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Sensitivity analysis of conservation targets in systematic conservation planning

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Abstract. Systematic conservation planning has rapidly advanced in the past decade and has been increasingly incorporated in multiple studies and conservation projects. One of its requirements is a quantitative definition of conservation targets. While the Convention on Biological Diversity aims to expand the world's protected area network to 17% of the land surface, in many cases such uniform policy-driven targets may not be appropriate for achieving persistence of various species. Targets are often set arbitrarily, often because information required for the persistence of each species is unavailable or unknown in the focal region. Conservation planners therefore need to establish complementary novel approaches to address the gaps in setting targets. Here, we develop and present a novel method that aims to help guide the selection of conservation targets, providing support for decision makers, planners, and managers. This is achieved by examining the overall flexibility of the conservation network resulting from conservation prioritization, and aiming for greater flexibility. To test this approach we applied the decision support tool Marxan to determine marine conservation priority areas in the eastern Mediterranean Sea as a case study. We assessed the flexibility of the conservation network by comparing 80 different scenarios in which conservation targets were gradually increased and assessed by a range of calculated metrics (e.g., the percentage of the total area selected, the overall connectivity). We discovered that when conservation targets were set too low (i.e., below 10% of the distribution range of each species), very few areas were identified as irreplaceable and the conservation network was not well defined. Interestingly, when conservation targets were set too high (over 50% of the species' range), too many conservation priority areas were selected as irreplaceable, an outcome which is realistically infeasible to implement. As a general guideline, we found that flexibility in a conservation network is adequate when ~10–20% of the study area is considered irreplaceable (selection frequency values over 90%). This approach offers a useful sensitivity analysis when applying target-based systematic conservation planning tools, ensuring that the resulting protected area conservation network offers more choices for managers and decision makers.

Key words: conservation targets; flexibility; Levant (eastern Mediterranean); Marxan; Mediterranean Sea; sensitivity analysis; systematic conservation planning.

Introduction

Successful systematic conservation planning often requires inputs from conservation biologists, interest groups, planners, and decision makers (Moilanen et al. 2009). Flexibility in planning relates to the way that the planning discipline reacts to changes in decision-making approaches, shifts in urban and regional development traditions, and to the recognition of diversity and public participation in the planning process (Tasan-Kok 2008). During the 1960s, flexibility was seen as a negative feature in the planning literature; however it is now being recognized as important, enabling stakeholders to better cope with the growing complexity and diversity of dynamic systems (Tasan-Kok 2008). One of the advantages of environmental decision support tools is that they provide a transparent and quantitative method to evaluate and compare different conservation plans and networks, allowing changes in input variables such as target conservation features, costs, and threats to biodiversity (Ball et al. 2009). An important aspect of relevance to real world planning is providing decision makers with a choice of different options and scenarios generated by systematic conservation planning and decision support tools. A variety of possible solutions provides flexibility and allows decision makers to consider additional stakeholders and socioeconomic factors that are either difficult or impossible to

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incorporate in computerized systematic conservation planning algorithms (Wilson et al. 2005, Moilanen et al. 2009).

One of the common tools used for conserving biodiversity is the designation of protected areas and their effective management (Chape et al. 2005). A key input required for systematic conservation planning is a clear definition of the targets for focal biodiversity features (Margules and Pressey 2000). A conservation target is an explicit goal in which the minimum size of a certain biodiversity feature (e.g., population size, habitat area) that one aims to conserve is quantified (Possingham et al. 2006).

Conservation targets can be aimed at the species level (e.g., area required for the preservation and persistence of a certain species) as well as at the ecosystem level (e.g., ecosystem area required for the preservation and persistence of all species of that ecosystem; Ward et al. 1999, Venter et al. 2014). According to the Conference of the Parties to the Convention on Biological Diversity (CBD) at its 10th meeting in Nagoya, Japan, by 2020, at least 17% of terrestrial and inland water areas, and 10% of coastal and marine areas, should be conserved through effectively and equitably managed, ecologically representative, and well-connected systems of protected areas (UNEP 2010). Such policy-driven targets are often considered by scientists as arbitrary, minimal, and possibly inadequate (Svancara et al. 2005). In many cases, even protecting the full 100% of the remaining native vegetation may be insufficient due to past habitat loss and fragmentation (Pressey et al. 2003). Ideally, targets for biodiversity features should be based on ecological principles that achieve species persistence. However, species vary widely in their spatial requirements, and conservation practitioners often lack the necessary information and criteria when it comes to setting evidence-based biodiversity targets (Tear et al. 2005). As a result of this, conservation planners often use policy-driven conservation targets or use arbitrary values for determining their targets, for example, 10% or 12% of the distribution area of a species or of a habitat (Pressey et al. 2003, Brooks et al. 2004), or a 20% no-take marine protected area recommendation (Bohnsack et al. 2002). While fixed policy-based targets (e.g., 10% of an ecosystem's area) are frequently used, they are often inadequate to achieve conservation goals or to insure the adequate functioning of ecological processes (Svancara et al. 2005). It is therefore recommended that additional criteria about the risk of species' extinction should be used along with the species' distribution area (sensu Pressey et al. 2003, Kark et al. 2009, Lieberknecht et al. 2010). As the selected targets for each biodiversity feature can have a major bearing on the shape and size of the resulting conservation network (Stewart et al. 2007), it is important to develop methods that can inform us of the relationship between conservation targets and the flexibility of the resulting conservation network.

When using decision support software (such as Marxan), sensitivity analysis as well as calibration can be useful tools in order to better achieve biodiversity targets while minimizing costs and threats. In the case of Marxan, two of the parameters that are usually calibrated are (1) the boundary length modifier (BLM), controlling the compactness of the resulting conservation network, and (2) the species penalty factor (SPF), controlling the importance with which we force the algorithm to reach the set targets for a selected species (Fischer et al. 2010). Biodiversity conservation targets can therefore be seen as another set of parameters for which we should be performing sensitivity analyses within conservation planning scenarios.

Native biodiversity and ecosystems in the Mediterranean Sea are currently facing a wide range of human-caused threats resulting from population growth, tourism, shipping, fishing, hydrocarbon extraction, and other factors (Coll et al. 2010, 2012, Micheli et al. 2013, Mazor et al. 2014*b*). Large-scale conservation planning in the Mediterranean is especially challenging due to the large number of countries, the large variation in their socioeconomic and political characteristics (Kark et al. 2009, Levin et al. 2013, Micheli et al. 2013), and the lack of much of the spatial biodiversity data necessary for systematic conservation planning (Levin et al. 2014).

Currently, coastal marine protected areas in the Mediterranean Sea cover less than 0.5% of the total Mediterranean's coastal area (Abdulla et al. 2008). Within the eastern Mediterranean, Israel's Mediterranean waters are subject to new threats and have become a strategic asset, due to the discovery and production of large, deep offshore natural gas reserves (Shaffer 2011, Goldman et al. 2015) and the increasing use of desalination as a major source for Israel's drinking water (Feitelson 2013). At present, there are seven small marine reserves in Israel's Mediterranean Sea area, none of which are no-take zones, covering a total area of 10.4 km^2, a very small percentage of Israel's territorial waters (<1%; Fig. 1b). Israel's Nature and Parks Authority (INPA) is currently in the process of promoting additional marine nature reserves and parks, including six large marine reserves covering a total area of 800 km^2 (Fig. 1b), aiming to have 20% of Israel's territorial waters declared as marine reserves (Yahel and Engert 2012).

In this study, we aim to test how setting different targets for biodiversity features affects the overall flexibility of the resulting conservation network, focusing on Israel's exclusive economic zone as a case study. We also aim to offer complementary guidelines for setting the targets for biodiversity features in systematic conservation planning.

Methods

Using Marxan as a decision support tool

We applied the software Marxan to examine and compare a range of conservation planning scenarios

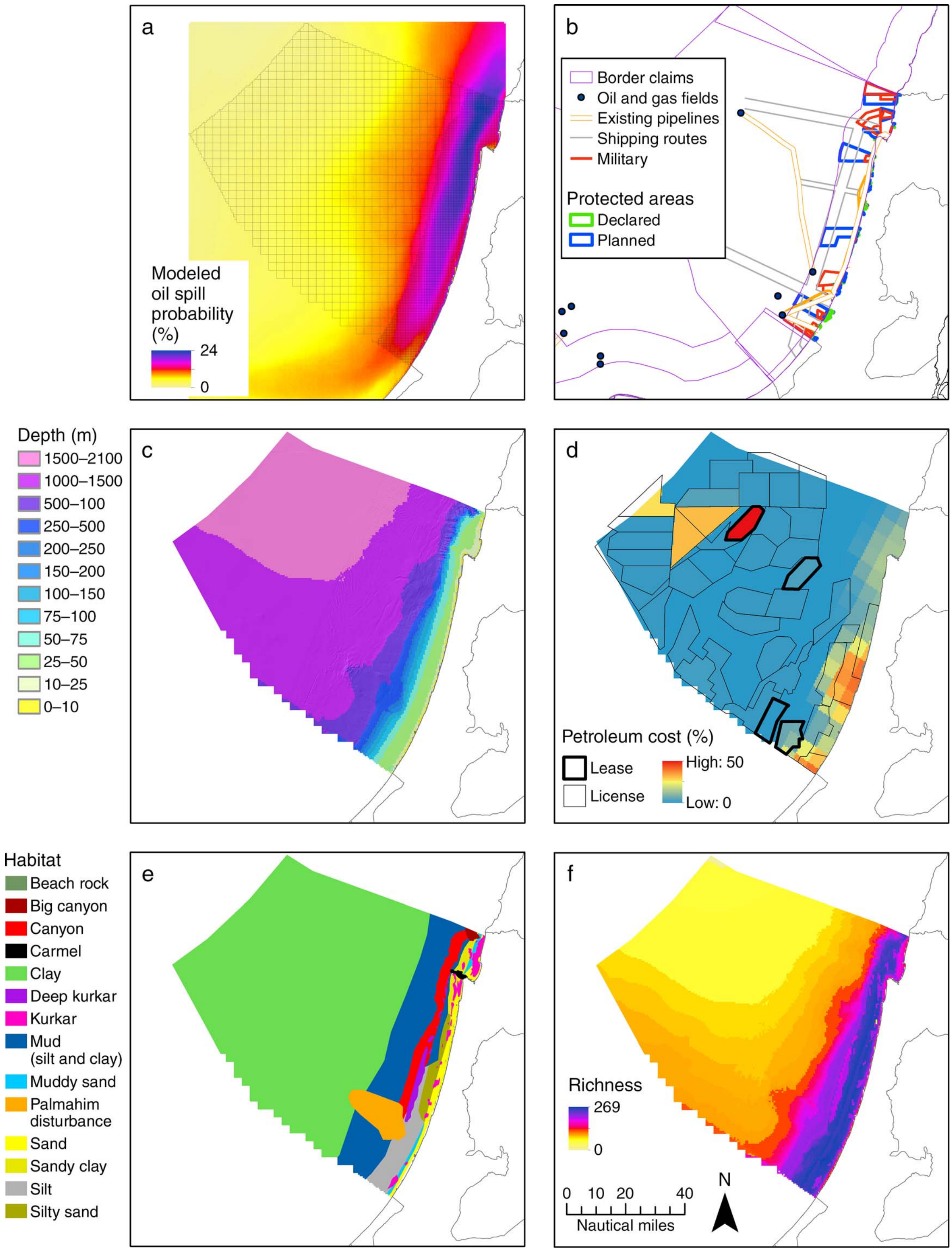

FIG. 1. Maps of the study area (Israel's waters in the eastern Mediterranean). (a) The planning units and modeled probability of oil spills, (b) marine uses and protected areas, (c) depth classes, (d) petroleum leases and licenses and the combined fishing and gas cost layer, as detailed in Table 1, (e) marine habitats, and (f) biodiversity features richness. One nautical mile = 1.852 km.

(Possingham et al. 2000). Marxan is a decision support tool for conservation planning (Moilanen et al. 2009), which finds efficient solutions to the problem of selecting a system of spatially cohesive areas that meet a suite of biodiversity targets (Possingham et al. 2000). Marxan provides flexibility in where conservation actions can occur and is therefore a decision support tool rather than an optimization algorithm providing a single answer (Possingham et al. 2000). Using a simulated annealing algorithm (Possingham et al. 2000), a widely used industry standard optimization method, Marxan provides a range of good (near-optimal) solutions rather than a single solution (the latter could be quite incorrect when data are incomplete). As each Marxan run provides a slightly different solution, we use the metric "selection frequency" to compare scenarios. Selection frequency is the number of times each planning unit is selected 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 can be considered high-priority conservation areas (e.g., 90%, as in Kark et al. [2009]). In this study, we used a new version of Marxan, namely Marxan with Probability, allowing us to incorporate threats (Tulloch et al. 2013). In our analyses, the boundary length modifier (BLM) was calibrated to 10 following the approach developed in Stewart and Possingham (2005). Each of our Marxan scenarios consisted of 100 repeat runs each with 1 000 000 iterations, resulting in a summed solution (the solution that combines the results from all 100 runs, also termed selection frequency). We did not lock in or lock out any areas in our Marxan scenarios.

Study area

Israel's territorial waters in the Mediterranean Sea cover an area of 5230 km^2, and its exclusive economic zone covers ~20 900 km^2. While Israel's marine borders have not been formally delineated (other than with Cyprus; Wählisch 2011, Katsanevakis et al. 2015), we used an approximate definition, to divide our study area into planning units of 1 km^2 in the territorial waters ($n =$ 5510), and of 25 km^2 beyond Israel's territorial waters (n = 916), totaling 6426 planning units (Fig. 1a). In our analysis, we excluded the marine areas offshore of the Gaza Strip, and had a total number of 5388 planning units.

Estimating opportunity cost

We used two types of cost in our scenarios. In half of the scenarios, area was used as a surrogate for cost, aiming to minimize the area needed to meet our conservation targets. To create a more realistic and spatially heterogeneous layer based on real costs, for the other half of the scenarios we combined two major uses to estimate opportunity costs: fishing revenues and the potential value from oil and gas fields. Opportunity cost is the lost benefit (e.g., forgone fishing revenue) when an area is declared a closed/no-take marine protected area; Cameron et al. 2008).

In order to estimate the fishing revenues, we calculated the distribution of annual revenue (within 1-km^2 planning units) retrieved by commercial fisheries in Israel's Mediterranean territorial waters. This cost layer was derived from effort maps that combined the four major fishing gears of Israel; entangling nets, long liners, purse seiners, and trawls. By using the most recent annual revenue (year 2009) reported by the Israel Department of Fisheries and Aquaculture (Edelist et al. 2013), we derived monetary values for each planning unit (for full details of this cost layer, see Mazor et al. [2014*b*]). While fishing revenues do not necessarily represent all opportunity costs (as fishermen can still catch fish in areas surrounding marine protected areas), we used fishing revenues as a surrogate for opportunity costs. As we were mostly interested in spatial cost differences, and because we eventually normalized our cost values, we only used a single year's fishery yield, and did not consider opportunity cost in the future (which would not be spatially different in future years).

The cost layer of natural gas fields was calculated using predicted gas yield for each field. Data was taken from the 2013 Noble Energy analyst report for the Eastern Mediterranean, and from open sources on the web (specific references in Table 1; Noble Energy report *available online* [In Hebrew.]).[5] Gas prices (as of 2014) were available from the Israel Ministry of Energy and Water Resources (*available online* [In Hebrew.]).[6] Polygons representing gas field concessions were given the value of the gas within them. Fields in which gas was not yet found were assigned a value of zero. The rest of the area was assigned a value derived from the total areal gas assessment minus the already-discovered gas (Table 1). While we have attempted to base our calculations on realistic values of gas field yields, our main aim was to represent relative cost differences in space rather than provide absolute values, and the data entered can be changed as financial data are revised.

The monetary revenue from newly discovered gas fields in Israel outweighs the fishing revenue. However, fishing is still considered an important factor in marine spatial planning in the region and in our analysis, so we combined the two cost layers by dividing each of them by their maximum value and averaging them (thus assigning an equal 50% weight to each cost layer; the final cost layer is shown in Fig. 1d). Thus, in this case study, the cost layer equally represents the spatial opportunity cost of the fishing and natural gas industries. This can be changed as required using different weights.

[5] http://www.nobleenergyinc.com/Operations/Eastern-Mediterranean-128.html

[6] http://energy.gov.il/GxmsMniPublications/NGguidebook.pdf

TABLE 1. Estimated opportunity costs of natural gas fields in Israel's Mediterranean waters, based on the 2013 Noble Energy analyst review and gas prices in Israel (as of 2014).

Name	Block number	Gas field area size, (1×10^9 m^3)	Gas field area size (Tcf)	Cost (US$)	Source
Total predicted		3416	122	902 800	
Leviathan	349+350	532	19	140 600	1
Tamar	I-12	280	10	74 000	1, 4
Tamar SW	I-12	19.6	0.9	6 660	1, 4
Aphrodite 2 (Ishay)	370	0	0	0	3
Myra	347	0	0	0	2
Sara	348	0	0	0	2
Tanin	400	33.6	1.2	8 880	1
Mari-B	I-10	24.36	0.87	6 438	1
Noa	I-7	1.12	0.04	296	1
Dalit	I-13	14	0.5	3 700	1
Dolphin (Hanna)	351	2.8	0.1	740	1
Karish	366	50.4	1.8	13 320	1
Shimshon	332	16.8	0.6	4 440	5
Total found		974.68	35.01	259 074	
Other		2441.32	86.99	643 726	

Notes: Costs are calculated assuming on Tcf (trillion cubic feet) corresponds to a cost of $7400 million US dollars. Other refers to total fields predicted for Israel, minus the total fields found. Sources used to estimate gas field area size are 1, Noble Energy (http://www.nobleenergyinc.com/Operations/Eastern-Mediterranean-128.html); 2, http://www.haaretz.com/business/dry-as-a-bone-sara-casts-doubt-about-the-israeli-energy-shares-1.471705; 3, http://www.tashtiot.co.il/2013/04/14/%D7%92%D7%96-%D7%98%D7%91%D7%A2%D7%99-427/ [In Hebrew.]; 4, http://www.tashtiot.co.il/2014/02/02/%D7%92%D7%96-%D7%98%D7%91%D7%A2-17/ [In Hebrew.]; and 5, http://www.tashtiot.co.il/2013/06/05/%D7%92%D7%96-%D7%98%D7%91%D7%A2%D7%99-485/ [In Hebrew.] Source for gas prices: http://energy.gov.il/GxmsMniPublications/NGguidebook.pdf [In Hebrew.].

Incorporating threats to biodiversity from oil spills into Marxan

To estimate the risk to biodiversity from potential oil spills, we used the output from multiple simulations of an oil spill model run by Goldman et al. (2015). In that recent study, numerical simulations of oil spill events were performed in order to estimate the conditional probability of different areas being polluted by oil, given that the origin of the spill is close to shipping routes, gas pipes, gas wells, and single buoy moorings. The simulations were carried out using the MEDSLIK oil spill model using realistic synoptic conditions by sampling the time of the initial spill from a year of atmospheric and ocean forecasts. More specifically, Goldman et al. (2015) used the SKIRON operational atmospheric forecasting system and SELIPS circulation forecasts from August 2012 to August 2013 to provide wind and currents. The oil spill risk was included as a threat in our Marxan with Probability runs, the maximum modeled probability being 24% (out of all simulations), a few kilometers to the north of Haifa (Fig. 1a).

Choosing targets for biodiversity conservation features

In our Marxan scenarios we used two types of biodiversity features: habitat surrogates (using depth and marine habitats), and the distribution range of fish species. Altogether, our conservation targets included 12 depth classes, 14 marine habitat classes, and the distribution area of 356 fish species. We used the following depth classes (meters below sea level): 0–10, 10–25, 25–50, 50–75, 75–100, 100–150, 150–200, 200–250, 250–500, 500–1000, 1000–1500, and 1500–2100 (based on data from the Israel National Bathymetric Mapping Project, conducted by the Israel Oceanographic and Limnological Research Institute and the Geological Survey of Israel; see depths in Fig. 1c). We mapped marine habitats based on data from INPA (Yahel and Engert 2012) covering Israel's territorial waters, and based on a 1:1 000 000 map from the International Bathymetric Chart of the Mediterranean (IBCM) showing unconsolidated bottom surface sediments (Emelyanov et al. 1996; see habitats in Fig. 1e). We created spatial data sets representing the distribution of fish species based on depth ranges provided by Golani et al. (2006; see Fig. 1f showing species richness) and on typical habitat type.

In our Marxan scenarios, we modified the conservation targets in two ways. In the first set, we applied uniform targets to all biodiversity features, ranging from 5% to 100% in increments of 5% (i.e., 20 different scenarios altogether). In the second set, we applied variable targets to all biodiversity features, based on their IUCN class and distribution area, as described in Table 2. Twenty different ranges were used for the targets (expressed in percentage of distribution area), ranging from a minimum of 0.5–10% (at steps of 0.45%) to a maximum of 10–100% (at steps of 9%). The example given in Table 2 is for the second set (ranging between targets of 1% and 10% at steps of 0.9%). Overall, we ran Marxan in 80 different scenarios (40

TABLE 2. The range of targets that were set (expressed in percentage of distribution area per species) in one of the 20 scenarios of the second set, ranging between 1% and 10% (at steps of 0.9%), based on the IUCN class and distribution area of biodiversity features (species, habitat classes, depth classes).

IUCN class of species	Distribution area of biodiversity features (%)					Total number of conservation features
	1–10 km^2	10–100 km^2	100–1000 km^2	1000–10 000 km^2	>10 000 km^2	
Critically endangered	10.0	9.1	8.2	7.3 (3)	6.4	3
Endangered	9.1	8.2 (1)	7.3 (1)	6.4 (1)	5.5 (2)	5
Vulnerable	8.2	7.3	6.4	5.5 (9)	4.6 (4)	13
Near threatened	7.3	6.4	5.5	4.6 (7)	3.7 (3)	10
Least concern	6.4 (1)	5.5 (8)	4.6 (16)	3.7 (15)	2.8 (17)	48
Data deficient	5.5	4.6	3.7 (1)	2.8 (16)	1.9	17
Not evaluated	4.6 (4)	3.7 (35)	2.8 (64)	1.9 (157)	1.0 (27)	291
Total number of features	5	44	82	208	43	382

Note: Cells in the table with numbers given in parentheses indicate combinations for which there were biodiversity features (in parentheses) in our study area.

scenarios with area as cost, 40 scenarios with the combined opportunity costs of natural gas and fishing).

Spatial analysis of Marxan scenarios

To analyze the results of the Marxan scenarios, we computed the following metrics for each of the scenarios: (1) average percentage of target set for each biodiversity feature, in each scenario, (2) average area of target set for each biodiversity feature, expressed as percentage of the total study area, (3) average selection frequency within the entire study area, (4) percentage of the study area in each of the following 11 classes of selection frequency: 0%, 0.1–9.9%, 10–19.9%, 20–29.9%, 30–39.9%, 40–49.9%, 50–59.9%, 60–69.9%, 70–79.9%, 80–89.9%, and 90–100%, (5) the coefficient of variation (CV) for the 11 selection frequency classes, (6) the number of individual regions based on the 11 selection frequency classes (computed using the GROUP function

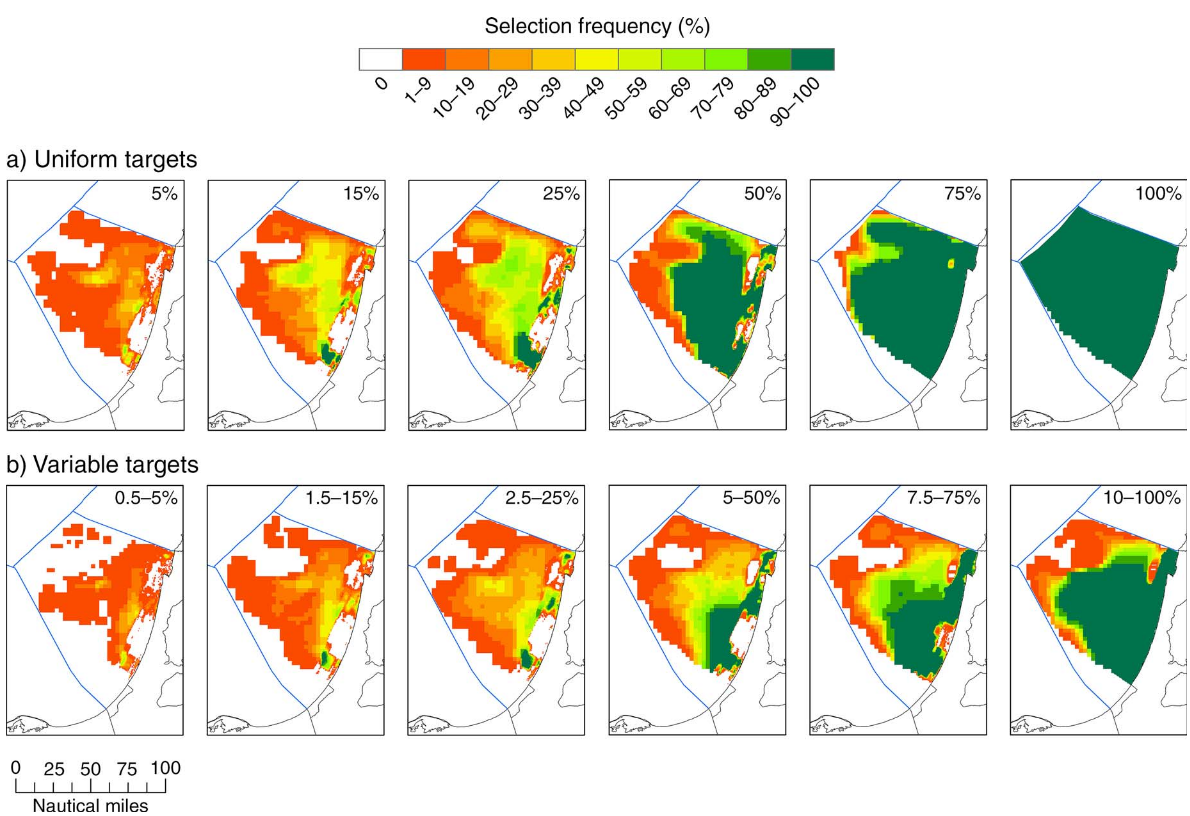

FIG. 2. Selection frequency maps in (a) uniform target scenarios and (b) the variable target scenarios, when opportunity costs were calculated by combining both natural gas and fishing. The percentages shown in the maps refer to the targets set to the biodiversity features in those scenarios. In uniform target scenarios, all biodiversity features had the same conservation targets, defined as percentage of their distribution area. In variable target scenarios, conservation targets were calculated for each biodiversity feature on based on its IUCN class and distribution area (see example in Table 2).

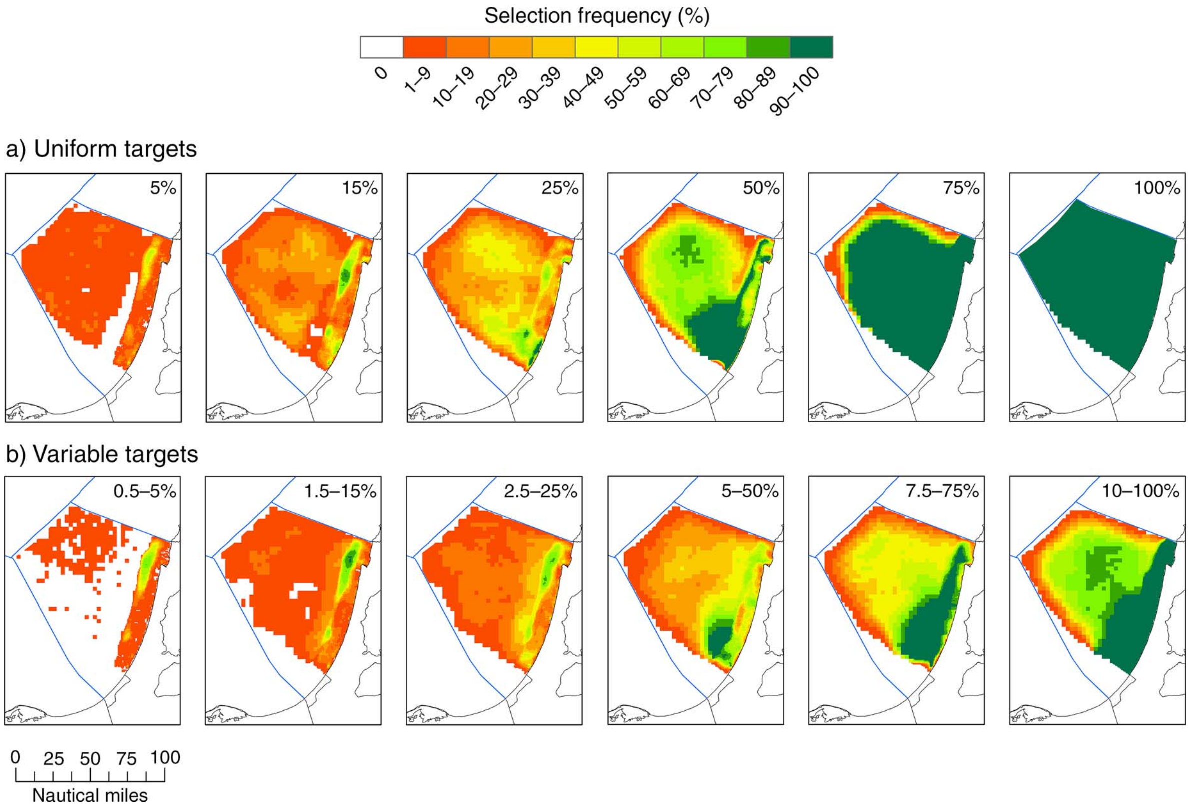

FIG. 3. Selection frequency maps in (a) Marxan uniform target scenarios and (b) the variable target scenarios, when costs were based on the area of planning units. The percentages shown on the maps relate to the targets set to the biodiversity features in those scenarios. In uniform target scenarios, all biodiversity features had the same conservation targets, defined as percentage of their distribution area. In variable target scenarios, conservation targets were calculated for each biodiversity feature on based on its IUCN class and distribution area (see example in Table 2).

within Idrisi Selva 17.02 GIS; Clark Labs, Worcester, Massachusetts, USA), (7) the average number of the selected planning units in the 100 solutions of each scenario, (8) the CV of the selected planning units in the 100 solutions of each scenario, (9) the average cost and score of the selected planning units in the 100 solutions of each scenario, and (10) the average connectivity (boundary length) of the selected planning units in the 100 solutions of each scenario. We then examined the correspondence between these variables across the 80 Marxan scenarios, in order to evaluate how changes in the target set for biodiversity features (in the different scenarios) affect the resulting conservation network.

RESULTS

We found that when relatively low targets were set for biodiversity features, few areas were selected as high-priority areas for conservation. These selected areas were predominantly located within Israel's territorial waters (Figs. 2, 3). In all of our Marxan scenarios, incrementally increasing the goals of our biodiversity targets led to an increase in the total area selected for inclusion in the conservation network. The scenarios with the highest goals for biodiversity features required the entire study area to be selected as a protected area in order to achieve the conservation targets (Figs. 2, 3). In both the uniform and the variable target scenarios, we observed both a monotonic increase in the overall percentage of the study area selected in over 90% of the runs, as a function of the percentage targets set, and a monotonic decrease in the percentage of the study area that was never selected (Figs. 4, 5). However, some of the metrics we calculated had a nonlinear unimodal curve in response to the average targets set. In the uniform targets scenarios, when the targets were set between 35% and 45% (of species distribution ranges), values of the CV of the selection frequency classes were the lowest, the number of individual regions (polygons defined based on selection frequency classes) was the highest, and total connectivity was the highest, irrespective of the cost variable used (Figs. 4a, 5a). A similar pattern in the response of the these three metrics (CV of selection frequency, number of individual regions, and total connectivity) was observed for the variable targets scenarios, when the targets were set between 10% and 20% (of species distribution ranges), irrespective of the cost variable used (Figs. 4b, 5b). When plotting these three metrics in which a humped-shaped curve was

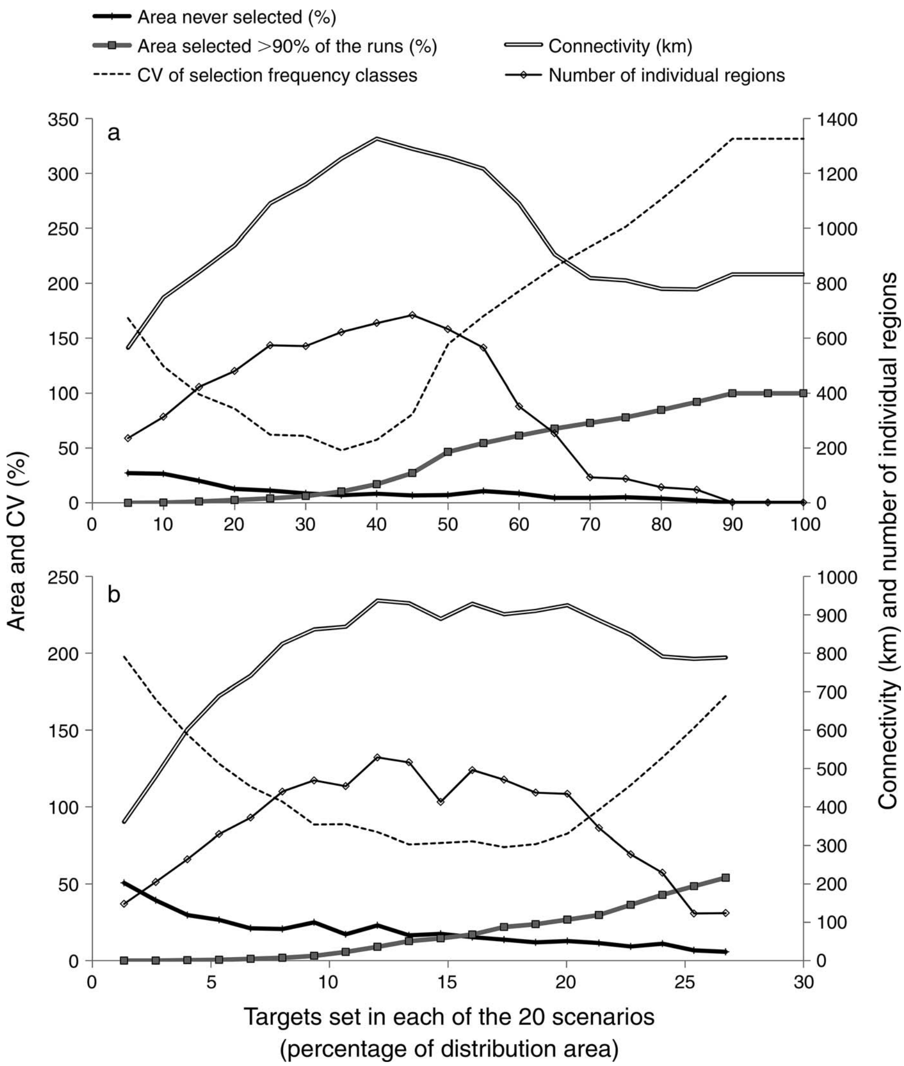

FIG. 4. The effect of target changes (expressed as percentage of distribution area, shown on the *x*-axis) on a range of metrics describing the conservation network, when opportunity costs were calculated combining both natural gas and fishing. Panel (a) shows the 20 scenarios with uniform targets, panel (b) shows the 20 scenarios with variable targets. The left-hand *y*-axis refers to three variables: percentage of area never selected and percentage of area selected in >90% of the runs (both ranging between 0% and 100%), and the coefficient of variation (CV) of selection frequency classes, which can have values above 1; the CV variable is dimensionless, yet it is expressed here as a percentage (with 1 shown as 100%), to fit it in the same figure without adding another *y*-axis. Connectivity refers to the boundary length of selected protected areas.

observed, but this time as a function of percentage of the study area selected in over 90% of the runs, in both the uniform and the variable target scenarios, the curves for most of the metrics reached their inflection points in the scenarios where 10–20% of the area was selected in over 90% of the runs (Fig. 6).

Four potential hotspot areas for MPAs were identified when incorporating opportunity cost. These hotspots partly correspond with three of the six new large MPAs promoted by INPA: Yam Rosh Hanikra-Akhziv, Rosh Hakarmel, and Evtah (Harkhava extension; Fig. 7). Two additional hotspots (not included in INPA's plan) for potential MPAs were identified offshore from Hadera (Fig. 7). When using area as cost, two of the potential hotspots areas for MPAs were located approximately in similar locations to those found when using the opportunity costs: offshore from Ashdod and Ashkelon, and just to the north of Haifa.

DISCUSSION AND CONCLUSIONS

In this work, we provide a new method to help guide the selection of conservation targets in systematic conservation planning. We incorporated a sensitivity analysis into decision support tools, which shows how changes in setting conservation targets can substantially alter the resulting conservation network as well as its flexibility. Performing sensitivity analyses in which a range of plausible targets are examined iteratively has

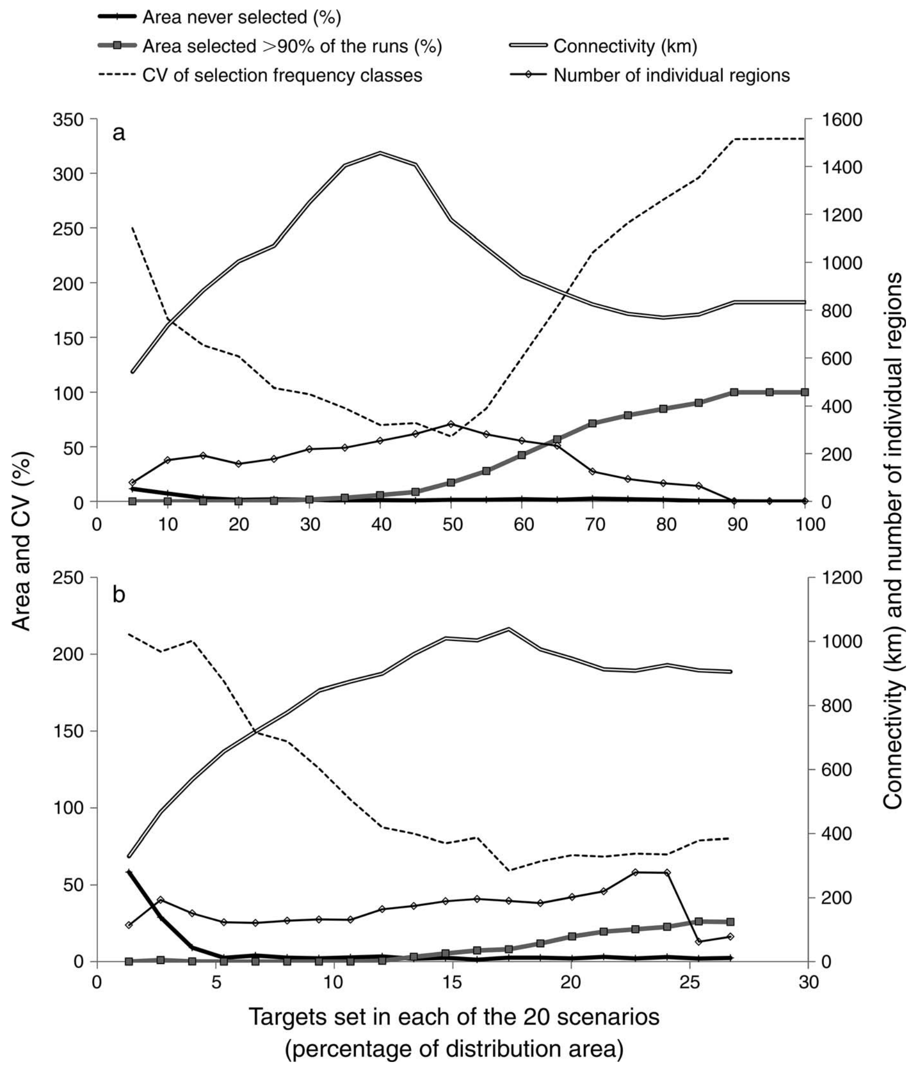

FIG. 5. The effects of changing the targets (expressed as percentage of distribution area, shown on the *x*-axis), on various metrics describing the conservation network, when costs were based on the area of planning units. Panel (a) shows the 20 scenarios with uniform targets, panel (b) shows the 20 scenarios with variable targets. The left-hand *y*-axis refers to three variables: percentage of area never selected and percentage of area selected in >90% of the runs (both ranging between 0% and 100%), and the CV of selection frequency classes which can have values above 1; the CV variable is dimensionless, however it is expressed here as a percentage (with 1 shown as 100%), to fit it in the same figure without adding another *y*-axis. See Fig. 4 for the definition of connectivity.

been proposed in the past (Lieberknecht et al. 2010), but few studies have carried this out, due to its added level of complexity. However, we propose that this analysis can be simplified and is important to routinely include in conservation planning projects. By performing a methodical sensitivity analysis we found, as predicted, that changing the targets set for biodiversity features also alters the resulting conservation network. We found that when conservation targets were set too low (i.e., below 10% of the species' distribution range), very few areas were identified as irreplaceable (i.e., too much flexibility), and the resulting conservation network did not have clear boundaries, and thus decision makers are not being provided much assistance from the systematic conservation planning tools. In comparison, when conservation targets were set too high (over 50% of the species' distribution range), the resulting conservation network included too many irreplaceable areas, proposing a solution that is realistically infeasible to implement, due to competing socioeconomic factors. From this study, we recommend that in conservation planning it is critical to gain a better understanding of the way conservation targets can shape the resulting conservation network. An analysis as presented here in this study can help guide the selection of conservation targets and can provide further guidance for decision makers, planners, and managers.

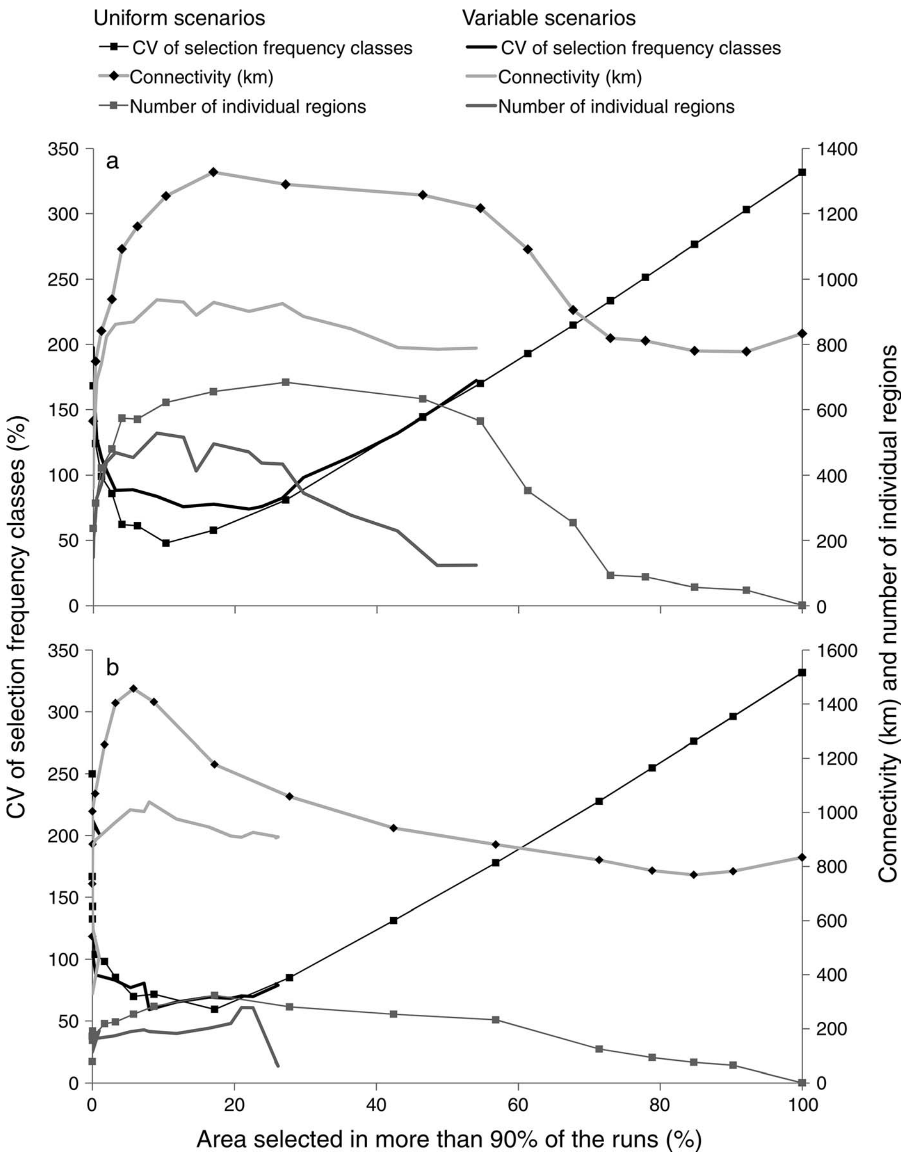

FIG. 6. The distribution of three conservation network metrics as a function of the percentage of the study area selected in more than 90% of the runs. Panel (a) shows the results when opportunity costs were calculated combining both natural gas and fishing. Panel (b) shows the results when costs were based on the area of planning units. The left-hand *y*-axis refers to the CV of selection frequency classes, which can have values above 1; the CV variable is dimensionless, however it is expressed here as a percentage (with 1 shown as 100%). See Fig. 4 for the definition of connectivity.

Using site prioritization algorithms such as Marxan, resulting reserve networks are not solely driven by biodiversity features, but also by additional constraints, such as cost. We explored the sensitivity of a marine reserve network to changes in conservation targets, using a case study of the full territorial and economic waters of Israel in the Mediterranean Sea. With regard to the spatial definition of a protected area network, when area was used as a surrogate for cost (and the planning units having approximately the same area), there were fewer constraints on the spatial allocation of protected areas compared to when we used opportunity costs based on revenues from fishing yields (within Israel's territorial waters) and natural gas (mostly beyond Israel's territorial waters). This can explain the difference in the planning scenarios for uniform targets of 25%, using the two different cost variables (Fig. 7). While area is a poor cost surrogate in marine systems (Mazor et al. 2014*a*) and using a realistic cost variable has its advantages (directing the conservation network to cheaper and more feasible sites, as in Levin et al. [2013]), one should be aware that cost has a great impact on the resulting network (Bode et al. 2008). Nonetheless, we found a partial correspondence between the potential

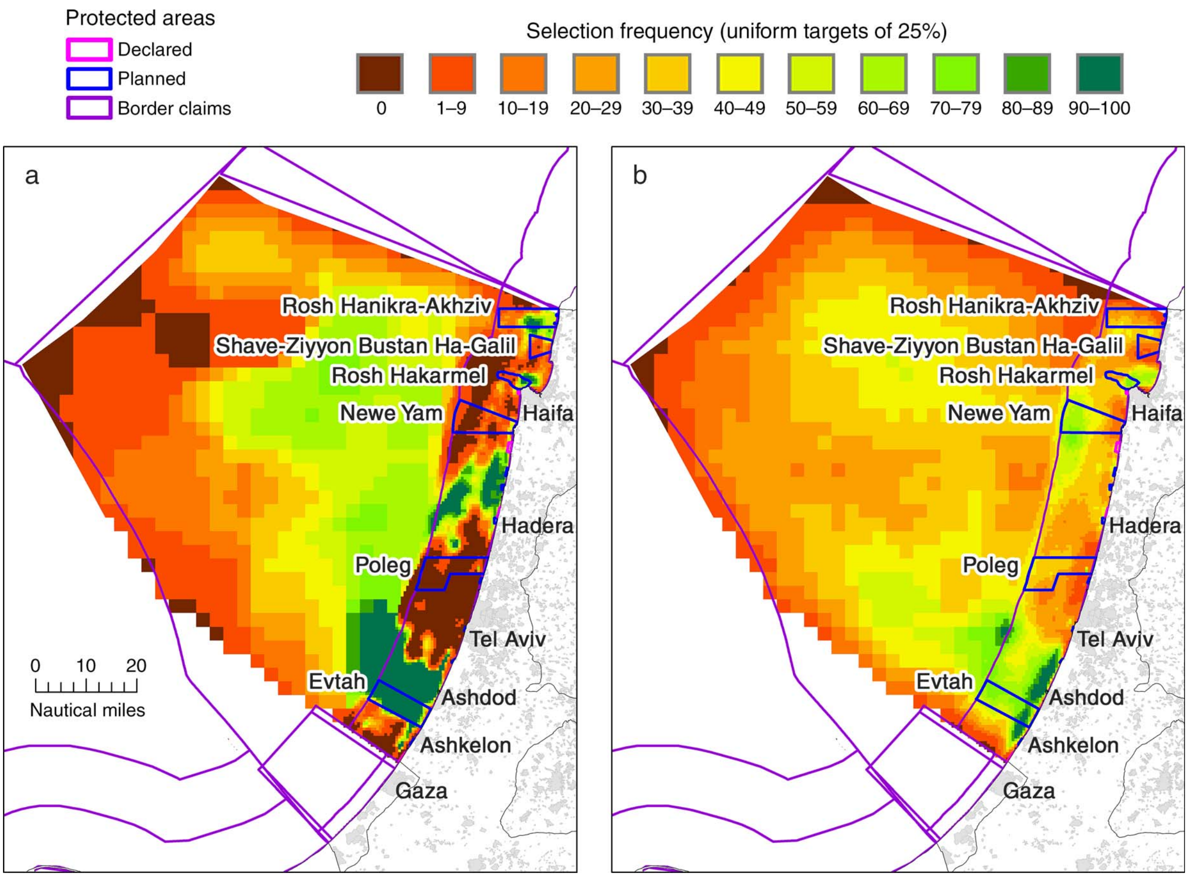

FIG. 7. The selection frequency of the Marxan scenario using uniform targets of 25%. Border claims include territorial waters, exclusive economic zones, and overlapping claims (as between Lebanon and Israel), using the Global Maritime Boundaries Database. (a) Results when opportunity costs were calculated by equally combining natural gas and fishing as cost layers. (b) Results when opportunity costs were based on the area size of planning units.

conservation hotspots identified in our scenarios, and those currently promoted by INPA (Yahel and Engert 2012).

The importance of flexibility in land-use planning is well recognized (Pahl-Wostl 2002), and one of the concerns raised about using set targets in conservation planning is that they might make conservation plans inflexible and override expert opinion (Agardy et al. 2003, Carwardine et al. 2009). In recent years, the importance of incorporating economic and social targets alongside biodiversity targets into conservation planning has been recognized (Kark et al. 2009, Klein et al. 2010, Weeks et al. 2010, Levin et al. 2013, 2014). However, adding socioeconomic factors makes it harder to meet all biodiversity targets as the algorithm becomes more constrained within a complex system, with multiple uses and interest groups (McDonald 2009, Halpern et al. 2013, Mazor et al. 2014*a*).

It is important to realize that Marxan should not be aimed at providing a single "best" conservation planning solution, but rather provides a set of multiple near-optimal solutions, from which the selection frequency can be calculated. Having alternative planning options is important for the realistic implementation of Marxan solutions, while taking into account the needs of different stakeholders. To make it easier to choose and distinguish between the various good solutions produced within a Marxan scenario, Linke et al. (2011) suggested the use of a multivariate cluster analysis to distinguish between a range of solutions based on their similarity. Irreplaceability as defined within Marxan is defined as the proportion of solutions in which a site is selected to be included in the conservation network within the runs of a certain scenario. While there are several systematic conservation planning tools that can be used (e.g., Marxan, Zonation, C-Plan), each with its own algorithms and definition of how to calculate irreplaceability, it has been found that priority areas are quite similar, and that the choice of software has less influence on the resulting conservation network than the biodiversity features and cost metrics which are used (Carwardine et al. 2007, Delavenne et al. 2012).

Our approach identifies interesting scenarios, which account for flexibility and offer more choices to planners, as scenarios in which there is greater spatial variability in output (e.g., maximum number of individual regions of selection frequency classes, and minimum values of CV in the distribution of selection frequency classes). In our case study, we found that some of our conservation network metrics (e.g., total connectivity, number of individual regions of selection frequency classes, and the CV in the area of these classes) were of a humped shape, reaching their inflection point when biodiversity targets were set between low and medium values. That peak value coincided with 10–20% of the study area considered irreplaceable (here defined as selection frequency values over 90%). Such a unimodal pattern can be expected when a wide range of conservation targets is used. When conservation targets are low, the total connectivity (boundary length) and number of individual conservation regions are small; as conservation targets are increased, more areas will be selected to be included in good solutions, and hence, the total connectivity and number of individual conservation regions will increase. However, beyond a certain threshold of conservation targets, high-priority areas for conservation will merge, and thus the total connectivity and number of individual conservation regions decrease when conservation targets are set high.

We suggest that this range of values where the conservation network metrics reach their inflection point may be used as a rule of thumb value for determining the values of conservation targets, in a way that may allow enough flexibility in the conservation network. While these values are similar to the CBD's recommendations, note that the CBD guidelines refer to percentage of area of a certain ecosystem (and for some ecosystems, even 100% may not be enough; Pressey et al. 2003), whereas we refer to percentage of the total study area. This range of irreplaceability values (between 10% and 20%) was consistent when using two different cost variables, and it can be used to further identify and guide the spatial selection of target areas in order to achieve the CBD goals. While this practical criterion may differ between regions, we suggest that the approach developed here, of running scenarios using a range of monotonically increasing targets set for the biodiversity features, provides an effective way to direct the proper selection of targets (when ecological criteria for target-setting are not available). Thus, the resulting conservation network can offer guidance for decision makers, while leaving them space and flexibility to weigh in additional considerations, both thematically and spatially. In a review of a wide range of conservation studies, it was found that average evidence-based conservation targets (30.6% ± 4.5% in conservation assessments, and 41.6% ± 7.7% in threshold analyses), were two to three times higher than those recommended in policy-driven approaches (13.3% ± 2.7%; Svancara et al. 2005). Our approach offers an additional method for setting conservation targets, using a sensitivity analysis step within systematic conservation planning tools, to ensure that the resulting conservation network is more flexible. Based on our findings, we recommend that efforts should be directed at further developing automated sensitivity analyses of model parameters that will be integrated into decision support tools and analysis more easily, as is being currently attempted in Marxan.net, using computer clusters and cloud technologies.

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Supplemental Material

Data Availability

Data associated with this paper have been deposited in Dryad: http://dx.doi.org/10.5061/dryad.2mb2h