Marine Policy 63 (2016) 135–143

Contents lists available at ScienceDirect

Marine Policy

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

Zoning for a multiple-use marine protected area using spatial multi-criteria analysis: The case of the Sheik Seid Marine National Park in Eritrea

Bereket Tesfamariam Habtemariam [a,b,1], Qinhua Fang [a,b,*]

[a] Fujian Provincial Key Lab for Coastal Ecology and Environmental Studies, Xiamen University, Xiamen 361102, PR China
[b] Coastal and Ocean Management Institute, Xiamen University, Xiamen 361102, PR China

ARTICLE INFO

Article history:
Received 21 April 2013
Received in revised form
22 October 2015
Accepted 22 October 2015
Available online 10 November 2015

Keywords:
Zoning
Marine protected areas
Spatial multi-criteria analysis
GIS
The Sheik Seid Marine National Park

ABSTRACT

Marine and coastal areas worldwide are now facing increasing pressures, particularly from intensified human activities; marine protected areas (MPAs) are therefore designated to conserve marine biodiversity, and zoning has been used as an effective means to minimize conflicts between human use and biodiversity conservation and that among different users. However, there are currently very few zoning practice examples of MPAs reported in developing countries. In this paper, an interdisciplinary method combining spatial multi-criteria analysis (SMCA), geographic information system (GIS) and stakeholder consultation to develop a zoning scheme in the multiple-use MPAs of Eritrea is illustrated. Three higher-level criteria and eight lower-level criteria are identified based on the value-focused approach to multi-criteria analysis, and stakeholder preference is represented by pair-wise comparison (AHP analysis). Subsequently, the simple additive weighting (SAW) method is used to determine the suitability of an area for each protection level using spatial analysis software. Through this study, a zoning scheme considering both the scientific soundness and the practical feasibility of the Sheik Seid Marine National Park (SSMNP) in the Eritrean waters is proposed. The method could serve as a model for developing a zoning plan for those similar cases, particularly in the developing countries with data and financial and technical limits.

1. Introduction

Marine protected areas (MPAs) are protected areas used for conservation purposes. As stated in Aichi Target 11, "by 2020…10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures and integrated into the wider landscapes and seascapes" [1], designating MPAs as an important area-based measure to protect biologically rich habitats and thereby conserving biodiversity. However, this simple numeric indicator of area coverage is the only element of Target 11, as there are many other crucial elements, among which effective, equitable biodiversity management tops the lists [2]. The primary importance of zoning/zonation for effective management of MPAs has been widely discussed in various regions [3,4].

Multiple-use zoning means dividing the marine area into different zones in which uses are regulated to accomplish specific goals [5]. The goals within each zone may vary from providing a high level of protection for marine habitats, such as nursery areas and breeding sites [6], to being set aside for reasonable uses (extractive or non-extractive), including research, education, resource extraction, fishing, and tourism. Multiple-use zoning also identifies areas of importance or sensitivity for natural or cultural heritage [7].

The zoning method plays an important role in its enforcement; the more transparent and objective the decision-making process is, the greater the likelihood of acceptance by the stakeholders and public will be [8,9]. There are a few analytical tools and approaches to develop the zoning scheme, among which InVEST and Marxan have been largely discussed recently [10]. However, there is no "best" method because the suitability of a zoning method depends on its ability to satisfy the features of the area to be designated, such as political and administrative issues, the objectives and the size of the MPA, the availability of the baseline data, and financial resources.

* Corresponding author.
E-mail address: qhfang@xmu.edu.cn (Q. Fang).
[1] Present address: Marine Biodiversity and Conservation Program, Biology Department, Ghent University Stallion 49 G429, Ghent 9000, Belgium

http://dx.doi.org/10.1016/j.marpol.2015.10.011
0308-597X/

Therefore the objective of this paper is to develop a suitable and feasible zoning method for those MPAs featuring the data, financial and technical limits that are common in the developing countries, taking as an example the multiple-use Sheik Seid Marine National Park (SSMNP) in Eritrea. Using SSMNP as a case study, Section 2 explicitly illustrates the step-by-step zoning approach with spatial multi-criteria analysis as a core component; Section 3 describes the detailed results and provides further discussion of the results; finally, Section 4 presents the conclusions.

2. Methods and materials

Ocean zoning is an area-based management activity that divides ocean spaces based on various compatible or conflicting sea uses at the spatial and temporal scale [11]. Two types of MPA-related zoning can be identified in practice: one is MPA site selection in a comprehensive ocean zoning, and the other is the zoning practice in a designated MPA. Both can be described as "deciding what to protect and what to allow where" at different scales [12]. Various tools for MPA zoning, varying in data/information requirements, technology level and financial support, have been applied worldwide. Initially, more attention was paid to scientific rigour; as a result, the zoning process is rooted in protected species features or their habitat assessment to evaluate the suitability of protection [13,14]. However, the issue of "paper parks" failing in the compliance of MPAs by various users has resulted in an argument about the effectiveness evaluation of MPAs [15–17]. Increasing numbers of discussions on multiple-use MPAs are also appearing [18]. The key principle of zoning methodologies for multiple-use MPAs is the introduction of social objectives through the stakeholder involvement process based on the original methods considering the natural features only [10].

Among all of the MPA zoning studies, various methods, including geographic information systems (GIS), Marxan (with Zones), user consultation/stakeholders involvement including questionnaire surveys, economic analysis, and decision support tools (such as nonlinear multi-objective decision-making (MODM) models), were used [19–24].

A trend of using high-tech tools combining GIS and decision support tools is observed from the above-described literature. The advance of these technologies greatly improves the quantification of the zoning process and thereby benefits the visualization of the results; however, it also requires high-level demands on data and information, analysis capacity and financial support, which is still a problem for those developing countries. Managers anywhere actually require timely and cost-effective techniques [25]. Therefore, in this study, a step-by-step method balancing scientific justification and practice feasibility was proposed to address the above-described issues, using an MPA of Eritrea as a case study.

2.1. Study site: Sheik Seid Marine National Park

Although there are traditionally managed fishing-prohibited coastal ecosystems (e.g., mangroves and lagoons) in some parts of the country, no coastal or marine protected areas have been officially declared in Eritrea [26]. Planning processes for MPAs are underway as part of the integrated coastal zone management initiatives [27]. Currently, two islands, Sheik Seid Island and Dessie Island (Fig. 1), out of the 354 largely uninhabited islands were proposed to be declared as marine protected areas to "conserve the nations' major biodiversity elements and rehabilitate some of

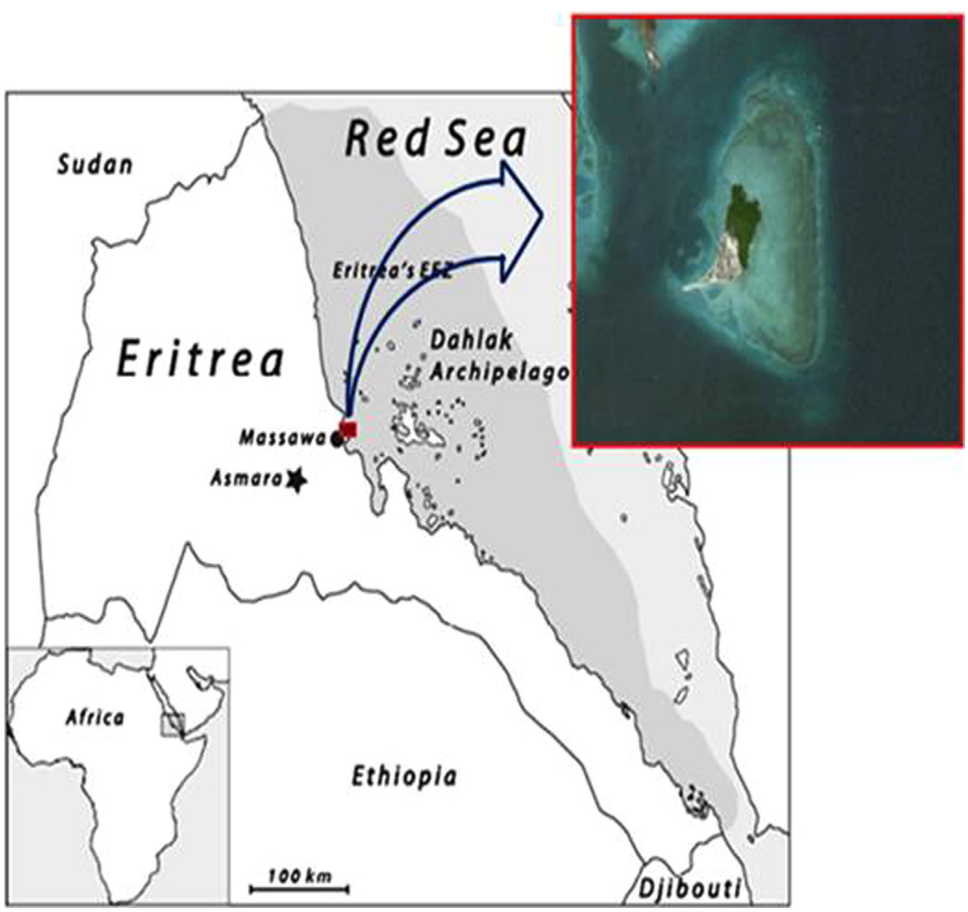

Fig. 1. Study site.

its ecosystems” based on their ecological, research and economic significance [26]. A provisional MPA management plan of Sheik Seid Marine National Park was prepared in 2006; however, its implementation has been hampered due to the fragmentation of sectorial management, the lack of financial support, and the absence of management activities, especially with regard to the sea use zoning design, which is the main focus of this paper [27,28].

Sheikh Seid Island (also known as Green Island) is one of 354 Dahlak archipelagos scattered along Eritrea's southern Red Sea coast. It is a small flat island with a maximum altitude of 1 m and with dense mangroves in the north and sandy shores in the south. The mangrove trees and the extended inter-tidal reef flat that completely emerges at low tide makes the island a suitable area for a nesting and resting site for marine birds. Further offshore, within the shallow waters, there exist patchy coral reefs. The climate is very hot in the summer, and there is very little rain in winter – the only source of its fresh water.

2.2. MPA zoning approach

Zoning is a decision-making process that requires the evaluation of multiple land and sea attributes according to multiple objectives [29]. In this study, a step-wise approach was developed in which spatial multi-criteria analysis (SMCA) is a core step (Fig. 2). SMCA is a process involving a sequence of activities that identifies a problem based on the existing marine and coastal activities and their compatibility analysis, followed by spatial multi-criteria analysis aimed at defining the various criteria for different human activities and quantitatively evaluating its suitability, and ending with a recommendation for a decision (a

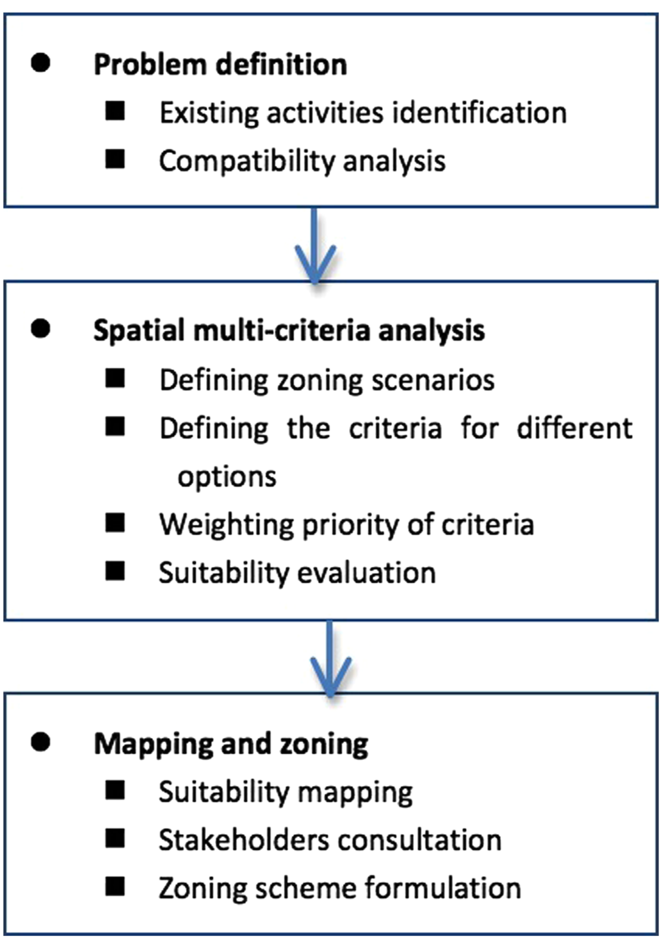

Fig. 2. Zoning approach.

Table 1
Existing use–use and use–environment conflicts and compatibility matrix of Sheik Seid Island and its surrounding waters.

Activity	Subsidence fishing: hook and line	Subsidence fishing: seine net	Shipping lines	Recreation: diving/ snorkelling	Recreation: sun bathing	Recreation: bird watching/ site seeing	Mining of tracus shell	Cultural and archaeological conservation	Biodiversity conservation
Subsidence fishing: hook and line	Y	Y	X	X	X	X	O	O	X
Subsidence fishing: seine net	Y	Y	X	X	X	X	O	O	X
Shipping lines	X	X	Y	X	X	X	O	O	X
Recreation: diving/ snorkelling	X	X	X	Y	O	O	O	O	O
Recreation: sun bathing	X	X	X	O	Y	Y	X	Y	O
Recreation: bird watching/ site seeing	X	X	X	O	Y	Y	X	Y	O
Mining of tracus shell	O	O	O	O	X	X	Y	X	X
Cultural and archaeological conservation	O	O	O	O	Y	Y	X	Y	Y
Biodiversity conservation	X	X	X	O	O	O	X	Y	Y

Note: Y– compatible, X – incompatible, and O – probably compatible.

Level 1-Goal	Natural Conservation		Public Awareness and Education
✧ Level 2-Objective	✧ Environmental	✧ Social	✧ Economic
■ Level 3- High level criteria	■ Natural Island Value (NIV)	■ Recreational & Cultural Value (RCV)	■ Extractible Value (EV)
● Level 4- Sub-criteria	● Coral reef areas ● Mangrove areas ● Presence/Suitability for marine birds	● Suitability for swimming ● Suitability for snorkeling ● Presence of sandy beaches ● Presence of archaeological sites	● Fishing areas

Fig. 3. Criteria tree for the performance of the stakeholder preferences.

Table 2
Weights assigned to the lower level criteria, used in obtaining value maps (NIV & RCV maps).

High level criteria	Sub-criteria	Weight
NIV	Coral reef area	0.425
	Mangrove area	0.333
	Presence/suitability for marine birds	0.242
RCV	Suitability for swimming	0.233
	Suitability for snorkelling	0.274
	Sandy shores	0.244
	Archaeological site	0.249

zoning scheme) after mapping and stakeholder consultation (Fig. 2).

2.2.1. *Identification and compatibility analysis of the existing activities*

As the first step, the existing human activities in SSMNP were identified based on the author's fieldwork; the compatibility among every use was also considered (Table 1), among which the conflicts between recreational activities and biodiversity conservation were identified as the major issues.

2.2.2. *Defining zoning scenarios*

The objective of SSMNP is to ensure biodiversity conservation while simultaneously allowing for economic development and livelihood improvement [30,31]. Three levels of protective zones are listed below [32].

- **Restricted access zone** (*no entry and no take*): the zone is designed to protect and conserve biologically significant habitats in a pristine condition without human activity, except for approved scientific research.
- **Sanctuary zone** (*entry but no take*): the zone provides a high level of protection, where the removal or harm of plants or animals is prohibited. Activities referred to as low-impact tourism, such as swimming, snorkelling, diving, beach-related activities (sun bathing), and cultural activities (pilgrimage to the ancient mosque located in the island), are allowed.
- **Habitat protection zone** (*entry and limited take*): the zone offers a certain level of protection and allows for a range of recreational activities and subsistence fishing activities that do not significantly affect habitat components, fish populations or ecological processes.

2.2.3. *Spatial multi-criteria analysis (SMCA)*

From the perspective of decision-making, the decision problems in a zoning scheme consist of two steps. First, decision makers must compare complex scenarios from socio-economic, ecological and institutional dimensions. To solve such complex conditions, multi-criteria analysis (MCA) can be used to integrate different socio-economic and institutional concerns for MPA zoning design [30].

Second, the decision making process involves a set of geographically defined alternatives, from which a choice of one or more alternatives is made with respect to a given set of evaluation criteria [33], making zoning schemes a spatial decision making issue. Spatial multi-criteria analysis (SMCA), refers to the application of MCA in a spatial context [5,30] and has therefore been used to address multiple-use zoning scheme decision problems in this study.

Step 1 defining the criteria for SSMNP. A criteria tree was developed for SMCA of SSMNP zoning (Fig. 3); the indicators are relevant to the SSMNP objective and are quantifiable and measurable [30,31,34].

In this study, raw data with regard to the biological, physical and social aspects of Sheik Seid Island were obtained from the Eritrea Coastal Marine and Island Biodiversity (ECMIB) project survey, as well as a field study and interviews with personnel from the Ministry of Marine Resources of Eritrea.

- ***Natural island value (NIV):*** NIV is related to species diversity and the distribution of plant and animal communities on the island, the presence of endemic or rare species, and the

Table 3
Weights assigned to the higher-level criteria under each zoning scenario.

Option	Restricted access zone			Sanctuary zone			Habitat protection zone		
Criteria	NIV	RCV	EV	NIV	RCV	EV	NIV	RCV	EV
Weight	0.78	0.21	0.01	0.52	0.44	0.04	0.50	0.24	0.26

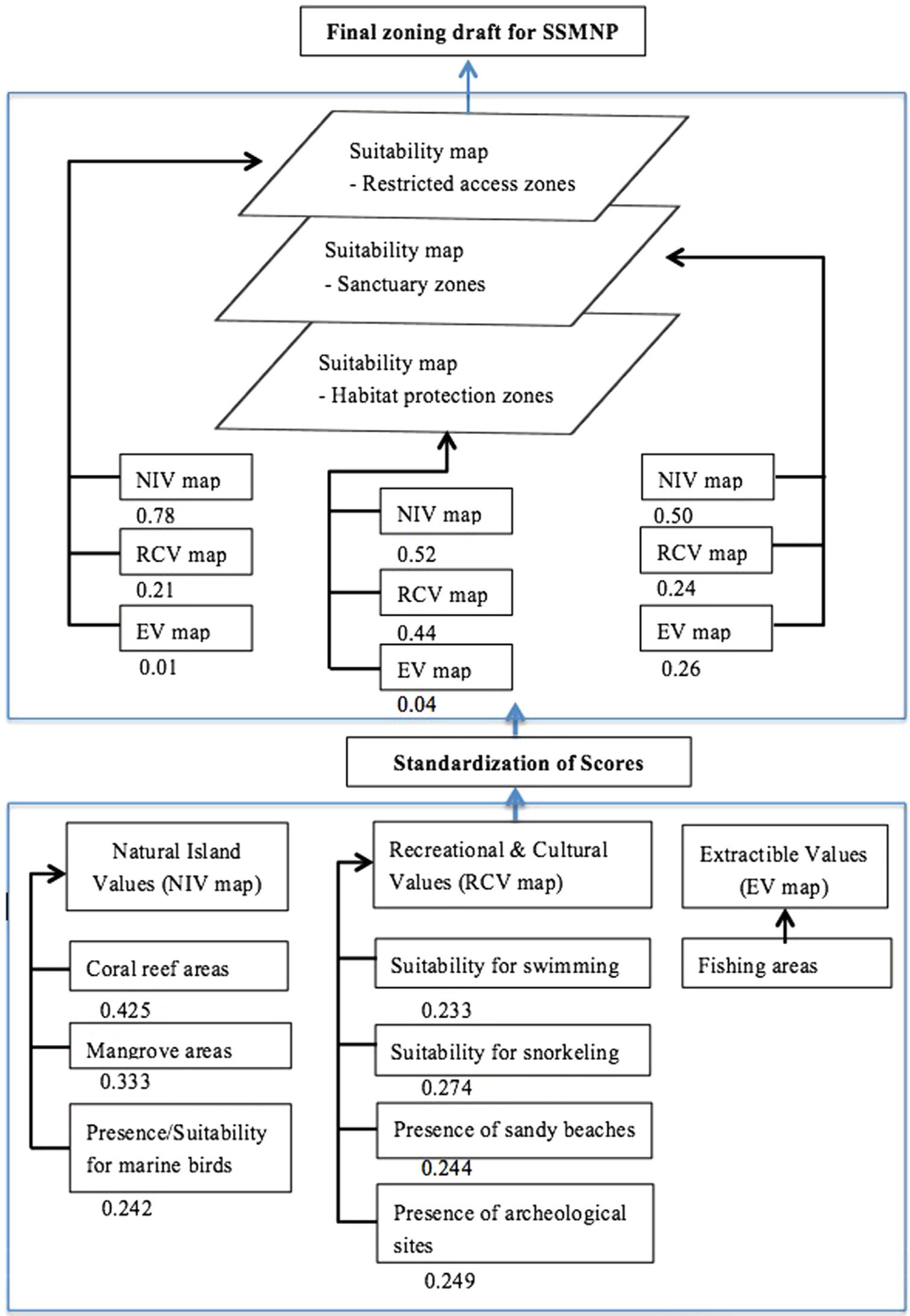

Fig. 4. Diagrammatical process of suitability evaluation.

presence of habitats that have an important role in ecosystem functions (e.g., breeding area, and nursery area). NIV of the study area was assessed according to the three Level 4 indicators, namely, coral reef area, mangrove area, and the presence or suitability for marine birds. The value of each indicator was divided into multiple classes, and then a score was assigned according to its suitability. Taking coral reef as an example, in the SSMNP, the area covered by healthy coral was scored as maximum suitability (score 5), and areas with the presence of coral reefs were scored as 4; a 50 m buffer around the coral reef was scored as medium suitability (score 3) [30]; other areas were given a minimum score of 0. The available scored species distribution maps were aggregated by assessing the presence/suitability of each habitat and/or species based on comparative weighting matrices obtained from experts representing different stakeholders. The final value map was obtained from the results of the SMCA.

- ***Recreational and cultural value (RCV):*** RCV is a value related to recreational activity (presence of beach, suitability for swimming, sun bathing, snorkelling and diving) and cultural activities (presence of archaeological sites and pilgrimage). Similar to the NIV map, the RCV map was obtained using SMCA. Each subcriterion, namely, suitability for swimming, suitability for snorkelling, presence of sandy beach, and presence of archaeological sites, was given a weight that represents its significance to the overall suitability measurement. Each indicator was also

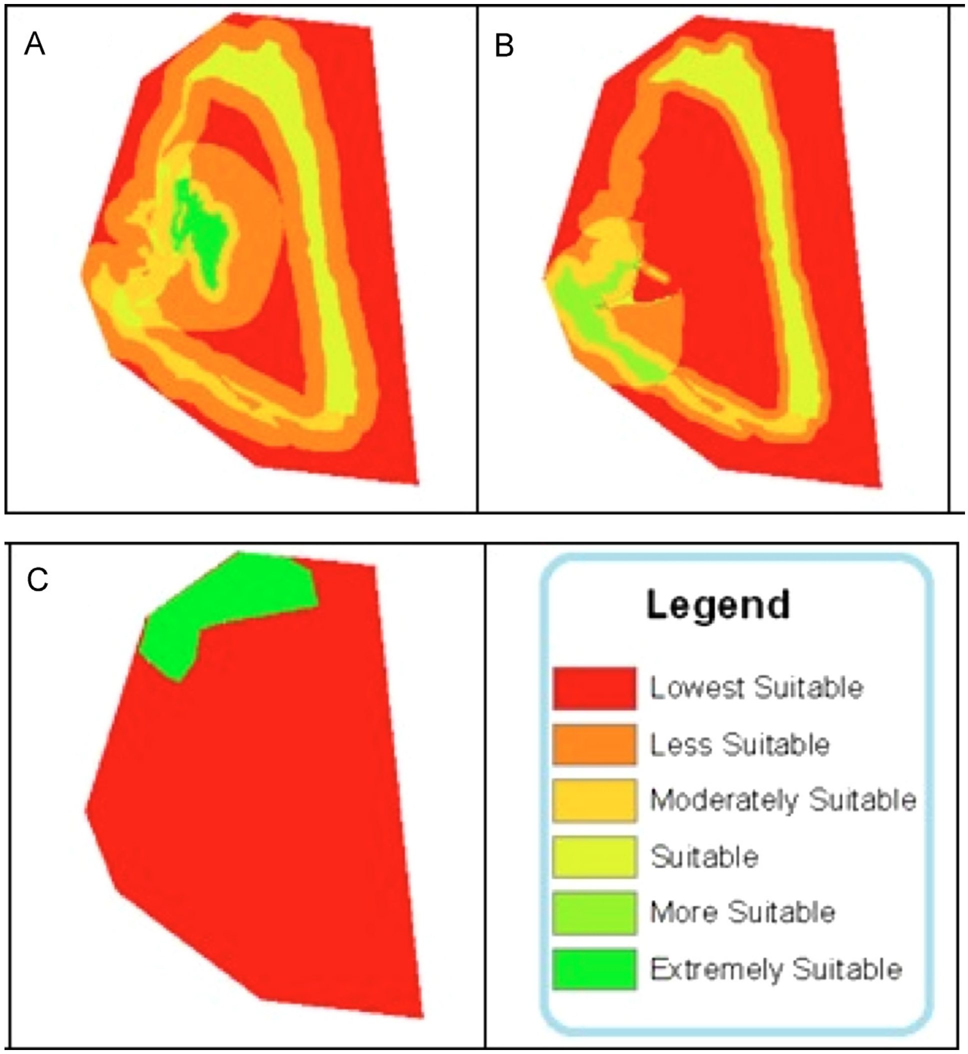

Fig. 5. Aggregated value maps (A – NIV; B – RCV; C – EV).

divided into different classes; taking suitability for swimming as an example, it was divided into five classes: shallow water with sandy coast (score-5), shallow water with muddy bottom (4), buffer area (3), sea area (2) and other areas (1). The same classification method was also applied to other RCV indicators.

- ***Extractible-use values (EVs)***: EVs are the values of the areas for resource exploitation. EVs consider activities such as subsistence fishing, sport fishing and boating tours. Because the only allowed and most dominant existing extractive use in SSMNP is subsistence fishing, the EV map was determined based on an area's suitability of fishing or the identified traditional fishing ground.

Step 2 defining the priority weights of the criteria. A weight is a value assigned to an indicator/criterion that reflects the importance of the indicator/criterion relative to others under consideration [35]. For this analysis, a pair-wise comparison-analytic hierarchy process (AHP)-was applied. A pair-wise comparison matrix questionnaire was prepared and distributed to the stakeholder representatives (seven experts from the Ministry of Tourism, the Ministry of Marine Resources, marine biologist, archaeologist, and a law expert, among others). Preferences were indicated for one high-level criterion over another on a scale of 1 (least importance) to 5 (extreme importance), which was later converted into the matrix values [30,36]. Finally, the relative weights (Tables 2 and 3) were calculated using AHP analysis. The consistency index (CI) result of 0.1086 (CR=0.18) indicates that the weight result is within the acceptable range of less than 20% CR.

Step 3 suitability evaluation. In the case study of SSMNP, the suitability index is estimated using the simple additive weighing (SAW) method (Eq. (1)).

$$SI = \sum W_i * X_i \tag{1}$$

where SI=overall suitability index, W_i=weight of criterion i, X_i=score of criterion i, and n=total number of criteria.

Using ArcGIS spatial analysis, these lower-level criteria maps were combined in a grid that contains all classes calculated from each of the separate grids (see Fig. 4). Next, criteria maps were multiplied by the relative importance weights of the criteria, as shown in Table 2. The suitability index of NIV and RCV maps was computed using the SAW method, and the Boolean Overlay Method was used for the EV map because it has been strictly classified into Boolean suitable or unsuitable layers with values of 1 (traditional fishing areas) and 0 (the rest areas), respectively [29,35]. Finally, NIV, RCV and EV maps were calculated simply by multiplying all classes with the ArcGIS spatial analysis (Fig. 5).

Once all of the maps were converted into partial suitability, criteria maps were standardized to the same value range from 0 to 1 to make them comparable. NIV and RCV maps were standardized

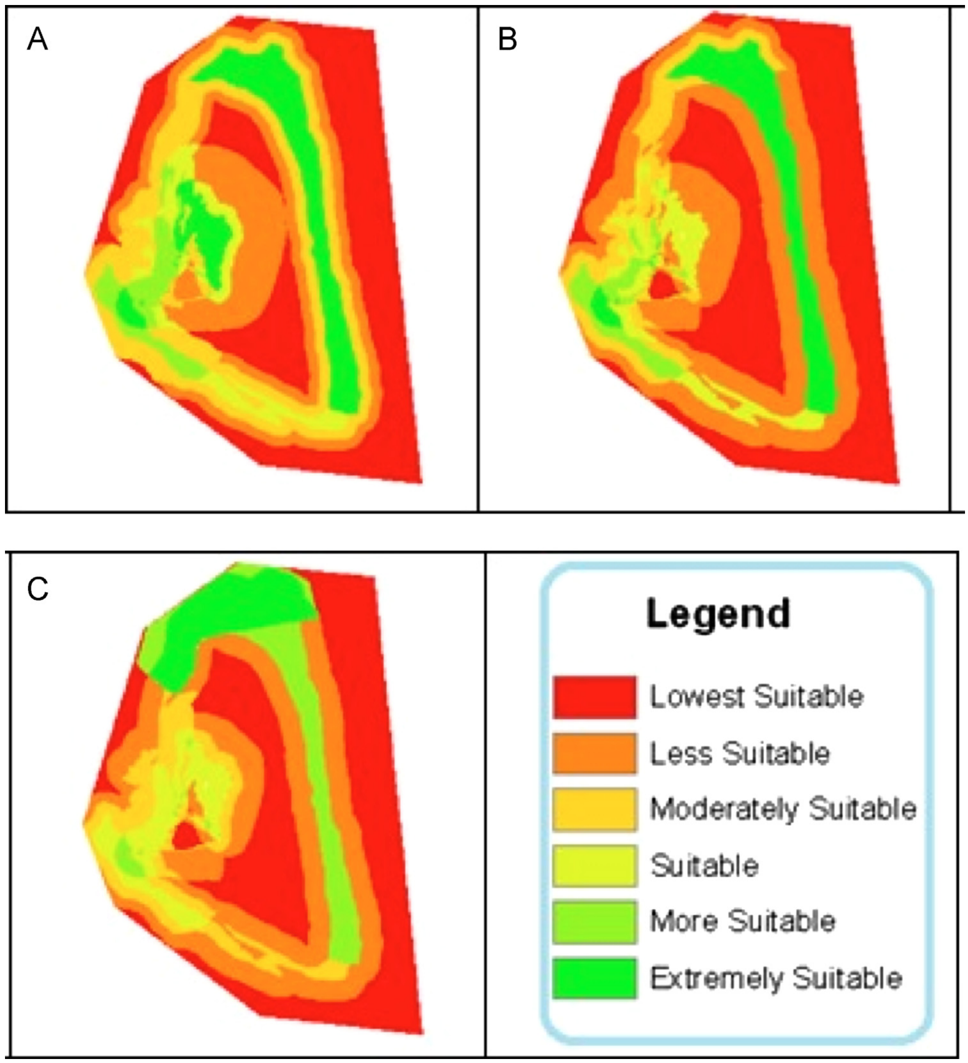

Fig. 6. Suitability under the three zoning scenarios (A – restricted access zone; B – sanctuary zone; C – habitat protection zone).

using the minimum and maximum values as scaling points, a process known as linear scaling, given by Eq. (2).

$$Xi = \left[(R_i - R_{min}) / (R_{max} - R_{min}) \right] {*} SR \tag{2}$$

where R_i – score of the criterion i, R_{min} –minimum score of the given criterion, R_{max} – maximum score of the given criterion, and SR – standardized range.

The resulting cell values in each high-level criterion map were multiplied by the weights of the three zoning scenarios using the SAW method to obtain the suitability layer for the three zoning options (Fig. 6).

3. Results

Finally, the draft zoning scheme was attained by selecting areas with the highest suitability for each zoning scenario [29]. Subsequently, the results of the selection made for the three protection levels were compared. Areas that showed the highest suitability to one zone only were directly allocated to that zone. For areas that were selected for more than one zone or that were never selected for any of the zoning options, their suitability values were compared and the areas were assigned to the zone with the highest value (Fig. 7).

In the case that the suitability values are exactly the same or very similar (e.g., healthy coral reef areas have a suitability value of 0.56 for a restricted access zone and 0.57 for a sanctuary zone), the objectives of the MPA will be taken into an account (restricted access zone is preferred in this case). In addition, experts from different stakeholder groups will be consulted to determine the final zoning scheme.

It is argued that the zonation plan should be as simple as possible [6]. Considering the small size of the studied MPA, dividing the SSMNP area into too many zones of the three protection levels would also mean greater complication and less effectiveness in the management of the SSMNP; thus, only three zones representing the three protections levels were considered as follows.

1. **Restricted access zone**: the restricted access zone includes all of the mangrove areas and the low-lying reef flats on the eastern side of Sheik Seid Island. The highest suitability values of the restricted access zone were found within the mangrove area; thus, it was directly assigned to a restricted access zone. Addition of the low laying reef flats was found to be advantageous for marine bird conservation because it serves as a feeding ground and also acts as a buffer from their resting site, which is the mangrove.
2. **Sanctuary zone**: sanctuary zones constitute the largest part of SSMNP, as one of the main objectives of the MPA is public awareness. Thus, the zoning result guarantees the public the

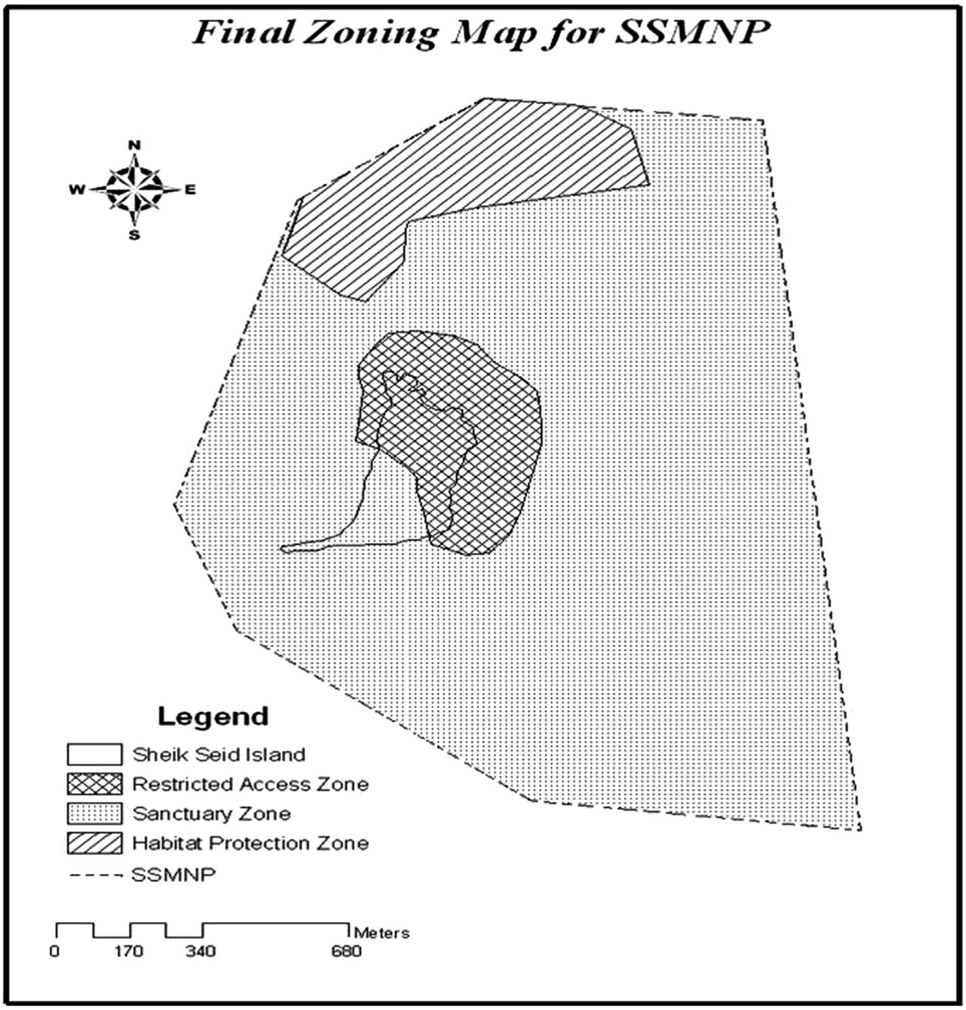

Fig. 7. Final zoning map for SSMNP.

opportunity to enter and enjoy the environment within SSMNP, but for protection purposes, nothing may be removed.

3. **Habitat protection zone**: the most suitable area for a habitat protection zone was located in the north and northwestern part of the MPA. This area coincides with the traditional fishing grounds. The zoning result will be helpful for its implementation because the local community's traditional use has been fully considered.

4. Discussion

Within multiple-use MPAs, zoning offers an opportunity to resolve use conflicts and maximize conservation efforts by spatially separating activities that pose different types and degrees of threats on marine and coastal ecosystems. In this study, the major use conflict was identified as the conflict between tourism and conservation. In the past, neither of the two responsible authorities, the Ministry of Tourism and the Ministry of Marine Resources, had full authority over the proposed MPA, even though it was proposed in 2006, and there was no institutional arrangement could bring both parties and other stakeholders together to discuss on issues facing. This situation, together with different managerial, political and financial aspects, has caused the lack of implementation of the MPA for years. However, the zoning process provides an opportunity for all stakeholders to cooperate with each other toward a win–win solution to address conflicts; therefore, as proven around the world [13,37], zoning will have great potential as an important tool for integrated coastal management in Eritrea, particularly for the ecosystem-based approach to MPAs management.

The applied zoning process with SMCA as a core step combines both qualitative and quantitative data to produce more scientific and reasonable zoning schemes. The flexibility in data collection makes SMCA more open, explicit and adaptive, especially in a context of lacking basic data, technical support and financial resources. Another advantage of SMCA techniques is that the objectives and criteria chosen by the decision making group are open to analysis and change if they are found to be inappropriate [31]. Moreover, SMCA is a participatory process that ensures that all stakeholders' interests are represented and taken into consideration through the process of identifying the criteria and determining their weights. The application of an SMCA-based zoning method to SSMNP in Eritrea is a good example that showcases such advantages. Even in the context of inadequate data, the areas most suitable for varying levels of protection and activities that are allowed or not allowed in specific localities of the SSMNP can be identified through SMCA-based zoning framework.

ArcGIS functions well for spatial analysis via mathematical calculation according to priority weights, which ensured that the decision makers made more objective and scientifically sound decisions for SSMNP zoning schemes. Furthermore, the mapping results based on ArcGIS also provide ease of scenario comparison for all MPA stakeholders. This zoning draft serves as a foundation for the development of the final zoning design of SSMNP and thus provides a forward thrust towards implementation of the MPA.

5. Conclusion

Marine protected areas (MPAs), in terms of both planning and management, play critical roles in the global marine biodiversity conservation. A sound zoning approach is important not only for scientific justification but also for practical feasibility. The zoning approach for multiple-use MPAs proposed in this study takes into account both the features of natural ecosystems and social demands on marine resources; therefore, it is able to guarantee compliance by involving all stakeholders in the zoning process while effectively protecting the endangered species or fragile ecosystem. The case study shows that this zoning approach combining spatial multi-criteria analysis, geographic information systems and stakeholder consultation can also function well in the conditions of poor data, limited technical capacities and insufficient financial resources.

Acknowledgements

We thank the Eritrea Coastal Marine and Island Biodiversity (ECMIB) project for providing data regarding the biological, physical and social aspects of Sheik Seid Island. This research project is financially supported by the Fundamental Research Funds for the Directly Affiliated Universities in China (the fundamental Innovation Research, Grant no. 2011121008, Xiamen University) and the National Natural Science Foundation of China (project # 41376114). We also thank the anonymous reviewers for their insightful comments.

References

[1] M.D. Spalding, I. Meliane, A. Milam, C. Fitzgerald, L.Z. Hale, Protecting marine spaces: global targets and changing approaches, Ocean Yearb. 27 (2013) 213–248.
[2] Barnes Megan, Louise Glew, Ian Craigie, Carina Wyborn, Protect biodiversity, not just area, Nature 526 (2015) 195.
[3] IUCN, Managing Marine Protected Areas: A Toolkit for the Western Indian Ocean, IUCN Eastern African Regional Programme, Nairobi, Kenya, 2004.
[4] P. Francour, J.G. Harmelin, D. Pollard, S. Sartoretto, A review of marine protected areas in the northwestern Mediterranean region: siting, usage, zonation and management, Aquat. Conserv. Mar. Freshw. Ecosyst. 11 (3) (2001) 155–188.
[5] Shiau-Yun Lu, Cheng-Han Shen, Wen-Yan Chiau, Zoning strategies for marine protected areas in Taiwan: case study of Gueishan Island in Yilan County, Taiwan, Mar. Policy 48 (2014) 21–29.
[6] J. Day, Zoning-lessons from the Great Barrier Reef marine park, Ocean. Coast. Manag. 45 (2002) 139–156.
[7] S. Boyes, et al., A proposed multiple-use zoning scheme for the Irish Sea: an interpretation of current legislation through the use of GIS-based zoning approaches and effectiveness for the protection of nature conservation interests, Mar. Policy 31 (2007) 287–298.
[8] C. Fara, W. Jack, Ocean zoning for the Gulf of Maine: a background paper. Gulf of Maine Council on the Marine Environment and NOAA Marine Protected Area Center. 〈http://www.gulfofmaine.org/council/publications/oceanzoningreport.pdf〉.
[9] J. Sanchirico, Marine Protected Areas as Fishery Policy: A Discussion of Potential Costs and Benefits, Discussion Paper 00–23, Resources for the Future, Washington, DC, 2000.
[10] Hedley S. Grantham, Vera N. Agostini, Joanne Wilson, Sangeeta Mangubhai, Nur Hidayat, Andreas Muljadi, Chris Rotinsulu Muhajir, Meity Mongdong, Michael W. Beck, Hugh P. Possingham, A comparison of zoning analyses to inform the planning of a marine protected area network in Raja Ampat, Indones. Mar. Policy, 38, (2013) 184–194.
[11] Q. Fang, Ran Zhang, Luoping Zhang, Huasheng Hong, Marine functional zoning in china: experience and prospects, Coast. Manag. 39 (6) (2011) 656–667.
[12] Tundi Agardy, Ocean Zoning: Making Marine Management More Effective, Rutledge, London, 2010.
[13] H. Bailey, P.M. Thompson, Using marine mammal habitat modelling to identify priority conservation zones within a marine protected area, Mar. Ecol. Prog. Ser. 378 (2009) 279–287.
[14] L. Ortiz-Lozano, A. Granados-Barba, I. Espejel, Ecosystemic zonification as a management tool for marine protected areas in the coastal zone: applications for the Sistema Arrecifal Veracruzano National Park, Mexico, Ocean Coast. Manag. 52 (6) (2009) 317–323.
[15] M. Hockings, Evaluating management of protected areas: integrating planning and evaluation, Environ. Manag. 22 (3) (1998) 337–345.
[16] F. Leverington, K.L. Costa, H. Pavese, et al., A global analysis of protected area management effectiveness, Environ. Manag. 46 (5) (2010) 685–698.
[17] S.J. Campbell, A.S. Hoey, J. Maynard, et al., Weak compliance undermines the success of no-take zones in a large government-controlled marine protected area, PLoS One 7 (11) (2012).
[18] K.B. Kincaid, G. Rose, H. Mahudi, Fishers' perception of a multiple-use marine protected area: why communities and gear users differ at Mafia Island, Tanzania, Mar. Policy 43 (2014) 226–235.
[19] F. Villa, L. Tunesi, T. Agardy, Zoning marine protected areas through spatial multiple-criteria analysis: the case of the Asinara Island National Marine Reserve of Italy, Conserv. Biol. 16 (2) (2002) 515–526.
[20] G. Merino, F. Maynou, J. Boncoeur, Bioeconomic model for a three-zone Marine Protected Area: a case study of Medes Islands (northwest Mediterranean), ICES J. Mar. Sci. 66 (1) (2009) 147–154.
[21] U. Rojas-Nazara, C.F. Gaymer, F.A. Squeo, et al., Combining information from benthic community analysis and social studies to establish no-take zones within a multiple uses marine protected area, Aquat. Conserv. Mar. Freshw. Ecosyst. 22 (1) (2012) 74–86.
[22] S.A. Loos, R.R. Canessa, Towards a GIS-based methodology for marine protected area zoning, Coast. Mar. Geospatial Technol. Coast. Syst. Cont. Margins 13 (2010) 245–254.
[23] R. Ulloa, A. Vargas, C. Hudson, et al., Zoning of the Mejillones Peninsula marine protected coastal area of multiple uses, northern Chile, Lat. Am. J. Aquat. Res. 41 (3) (2013) 506–518.
[24] H.C. Cheng, P.A. Chateau, Y.C. Chang, Spatial zoning design for marine protected areas through multi-objective decision-making, Ocean. Coast. Manag. 108 (SI) (2015) 158–165.
[25] M.L. Campbell, C.L. Hewitt, A hierarchical framework to aid biodiversity assessment for coastal zone management and marine protected area selection, Ocean. Coast. Manag. 49 (3–4) (2006) 133–146.
[26] Eritrea's Coastal Marine and Island Biodiversity (ECMIB), State of the Coast Eritrea, 〈http://www.eritreaembassy-japan.org/data/State_of_the_Coast_2006-2007_full.pdf〉, 2007.
[27] T. Iyob, The need for a protected area system in fisheries and biodiversity management: the case of Eritrea. Oral presentation, in: Proceedings of the EU-Workshop: Policy Options for the Sustainable Use of Coral Reefs and Associated Coastal Ecosystems, Mombasa, Kenya, 2000.
[28] S. Young, Would ocean zoning be an effective ccean management tool for the waters off the coast of Massachusetts? Vermont, J. Environ. Law (2006) 〈http://www.vjel.org/editorials/ED10051.html〉.
[29] D. Geneletti, I. van Duren, Protected area zoning for conservation and use: a combination of spatial multicriteria and multiobjective evaluation, Landsc. Urban Plan. 85 (2008) 97–110.
[30] M. Portman, Zoning design for cross-border marine protected areas: the Red Sea Marine Peace Park case study, Ocean. Coast. Manag. 50 (2007) 499–522.
[31] Department of the Environment, Transport and the regions statements of National Planning Policy (DETR), Multi-criteria Analysis Manual, 2000 〈http://www.communities.gov.uk/index.asp?id=1142254〉.
[32] S. Gubbay, Marine Protected Areas in the Context of Marine Spatial Planning – Discussion Paper for WWF-UK 〈http://www.wwf.org.uk/filelibrary/pdf/zoning_mpa__msp.pdf〉, 2004.
[33] J. Malczewski, GIS and Multicriteria Decision Analysis, John Wiley & Sons, Toronto, 1999.
[34] T. Stewart, A critical survey on the status of multiple criteria decision making theory and practice, Omega 20 (5/6) (1992) 569–586.
[35] S. Drobne, A. Lisec, Multi-attribute decision analysis in GIS: weighted linear combination and ordered weighted averaging, Informatica 33 (2009) 459–474.
[36] T. Saaty, A scaling method for priorities in hierarchical structures, J. Math. Psychol. 3 (1977) 234–281.
[37] Rong Mu, Luoping Zhang, Qinhua Fang, Ocean-related zoning and planning in China: a review, Ocean. Coast. Manag. 82 (2013) 64–70.