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DISTRIBUTION OF THREATENED–UNPROTECTED VERTEBRATES AS A BASIS FOR CONSERVATION PLANNING

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ABSTRACT

The distribution of threatened species often serves to drive conservation decisions. Much of the distribution of many threatened species is already protected. These species may need fostering, but not necessarily further protected areas. We propose a simple and generic means of assessing the degree of protection presently offered to a threatened species, namely, the proportion of its distribution that is unprotected. This index classifies threatened species into two classes: most of their distribution range is either (1) inside protected areas (protected), or (2) outside of protected areas (unprotected). We propose that evaluation of land for planning and conservation should be based chiefly on the distribution of those threatened species that are not yet protected by the current reserve network. Our approach is exemplified in a case study of vertebrate species in Israel. We constructed a "hotspots map" using only the threatened species that have more than 60% of their distribution unprotected (n = 57), and compared it to a similar map with all threatened vertebrates (n = 118). This latter map had all hotspots around the Rift Valley in the eastern part of the country, while the former map had some hotspots in the western parts of the country as well. This study highlights the importance of a clear decision regarding which species should be used in prioritizing areas for conservation.

Keywords: threatened species, GAP analysis, species distribution, vertebrates, protected areas, priority areas, Israel

INTRODUCTION

Mapping priority areas for biodiversity conservation typically involves the use of available species distribution maps for a given taxon (or several taxa), with the goal of designating a reserve network that would provide long-term protection for the entire biodiversity (Margules and Pressey, 2000; Reyers et al., 2002). However, hotspots mapped using all species within a taxon do not necessarily correspond to hotspots of threatened species within that taxon (Bonn et al., 2002; Orme et al., 2005). Thus, a different ap-

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proach proposes that using species of particular conservation interest (rare, endemic, or threatened) in such analyses would reveal areas of particular conservation value in terms of the pressing threats to biodiversity (Rebelo and Tansley, 1993).

We suggest that prioritizing land based on the distribution of threatened species only (as opposed to using all species) would highlight critical areas for conservation, and may culminate in an indispensable tool for land planning. We further claim in this article that only threatened species whose distribution is largely unprotected should be selected for highlighting the most critical areas for urgent conservation. To clarify this concept, we distinguish between two types of threatened species. The distribution of some threatened species is largely contained within nature reserves. We refer to these species as "threatened–protected". The second type of species is found primarily outside of reserves, and thus the current reserve network offers very limited protection to these species. We term this type of species "threatened–unprotected". The difference between the two types is exemplified in Fig. 1, which shows the distribution of the griffon vulture (*Gyps fulvus)* and the mountain gazelle (*Gazella gazella*) in Israel, and the distribution of protected areas (nature reserves, national parks, and planted forests) in the country. For threatened–unprotected species, such as the mountain gazelle, protecting additional parts of their distribution may be critical for their survival. In contrast, adding more protected areas for species with a distribution that is already largely protected, such as the vulture, would probably have little effect on the population viability of this species.

Few studies have proposed to include an index of the degree of current protection by reserve network in deciding whether a species should be included in systematic conservation planning. Kirkpatrick and Brown (1994) proposed a distinction between reserved, poorly reserved, and unreserved communities. Lombard et al. (2003) suggested a distinction between represented species—at least a single record within protected areas, and unrepresented species—no such records. Our approach, which proposes a simple mapping index ranging from 0 (the entire distribution is protected) to 1 (no part of species distribution is under any sort of protection) may be regarded as an extension of these two approaches. It is similar to the proposition of Solymos and Feher (2005), in which an index of "protection by reserves" (in a 1–4 scale) is one component of their "conservation priority index" to be assigned to each threatened species. This method is particularly useful in situations where designation of new areas for conservation is unlikely, yet decisions regarding alternative development scenarios may be aided by information of the intrinsic conservation value of specific land parcels.

In principle, this concept could be applied via either one of the major approaches to conservation planning, namely GAP analysis, and systematic conservation planning. In GAP analysis, species distribution maps are overlaid to produce a map of species richness patterns, and areas of "hotspots" emerge as worthy of conservation (Scott et al., 1993; Tognelli et al., 2008). Systematic conservation planning attempts to select **a set** of sites or areas that, if protected, would enhance biodiversity conservation (Margules and Pressey, 2000).

In recent years, systematic conservation planning became the prevalent approach for conservation (Moilanen, 2008). Various algorithms that select sets of potential areas for

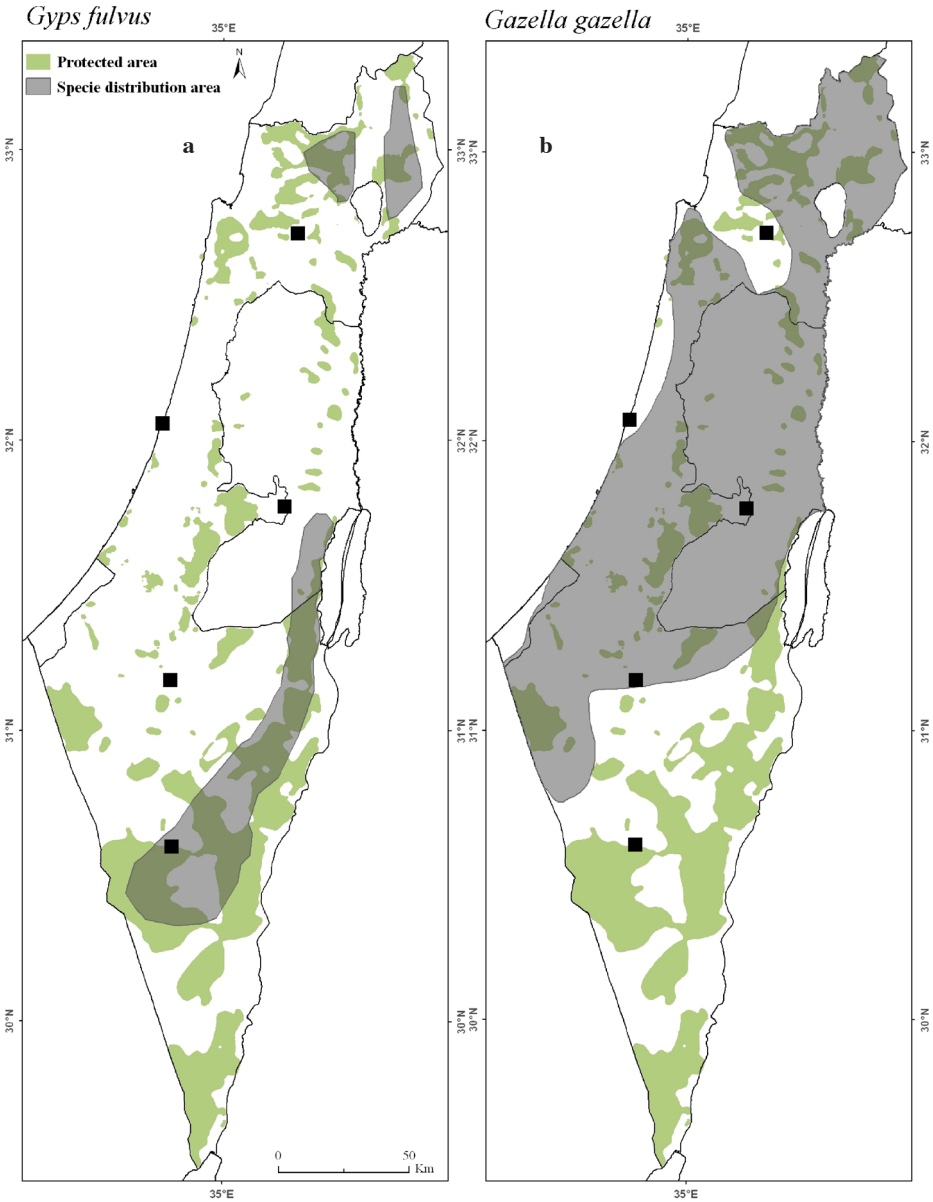

Fig. 1. The distribution of two threatened species in Israel. (a) griffon vulture as an example of threatened–protected (with 41% of its distribution unprotected), and (b) mountain gazelle, as an example of threatened–unprotected species (with 74% of its distribution unprotected). The distribution of protected areas is shown in green. The cities marked in black squares for orientation, are, from north to south, Nazareth, Tel Aviv, Jerusalem, Be'er Sheva, and Mitzpe Ramon.

maximizing protection for biodiversity were developed, such as MARXAN (Stewart et al., 2003; Shriner et al., 2006). However, these applications may not be useful in some regions, where dense human populations strongly restrict the designation of new areas for conservation. In such cases, a map showing "hotspots" of threatened species may be a valuable tool in land planning, and thus, restrict development in sensitive areas (Mandelik et al., 2005).

Here, we demonstrate this concept using GAP analysis. GAP has become one of the major tools for decision making in allocating conservation areas (Cantu et al., 2004; Dietz and Czech, 2005; Tognelli et al., 2008). It uses multiple maps of species distributions to delineate centers of species richness ("hotspots"), and to highlight hotspots that are currently unprotected, as candidates to be added to the reserve network. GAP is typically conducted using the distribution of all species in a given taxon (Davis et al., 1998), although recently the same methodology was applied using threatened and endemic species (Benayas and de la Montana, 2003; Tognelli et al., 2008).

Thus, current products of GAP analysis reflect three groups of species: (a) species that currently need no protection (non-threatened), (b) species that need protection but not further protected areas (threatened–protected), and (c) species that are in critical need of additional protected areas (threatened–unprotected). The present study proposes and evaluates a focused GAP analysis, applied to the species of group (c) only. We suggest that such an analysis would elucidate the areas that, upon protection, would offer the best possible added value for conservation.

Here, we conduct a focused GAP analysis for the state of Israel, where dense human populations strongly restrict designation of additional conservation areas. Based on vertebrate species, we investigate two alternatives for the selection of species to be included in the analysis: (1) all species that were classified as "threatened" by *The Red Book of Vertebrates in Israel* (Dolev and Perevolotsky, 2004), and (2) "threatened–unprotected". From these threatened species, we selected only those for whom the majority of their distribution area is not protected.

PART 1: QUANTITATIVE DEFININITION OF "THREATENED–UNPROTECTED"

A prerequisite for such a project is an analysis of the degree of protection currently offered to each threatened species. For the purpose of the current study, we defined this protection as the proportion of protected areas within a species distribution, regardless of the size of its distribution. This "degree of protection" of a species is a continuous parameter, ranging from 0 (no overlap between protected areas and the species distribution) to 1 (the entire distribution is contained within protected areas). However, for the purpose of conservation planning, a threshold below which a species would be considered as "threatened–unprotected" must be set. Here, we used an empirical analysis to assess the consequences of choosing alternative thresholds, in terms of the proportions of species that would be assigned as "unprotected" under each threshold.

The term "threatened" refers to a broad class containing three IUCN categories: Critically Endangered (CR), Endangered (EN), and Vulnerable (VU) (IUCN, 2001). There are 452 vertebrate species in Israel (Table 1), of which 143 are considered regionally

Table 1. Numbers of vertebrate species in Israel by class / functional group. The number of species corresponding to each threshold is recorded, representing species whose proportion of unprotected distribution is equal to or higher than the respective threshold. The percentage in brackets is the percentage of all threatened species in the respective class

	All species	Threatened species	Threshold of the proportion of distribution that is unprotected								
			10%	20%	30%	40%	50%	60%	70%	80%	90%
Freshwater fish	32	6	6 (100%)	6 (100%)	5 (83%)	5 (83%)	5 (83%)	4 (67%)	3 (50%)	2 (33%)	2 (33%)
Amphibians	7	5	5 (100%)	5 (100%)	5 (100%)	5 (100%)	3 (60%)	3 (60%)	1 (20%)	0 (0%)	0 (0%)
Reptiles	103	8	8 (100%)	7 (88%)	6 (75%)	2 (25%)	2 (25%)	2 (25%)	1 (13%)	1 (13%)	0 (0%)
Breeding birds	206	36	36 (100%)	35 (97%)	35 (97%)	34 (94%)	27 (75%)	23 (64%)	16 (44%)	8 (22%)	1 (3%)
Bats	33	27	27 (100%)	24 (89%)	22 (81%)	20 (74%)	12 (44%)	8 (30%)	0 (0%)	0 (0%)	0 (0%)
Terrestrial mammals	71	34	28 (82%)	28 (82%)	26 (76%)	23 (68%)	19 (56%)	17 (50%)	7 (21%)	0 (0%)	0 (0%)
Total	452	116	110 (95%)	105 (91%)	99 (85%)	89 (77%)	68 (59%)	57 (49%)	28 (24%)	11 (9%)	3 (3%)

threatened (Dolev and Perevolotsky, 2004). The distribution maps of 116 threatened vertebrate species were included in this study. Distribution maps were unavailable for 25 threatened species of reptiles (due to scarce data) and two bird species. At present, each of the 116 species has at least a single viable population within its distribution range in the country (Dolev and Perevolotsky, 2004).

The distribution maps of each vertebrate class were produced by expert zoologists, each specializing in a specific vertebrate class, for *The Red Book of Vertebrates in Israel* (Dolev and Perevolotsky, 2004): freshwater fish (M. Goren); amphibians (S. Gafni); reptiles (A. Bouskila); birds (A. Mayrose and D. Alon); and mammals (B. Shalmon). All maps were drawn in 2000 based on all available databases at that time, at a scale of 1:1,750,000. For the present analysis, the maps were incorporated in ArcGIS 8.3 (ESRI, 2001), and transformed from vector to raster format, using a 1 km^2 grid.

The proportion of a species distribution that is currently unprotected is termed hereafter "proportion of unprotected distribution". We calculated this proportion for each threatened species using the distribution map for that species, and the map of protected areas. This parameter denotes the degree of protection offered to the species by the current reserve network. We found a high variability in the proportion of unprotected distribution among threatened species (Fig. 2). This proportion ranged from 0.08 (lesser Egyptian gerbil, *Gerbilus gerbilus*), to 0.96 (*Nemacheilus dori*).

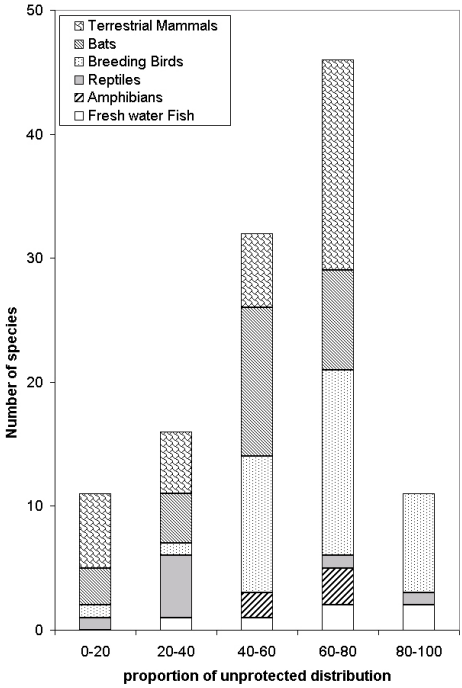

Fig. 2. Histogram of the proportion of unprotected areas within the species distribution, for 116 threatened vertebrates in Israel.

In order to assess possible relations between distribution size and the proportion of unprotected distribution, we conducted a simple correlation analysis between these two parameters. We found that proportion of unprotected distribution and distribution size were uncorrelated ($r^2 = 0.06$, $p > 0.05$, N = 116).

An unprotected species is defined here as having most of its distribution outside of protected areas. This concept requires that a threshold is specified for the minimum proportion of unprotected distribution, above which a species is designated as unprotected. A large threshold may be desired, so only the species that really need protection are included. However, a large threshold may result in a very poor representation of biodiversity. We looked for a threshold that maximizes both conflicting aspects, namely, large values of both the threshold of minimum proportion of unprotected distribution and the number of species corresponding to that threshold. We considered alternative thresholds. Based on Table 1, we found that a threshold of 0.6 designated 57 species as unprotected (49% of available maps), while thresholds of 0.7 and larger designated only 28 species as unprotected (24% of available maps, Table 1). We thus defined arbitrarily an unprotected species as having more than 0.6 of its distribution unprotected.

Looking for a more robust and less arbitrary way to decide on an optimal threshold for unprotected species, we assessed the plausibility of our preliminary decision using a two-step sensitivity analysis. First, we portrayed the number of threatened species corresponding to each possible threshold, and found that it had a sigmoid shape (Fig.3a). Next, we performed a pareto-optimization procedure (Fonseca and Fleming, 1995) for the two conflicting factors of interest (large threshold level and large number of species). We multiplied these two factors, assuming same weights, and portrayed the product against the possible thresholds (Fig. 3b).

We found that the maximum of this function (m = 36.5) is at a threshold of a minimum proportion of unprotected distribution of 43%. However, for a wide range of thresholds, approx 40% through 60%, the gain function is near its peak (Fig. 3b). Our preliminary threshold of 60% did not maximize the gain function, but was found to be a robust choice, being the largest threshold that still nearly maximized this function (m = 34.5). We therefore labeled all threatened species with more than 60% of the distribution unprotected as "threatened–unprotected".

PART 2: GAP ANALYSIS FOR THREATENED VERTEBRATES IN ISRAEL

A simple summation of the distribution maps yielded species richness maps. This procedure was done twice, first using all threatened species, and then using only the threatened–unprotected species. The first species richness map, accounting for all threatened vertebrates, reveals that most of the threatened vertebrates are concentrated along the Rift valley, in the eastern part of the country (Fig. 4a). The western half of the country, where most of the human population resides, is poor in terms of threatened vertebrate richness. A similar pattern appears in the map of "threatened–unprotected" (Fig. 4b). However, there are several important differences between these two maps. In the "all threatened" map (Fig. 4a), the entire western part of the country, including the coastal

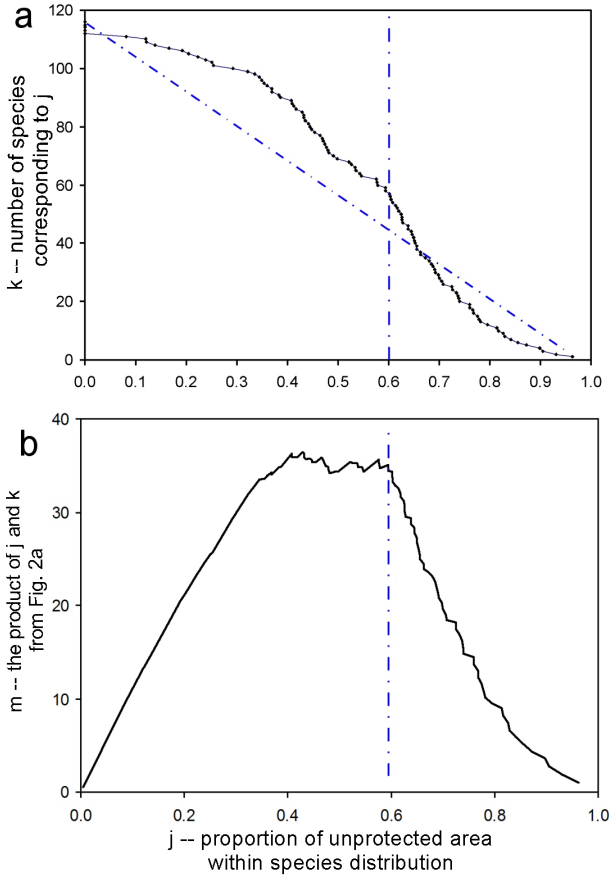

Fig. 3. Assessment of possible thresholds for "threatened–unprotected" species. (a) The number of species that would be defined as "unprotected" for each decision on the minimum value of unprotected habitat that assigns the species as "unprotected". *J* is the proportion of unprotected area in the distribution of a species. *K* is the corresponding number of species, of which at least *J* proportion of their distribution is unprotected. (b) The same *J*, the proportion of unprotected area in the distribution of a species, is portrayed on the *x* axis. *M*, a gain function, is portrayed on the *y* axis. It is the product of tradeoff parameters *J* and *K* depicted on the *x* and *y* axes of (a), designed to facilitate pareto-optimization (see text for details).

plain and central mountain range, has no hotspots. In contrast, in the map of "threatened—unprotected species", three secondary hotspots emerge: the Jezre'el Valley, the Beit Shemesh region, and the Besor region (marked 1, 2, and 3, respectively, in Fig. 4b). The southern part of the country, including the Negev Desert and Elat region, is highlighted as a "hotspot" in the "all threatened" map (Fig. 4a), while in the "threatened–unprotected" map (Fig. 4b), the Negev Desert is a "coldspot". This is likely because the distribution of threatened species in the Negev coincides with the large nature reserves

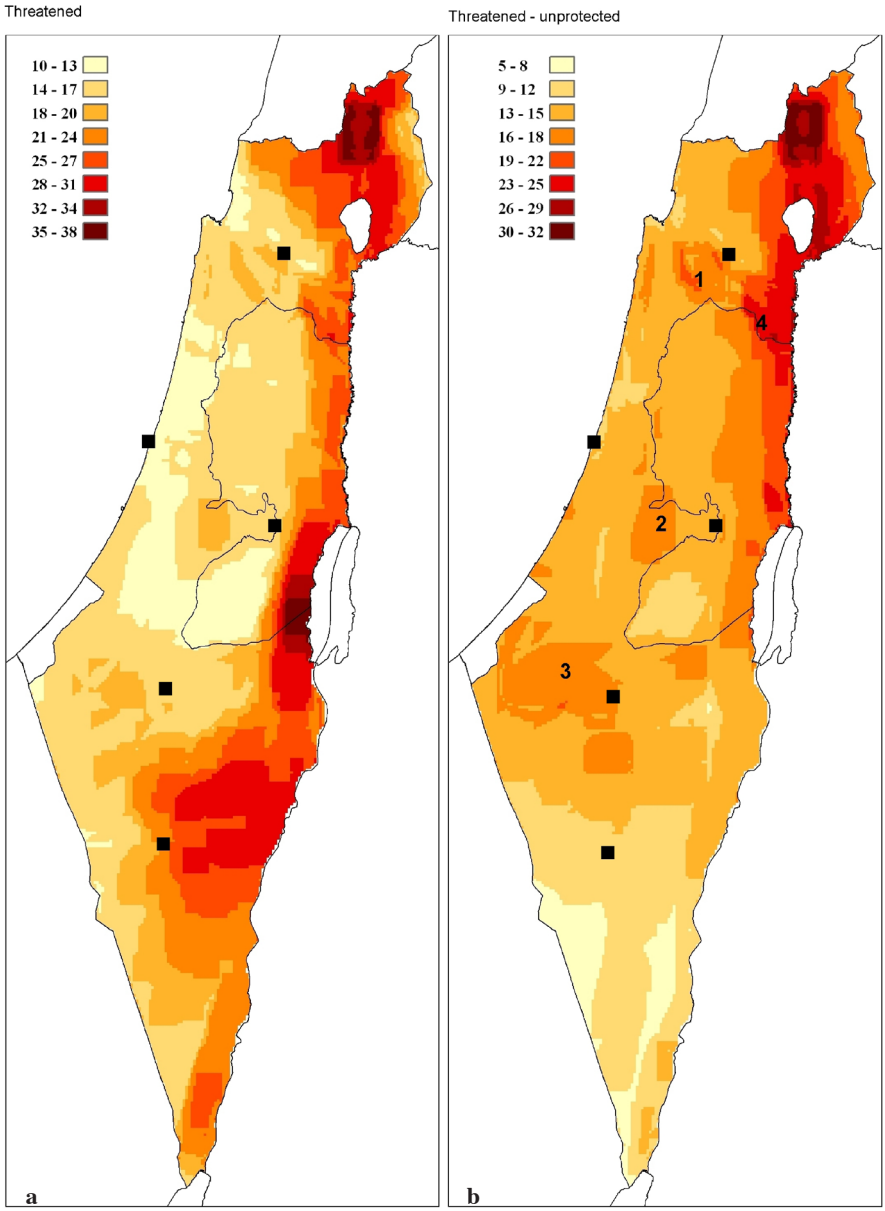

Fig. 4. Richness of threatened vertebrates in Israel for (a) all 116 threatened species and (b) for the 57 threatened–unprotected species. Colors represent numbers of species. Items 1–4 are the Jezre'el Valley, Beit Shemesh region, Besor region, and Mt. Gilboa, respectively. The cities marked in black squares for orientation, are, from north to south, Nazareth, Tel Aviv, Jerusalem, Be'er Sheva, and Mizpe Ramon.

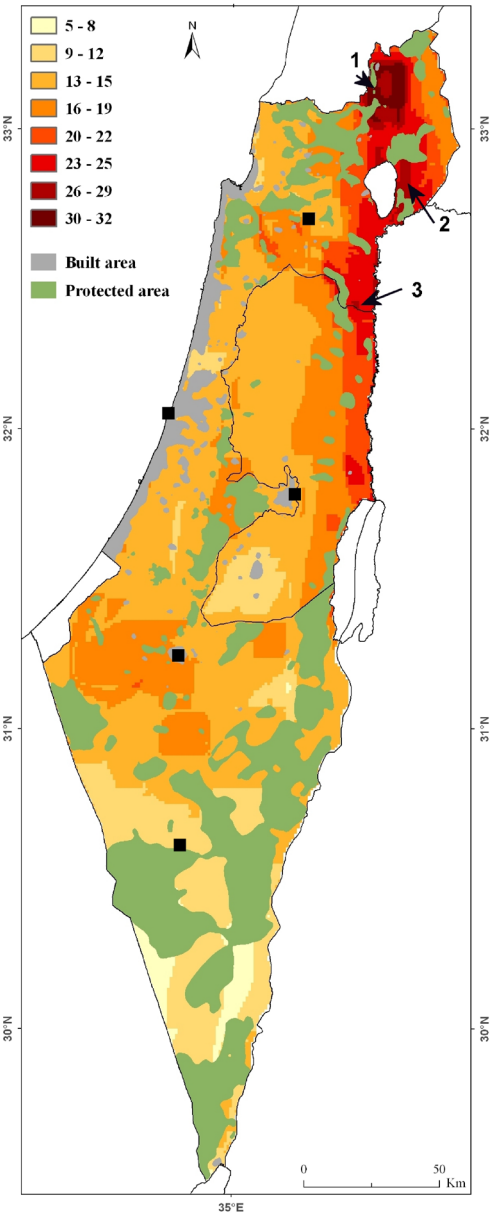

Fig. 5. GAP analysis for threatened–unprotected vertebrates. Urban areas (gray) and protected areas (green) are shown on top of the richness of threatened–unprotected vertebrates in Israel. The numbers 1–3 on the map correspond to Hula Valley, Lake Kinneret area, and Beit She'an Valley/Mt. Gilboa, respectively. The cities marked in black squares for orientation, are, from north to south, Nazareth, Tel Aviv, Jerusalem, Be'er Sheva, and Mizpe Ramon.

that cover much of that area, and consequently, most threatened species in the south are relatively well protected.

In order to identify regions where high species richness coincided with no protection ("gaps"), we overlaid two layers on top of the map of "threatened–unprotected" species richness (Fig. 4b): a layer of protected areas, and a layer of built-up areas (Fig. 5). The large majority of the areas highlighted as hotspots in this map have no legal protection (Fig. 5). The three major hotspots of threatened–unprotected species (Hula Valley, Lake Kinneret area, and Beit She'an Valley, marked 1, 2, and 3, respectively, in Fig. 5) contain only a few small nature reserves and emerge as the highest priority areas to be added to the Israeli conservation network.

GAP analysis, and other multi-species algorithms for prioritizing land for conservation, may suffer a lack of biological realism. While accounting for species distribution, they cannot account for other important variables, such as the spatial structure of metapopulations within species distribution, important corridors, source–sink relations, and interspecies interactions. We therefore evaluated the GAP map for all threatened species in a particular geographic region that was highlighted as a "hotspot" in that map (the Jezre'el Valley). Based on a detailed, species-by-species biological analysis, we recorded all species for which this small region was essential for survival. To be recorded as "essential for survival", at least one of two conditions had to be met: the region consists of a significant portion of the entire distribution of the species, and/or it is an important corridor between otherwise isolated relict populations. Jezre'el Valley (250 km^2, marked 1 in Fig. 4b) is comprised largely of agricultural fields, and thus was not considered important for conservation planning. However, our analysis revealed that it is a key area for the survival of at least five of the 20 threatened vertebrates that reside in this region. In our evaluation we were conservative, and selected only species for which this region is no doubt a key component of their distribution, while a few species for which it is important but not critical, are not listed here. For the jungle cat (*Felis chaus*) and the Eurasian otter (*Lutra lutra*)—both critically endangered—it is the only corridor between the eastern and western portions of their distribution (Amit Dolev, pers. comm.). It contains rare riparian habitats, which are crucial for the survival of both species. These riparian habitats support also a couple of the few remaining populations of the banded newt (*Triturus vittatus*), which are the only "stepping stones" between isolated populations in the Galilee Mountains and the populations in Mount Carmel. A large portion of the remaining riparian habitats of two critically endangered bird species (Dan Alon, pers. comm.), ferruginuous duck (*Aythya nyroca*) and Kentish plover (*Chradrius alexandrinus*), are also in the Jezre'el Valley.

DISCUSSION

Typically, conservation planning prescribes using all species of a given taxon in the process of selecting priority areas for conservation (Ferrier, 2002; Jennings, 2000; Faith et al., 2003), with the rationale that given accelerating anthropogenic activity, many currently non-threatened species may become threatened in the future. Yet, a growing

body of literature suggests that some index of threat should be incorporated in prioritizing locations for conservation (Reyers et al., 2002; Moore et al., 2003; Eken et al., 2004; Rodrigues et al., 2004; Burgess et al., 2005; Deguise and Kerr, 2006; Fleishman et al., 2006). For example, in many practical situations, a typical question is "which area to protect next" rather than "what is the set of proposed areas for long-term conservation". In such situations, systematic conservation planning that uses threatened species only may provide better answers than an equivalent that uses all species.

Only a few attempts were made to focus conservation targets yet further, relating not only to the conservation status of a species, but also to the protection already offered to it by the current reserve system (Kirkpatrick and Brown, 1994; Lombard et al., 2003; Solymos and Feher, 2005; Burgess et al., 2006). The rationale of this approach is that threatened species that are already largely protected may need means of protection other than further protected areas, while the threatened species that are largely unprotected by the current network are in most urgent need for further protected areas. When looking for the next piece of land to be appended to the network, one should consider mainly these threatened–unprotected species.

This study develops an approach for classifying threatened species in the context of prioritizing land for conservation. An important characteristic of threatened species in this context is the proportion of their distribution that is unprotected. We use this proportion as a generic surrogate to the degree of protection currently offered to a threatened species. We propose that each threatened species be given a label of the proportion of its distribution that is unprotected. Such a label may become particularly useful for land planning, in at least two general situations. First, where a network of conservation areas is to be designated, using algorithms such as MARXAN (Stewart et al., 2003; Shriner et al., 2006), the proportion of protected distribution may be used to filter out species that are already protected in existing reserves. Second, the map of hotspots of threatened–unprotected species by itself may become a useful tool for planners, where alternative development scenarios are being considered for a given region.

Assessing this proportion for a threatened species is a relatively simple process, although conditional on the availability of a distribution map. The threshold for designating a species as "unprotected" should not be prescribed as a general rule, but decided according to the specific situation. Here we suggested means of selecting a threshold based on a pareto-optimal analysis of two parameters—the threshold, and the number of species designated "unprotected".

An important advantage of this label is its generality, since the land is a common resource for all (terrestrial) species. It may be used to compare species of the same taxon, but may also be employed to compare various higher taxa (e.g., comparing the proportion of unprotected distribution of birds and mammals may indicate which group is being given better protection). Furthermore, these labels make it easy to contrast different geographic regions and countries (e.g., proportions of unprotected distributions of threatened species in different states).

Quantitative methods for prioritizing areas for conservation, based typically on distributions of numerous species, may overlook species-specific traits, such as the spatial

structure of meta-populations. They also lack the capability to relate to expected impact of future land cover change on population viability. Therefore it is important that such products are evaluated against detailed biological data wherever possible. Here, we exemplified such an evaluation for a single area, the Jezre'el Valley, and found that for five threatened species this small valley is a major component of their distribution, essential for their long-term survival. The region was not considered important for conservation previously, and the richness map based on all threatened species did not highlight it as important for conservation either. It was only the map based on threatened–unprotected species that illuminated it as an important hotspot. These findings indicate the capability of our method to highlight areas of real conservation importance.

This approach should not be applied exclusively. A comprehensive approach would prescribe the use of two systems of priority areas simultaneously. The first would be based on an analysis that uses only "threatened–unprotected" species. Its output should be used to drive short-term, "fire-fighting" decisions. One example of such cases where a map of the short-term priorities becomes valuable, is a plan to develop a new settlement in the heart of an undeveloped, rural region in Mt. Gilboa, Israel (Kintisch, 2005). Such a plan, if it materializes, jeopardizes future options to conserve the entire area, which is a hotspot for threatened–unprotected vertebrates (marked 4 in Fig. 4b).

On the other hand, long-term sustainability requires a network that accounts for the entire range of biodiversity. Thus, a second system to be used in parallel to the first system would prescribe the "strategic plan" for long-term expansion of the protected areas network. There are various approaches to the construction of such systems, including species and higher taxa (Sarakinos et al., 2001; Moore et al., 2003; Moilanen, 2005; Wiersma and Urban, 2005), phylogenetic diversity (Faith et al., 2004), focus on persistence (Cowling et al., 1999), and environmental surrogates (Bonn and Gaston, 2005; Trakhtenbrot and Kadmon, 2005; Carmel and Stoller-Cavari, 2006; Levin and Shmida, 2007). Their prospects and challenges were reviewed by Ferrier (2002). A simultaneous use of the two systems may account for long-term conservation strategy, as well as today's most pressing conservation issues.

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