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Zoning design for cross-border marine protected areas: The Red Sea Marine Peace Park case study

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Abstract

In marine protected areas (MPAs), zoning schemes can help balance multiple resource uses. Literature on ocean zoning design methods points out the need for analytical tools that guarantee stakeholder involvement and that address the unique spatial characteristics of the sea, especially under multiple jurisdictions. I illustrate the use of a method of spatial multi-criteria analysis (MCA) that combines data of the land and ocean environment with stakeholder preferences to identify areas most suitable for varying levels of protective zoning. To solicit preferences, I apply social science survey techniques at an early stage in the process. I synthesize the resulting preferences with physical data using a geographical information system. This comprehensive approach addresses some of the challenges of designing zoning for a cross-border, multi-jurisdictional MPA such as varying levels of information between countries, limited cooperation between managers and scientists, differing statutory regimes, and difficulties bringing stakeholders together to solicit their opinions. As a case study, I developed a zoning proposal for the Red Sea Marine Peace Park (RSMPP), a proposed MPA to be jointly managed by Jordan and Israel in the northern Gulf of Aqaba.

1. Introduction

Marine protected areas (MPAs) now number in the thousands worldwide. These are sites in the ocean where legal or regulatory mechanisms limit or restrict human activities to protect natural, historic, or cultural resources (World Conservation Union definition). They have been established to counter varied and increasing threats such as overfishing, impacts to coral reefs, and ship strikes to marine mammals. To counteract threats, MPA

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managers commonly use spatially specific regulatory techniques such as complete and/or seasonal closures, equipment constraints, permits, and economic incentives/disincentives [1–3]. Usually part of a comprehensive management plan, zoning defines spatial objectives and accompanying restrictions in a format understandable to those who have a stake in protected area management and are on-going users of area resources.

Originally used for town planning, zoning has been applied to biosphere reserves, parklands, fisheries [4,5] and to MPAs [2,6,7]. MPA zoning schemes must contend with unique spatial characteristics of the marine environment and the public character of marine resources; most terrestrial zoning provisions regulate uses of private property [8]. Marine resources are largely mobile, dynamic and not conducive to clear boundaries [9,10]; the ocean and its treasures belong to the public domain making public interest and participation in management essential. This is particularly important and at times exceedingly difficult, in cross-border settings.

This paper reports on research that tests a method of multi-criteria analysis (MCA) as a model for MPA zoning design. The case study, the Red Sea Marine Peace Park (RSMPP), is a bi-national MPA proposed to protect an ecosystem characterized by dense development, conflicting user demands, and diverse stakeholder groups in a multi-jurisdictional context.

2. MPAs, Zoning, and Multi-criteria Aanlysis

A preliminary review of literature on MPAs reveals a consistent focus on the importance of incorporating the human element in reserve design and difficulty dealing with the spatial characteristics of the sea. Marine resources are usually part of the public domain. In many places, they have long been open access resources. Therefore, it is not surprising that the feasibility and success of an MPA is often dependent on public support and community involvement [11–15]. Both empirical and theoretical research on MPAs finds stakeholder involvement and community participation in design to be an essential element of MPA success [13,16–18].

Public involvement in zoning design alone is not enough to ensure that MPAs succeed. Zoning design should integrate ecological, socio-economic, and institutional concerns. Ecosystems are regional in nature and frequently straddle political borders. This results in different statutory conditions, governing entities, and regulatory frameworks between countries. The level of scientific information available on physical attributes of the ecosystem may also vary. There has been very little research on the design and management of cross-border protected areas and virtually none focusing on the application of spatial planning methods under these conditions.

Within the past decade, researchers have illustrated the use of MCA as a method that can integrate disparate socio-economic and institutional concerns for MPA zoning design [19,20]. Beginning in the late 1960s, planners and policy makers began using MCA to analyze conflicts between policy objectives. In the 1980s, MCA became one of the most powerful methodologies in optimization analysis [21]. Adding a spatial component using geographic information system (GIS) technology, Villa et al. [22] uses MCA to combine heterogeneous data on the physical environment with stakeholder preferences to design a city park. Later he adapts the method to design a zoning scheme for an MPA in Italy [19]. Without incorporating a spatial component, Brown et al. [23] uses MCA to explore different management options for an MPA in Tobago, West Indies.

Generally, MCA consists of the following major components: criteria, criterion priorities (or weights), and concordance scores. Concordance scores reflect the degree to which an area meets certain physical criteria and matches stakeholder preferences. Planners compute scores by combining physical attribute data of an area with priority weights. For analyses that include a spatial component—such as zones indicating different levels of protection—different sets of preferences (weights) are determined for any number of zoning alternatives [21]. The final product of a spatial MCA is a map or series of maps that show the degree to which a spatial unit meets the stated goals or planning objectives that represent user preferences.

To implement spatial planning models, including MCA, researchers frequently use GISs [19,23–26]. Today most GIS software applications facilitate presentation of alternatives, integration of various data types, and incorporation of new information as design processes progress including input from the public and variable socio-economic data.

3. Spatial MCA for the RSMPP

3.1. Study area: the Northern Gulf of Aqaba/Eilat

The Gulf of Aqaba is a semi-enclosed sea that makes up the northernmost basin of the Red Sea—a long, narrow ocean separating the African continent from Asia.[1] In past decades, the Red Sea has been known for its outstanding corals, home to hundreds of varieties of fish and other marine life, many of them unique to the region. These spectacular reefs represent the northernmost latitude for coral reefs in the western Indo-Pacific region [27]. But, today the reefs, like most coral worldwide, are showing signs of degradation. The Gulf's corals are particularly threatened due to their isolation from oceanic processes of flushing and circulation [28], but also due to pressures from tourism, fishing (including aquaculture), and extensive landside development on the shores of the Gulf's bordering countries: Israel, Jordan, Saudi Arabia and Egypt.

Bounded in the south by the relatively shallow Straits of Tiran (approximately 250 m deep), the Gulf of Aqaba has maximal depths of up to 1830 m. While much of the 180 km long Gulf is unusually deep, averaging around 650 m, its northern half contains a relatively shallow shelf that is adjacent to the major population centers of Eilat, Israel and Aqaba, Jordan [28]. The two cities are important industrial and tourist centers and major ports, especially Aqaba which is Jordan's only outlet to the sea.

The greatest athropogenic impacts to the area of RSMPP situated between Israel and Jordan are concentrated in the northernmost part of the Gulf, although tourist developments are rapidly being planned and constructed in several areas southward. Tourism and port related industrial and military uses dominate the approximately 7-km long Israeli shoreline. The 27-km Jordanian shoreline is currently undergoing extensive development for tourism while other parts of the Jordanian coast are used for intensive marine industrial activities, utilities, and infrastructure.

Aqaba and Eilat have populations of roughly 55,000 and 86,000, respectively. The former is much larger with an area of 375 km^2 compared to Eilat's 112 km^2 [29,30].

[1]The northern part of the Red Sea is split by the Sinai peninsula into the Gulf of Suez in the west and the Gulf of Aqaba/Eilat off the Sinai's eastern shores.

Populations of both cities have skyrocketed in recent years. The growth rate of the Aqaba governorate region has been around 5.7% annually for the last decade [31]. Eilat grew by approximately 6.4% annually during that same period. The population of Aqaba is expected to rise to an estimated 300,000 by the year 2020 [32]. Rapid population growth, physical development, and increased reliance on a tourism-based economy that seasonally brings many more people to the region, has resulted in severe stress on the Gulf's fragile coral ecosystem. There is evidence of decline in marine resources, the very components upon which most development plans and policies depend.

3.2. The Red Sea Marine Peace Park

The RSMPP is an outcome of the peace accord signed between Jordan and Israel in 1994. Its main objectives are to protect the two countries' shared marine resources while fostering peace and coordination [33]. Designed following a US-led workshop held in Aqaba in 1996, the RSMPP project consists of two main components: (1) creation of a coordinated management and educational outreach program; and (2) development of a collaborative, long-term monitoring and research program [34]. The project has reached its primary objective of initiating a cooperative research and monitoring program that addresses pressing environmental concerns and development issues in the RSMPP area. But other hoped for goals, particularly the creation of the bi-national RSMPP, remain elusive, most likely a victim of political tensions in the region.

The proposed park area is contained between the shores of the adjacent towns of Eilat and Aqaba in the northernmost stretch of the Gulf of Aqaba. The Gulf reaches a maximum width of about 26 km, however the area of the RSMPP stretches only about 10.5 km across at its widest point and narrows to about 5 km across at its northern end [27] encompassing approximately 70 km^2 (Fig. 1). The two countries are motivated to work together despite political division because it is clear that without environmental controls and proper management, the region could rapidly become a degraded "sink" for pollutants, virtually a dead zone, in which case opportunities for tourism, recreation, and conservation of unique resources will be lost [33].

The RSMPP program has involved the following institutions: Israel's Nature and National Parks Protection Authority (NNPA) and the Inter-University Institute; Jordan's Aqaba Special Economic Zone Authority and Marine Science Station; and the US National Oceanic and Atmospheric Administration (NOAA) and the Agency for International Development (USAID). The Middle East Regional Cooperation Program of USAID provided most of the funding together with in-kind contributions from Israel and Jordan. The Jordan Global Environmental Facility sponsored by the World Bank provided additional funds while NOAA headed up overall coordination of the project [34].

The most significant part of the RSMPP program has been a monitoring and joint research program led by various public agency officials and marine scientists of Israel, Jordan and the US. A major milestone for the program was the publication of the RSMPP Cooperative Research Monitoring and Management Program's final report in 2003. The report presents summaries of joint team accomplishments; it contains data from monitoring of coral reef fish, circulation patterns, zooplankton, biogeochemical dynamics, reef metabolism, and coral reef mapping [35].

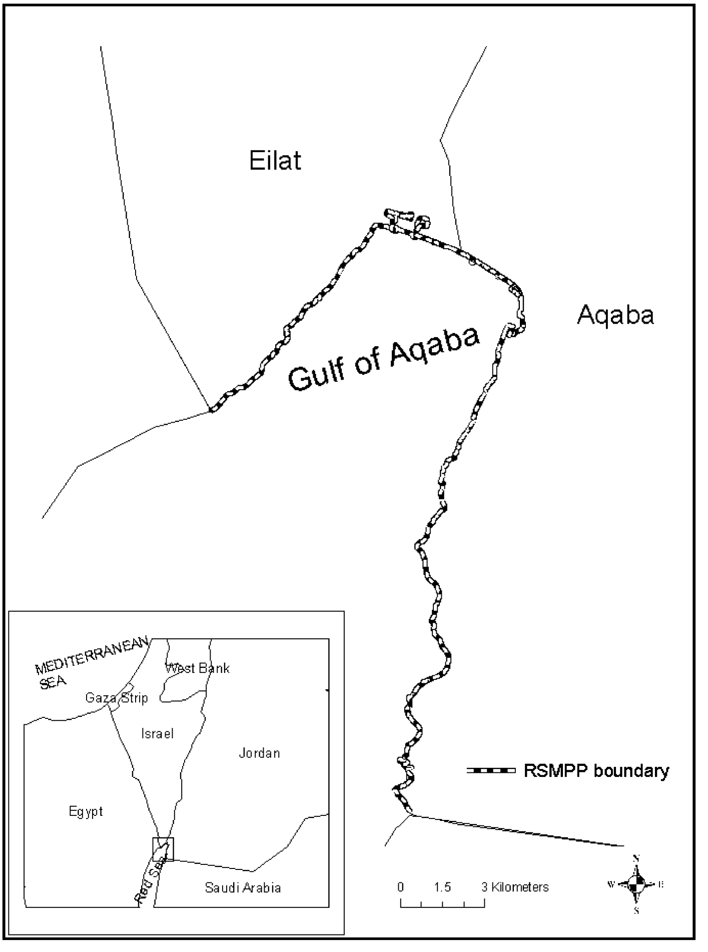

Fig. 1. Locus map of the Red Sea Marine Peace Park.

3.3. *Defining zoning scenarios*

As suggested by Brown et al. [23], I used zoning options that represent realistic possibilities for local stakeholders. I based the three levels of protection used for this study on conservation zones that exist in Israeli and Jordanian regulations, and on literature that addresses zoning for marine conservation [1,19,22,36].

There are currently two levels of protection used on the Jordanian side of the Gulf: (1) the marine reserve designated as a "no take, limited entry" area, and (2) the general marine park area which is known to be a sensitive area but has few restrictions [37,38]. The Israel National Plan for Nature Reserves (NMP 8) stipulates three categories of protected areas with decreasing restrictions: (1) nature reserves, (2) national parks, and (3) scenic (landscape) reserves [39].

The three levels of protection I adopted for this study are the following: Fully Protected Marine Nature Reserve, Marine Seascape Reserve and Marine Park. A brief description of these levels was presented to the stakeholders before they expressed their preferences for attributes (see below). The descriptions were brief and avoided suggestions of any specific regulatory details that might influence survey participants' answers. The main point was to clarify that stakeholders should consider high, medium, and low levels of ecosystem protection for each zoning alternative. In general, stakeholders can consider any number of zoning scenarios using the method.

3.4. Defining criteria of the RSMPP

Criteria are attributes that characterize the environment. Multi-criteria analyses use "high-level" criteria that consist of "low-level" criteria (or sub-criteria) of similar types that are grouped together. Criteria values can be expressed in a quantitative form (real numbers or integers) or qualitative form (e.g., by means of verbal scales or signs). Standardization, or scaling, that conveys only the order of dominance, as opposed to actual measurements, facilitates the use of different types of criteria together. This is convenient in many real-world cases.

I chose four high-level criteria indicative of the physical environment of the park and representative of activities and uses, some existing (e.g., dive sites) and some planned (e.g., proposed land uses). The chosen criteria relate to national and local development aspirations as well as to environmental conservation but they do not describe the entire system under consideration and are not, therefore, an attempt to develop a comprehensive ecosystem model. Rather they are usable, widely understood, and available indicators of important aspects of the overall picture of the environmental and socio-economic functions of the area. The final selection of sub-criteria was limited by availability of data and influenced by financial and time constraints. Jordanian and Israeli data had to be comparable which resulted in some further limitations (Table 1).

3.4.1. Natural marine values (NMV)

Natural marine values include the sub-criteria: biodiversity, water quality and coral reefs/coral health. Ordinal qualitative rankings from one to three were assigned spatially according the total range of quantitative measurements. A low rank (i.e., one) means that the sample site showed low quality in relation to the other sites sampled for that physical attribute. I use the inverse distance weighting (IDW) function of ArcGIS 9.0 Spatial Analyst to create a continuous surface from the data for sampled sites. For only one natural marine value sub-criteria, the location of coral reefs, I designated highly sensitive core areas and secondary buffer areas.

I use nitrate and chlorophyll *a*[2] as biochemical water quality indicators. Nitrate is an indicator of excess nutrient accumulation in marine ecosystems from point and non-point sources [40,41]. Increased nutrient loading causing eutrophication that degrades coral ecosystems has been well documented in numerous settings [20,42], including the Red Sea [43]. Chlorophyll *a* concentrations in free-floating microscopic aquatic plants are used to measure the abundance and variety of algae. Excessive nutrients can stimulate harmful algae blooms, resulting in reduced water clarity, food supply imbalances, and depleted

[2]Chlorophyll is the pigment that allows plants (including algae) to convert sunlight to organic compounds (photosynthesis). Chlorophyll *a* is the predominant type of algae and measuring chlorophyll *a* concentrations in water is a surrogate for actual measurement of algae blooms.

Table 1
Criteria for pairwise comparisons of the three zoning scenarios

High-level criteria	Sub-criteria	Measure/basis of calculation	Sources of data
Natural marine values (NMV)	Water quality	Nitrate	RSMPP Report (2003)
		Chlorophyll-*a*	RSMPP Report (2003)
	Biodiversity	Zooplankton	RSMPP Report (2003)
	Coral reefs/coral reef health	% coral recruitment	RSMPP Report (2003)
		% live coral cover	RSMPP Report (2003)
		Coral reef location and buffer zones	Hebrew university/IUI GIS shape file
Commercial values (CV)	Aquaculture sites	Site location and buffers	Key informant interviews
	Tour boat lanes	Lane locations and buffers	Key informant interviews
Water sport and recreational values (WSRV)	Dive sites	Sites and buffer zones	Dive maps; informant interviews; Jordanian Royal Ecological Diving Society
	Recreational access points	Distance from recreational access landuses[a]	National Coastal Masterplan, NMP 13-Gulf of Eilat Beaches; Aqaba Land Use Plan; Draft Instructions for General Zoning of the Aqaba Special Economic Zone
Land use values (LUV)	Proposed land uses	Estimated % of impervious surface	National Coastal Masterplan, NMP 13-Gulf of Eilat Beaches; Aqaba Land Use Plan; Draft Instructions for General Zoning of the Aqaba Special Economic Zone

[a]The top-ranked recreational access areas in Jordan are: buffer/open space/recreational, resort tourism, rural tourism. In Israel: existing or future bathing beaches, and marinas.

oxygen levels. Water quality impairments caused by algae are site-specific so that appropriate chlorophyll *a* levels vary [44]. The northern Red Sea is naturally an oligotrophic,[3] nutrient-poor body of water characterized by low phytoplankton biomass [45]. Higher chlorophyll *a* levels indicate greater influx of nutrients from anthropogenic sources. For both of these indicators, nitrate and chlorophyll *a*, the lower values indicate higher quality rankings.

I calculated annual averages for 10 sites from nitrate and chlorophyll *a* samples collected in January and June 2002. The Gulf of Aqaba is characterized by seasonal, vertical thermal stratification that develops in early summer when the upper surface layers become depleted of nutrients. In winter, due to the cooling of the upper layers, the thermocline erodes and there is a mixing of the Gulf's water [45]. Since there is such high seasonal variation an average of a winter and a summer month are sufficiently representative [46].

Zooplankton is a sensitive and frequently used indicator of the state of marine ecosystems and biodiversity [47–49]. Its biomass depends on the abundance and growth

[3]A waterbody with low productivity, deficient in plant nutrients, rich in oxygen throughout its depth and with good water clarity.

rate of both its prey (mostly phytoplankton) and predators (mostly large zooplankton and fish). Researchers suggest that sites with greater zooplankton biomass are also those with abundance of zooplanktivorous fishes, a sign of greater biodiversity [47]. Also, zooplankton generation times are short enough that they quickly respond to acute stress but long enough for them to integrate the effects of chronic problems, making them a good indicator of ecosystem health [48]. The clarity of the water column, a critical factor for coral growth and survival may depend on zooplankton grazing; zooplankton may have a major role in dispersing and "diluting" the spatial effects of eutrophication [47].

The zooplankton monitoring data used in this study consists of bi-monthly samples collected at nine monitoring stations between February and December of 2002. I used annual averages of total zooplankton dry weight in milligrams per cubic meter. Data indicate that the distribution of zooplankton biomass across the sampled region was fairly homogenous with temporal changes usually occurring to a similar degree at most locations. Overall, slightly higher biomass along the eastern side of the Gulf was correlated with higher rate of coral recruitment along the Aqaba reefs compared with those in Eilat [47].

I used two main parameters to rank coral reef attributes: reef location and indicators of coral reef health. Most of the reefs are located away from the northernmost stretch of the Gulf that consists mostly of alluvial sands that have washed into the Gulf from the Arava Valley. Marine scientists have suggested several parameters as indicators of the state of health of coral communities, particularly, the ratio between living and dead corals, indicators of the recruitment rate of corals to reefs, and measures of live coral cover on reefs [50]. The latter two are commonly used and have been applied widely to document the degradation of coral reefs worldwide [51,52], including in the Gulf of Aqaba [50,53,54]. Monitoring programs of coral reefs have traditionally quantified temporal change in benthic cover with high and/or increasing coral cover regarded as indicative of a healthy reef [55].

For stony coral cover, RSMPP monitoring program researchers marked transects parallel to the shore at the various sites, and then surveyed them over a period of 3 years. The percent of major space-occupiers (live stony corals, dead coral, macroalgae, sponges, sea anemones, soft corals, and sand) was recorded at 5 and 15 m depth. Also, the recruitment of very young corals on ceramic tiles was measured. Data show that the live cover and recruitment rate of stony coral are generally higher on reefs in Jordan (southern area) than in Israel. As expected, coral recruitment to ceramic tiles is higher near reefs with high percent coral cover and low near sites with low coral cover [56].

Coral reef locations and surrounding buffer areas qualify the last natural marine value sub-criteria. Generating spatial buffers at pre-determined distances is a frequently used function of GIS. Despite their wide usage for ecosystem protection, it is difficult to find information recommending specific buffer size or scale. ReefGuardian International, an NGO dedicated to the worldwide protection of coral reefs, recommends the establishment of 600 ft (183 m) wide buffer zones in the vicinity of coral reefs to prevent damage to reefs in the Florida Keys from dredging activities [57]. Another example is a similar 200 yd (183-m) marine buffer zone recommended by the US Fish and Wildlife Service around each of the 83 refuge sites that make up the San Juan Islands National Wildlife Refuge. The USFWS maintain these near-shore buffer zones to help minimize disturbances to birds, marine mammals, and endangered species [58]. For this study, areas within 200 m of the outer contour of the reefs (as identified in the GIS coverage layer showing coral reef locations) are the highest ranked "core" areas and areas at distances of 200 to 400 m away are given a medium rank. All other areas received the lowest rank for this attribute.

3.4.2. Commercial values (CV)

Highly valued commercial areas are those supporting business related activities. I used two activities with defined spatial characteristics: fishing and boat touring. Commercial shipping lanes, would ideally be included, however shipping lane information in both countries is restricted due to security concerns. I collected information from primary sources: fisherman, personal field observation, tour guides, and boat operators who indicated the launch points, destinations, and routes they most frequently use.

Fishing activity is decreasing throughout the RSMPP, especially at near-shore sites where fish populations are impacted by anthropogenic activities. The prominent uses of the area—commercial development, tourism, industry—are at odds with most fishing that requires undisturbed waters and some isolation. There are basically three types of fishing activities: artisanal/commercial fishing, recreational fishing conducted by divers and amateur line fisherman from boats and from shore, and aquaculture.

Artisanal fishing has decreased rapidly over the past two decades. Within the artisanal sector, local fishermen individually own and operate their vessels. There are no large commercial fisheries. In Jordan, there are no significant fish processing capabilities and in Israel, fish processing is done in conjunction with the large marine and terrestrial aquaculture operations. The artisanal fishing industry in Aqaba is small and decreasing. It consisted of only approximately 85 fisherman and 40 boats in 1995 when the total marketable catch was an estimated 15 tons. This represented a significant drop from the 1993 catch of 105 tons [59].

The number of artisanal fisherman in Eilat—reportedly only two that own more than one boat, fish on a regular basis, and market their catch—makes for negligible landings. Also, their preference for sites varies according to temporal conditions. I therefore assume that the high-valued fishing area is the site used for aquaculture. The large off-shore aquaculture operation run by two Israeli companies is highly controversial because of suspected environmental impacts but also because it is an unauthorized use of the public domain. Many environmental advocacy groups, marine scientists, and planners object to the massive fish cages that produce about 21,000 tons of fish annually.[4] High-level policymaking entities have intervened including the Israeli parliament (Knesset) that made a preliminary decision in May, 2005 ordering staged removal of the cages. I use their current location as an aquaculture site because it appears geographical suited to such operations.[5] Also a number of local stakeholders expressed doubt as to whether all the cages will actually be removed as ordered.

The two main fishing sites, that of artisanal fishermen in Jordan and that of the aquaculture operations, are the most highly valued sites for commercial fishing activities. The actual sites are "core" areas, similar to areas I used for sensitive resource locations such as coral reefs. Similarly, buffer areas surround the core areas at distances from 200–400 m and the lowest value areas are those farther than 400 m from the outer contour of the fishing sites.

[4]The cages are concentrated about 700 m from the shore, where depths are approximately 40–45 m. They hang about 11 m under surface rafts to which they are tied [60].

[5]Because of proximity to the landside fish farms company headquarters in the Arava Valley, the alluvial sand seabed and the absence of natural corals along all of the north beach.

Every year thousands of tourists take boat tours that sail along the shore of both Aqaba and Eilat from north to south. On these trips, participants view the shorelines, get a sense of activities along the coast and can experience the area's most spectacular coral reefs on glass bottom boats or by snorkeling around an anchored tour boat. In both countries, boats leave from the marinas close to the northern beaches where the most intense tourist activity occurs and the hotels are concentrated. Assuming that these routes make up the most highly values areas of the RSMPP for this type of commercial activity, I assigned the highest rankings to the boat routes themselves, designated spatially in GIS as polygons. As for fishing and aquaculture sites, I applied a medium ranked 200–400 m buffer around the lanes. To areas not within the lanes or in their "buffer" areas, I gave the lowest rank.

3.4.3. Water sport and recreational values (WSRV)

Water sports and recreational values consist of two sub-criteria: dive sites and recreational access. Dive sites are difficult to distinguish from commercial values because there are significant business opportunities related to the sport of scuba diving, especially on the Jordanian side of the RSMPP. In Jordan, diving is highly regulated and certified "divemasters" employed through the various dive shops and clubs must accompany scuba divers. But snorkelers use the sites as well and they can be more independent. I determined the level of recreational access based on the shoreline activities proposed in the master plans for Aqaba and Eilat.

The northern Gulf of Aqaba is touted as having some of the finest snorkeling and diving in the world boasting beautiful corals, interesting marine life, and comfortable conditions year-round. The sea water is usually calm with temperatures varying between 19/20 °C in winter months to 26 °C in summer. Most of the dive sites are located close to the shore and include both natural coral sites and areas that have artificial, man-made elements such as sunken ships, submerged artifacts, artificially planted corals, and unique geological features [61–65].

There are 18 dive sites on the Jordanian side, mostly located between the northern border of the Aqaba marine reserve and the Saudi border, and accessible without boats. The 11 sites on the Israeli side are dispersed along the entire shoreline, many within swimming distance from the coast. I use a 200 m buffer around a 200 m core dive site area. I ranked core areas highest. These are areas within 200 m of a point taken from the maps indicating the dive site. I ranked areas 200–400 m with a middle value and to all other areas of the RSMPP, those 400 m and more from dive site points, I assigned a low rank.

The sub-criteria "recreational access" indicates estimated accessibility for all types of marine sports and recreation along the shoreline: windsurfing, recreational boating, swimming, snorkeling, sailing, and kayaking. To determine access levels, I considered proposed land uses that border the shoreline and those landward up to 250 m from the shore based on masterplans.[6] Since the determination of accessibility includes many "non-motorized" activities, I assume that accessibility affects the RSMPP area for about 1 km out to sea. Any overlapping areas take the higher value. I adopt this lenient approach because landside access can facilitate further seaward lateral access.

[6]The National Coastal Masterplan (NMP 13) Gulf of Eilat Beaches and the draft Instructions for General Zoning of the Aqaba Special Economic Zone.

The highest ranked areas are those expected to provide the best and most diverse level of recreational access. Bathing beaches, municipal marinas (Israel), buffer/open space/recreational land uses, resort tourism, and rural tourism areas (Jordan), are high-ranking areas. I assigned a middle ranking to those areas adjacent to uses that have the potential to offer recreation but whose objective is not recreation or water sports. Existing and proposed nature reserves make up this category including upland and submerged areas (respectively, beach and marine reserves) slated for protection. Finally, I determine all other areas along the coast and areas farther than 1 km out to sea to be low ranking recreational access areas. These include sites slated for commercial and retail use, a "special use" area in Jordan known to be King Abdullah's closed compound, mixed uses including private residences, time-share condos, and areas reserved for port, infrastructure and industrial projects [30,66].

3.4.4. Land use values

The land/sea interface is intensely integrated. Land uses established on the shores of the park will undoubtedly affect marine zoning design, especially along the densely developed coast and relatively small and enclosed RSMPP. Therefore, the question of how to qualify adjacent land uses is an important one.

I ranked land uses according to compatibility with seaside conservation and the potential for non-point source pollution impacts to marine resources (Table 2). I gave a high rank to landside uses that preserve open space. Such "compatible" land uses include areas proposed as beach reserves, open space, public parks, etc. I also ranked land uses according the amount of impervious surface area expected for that type of land use giving higher rates a lower rank.

Impervious surface coverage is a quantifiable land-use indicator that correlates closely with pollution runoff [67–70]. Impervious surfaces greatly increase natural transporting mechanisms such as rainwater and wind, thus contributing to non-point source pollution that severely impacts watershed resources. The watersheds surrounding the RSMPP are both steep and arid. The ability of the soil to absorb water is poor, so that during a rain event transport is especially rapid from landside to adjacent marine areas [71].

The percentage of land covered by impervious surface varies significantly with land use. Most of the studies conducted relating percentage of impervious surface areas to non-point source pollution in waterways have focused on streams and estuaries in temperate climates [67,70,72]. All aspects of these models may not translate directly to steep watersheds in arid climates such as that of Eilat and Aqaba. Furthermore, land uses described in these studies are not detailed; rather land uses are lumped together in general categories not completely consistent with the land uses contained in the masterplans for the two Gulf cities.

Nevertheless, Arnold and Gibbons [68] estimate that "strip" type commercial development has the highest rate of impervious surface coverage at about 95% with other business areas and industrial development lagging slightly behind. For residential areas there is a wide range of imperviousness that varies predictably with lot size, going from about 20% in one-acre zoning to as high as 65% in one-eighth acre zoning. Massachusetts Coastal Zone Management (CZM) has made recent estimates of impervious surface cover for more detailed types of land uses. By carefully tracing impervious features from aerial photography using GIS for a number of watersheds, CZM generates mean impervious area ratios (coefficients). The coefficients relevant for this study are those for open land (3%), commercial (64%), industrial (54%), urban open (31%),

Table 2
Rankings for landuses of the Aqaba Masterplan and the National Masterplan for Eilat Coast based on estimated percentages of impervious surface coverage and compatibility to conservation

	>60% imperviousness (commercial)	20–60% imperviousness (industrial/ residential)	Open space: <20% imperviousness
Rank	1	2	3
Aqaba land uses	Special use	Residential	Buffer, open space, recreational[a]
	Urban tourism	Government, community services	Historical/archaelogical
	Commercial/retail	Industrial—light	Wilderness reserve
	Mixed use	Industrial—heavy	
	Reserved for development	Port/airport/rail facility	
		Utilities	
		Institutional	
		Resort tourism[a]	
Eilat land uses	Urban area	Filled special port area	Bathing beach[a]
	Hotel area	Suburban tourism	Mechanical structures—future bathing beach[a]
	Commercial retail	Rural tourism	Mechanical structures—future beach reserve
	Municipal marina[a]	Filled port area	Open landscape area
	Port uses—future urban tourism	Special port	Nature reserve
	Lagoon	Port	Beach reserve
	Mechanical structures–future urban tourism	Utilities corridor	Special open space
		Airport—future green strip	Bathing, sport, boating[a]
			Marine nature reserve
			Marina—future bathing, sport, boating area[a]
			Marina—future marine nature reserve
			Public open space
			Public institutions area

[a]Recreational access land uses considered under water sports and recreational values as high value areas.

transportation (50%), participation recreation (6%), and water based recreation (34%). Residential use ranges from 39% to 54% imperviousness depending on lot size [73].

Although the topography and desert climate of the Gulf of Aqaba is significantly different than that of the areas surveyed for the estimates of imperviousness in Massachusetts, conceptually these estimates should still apply. First of all, they are based on careful tracing of impervious features from aerial photography of varied coastal watersheds throughout the state. Features of land uses, such as asphalt surface, are most likely specific to the type of land use and not to the geographic region. Secondly, similarities between coastal areas of Massachusetts and those of the case study area do exist, namely, both regions have significant portions of their coastal watersheds dedicated to maritime industrial uses (i.e., ports), transportation infrastructure, and commercial activities.

I adopted estimated percentages of land covered by impervious surface for two general categories of urban land uses from the literature: commercial and industrial/residential. I used a third category, open space, for those land uses most compatible with marine conservation (such as beach reserves, open space, public parks) and I assumed that this category would have the least amount of impervious surface area (i.e., less than 20%). Only those land uses that were within 250 m of the shoreline were considered and the ranking was conservative in that areas that ended up with overlapping values or bordered within 50 m on cells of lower value, took on the lower values. I also assumed that land uses would influence areas only up to 2 km seaward from the shore.

4. Stakeholder preferences

This model uses a questionnaire to solicit stakeholder preferences by comparing criteria, two at a time, based on a method developed by Saaty [74]. The questionnaire is easily replicable and can be widely administered to many stakeholders even when contact between them is limited.

Stakeholders express preferences by comparing pairs of high-level criteria under each zoning scenario. Preferences are indicated for one high-level criteria over another (for example, recreational values over natural values) on a scale of zero to nine [74]. Rankings are then listed in a "priorities matrix" [21]. A relative weight is derived for each high-level criteria under each zoning scenario by calculating the eigenvector associated with the greatest eigenvalue of each priorities matrix. The associated eigenvector provides a weight ($\boldsymbol{w}$) for each high-level criterion. Advantages to this weighting method are that stakeholders easily articulate their preferences and do not know how their expressed preferences will influence outcomes [19,21,22,75].

I administered a four-page questionnaire available in English, Hebrew, and Arabic, to 27 stakeholders (Table 3). The questionnaire, consisting of 18 questions, surveyed preferences for one attribute type over another. I asked six questions regarding each of the three zoning scenarios. An introduction to the questionnaire briefly explained the research project and described each attribute category and protection level (i.e., the zoning scenarios).

I converted the responses to matrix values of 9, 4.5, 1, 0.111111 or 0.222222 (Table 4). Nine signified the highest value of one attribute category over another. As an example, a score of nine indicates that the stakeholder believes that the first set of values are much more important than the second set of values in determining which are as should be

Table 3
Questionnaire administered categorized by stakeholder group and nationality

Stakeholders	EGAs[a]	NGOs[b]	Local planners	Fishers	Marine scientists	Business managers	Total
Israeli	2	3	2	2	4	2	15
Jordanian	1	3	2	1	3	2	12
Total	3	6	4	3	7	4	27

[a]Environmental government agencies.
[b]Environmental non-governmental organizations.

Table 4
High-level criteria comparison scores obtained from questionnaire answers

Level of importance	Score
Much more	9
Slightly more	4.5
Neutral (equal)	1
Slightly less	1/4.5
Much less	1/9

designated for a particular protection level. A score of 4.5 means that a criterion is slightly more important than the criterion it is compared to.

Saaty [74] bases justification for the use of scores between zero and nine on psychological experiments that show that an individual cannot simultaneously compare more than seven objects (plus or minus two) without becoming confused. Therefore, preferences are limited to 7 ± 2 rankings. Villa et al. [19], implementing Saaty's method, uses seven values between zero and nine to depict varying degrees of preference. In developing the questionnaire for this study, I offered only five scoring options to keep questions more succinct and convenient for the survey respondent.

I obtained a matrix for each set of six questions. Table 5 lists the averaged weights extracted from the completed questionnaires using the matrices' highest eigenvalue and associated eigenvector as previously described. These weights $\boldsymbol{w}$, from among $0 < \boldsymbol{w} < 1$, show the relative importance survey respondents give to each attribute $\boldsymbol{k}$ for determining conservation zoning within the RSMPP. These are average weights for each stakeholder group under each of the three zoning scenarios.

The numbers in Table 5 indicate what attributes are most important to the different stakeholder groups when considering how to zone areas of the RSMPP. Of special interest are comparisons between stakeholder groups. Stakeholders that work on conservation and environmental protection in some capacity (environmental government agency officials, environmental NGOs, marine scientists) agree that NMV is consistently the most important attribute category in all three of the zones. To a lesser extent that is also true of local planners but in the two less protected zones the importance of NMV is less distinct (e.g., 0.76 for NMV compared to 0.40 for WSRV). Fishers and business managers do not consider NMVs to be as important as do the other stakeholders even under the highest protection scenario (roughly 0.6 compared to 0.9, respectively). In fact, under the lower two protection levels, fishers and business managers consider NMVs less important than other attribute categories.

The weights extracted coincide with what one would expect from such participants suggesting that the survey instrument is a valid one. For example, one would expect that representatives of environmental NGOs would value NMVs over other attributes in determining areas most suitable for protection. Fishers and business managers would be expected to give higher preference to CVs than would other stakeholder groups.

5. Bringing it all together: concordance scores

I created one coverage layer (GIS grid) for each of the higher-level criteria using ArcGIS 9.0 spatial analysis module for most of the operations. Coverage layers consist of a large

Table 5
Average weights (*w*) that indicate preferences by stakeholder group for each high-level criterion (attribute category)

Zone	Fully protected marine											
	Reserve				Marine Seascape Reserve				Marine Park			
Attributes	NMV	CV	WSRV	LUV	NMV	CV	WSRV	LUV	NMV	CV	WSRV	LUV
EGAs[a]	0.9006	0.1020	0.1235	0.3274	0.7609	0.2277	0.3649	0.3305	0.8008	0.0954	0.3673	0.3556
ENGOs[b]	0.9613	0.0991	0.1871	0.1400	0.9321	0.1547	0.2079	0.1670	0.6844	0.1716	0.4451	0.2542
Local planners	0.9021	0.0999	0.2879	0.1442	0.7602	0.1271	0.3644	0.3939	0.7619	0.2297	0.4096	0.2683
Fishers	0.6057	0.2862	0.4936	0.1682	0.5378	0.5474	0.4373	0.1787	0.1527	0.7418	0.4158	0.3788
Marine scientists	0.9308	0.1906	0.0937	0.2559	0.8241	0.3375	0.1770	0.2789	0.8232	0.2083	0.2667	0.3805
Business managers	0.6621	0.1806	0.2482	0.4575	0.2457	0.4912	0.5744	0.4916	0.0996	0.4727	0.6752	0.4196
All groups	0.8271	0.1597	0.2390	0.2489	0.6768	0.3143	0.3543	0.3068	0.5538	0.3199	0.4300	0.3429

[a]Environmental government agencies
[b]Environmental non-governmental agencies

set of 100-m grid cells generated by the GIS application; these cells form the basic spatial unit for analysis. The cells in each of the coverage layers have values that indicate qualities of that geographic location on a scale of one to three. I generated these values by averaging the rankings of the lower-level criteria that make up the higher-level criteria.

For the first step in determining concordance scores, every cell is compared to every other cell in the spatial plane. For example, if the first cell is e_{11} , it is compared in turn to cells $e_{12}, e_{13}, e_{14}\ldots$ and so on until it has been compared to all the other cells of that higher-level criteria coverage layer. Comparisons result in values of 1, -1, or 0, depending on whether cell e_{11} is greater, less than, or equal to the cell it is being compared to. Values resulting from each comparison accumulate to cell e_{ij} so that its value indicates its relation (i.e., relative superiority or inferiority) to all other cells. I used a Visual Basic script to perform this step and ran the program on each of the four grids.

The next step consists of multiplying the resulting cell values in each grid by the stakeholder weights determined under each zoning scenario. The last step generates scores for the cells by combining all four resulting layers (Fig. 2). The use of ArcMap module of ArcGIS 9.0 allows various presentation options. Fig. 2 maps show cells grouped by concordance score values into four classes of equal interval from among the full range of possible values. Classification in four classes, as opposed to a stretched gradient, is visually easier to understand. The maps can easily be color-coded for greater clarity.

6. Results

Fig. 3 shows an overall zoning proposal for the RSMPP based on the results from Fig. 2. Because the Marine Seascape scenario and the Marine Park scenario maps are similar, the overlay map uses only the Fully Protected Marine Reserve and the Marine Seascape Reserve.

Fig. 2 shows that the most suitable areas under all three zoning scenarios are similar. This is likely a result of the lack of substantial difference in preferences for one higher-level criteria over others (refer to Table 5). Greater differences are apparent between the Fully Protected Marine Reserve map and the other two scenarios. Weights are most alike between the Seascape Reserve and Marine Park scenarios so these two maps look most similar. Villa et al. [19] produced a similar result. They found that the stakeholder weights were not different enough to discriminate between no entry, no-take and entry, and no-take zoning scenarios.

The maps are a good starting point for developing MPA zoning. They provide an effective visual that can be easily understood and modified. However, additional local knowledge and common sense should be brought to bear throughout the planning process. As an example, an area on the Israeli north beach shows up consistently, especially for commercial values and water sports and recreation, as highly suitable for the highest level of protection. Because of high levels of zooplankton indicating greater biodiversity the area is ranked as good quality for natural marine values too. It is the site of the Israeli fish farms, valued commercially as an aquaculture site and for water sports and recreation because the farms have become an attraction for scuba divers. Yet, objectively speaking, the natural environmental quality of the area is relatively degraded. In follow up discussions, stakeholders and policymakers would most likely adjust any high protection proposal for this area.

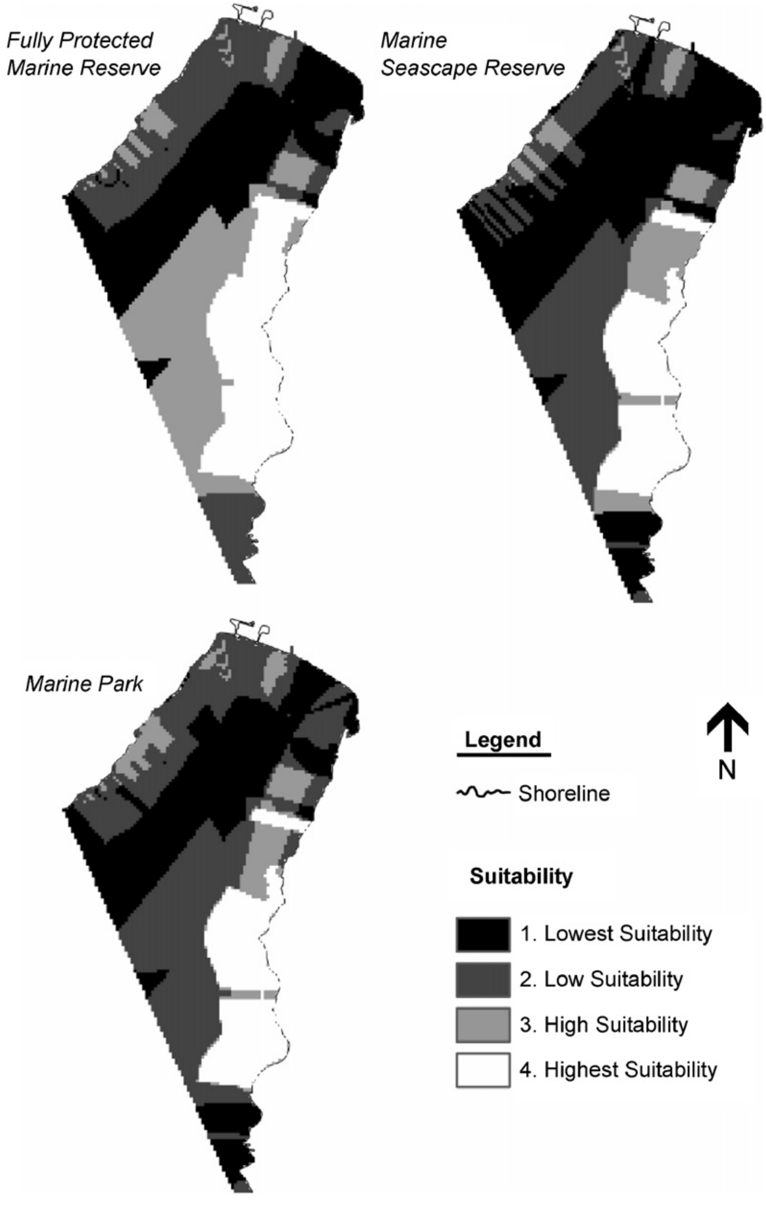

Fig. 2. Final maps for the zoning scenarios showing suitability as determined by concordance scores.

In relation to the jurisdictional issue, an example is the area indicated as most suitable for a Fully Protected Marine Reserve on the RSMPP's Jordanian side—the site of the best coral reefs. Any discussion of the RSMPP jurisdictional issues might suggest that an area of proportionate size be designated on the Israeli side for the highest level of protection even if not indicated in preliminary maps. This might occur because Israel and Jordan have very separate governance regimes and Israelis and Jordanians cannot benefit equally from

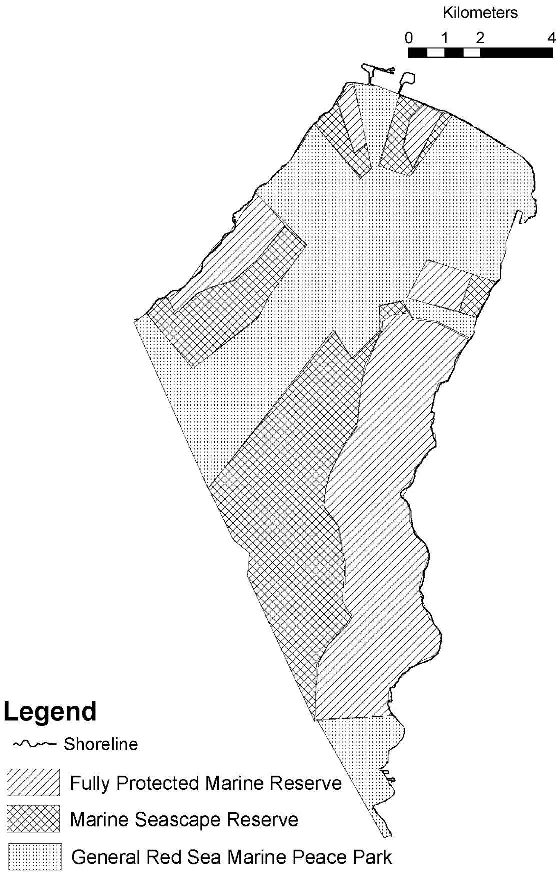

Fig. 3. Overall proposal based on overlaying the areas most suitable for Fully Protected Marine Reserve and Marine Seascape Reserve.

each other's natures reserves under present circumstances. Goodwill between the two countries is subject to change at any time in the future, just as it has fluctuated in the past.

7. Discussion

Models reduce the complexity of problems. Identifying a model's most sensitive elements, or drivers, helps to develop, refine and implement it. If small changes in the physical attribute data or in the stakeholder weights cause the resulting zoning proposal to be significantly different, then the model is highly sensitive to those parameters. Similarly, if the calculation method, such as the algorithm used for the concordance scores, renders an outcome that is significantly different from one resulting from the use of a different method, then the equation is a sensitive element of the model. Inputs to the model, in this case changes in the physical attribute data or in the stakeholder preferences, should ideally be the factors driving outcomes. By determining which elements of the model affect the outcome most, policymakers learn what steps require the most attention. For example, if the model is very sensitive to small differences in stakeholder weights, the choice of stakeholder participants, who they represent, and how many of them there are, will be very important.

To test the model, I concentrated on three fundamental aspects. I used a weighted average method instead of the concordance score formula to explore the validity of the algorithm used for the final scoring of the cells in the spatial plane. I clarified how the inclusion (or conversely, the exclusion) of various stakeholders would affect the model by using specific stakeholder groups instead of an average of weights expressed by all groups. Finally, to test the method used to develop the overall zoning proposal, I tried an alternative method that compares the final concordance scores under each zoning scenario to determine how each cell in the spatial plane should be zoned.

These tests, the results of which are not detailed here, confirm the validity of elements of the model and the significance of stakeholder preferences as drivers. The first test suggests that alternative algorithms that integrate both stakeholder preferences and physical attribute data, such as weighted averages, can be used. The subsequent two tests prove the significance of the stakeholder weights. Slight changes in weights or exclusion or inclusion of different stakeholder groups will result in proportionate differences in results. Therefore, planners should include as broad a selection of stakeholders as possible.

Although I did not test them, changes in the physical attributes—the other major variable of the model—are likely as important as stakeholder preferences. Optimally planners should include as many clearly distinguishable attributes as possible, yet not so many that stakeholders are burdened or confused by too many choices or definitions. Also, how lower-level criteria are grouped into higher-level criteria is important. Some lower-level criteria could have fallen into more than one category and this may have influenced outcomes. (For example, are dive sites truly commercial or recreational values or both?) There were too few lower-level sub-criteria available for this case study to test how slight changes in grouping of the higher-level attributes would influence outcomes.

The qualifying of physical attributes and activities along the shore for different purposes is complex yet essential for improved implementation of the model. For example, an aquaculture site is a source of revenue for area stakeholders yet it may also restrict recreational boating in close proximity. Similarly, it is difficult to qualify the physical impact of landside development on marine resources. Certain types of coastal development improve access for recreational purposes, yet runoff and shoreline changes that cause erosion or accretion will negatively affect other recreational uses. How do planners identify such factors and evaluate them in the spatial plane? A lack of information on these subjects limits the ability of policymakers to apply spatial multi-criteria analysis in real-world situations. Developing and expanding indices characterizing these affects would be helpful and is a subject that requires further research.

Even with better physical data and indices, the application of this model for the entire RSMPP as a whole may be limited. The planning process in both Israel and Jordan is a largely left up to professional and bureaucrats with little or no public input guaranteed by law or regulation.[7] However, it is worth noting that while zoning and land use plans are extensive for the terrestrial areas along the RSMPP shores, decision makers have yet to address allocation and use plans for the marine areas. The Eilat Beaches plan extends only 500 m from the shoreline [66] and the only submerged area zoned along the Jordanian

[7]Besides the right of affected parties to file objections.

shore, the Aqaba Marine Reserve, extends only as far as 350 seaward from mean high water [30].

Since publication in 2003 of the joint monitoring effort funded by USAID, further funding and international interest continue to support joint scientific research projects involving the Interuniversity Institute in Eilat and the Marine Science Station in Aqaba. These projects focus on examining coral health and other resources of the RSMPP.[8] Environmental agencies of the two governments have become more involved in research projects and are looking for ways to use the information generated [76]. A challenge will be to broaden the scope of projects to better integrate bio-centric and anthropocentric concerns. The collaboration of scientists and bureaucrats does not necessarily guarantee cross-border participation at all levels of society. There is a need to fulfill the original objectives of the RSMPP Program that included park staff training programs, community outreach such as public awareness campaigns, and educational programs led by the Israel Nature Reserves Authority and the Aqaba Regional Authority [34]. In any case, while the progress on institutional development of the RSMPP as envisioned in the early days following the 1994 Israeli–Jordanian Peace Accord has not materialized, new opportunities to apply this model may be forthcoming as the cost of lack of cooperation and lost opportunity in this unique micro-environment are realized.

8. Lessons learned

The application of this model addresses some of the challenges inherent in zoning a cross-border, multi-jurisdictional MPA where there are varying levels of information between countries, limited cooperation between managers and scientists, differing statutory regimes, and difficulties bringing stakeholders together. It does so by integrating disparate information on the physical environment, proposing protection levels based on the existing statutory protection possibilities, and determining preferences of stakeholders in both countries by questionnaire.

Physical criteria and stakeholder participants are clearly the most significant drivers of this model. Physical data must sufficiently characterize the environment while stakeholder participants must adequately represent users of the area. To address the latter, policymakers and planners can broaden the stakeholder base by increasing the number of survey participants and by reaching out to more stakeholder groups. They should also pay significant attention to the validity of the survey technique.

Incorporating a wider range of criteria to characterize the marine environment requires identification of parameters and acquisition of as large a set of meaningful measurements as possible. Optimally, development parameters should be included (as in this study) and they should incorporate planned as well as existing land uses. If possible, depth and varying quality throughout the water column should be considered to depict a three-dimensional spatial plane.

[8]Such as a project monitoring the effects of natural and anthropogenic aerosol pollution on ecosystems in the Gulf to be completed by August 2009 by Israeli and Jordanian scientists. Like the RSMPP Program, the research is funded by USAID Middle East Regional Cooperation Program (MERC) that supports collaboration among Israel and its Arab neighbors on common priority development problems. Despite unrest in many parts of the region, 36 MERC projects were active in 2005, triple the number of projects that were concurrently active during any year before 1999 [76].

Planners should modify outcomes of this method as needed using a complementary traditional planning process that includes focus groups, charrettes, and public hearings. While such planning forums are difficult in cross-border situations with a history of conflict, they could be conducted on a limited scale to the extent possible. Because physical attribute data are hard to come by especially in situations with limited cooperation between researchers, and because distinctions may be small between different stakeholders for varying levels of protection, if used alone this method is probably most suited for determining zoning schemes for contained areas already designated for some level of protection.

The clarification of stakeholder preferences using the pairwise comparison survey and their application using MCA informs regulators, policymakers, and the larger stakeholder community of what these views and values mean when applied to conditions in the field. Planners can generate this information at an early stage in the process, before solidifying zoning proposals. The use of GIS software to conduct the analysis allows for modifications in the process at any point, the addition or subtraction of new information, plus the replication of the method under different and evolving political and socio-economic conditions.

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