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Using ecological modelling in marine spatial planning to enhance ecosystem-based management

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ABSTRACT

Growing awareness of the role of marine spatial planning (MSP) in promoting sustainable development and ecosystem-based management highlights the need to use decision-support tools, and specifically ecological modelling tools, to consider the future impact of planning and management on the marine environment. However, how these tools can be incorporated into planning and their expected contribution is not always clear. Here, an Ecopath with Ecosim and Ecospace food-web model was used in a hypothetical planning process to examine the integration of food-web tools in specific stages of MSP. The model was used to examine spatial alternatives and management strategies for Orot Rabin coastal infrastructure facility in the Israeli Mediterranean coast, in an attempt to assess how such facilities might promote marine conservation. The results revealed the effect of different management protocols on the ecosystem, and provide the maximum allowable catch for sustaining the biomass of vulnerable fish species in the area, which can be used in MSP to address specific marine conservation goals. The model led to counterintuitive understandings regarding the management of the area. It demonstrated that intensive development under specific management strategies may promote conservation goals better than some management strategies directed towards ecological and recreational purposes. This study confirms the potential usefulness of food-web models for MSP; it specifies the stages and means by which planners can use models. Furthermore, it is suggested that tool's development should be planning-oriented and should include more applications to serve planners who aim to promote ecosystem-based management and marine conservation goals.

1. Introduction

At the national and international level, marine conservation goals are often addressed through marine spatial planning (MSP). The aim of this process, which deals with allocating the uses of a space that includes marine protected areas, is to reduce conflicts between different uses and between the various uses and the continued protection of the marine environment [20]. However, the increasing human activity in the marine environment challenges marine planning to adapt and find creative solutions to potentially negative interactions between uses and the environment, while promoting marine conservation goals and ecosystem-based management [18,19,42]. For example, MSP attempts to explore marine conservation opportunities beyond the boundaries of marine protected areas (MPAs) (e.g., [24,34,44]), and even within areas dedicated to human activity [46]. Questions remain on how to consider and explore conservation opportunities as part of the planning process. Decision-support tools and spatial prioritization tools are often suggested for use in MSP, to handle multiple conflicts between human activity and marine ecosystems, and to secure the protection of valuable, unique and vulnerable marine habitats and populations [11,40,56]. At the same time, further methodological advances are required in order to devise comprehensive MSP, in which marine conservation goals constitute the basis for all developments [30].

Advances in this direction include the use of ecological models as decision-support tools to explore the effects of human activity on ecosystems as a whole. The main advantage of incorporating such models into planning and management procedures is that they allow users to predict not only the cumulative impact of human activity on the environment over time and space, but also the indirect impact of management on the environment [26,33]. In addition, recent advances in the design of food-web modelling tools has increased their diagnostic capabilities, and the ability to account for uncertainty (e.g., [35,54]). The significant progress in the ability of food-web modelling tools to assess cumulative impacts on the environment led to their application

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for various purposes. Alexander et al. [1] used food-web model to examine the effect of the structure and management of renewable energy installations on a marine ecosystem. In addition, Pastorok et al. [36] demonstrate the importance of using ecological modelling in chemical risk assessment. Notwithstanding, ecological modelling tools have limitations. One of the most significant limitations of the modelling approach to planning is the difficulty of interpreting model results for the purpose of planning and management [12,26]. The incorporation of ecosystem modelling results into the MSP process is still lacking.

This study focuses on a marine infrastructure area of a coastal power station to which public access is limited; this managerial policy supports populations of highly vulnerable marine species [47]. Our assumption is that the MSP process can be aided by food-web modelling. The goal of this study was to examine how food-web modelling can be used as part of a MSP process, to explore the possibility of promoting marine conservation goals within an area that is subjected to intense human impact. To this end, the marine ecosystem within the area of Orot Rabin coastal power station was modelled and used in a hypothetical MSP process. The model was used to examine the effects of different spatial alternatives and management schemes on the marine ecosystem.

2. Methods

Ecological modelling was incorporated into the planning process in order to provide a means for predicting the possible effects of spatial and temporal uses and their management on the marine ecosystem. The process followed the Ehler and Douvere [20] step-by-step guide for MSP. Stages selected in the planning process were identified as suitable for considering alternatives whereby marine conservation goals can be maintained and supported within developed marine areas (See [11]).

A food-web model of the area of the marine infrastructure in question was developed. The area, to which public access is limited, was found to provide a suitable habitat for several vulnerable fish species. Based on the food-web model, hypothetical planning process was applied, with a 15-year planning horizon. Within this framework, different management scenarios of the infrastructure enclosure were examined, according to the pre-set, relevant stages of the planning process. Incorporating the model as a decision-support tool in the planning process allowed determination of the best way to adapt the infrastructure enclosure to serve as a multiuse area, while including marine conservation among the added uses.

2.1. The planning process

In the MSP process, 2 of the 10 stages were identified as suitable for examining the promotion of marine conservation goals (stages 6 and 7 in [20], see Table 1), within areas of marine infrastructure. Then a food-web model was used to predict the effect of different spatial alternatives and management schemes on the food-web.

2.1.1. Defining and analyzing future conditions (Stage 6 in MSP process)

This stage is the sixth of ten stages [20]. The business-as-usual scenario (BAU) was simulated as a reference, as well as two spatial alternatives, each under three management strategies. Each spatial alternative represents the incorporation of a different target: (1) The spatial alternative that prioritises 'Ecology and recreation' (ER) emphasises development guided by marine conservation needs, following the conservation targets outlined by the Israel Nature and Parks Authority – INPA [28], which highlight educational and recreational activities in MPA areas; 2) The spatial alternative that prioritises ‘Intensive development’ (ID) emphasises development of the area for further energy production and for the benefit of other industries that rely on ports.

2.1.2. Preparing and approving the spatial management plan (Stage 7 in MSP process)

Decision-support tools are often used in MSP in the seventh stage, to examine different management scenarios [11,40]. The seventh stage of the planning process (Table 1) was followed to examine the selected spatial alternatives under three management strategies: exclusive, cooperative, and inclusive management. Exclusive sectoral-management represents operation of the area according to sector needs only. Cooperative management represents operation of the area according to sector needs while promoting benefits of additional sectors from the area. Inclusive management represents operation of the area by multiple sectors, to allow maximum benefit for each sector. Thus a total of seven scenarios were employed: two spatial alternatives under three management strategies (=6), and the BAU scenario, which served as a baseline, for comparing measures from each of the simulated scenarios.

The spatial alternatives and the related management strategies are detailed in Table 2. The ER alternative focused on the natural components of the area, choosing to exclude artificial structures constructed for energy-production purposes, while allowing recreational activities such as swimming, snorkeling, SCUBA diving and sport fishing. In the ID alternative, the focus was on the construction of additional structures, to enhance production and port activities. Management strategies adjust the activity in the area according to the level of other sectors' involvement. The rationale for each spatial alternative and management strategy is described in Appendix 1.

2.2. Study site

The Orot Rabin Power Station is located on the coast of the Israeli Mediterranean Sea near the city of Hadera. It encompasses a marine area of approximately 1.5 km^2 and includes submerged and above-water structures (Fig. 1). The shallow area has a depth of approximately 5 m and includes an intake basin, into which seawater is pumped to cool the power station turbines. The intake basin is bordered by breakwaters from the west, south and partly from the north, to minimize turbulence which might cause pumping disruptions. Seawater in the intake basin is not treated in any way before uptake by the turbines, and water flows freely in and out of the basin.

The intake basin encompasses the tugboat harbour, a dock for military vessels and another dock for small maintenance and security patrol boats. The coal jetty, where ships unload coal for the operation of the power station, is the deepest area, at a depth of approximately 29 m. The jetty is located 3 km west of the power station and from there a

Table 1
Ehler and Douvere [20] stages of marine spatial planning where ecological modelling tools could be used for achieving marine conservation within areas of human activity.

Planning stage according to Ehler and Douvere [20]	Stage order	Stage description
Defining and analyzing future conditions	Sixth	Planners project the current existing human activities over space and time and then predict future demand for space by variety of existing and future activities. Based on these predictions, planners examine alternative future scenarios for the area.
Preparing and approving the spatial management plan	Seventh	Planners examine management alternatives for the area and select management measures for evaluation. At the end of this stage, planners prepare a comprehensive management plan.