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ARTICLE

Incorporating expert knowledge for development spatial modeling in assessing ecosystem services provided by coral reefs: A tool for decision-making

Incorporando conocimiento experto en el desarrollo de modelos espaciales para la evaluación de servicios ecosistémicos en arrecifes coralinos: Una herramienta para la toma de decisiones

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Resumen.- Es bien reconocido que los arrecifes coralinos proveen a los habitantes de las zonas costeras de valiosos servicios ecosistémicos. Tal vez debido a la heterogeneidad espacial de estos ecosistemas, existen pocos estudios que exploren el contexto espacial en que estos servicios se proveen. En este estudio se presenta un enfoque en el que se desarrollan modelos espaciales para la evaluación de los servicios ecosistémicos que proveen los arrecifes coralinos. Este enfoque permite incorporar el conocimiento experto de usuarios locales, integrando herramientas de análisis espacial y evaluación multicriterio, para el desarrollo de modelos espaciales que permitan evaluar los servicios ecosistémicos en el Parque Nacional Sistema Arrecifal Veracruzano. Se contrastaron los modelos obtenidos con información de monitoreos proporcionada por las autoridades del parque. Los modelos fueron consistentes y mostraron concordancia con los usos que se realizan actualmente dentro del sistema. Esto indica que la incorporación del conocimiento de usuarios locales es útil para identificar, agrupar y evaluar los servicios ecosistémicos en ambientes complejos. Este enfoque puede ser un aporte importante para el proceso de toma de decisiones, cuando se generan propuestas de zonificación y otras estrategias de manejo en sistemas arrecifales.

Palabras clave: Arrecifes coralinos, modelos espaciales, servicios ecosistémicos, conocimiento experto, toma de decisiones

Abstract.- Coral reefs provide coastal populations with valuable ecosystem services but few studies explore the spatial context in which those services are provided. This study presents a spatial modeling approach to assess ecosystem services provided by coral reefs. Our approach integrates spatial analysis tools and multi-criteria evaluation techniques to develop spatial models for assessing ecosystem services in the Parque Nacional Sistema Arrecifal Veracruzano (Veracruz Reef System National Park), incorporating local users´ knowledge. We compared the resulting models with both records of activities provided by park authorities, and information on distribution of fishing zones obtained from a workshop with fishermen. We found the models consistent with the actual uses within the system. This indicates that incorporating local users´ knowledge is useful in identifying, grouping, and evaluating ecosystem services in complex environments lacking hard data. This approach is an important contribution for the generation of zoning proposals and other management strategies in coral reef areas.

Key words: Coral reefs, spatial models, ecosystem services, decision making

INTRODUCTION

Coral reefs are among the world´s most complex, biologically diverse and productive ecosystems (Bellwood *et al.* 2004). They provide important ecosystem services (ES) such as regulation, physical structure, food supply, and various aesthetic and cultural attractions (Costanza *et al.* 1997, Moberg & Folke 1999, MEA 2005). Their complexity and frequent lack of adequate organization underscore the need for science-based management dealing with the representation of their environmental and social heterogeneity (Turner *et al.* 1995, Pickett & Cadenasso, 1995, Hein *et al.* 2006). The reefs also have a convergence of multiple activities including fishing, skin diving, research, and tourism. This requires the implementation of effective planning tools. These tools would integrate key stakeholders´ vital input required for successful management programs (Tompkins *et al.* 2000, Brown *et al.* 2001, Theobald & Hobbs 2002, Wilkinson 2008).

Geographical Information Systems (GIS) and remote sensing technology (Green *et al.* 2000) are valuable tools in resource allocation planning. These tools are also important to ES spatial variability mapping used to develop models for coral reef areas (Gustavson *et al.* 2000, Bruce & Eliot 2006, Müller *et al.* 2010). The integration of these tools, coupled with multicriteria evaluation methods have been used to incorporate local knowledge in the development of spatial assessment models (Fernandes *et al.* 1999, Malczewski 2006, Bello-Pineda *et al.* 2006). These models in turn have been used to characterize coral reef areas (Mumby & Harborne 1999, Mumby & Edwards 2002, Bello-Pineda *et al.* 2005a), evaluate and manage fishing resources (Bello-Pineda *et al.* 2005b, Ríos-Lara *et al.* 2007, Jiménez-Badillo 2010), and analyze the distribution of ecosystem services (Mumby *et al.* 2007, Naidoo *et al.* 2008, Sanchirico & Mumby 2009). However, the spatial context in which those services are provided within reef areas has been marginally studied.

Marine Protected Areas (MPAs) have become imperative in the management of coastal and coral reef resources (Beck & Odaya 2001, Syms & Carr 2001, NOAA 2009[1]). In Mexico, approximately 4.8% of coral reef areas receive some protection under Mexico´s national system of natural protected areas (CONABIO-CONANP-TNC-PRONATURA, 2007)[2]. The Comision Nacional de Áreas Naturales Protegidas (CONANP) is responsible for their protection, management, and recovery (CONANP 2013)[3]. However, the establishment and further development of conservation and management programs in these protected areas represents a significant challenge (Jordan *et al.* 2005, Burke *et al.* 2011). Herein, we provide information to managers to improve the process of management plans.

In the Gulf of Mexico, the Veracruz Reef System National Park (VRSNP), hereafter referred to as the park, was decreed to 'preserve and promote conservation by protecting the continuity of its ecological processes as well as preserving its biodiversity' (CONANP 2007)[4]. Despite this announcement, the reef system is threatened by coastal population growth and urban expansion over fringing reefs, including mining for construction material. Currently, part of the reef area is being covered with tons of sand used as foundations for a major port expansion (Valadez-Rocha & Ortíz-Lozano 2013). The threats ES face in these areas affect local users whose livelihoods depend upon the park (Ortíz-Lozano 2012). The park has been studied by several research groups (Granados-Barba *et al.* 2007, Tunnell Jr. *et al.* 2007) that developed methodological and conceptual frameworks. These frameworks not only need to be used to address serious issues threatening the reefs, they can provide a call for action to manage and protect this vulnerable area (Ortiz-Lozano *et al.* 2009, Reyna-González *et al.* 2012). Unfortunately, there is no comprehensive approach incorporating an array of local knowledge to spatially represent the importance of ecosystem services provided by this system.

Our study aims to develop a methodological approach integrating perceptions of local stakeholders to develop spatial models and assess ecosystem services provided by coral reefs within the park. We then compared the results with data from two sources: activity reported in the monitoring and surveillance records provided by park authorities, and information gleaned from a fishing zone distribution workshop held with experienced fishermen. The purpose of the present study is to incorporate stakeholders´ perceptions when constructing models for development of management strategies. This approach would allow park authorities to establish conservation priorities, setting zones for different uses, and defining alternative management strategies, all in accordance with the activities and needs of park users.

Materials and methods

Study area

The VRSNP is located in the southwestern shelf of the Gulf of Mexico, adjacent to the cities of Veracruz and Boca del Rio, which have become one of the largest urban

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[1]NOAA. 2009. Coral Reef Conservation Program. International Strategy 2010-2015. <http://coralreef.noaa.gov/aboutcrcp/strategy/currentgoals/resources/intl_strategy.pdf>
[2]CONABIO-CONANP-TNC-PRONATURA. 2007. Análisis de vacíos y omisiones en conservación de la biodiversidad marina de México: océanos, costas e islas. <http://www.biodiversidad.gob.mx/pais/pdf/LibroGapMarino.pdf>
[3]CONANP. 2013. Parques nacionales, CONAMP, México. <http://www.conanp.gob.mx/que_hacemos/parques_nacionales.php>
[4]CONANP. 2007. Anteproyecto Programa de Conservación y Manejo Parque Nacional Sistema Arrecifal Veracruzano, Documento de Consulta Pública, 207 pp. Comisión de Áreas Naturales Protegidas, Veracruz.

areas in the Gulf of Mexico. Veracruz is the second most important trading port in the country (Martner 2002). The current polygon of the park has a total area of 52.23 x 10^3 ha (DOF 1992)[5] (Fig. 1), and consists of 23 platform reefs (Lara *et al*. 1992) including 6 islands and sandy keys. It was decreed a national park (DOF 1992), a Ramsar Convention wetland (FIR 2004)[6], and a biosphere reserve by UNESCO (UNESCO 2006)[7]. Despite national and international recognition, the park still lacks an official management plan. Consequently, it hosts many activities, including commercial and sport fishing, boat tours, SCUBA diving, and specimen collection, with little surveillance and law enforcement (CONANP 2007).

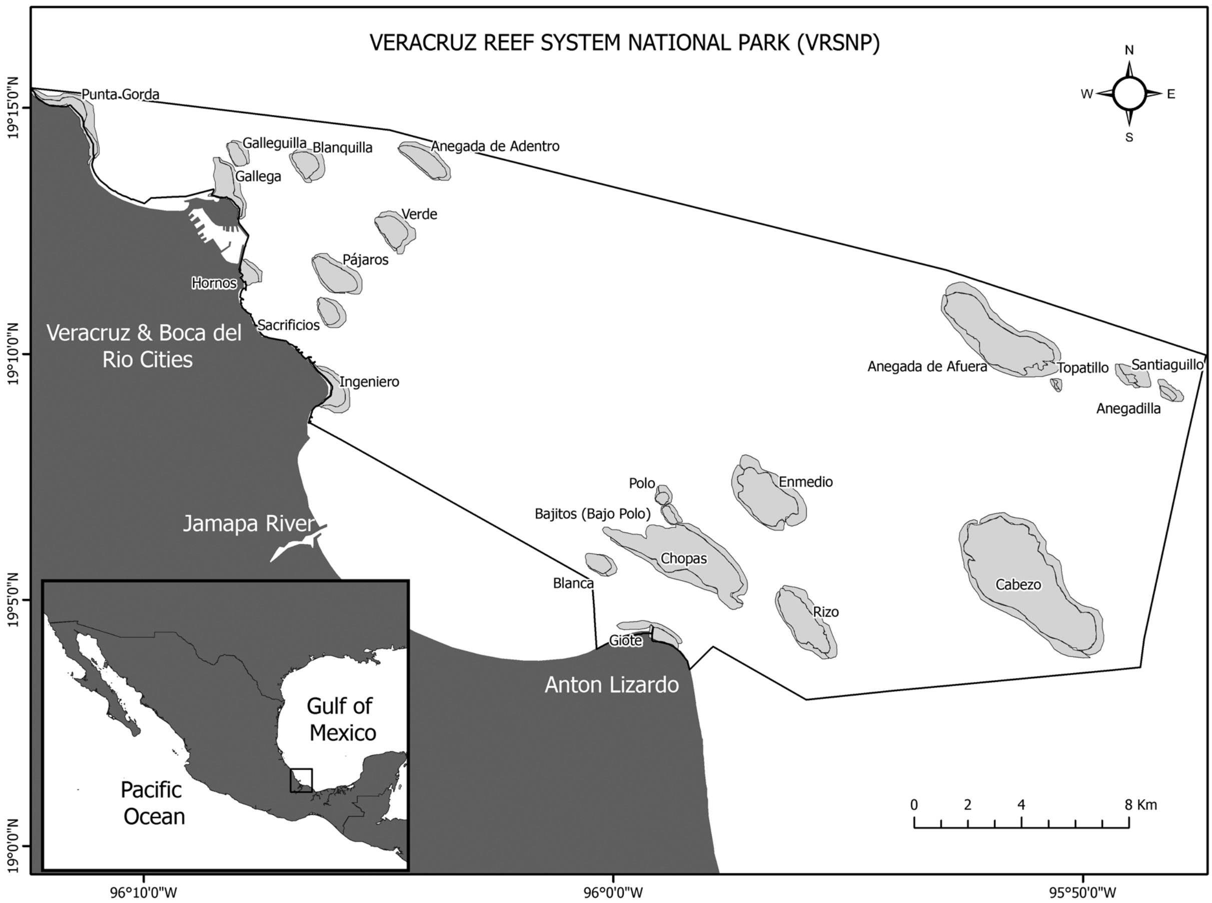

Figure 1. Veracruz Reef System National Park (VRSNP) / Parque Nacional Sistema Arrecifal Veracruzano (PNSAV)

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[5]DOF. 1992. DECRETO por el que se declara área natural protegida con el carácter de Parque Marino Nacional, la zona conocida como Sistema Arrecifal Veracruzano, ubicada frente a las Costas de los municipios de Veracruz, Boca del Río y Alvarado del estado de Veracruz Llave, con superficie de 52,238 hectáreas. <www.conanp.gob.mx/sig/decretos/parques/sav.pdf>

[6]FIR. 2004. Ficha Informativa de los Humedales de Ramsar. Sitio Ramsar. <http://portal.veracruz.gob.mx/pls/portal/docs/page/cgma/difusion/enps/ramsar/sitio%20ramsar%20sistema%20arrecifal%20veracruzano.pdf>

[7]UNESCO. 2006. Sistema Arrecifal Veracruzano. Man and Biosphere Programme. <http://www.unesco.org/new/en/natural-sciences/environment/ecological-sciences/biosphere-reserves/latin-america-and-the-caribbean/mexico/sistema-arrecifal-veracruzano/>

Definition of Environmental Management Units (EMUs)

For the methodological approach we assumed that each reef has particular characteristics, allowing to the provision of ecosystem services to be heterogeneously distribute within the system. To carry out the analysis on how services are provided in the park, we used a multi-scale hierarchical system based on previously proposed zoning schemes to define analysis units in 3 scales: a broad scale is the ecosystem zoning (subsystems) proposed by Ortiz-Lozano *et al.* (2009), an intermediate scale of reef groups proposed by Lara *et al.* (1992), and a fine scale the definition of Environmental Management Units (EMUs) corresponding to the reef lagoon and the windward and leeward slope for every individual reef as discriminated using the information available on ReefGIS server (ReefBase 2011). EMUs were defined based upon the concept proposed by López-Barajas & Cervantes-Borja (2002) and Brenner *et al.* (2006), as representative morphofunctional units with a certain degree of homogeneity and connectivity among their biotic and abiotic components, which have both ecological and administrative management applied to a fine spatial scale.

Development of spatial models to assess ecosystem services

On August 2011, the federal government indicated the current polygon of the VRSNP could be modified for the expansion of Veracruz port (CONANP 2011)[8]. To obtain the opinion from local users, CONANP officials organized a participatory workshop with a scientific research subcommittee (composed of the local academic community, of which the 4 first authors of this article were included, and park authorities). The objective of the workshop was to obtain and process the information to assist in defining zoning criteria for the area´s management program.

During the workshop, the first 2 authors of this article proposed a participatory exercise to incorporate the participants´ perception about the ecosystem services provided by coral reefs, using the scientific evidence available including: peer reviewed articles (Costanza *et al.* 1997, Moberg & Folke 1999), books (Ash *et al.* 2010, Burke *et al.* 2011), technical reports (UNEP 2006), research reports (Pérez-España & Vargas-Hernández 2008, Horta-Puga & Tello-Musi 2009, Reyes-Bonilla *et al.* 2011), as well as their personal experience and knowledge.

To code local experts knowledge for the development of the spatial models, the ecosystem services were grouped into categories (MEA 2005) by using the Analytic Hierarchy Process (AHP) (Saaty 1980) as implemented in the software package Expert Choice (EC 1998)[9], which systematically structures disorganized decision-making problems (Saaty 1990). Taking into account their knowledge, participant's assigned weights to ecosystem services provided by the park, using the pairwise comparisons method (EC 1998). By using the rating routine in the EC software, participants also assigned weights to each EMU based on its importance in the provision of every ES evaluated. Results were processed using the ArcMap™ Version 9.3 software (ESRI 2009)[10] to develop 4 theoretical spatial models, each associated to an ES category. To highlight the importance of each EMU in the provision of the ES evaluated, a color scale was used as proposed by TNC (2005).

Comparing spatial models with actual uses occurring at EMUs

Based on information of monitoring and surveillance records provided by park authorities (CONANP 2010)[11] and the results of the workshop held in 2000 with the participation of government authorities, academics, and local fishermen (CEP 2000), we produced digital maps (ESRI 2009) which represent the spatial distribution of tourism and recreational activities and fishing zones within the system. This information was compared with our results to verify the predictive accuracy of the 4 spatial models generated.

Results

Definition of Environmental Management Units (EMUs)

Results show the distribution of 61 EMUs grouped into 2 subsystems proposed by Ortíz-Lozano *et al.* (2009): 26 of

[8]CONANP. 2011. Estudio Previo Justificativo para la modificación de la declaratoria del Parque Nacional Sistema Arrecifal Veracruzano, 87 pp. Comisión de Áreas Naturales Protegidas, Veracruz.
[9]EC. 1998. Expert choice professional software. CD Version 9.5 for Windows©
[10]ESRI. 2009. ArcMap by ArcGIS software. CD Version 9.3 for Windows
[11]CONANP. 2010. Comisión de Áreas Naturales Protegidas. Bitácora de uso del PNSAV 2010

which were assigned to reefs at the northern Veracruz subsystem (VS), and 35 were allocated to the southern Anton Lizardo subsystem (ALS) as shown in Figure 2.

Development of spatial models to assess ecosystem services

Workshop participants identified and evaluated some of the most conspicuous ecosystem services provided by the park, and grouped them into 4 broad categories: cultural, regulatory, support, and provision (Table 1). The structure of the hierarchical assessment scheme generated by AHP is shown in Figure 3. At the first hierarchical level the groups of ecosystem services were allocated. Then, at the second level they were disaggregated by individual ecosystem services provided by the EMUs evaluated. The resulting AHP-derived weights assigned to ecosystem services of the park as presented in Table 1.

Participants agreed that the EMUs evaluated are very heterogeneous and provide a diversity of quantity and quality of ES. The resulting spatial models (Fig. 4) show the level of importance of EMUs depending upon the ecosystem service contribution of each group.

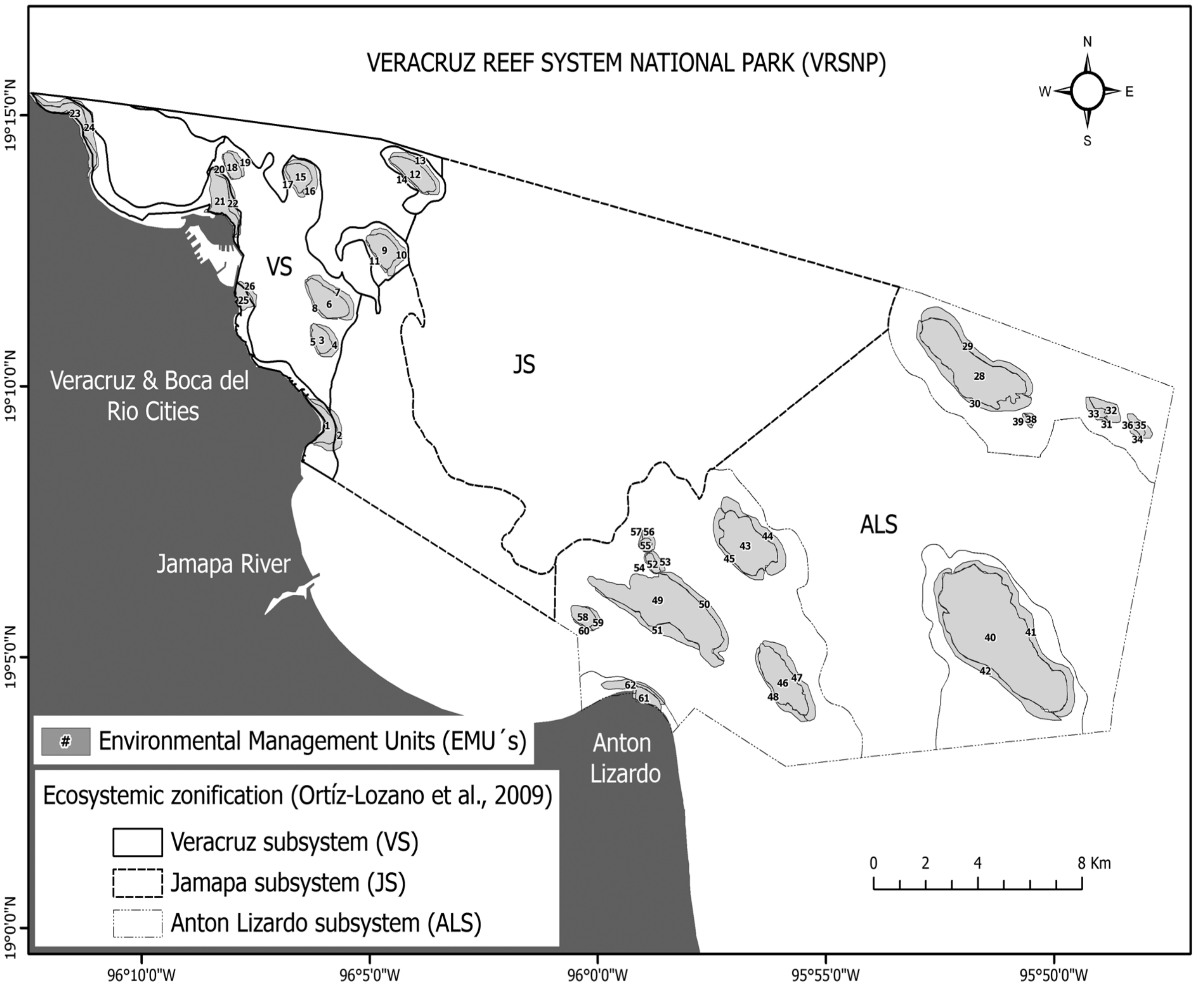

Figure 2. Spatial distribution of the Environmental Management Units in the VRSNP considering subsystems proposed by Ortiz-Lozano *et al.* (2009) / Distribución espacial de las Unidades Ambientales de Manejo (UAM) en el Parque Nacional Sistema Arrecifal Veracruzano considerando los subsistemas propuestos por Ortiz-Lozano *et al*. (2009)

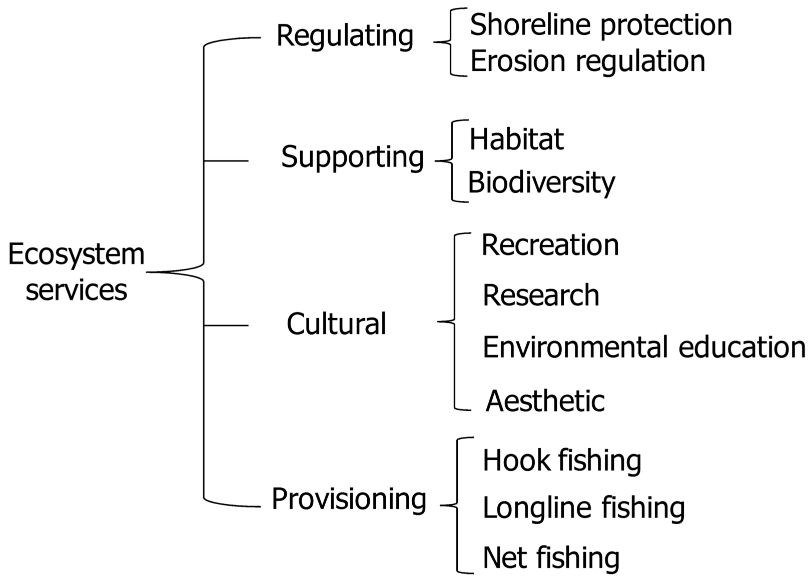

Figure 3. Veracruz Reef System National Park's ecosystem services hierarchical assessment scheme / Esquema jerárquico para la evaluación de los servicios ecosistémicos del Parque Nacional Sistema Arrecifal Veracruzano

Table 1. AHP-derived weights assigned to ecosystem services of Veracruz Reef System National Park / Pesos derivados del AHP asignados a los servicios ecosistémicos del Parque Nacional Sistema Arrecifal Veracruzano

Groups	Weight	Ecosystem services	Weight
Regulating	0.25	Shoreline protection	0.500
		Erosion regulation	0.500
Supporting	0.25	Habitat	0.500
		Biodiversity	0.500
Cultural	0.25	Recreation	0.310
		Research	0.296
		Environmental education	0.293
		Aesthetic	0.226
Provisioning	0.25	Hook fishing	0.363
		Longline fishing	0.341
		Net fishing	0.296

Comparing spatial models with current activities in the management units

According to CONANP´s monitoring and surveillance records, activities are distributed heterogeneously for both the Veracruz and Anton Lizardo subsystems. Reports show that EMUs located at Veracruz received considerably more visits than those at Anton Lizardo. EMUs located in the Verde and Anegada de Adentro reefs are the most visited for underwater activities (SCUBA diving) while those in Pájaros and Sacrificios reefs are the most visited for tourism and recreation activities, as shown in Figure 5. The Anton Lizardo EMUs located at Enmedio and Chopas reefs have been identified as the most important for tourism activities due to the number of visits to their islands. The EMUs at Giote reef are the most important for water sports and recreational activities (boating, jet skiing, kite surfing, water sledding and kayaking), as shown in Figure 6.

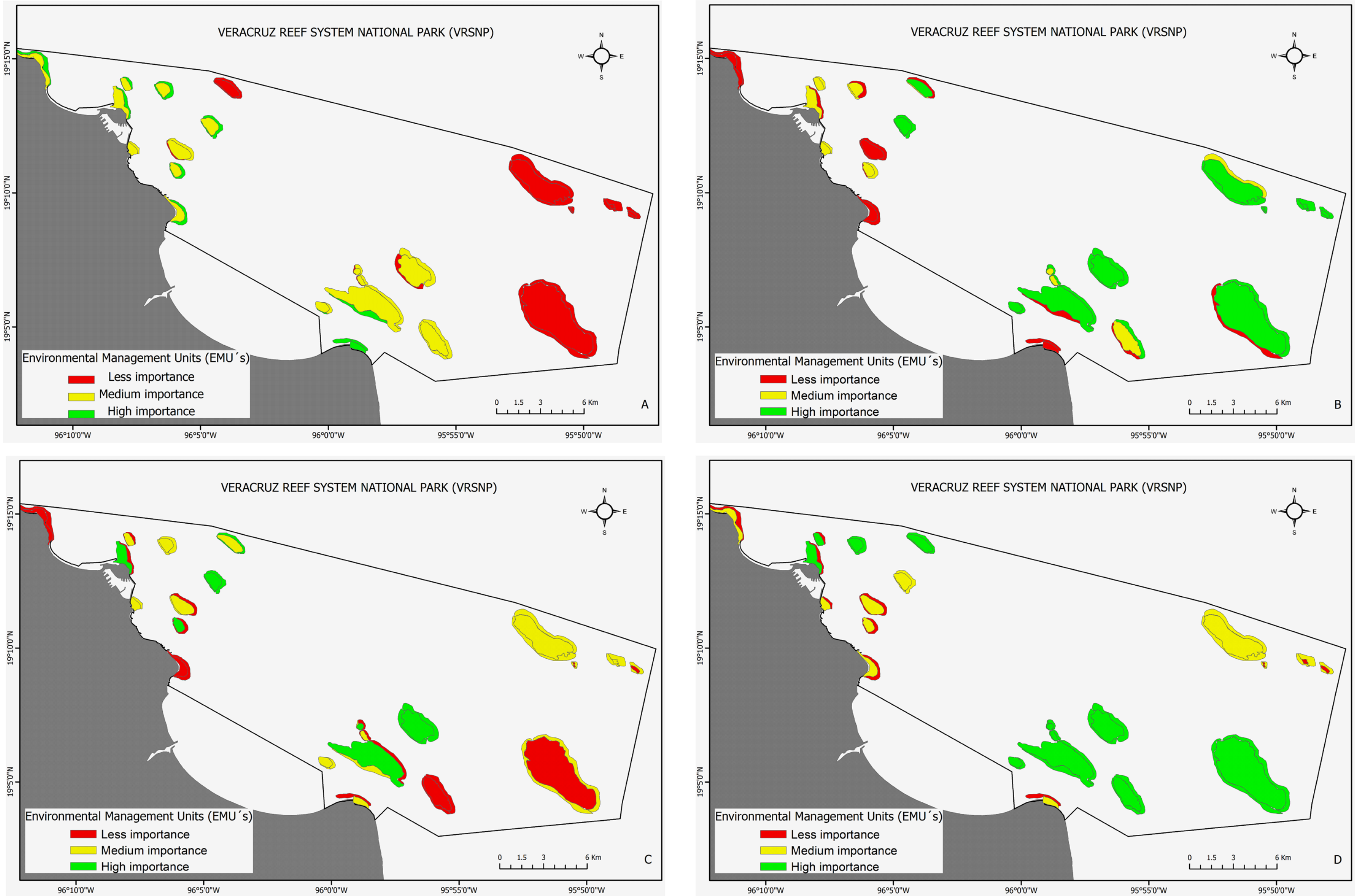

Figure 4. Spatial models showing the overall importance of EMUs in terms of their contribution to the provision of environmental services in VRSNP using a color scale (Green represents high, yellow medium and red low importance). a) Regulating ES model; b) Supporting ES model; c) Cultural ES model and d) Provisioning ES model / Modelos espaciales que muestran la importancia general de las UAM en términos de la contribución para la provisión de los servicios ecosistémicos en el Parque Nacional Sistema Arrecifal Veracruzano usando una escala de color (Color verde representa alta, amarilla media y rojo, baja importancia). (a) Modelo de los servicios ecosistémicos de regulación; (b) Modelo de los servicios ecosistémicos de soporte; (c) Modelo de los servicios ecosistémicos de tipo cultural y (d) Modelo de los servicios ecosistémicos de provisión

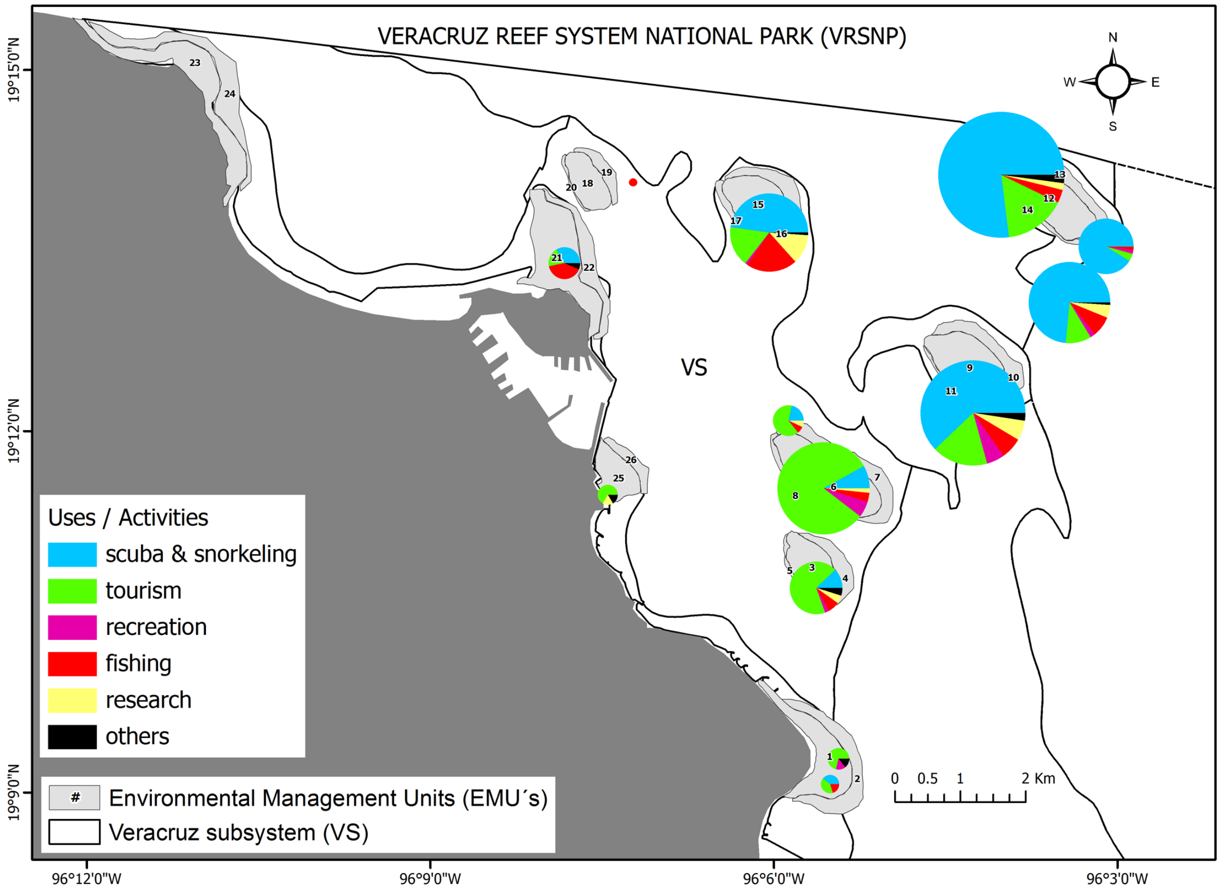

Figure 5. Spatial distribution of uses and activities occurred at EMUs in Veracruz Subsystem. The size of circle is proportional to total number of registers as provided by CONANP. Colors represent different uses / Distribución espacial de los usos y actividades que se desarrollan en las UAM en el Subsistema Veracruz. El tamaño del círculo es proporcional al número de registro total reportado para ese arrecife. Los colores representan cada una de las diferentes actividades

Results obtained from a workshop held in 2000 (government authorities, academics and local fishermen) showed that all EMUs within the park have significant importance for small-scale fishing which targets some valuable species. King mackerel (*Scomberomorus cavalla*), spanish mackerel (*Scomberomorus maculatus*), yellow tail snapper (*Oscyurus crysurus)*, octopus (*Octopus vulgaris*), and conch (*Strombus pugilis*), were among the species targeted using different fishing techniques (hook, longline, and nets). Fishing activity is currently being carried out by local fishermen inside and outside the park polygon, as illustrated in Figure 7.

The spatial models we developed showed an overall concordance with CONANP´s monitoring and surveillance records, an indication that the results closely match records provided by the park. Some information gaps are evident because no records exist for activities in some EMUs, especially for those at the Anton Lizardo subsystem, which are located at greater distances from shore.

Discussion

Results indicate that academics participating in the workshop perceived the provision of ecosystem services by the EMUs in the park is heterogeneous. Spatial models generated to assess ecosystem services indicated all EMUs differ in level of importance for the development of economic activities (SCUBA diving, tourism and recreational, research-academic and fishing) within the park. The model representing distribution of cultural

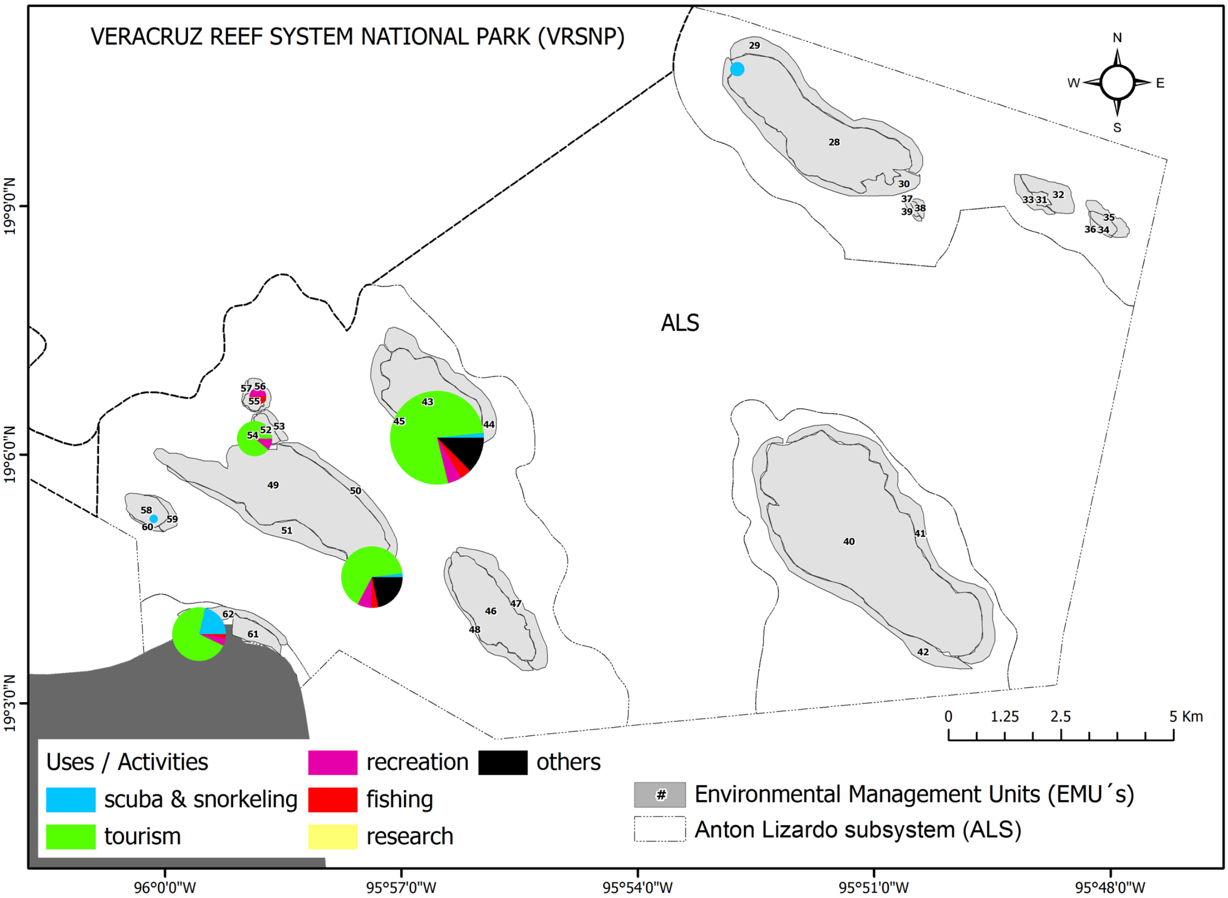

Figure 6. Spatial distribution of uses and activities occurred at EMUs in Anton Lizardo Subsystem / Distribución espacial de los usos y actividades que se desarrollan en las UAM en el Subsistema Anton Lizardo

services (Fig. 4-c) showed Veracruz EMUs, especially Verde and Anegada de Adentro reefs, of both high and medium importance. Our results agree with those of Arceo *et al.* (2010) who concluded these reefs have important economic values attributed to underwater activities (SCUBA diving and snorkeling). They also indicated EMUs of high and medium importance in Anton Lizardo´s Enmedio and Chopas reefs.

When comparing the spatial models generated from CONANP reports, it was evident that surveillance efforts by park rangers focus preferentially on EMUs located at the Veracruz subsystem, probably due to the intensity of visitors to the reefs of this subsystem. Unfortunately, we found no evidence of a regular monitoring program at the Anton Lizardo reefs. Our study can help improve park management by enabling authorities to identify cultural services that EMUs provide, and consider management strategies to lessen the intensity of visits in Veracruz subsystem.

The lack of information on supporting ecosystem services provided by the reefs is another important gap, which was identified by current analysis. In accordance with the supporting ES model (Fig 4 b), we can identify EMUs of high and medium importance for this type of service. Our results agree with studies on the biological characterization and current condition of the park (Pérez-España & Vargas-Hernández 2008, Horta-Puga & Tello-Musi 2009, Reyes-Bonilla *et al.* 2011), which identified and evaluated the composition and structure of the fish community, including coral reefs in the Veracruz subsystem. The studies indicated these units are under environmental stress caused by marine outfall, sediment runoff from the Jamapa River watershed, and increased port activities (Crosby *et al.* 2002, Lough 2008, Ortíz-

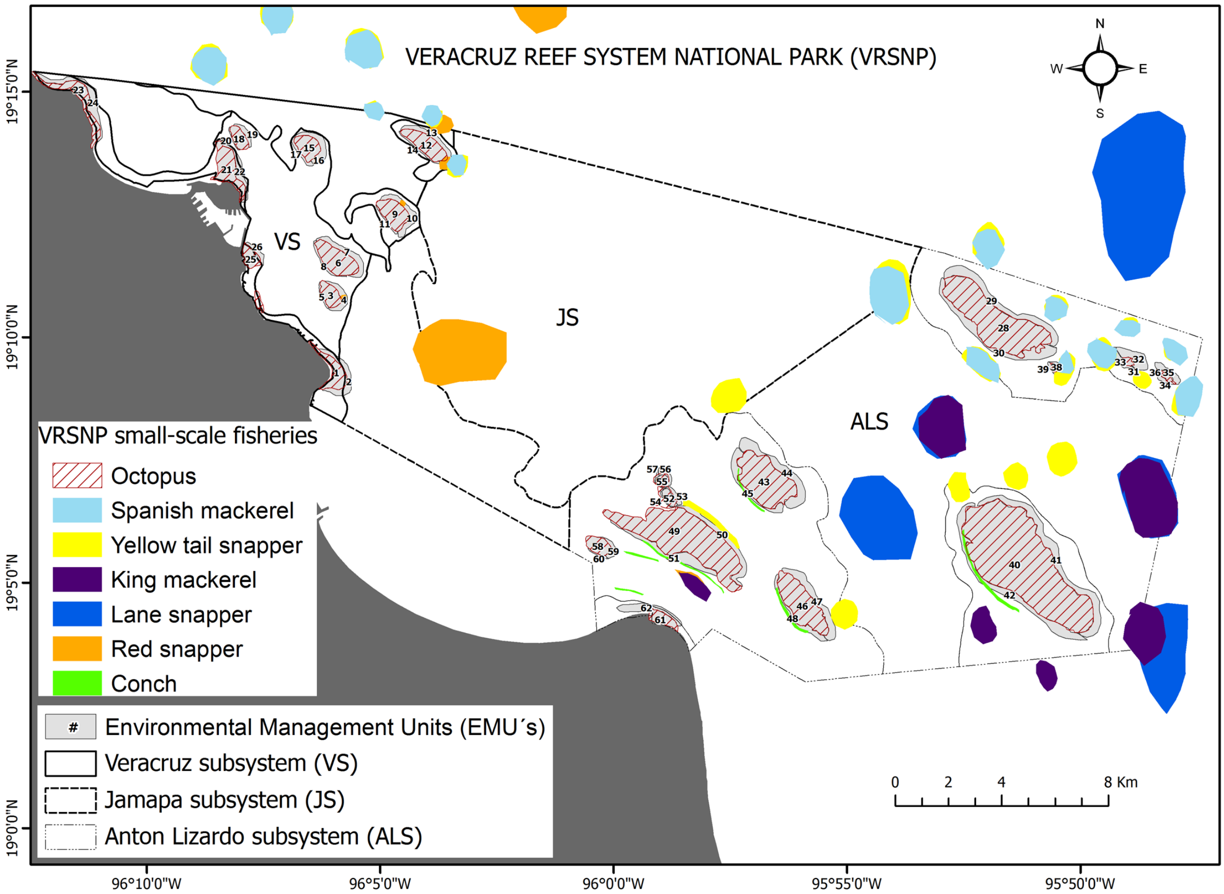

Figure 7. Spatial distribution of fishing zones at EMUs for the VRSNP / Distribución espacial de las zonas de pesca en las UAM del PNSAV

Lozano 2012). As a result of these processes, the park suffers a serious decline of coral cover (Jones *et al*. 2008). We believe our results will help identify high level EMUs with supporting ecosystem services, which will contribute to the establishment of a continuous biological monitoring program.

Workshop participants believe the model representing distribution of regulating ecosystem services provided by EMUs at fringing reefs has a high level of importance. These units contribute in many ways, from sediment capture to protecting the coast from destructive events such as tropical storms and hurricanes (Souter & Lindén 2000, PIANC 2010). Our results agree with Valadez-Rocha & Ortíz-Lozano (2013), which mentioned that EMUs at Punta Gorda reef (located at the northern end of the system) acts as a buffer zone for the discharge from sewage treatment plants, reducing the impact on other units of the system. However, according to available plans, this reef is targeted to be excluded from the current park polygon to allow expansion of the port (Valadez-Rocha & Ortíz-Lozano 2013). Consequently, the provision of these services may be threatened in the short and medium term.

Our present approach proved useful for systematically coding our knowledge, and by allowing interaction between system users and stakeholders (Müller *et al*. 2010). Local academics input suggested that 90% of the EMUs have medium or high importance for provision ecosystem services, mostly fishing; nevertheless, there are many issues and challenges to resolve for the management of artisanal fisheries in the park. According to Jiménez-Badillo (2008) 60% of Anton Lizardo families depend entirely upon this source of revenue. Their wellbeing will be threatened if no regulatory fishing management is implemented for the park. According to Fernandes *et al*. (2005, 2009) better management of reef fisheries suggest including the establishment of no-taking zones. The implementation of closed zones in the park would be a serious challenge for both fishermen and local authorities.

The integrated and sustainable management of ecosystem services in a marine protected area require consideration about knowledge of the ecosystem functioning and its response to disturbance (Bellwood *et al*. 2005, MEA 2005, UNEP 2006), existing regulation (CONANP 2007), as well as the social and political aspects involving local users´ knowledge to contribute in resource generation, allocation and management (Brown *et al*. 2001, Wilkinson 2008). The environmental heterogeneity in a natural system demands the implementation of a multi-scale approach (Pickett & Cadenasso 2002, Wu & David 2002, Hein *et al*. 2006), providing an opportunity for the development of spatial models to represent the series of activities (fishing, scuba diving, tourism trips, research), that have to be considered in the park management program. In this regard, Lara *et al*. (1992) was the first to generate the concept of a zoning method to describe the main structure of reef communities in the park. The ecosystem-zoning proposed by Ortiz-Lozano *et al*. (2009) could allow a better understanding of the structural complexity of the park. Our methodological framework integrates theoretical principles of previous work with a hierarchical perspective to better understand and represent the ecosystem services provision at a finer scale.

In conclusion, the described approach was useful for systematically identifying, grouping and evaluating the ecosystem services that, according to local users´ perceptions are provided by coral reefs systems. Because the workshop exercise included the participation of only two local experts groups (authorities and academics) and not all disciplines were represented, it would be desirable to conduct similar exercises involving other groups of stakeholders (diving & tourism service providers) and particularly artisanal fishermen, in case authorities develop and eventually implement a fishing management program in the park. Despite of the low diversity in stakeholders´ participation, we found that this type of approach may be useful in decision-making scenarios when dealing with unstructured problems and lack of hard data. The results of our study can provide input for further workshops, and also become a useful tool to support the decision-making process for the design of zoning schemes and to define strategies in the design of a management plan for the park.

We finally recommend participatory workshops such as the ones described in this study; however it would be equally important that authorities involved in this process improve their awareness capability to provide incentives, which would enhance stakeholder’s participation.

Acknowledgments

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