Biological Conservation 169 (2014) 158–166

Contents lists available at ScienceDirect

Biological Conservation

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

Can agro-ecosystems efficiently complement protected area networks?

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ARTICLE INFO

Article history:
Received 17 May 2013
Received in revised form 29 October 2013
Accepted 6 November 2013

Keywords:
Systematic conservation planning
Gap analysis
Protected areas
Agri-environmental schemes
Wildlife-friendly agriculture

ABSTRACT

Threats to biodiversity are often enhanced in human-dominated and densely-populated regions. The prospects for establishing new protected areas are generally more limited in such regions, due to competition with other land-uses. Improving the conservation value of agricultural lands has been proposed as a complementary strategy. Our goal was to compare alternatives for expanding an existing protected area system. We used the conservation planning software Marxan to select candidate sites for addition to an existing protected area system, based on the following three strategies: (1) focusing on remaining natural habitats; (2) prioritizing agricultural lands for wildlife-friendly farming and agri-environmental measures that can improve conservation value; and (3) a strategy combining the former two. We used area as a surrogate for cost with the aim of minimizing the total area needed to meet our conservation objectives. We evaluated the sites found via each strategy with respect to their landscape structure and the coverage they provided to the target species' habitats. We focused on breeding bird species in Israel's Mediterranean region, a challenging and relevant case study due to the area's high level of urbanization, population density, and its heterogeneous landscape. We found that the existing protected areas provided adequate coverage to only 23% of the target species, clearly demonstrating the need for action. Of the three strategies, expanding the existing protected area system based on the combined strategy was the most beneficial since it provided greater coverage to the target species' habitats, and resulted in a larger, more compact, and less patchy conservation area network. In addition to protected area planning, our approach can be used to target agricultural lands for agri-environmental schemes, particularly in human-dominated and densely-populated regions.

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1. Introduction

In Israel's Mediterranean region, the human population density and growth rate, as well as urbanization levels, are higher than those found in countries with a similar economic profile (Orenstein and Hamburg, 2010; Population Reference Bureau, 2012). As is characteristic of human-dominated landscapes, specifically in the Mediterranean (Blondel et al., 2010), the region is primarily agricultural and the landscape is a mosaic of agricultural land, natural and semi-natural habitats, and built-up land. Major changes have occurred in Israel in recent decades: urban sprawl and development (Orenstein and Hamburg, 2010), agricultural intensification (Yom-Tov, 2012), and a decline in wetlands and riparian ecosystems (Levin et al., 2009; Yom-Tov, 2012). Consequently Israel's Mediterranean region constitutes a challenging case study for conservation planning. It is also globally relevant, given both the large extent of densely-populated and human-dominated regions worldwide, and the human population growth and expansion of urbanization (Angel et al., 2011; Williams, 2012) and agriculture (Dobrovolski et al., 2011) predicted for the developing world.

Threats to biodiversity are often enhanced in human-dominated and densely-populated regions, as edge effects and isolation of natural habitats are often more severe and the natural/semi-natural patches and protected areas (PAs) are smaller (Di Giulio et al., 2009). Human population density has been found to be positively related to extinction rates (Cardillo et al., 2008) and to environmental threats such as deforestation (Sodhi et al., 2010) and invasive species abundance (Pysek et al., 2010). Competition between multiple land-uses and conflicts between human needs and biodiversity tend to be stronger in densely-populated regions (Langevelde et al., 2000; Deelstra et al., 2001). Whether there is a positive relationship between human density and biodiversity conflicts is debatable (Luck et al., 2004; Gaston, 2005). Nevertheless, it is widely accepted that in densely-populated regions the prospects for PA expansion or establishment are often limited, due to local constraints (e.g., social, financial, cultural and land-use).

Abbreviations: PAs, protected areas; LC, land cover; PU, planning unit.

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http://dx.doi.org/10.1016/j.biocon.2013.11.009

Yom-Tov et al. (2012) reviewed the past century's population trends of breeding birds in Israel. In Israel's Mediterranean region nearly half of the species experienced declines, and this was attributed to high human population density and habitat alteration, more specifically, the intensification of agriculture and agriculture-related land-uses, such as aquaculture, water reservoir construction, wetland drainage, cultivated area expansion, and afforestation. A decline in the number of threatened and common bird species, due to agricultural intensification and natural habitat depletion have been reported widely also in other regions (Donald et al., 2006; Maiorano et al., 2006; Johnson et al., 2011).

The worldwide expansion of agriculture has resulted in concern over its environmental consequences (Green et al., 2005; Dobrovolski et al., 2011) and led to a debate among conservation scientists and practitioners regarding the best approach for minimizing its negative impact and maximizing conservation. This cost-benefit problem in agricultural landscapes is related to the land sparing–sharing debate (Fischer et al., 2008; Phalan et al., 2011a,b; Balmford et al., 2012). On the one hand, land sparing favors separating land for nature conservation from land for agricultural production, and intensive use of the latter in order to maximize agricultural yield (Balmford et al., 2005; Fischer et al., 2008). Overall, this approach conforms to the traditional focus of nature conservation on natural and wilderness habitats (Sutherland, 2002; Mittermeier et al., 2003). On the other hand, land sharing is based on the idea that biodiversity conservation and agricultural production can co-occur, or even create synergies, through the implementation of wildlife-friendly farming methods (Balmford et al., 2012; Lin and Fuller, 2013). This approach is supported by the idea that conservation should focus also on agro-ecosystems (Tscharntke et al., 2005; Maiorano et al., 2006; Vandermeer and Perfecto, 2007; Norris, 2008) and that agro-ecosystems can persistently mimic essential functional attributes of "natural ecosystems" or even create novel ecosystems that are relevant for native biodiversity (Hobbs et al., 2006). In line with this approach, methods of sustainable and wildlife-friendly agriculture have been implemented throughout the world, e.g., through agri-environmental schemes (Harvey et al., 2008; Vepsäläinen et al., 2010; Tomich et al., 2011).

There is evidence that agriculture, particularly extensive and traditional practices, can support biodiversity and provide important, or even essential, habitats for a substantial number of species (Tscharntke et al., 2005; Vandermeer and Perfecto, 2007; Norris, 2008; Johnson et al., 2011). However, the effectiveness of agri-environmental schemes in promoting biodiversity conservation is debatable (Kleijn and Sutherland, 2003; Kleijn et al., 2006; Filippi-Codaccioni et al., 2010) and has been found to depend among other things on the species and taxa in question (Kleijn et al., 2006; Billeter et al., 2008; Phalan et al., 2011a,b) and on the targeting of such measures (Davies et al., 2009; Moreno et al., 2010).

Systematic conservation planning (Margules and Pressey, 2000) can be utilized to inform and spatially prioritize such agri-environmental efforts. Recently, Arponen et al. (2013) demonstrated that conservation management could be improved by the spatial reallocation of agri-environmental schemes in Finland. Similarly, Davies et al. (2009) found that aquatic biodiversity could be better protected if agri-environmental resources were reallocated. Nevertheless, within the field of conservation planning, agriculture is still commonly regarded as a threat (e.g., Jarvis et al., 2010; Visconti et al., 2010; Vimal et al., 2012), and the use of spatial prioritization tools to designate areas for low-impact agricultural practices has been very limited.

Central questions in conservation planning are how to prioritize areas for protection and where to allocate resources and efforts. The land sharing–sparing debate described above represents a highly relevant question of whether to invest in additional PAs and conservation efforts on remaining natural habitats or to increase the conservation value of agricultural lands in human-dominated regions. Comparing and evaluating the conservation benefits of each option is especially pertinent, since the expansion of PAs is not always possible.

In this case study, we compared three main conservation planning strategies: (1) expanding the PA system by focusing on the protection of remaining natural habitats (in line with land sparing); (2) complementing the PA system by improving the conservation value of agricultural habitats (in line with land sharing); and (3) a combination of the two approaches. Focusing on the breeding birds of Israel's Mediterranean region, we evaluated the coverage provided by the existing PAs by means of a gap analysis (Scott et al., 1993). We then used a site selection algorithm to identify conservation priority areas under each strategy. We used area as a surrogate for cost with the aim of minimizing the area needed to meet our conservation objectives. We then evaluated and compared the sites selected in each option with respect to their landscape structure and the habitat coverage they provide to the target species.

2. Methods

2.1. Study area

Israel's Mediterranean region (Fig. 1a) is characterized by a high level of biodiversity relative to its size, a diversity of habitats and a rich avifauna (Dolev and Perevolotsky, 2004; although see Roll et al., 2009). Due to its geographic location, the region is part of several important bird migration routes and serves as a junction for species from several biogeographic regions (Shirihai, 1996; Dolev and Perevolotsky, 2004). We excluded the Tel Aviv municipal district and the Golan Heights from the analysis, since land cover data for these regions were incomplete.

2.2. Land cover and protected areas

We produced a land cover (LC) map by integrating data from several sources (Table 1 and Fig. 1b). We approximated the distribution of riparian vegetation and cliffs (both important habitats for many bird species) by overlaying the LC map with a 50 m buffer around the running streams and cliffs layers, respectively. The resulting map included thirteen LC classes (Table 2). We refer to classes 1–8 and 9–10 as natural and agricultural LC, respectively. PAs included nature reserves and national parks, as well as forests, managed by the Israel Nature and Parks Authority and the Jewish National Fund's Forest Authority, respectively. These organizations provided us with maps of the areas under their management. All layers were provided as vector layers and converted into raster format at a resolution of 50 m.

2.3. Target species

We focus our analyses on breeding bird species ($N = 87$, see Appendix), excluding 23 species which are strongly associated with human settlement areas. We used breeding distribution maps from a bird atlas (Shirihai, 1996) that indicate the population density of each species (high, low, sporadic, localized and historical) at a spatial resolution of $7.5' \times 7.5'$ lat/long (corresponding to 11.8×13.8 km). We excluded historical records and used the remaining classes as indicative of each species' presence. For 19 species, we used distribution range maps from the Red Book of Vertebrates (Dolev and Perevolotsky, 2004).

We then used information on species-habitat associations for each species to obtain maps of potential suitable habitat within

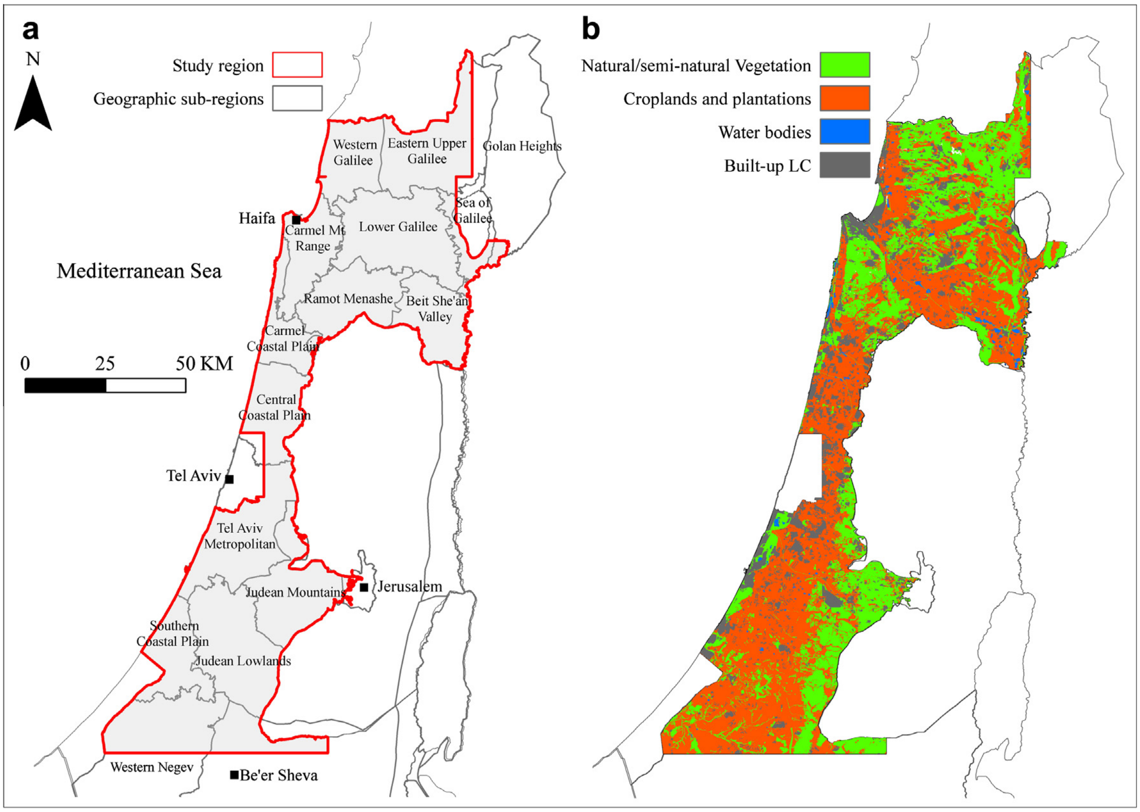

Fig. 1. Geographic sub-regions (a) and LC classes (b) in the study region.

Table 1
Land cover data sources.

Data	Source	Year
LC/vegetation	Israel Nature and Parks Authority	1995
Agricultural plantations and croplands	Israel Central Bureau of Statistics	2002
Built-up area	Israel Ministry of Interior	2007
Cliffs, Running streams, Water bodies	The Hebrew University GIS Center	2008
LC/Vegetation in JNF managed areas	Jewish National Fund	2009

Table 2
Land cover classes in the entire study region and PAs.

No.	Class	% Of study region	% Of class within PAs
1	Herbaceous vegetation	2.13	2.42
2	Sparse shrubs	3.06	6.07
3	Dense shrubs	2.39	3.26
4	Sparse trees	5.39	10.68
5	Dense trees	7.42	18.83
6	Planted forest	9.25	41.93
7	Other natural	2.76	9.12
8	Riparian vegetation	0.52	0.77
9	Plantations (orchards, groves, etc.)	14.60	4.18
10	Croplands	38.00	2.66
11	Water bodies (fish ponds, water reservoirs, etc.)	1.08	0.06
12	Built-up	13.40	–
13	Cliffs	0.01	0.03
	Total area (km^2)	7804	1412

its range of occurrence. Land cover is considered the most dominant factor influencing bird presence at the scale of our study (Shirihai, 1996). We therefore used LC as a proxy for habitat. Three ornithologists ranked each species' habitat associations (strong, moderate, weak/none) for each of the 13 LC classes.

For each species, we extracted the suitable habitats (moderate and strong associations) within its distribution range (similarly to the method used in Chiozza et al., 2010), by intersecting the distribution range maps with the maps of suitable habitats. We repeated this procedure using different definitions of suitable habitat: (1) only natural LC included as suitable; (2) only croplands and plantations included as suitable; and (3) both natural and agricultural LC included as suitable. The three resulting map sets are referred to as map sets 1, 2 and 3, respectively and used to compare conservation strategies (see below). Water bodies, whether agricultural or not, were included as suitable habitat in all sets.

Hereinafter we distinguish between two subsets of species: (1) non-agricultural species – species with no affinity to croplands and/or agricultural plantations ($N = 39$). This subset includes aquatic and wetland species that utilize artificial water bodies (e.g., fish ponds) and (2) agricultural species – species that have either moderate or strong affinity to croplands and/or agricultural plantations ($N = 48$).

2.4. Gap analysis

For each species, we determined a representation target based on its area of available natural habitat (map set 1). We employed the methodology introduced by Rodrigues et al. (2004). For species with available habitat of <100 km^2, the representation target was set at 100% of the area. For widespread species (available habitat >1000 km^2) representation target was set at 10% of the area. For species with intermediate sizes of available habitat (100–1000 km^2), the representation target was determined by interpolating between the two thresholds, using a linear regression. Hereinafter we refer to a species for which the representation target is met as *Covered*. We define species for which the representation target is not reached as *Underrepresented*.

2.5. Conservation area prioritization

We used Marxan (Version 2.4, Ball et al., 2009) a site-selection software that implements simulated annealing (an optimization method) and is widely used for decision support in reserve design and other conservation problems. We employed Marxan to identify efficient configurations of high priority conservation areas that achieve the representation targets at a minimal cost. Planning units (PUs) were 1 km^2 hexagons arranged in a grid and clipped to the study region's extent (a total of 8257 PUs). PUs with >50% built-up LC or >50% PAs were marked as unavailable for selection or already protected, respectively (Fig. 3a). We used PU area as a surrogate of PU cost. Since the software's algorithm attempts to minimize the cost of the selected priority sites, this served the objective of minimizing the total area needed to meet our defined representation targets.

Marxan enables control over the degree of spatial aggregation of the selected priority areas through the boundary length modifier (BLM). We set this parameter to 0.001 based on the method proposed in Stewart and Possingham (2005). We created the input boundary files using the ABPmer boundary creation tool for ArcGIS 10 (ABP Marine Environmental Research, 2011). We calibrated the species penalty factors according to an iterative method (Ardron et al., 2010), gradually increasing the values until representation targets were met in >90% of the restarts. The number of restarts and iterations were set to 1000 and 1,000,000, respectively.

We ran Marxan three times using a different map set each time, to identify the high priority areas for conservation according to three previously outlined strategies: (1) including only natural habitats (Natural-only; map set 1); (2) including only agricultural lands suitable for wildlife-friendly measures (Agricultural-only; map set 2); and (3) including both natural and agricultural habitats (Combined; map set 3). We defined the natural and agricultural habitats within the most frequently selected (>90%) PUs as the conservation priority areas in each strategy.

The spatial configuration of PA networks affects their functioning and management (e.g., Williams et al., 2005). We used Fragstats 3.3 (McGarigal et al., 2002) to calculate the following landscape structure indices for the priority area network identified in each strategy: number of patches, largest patch index, area-weighted mean patch size, total edge, and area-weighted mean perimeter-area ratio.

3. Results

3.1. Protection by existing PA network

Agriculture (croplands and plantations together) constituted 52.4% of the study area, while 13.2% of the area was built-up (Table 2). The remaining 35% were mostly natural/semi-natural vegetation formations. PAs covered 1412 km^2 (18.3%) of the study area. Planted forests covered 41.9% of the PAs.

The existing PA system provided protection (full coverage) to some 21 species (23% of the studied species). The major findings of this analysis were: (1) All threatened species were underrepresented (Fig. 2a); (2) The covered species were almost exclusively generalists ($\geqslant$3 suitable habitat types; Fig. 2b); (3) All aquatic and wetland species were underrepresented (compared to $\sim$70% of raptors/owls and passerines/near passerines (Fig. 2c); and (4) All 61 species with <100 km^2 of available habitat were underrepresented (Fig. 2d).

3.2. Conservation priority areas

3.2.1. Location and overlap

In addition to the existing PAs, 1746 km^2 of PUs were identified as high priority areas by all three strategies (Fig. 3a). In these high priority and overlapping PUs which were equivalent to 54% of all the PU areas identified as high priority (by the three strategies), both approaches, i.e., the establishment of additional PAs and the implementation of agri-environmental practices, would be beneficial. Water bodies (82 km^2) were identified as high priority conservation areas in all three strategies (the areas marked as "All three strategies" in Fig. 3b). According to these findings, meeting representation targets for all species using strategy 1 (natural-only), which prioritizes only areas of natural habitat, would require establishing additional PAs on 1005 km^2 (Table 3). Meeting representation targets for all agricultural species using strategy 2 (agricultural-only), which prioritizes agricultural areas for the implementation of agri-environmental measures, would require designating an additional area of 1520 km^2 for this purpose (Table 3). Since > 50% of the high priority PUs were selected by all three strategies, it is evident that the combined conservation strategy which involves both nature reserve establishment and implementation of agri-environmental measures, would yield the largest PA system (Table 3).

The coastal plains (particularly in the study region's central part) contain relatively few priority areas (Fig. 3b). Most priority areas are in the northern part of the study region, while its southern part consists of smaller priority areas (Fig. 3b). High priority natural habitats (approximately 642 km^2 are found mainly in the Carmel Mountain range, and in the Western Galilee and Eastern Upper Galilee (Fig. 3b). High priority agricultural lands (approximately 1144 km^2) are found particularly in the Beit She'an Valley and in the areas surrounding the Carmel Mountain range (Fig. 3b).

The high priority natural habitats identified by the natural-only and the combined strategy overlapped on an area of 642 km^2. Essentially, the difference between the natural-only strategy and the combined strategy amounts to the choice between establishing new nature reserves on an area of 298 km^2 (mainly expansion of existing PAs in the Judean Mountains and Lowlands) and implementing agri-environmental practices on 1263 km^2 (mainly in the northern part of the study region), respectively.

3.2.2. Habitat coverage

Each strategy resulted in different levels of habitat coverage for each species. Fig. 4 shows the average coverage area that each strategy would provide for the agricultural and non-agricultural species groups, relative to the representation target.

By applying the agricultural-only strategy (expanding the PAs only by adding agricultural lands) it would not be possible to achieve the representation targets for all of the non-agricultural species – 18 species would remain underrepresented. Under this strategy the average habitat coverage for the non-agricultural species would be 73% (Fig. 4).

Meeting the representation targets for all species would necessitate either the natural-only strategy or the combined strategy. For the non-agricultural and aquatic and wetland species, both of these strategies offer a similar degree of suitable habitat coverage (average habitat coverage of 107% and 104% of the representation targets, respectively).

For the group of agricultural species, the agricultural-only and combined strategies resulted in higher levels of habitat coverage (median values of 578% and 539%, respectively) than the natural-only strategy (median value of 208%). Therefore, for the

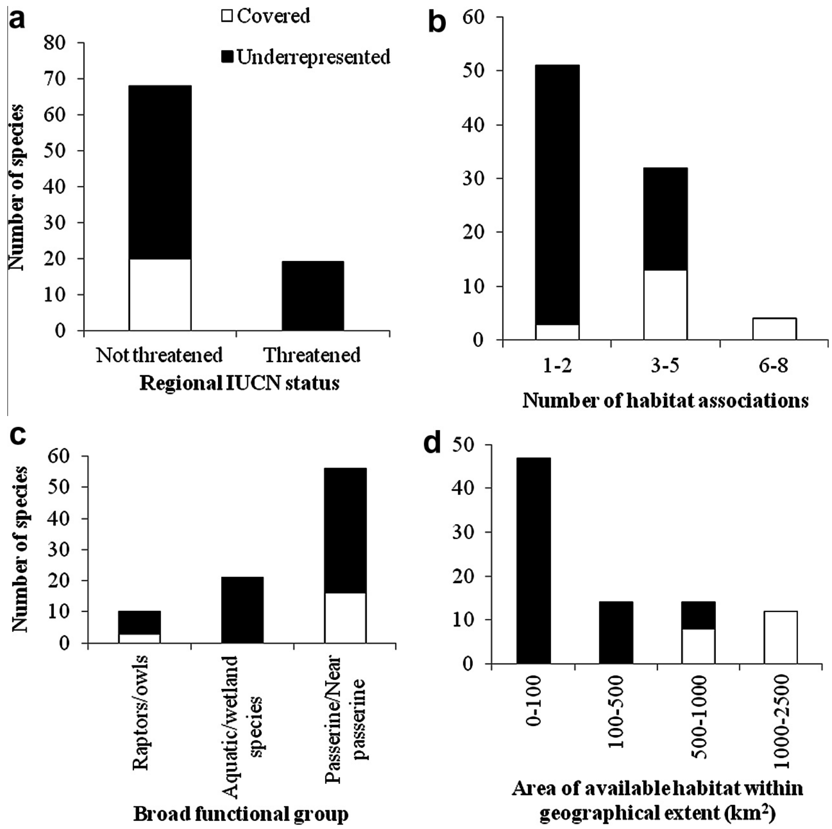

Fig. 2. Gap analysis results according to various criteria.

agricultural species, the combined and agricultural-only strategies have the advantage of covering larger areas of suitable habitat (Fig. 4).

3.2.3. Landscape structure

The spatial configuration of the prioritized conservation area network differed between the three strategies. These differences are evident when examining the landscape structure attributes of the priority areas (Table 4). Compared to the current PA network and the other two strategies, the network prioritized in the combined strategy was less patchy and more compact (e.g., fewer patches, larger patch areas, smaller total edge, and smaller mean perimeter-area ratio; Table 4).

4. Discussion

We evaluated the current coverage provided to the breeding bird species in Israel's Mediterranean region by the existing system of protected areas, and compared three alternative approaches for expanding this system: (1) establishing reserves on remaining natural habitats, (2) complementing the existing protected areas by improving the conservation value of agricultural landscapes, and (3) a strategy combining both approaches. Approaches that emphasize the positive role of sustainable agriculture in biodiversity conservation have become more common in the recent decade (Banks, 2004; Donald and Evans, 2006; Vandermeer and Perfecto, 2007; Scherr and McNeely, 2008). Although agri-environmental schemes are implemented in many countries for the purpose of biodiversity conservation, we are aware of only two studies that used a systematic conservation planning framework to target such schemes for conservation purposes (Davies et al., 2009; Arponen et al., 2013). To the best of our knowledge, this is the first study to compare the attributes of protected area networks that include or exclude agricultural land.

4.1. Protection by current protected areas

Major motivations for establishing PAs are to represent biodiversity, promote its persistence, and protect ecosystems and habitats from threats (Margules and Pressey, 2000). The assessment of existing PA networks is a standard stage in systematic conservation planning (Margules and Pressey, 2000). Very few systematic assessments of PA coverage have been conducted in the study region. Dolev and Carmel (2009) found that approximately 50% of the region's threatened vertebrate species were unprotected (with >60% of their distribution range outside of PAs). Similarly, our analysis indicates that the existing PAs in Israel's Mediterranean region provide insufficient coverage to the habitats of the region's breeding birds (Fig. 2). Although over 18% of the study region is protected, placing it above the global terrestrial coverage (12.2%; World Database on Protected Areas, 2011), none of the threatened species (Dolev and Perevolotsky, 2004) is adequately covered (Fig. 2a). As elsewhere (Pressey, 1994; De Klerk et al., 2004), PA establishment in the study region has not been aimed to systematically represent a variety of habitats or species, but rather it has been a continuous and ad hoc process (Tal, 2006). Thus, it is unsurprising that the PAs do not cover the habitats of the breeding birds efficiently and that the covered species are primarily generalists and widely distributed (Fig. 2b and d).

4.2. Alternative strategies for expanding protected areas

We examined three strategies for improving the protection of the breeding avifauna. Each of these strategies offers increased habitat protection for the target species compared with the

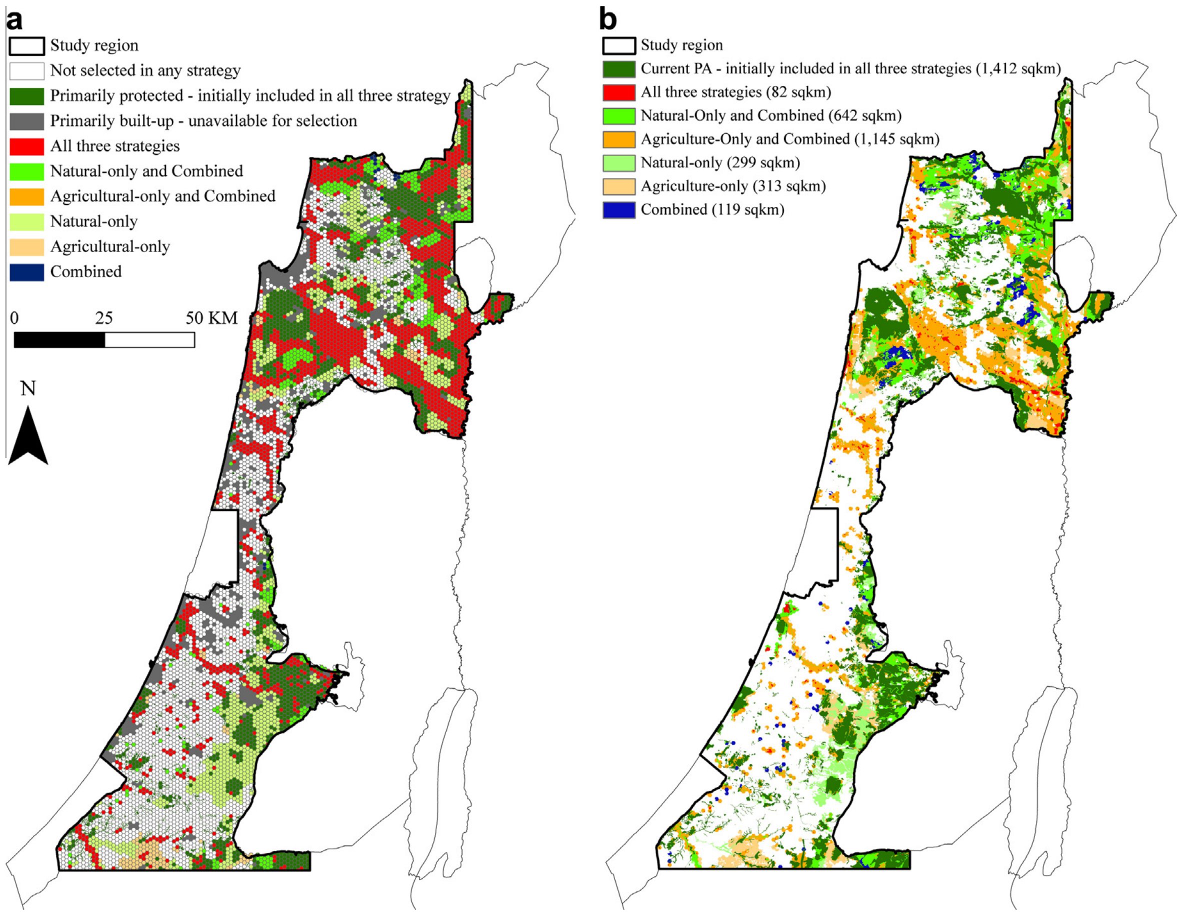

Fig. 3. Most frequently selected planning units (a) and priority areas (b) according to the three different strategies.

Table 3
Area (km^2) of water bodies, agricultural and natural habitats, and the total additional area required in each strategy.

Land cover	Current PAs	Natural-only	Agricultural-only	Combined
Agricultural	97	97	1536	1352
Water bodies	1	83	82	82
Natural	1314	2237	1314	1947
Total	1412	2417	2932	3381

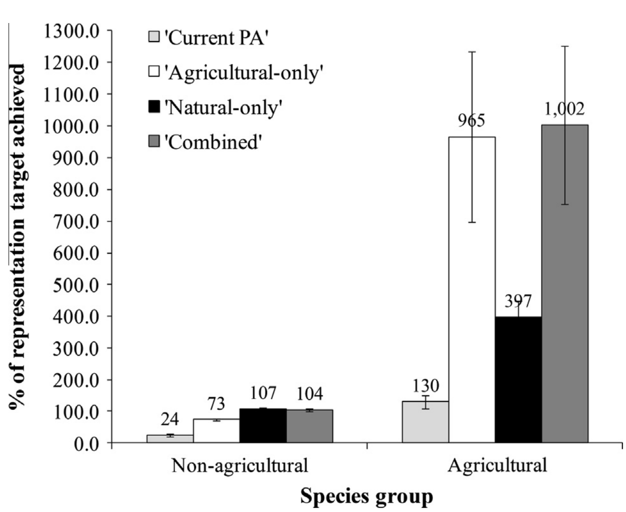

Fig. 4. Average and S.E. percentage of representation target achieved for the non-agricultural and agricultural species in each strategy.

existing PA system (Fig. 4). The common approach of expanding and establishing PAs in line with the natural-only strategy is an obvious alternative (Vandermeer and Perfecto, 2007; Scherr and McNeely, 2008), but in densely-populated landscapes, opportunities for this are often limited. Furthermore, in such landscapes, PAs alone may provide insufficient protection for many species, as they are often small and fragmented (Saunders et al., 1991; Gurd et al., 2001; Rodrigues and Gaston, 2001). Under these circumstances, improving the conservation value of agricultural habitats is a potentially worthwhile alternative (Harvey et al., 2008; Gardner et al., 2009).

Agricultural land-uses constitute important habitats for many species and are of conservation significance in the Mediterranean basin (Maiorano et al., 2006; Billeter et al., 2008; de la Montaña et al., 2011) and elsewhere (Stralberg et al., 2011; Wright et al., 2012). In our case study, the aquatic and wetland species thrive mostly in agricultural and agricultural-related habitats (e.g., water reservoirs and fish ponds), as most of their natural habitats have been dried-up in recent decades (Levin et al., 2009; Yom-Tov, 2012). Moreover, for several habitat-specific species, including the threatened *Glareola pratincola* and *Francolinus francolinus*, agricultural lands constitute a primary habitat.

The agricultural-only and the combined strategies both prioritize agricultural areas for conservation management. A major shortcoming of the agricultural-only strategy is that the desired habitat coverage cannot be achieved for all of the target species under this strategy (18 non-agricultural species remain underrepresented; Fig. 4). Nonetheless, this strategy could be useful if expanding and establishing PAs in natural areas proves unfeasible or too complicated (e.g., due to competing land-uses or economic pressures).

Table 4
Landscape structure metrics for conservation area networks under each strategy.

Metric	Current PA network	Natural-only	Agricultural-only	Combined
Number of patches	2422	2511	2269	1633
Largest patch index	1.9	8.3	12.1	25.6
Area-weighted mean patch size (ha)	4807	25,127	38,203	120,257
Total edge (km)	9551.9	13,046.6	14,140.8	9395.6
Area-weighted mean perimeter-area ratio	66.8	53.6	47.9	27.6

As noted above, the essential difference between the natural-only strategy and the combined strategy amounts to the choice between establishing new nature reserves on a relatively small area, and implementing agri-environmental practices on a larger area, respectively. The conservation area network based on the combined strategy has several advantages over the one based on the natural-only strategy: (1) It covers a larger overall area and provides a greater degree of habitat coverage to the target species (Fig. 4; Table 3); (2) It results in a smaller number of patches and a larger area-weighted mean patch size compared with the areas identified by the other strategies (Table 4). While there is no definite answer as to whether it is better to have fewer larger patches or many smaller patches in a PA network, several studies on birds have found that a single large reserve is more favorable (reviewed by Ovaskainen, 2002); (3) The combined strategy results in a network that is more compact, e.g., smaller total perimeter length and more regularly-shaped patches (smaller average patch perimeter-area ratio; Table 4). These attributes are more likely to have a positive effect on bird species composition and abundance (King et al., 2009; Banks-Leite et al., 2010) as well as reduce exposure to edge effects (Williams et al., 2005); and (4) The implementation of agri-environmental schemes in the combined strategy may benefit also non-agricultural species, e.g., by facilitating their movement and dispersal (Donald and Evans, 2006; Haslem and Bennett, 2008). For non-agricultural priority areas and species, sustainable agriculture practices could reduce threats, harmful effects and conflicts that might be caused by intensively-managed agricultural lands (Stephens, 2004; Matson and Vitousek, 2006; Hellmann and Verburg, 2010).

4.3. Implementation of the combined strategy

There are basic differences between conventional PAs and areas of wildlife-friendly agriculture: while the former commonly have statutory designation and are managed by institutional agencies, the latter are generally presented as a voluntary option for farmers, and are typically encouraged through economic programs that offer financial incentives to farmers (Harvey et al., 2008; Johnson et al., 2011). Given these differences, we briefly touch upon several issues that are likely to be critical to the successful implementation of combined strategies, such as the one we propose.

At the planning stage, existing PAs can serve as the cores for identifying priority areas for wildlife-friendly agriculture, and spatial prioritization methods which account for spatial structure and connectivity can be used to identify those areas. In order to render agricultural landscapes efficient in complementing PAs, agri-environmental practices that increase landscape heterogeneity and structural complexity should be emphasized (Benton et al., 2003; Concepción et al., 2012). These may include mixed farming and permitting natural vegetation growth in field margins, hedgerows, or in-field strips (Johnson et al., 2011; Keenleyside et al., 2011; Wright et al., 2012). Finally, successful implementation of the combined strategy requires the spatial aggregation of areas for wildlife-friendly agriculture and the maintenance of proper and ongoing conservation-oriented management of these areas. Achieving these objectives depends on a coordinated effort at local and regional levels in order to enlist the support and cooperation of individual farmers (e.g., Prager and Freese, 2009) and effectively manage a conservation program.

5. Conclusions

Conflicts between biodiversity conservation and intensive agriculture (and other anthropogenic land uses) are not unique to our case study, nor is the need to compare and assess the different possible conservation strategies, e.g., land sparing versus land sharing. Our systematic conservation planning approach included: (a) the use of a site-selection algorithm to identify conservation priority areas under the different strategies and (b) a quantitative comparison of landscape structure attributes and habitat coverage provided to the target species by the resultant conservation area networks. This methodology can be applied to other groups of organisms and other regions worldwide. It would be particularly useful in human-dominated regions comprised of heterogeneous land uses.

Based on our results, the combined strategy, which constitutes a mixture of the land sparing (e.g., PA establishment in natural landscapes) and land sharing (e.g., agri-environmental measures) approaches, is the best alternative for ensuring the achievement of the defined conservation objectives. Compared to the other strategies, the combined strategy would be more efficient in providing habitat coverage, spatially complementing existing PAs, and buffering them from high-intensity agricultural areas. Phalan et al. (2011a,b) remarked on strategies that combine elements of land sparing and wildlife-friendly farming that: "*Such solutions might be intuitively appealing, but there has been no rigorous evaluation of their merits relative to other possible strategies*". Our study addresses this need to compare the benefits of alternative strategies. As agriculture is a prevalent land-use worldwide, such combined strategies should be carefully assessed, since they may be a preferable option – or even a necessity – for conservation.

Acknowledgements

We thank two anonymous reviewers for their thoughtful comments and suggestions. We are grateful to N. Sapir, E. Shochat, and B. Granit for providing expert opinion on species-habitat associations.

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.2013.11.009.

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