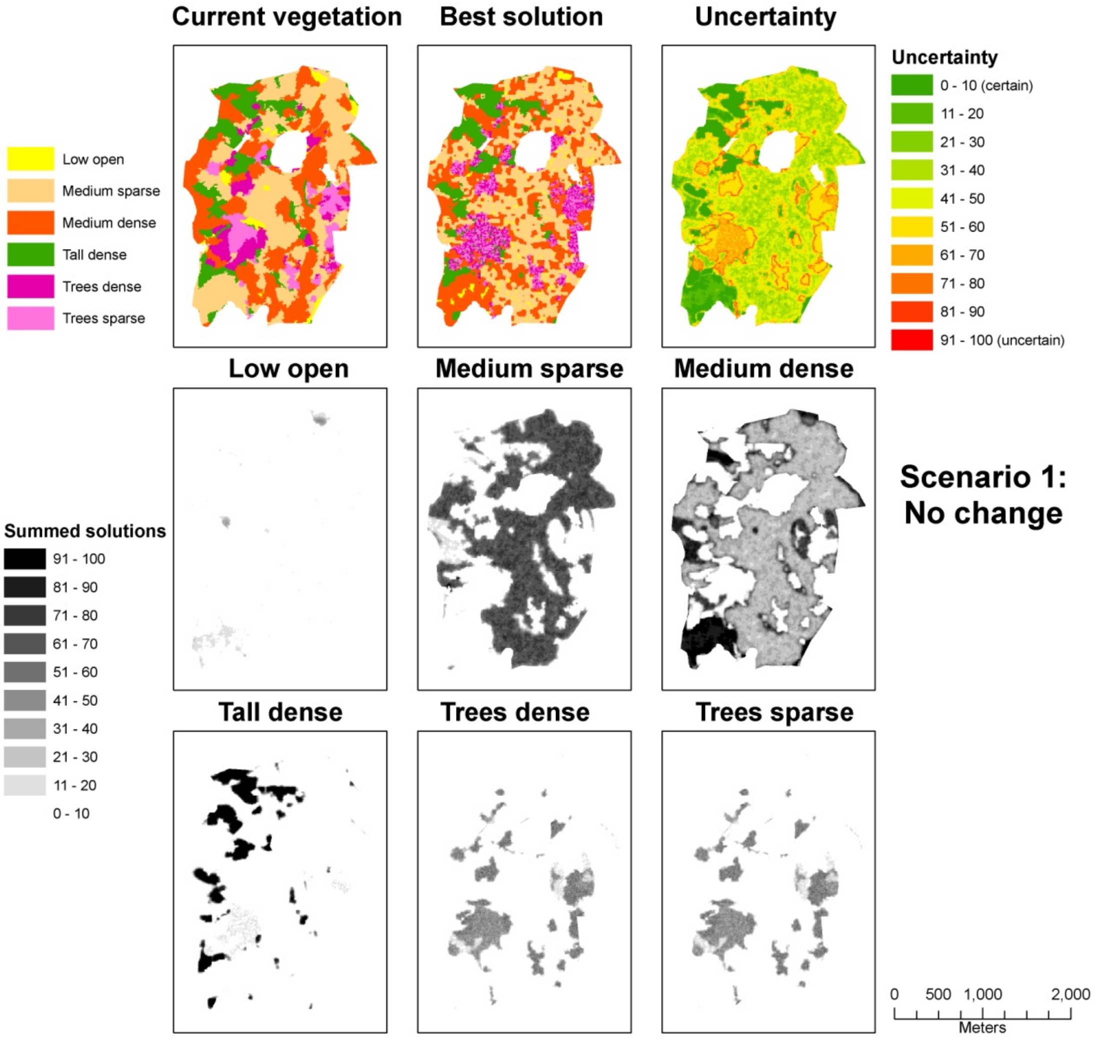
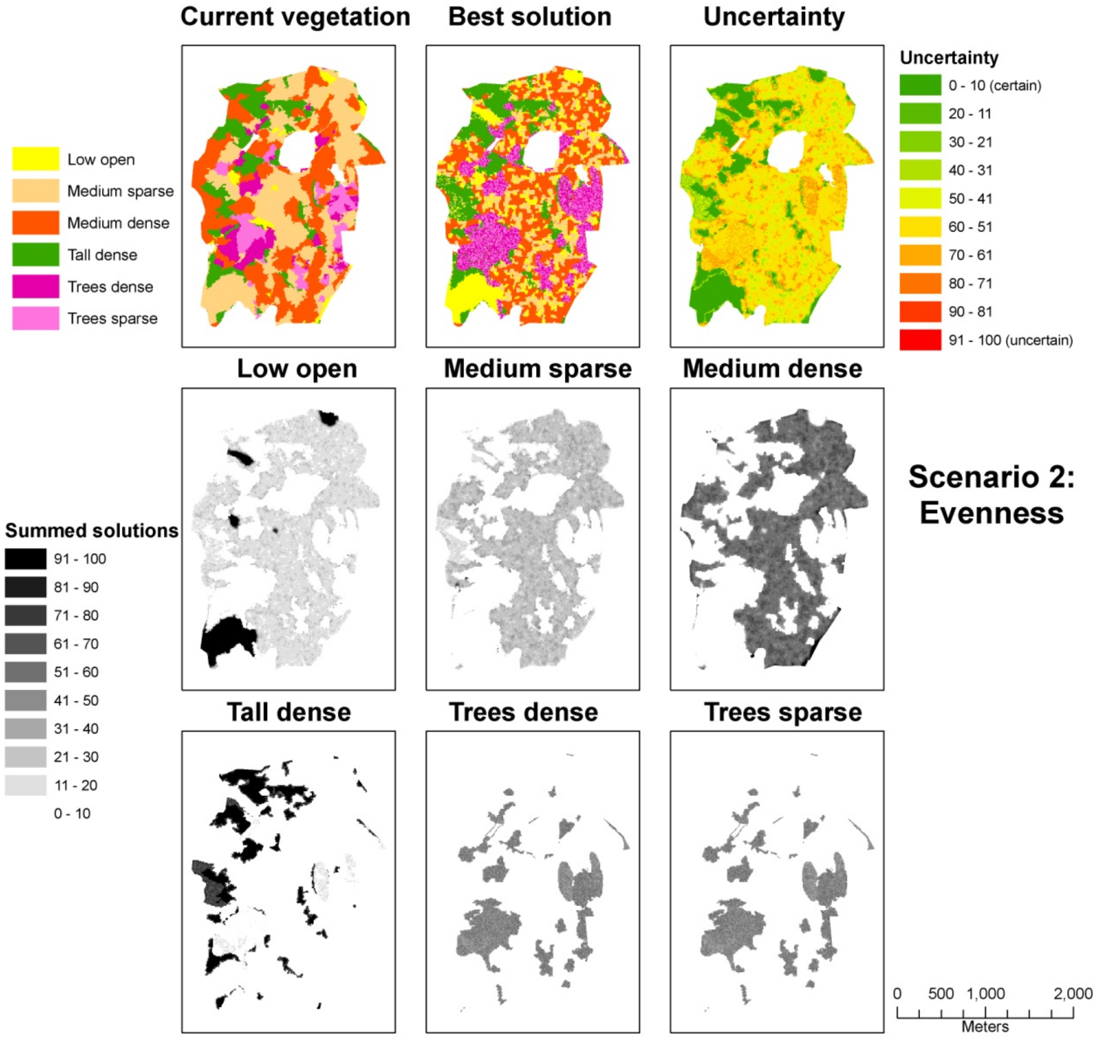

Low Open
Med Sparse
Med Dense
Tall Dense
Trees Dense
Trees Sparse
Current distribution
Potential distribution
0
.5
1
2
Kilometers

Figure 3


Current vegetation
Best solution
Uncertainty
Low open
Medium sparse
Medium dense
Tall dense
Trees dense
Trees sparse
Uncertainty
0 - 10 (certain)
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100 (uncertain)
Low open
Medium sparse
Medium dense
Scenario 1:
No change
Summed solutions
91 - 100
81 - 90
71 - 80
61 - 70
51 - 60
41 - 50
31 - 40
21 - 30
11 - 20
0 - 10
Tall dense
Trees dense
Trees sparse
0
500
1,000
2,000
Meters

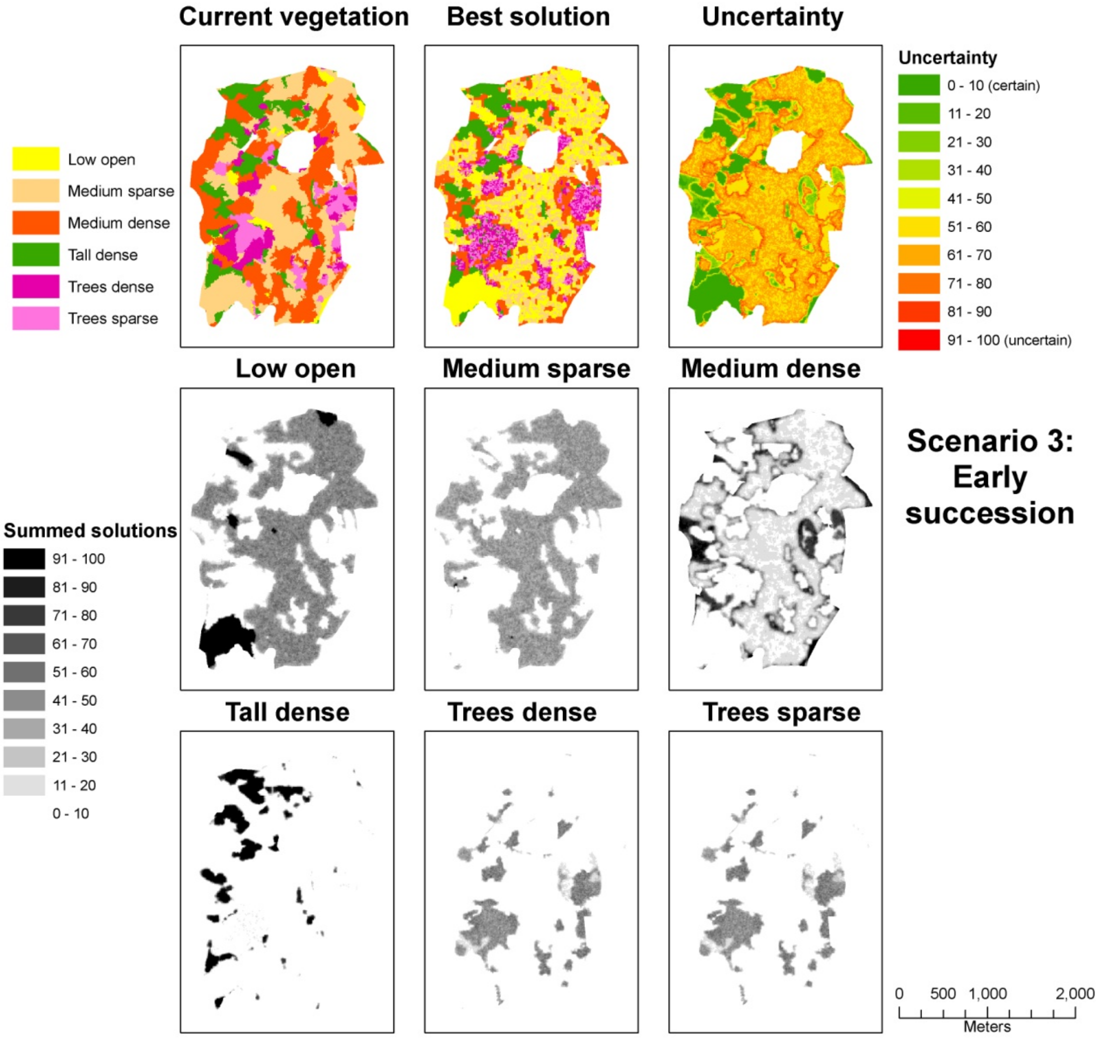
33 Figure 4



34

35

Figure 5


Current vegetation
Best solution
Uncertainty
Low open
Medium sparse
Medium dense
Tall dense
Trees dense
Trees sparse
Uncertainty
0 - 10 (certain)
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100 (uncertain)
Low open
Medium sparse
Medium dense
Scenario 3: Early succession
Summed solutions
91 - 100
81 - 90
71 - 80
61 - 70
51 - 60
41 - 50
31 - 40
21 - 30
11 - 20
0 - 10
Tall dense
Trees dense
Trees sparse
0
500
1,000
2,000
Meters