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Introducing dynamics into coastal recreational management: Humans-sharks interactions case study

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A B S T R A C T

Area-based management tools, including marine protected areas (MPAs) and time-area closures, are accepted and effective forms of management utilized to mitigate local human impacts on marine species and ecosystems. In the Hadera Stream estuary in Israel, two vulnerable shark species aggregate every winter in a highly active coastal area frequented by snorkelers, SCUBA divers, recreational fishers, and motorized and non-motorized water sports enthusiasts. The interaction between humans and sharks raises important concerns for the safety of individuals near these apex predators and for the sharks' welfare. The Hadera Stream estuary, impacted by heated water discharged from the nearby Hadera power station, experiences significant anthropogenic effects, leading the Israeli Nature and Parks Authority to disqualify it from designation as an MPA. By employing the Delphi technique with relevant experts, we identified activities posing the greatest threats in human-shark interactions. Using this information, we have proposed restricting human activities to only during specific times. Our research findings provide valuable insights for potential regulators. This study represents the initial step in promoting area-based conservation in Israel, aiming to dynamically balance human recreational needs with shark conservation. The study underscores how utilizing specific technological advancements in shark tracking can advance an ecosystem-based approach, enabling tailored management practices that account for both conservation and recreational uses.

1. Introduction

The intensification of human activities on marine ecosystems is leading to increasingly severe consequences (Halpern et al., 2019; Portman, 2016). Planning for a sustainable future necessitates improved management of various human activities in the ocean and a deeper understanding of the responses of natural and socio-economic systems to our interventions (Domínguez-Tejo et al., 2016). As the utilization of marine space continues to grow, many countries are seeking to apply the ecosystem-based approach (EBA) which involves considering humans as part of the ecosystem and applying the precautionary principle (Kirkfeldt, 2019). The EU member countries, for example, are directed by The Marine Strategy Framework Directive (MSFD, 2008/56/EC) and the Maritime Spatial Planning Directive (MSPD, 2014/89/EU) to apply an EBA to ensure that the cumulative impact of all activities remains within levels that maintain a favorable environmental status.

Unlike its terrestrial counterpart, the marine environment is highly dynamic and has a relatively young planning history. To implement the EBA, marine planners and managers are embracing a holistic, integrated approach, that is less sectoral and aims to provide a comprehensive understanding of the environment and its challenges (Douvere and Ehler, 2009; Kidd and Ellis, 2012). Marine environmental planners and managers can benefit from incorporating practices from established marine sectors, such as the shipping and fisheries industries. One of these practices is dynamic ocean management.

Dynamic ocean management (DOM) directs uses to ever-changing, real-time ocean conditions, encompassing its biotic and abiotic elements, as well as to the activities of other human users (Maxwell et al., 2015). For example, fisheries management commonly uses spatiotemporal regulations of human activity in a specified area for conservation or sustainable resource management objectives (Gjerde and Muraki-Gottlieb, 2022); marine traffic slows down in areas of whale migrations during specific seasons (Guzman et al., 2020). Compared to setting annual or seasonal restrictions to reduce conflicts between high species mobility and human uses, DOM can also address changes in species' presence over short temporal scales and in relatively small

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spatial areas by using cutting-edge technologies, thus providing an effective alternative to traditional and more static management tools (Dunn et al., 2016; Lewison et al., 2015; Maxwell et al., 2015; Schwartz-Belkin and Portman, 2023).

Although some marine sectors (e.g., fishing, shipping) may be familiar with DOM, challenges exist in operationalizing these approaches, especially for less traditional sectors such as marine sports and tourism. Time-area closures are a specific spatiotemporal management tool commonly used in fisheries, aimed at reducing bycatch or preventing overfishing by considering the temporary habitat usage of a mobile animal or the organism's life stages (Dunn et al., 2011). We propose adapting DOM and time-area closures to regulate coastal tourism and recreational activities near seasonal wildlife aggregations. Additionally, we introduce the concept of "dynamic time-area closures" tailored to restricting activities only when wildlife is actually present.

We use the Hadera Stream estuary, Israel (hereafter "Hadera site") as our case study. This area is used year-round for recreational fishing (angling) and motorized and unmotorized water sports. In recent winters (November to April), dusky sharks (*Carcharhinus obscurus*) and sandbar sharks (*C. plumbeus*) aggregate near the hot water outlet of the Hadera Power Station, located at this site, and become a major attraction for snorkelers, SCUBA divers, and motorized and unmotorized water sports enthusiasts. The visitors' presence around the sharks is of concern for sharks' well-being and human safety; visitors have harassed the sharks and sharks have exhibited stress-induced behaviors such as using their snouts to push away crowds in shallow waters. However, little progress has been made in managing these interactions (Zemah Shamir et al., 2019a, 2019b, 2023).

With a formal regulation format in mind, we hypothesize that implementing time-area closures could effectively enforce specific restrictions on human activities during the shark season. Specifically, we propose favoring seasonal or dynamic time-area closures, to target the most accurate restriction period. A seasonal time-area closure relies on historical data to predict the temporal appearance of sharks, while dynamic closure uses near-real-time data. This study evaluates the feasibility of implementing dynamic time-area closures based on near-real-time monitoring of shark occurrences at the Hadera site.

The activities that should be restricted as sharks aggregate are the ones that might harm the sharks or may be harmed by the sharks. To identify the activities and their related need for spatiotemporal restrictions, we surveyed experts familiar with the Hadera site. We also assessed their acceptance of using DOM as a spatiotemporal area-based management tool (ABMT) on site. We aim to identify the key issues concerning human-shark interactions at the Hadera site and to gather recommendations for managing the risks associated with these human-wildlife interactions. Additionally, we explore perceptions of using near real-time data to facilitate the EBA, aiming for efficient management of human activities while achieving marine conservation goals.

2. Methods

In Zemah-Shamir et al. (2023), we identified DOM as an approach to manage human-shark interactions. Here, we use the Delphi technique (Section 2.2) to understand perceptions of establishing multi-use zones for DOM at the case study site. The Delphi technique aims to reach a consensus among experts on the following questions about the Hadera site: (1) what are the main conflicts and compatibilities (a) between different uses and (b) between uses and sharks? (2) What solutions or strategies can best mitigate these incompatibilities? (3) How well-accepted is DOM for mitigating these incompatibilities?

2.1. Study site

As mentioned, the Hadera site is on the Israeli Mediterranean coast, and is a well-known aggregation spot for adult dusky and sandbar sharks during winter (Fig. 1). The sharks are attracted to this spot due to the warm water discharged from the cooling turbines of the "Orot – Rabin" Hadera power station (Zemah Shamir et al., 2019a; 2019b). Acoustic telemetry has identified the spatiotemporal presence of sharks in the Hadera site, showing when and where sharks frequently aggregate. The sharks only aggregate near the hot water outlet under certain environmental conditions, specifically in winter, when the hot water outlet raises the temperature of the surrounding water by 5–10 °C (Zemah-Shamir et al., 2022). The Israel Oceanographic and



Fig. 1. Left: Hadera site location within Israel (32° 27′ N, 34° 52′ E). Right: Large image: shark aggregation location in the Hadera site (orange rectangle). Red arrows mark the hot water outlet from the power station (map source: Google maps). Right inset: the power station's chimneys; the estuary; red arrows mark the hot water outlet from the power station.

Limnological Research Center conducts regular water temperature measurements, while the L. Charney School of Marine Sciences in Haifa University uses drones to monitor shark aggregations as the water temperature drops. This indicates dynamic area closures could be implemented here based on near real-time data on shark aggregation.

The Hadera site does not fall under the Israel Nature and Parks Authority (INPA) criteria for designation as an MPA and is not managed or protected by the INPA (Yahel and Angert, 2012). Without MPA status which restricts human activities, the ability of an INPA enforcement officer to protect sharks from negative interactions is limited or non-existent. By law, unless direct harm is undergone by the protected elasmobranchs (such as actual shark capture), the INPA cannot apply any sanction (Declaration on National Parks, Nature Reserves, National Sites, and Memorial Sites (Protected Natural Assets), Proclamation, 1998 and the 2019 update, Act no. 8302) despite most of them being endangered species (Grossmark et al., 2024).

Although a designated MPA is unlikely in the near future, voluntary restrictions and regulations are not suggested here. This is because the sharks inhabit shallow waters near the shore, allowing easy access for all visitors. Unlike observing other megafauna, such as dolphins, visitors do not require a boat, eliminating any financial barrier to access this wildlife-watching site. No operators depend on the activities at this site for their livelihood or business success, so there is no financial motivation to promote voluntary regulations (Gjerdalen and Williams, 2000; Kanstinger et al., 2017; Richards et al., 2015). Therefore, we also asked experts which approach and formal body would be most feasible for implementing and enforcing formal regulations.

2.2. The Delphi technique

The Delphi technique involves arriving at consensus among experts (typically 10–25 individuals (Diamond et al., 2014; Okoli et al., 2004)) who provide anonymous opinions on as many topics as possible without meeting in person. Several rounds of questionnaires are administered and only the topics that do not reach a consensus (here, defined as 75% agreement) are revisited in subsequent rounds. In each consecutive round, participants review other experts' responses and may change their responses. Surveying typically stops after the third round of questioning, even if a consensus is not reached, to avoid sample fatigue, when participants stop responding.

The experts represent various stakeholders with conflicting interests. Each panel member reaches an independent conclusion without in-person group pressure, while still being informed of the group's opinions and able to change their responses anonymously (Linstone and Turoff, 1975). The process is outlined in Fig. 2 (see Supplementary materials for questionnaire development, design and data analysis).

We used Delphi-technique information-gathering methods to explore the following aspects (as in Ratsimbazafy et al., 2019):

- Actors: Identification of active user types within the shark aggregation site.
- Discourse: Analysis of views, narratives, challenges, and potential solutions related to management and protection from the involved stakeholders.
- Rules: Examination of current regulations and management procedures, encompassing legislative, formal, and informal aspects.
- Resources: Assessment of power distribution among actors, the extent of their influence, and decision-making authority in deploying policy outcomes.

These aspects guided the formation of the questionnaire. We consulted with ten local experts who had participated in the "Krishim BaZerem" (in English "Sharks in the Flow") project (*Conduct code for shark watching near the Hadera power station, "Krishim Bazerem" Project* [In Hebrew], n.d.). Insights gained from the consultations and the code of conduct were instrumental in crafting the first-round questionnaire

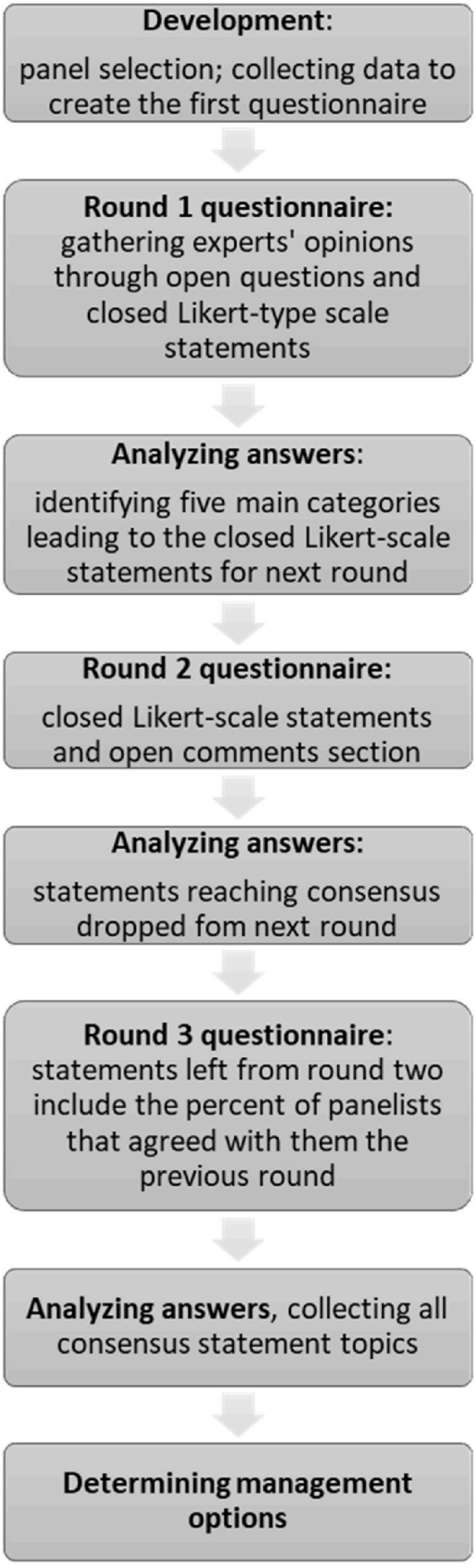


Fig. 2. Overview of the Delphi technique we performed to identify management options for the Hadera site.

and identifying relevant sectors and users to serve as respondents.

2.2.1. Selection of participants

We selected participants who could provide insider perspectives and new insights. Methodologically, it is acceptable to rely on expert opinions to evaluate complex situations and obtain advice for policy-relevant protocols. While the Delphi technique does not demand the selection of a statistical sample of respondents, the selection of panel participants remains crucial (Ratsimbazafy et al., 2019).

We initially relied on preselected categories to identify sectors and representative users. These included relevant individuals from academia, NGOs, the local municipality, governmental authorities, semi-public companies, and private environmental education institutions, such as local SCUBA diving and sailing centers. Subsequently, we reached out to specific contacts identified by their official roles. For instance, from among governmental authorities, we contacted the INPA to identify their relevant local enforcement agent.

The exact participants' positions are not reported here to protect the participant's identity. Generally, NGOs included spokespersons for pro-recreational fishing, pro-SCUBA diving, and pro-nature conservation organization spokespersons. Governmental and local authorities included planners, marine ecologists, different authorities' marine enforcement officers, and representatives from the Ministry of Culture and Sports. Governmental companies included the "Orot Rabin" power station and the associated Hadera port, where the coal supply is unloaded for the power station's use.

We contacted 51 potential participants by phone or email. Many of these individuals used this initial opportunity to assert their opinions on the conflicts in the area, which also benefitted us in refining and focusing on the first-round questionnaire. Potential participants also suggested other potential participants. Those who agreed to participate were all asked to commit to answering three rounds of questioning if necessary following their signing of the consent form required by the Technion's Institutional Review Board.

3. Results

3.1. Profile of participants

A total of 29 experts agreed to participate, each one a professional representative of one sector. Many also identified as having a relevant academic background and/or regularly participating in sailing and/or SCUBA diving which indicated their familiarity with the area in addition to their professional responsibilities (see Table 1).

Overall, the affiliation and experience of the complete panel made their knowledge and opinions appropriate for discussion discourse, commenting on rules and resources of key actors as well as on suitable solutions to conflicts. Most participants easily agreed to partake in the study and had strong opinions on the area and the key conflicts they identified in their field. They also cared deeply about the issues at hand.

3.2. Round One

Twenty-four participants answered the first-round questionnaire. All reported that they understood the complexity of the human-shark interaction in the Hadera site either "well" (4/5) or "very well" (5/5). Twenty-one of the twenty-four participants agreed that the current human-shark interactions in the area must change. Panelists rated a few of the closed Likert-style statements about the importance of different parameters in fisheries management. There was a high consensus both about the importance of fisheries closures being highly responsive to changing species distribution, and that shark by-catch reduction is vital.

The participants identified topics needing attention in regards to the Hadera site, which we classified into five categories for the following questioning round: (1) recreational fishing, (2) SCUBA diving, (3) motorized and non-motorized water sports, (4) shark-watching activities and conduct, and (5) enforcement and management regulations. Other than human-shark interactions, participants reported human-to-human conflicts among the above uses and suggested changes and potential solutions to the conflicts. We included this information in the next round of questioning.

Table 1
Expert panelists' background.

Affiliation	Number of Participants	Round no. and (number of respondents)	Description of affiliation
NGO (environmental)	4	R1(4), R2(3), R3(4)	Three NGOs. Two have an academic background specifically in sharks and marine planning
Private diving company	2	R1(1), R2(2), R3(2)	Two diving centers working in the area
Academia	5	R1(4), R2(3), R3(2)	
Governmental authorities (enforcement)	4	R1(3), R2(4), R3(4)	INPA and Marine police, Two of the participants with an academic background specifically in sharks
Local municipality	2	R1(2), R2(1), R3(1)	City planner, city engineer
Governmental authority (environmental)	2	R1(2), R2(1), R3(1)	Planner (R1) and Marine ecologist (R1-3)
Governmental Company	2	R1(2), R2(2), R3(2)	Hadera Port authority and "Orot Rabin" power station company.
Governmental authority	1	R1(1), R2 (1), R3(1)	Ministry of Culture and Sports
NGO (Diving organization)	2	R1(2), R2(1), R3(1)	Participants with academic background
NGO (fisheries)	3	R1(2), R2(2), R3(1)	Two NGOs, R1 one representative from each NGO, R2+R3 two representatives from one NGO
Education	3	R1(1), R2(2), R3(2)	Local sailing schools, one participant with an academic background specifically on sharks

3.3. Round Two

Round Two comprised five sections respective of the five categories identified in Round One. After each section of closed Likert-type statements, there was an optional comments section (open-ended). See Table S1 in the supplementary materials for the main consensus topics reached by the end of Round Two.

The recreational fishing section focused on recreational angling from shore, a use identified in Round One as conflicting with other uses. The Likert-type statements from Round One now included information on how many panelists agreed with them in the previous round. The statements discussed management, including temporal restriction options, and were positively received by the panel.

The SCUBA diving section showed that the diving sector is aware of the complexity of SCUBA diving on site and the need for more diver supervision. The motorized and non-motorized sports section discussed keeping a safe distance between these uses and from other uses and sharks; the proximity of all uses is a concern that should be addressed. Shark-watching conduct explored ideas like broadcasting real-time footage of the sharks.

Most of the ideas proposed by panelists in Round One were not agreed on by all in this round (Table 2). Enforcement and regulations issues explored the level of enforcement thought needed for each sector needed and which enforcement entity might be most suited to take on

Table 2
The number of statements reaching consensus on each round. Round Two shows only high consensus; Round Three includes moderate consensus. Between rounds, a few statements were combined or dropped based on panelists' comments in the open-response section.

Category	Round Two	Round Three
Recreational fisheries	7/15	4/6
SCUBA diving	2/5	3/3
Motorized and non-motorized sports	4/5	1/1
Shark-watching conduct	3/12	5/7
Enforcement and regulation	4/10	2/2

the responsibility. Although agreeing on the need for greater enforcement, no authority agency was keen to take on this task.

3.4. Round Three

Round Three included clarification of previous statements; a few statements were dropped, reworded and in some cases combined with others (see Table 2).

Most Round Three statements reached consensus to an accepted statistic level according to Delphi literature standards. Even though most reached moderate consensus, the convergence of panel answers from the second to the third round was notable (see Table S2). If the questionnaire would have closed after Round Two without a third round, we would have had fewer consensus statements.

At the end of Round Three, the panel did not reach a consensus about whether recreational fisheries should be restricted during shark season. In the previous round, panelists agreed that if fisheries were restricted, then dynamic management is in order. Overall, the panel did not reach a consensus about whether enforcement is preferred to promoting awareness and education. Nevertheless, all government representatives believed that fishing near the power station should be restricted during the shark aggregation season with opponents to this being the fishers' representatives.

SCUBA diving had three statements left for this round, all reaching a moderate consensus of agreement. The governmental authority representative, related to sports management, agreed to regulating diving, despite avoiding any official support for diving in the area. More consensus among participants regarding shark-watching was expressed in this round (see Table 2) but all agreements reached were of moderate consensus, suggesting that anything done to lower human activities around sharks would be more effective than the current situation.

A joint management authority made up of the entities involved was considered at this point.

3.5. Panel open section comments

In addition to the closed-ended questions, all rounds had open comment areas, which appear in the supplementary materials and provide a deeper understanding of the stakeholder's opposing views.

3.6. Identfied conflicts

Table 3 summarizes existing conflicts between uses and between sharks and users, as described by panelists. Motorized sailing incidents with SCUBA divers, snorkelers, non-motorized sailors, or sharks might be very harmful. Fishing gear might entangle not only sharks but also snorkelers and SCUBA divers. Sharks can sustain injuries from various fishing gear, including commercial ghost gear, and get their fins tangled in recreational fishing lines. Fishers may also be negatively affected by sharks tearing their gear as sharks are competing fishers, while human fishers may potentially injure themselves attempting to release sharks caught as bycatch. Non-motorized sailors, snorkelers, and SCUBA divers might be harmed by getting too close to sharks, and sharks may suffer from repeating stress caused by recurring proximity, touch, or feedings by users. These conflicts reported by the panelists demonstrate that the management on site is lacking and threats are not only to sharks' well-being but also to humans (Fig. 3). This data is presented qualitatively rather than quantitatively (i.e., documenting case numbers of each conflict), as local enforcers explained they are aware of all these incidents, yet they do not record them, since they have little jurisdiction on site; instead they are prioritizing efforts in areas as MPA where they actually have authority.

Current restrictions within laws and by-laws around the shark aggregation site still allow many human uses around the sharks as SCUBA, fishing, and non-motorized sailing (Fig. 4). Fig. 4 presents that no single organization or entity controls the entire area. The marine police are authorized to keep motorized recreational vessels at a minimal distance of 300 m from shore and 100 m from ports. Keeping at least 100 m from Hadera port is required by all other recreational users as well (revised warrant no. 100(1) from year 2022 [in Hebrew]). The Hadera Municipality has the authority to implement the "no swimming" policy since this beach is designated as a no-bathing area (Municipal by-law on beaches and bathing areas,1969 and the 2016 ordinance on bathing areas under the administrative law of local municipalities)[1]. The INPA panel participants clarified that they could enforce shark conservation in any waters, but only if they clearly observed harm or injury to sharks.

4. Discussion

As technologies advance and enable more efficient and effective data gathering on marine environments and their constituents, planning and implementing marine management regimes should incorporate more dynamic, localized, and temporal management measures. We propose a management regime that considers the temporal presence of sharks near power stations to regulate human activities rather than full-time restrictions, as recommended in the Marine Policy for Israel's Mediterranean Maritime Policy for Israel's Mediterranean Waters (2022).

INPA dismissed the option of declaring an MPA to manage human uses on-site, which opened the possibility of exploring how a temporal natural phenomenon could be addressed through another type of ABMT. Despite their conflicting interests, panel members agreed on using geospatial technology to 1) restrict activity to those times when it is necessary to do so, and 2) bring about consensus between panelists. They agreed on adjusting restricted recreational fishing areas using near real-time data on shark aggregation.

Our previous paper (Zemah-Shamir et al., 2023), as well as other research (Armsworth et al., 2010; Hugé et al., 2018; Smith et al., 2021), present the benefits of introducing dynamic management for the marine environment. Similar to Hazen et al., (2018), we show the advantage of minimizing restrictions based on near real-time data. However, unlike past research on DOM, we consider it for recreational uses rather than commercial fisheries.

Based on all three rounds of panel discussions and the identified conflicts and panel suggestions, we recommend separately zoning recreational activities to ensure the safety of humans and sharks on site. From hereon, we elaborate on our management recommendations and provide a summary at the end of the discussion.

We propose a temporal closure of recreational fishing during the peak shark aggregation months near the hot water outlet. This restriction should be informed by real-time data to minimize its duration and impact. This recommendation is based on the fact that dispersing fishers on-site is not feasible because they can only fish from accessible locations (Fig. 3A). Therefore, a temporal closure around the hot water outlet would minimize direct contact with the sharks.

In the open comments, some panelists suggested closing fisheries only when sharks aggregate in high density near the hot water outlet

[1] List of officially declared beaches in Israel; Haifa District: https://www.gov.il/en/departments/guides/yam-muchrazim?chapterIndex=2.

Table 3
Conflicts identified by the panel: HH human to human (where humans may harm other humans); HS human to shark (where humans may harm sharks); SH shark to human (where sharks may harm humans).

	Recreational fisheries	SCUBA diving	Motorized water sports	Non-motorized water sports	Shark-watching conduct
Recreational fisheries	-	HH		HH	
SCUBA diving	HH	-	HH		HH
Motorized water sports		HH	-	HH	HH
Non-motorized water sports	HH		HH	-	HH
Shark-watching conduct		HH	HH	HH	-
Sharks	HS+SH	HS+SH	HS	HS+SH	HS+SH



Fig. 3. Conflicts. (A) Recreational anglers standing on the breakwater near the power station hot water outlet where sharks are most aggregated. Red arrow pointing up: hot water outlet current direction. (B) Anglers, SCUBA divers, swimmers, and non-motorized recreationalists in the shark aggregation zone. (C) Motorized sailing near shore and other users. (D) Shark harassment by snorkeler. Photo credit: (A,B) Bar Sternbach, (C) Moshe Gilad, (D) Ran Golan.

(see Fig. 4). This suggestion is reasonable since aerial drones monitor the sharks' presence and based on past data, aggregations start around November and increase as surrounding water temperatures drop during the depth of winter (Zemah-Shamir et al., 2022).

An alternative to a closure is based on a comment from one panelist on Round Three, who suggested building a long dock into the water, where fishing is only allowed at the edge (beyond the shark aggregation site); however, the panel did not consider this because Round Three was the last. Such boardwalks work in other parts of the world. One example is in Florida, where during the high aggregation season in winter, visitors in the Crystal River Refuge can only see manatees from the boardwalk vantage point ("Crystal River National Wildlife Refuge," n.d.). Dimech et al. (2009) researched fishers' perceptions to understand their compliance with fisheries protection measures and suggest that some stakeholder sectors may require additional incentives to accept restrictions on access if spatial management is to achieve its intended objectives. In our case study area, a long dock could serve as an incentive and help redistribute fishers in a manner consistent with other uses. However, it would require financial resources, possibly including compensation for the part of the beach area that is private property, as the Hadera engineer (planner) informed us. Thus, we remain with our recommendation for a temporal closure at peak aggregation times.

Additional lessons from the Delphi questionnaire relating to a recreational fishing closure would be prioritizing trust building and fostering positive attitudes toward regulations among fishers (Davis and Harasti, 2020; Diogo et al., 2016; Smallwood et al., 2012; Veiga et al., 2013). Fishers' resistance to reforms is not uncommon worldwide. Recognizing and accepting the legitimacy of regulations are key drivers



Fig. 4. Current use limitations around the shark aggregation site (photo adapted from Shabtay et al., 2021). Red arrows mark the hot water outlet from the power station. The right photo shows the Hadera site. The top of the left photo shows the Hadera port and power station area; on the right is the beach.

for stakeholder compliance and resolving conflicts related to management reforms (Haggarty et al., 2016; Lester et al., 2017; Richardson et al., 2005; Sawchuk et al., 2015; Thomas et al., 2016). The responses we received indicated that enforcement efforts will be necessary to implement recreational fishing restrictions at the Hadera site. Additional research on these anglers' perspectives is necessary to enhance compliance, acknowledging that conservation involves managing people as much as managing species (Clark and Wallace, 2002; Mascia et al., 2003). Enforcement and education often go hand in hand in marine conservation, particularly for shark-watching tourism (Alder, 1996; Kanstinger et al., 2017; Richards et al., 2015).

To further enhance safety and minimize disturbances to sharks and recreationalists, we recommend enforcing the motorized sailing regulations as outlined in the Israeli Port Regulations (Navigation Safety, 1982), which mandate that motorized vessels remain at least 300 m from the shore. This measure will protect both marine life and human activity in the area. Additionally, we propose the installation of mooring buoys to enable motorized sailors to observe sharks from a safe distance. These mooring systems should be designed with reference to prior research on appropriate designs and sizes to ensure effectiveness and raise awareness (Martin et al., 2015; Venturini et al., 2021).

We suggest establishing a temporary zone dedicated exclusively to non-motorized sailing, which would be separated from areas designated for motorized sailing and shore-based shark-watching. This zoning would help reduce crowding and human presence around sharks in shallow waters.

As our zoning recommendations include areas for shore-based shark-watching practices, we note that the expert panel expressed uncertainty about the best approach to promote safe shark-watching practices. They considered options such as organizing snorkeling tours, limiting the number of people entering the water, or creating a buoy zone to mark a safe distance for watching sharks.

Wildlife watching is an educational experience that can promote conservation. When more aggressive species are involved, raising awareness of the inherent risks is part of the educational experience (Grossmark et al., 2024; Techera and Klein, 2013). We conclude that if relevant authorities intend to promote shark-watching, educational approaches within the framework of shark-watching conduct are desirable. Carlucci et al. (2021) argue that effective communication is crucial to preventing resentment and resistance toward regulations and limitations regarding cetacean conservation. Therefore, further research is needed to help managers make well-informed choices about outreach and education needs, as well as conservation actions.

Furthermore on shore-based practices, the case study site is not a designed swimming beach[1] and does not officially allow snorkeling. If the local authority decides to allow entrance within a safe distance, it will require a regulation change rather than a restriction. At the Hadera site, the panel did not consider that if water entrance is officially allowed during shark season, the local municipality would need to provide lifeguard services, which are currently unavailable. Moreover, activities would be extended beyond the local official swimming season, which runs from the end of March to mid-October. Managing water entry using near real-time data offers the advantage of actual shark presence. However, properly organizing beach services, such as hiring lifeguards and snorkel tour staff, excludes these uses from being managed dynamically and should be based on historical presence data. Additionally, authorities must consider measures to protect sharks from harassment, beyond voluntary measures such as adherence to guides' advice (Elias et al., 2016; Patroni et al., 2018).

Similarly, SCUBA diving also requires appropriate regulatory adjustments rather than spatial restrictions given its potential risks, particularly in the presence of sharks. The lack of supervision over SCUBA diving operations has led to an increase in informal operators and private users accessing the Hadera site where sharks aggregate. Regulating SCUBA dives through mandatory guided tours could limit access to selected nearby SCUBA diving centers licensed through a competitive process such as bidding or certification. This approach, as demonstrated in Lamb et al. (2014) and Techera and Klein (2013), helps reduce pressure on the site, enhance diver safety, and improve control over the SCUBA sector.

Panelists noted that the marine police enforcement in the area is currently inadequate. Fig. 4 suggests that further declarations or regulations are needed to effectively restrict SCUBA diving, and non-motorized sailing, and ensure proper shark-watching conduct. Presently, there is no overseeing enforcement body at the site (e.g., as shown in Fig. 3C depicting illegal motorized sports use). Conversely, some reports indicate that the municipality is attempting to enforce regulations beyond its jurisdiction, restricting non-motorized sports activities in the area. The panel considered enforcement topics since it included representatives from INPA, Hadera municipality, marine police, Hadera port, and the power station. The panel agreed that a joint body with representatives from all bodies could manage the area best.

A joint body of stakeholders and enforcement officers helps coordinate and improve the efficiency and quality of management operations by enabling communications, resource management, and information sharing, among different individuals, organizations, and jurisdictions (Coppola, 2020; Gissi et al., 2022). Clarifying authority, delineating jurisdictional limits, and ensuring effective coordination could significantly improve human-wildlife interaction at the Hadera site, thereby promoting conservation efforts.

Most panelists believe that INPA currently possesses the most relevant authority and knowledge. However, INPA lacks jurisdiction over

the site's users since it is not designated as and will not become an MPA. Additionally, the constraints faced by INPA officers stem from the laws they administer; clear evidence of harm to sharks is required for them to take action.[1 and 2] Stress or physical contact is not always clearly considered harmful, making enforcement challenging. This contrasts with approaches in Australia or the United States, where interfering with protected animals includes various human behaviors, including touching (Kanstinger et al., 2017; The American Endangered Species Act of 1973).

Panel members expressed the need for an independent scientific body, free from conflicts of interest, to study human-wildlife interactions on-site. The panelists recommended establishing such a body due to distrust toward the Society for the Protection of Nature in Israel (SPNI), a well-established NGO, and the INPA within these fields of expertise.

The SPNI recently published a study on human-shark management requirements at the Hadera site, proposing activity zoning and designated areas for sharks to retreat to (Shabtay et al., 2021). Lack of trust toward SPNI's recommendations arises from fishers' and scientists' side. The lack of trust of fishers originates from previous conflicts with SPNI, who oppose fishing, while the scientists' lack of trust in such a solution arose from the perception that SPNI presents a biased perspective supporting only their views. Similarly, some panel members have lost trust in INPA areas and charging entry fees. This may explain why the Hadera municipality gained support from the panel as the body in charge of enforcing proper in-water conduct. But this was objected to by the city itself, which did not want to take on more responsibilities. The panelists' suggestions indicate that users would be more receptive to restrictions if implemented and enforced by a neutral body representing all stakeholders.

According to Lewison et al. (2015), critical elements for the success of DOM include the existing regulatory framework, incentive structure, stakeholder participation, and technological and analytical capabilities. Applying these elements to the Hadera site indicates a need to adjust and adapt regulations, boost the incentive structure through education, and improve stakeholder engagement while the necessary technology exists and functions. Regarding regulation and incentives, the social acceptance of implementing restrictions in the Hadera site is expected to face significant resistance from recreational fishers.

While our study does capture the current state of the Hadera site, it is limited by the lack of a foundational framework for measuring pre- and post-management, impeding effective comparisons. Identifying measurable quantitative or qualitative indicators is crucial for assessing changes resulting from new management measures (Ehler and Douvere, 2009; Portman, 2016). The Delphi technique captures expert insights yet should not solely guide management plans. Respondents introduce subjectivity despite being transparently selected from a pool of experts with verifiable qualifications. Ideally, the number of fisher participants would match that of other pro-nature NGO participants, yet only two marine recreational fisher NGOs represented users on the Hadera site, compared to the three pro-nature NGOs, which were also more responsive to the questionnaire. The fishers who disagreed with exploring possible marine use restrictions were the most challenging participants to convince to participate. Despite limitations, the Delphi technique effectively led to converging expert opinions, as demonstrated in Table 2.

The adoption of more diverse ABMT, other than conventional MPAs, could effectively increase conservation efforts and meet commitments to international conventions such as the Convention on Biological Diversity. As of 2022, Israel has only protected 2.6% of its waters (INPA, 2022). Implementing ideas raised in this paper could contribute by assisting Israel in meeting its commitment to protecting 30% of its waters by the year 2030.

4.1. Policy recommendations

To summarize, we propose seven coastal management reforms based on all Delphi rounds. Some of these have spatial implications (1–4) and some (5–7) require non-spatial regulation changes.

1. Temporal closure of recreational fishing: Close recreational fishing during peak shark aggregation months near the hot water outlet, using real-time data.
2. Enforcement of motorized sailing regulations: Enforce the (Israeli Port Regulations (Navigation Safety, 1982), requiring motorized vessels to stay at least 300 m from shore, protecting both sharks and recreationalists.
3. Use of mooring buoys for motorized sailors: Install mooring buoys to help motorized sailors observe sharks from a safe set distance. Mooring should note previous research on specific designs and sizes of mooring buoys to raise proper awareness (Martin et al., 2015; Venturini et al., 2021).
4. Establishment of a temporal non-motorized sailing area zone: Create a temporary zone exclusively for non-motorized sailing, separating it from motorized sailing and snorkeling areas, to reduce crowding around the sharks in shallow waters.
5. Regulation change on SCUBA diving practices: Regulating SCUBA dives through mandatory guided tours to restrict access to nearby licensed centers, reduce pressure on the site, enhance diver safety, and improve control over the SCUBA sector.
6. Creation of a joint body with representatives of all stakeholders to manage the area.
7. Amend the Israeli Protected Natural Assets law to include harassment in addition to harm: An amendment will allow the INPA officers more authority to protect the sharks.

5. Conclusion

This study examines the interplay between recreational activities and the sharks at the Hadera seasonal aggregation site through the use of the consensus-building Delphi technique. While more commonly applied in commercial fisheries and shipping contexts (Dunn et al., 2016; Lewison et al., 2015; Maxwell et al., 2015), the idea that dynamic management could be effective in recreational areas represents a novel approach to planning and the management of the marine environment. Ever-growing technological advances enable tailoring restrictions to specific spatiotemporal needs to improve compliance. These technological advances could aid conflict mitigation in future marine plans and foster greater spatial compatibility, such as through dynamic ocean management.

CRediT authorship contribution statement

Shiri Zemah-Shamir: Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization. **Inbar Schwartz Belkin:** Writing – review & editing, Writing – original draft, Visualization, Validation, Formal analysis, Data curation. **Ziv Zemah-Shamir:** Writing – review & editing, Supervision, Conceptualization. **Michelle E. Portman:** Writing – review & editing, Supervision.

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.

[2] Declaration on National Parks, Nature Reserves, National Sites and Memorial Sites (Protected Natural Assets), Proclamation, 1998 and the 2019 update, Act no. 8302.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2024.107524.

Data availability

Data will be made available on request.

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