Marxan analysis for the identification of priority conservation areas in the Israeli Exclusive Economic Zone

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Summary

The "Israeli EEZ MPAs masterplan" project is a systematic conservation planning initiative led by the Society for the Protection of Nature in Israel (SPNI) in collaboration with the ministry of environment, academia and the Israel Oceanographic and Limnological Research (IOLR) institute. After the collection and analysis of environmental and socio-economic data was completed by the respective teams, we used these spatially georeferenced datasets and the conservation planning software Marxan to identify priority conservation areas in the Exclusive Economic Zone (EEZ) of Israel in the Mediterranean Sea. We included in the analyses: 19 representative benthic habitat types, five unique benthic habitats, four representative pelagic habitats, and one special pelagic habitat. For all these conservation features, conservation targets were set by local experts considering the conservation value of the features (representative / unique habitat), their spatial extent, and level of certainty regarding their distribution. We also included in the analysis available spatial data on activities belonging to the sectors of: hydrocarbon production, shipping and trade, fishing, security, telecommunications, and waste disposal. By applying Marxan, we tried to overcome the challenge of creating a protected area system, while accommodating existing users. We developed four sets of planning scenarios considering: different sets of conservation targets, whether MPAs in territorial waters are included or not in the analysis, and the different cost of hydrocarbon exploration licences. In all Marxan scenarios, the planning solutions (reserve systems) identified corresponded to approx. 40% of the Israeli EEZ (ranging from 41 to 43%) with the exception of scenario 3 which had lower conservation targets and the identified priority areas corresponded to approx. 30% of the EEZ. It is important to stress that the conservation targets for two features: the 'cold seeps with high probability of occurrence' and the benthic habitat 'southern slope' were not met in any scenario. The reason is that the spatial distribution of these features overlapped with the distribution of activities that were incompatible with protection (treatment and production rigs, non-active well systems, and restricted security zones) and thus areas of overlap were excluded from selection and target (100%) achievement was impossible. Areas corresponding to 24% of the EEZ presented high selection frequency across all scenarios. The map presenting the areas with high irreplaceability, and thus the areas that should be included in future MPAs, could be used as the basis for discussions with stakeholders and decision makers. Alternatively, scenario 3 in which priority areas correspond to approx. 30% of the EEZ could be used as the basis for such discussions in order to achieve the 30x30 target, i.e. protect 30% of Israel's marine environment by 2030. It is important to stress that Marxan is meant to support decision-making and act as a starting point for planning discussions. Its results must be refined by decision-makers to consider the full range of political, socio-economic and practical factors affecting planning implementation.

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2. The conservation planning software Marxan

Marxan (Ball et al. 2009) is a freely available software designed to help decision makers find solutions to conservation, and other spatial planning problems. Marxan was developed to address the problem of creating a protected area system, while accommodating existing users. The basic idea behind a reserve design problem is that a conservation planner has a large number of potential sites (or '*planning units*') from which to select new conservation areas. The objective is to devise a reserve system which is made up of a selection of these planning units which will solve a problem that includes several ecological, social and economic criteria and principles.

Marxan is primarily intended to solve a class of reserve design problem known as the '*minimum set problem*', where the goal is to achieve some minimum representation of biodiversity features for the smallest possible cost (Ball et al., 2009). The rationale here is that cheaper or less socially disruptive reserve networks are more likely to be implemented. In minimum set problems, the features of biodiversity that one wishes to conserve (hereafter referred to as 'conservation features') are treated as constraints to solutions of the problem (Possingham et al., 2000) – e.g. we must conserve at least 300 km^2 of coral reefs or 30% of their known spatial distribution. Conservation features can reflect the presence or distribution of species, habitats, and any other elements of biodiversity that can be spatially represented. Given reasonably comprehensive data on features, Marxan aims to find a suite of solutions for reserve network designs that meet user-defined 'targets' for the minimum 'cost' (Possingham et al., 2000).

Marxan contains a variety of algorithms, but the most commonly used is simulated annealing, to find good solutions to a version of the 'minimum set problem' that includes spatial compactness. Algorithms solve problems, and the ***Marxan problem is to find a reserve system that is a combination of three objectives: 1. conserve a certain amount of every conservation feature, 2. minimise the impact of those decisions on other users of the land- or sea-scape, and 3. keep the reserve system compact.*** Compact solutions (i.e., the selection of planning sites that are adjacent) are preferable by decision-makers because they are managed more easily than sites that are scattered across a region.

With each run, Marxan produces multiple 'good' solutions for reserve network configurations, thus increasing the chance of finding a solution that maximizes conservation interests while minimizing socioeconomic or other types of impacts. It can enhance the rigor, transparency and repeatability of decisions that are inherently complex and potentially subjective**. *Marxan is meant to support decision-making and act as a starting point for planning discussions. Its results must be refined by decision-makers to consider the full range of political, socio-economic and practical factors affecting planning implementation.***

Marxan key terms and definitions are reported below for future reference.

- **Conservation feature**: The feature (e.g., species, habitat, process, etc.) for which a target is set for inclusion in the reserve system.
- **Conservation targets**: The minimum quantity or proportion of the conservation feature in the planning region to be included in the solution (e.g., protect 30% of each habitat type in the reserve system).
- **Cost**: A function Marxan acts to minimize in its pursuit of achieving the conservation targets. It is meant to reflect the cost of including a 'planning unit' in the reserve design. Costs are flexible and

often pertain to socioeconomic implications of establishing a reserve (e.g., land acquisition cost; management cost; opportunity cost).

- **Planning region** (also known as planning area/extent, study area): The spatial domain over which the planning process occurs. This area is subdivided into planning units.
- **Planning unit**: Spatial units within the planning region, which can be defined as regular shapes (grids or hexagons) or irregular landscape-based features (e.g., watersheds). The planning unit size reflects the minimum size of an acceptable MPA.
- **Solution**: A binary output of Marxan reflecting whether a planning unit is selected (1) or not selected (0) as part of the reserve system.
- **Selection Frequency**: the summed output of all solutions

3. Marxan as a tool for implementing Systematic Conservation Planning

Marxan is often employed as part of a larger systematic conservation planning (SCP) process. SCP is a framework for identifying potential protected areas that efficiently achieve a specific set of objectives, commonly some minimum representation of biodiversity (Margules & Pressey, 2000; Pressey & Bottrill, 2009). It is a major advance compared to conventional conservation planning approaches, which have often been applied to select reserves based on urgency, scenery, the evaluation of planning units independently, and ease of designation (Kukkala & Moilanen, 2013). It also differs from the approach of identifying biodiversity hot spots, because the selection of conservation sites takes into account the complementarity of sites in achieving the representativeness of the conservation features as well as efficiency in meeting the targets. This means that when applying SCP with Marxan, site A which has the highest number of species (e.g., 10 species) and high socioeconomic cost (e.g., an area where hydrocarbon exploration occurs) may not be selected but two complementary sites B (with 6 species) and C (with another 5 species) will be selected instead because collectively they cover more species (11 in total) and collectively have a lower socioeconomic cost in comparison to site A. SCP is widely considered 'best practice' in creating systems of protected areas because it facilitates a transparent, inclusive and defensible decision-making process.

The SCP framework consists of 11 stages (Table 1) encompassing the design, implementing, and monitoring of conservation areas (Pressey & Bottrill, 2009). The ninth stage, commonly referred to as ‘spatial conservation prioritization’, involves the selection of new reserves to achieve conservation objectives. Although Marxan can be used for a variety of purposes at various stages of the SCP process, it was designed primarily to facilitate spatial conservation prioritization by providing decision support. It also helps incorporate core conservation planning concepts, such as complementarity and representativeness into the earlier stages of identifying goals and objectives for the process (Kukkala & Moilanen, 2013).

Marxan is the most widely used systematic conservation planning tool globally. Several case studies illustrating the various applications of Marxan can be found at www.maxansolutions.org .

Table 1 Key Stages of Systematic Conservation Planning (Pressey & Bottrill, 2009)

1. Scoping and costing the planning process
2. Identifying and involving stakeholders
3. Describing the context for conservation areas
4. Identifying conservation goals
5. Collecting data on socio-economic variables and threats
6. Collecting data on biodiversity and other natural features
7. Setting conservation objectives (spatially explicit targets)
8. Reviewing current achievement of objectives
9. Selecting additional conservation areas
10. Applying conservation actions to selected areas
11. Maintaining and monitoring conservation areas

4. Mathematical formulation of Marxan

Marxan finds solutions to a well-defined mathematical problem. Commonly, it minimizes the combined cost of the reserve network and the boundary of the entire network, while meeting a set of conservation targets. This problem can be expressed mathematically as:

$$minimize \sum_i^{N_s} x_i \, c_i + b \sum_i^{N_s} \sum_{ii}^{N_s} x_i (1 - x_h) cv_{ih} \tag{1}$$

subject to meeting all conservation targets

$$\sum_i^{N_f} x_i \, r_{ij} \geq T_j \forall \, j \tag{2}$$

and x_i is either 0 or 1

$$x_i \in \{0,1\} \, \forall \, i$$

where r_{ij} is the occurrence level of conservation feature *j* in planning unit *i*, c_i is the cost of planning unit *i*, N_s is the number of planning units, N_f is the number of conservation features, and T_j is the target for conservation feature *j*. The variable x_i has value ‘1’ for planning units selected to form part of the reserve network, and value ‘0’ for sites not selected.

The first term in Equation 1 is a penalty associated with the cost of the network. The second term is a penalty associated with the spatial configuration or shape of the network, also known as boundary cost. The parameter cv_{ih} reflects the cost of the connection between planning unit *i* and planning unit *h*, typically measured as the shared boundary between these two planning units. If one planning unit is in the reserve system, and the other is not, then a connection cost is applied. If both planning units are out or in, the connection cost is not paid. The parameter b is the boundary multiplier (or the boundary length modifier, BLM), a user-defined parameter that controls the importance of minimizing the boundary cost (or total boundary length) of the reserve system. The higher the *b* value, the more importance is given to achieve a more compact reserve configuration.

In Equation 2, T_j is the target for a given biodiversity feature. Targets can be expressed as an amount (e.g., km^2 of a particular habitat) or as the number of occurrences (number of individuals) or a proportion of the distribution of every feature that is the focus of the reserve system. Targets in Marxan are specific to the conservation features and not for other configuration characteristics, such as the minimum size of areas zoned, or the number of distinct areas zoned for conservation.

Marxan solves the problem by placing the objectives (Equation 1) and the constraints (Equation 2) together into an 'objective function' by transforming the constraints into an additional penalty term. This allows Marxan to calculate a value for a collection of planning units, which in turn can be used to compare alternate solutions (i.e. collections of planning units) and hence identify better solutions.
Thus, the **objective function** in Marxan takes the form:

$$\sum_i^{N_s} x_i\, c_i + b \sum_i^{N_s} \sum_{ii}^{N_s} x_i (1 - x_h) c v_{ih} + \sum_j^{N_f} FPF_j FR_j H(s) \left(\frac{s}{T_j}\right) \qquad (3)$$

where the first term is the total cost of the reserve network and the second term if the boundary cost of the reserve network multiplied by the boundary length modifier. The third term includes the target constraints presented in Equation 2, but now as a shortfall penalty equation. The terms FPF_j and FR_j are the feature penalty factor (also commonly referred to as the 'species penalty factor (SPF)') and feature representation respectively. FPF_j is a scaling factor that determines the relative importance of meeting the representation target for feature *j*. FR_j is computed as the representation cost of meeting the representation target of feature *j*.
The shortfall *s* is the amount of the representation target not met and is given by:

$$s = T_j - \sum_i^{N_f} x\, r_{ij}. \qquad (4)$$

The Heaviside function, H(*s*), is a step function which takes a value of zero when $s \geq 0$ and 1 otherwise. The feature specific parameter T_j is the target representation for feature *j*. The expression (s/T_j) is the measure of the shortfall in representation for feature *j*. It is reported as a proportion and equals '1' when feature *j* is not represented within the configuration and approaches '0' as the level of representation approaches the target amounts. The Heaviside function ensures the whole equation becomes zero when the representation is greater than the target amount. The shortfall penalty is zero if every biodiversity feature *j* has met its representation target in the selected reserve network. It is greater than zero if the targets are not met and gets larger as the gap between the target and the amount not included in the solution increases.

5. Marxan application for the identification of priority conservation areas in Israel's EEZ

א. 4.1. Israeli EEZ MPAs masterplan

The "Israeli EEZ MPAs masterplan" project is a systematic conservation planning initiative led by the Society for the Protection of Nature in Israel (SPNI) in collaboration with the ministry of environment, academia and IOLR. The first step of this process (Figure 1) of collecting and analysing environmental data was completed in July 2022. This report presents the results of the process of prioritizing areas for conservation using the

Marxan planning tool, as part of the second step of the project of applying decision support tools. The work described in this report was carried out between August and October 2022.

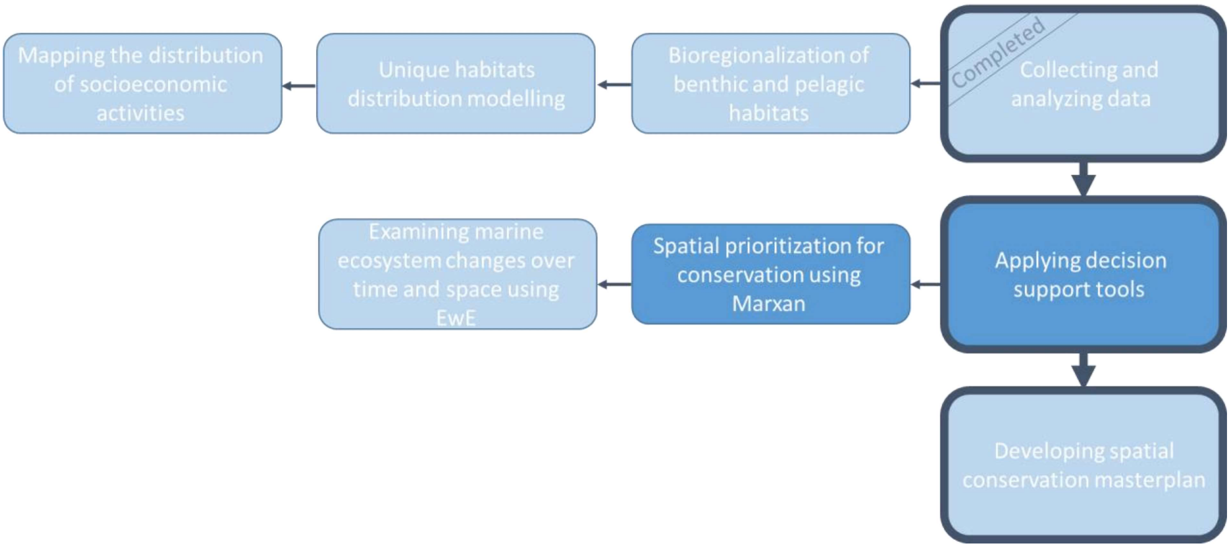

Figure 1. Israeli EEZ MPAs masterplan workflow. The steps realized in this report are presented in dark blue.

ב. 4.2. Objective of the study and planning region

The software Marxan was used to identify priority conservation areas in the Exclusive Economic Zone (EEZ) of Israel in the Mediterranean Sea. Israel’s EEZ boundary negotiations are still on-going with neighbouring countries. The present study used the boundaries delineation proposed by the Israeli Planning Administration. More specifically, this study aims to identify priority areas to be included in a representative and efficient network of Marine Protected Areas (MPAs) in the Israeli EEZ considering 36 conservation features (including deep-sea and pelagic habitats and pseudo-habitat categories as reported in section 4.2) and socioeconomic activities belonging to six economic sectors (detailed in section 4.3).

The planning region encompassed not only the EEZ but also Israel’s territorial waters in the Mediterranean Sea as we wanted the reserve system to be connected to the existing network of MPAs (at different fulfilment stages, from planned through declared to actively managed) which is located in the territorial waters, along the continental shelf (Figure 1). This connectivity is especially important since transportation processes down the continental slope were recently found to play a significant role in deep sea ecosystem dynamics in the region (Guy-Haim et al. 2022). The entire region of 25893 km^2 was divided into 6690 planning units of ~4 km^2; the planning units belonging to the EEZ covered an area of 21831 km^2. Identifying further MPAs in the territorial waters was beyond the scope of the study; therefore, all planning units in the territorial waters that did not overlap with MPAs were excluded from selection. More details about the treatment of planning units in the territorial waters and planning scenarios are provided in section 4.4.

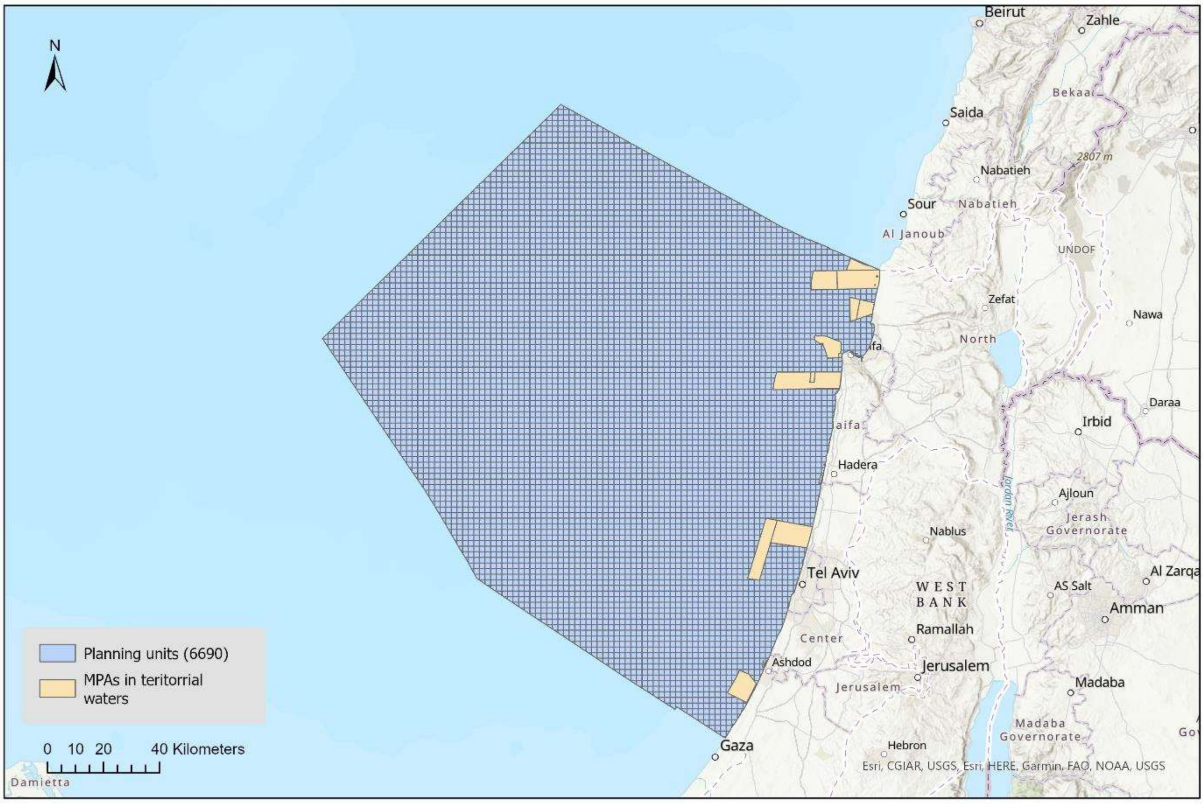

Figure 2. Planning region divided in 6690 planning units of 4km^2. Yellow polygons correspond to declared, approved, and suggested marine reserves in the territorial waters of Israel, including special marine areas (Israeli Planning Administration 2020).

ג. 4.3. Conservation features and targets

Overall, 36 conservation features were defined for which targets were set for inclusion in the reserve system (Shabtay et al. 2022). More specifically, we included in the analyses: 19 representative benthic habitat types, five unique benthic habitats, four representative pelagic habitats, and one special pelagic habitat. Four unique benthic habitats (soft bottom sponge grounds, coral gardens, cold seeps, sea pen fields, and rock and pockmarks) as well as the special pelagic habitat (cyclone presence) were further split into different features based on the probability of occurrence as predicted by habitat suitability models (see Table 2). The spatially explicit information for each feature was attributed to each planning unit as presence (1) or absence (0) data.

For each conservation feature, a target was set as a percentage of its total distribution to be included in the reserve system (Table 2). The targets were set after consultation with local experts and considering the conservation value of the features (representative / unique habitat), their spatial extent, and level of certainty regarding their distribution (Shabtay et al. 2022). A second set of lower targets was considered to allow for more flexibility in Marxan’s solutions and allow smaller area requirement for meeting the conservation targets. Yet, targets for some features remained unchanged because their spatial coverage was restricted and a lower target would not secure their adequate protection.

Table 2 Conservation features and coverage target for their inclusion the planning solutions. EEZ coverage percentage is summed for representative benthic habitats that fully cover the entire area of the EEZ. Overlapping habitats area which include the unique benthic habitats that are nested in representative habitats, and pelagic habitats are not summed to avoid multilayer counting.

Feature type	Conservation feature	% EEZ	Total % of EEZ	Conservation target %	Lower target %
REPRESENTATIVE BENTHIC HABITATS	Bathyal plain – Deep-Sea Fan	7.0	7	30	20
	Foraminiferous assemblage	8.4	15.4	30	20
	Northern Slope - Base Slope	3.3	18.7	50	50
	Northern slope- Lower Slope	0.4	19.1	100	100
	Palmahim A	0.9	20	100	100
	Palmahim B	1.0	21	100	100
	Palmahim C	0.7	21.7	100	100
	Southern Slope	0.7	22.4	100	100
	Sponge ground - Deep Sea Fan	2.3	24.7	50	30
	Sponge ground - Sediment Waves	3.4	28.1	50	30
	Sponge ground- Deep plain	3.7	31.8	50	30
	Unknown - Base Slope	7.2	39	30	20
	Unknown - Lower Slope	4.3	43.3	50	30
	Unknown - Main Deep-Sea Fan	31	74.3	20	10
	Unknown - Sediment Waves	12.4	86.7	20	10
	Unknown - Southern Deep-Sea Fan	9.4	96.1	30	20
	Unknown - Upper Slope	1.0	97.1	100	100
	Unknown- Deep plain	2.8	99.9	50	30
UNIQUE BENTHIC HABITATS	Soft bottom sponge ground (prob. 0.7-1)	0.38		100	100
	Soft bottom sponge ground (prob. 0.3-0.6)	1.6		60	60
	Soft bottom sponge ground (prob.<0.3)	11.2		30	20

	Coral garden (prob. 0.7-1)	0.1	100	100
	Coral garden (prob. <0.7)	2.2	70	70
	Sea pen field	0.1	100	100
	Cold seeps (prob. 0.7-1)	0.2	100	100
	Cold seeps (prob. <0.7)	1.6	70	70
	VME indicator habitat (rock and pockmarks-0.7-1)	1.2	100	100
	Rock and pockmarks (prob. 0.4-0.7)	1.8	50	30
	Rock and pockmarks (prob. <0.4)	10	30	20
	Levant channel*	3.3	20	10
REPRESENTATIVE PELAGIC HABITATS	Pelagic slope	11.5	20	10
	Pelagic warm	28.7	20	10
	Pelagic cold	4.8	20	10
	Pelagic high Oxygen	28.8	20	10
SPECIAL PELAGIC HABITATS	Cyclone presence (0.7-1)	4	100	70
	Cyclone presence (0.4-0.7)	23	50	30

*Unique feature. A conservation target of 20% was suggested by experts in the consultation process

т. 4.4. Socioeconomic activities considered and cost

The spatial distribution of predominant human activities in the planning region and their relative costs were adopted in the analyses from Amir and Karniel (2022) who collected and analysed data on socioeconomic activities in the Israeli EEZ. Data corresponded to existing activities and activities that are expected to be executed in the near future (Table 3). More specifically, we considered activities belonging to the sectors of: hydrocarbon production, shipping and trade, fishing, security, telecommunications and waste disposal (see Table 3). For each activity, a cost was attributed by experts based on its economic importance and compatibility with MPAs.

Economic importance was adopted from the Maritime Policy for Israel's Mediterranean Waters (Israeli Planning Administration 2020). The policy document defined shipping and trade, and hydrocarbon production as strategically important sectors with high economic importance. Additionally, the policy document prioritized security and defence uses for spatial allocation as they enable the strategically important activities existence. Qualitative ranking of economic importance of the socioeconomic activities for Marxan was performed on a scale of 1 to 6, from low importance to high importance, respectively.

Compatibility with MPAs was qualitatively assessed (compatible/incompatible) as a spatial conflict of uses and not an impact on habitats due to lack of quantitative data and knowledge on impacts to deep-sea and pelagic habitats from each specific activity. For example, the scientific literature clearly demonstrates the impact of hydrocarbon production drilling on benthic and pelagic habitat, and therefore the activity was assigned as incompatible with MPA, although the impact extent might differ among habitats.

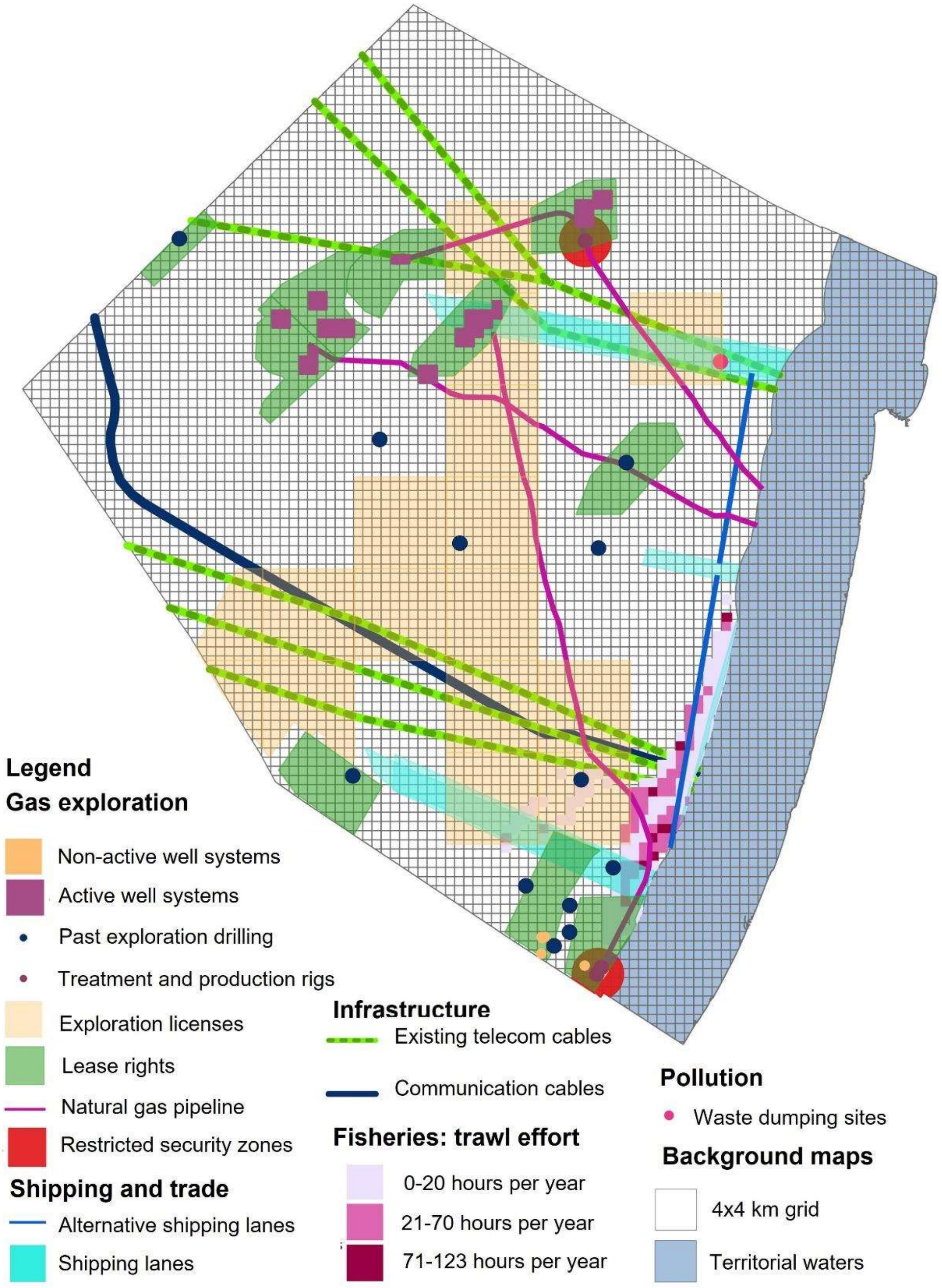

Figure 3. Planning region with economic activities occurring in the EEZ and considered in the Marxan analysis.

Table 3. Socioeconomic activities included in the spatial prioritization analysis.

Sector	Existing or past activity	Description	Economic impo	Competability with MPA	Cost
Hydrocarbon Production	Non-active well systems	Areas where gas was formerly extracted for commercial production and are no longer active	1	No	locked out
	Active well systems	Areas where gas is being extracted for commercial production. Located within areas of lease rights	6	No	locked out
	Past exploration drilling	Areas where exploration drilling were preformed but did not lead to commercial production	1	Yes	low cost
	Treatment and production rigs	Facilities to extract and process natural gas. Located within areas of lease rights	6	No	locked out
	Exploration licenses	Areas where license exist for conducting exploration gas drilling	5	Yes	medium cost
	Lease rights	Areas leased for commercial production of gas. Usually contain several active well systems and production rigs	6	Yes	high cost
	Natural gas pipeline	Pipeline that transport the extracted hydrocarbons to and from commercial facilities	6	Yes	high cost
Shipping and Trade	Shipping lanes	Official shipping lanes defined by the Israeli Planning Administration	6	Yes	high cost
	South-north lane - alternative shipping lane		6	Yes	high cost
	AIS Density Maps - all	Vessels density calculated from AIS data on all types of vessels in the region between 2017 and 2021	5	Yes	medium cost
Security	Restricted security zone	Restricted areas around strategically important facilities such as gas production rigs	6	No	locked out

Fishing	Trawling Effort	Trawling effort calculated by processing AIS data. Effort was calculated following García-Barón et al. (2021) Other fishing methods such as longline fishing exist in the area but no spatial data was available and therefore only trawl fishing was included in the sector	1	No	low cost
Telecommunications	Existing Communication cables	Existing communication cables stretched from Israel to other countries	6	Yes	low cost
	Blue-Raman cable	Planned Hi-Tech communication cable from Israel to other countries. Expected establishment in the next few years	6	Yes	low cost
Waste management	Waste dumping site	Dumping sites, mainly of coastal constructions waste that is accumulated following dredging and digging	4	No	locked out

Locations with activities that are incompatible with marine conservation and that have high economic importance, such as sites with hydrocarbon active well systems, were excluded from selection ('locked out' in Marxan terminology). For all other areas, economic importance ranking and compatibility with MPAs were qualitatively categorized as low-medium-high. The locations encompassing activities of low economic cost were given a value of 10, those of medium economic cost a value of 100, and those of high economic cost a value of 1000. The total cost of a planning unit was estimated as the sum of the cost of the economic activities taking place within the planning unit. An order-of-magnitude difference was given among the different cost categories (low, medium, and high) to differentiate and highlight the areas of high cost and thus guide Marxan to avoid the selection of such areas. The planning units without economic activities were given a value of 1 because Marxan has the tendency to add planning units with zero cost (even if they do not contain conservation features) when the connectivity penalty increases (see section 3).

ה. 4.5. Marxan scenarios and parameters

Different planning scenarios were developed (Figure 4) considering: whether MPAs in territorial waters are included or not in the analysis (resulting in scenarios a & b), different sets of conservation targets (Table 2), and the different cost of hydrocarbon exploration licences.

Scenario 2 (a & b, i.e. including territorial MPAs in the analysis or not) was chosen because experts' opinions were divided regarding the protection of the unique habitat 'soft bottom sponge ground'. The reason is that the distribution models predicted relatively vast distribution (with low probability) and in some way it contradicted the concept of protecting 100% of unique habitats due to their very limited distribution and great sensitivity. Therefore, we proposed this scenario to be able to evaluate the sensitivity of the results to these specific targets to make more educated decision in the planning process. In Scenario 3, we examined the sensitivity of planning solutions when using a different set of targets, allowing for more flexibility in Marxan's solutions resulting in smaller area

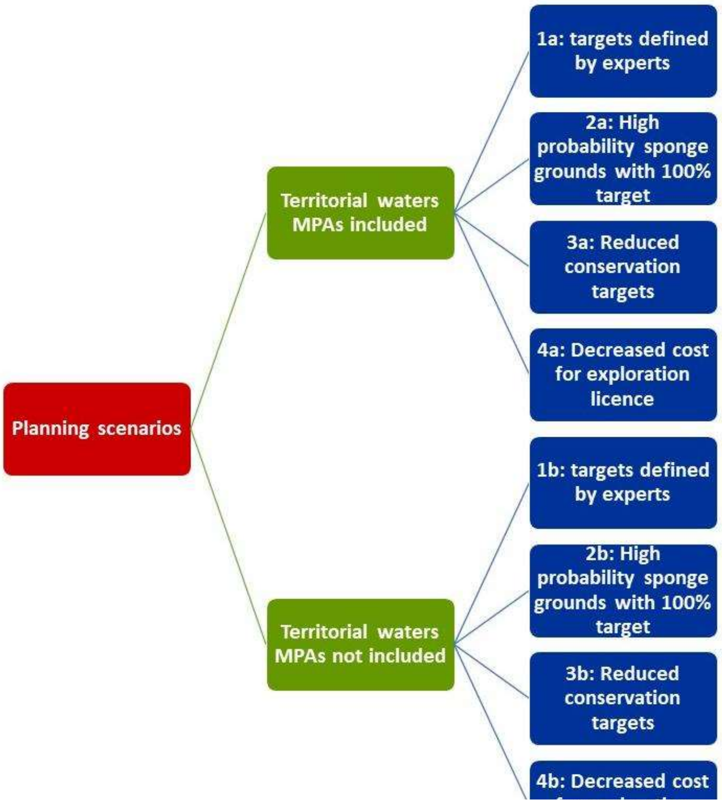

Figure 4. Planning scenarios for the identification of priority areas for conservation in the Israeli EEZ.

requirement for meeting the conservation targets. In Scenario 4, we investigated the sensitivity of the planning solutions when using a different cost for the activity of gas exploration (from high cost to medium). In all scenarios, the Palmahim disturbance area was ‘locked in’ the planning solutions because it is designated for conservation in the Israeli MSP (planning administration, 2020) and proposed as the first EEZ marine reserve by the Israeli Minister of Environmental Protection. This area includes several rare and highly vulnerable benthic habitats such as deep sea coral gardens, brine pool, and cold methane seeps.

In all scenarios, the feature penalty factor (FPF which is a scaling factor that determines the relative importance of meeting the representation target for a feature; see section 3) was set to 100 for all features except for the representative pelagic habitats and two other features (the coral gardens and the rock and pockmarks both with low probability of occurrence) for which a value of 1 was enough to ensure the achievement of the representation target. However, **it is important to stress that no matter how high was the FPF value, the conservation targets for two features: *the cold seeps with high probability of occurrence and the benthic habitat ‘southern slope’* were never met.** The reason is that the spatial distribution of these features overlapped with the distribution of activities that were incompatible with protection (treatment and production rigs, non-active well systems, and restricted security zones) and thus areas of overlap were excluded from selection and target (100%) achievement was impossible (see Figure 5).

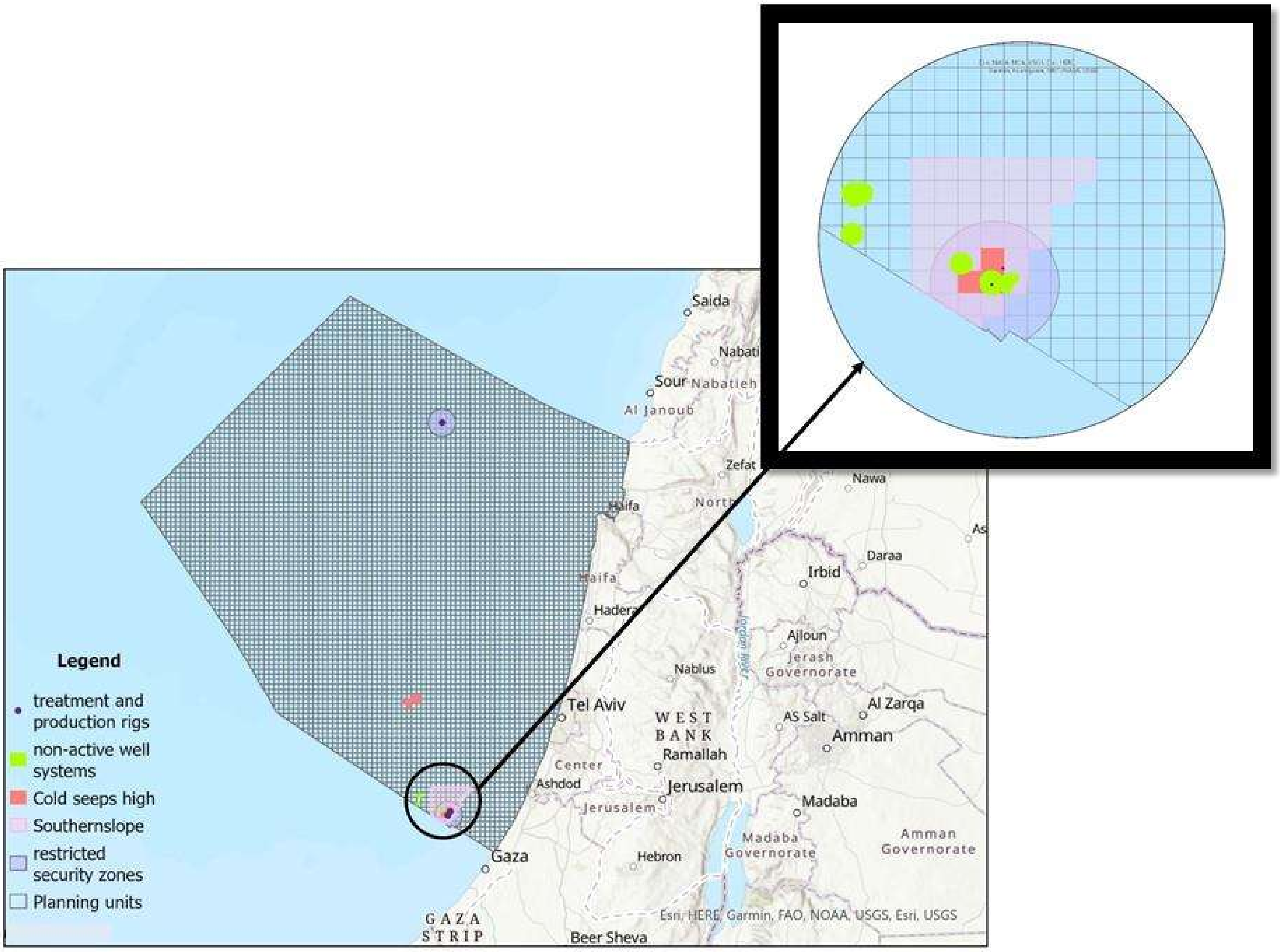

Figure 5. Overlap of human activities and conservation features for which conservation targets were never met (cold seeps with high probability of occurrence and the habitat 'southern slope'.

To calibrate the Boundary Length Modifier (BLM, a parameter that controls the importance of minimizing the boundary cost or total boundary length of the reserve system; see section 3) and find a solution of acceptable compactness, we used the QMarxan plugin for QGIS. Through the parametrisation of the BLM we aimed to provide a measure of structural connectivity to the planning solutions. At present, data on functional connectivity regarding species in the Israeli EEZ are unavailable. After calibration (Figure 5), we found that beyond the value of 100, the cost of the reserve system increases disproportionately and that the best BLM values are within the range of 10 and 100. After consultation with SPNI, a BLM value of 30 was selected for all scenarios. Nevertheless, for the scenarios 3a and b for which an area of about 30% of the EEZ was selected for protection, additional scenarios were tested with a BLM value of 200 for generating more clumped solutions. Through the parametrisation of the BLM we aimed to provide a measure of structural connectivity to the planning solutions. At present, data on the functional connectivity regarding species in the Israeli EEZ are unavailable.

All scenarios were run 100 times (10 million iterations each run), from which the best solution was retained for comparison as well as the selection frequency across all solutions.

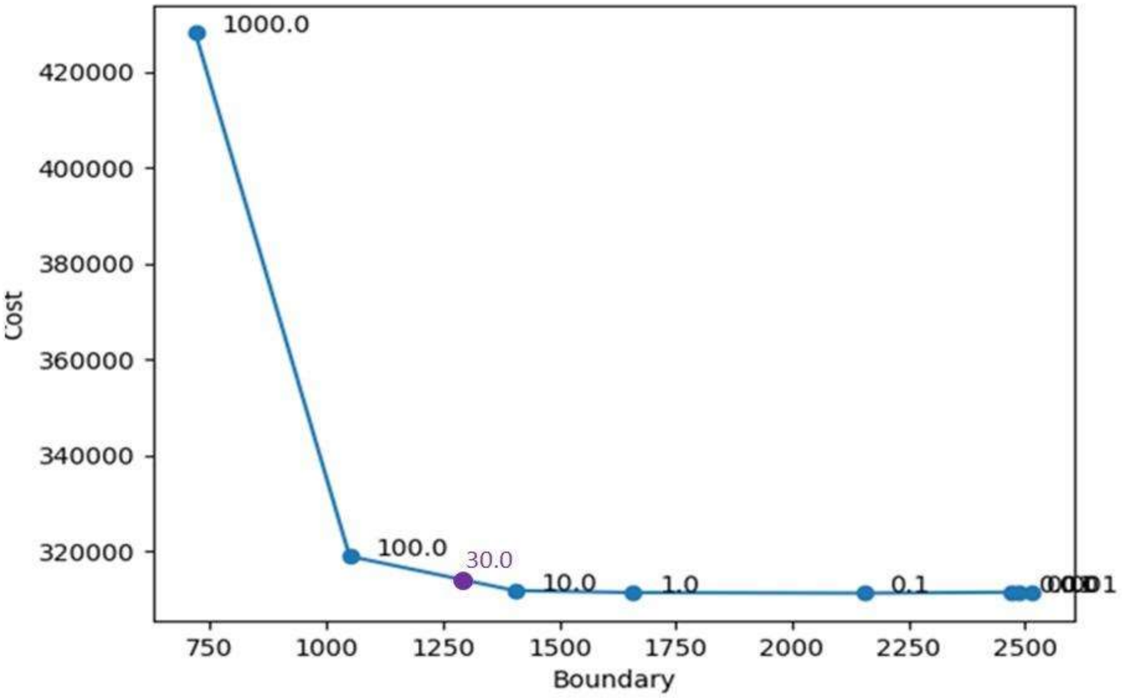

Figure 6. Boundary Length Modifier (BLM) calibration for finding clumped solutions that balance cost and boundary length in planning solutions.

6. Priority conservation areas in Israel's EEZ in the Mediterranean Sea

In all Marxan scenarios, the planning solutions (reserve systems) identified ranged from 41% to 45% of the Israeli EEZ with the exception of scenarios 3a and b (with BLM values 30 and 200) which had lower targets and the identified priority areas corresponded to approx. 30% of the EEZ (Table 4). The cost was higher for scenarios 1 and 2 than for scenarios 3 and 4. In the case of scenarios 3 (a & b), this was because of the lower % area selected (as a result of setting lower targets) whereas in the scenarios 4 (a & b), the lower cost resulted from reducing the hydrocarbon exploration licence cost from medium to low.

Table 4. Area and percentage coverage of the Israeli EEZ, cost of the best solutions, and targets not met in planning scenarios.

Scenarios	Description	Area (km^2)	% of EEZ	Cost (Marxan values)	Features for which targets were NOT met
1a	Targets defined by experts for all features and territorial MPAs locked in	8968	41.25	190979	cold seeps (with high probability of

					occurrence), and ‘southern slope’
1b	Same as 1a but all planning units in territorial waters are locked out	8990	41.35	190343	cold seeps (with high probability of occurrence), and ‘southern slope’
2a	Sponge grounds as one feature with probability of occurrence more than 0.3 and target 100% and territorial MPAs locked in	9997	45.79	195731	cold seeps (with high probability of occurrence), and ‘southern slope’
2b	Same as 2a but all planning units in territorial waters are locked out	8974	41.10	195491	cold seeps (with high probability of occurrence), and ‘southern slope’
3a	Targets reduced for some conservation features (see Table 2) and territorial MPAs locked in	6229	28.65	148838	cold seeps (with high probability of occurrence), and ‘southern slope’
3b	Same as 3a but all planning units in territorial waters are locked out	6292	28.94	148619	cold seeps (with high probability of occurrence), and ‘southern slope’
4a	Same as 1a but exploration licence cost is low instead of medium	6187	28.46	162120	cold seeps (with high probability of occurrence), and ‘southern slope’
4b	Same as 4a but all planning units in territorial waters are locked out	6163	28.35	162585	cold seeps (with high probability of occurrence), and ‘southern slope’

Below (Figures 7-11), the best solutions and selection frequency for each scenario are presented. It is important to bear in mind that the best solution (on the left of each panel) demonstrates the most efficient reserve system to achieve all the targets set with the exception of the two features mentioned above: the cold seeps with high probability of occurrence and the benthic habitat ‘southern slope’. The figures with the selection frequency (on the right of each panel) show the number of times a planning unit was selected across Marxan runs and thus indicate the areas that have a higher irreplaceability for achieving the conservation targets.

Planning solutions across all scenarios included common areas: a large area in the centre of the planning region, an area in the southwest, another in the north, and the planning units adjacent to the territorial waters. However, planning units in the northeast of the region are selected only in “scenarios a” where the selection of territorial MPAs is forced into the planning solution (these areas are indicated with circles and arrows in Figures 7-11). The selection of these planning units enhances the coherence of the designed reserve system with the current network of territorial MPAs and does not affect the cost of the planning solution nor the percentage of area required for protection (see Table 4).

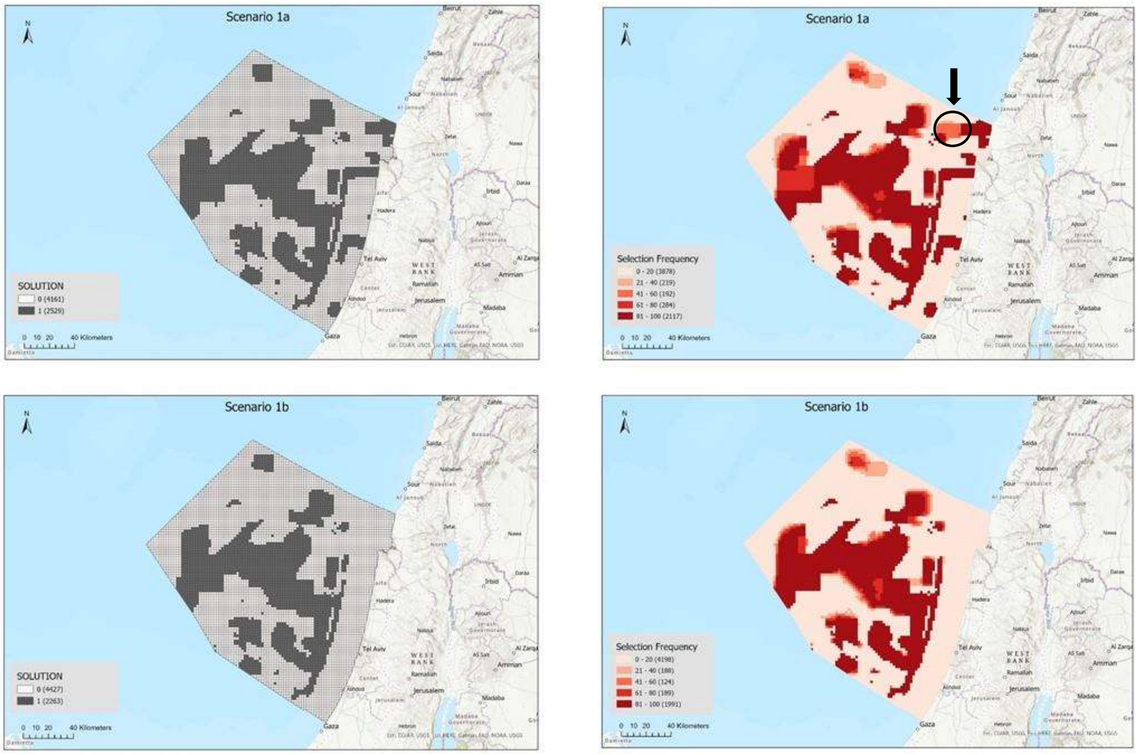

Figure 7. Best solution (on the left) and selection frequency (on the right) for scenarios 1. In scenario 1a, the territorial MPAs are selected by default. In the selection frequency figures, the darker red a planning unit is, the more times it was selected across Marxan solutions. Arrows point to planning units that were highly selected only in the scenario a.

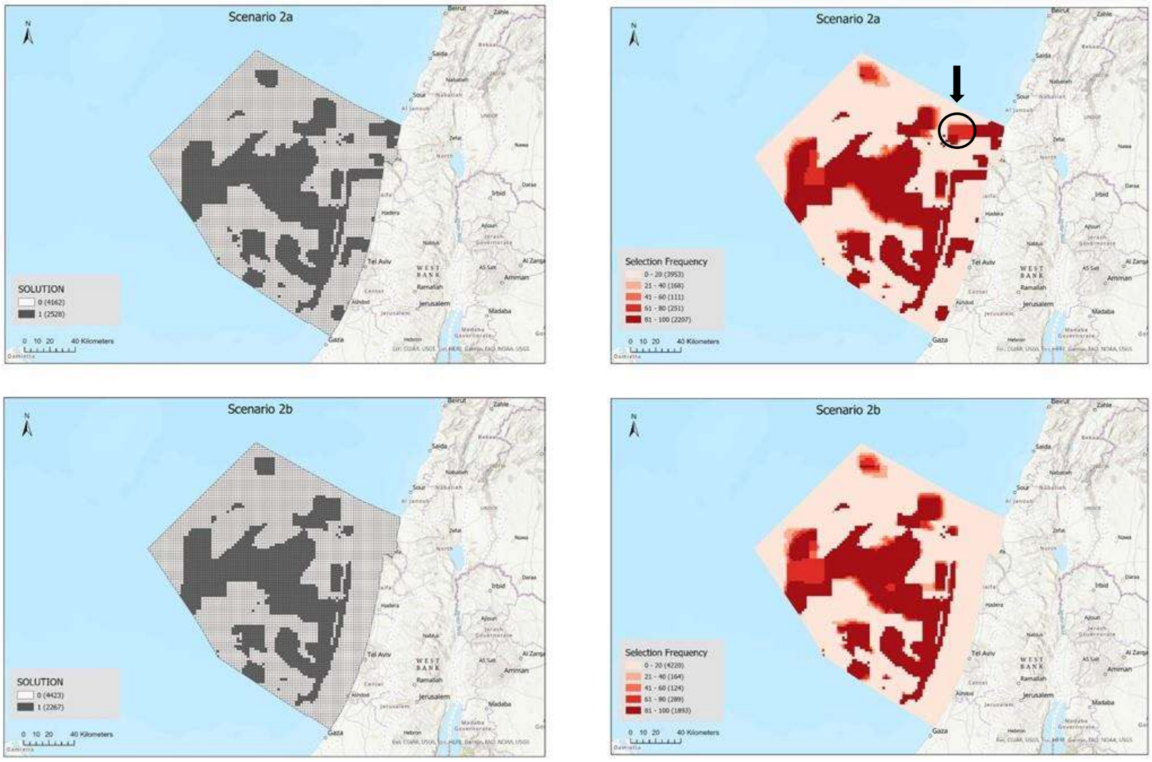

Figure 8. Best solution (on the left) and selection frequency (on the right) for scenarios 2. In scenario 2a, the territorial MPAs are selected by default. Arrows point to planning units that were highly selected only in the scenario a.

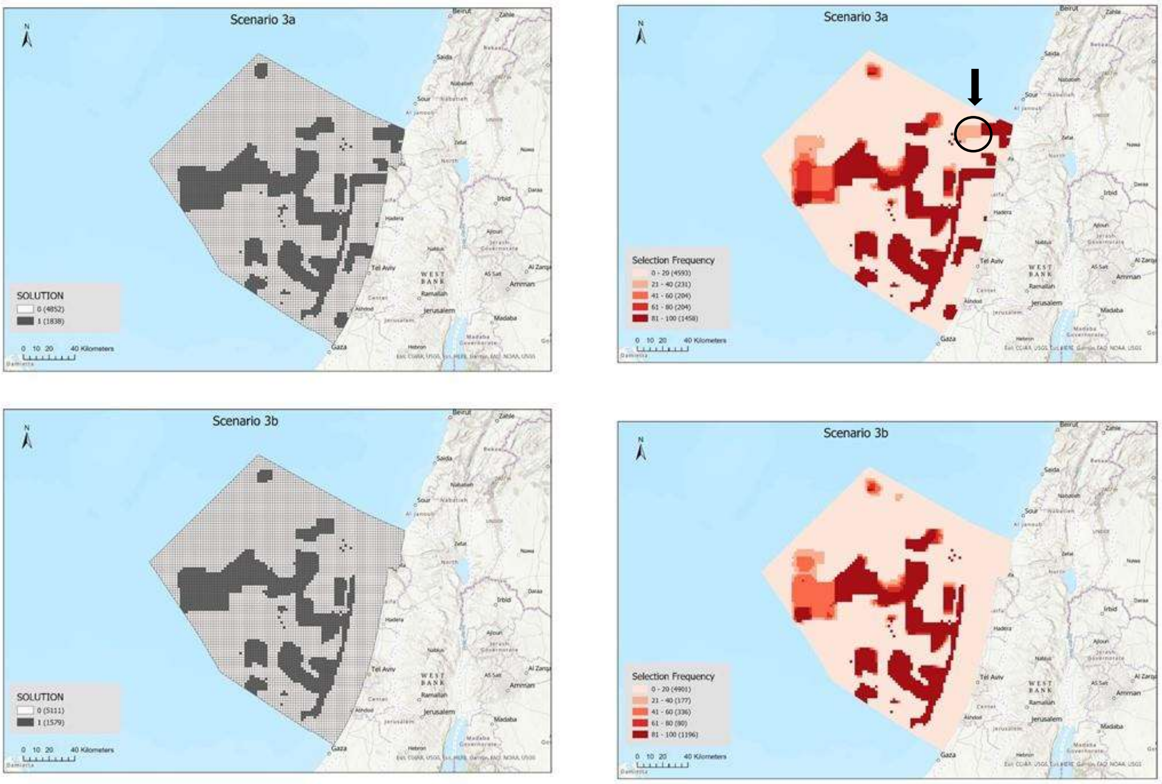

Figure 9. Best solution (on the left) and selection frequency (on the right) for scenarios 3. In scenario 3a, the territorial MPAs are selected by default. Arrows point to planning units that were highly selected only in the scenario a.

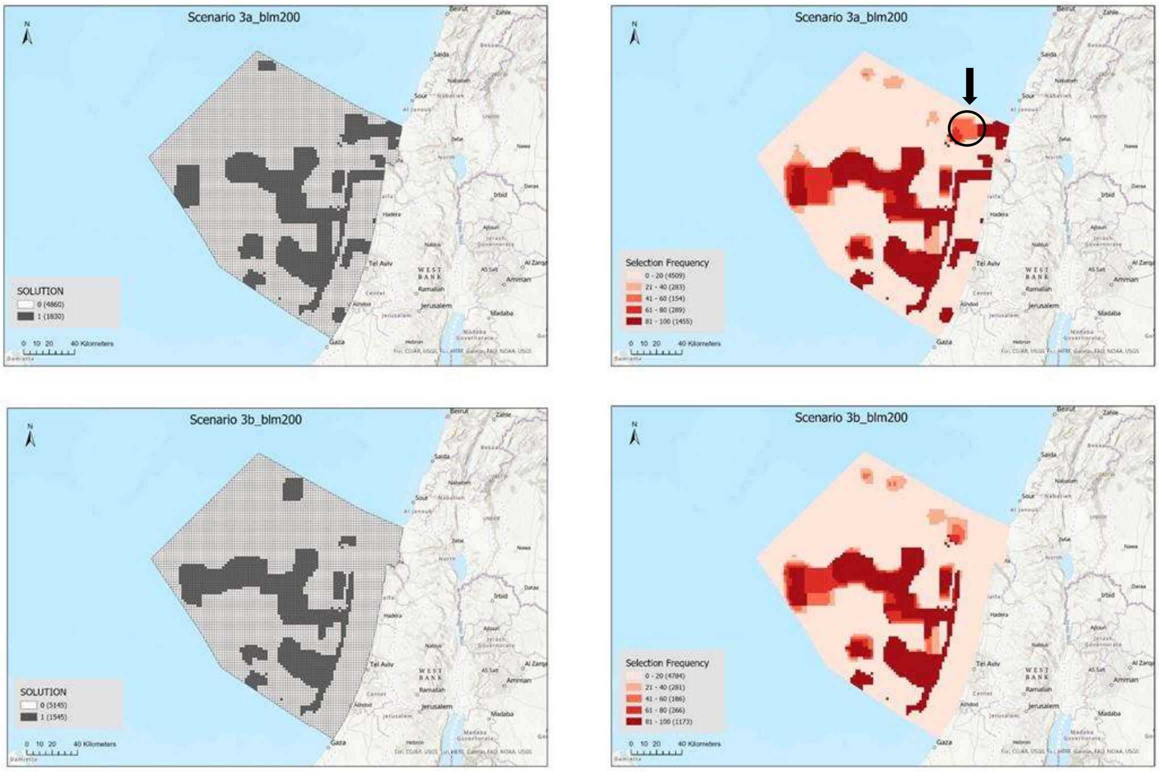

Figure 10. Best solution (on the left) and selection frequency (on the right) for scenarios 3 with BLM value of 200. In scenario 3a, the territorial MPAs are selected by default. Arrows point to planning units that were highly selected

only in the scenario a.

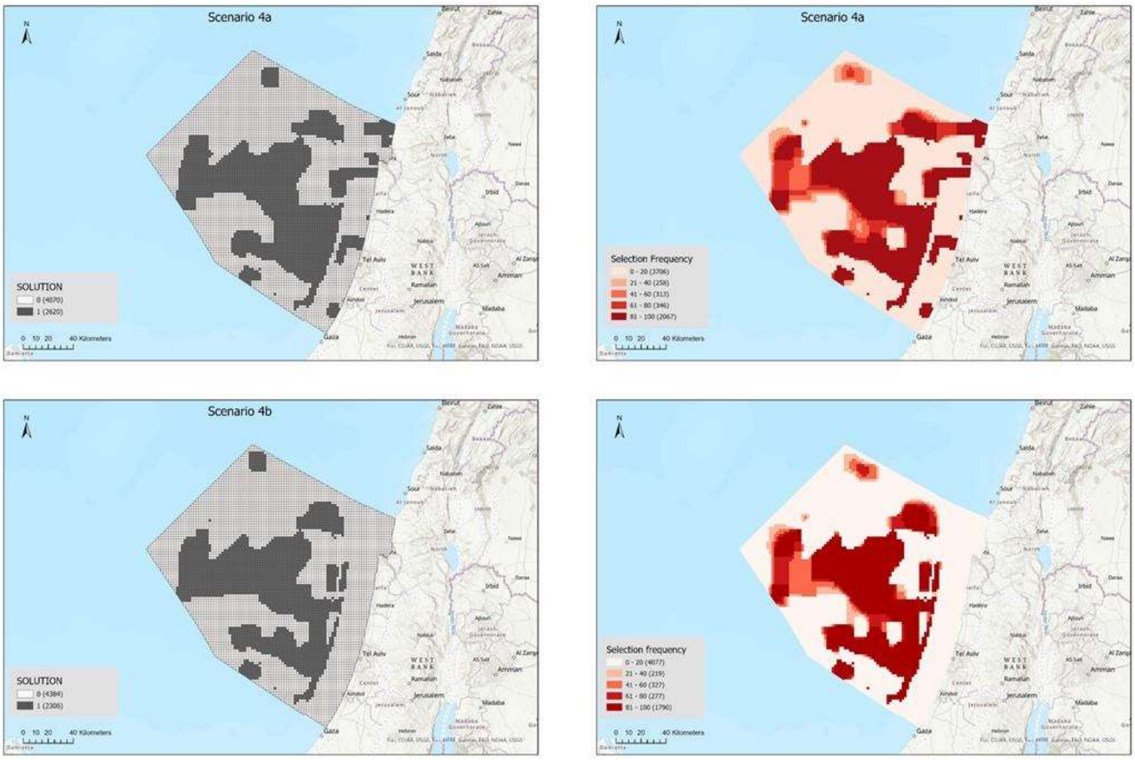

Figure 11. Best solution (on the left) and selection frequency (on the right) for scenarios 4. In scenario 4a, the territorial MPAs are selected by default.

In Figure 12, the overall selection frequency of planning units across all scenarios is presented. The darker red areas are the planning units with higher irreplaceability (selection frequency 81-100%) and correspond to 24% of the EEZ. These planning units contribute the most to the achievement of the conservation targets while overlap with high cost areas (i.e., areas with high cost activities) is avoided (Figure 13). These highly selected areas are the most crucial to include in the future network of MPAs in the EEZ for the protection of the habitats included in this study. The map in Figure 12 could serve as a basis for discussion with stakeholders for the definition of the exact location and delimitation of MPA boundaries. However, it is important to remind the reader that only the best solutions presented in Figures 7-11 (maps on the left side of the panels) ensure that the predefined conservation targets are met. Alternatively, and to ensure that the conservation targets that were set are met (with the exception of those set for the features: cold seeps and southern slope), Scenario 3 could be selected as a negotiation basis, since the priority areas identified cover approx. 30% of the EEZ.

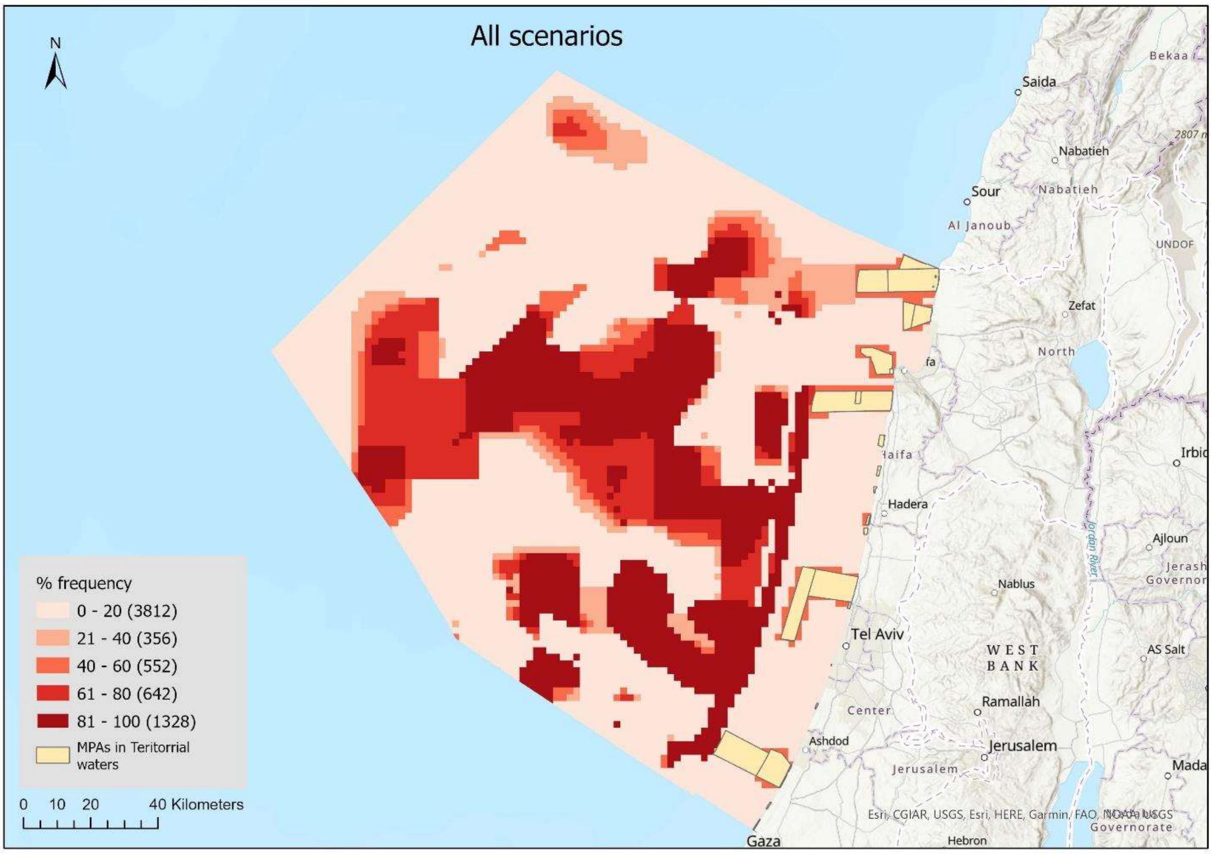

Figure 12. Selection frequency of planning units across all scenarios. Dark red areas were selected in 81-100% of the reserve systems designed with Marxan. The MPAs in the territorial waters are indicated with yellow polygons.

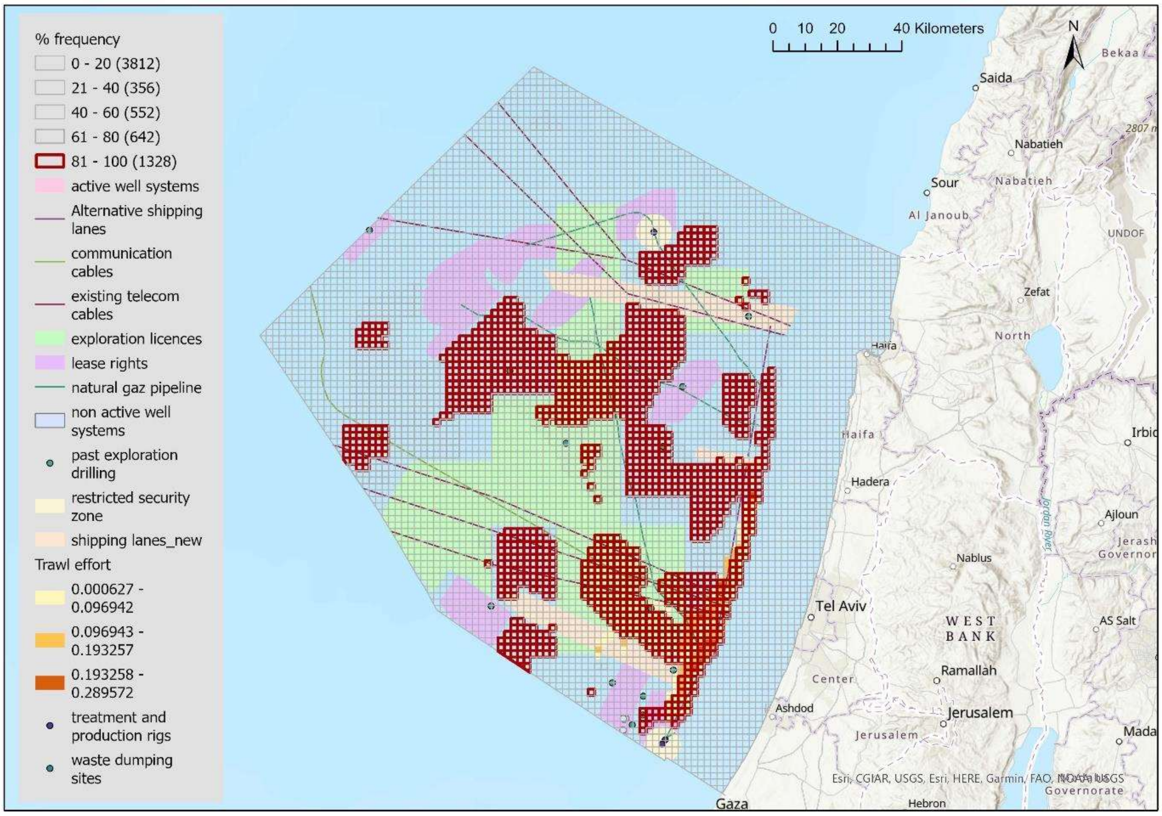

Figure 13. Planning units with high irreplaceability and the distribution of human activities in the background.

7. Conclusions

Knowledge gaps are a serious bottleneck for efficient conservation planning, especially when shifting from coastal to offshore EEZ-wide conservation. While deep-sea ecosystems represent the largest biome globally, deep-sea species richness is still largely unknown (Danovaro *et al*. 2010). Sampling deep-sea biota over large areas is time consuming and costly (Anderson *et al*. 2010). In the absence of biodiversity data, the use of geomorphological, physical, and chemical oceanographic features as surrogates for biological data has become common practice both in coastal and deep-sea ecosystems (Katsanevakis *et al.* 2015). In this broader study, Shabtay et al. (2022) were able to define 36 conservation features in the Israeli EEZ using field data, surrogates and modelling. Therefore, the lack of data should not be used as an excuse for inaction regarding ecosystem management, and best practices for marine spatial and conservation planning should be adopted.

We used the most popular worldwide conservation planning software, Marxan, for identifying priority areas for conservation in the Israeli EEZ in the Mediterranean Sea. Marxan has been used for the identification of MPA networks in the territorial waters of several Mediterranean countries (e.g., Giakoumi *et al*. 2011, 2012, Mazor *et al.* 2014) but rarely for planning MPAs in the EEZ and when this was the case, coarse habitat categories were used (e.g., Levin et al. 2015). Using 36 refined habitat categories, we developed different planning scenarios demonstrating key areas for biodiversity conservation in the Israeli EEZ that cover between 28% and 45% of its extent depending on the conservation targets to be met. The reserve systems presented herein achieve the conservation targets for all but two conservation features because their distribution overlaps with areas where socioeconomic activities that are incompatible with marine biodiversity conservation occur. For these two features (cold seeps with high probability of occurrence and the benthic habitat 'southern slope'), setting a conservation target of 100% is unrealistic and management actions should be sought to minimize impacts on these habitats beyond the borders of MPAs. At the same time, stakeholders should pay attention to the fact that we cannot protect 100% of these habitats due to their partial distribution in highly impacted areas and should therefore be even more cautious in other areas where these habitats exist. A potential measure to secure the preservation of these habitats of limited extent within MPAs, could be the adoption of buffer zones of adequate size, based on scientific literature, beyond the borders of the MPAs.

Across all scenarios, 24% of the EEZ was consistently selected as a priority area for conservation. The map demonstrating these areas (Figure 12) could be used as a basis for discussion with stakeholders and decision makers. It is important to stress that ***Marxan operates as part of a planning process and is not designed to act as a stand-alone reserve design solution***. Marxan should be used as part of a systematic conservation planning process and in collaboration with other forms of knowledge (e.g., local ecological knowledge which is developed through long-term interactions with the natural environment, generating a deep understanding of the surrounding ecology and/or the use of other scientific tools such as ecosystem modelling). These other forms of knowledge are essential to the refinement of Marxan inputs, the interpretation of Marxan outcomes and the refinement of final conservation area boundaries. Besides the development of a dynamic model that will give additional scientific evidence improving the design of the reserve system, ***an equitable and transparent stakeholder engagement process is necessary for the adoption of a final plan.*** As stated in the introduction: "*Marxan is meant to support decision-making and act as a starting point for planning discussions. Its results must be refined by decision-makers to consider the full range of political, socio-economic and practical factors affecting planning implementation."*

8. References

Amir and Karniel. 2022. Current state of socioeconomic activities in the Israeli exclusive economic zone. Report submitted to the Israeli EEZ MPAS masterplan project working committee. October 2022.

Anderson TJ, Nichol SL, Syms C, Przeslawski R, Harris PT 2011. Deep-sea biophysical variables as surrogates for biological assemblages, an example from the Lord Howe Rise. Deep Sea Res Part II;58: 979–91.

Ball, I.R., H.P. Possingham, and M. Watts. 2009. Marxan and relatives: Software for spatial conservation prioritisation. Chapter 14: Pages 185-195 in Spatial conservation prioritisation: Quantitative methods and computational tools. Eds Moilanen, A., K.A. Wilson, and H.P. Possingham. Oxford University Press, Oxford, UK.

Danovaro R, Comparny JB, Corinaldesi C, D'Onghia G, et al. 2010. Deep-sea biodiversity in the Mediterranean Sea: the known, the unknown and the unknowable. PLoS One;5(8): e11832.

García-Barón, I., Giakoumi, S., Santos, M.B., Granado, I. and Louzao, M., 2021. The value of time-series data for conservation planning. *Journal of Applied Ecology*, *58*(3), pp.608-619.

Giakoumi S, Grantham HS, Kokkoris GD, Possingham HP 2011. Designing a network of marine reserves in the Mediterranean Sea with limited socio-economic data. Biological Conservation 144:753-63.

Giakoumi S, Katsanevakis S, Vassilopoulou V, Panayotidis P, Kavadas S, Issaris Y, Kokkali A, Frantzis A, Panou A, Mavromati G 2012. Could European marine conservation policy benefit from systematic conservation planning? Aquatic Conservation: Marine and Freshwater Ecosystems 22: 762-775.

Guy-Haim, T., Stern, N. and Sisma-Ventura, G., 2022. Trophic ecology of deep-sea megafauna in the ultra-oligotrophic Southeastern Mediterranean Sea.

Israeli Planning Administration. 2020. Maritime Policy for Israel's Mediterranean Waters. Israeli Planning Administration. May 2020.

Katsanevakis S, Levin N, Coll M, Giakoumi S, et al. 2015. Marine conservation challenges in an era of economic crisis and geopolitical instability: the case of the Mediterranean Sea, Mar. Policy 51: 31–39.

Kukkala, A S, & Moilanen, A (2013). Core concepts of spatial prioritisation in systematic conservation planning. *Biological Reviews*, *88*(2), 443–464.

Levin, N., Mazor, T., Brokovich, E., Jablon, P. E., & Kark, S. (2015). Sensitivity analysis of conservation targets in systematic conservation planning. *Ecological applications*, *25*(7), 1997-2010.

Margules, C R, & Pressey, R L (2000). Systematic conservation planning. *Nature*, *405*: 243–253.

Mazor, T, Possingham, H P, Edelist, D, Brokovich, E, Kark, S 2014. The crowded sea: incorporating multiple marine activities in conservation plans can significantly alter spatial priorities. PLoS ONE 9 (8)e104489.

Pressey, R L, & Bottrill, M C (2009). Approaches to landscape- and seascape-scale conservation planning: convergence, contrasts and challenges. *Oryx*, *43*(4): 464.

Shabtay, A, Goren, L, Slavenko, A, Idan, T, Neuman, A, Bialik, O, Makovsky, Y (2022). Environmental data collection and analyses to support conservation planning in the Israeli EEZ. Report submitted to the Israeli EEZ MPAS masterplan project scientific committee. July 2022.

Appendix 1. Post-analysis updates of international EEZ border change and gas explorations spatial distribution.

Several months after reporting Marxan analysis results for the Israeli EEZ, several spatial changes have occurred (Figure A1). Political negotiations between Israel and Lebanon reached an agreement on the maritime border between the two countries. The official new border differs from the border that was accounted for in the analysis reported. In addition, over 4,000 km^2 of gas exploration licenses were returned to the state without being explored. Finally, gas reservoirs were discovered in other 1164 km^2 of gas exploration blocks.

The overall area of these spatial alternations encompass about a third of the EEZ area and therefore additional examination of the impacts of these changes is required.

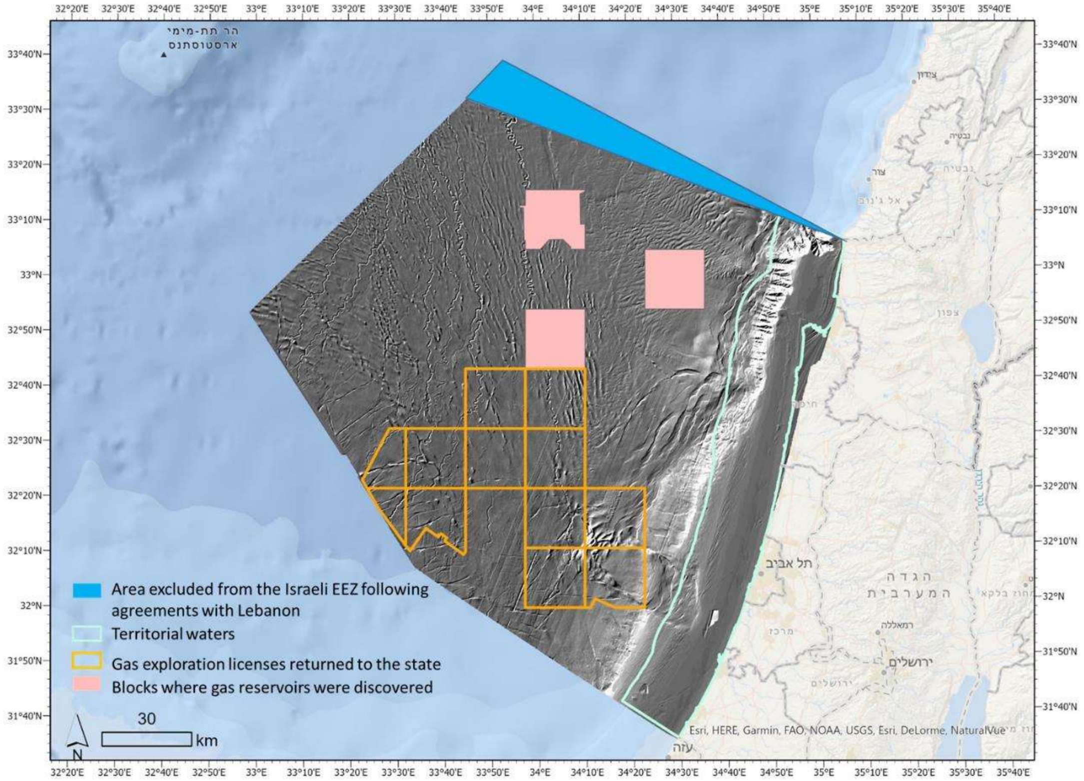

Figure 1. Spatial alternations in the Israeli EEZ occurred after initial use in Marxan

To address this requirement, we used scenario 3a as a basis for examining the impact of the spatial alternations. This scenario (hereafter = scenario 5) accounts for the lowest possible conservation targets, and therefore, it may highlight the impact of changes in socioeconomic activities. The following parameters for this scenario were changed:

1. Planning units in the area that was excluded from the Israeli EEZ following the agreement with Lebanon were locked-out of the analysis.
2. The cost of planning units in the areas where gas exploration licenses were returned to the state was reduced from medium cost to low cost.
3. The cost of planning units in the blocks where gas reservoirs were discovered (blocks 12,23,31) was increased from medium cost to high cost, as it is expected to change from exploration license to lease production rights.
4. Conservation target for Soft bottom sponge ground (prob. <0.3) was set to zero as in scenario 2a.

Selection frequencies of planning units in scenario 5 are presented in Figure 2.

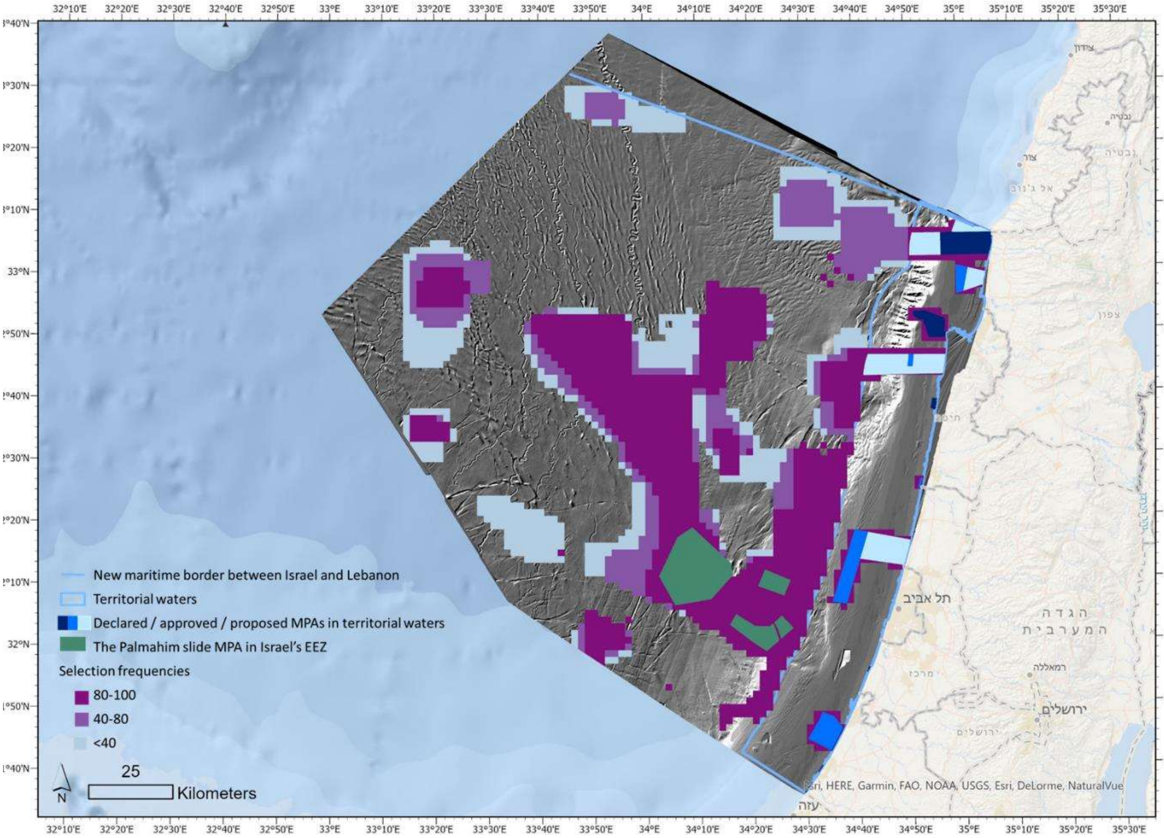

Figure 2. Selection frequency in scenario 5.

We recommend planners to account for the results of this scenario among all previous Marxan outputs in the planning process and the finalization of the MPA masterplan draft.