Journal of Environmental Management 337 (2023) 117691

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Short communication

Comparing spatial management tools to protect highly migratory shark species in the Eastern Mediterranean Sea hot spots

Shiri Zemah-Shamir [a,*,1], Ziv Zemah-Shamir [b,c,1], Yoav Peled [a], Ole Johannes Ringnander Sørensen [b,c], Inbar Schwartz Belkin [d], Michelle E. Portman [d]

[a] School of Sustainability, Reichman University (IDC Herzliya), P.O. Box 167, Herzliya, 4610101, Israel
[b] Department of Marine Biology, Leon H. Charney School of Marine Sciences, University of Haifa, Haifa, 3498838, Israel
[c] Morris Kahn Marine Research Station, University of Haifa, Haifa, 3498838, Israel
[d] Faculty of Architecture and Town Planning, Technion-Israel Institute of Technology Technion City, Haifa, 3200003, Israel

ARTICLE INFO

Handling Editor: Jason Michael Evans

Keywords:
Time-area closures
Sharks
Recreational fishers
Bycatch mitigation
Dynamic ocean management (DOM)
Marine spatial planning

ABSTRACT

Bycatch of non-target species is a pressing problem for ocean management. It is one of the most concerning issues related to human-wildlife interactions and it affects numerous species including sharks, seabirds, sea turtles, and many critically endangered marine mammals. This paper compares different policy tools for ocean closure management around a unique shark aggregation site in Israel's nearshore coastal waters. We provide a set of recommendations based on an optimal management approach that allows humans to enjoy marine recreational activities such as fishing, while maintaining safe conditions for these apex predators which are vital to the local marine ecosystem. To learn more about recreational fishers' derived benefits, we use a benefit transfer method. Our main conclusion is that dynamic time-area closures offer sustainable and effective management strategies. Since these closures are based on near real-time data, they might successfully preserve specific species in limited areas (i.e., small areas).

1. Introduction

Coastal sharks are vulnerable to human activities and challenging to manage over space and time. They especially suffer from overfishing and bycatch which includes both discarded and incidental catch, and from competing stakeholder interests such as those of coastal recreationalists (Peterson et al., 2022). Coastal recreational fishers, for example, compete with sharks over food resources, targeting the same prey fish. In addition, sharks may be harmed by fishing gear which may threaten the sharks' well-being and even continued existence.

While sharks have long lifespans, they also have only a few offspring during their lifespan, making them very vulnerable as a population (Zemah Shamir et al., 2019, Zemah-Shamir et al., 2022b). Once a shark's population is heavily reduced, recovery may take a long time, even decades. A recent global assessment of 1199 species in Class Chondrichthyes—sharks, rays, and chimeras—revealed that almost one-third of the known shark species (n = 536) are threatened with extinction (31.2%, n = 167) (Dulvy et al., 2021).

Sharks in the Mediterranean Sea face an elevated risk of extinction; some Mediterranean Sea populations have declined by up to 99% (Ferretti et al., 2008; Taklis et al., 2020). Yet, while emerging scientific tools advance the understanding of regional impacts and adaptive responses to marine ecological threats, these tools' development lags behind that of terrestrial ones (Rölfer et al., 2021). The lack of creative, innovative management tools delays decision-making and increases the likelihood of misguided decisions that preserve short-term gains over long-term costs (Holsmanet al. 2019). There is still limited evidence on the rate at which shark populations can rebound from over-exploitation in protected areas. However, recent studies show promising results in places such as Ashmore Reef in Western Australia (Speed et al., 2018) and U.S. Palmyra Atoll National Wildlife Refuge (White et al., 2017).

One of the biggest challenges to shark protection is their mobility. Dwyer et al. (2020) found that high levels of protection for mobile shark species occur in countries where sharks are protected within large marine reserves. However, as with other highly mobile megafauna, most Marine Protected Areas (MPAs) fail to cover the full range of the species, resulting in limited or no protection when the species swim beyond MPA boundaries (Hobday et al., 2014). In addition, it has been suggested that

* Corresponding author.
E-mail address: shiri.zemahshamir@runi.ac.il (S. Zemah-Shamir).

[1] The first two authors have an equal contribution.

https://doi.org/10.1016/j.jenvman.2023.117691
Received 21 September 2022; Received in revised form 28 February 2023; Accepted 6 March 2023
Available online 15 March 2023
0301-4797/

stakeholders involved in the planning and management of MPAs have different and sometimes conflicting interests, therefore the areas may have goals other than marine protection (Coppa et al., 2021).

Another spatial management tool is the time-area closure which is used to systematically close an area to fishing during times of high bycatch risk. Time-area closures, also called spatiotemporal closures, which restrict activities in areas that coincide with an expected presence of species targeted for protection within them, can counter some of the problems of mobility and bycatch (Smith et al., 2021), as mentioned above. As opposed to static closures which may unnecessarily restrict fishing activity in times and areas where bycatch risk is low, dynamic closures are based on near real-time data on the target species' location to guide the spatial distribution of human activities. Advancing the spatiotemporal resolution of time-area closures better balances human ocean uses and conservation (Hazen et al., 2018; Lewison et al., 2015; Smith et al., 2021).

For the most part, spatiotemporal management and its derivatives have been considered mainly for fisheries management (Dunn et al., 2016; Hobday et al., 2014). Here we consider establishing such a regime through ecosystem-based marine spatial planning (MSP). Marine spatial planning is considered one of the many area (place)-based management tools for the marine environment (Portman, 2016). It is a cross-sectoral, area-based tool that seeks to coordinate multiple uses at sea to advance the common overarching objective of sustainable development; MSP processes are designed to contain and manage conflicting interests (Gissi et al., 2022).

Agardy et al. (2011) suggested addressing the shortcomings of MPAs through MSP over a decade ago. Marine spatial planning that considers numerous ocean activities simultaneously and is implemented at large scales and with significant public participation, can provide hope as a mediating process leading to time-area closures (Shabtay et al., 2020; Lewison et al., 2015; Pennino et al., 2021, Uhlmann et al., 2019). Yet, it must be clear that MSP is not synonymous with marine protection (Trouillet and Jay, 2021). The reason MSP should consider various types of closures – and preferably those that are most efficient – is that MSP aims to be ecosystem-based (Portman, 2016, Ehler and Douvere, 2009). Apex predators, such as sharks, are often essential, yet threatened, elements of the marine ecosystem (Wang et al., 2022; Collie et al., 2013).

Our main research question is: what is the best management practice from an economic and ecological perspective? More specifically, what tool can lead to the rebound of shark populations from over-culling in places such as estuaries, power plants, or other areas characterized by complex human-wildlife interactions?

We believe that time-area closures can be considered to simultaneously address fishing and conservation needs. Whether mandated as part of fisheries management or within the framework of a marine plan arrived at through a process of MSP, one of the advantages of time-area closures as opposed to a static full-time closure, is their targeted approach leading to greater efficiencies (Dunn et al., 2016; Hazen et al., 2018).

1.1. *Different closure types*

In this paper, we compare types of time closures. Some closures engender unnecessary restrictions of human activities when mobile species are not present. The three types of time-area closures we consider are: 1) full-time closures; 2) seasonal closures; 3) dynamic closures.

Seasonal closures time-area closures for fishing are common policies that, in the case of recreational and commercial angler fishing, aim to reduce fishing mortality (Chagaris et al., 2019). Globally, seasonal closures are commonly used; however, they are not responsive to spatiotemporal changes in fishing effort or species distribution (Smith et al., 2021). They have pre-defined spatial and temporal dimensions based on a static assessment of environmental, biological, and economic management factors (Welch et al., 2019), making them rigid, yet easily communicated. Seasonal management measures have proven efficient in protecting site-specific locations, but these approaches may be less successful at managing highly mobile species (Hyrenbach et al., 2000).

Dynamic closures are a tool of dynamic ocean management (DOM), defined by Maxwell et al. (2015) as "management that rapidly changes in space and time in response to changes in the ocean and its users through the integration of near real-time biological, oceanographic, social and/or economic data". This type of management allows for updated distribution patterns to determine effective strategies. Regulations are predefined, while spatial and temporal distribution patterns of the pertinent species can be constantly updated and delivered to users in near real-time (Hazen et al., 2018). Dynamic closures are generally considered the most efficient strategy for improving the conservation of mobile species, while still minimizing economic loss and conflict with stakeholders (Smith et al., 2021).

Pons et al. (2022) found that dynamic management provides substantially better outcomes than classic seasonal marine area closures. Since a dynamic area closure is sensitive to changes in species distribution in space and time, the boundary radius of the nature-preserve area can be minimized. Maxwell et al. (2015) modeled temperature-dependent habitats which projected that DOM could limit the required closure area by up to 34–82%, compared to regular full-closure. This highlights the benefits to other stakeholders with access to the parts of the management area not necessary for species' wellbeing at any given time.

While dynamic closures have the potential to optimize the biological and economic outcomes, the method still requires up-to-date data on the movement and distribution patterns of the relevant species throughout the year. Fortunately, there have been great advances made in data collection. As an example, the tagging of Pacific Predators, a field program of the Census of Marine Life which deployed 4306 tags on 23 species showed that top predators exploit their environment in predictable ways, providing the foundation for spatial management of large marine ecosystems (Block et al., 2011). Furthermore, direction and guidance for the usage of these technologies can be called for as part of a MSP process (Schwartz-Belkin and Portman, 2023).

To summarize, full-time and seasonal area closures are strategies that incorporate conservation efforts. However, for highly mobile species, full-time closures do not consider stakeholder interests in times when the sharks are not present. Similarly, seasonal closures are limited in their ability to match the needs of highly mobile species whose range and activities depend on environmental conditions (Armsworth et al., 2010; Dunn et al., 2011) with those of stakeholders.

In this work, we investigated dynamic management schemes and compare them to seasonal and full-time fisheries area closures. The Hadera River estuary in Israel serves as a case study for this comparison. The estuary is an aggregation zone for cartilaginous fish, which, despite their protected status, are threatened by coastal recreational fishing where they are commonly killed or maimed as bycatch. The area is unsuited for MPA consideration since it does not meet the necessary criteria (Kelleher, 1999). In fact, the aggregation near a warm water outlet originates in a nearby coal-fired power plant, and the area is considered a non-natural habitat, heavily anthropogenically affected (Shamir et al., 2019, Zemah-Shamir et al., 2019). As such, other conservation methods require consideration.

MSP provides an opportunity to address both fisheries management and marine protection and therefore it can be a good way to implement DOM (Hazen et al., 2018). So far the lack of DOM in marine plans (Lombard et al., 2019) may be related to the fact that most dynamic closures are proposed in high seas areas (Maxwell et al., 2020) whereas MSP is usually focused on nearshore waters where authorities have more comprehensive jurisdictional authority. However, this is changing as more and more marine plans address areas farther out to sea (such as EEZs) (Portman, 2016). In any case, MSP allows opportunities for conservation (Vaughan and Agardy, 2020), and its extensive use of decision support tools featuring spatially explicit datasets (Depellegrin et al., 2021; Schwartz-Belkin and Portman, 2022) means that dynamic data could be incorporated as readily as static data, at least for the purposes of identifying areas suitable for DOM.

Here, we aim to derive an optimized policy recommendation to manage the Hadera River estuary which is the chosen case study. Here management is needed to prevent unwanted fisher-shark interactions (Gallagher et al., 2017), while still considering fishers' socioeconomic needs. Seasonal closures could lead to unnecessary closures when bycatch risks are low. Every conflict mitigation strategy we presented consists of different costs for stakeholders (Dunn et al., 2011; Silva et al., 2021). Our aim is to inspect overall cost reduction according to Pareto efficiency while reducing bycatch and protecting endangered and critical species that hold an essential position in the Hadera nearshore marine ecosystem.

2. The case study – Hadera River

In Israel, all sharks are regarded as protected species, and it is illegal to harm or fish them. Two large coastal shark species with a widespread distribution are found off the coast of Israel: the sandbar shark *(Carcharhinus plumbeus)* and dusky shark *(Carcharhinus obscurus)*. These two species have been listed as Endangered and Data-Deficient, respectively, in the Mediterranean Sea and Vulnerable for the rest of the world according to the IUCN Red List of threatened species.

The best-known aggregation of such sharks on the Israeli coast is in the Hadera River estuary (Fig. 2), where 40–80 sharks gather every winter (November till May) near a warm water outlet originating in a nearby coal-fired power plant (Alexandri et al., 2019, Zemah-Shamir et al., 2019, Zemah-Shamir et al., 2022a). The furnace heat converts boiler water to steam, which is then used to spin turbines that turn generators within the plant. The hot water that cools the turbines is emitted to the adjacent coastal waters at the end of this process creating a wintering shark aggregation, wherein 40–80 individuals of dusky, and sandbar sharks congregate. These two species aggregate in the shallow waters (<10 m) of the relatively warmer water effluent (+5–10 °C) for 5 months enjoying a metabolic advantage due to the high temperature and the prey (several species of intermediate predators) that also aggregate in this spot (Zemah-Shamir et al. 2019, Zemah-Shamir et al., 2022b).

Recreational fishing activities along Israel's Mediterranean coast have grown steadily since the 1950s (Pauly et al., 2020). Sportfishing is estimated to account for 36% of the total annual fishing catch with about 70,000 fishers active in sport fishing along Israel's Mediterranean coastline (Siemazko-Koch, 2020). Since most of the coastline is neither protected nor regulated, sharks are sometimes caught or injured by recreational fishers, although not purposely fished (Fig. 1). The Hadera River estuary (Fig. 2A and B) is one of the preferred places for fishers due to the convenience of fishing activity in this area. The fishers sit along the estuary and spread out along the stream towards the river mouth as the flow takes the bait to the river's outlet causing a conflict between fishers and sharks. The pervasive bait-type fishing in the estuary that uses fishing hooks and other harmful equipment proves quite detrimental (see Fig. 1B and C).

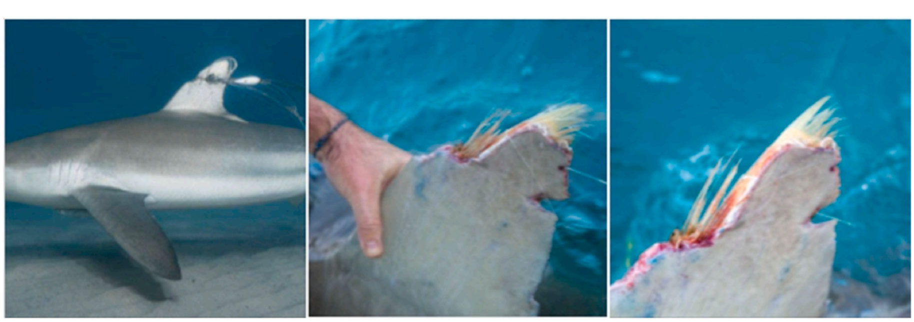
The power plant emissions have generated a literal "hotspot" of human-wildlife where sharks and humans meet. The local municipality and the Israeli Nature Park Authority (INPA) are very concerned about these encounters. The main role of the INPA is, among others, to preserve and maintain natural biodiversity. However, INPA will not designate the area as a nature reserve due to its highly disturbed characteristics and lack of salient environmental (natural) values claiming that without the power plant there would not be hot water discharges and, consequently, no shark aggregation. We compare and analyze the efficiency and the expected conflict mitigation capacity of three management methods – dynamic, seasonal, and full-time area closures with the suggestion that spatial-temporal closure could be implemented here as a type of other effective conservation measure (OECM).

3. Materials and methods

We present the three types of closures in a flowchart, (see Fig. 3). As mentioned, the first type forbids stakeholders from active use of the area at all times on a permanent basis. The other two are temporal restrictions, one seasonal and the other dynamic.

To do so, we identify different parameters from recent literature (published since 2015) that are most relevant to the case study of Hadera's shark aggregation. Based on SCOPUS search engine, we reviewed papers published between 2015 and 2022 (only state-of-the-art new articles) using the keywords of: "Time-area closures" together with "Management". These articles were screened by the authors and the relevant parameters were taken and used for the evaluation of those three methods. The parameters specify the associated requirements and impacts of each management strategy. These parameters are those with a major impact on Hadera River estuary users, chosen through keywords to environmental, social, economic, and managerial implications and also take into account the often-forgotten advantages to fishermen. Each parameter is graded and ranked based on its suitability for conservation by the authors (all experts from different disciplines-marine management, economics, and environmental science). This expert-opinion method has been used by numerous other studies (e.g., Portman, 2007; Gissi et al., 2022). Based on these parameters we established a weighted grade for each management option to learn which tool is most effective.

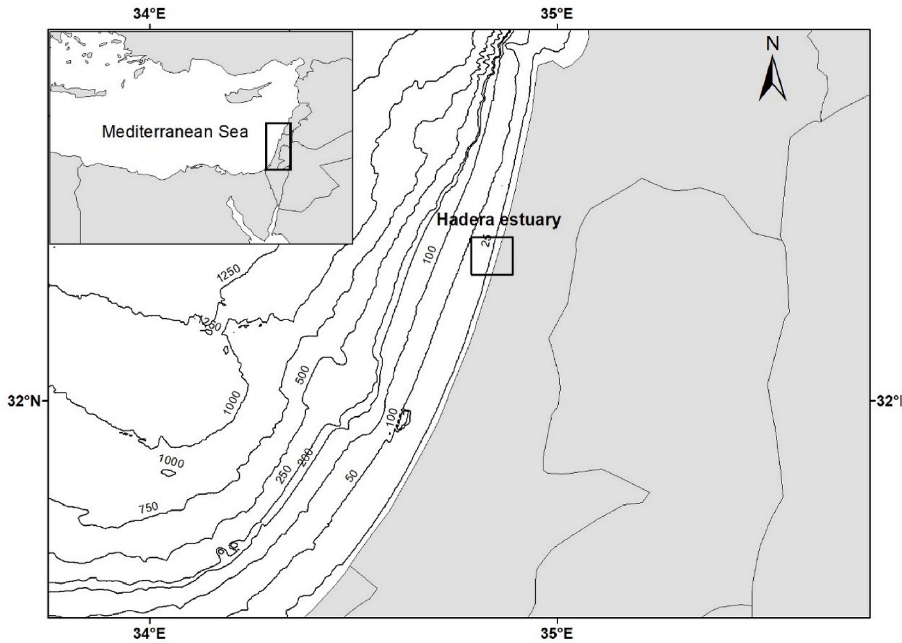
Next, we carried out a review of the economic aspects of each closure strategy on fishers' welfare. A recent meta-analysis study of recreational fishing, featuring 392 value observations (of which 88% are from the USA), yielded a mean value of 231.9 USD per fishing day (Gren and Marbuah, 2022). We combined this value with the INPA's assessment of an average of 14.8 fishers per day in the Hadera River estuary to obtain the overall recreational fishing value per day in the study site. By



(A) (B) (C)

Fig. 1. Female dusky shark *(Carcharhinus obscurus)* caught in fishing gear (A) and dorsal fin damage (B + C) after releasing (Photos by Ran Golan and Aviad Scheinin).

A.



B.

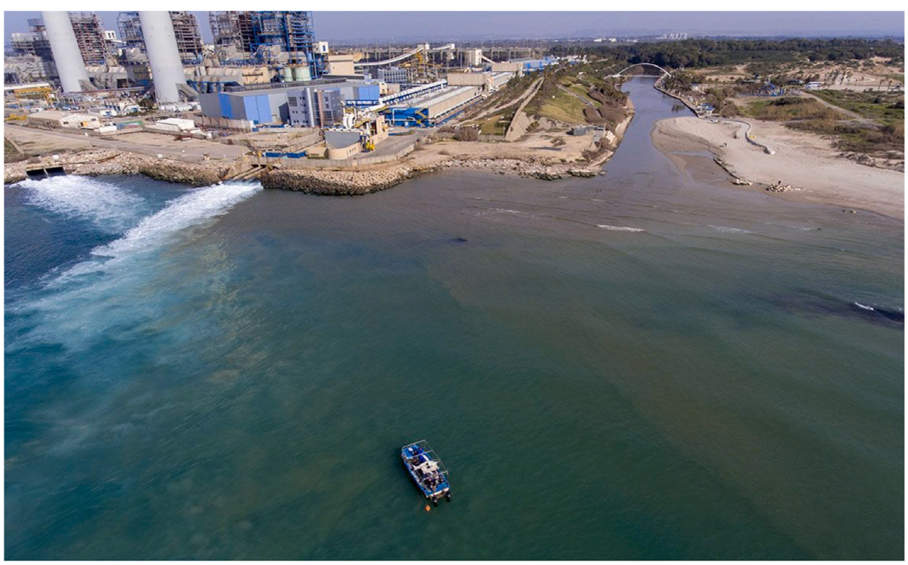


Fig. 2. A. Location of Hadera Estuary in the Eastern Mediterranean Sea. B. The Hadera River estuary where sharks aggregate (Photo by Ziv Zemah-Shamir).

comparing the three closure scenarios, we assessed the potential economic impact on fishers' welfare. Each closure scenario is defined by the number of days inaccessible to fishers, matching the days sharks are present. Under the full and seasonal closures, 365 and 150 days respectively, are inaccessible to recreational fishers in the Hadera River estuary park,. Under the dynamic closure scenario, which is determined by shark presence and underlying temperature, inaccessible days are assumed to range between 120 and 150 days.

4. Results and discussion

By examining the chosen parameters' sensitivities and strengths, we found that 7 out of 9 cases achieve better conservation effects when using dynamic or seasonal closures rather than full-time closures (Table 1).

Reducing bycatch of multiple species and optimal implementation cost, we get a better score by having implemented a full-time closure, but the costs to the recreational fishery increase dramatically. We found that if we adopt the seasonal or dynamic closure strategies rather than full-time closures respectively, the predicted annual loss may decrease by 58.9–67.1% (Table 2).

Realizing that recreational and societal support would increase the efficacy of any intervention, we highlight the need to minimize conflict. We suggest the inclusion of stakeholder interests to elucidate consumer surplus, especially in the case of dynamic closures which marine spatial plans can potentially promote, or even mandate, while integrating optimal trade-offs between economic, social, political, and ecological goals (Pennino et al., 2021; Portman, 2016).

The overall results of our analysis show that conflict mitigation can lead to compromise for the stakeholders involved. Interventions may not

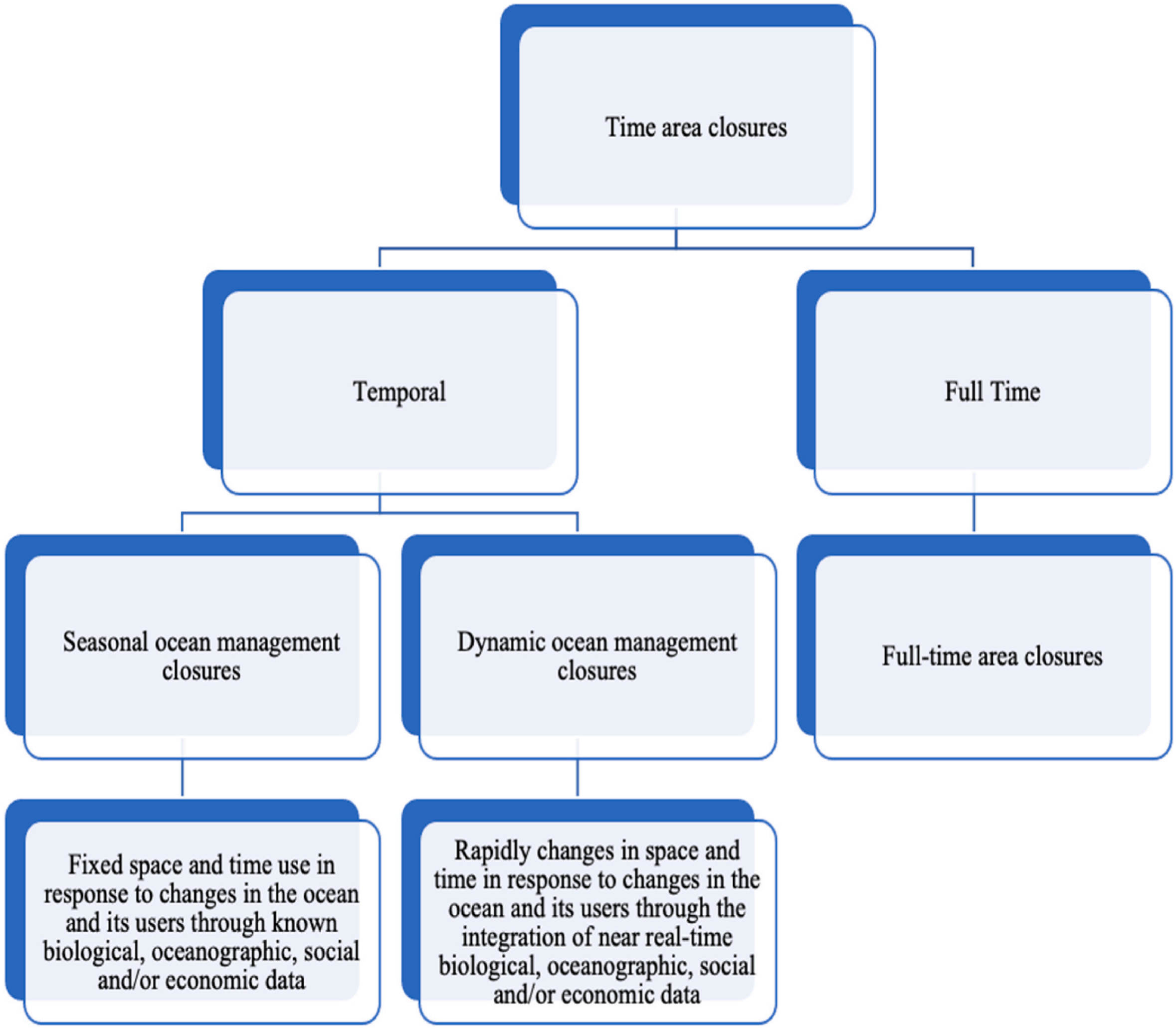


Fig. 3. Classification of time-area closures related to our case study.

be in line with stakeholder interests and efficiency may be limited if only discussed in closed forums. However, going beyond the conflict, it is likely the interest of all stakeholders to protect and secure natural resources for generations to come. Furthermore, as mentioned, all sharks are considered protected in Israeli waters. Hence, we are obliged to limit further damage to these already vulnerable species. Moreover, those species and others are subjected to international exploitation unmanaged by developed countries (as a case in point, see the sandbar shark case study from the southeast United States in Peterson et al., 2022).

Regarding supportive policy and management issues, Smith et al. (2021) found that dynamic closures are more difficult to enforce, communicate and deliver to stakeholders. Furthermore, the legal capacity for DOM can be cumbersome, and even voluntary DOM approaches face legal challenges, sometimes due to data confidentiality and intellectual property protections sometimes when competing or overlapping agencies do not disclose data (Hobday et al., 2014).

While it is difficult to regulate fisheries operated on a large scale, it is feasible to regulate fishing in discrete or small-scale areas, like local hotspots where species aggregate (Smith et al., 2021). In a smaller, compact and continuous area such as our case study, the Hadera Power plant, in Israel, regulatory issues could be negligible and could be addressed within marine spatial plans. A recent study by Di Lorenzo et al. (2022) suggests that partially protected areas have the potential to benefit threatened elasmobranchs, yet when the small-scale fisheries management inside a MPA is poor, conservation goals such as the protection of these threatened species might fail (Di Franco et al., 2016). Considering Israel has recently published its first two marine policy documents, one for the Red Sea and before that for the Mediterranean Sea which will lead to additional marine spatial planning efforts and implementation, we recommend incorporating guidelines for dynamic closures where human-wildlife interactions are problematic and as OECM. In the meantime, management measures could take placed by appropriate governmental and local authorities to balance the needs of extractive fisheries with conservation.

5. Conclusions and future research

Fisher-shark interactions cause the depletion of sharks' population when fishing is allowed, while fishers' welfare is reduced when fishing is forbidden (Robinson et al., 2022). The prioritization of one potential strategy over the other is often case-specific, as in this study. This case study is unique in that it considers the impact of human infrastructure (the power plant) alongside a unique cluster of dozens of sharks for many winter months. While sharks are defined by the INPA as protected species, the authority opposes declaring this place an MPA. Therefore, there for an OECM guided by MSP. The economic difference is significant for the investigated sectors and may be an adequate solution to this complex conflict.

Future research should fill the knowledge gaps regarding local recreational fishing consumers' surplus, changes in this surplus, and the status of recreational fishing activity regulations in Israel. Filling in such gaps will provide recommendations for updating policy. Such gaps in

Table 1
Parameters that determine sensitivity levels of marine conservation: High, Moderate, and Low.

Parameter	Supportive literature Reference	Temporal		Full-time closures [1]
		Dynamic closures	Seasonal closures	
Sensitivity to varying boundaries across space and time	Smith et al. (2021)	High	Moderate	Low
Decrease boundaries distance radius and time of closure	Dunn et al. (2016)	High	Moderate	Low
Responsive to changing species distributions	Smith et al. (2021); Maxwell et al. (2020)	High	Moderate	Low
Increase trust to achieve fisheries management goals	Silva et al. (2021)	high	High	Low
Strength to avoid unnecessarily restrictions of fishing activity	Smith et al. (2021); Little et al. (2015)	High	Moderate	Low
Sensitivity to global changes	Smith et al. (2021); Maxwell et al. (2020)	High	Moderate	Low
Data and technology requirements for real-time or forecasted	Dunn et al. (2016); Maxwell et al. (2020)	High	Moderate	Low
Reducing economic impacts (on fishery) or economically costly	Smith et al. (2021); Armsworth et al. (2010)	High	Moderate	Low
Reduce bycatch of multiple species	Little et al. (2015)	Low	Moderate	High
Reduce optimal implementation cost	Smith et al. (2021)	Low	Moderate	High

Table 2
The estimated losses in fishers' welfare under the three closure scenarios.

Management strategy	Predicted annual losses (USD 2022)
Dynamic closures (120–150 days closure)	411,854–514,818
Seasonal closures (150 days closure)	514,818
Full-time closures (365 days closure)	1,252,723

knowledge were recognized during the marine spatial planning process conducted in the country which culminated in 2020 (see: https://www.gov.il/he/Departments/General/policy_maritime).

Finally, in the Hadera River Park estuary, there is not one clear authority managing the site and regulating human uses, which makes instituting a workable DOM system, or even advocating for such a system through a marine spatial planning process, difficult. This fragmentation of governance must be addressed and solved for the shark populations to be clear of dangerous anthropogenic threats in Israel's nearshore coastal waters.

Authors contribution

Shiri Zemah-Shamir: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Supervision; Validation; Visualization; Roles/Writing - original draft; Writing - review & editing. Ziv Zemah-Shamir: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Validation; Visualization; Roles/Writing - original draft; Writing - review & editing.Yoav Peled: Data curation; Formal analysis; Visualization; Roles/Writing - original draft;.Ole Johannes Ringnander Sørensen: Roles/Writing - original draft;. Inbar Schwartz BelkinFormal analysis; Roles/Writing - original draft; Writing - review & editing.Michelle E. Portman: Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Supervision; Validation; Visualization; Roles/Writing - original draft; Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgment

We would like to express our appreciation to Dr. Aviad Scheinin and Mr. Ran Golan for their valuable and constructive suggestions. We would also like to thank our colleagues from Morris Kahn Marine Research Station (University of Haifa, Israel), School of Sustainability (Reichman University, Israel), and the Faculty of Architecture and Town Planning (Technion, Israel) for their help and support to establish this multidisciplinary manuscript.

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