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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 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 spatio-temporal 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 structural types of vegetation 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 (4.5 km^2) holds 660 species of native plants and six structural types of vegetation. 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). By spatially redistributing the six structural vegetation types under three scenarios, representing different conservation objectives (no change, equal distribution – evenness of structural types, preference to 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 structural types and the cost of changing one structural 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 relatively inexpensive structural type to maintain. The approach presented here can be further applied to spatially prioritize conservation goals in the face of shifting environments and climates, allowing dynamic conservation planning at multiple spatial scales.

1. Introduction

Systematic conservation planning tools and approaches are increasingly used by both government and non-government organizations (NGOs) 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

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can help to both clarify goals and plan strategically (Joseph et al., 2009; Watson et al., 2011a). Spatial decision support tools (e.g., Marxan, developed by Ball and Possingham, 2000; Possingham et al., 2000; Zonation, developed by 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 actions (Knight et al., 2006; Pressey and Bottrill, 2009; Joseph et al., 2011; Marignani and Blasi, 2012).

One major limitation to current 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, 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 have not been used in reserve site selection models (such as Marxan, developed by Ball and Possingham, 2000).

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), designing 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 usually 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 ecological 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 dynamics in space or in time need to taken into account in dynamic conservation planning (Pressey et al., 2007). The bias towards conservation planning at regional and global scales unfortunate as many conservation decisions occur at the local level (a reserve or park) and local conservation efforts can 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 conventional 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 in the Mediterranean Basin during the last few decades due to socio-economic changes (Perevolotsky and Seligman, 1998). Nowadays, conservation management in these regions is complicated also 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 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; Levin and Heimowitz, 2012). 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 over 30 years while minimizing 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).

2. Methods

2.1. 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, and operated for the benefit of the general public by the Rothschild Foundation (Yad Hanadiv). The site covers approximately 4.5 km^2 on a plateau at the southern tip of the Carmel mountain range in NW Israel (Fig. 1). In comparison, the average area of nature reserves in Israel 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 1970s, 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 managers seek to conserve and nurture diverse habitats to support high species richness and biodiversity (660 plant species; Liat Hadar, personal communication). In order to achieve these goals, various management operations have been

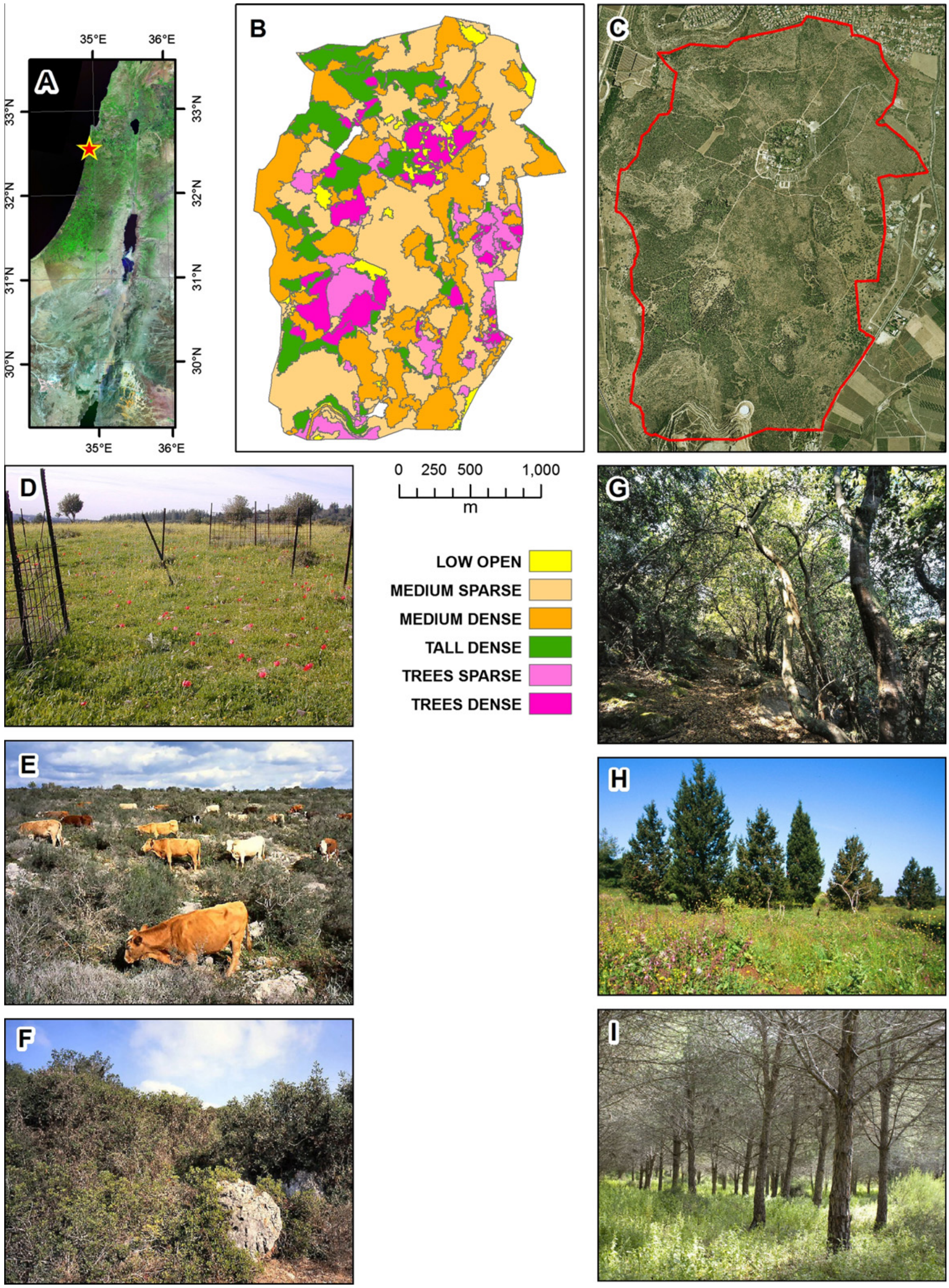

Fig. 1. Location of Ramat Hanadiv Park within Israel (A); the present distribution of structural vegetation types (B) and a 2009 orthophoto of the study area (C). Representative photos of the six structural types: low open (D), medium sparse (E), medium dense (F), tall dense (G), trees sparse (H), and trees dense (I).

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 and 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 at all levels. As such, it can serve as an example of nature conservation and management of Mediterranean ecosystems in Israel and the region. Here, we demonstrate a stakeholder engagement process for identifying conservation objectives (sensu Nicholson and Possingham, 2006) and targets (sensu Sanderson, 2006), using realistic working definitions of benefits and costs.

2.2. Spatial analysis using Marxan with Zones

2.2.1. Marxan with Zones

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:

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

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 (*ConValue*) in the reserve system (conservation feature penalty factor; *CFPF*). For the formal formulation of the Marxan algorithm see Watts et al. (2009).

However, the original version of Marxan was limited to certain conservation applications and 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 included 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 designate areas for specific purposes (McCook et al., 2010). Marxan has recently been revised and can now be used to 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 structural types of vegetation 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 structural type to be created or maintained using a defined set of management actions.

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

2.2.2. 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 for 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.

2.2.3. 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, dominated by annuals plant species), medium-sparse garrigue (medium-sized shrubs, dominated by *P. latifolia* and *P. lentiscus*, partial cover), medium-dense garrigue (medium-sized shrubs, dominated by *P. latifolia* and *P. lentiscus*, complete cover), tall-dense maquis (stands of oak trees on favorite habitat), trees-sparse (thinned planted groves of either pine or cypress trees) and trees-dense (planted groves of either pine or cypress trees). A more comprehensive definition for each of these structural types of vegetation and their dominant plant species is provided in Table 2.

2.2.4. Step 3: spatially map assets

The next step was to spatially map the present distribution of assets in the park and to determine 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 as $10\,m \times 10\,m$ grid cells resulting in 43,998 units. We selected $10\,m \times 10\,m$ because of the spatial heterogeneity within the park and the availability of high spatial resolution data. The present distribution of the structural vegetation types was derived from GIS layers created through automated seg-

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); and (3) early succession stages – favoring low vegetation cover and herbaceous vegetation:

<table>
<tr><th>Assets</th><th>Description</th><th colspan="2">Dominant species</th><th>Current area (ha)</th><th>Scenario 1: no change (%)</th><th>Scenario 2: evenness (%)</th><th>Scenario 3: early succession (%)</th></tr>
<tr><td>Low-open</td><td>Open habitats that are mostly covered with herbaceous vegetation (<0.5 m) with sparse scrub (<33% cover) within them</td><td colspan="2">Sarcopoterium spinosum, rich herbaceous vegetation: 70% annuls (Brachypodium distachyon, Urospermum picroides); 30% perennial grasses (Piptatherum blancheanum), and geophytes (e.g., Asphodelus ramosus, Anemone coronaria)</td><td>11.0</td><td>2.6</td><td>16.7</td><td>32.6</td></tr>
<tr><td>Medium-sparse</td><td>Mediterranean garrigue comprised of woody vegetation which is of medium height (<2.5 m) with low vegetation cover (<33%)</td><td colspan="2" rowspan="2">Phillyrea latifolia, Pistacia lentiscus, Calicotome villosa[4] climbers</td><td>162.4</td><td>38.0</td><td>16.7</td><td>22.3</td></tr>
<tr><td>Medium-dense</td><td>Mediterranean garrigue comprised of woody vegetation which is of medium height (<2.5 m) with vegetation cover greater than and equal to 33%</td><td>136.1</td><td>31.8</td><td>16.7</td><td>17.4</td></tr>
<tr><td>Tall-dense</td><td>Mediterranean maquis comprised of woody vegetation whose height is between 2.5 and 5 m and the vegetation cover is greater than and equal to 33%</td><td colspan="2">Quercus calliprinos, Phillyrea latifolia, Pistacia lentiscus + climbers</td><td>55.6</td><td>13.0</td><td>16.7</td><td>13.0</td></tr>
<tr><td></td><td></td><td>Cypress</td><td>Pine</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Trees-sparse</td><td>A planted forest where the tree height is above 5 m and the vegetation cover is low (<33%)</td><td>Cupressus sempervirens, rich herbaceous vegetation (e.g., Allium schubertii, Salvia pinnata)</td><td>Pinus brutia or Pinus pinea, Rhamnus lycoides, rich herbaceous vegetation (e.g., Anemone coronaria)</td><td>31.5</td><td>7.4</td><td>16.7</td><td>7.4</td></tr>
<tr><td>Trees-dense</td><td>A planted forest where the tree height is above 5 m and the cover of the species is greater than and equal to 33%</td><td></td><td>Pinus brutia, Asparagus aphyllus, Cyclamen persicum</td><td>31.3</td><td>7.3</td><td>16.7</td><td>7.3</td></tr>
<tr><td>Total</td><td></td><td></td><td></td><td>427.9</td><td>100.0</td><td>100.0</td><td>100.0</td></tr>
</table>

mentation of remotely sensed vegetation height and cover maps derived from LiDAR imagery (Bar Massada et al., 2012; Fig. 1). The potential distribution of the structural vegetation types was defined by experts (Ramat Hanadiv research team and park managers), based on the best available knowledge using soil, lithology, topography and micro-climate considerations, as well as previous modelling of vegetation succession dynamics (Koniak and Noy-Meir, 2009; Fig. 2). Additional considerations in the potential distribution map, related to the sustainability vision of the park, e.g., in which areas of the park plantations are wanted and in which areas not, and what seems to be management-wise feasible. 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.

2.2.5. Step 4: set targets

For the fourth step of target setting, we asked experts to (as explained previously) 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 the following three scenarios. Each of the scenarios is described hereby, including the percentage of each asset (i.e. of each of the structural vegetation formations; 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 (even proportions) 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, favoring 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 favor higher species richness and high primary productivity areas, as more annual species are able to thrive there (Osem et al., 2002).

2.2.6. 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 between states, we identified the full sets of actions required over a period of 30 years. The following actions were de-

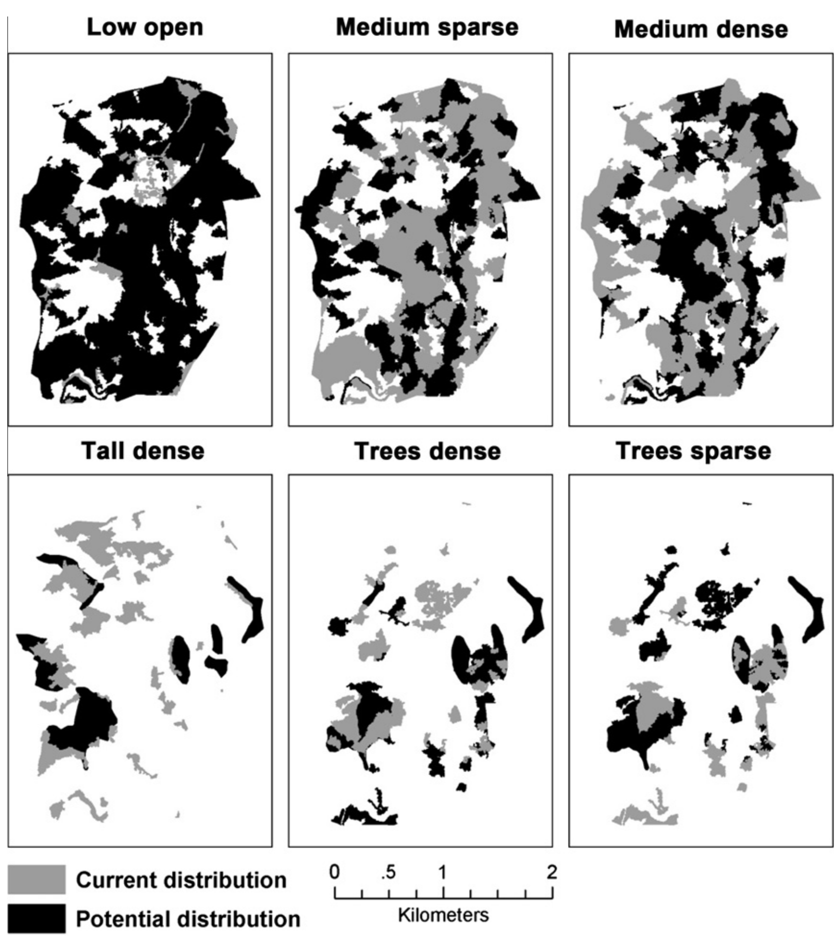

Fig. 2. The potential distribution of the six structural vegetation types as identified in this study (the current distribution area is also a potential distribution area).

Table 3
The cost in New Israel Shekel (NIS; US $1 = ~4 NIS) for maintaining or changing each structural vegetation formation (see Fig. 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	9500	49,000	41,500	25,000	3500	4000
Medium sparse	2750	12,000	14,000	4500	5000	5500
Medium dense	2000	1000	1500	4500	4000	4500
Tall dense	4750	4750	4750	250	4000	4750
Trees sparse	11,500	11,750	11,750	9750	250	2250
Trees dense	11,500	15,500	15,500	11,750	2250	2250

fined: '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.

2.2.7. Step 6: estimate costs

The cost of each set of management actions for every transition between the structural 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 (only expenses were considered, whereas possible incomes from; e.g., livestock sales or tourism were not included); whereas, past outlays were not considered.

2.2.8. Step 7: choose set of actions

Each Marxan with Zones run had 1,000,000 iterations, and we repeated the runs for each scenario 100 times 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 always 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 analyze 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". This best solution 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 following the common approach used in remote sensing studies (Eastman, 2009):

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

where *max* is 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) and *n* is 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 structural type) and not to alternative zones can also be interpreted as certainty for assigning that planning unit for that zoning.

2.2.9. 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 $652,500) for park management. Nonetheless, they have not 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.

3. Results

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

Based on the management actions listed by the park managers required to transform from any one structural type to any other, we calculated the cost matrix (Table 3). Supplementary Tables 1–6 explain 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

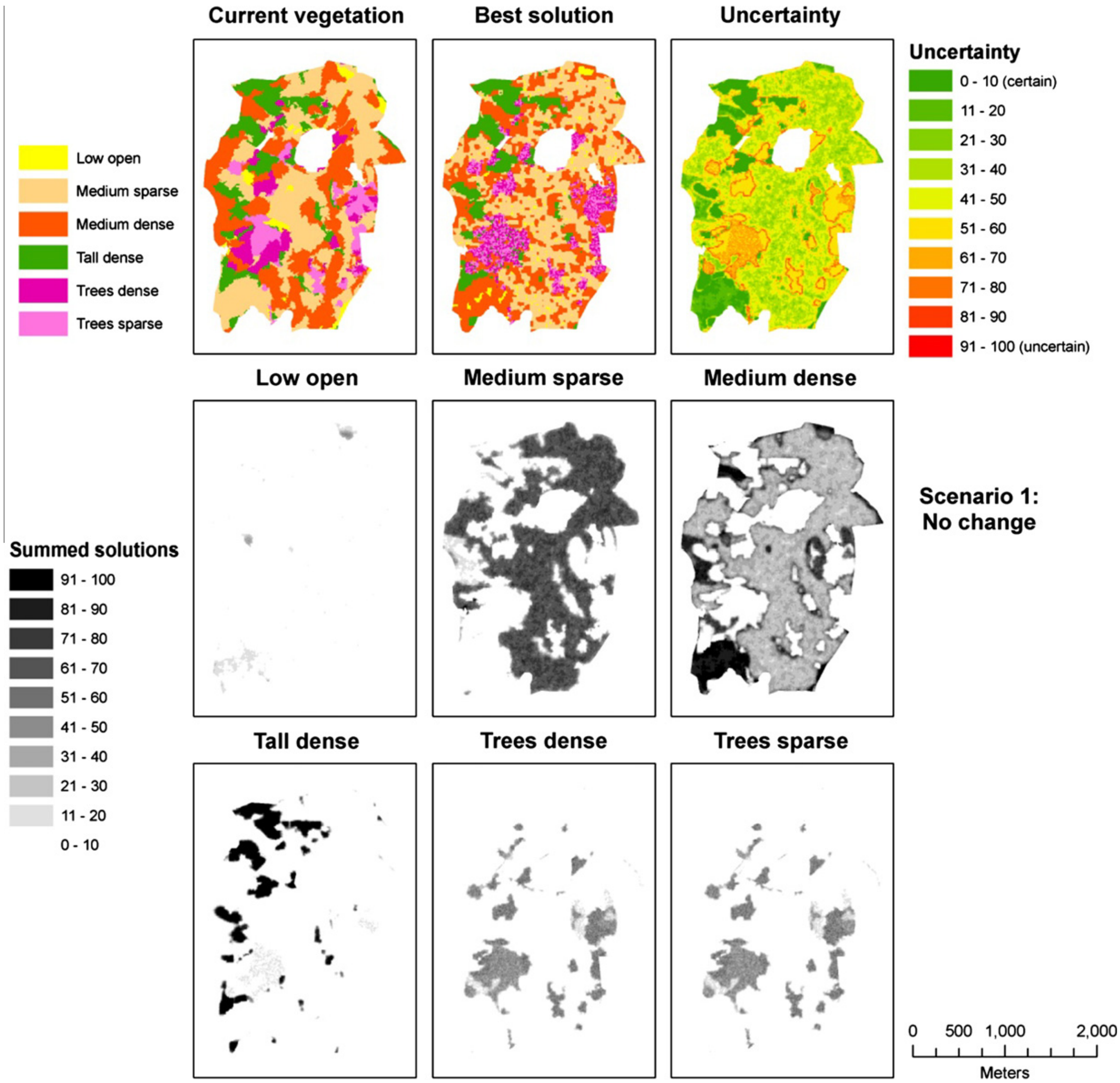

Fig. 3. Results for scenario 1 (as present). The current distribution can be compared with the best solution within the Marxan runs. The uncertainty map expresses whether in different runs a planning unit was assigned to different zones or to the same zone (i.e. high certainty). The six gray scale maps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

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' structural types, the least expensive vegetation formation to transition into was 'medium dense'. For the 'tall dense' and for the two trees formations, the most inexpensive transition was maintaining the same formation as in 30 years present. Out of all possible combinations, the most inexpensive vegetation formation to transform into was 'medium dense' (average value of 2920 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 structural types in scenario two; Table 4). Out of the three scenarios, the most expensive one was scenario three, in which the objective to was 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 least expensive 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 structural types into 'medium dense', is the most inexpensive 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 with high patchiness were those that are at present with planted trees.

Table 4
The achieved distribution (in%) 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 targets in 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; and (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 (NIS) 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 (millions of NIS/year)		1.0	1.0	0.7		1.6	1.6	0.7		2.6	2.1	0.7

The costs of transforming between these two zones ('trees dense' and 'trees sparse') were 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 structural types and their ability to transition to the desired structural types within 30 years, given the penalty factors that were used. Generally, the structural type of 'medium dense' remained with the same percent cover as in the present distribution ($\sim$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 (Figs. 3–5). 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 were quite small in size, management in the field would be facilitated by having larger compact zones.

When the full budget of the managing 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 (700,000 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 least expensive zone to transform into (Table 3). The two 'trees' classes were the least affected by changes in the available budgets, as for them the least expensive option was to remain the same (Table 3).

4. 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.

In order to include management options in our 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 of 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 step includes defining the management actions required in order to shift among system states 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 reran 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 within a long-term ecological research station in Israel this type of spatial management plan can be applied at the local scale, using detailed biodiversity, management and cost data. A similar zoning approach can easily be 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 working 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 with no disturbance tall woody plants dominate (Koniak and Noy-Meir, 2009). While basic 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. There are multiple benefits gained from vegetation in Mediterranean landscapes, however different structural vegetation types maximize different benefits; e.g., herbaceous vegetation maximizes the abundance of geophytes and nectar for honey, whereas tall shrubs provide more fleshy fruits used by birds (Koniak et al., 2009). Heavier grazing pressures appear to increase ge-

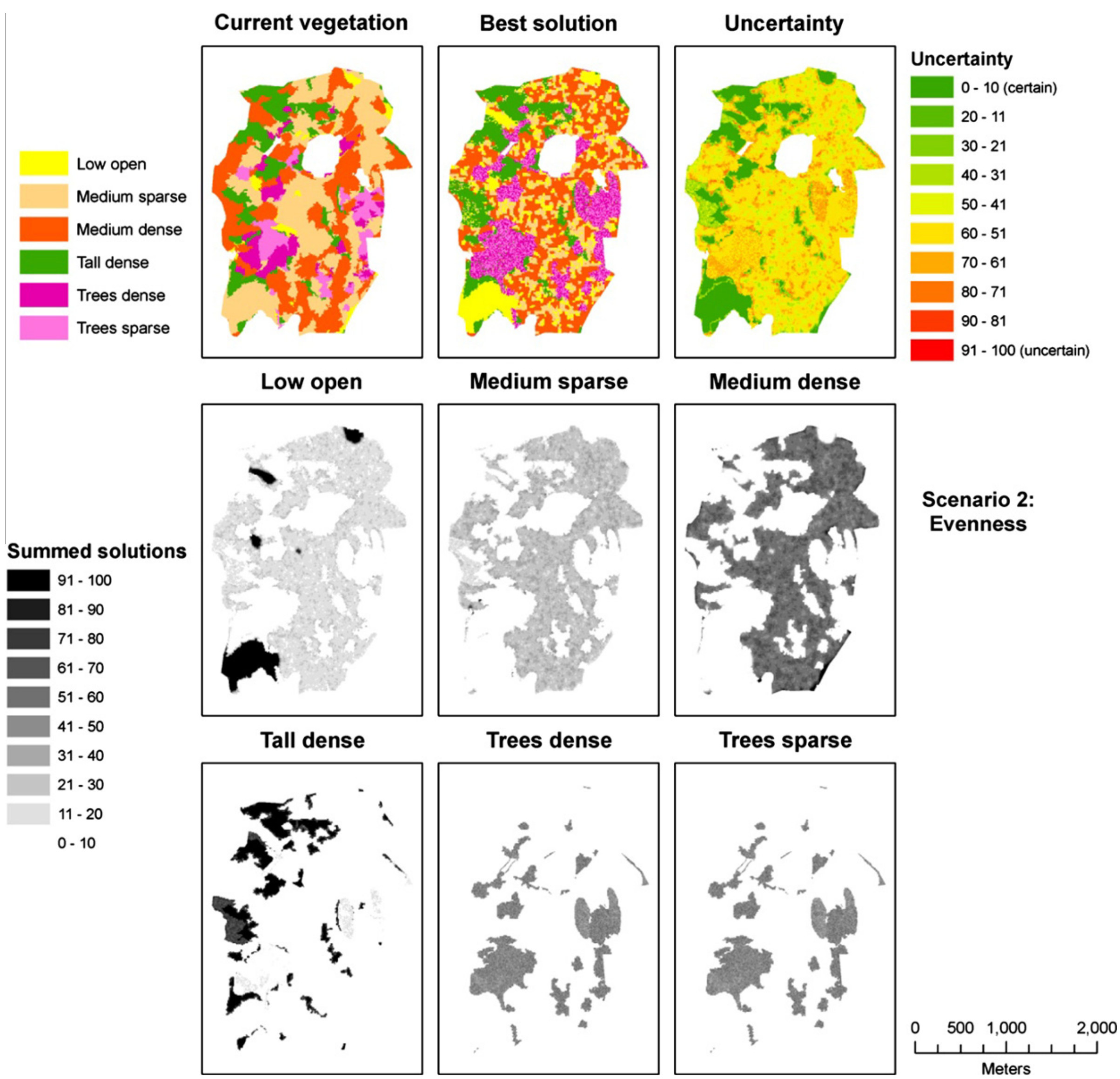

Fig. 4. Results for scenario 2 (evenness). The current distribution can be compared with the best solution within the Marxan runs. The uncertainty map expresses whether in different runs a planning unit was assigned to different zones or to the same zone (i.e., high certainty). The six gray scale maps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

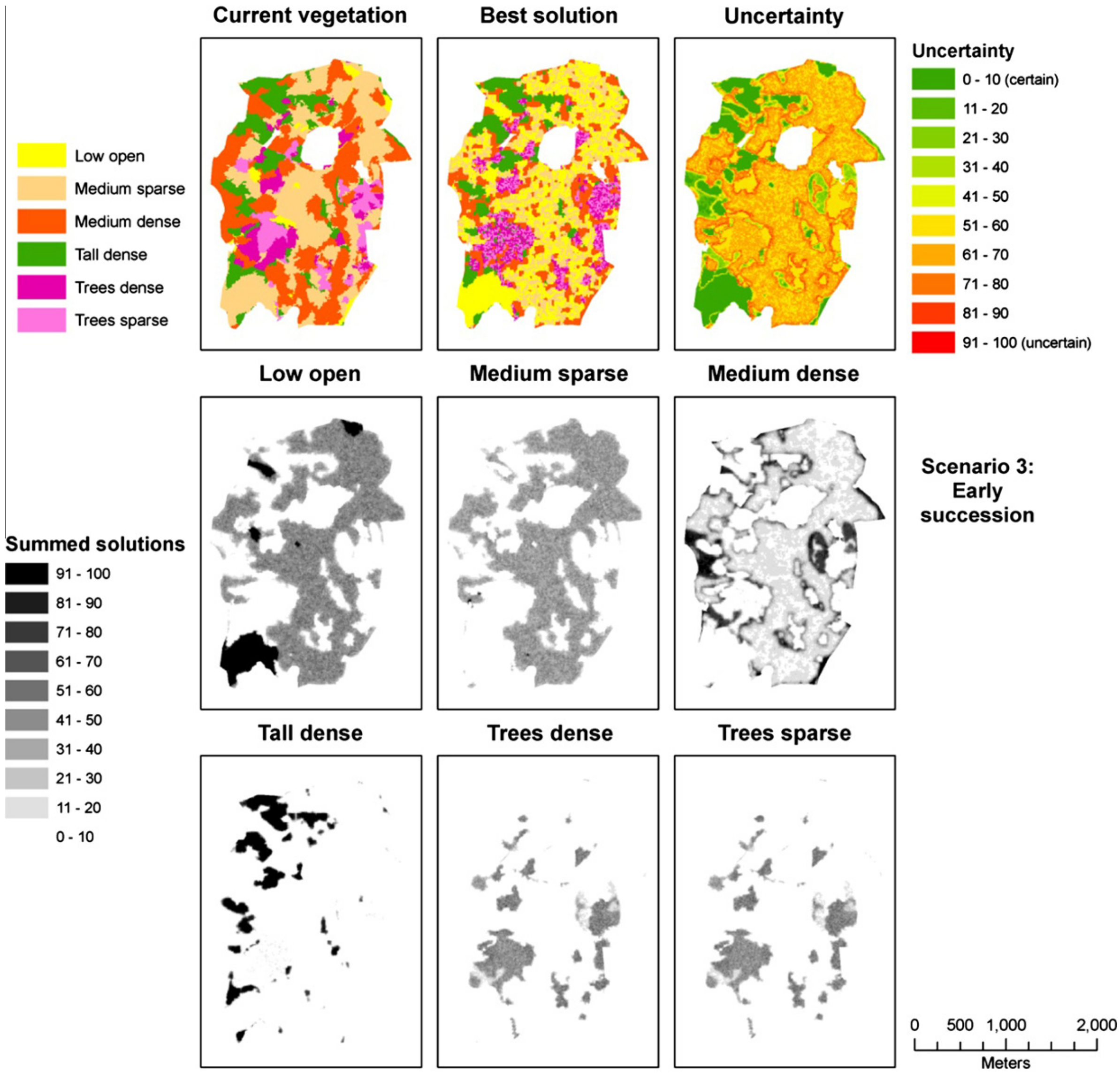

Fig. 5. Results for scenario 3 (opening up). The current distribution can be compared with the best solution within the Marxan runs. The uncertainty map expresses whether in different runs a planning unit was assigned to different zones or to the same zone (i.e., high certainty). The six gray scale maps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

netic diversity within plant populations, as well as increase the richness and diversity of flowering plants (Perevolotsky, 2006; Newton et al., 2011). As different structural types provide different benefits, depending on the benefit one wishes to maximize, a different management will be required. As agricultural fields in mountain areas are increasingly abandoned in European Mediterranean landscapes, shrub cover is increasing, raising fire risk and decreasing grazing resources (Lasanta et al., 2006). One of the management goals proposed for such landscapes is that of converting shrubland areas to grasslands (Lasanta et al., 2006), similar to the third scenario we explored. However, the management goals vary between countries, especially between European and North African Mediterranean countries, due to differences in climate, land-use and demography (Pausas, 1999; Le Houérou, 2000).

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 have been applied to spatially allocate the conservation status or management of a planning unit. A novelty of this study is that the 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, and weeding. Because the entire study area is managed as a private nature park and because the park is rather small (~4.5 km^2) manipulation of the landscape is feasible and some (management cattle and goat grazing) has already been applied.

The results of the Marxan runs were strongly 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 a planning unit was assigned to a specific zone of all the possible zones. Mapping this metric enables the park managers to visually grasp the areas in which 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 Mediterranean as well as other systems, areas and spatial scales.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.biocon.2012.08.032.

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