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Ecosystemic zonification as a management tool for marine protected areas in the coastal zone: Applications for the Sistema Arrecifal Veracruzano National Park, Mexico

L. Ortiz-Lozano [a], A. Granados-Barba [a], I. Espejel [b,*]

[a] Unidad de Investigación de Ecología de Pesquerías, Universidad Veracruzana, Av. Hidalgo #617, Col. Río Jamapa, C.P. 94290, Boca del Río, Veracruz, Mexico
[b] Facultad de Ciencias, Universidad Autónoma de Baja California, Carretera Tijuana-Ensenada Km 103, C.P. 22860, Ensenada, Baja California, Mexico

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ABSTRACT

Protected marine areas management depends mainly on the zonification schemes applied. The aim of the present work is to propose a zonification scheme for protected marine areas in the coastal zone, based on the ecosystem features. This ecosystemic zonification is based on structural and functional elements of marine ecosystems, and allows the incorporation of the main environmental characteristics into the management plan of these areas, whether information about biotic factors is available or not. Based on this, a zonification of the Sistema Arrecifal Veracruzano National Park is proposed, which considers the identification of various subsystems, seascapes and environmental units within nested scales, to be included in the national park management plan.

1. Introduction

During the eighties and nineties of the 20th century, conceptual schemes and ecologically-oriented methodologies for planning and managing territory thrived. The schools of thought directed towards environmental planning stemmed from different areas; (a) the theory of complex systems [1–3]; (b) landscape ecology [4,5]; (c) geographical models [6] and (d) ecosystemic simulation models [7].

Several methodological proposals have been developed from these fields [8–16]. Particularly, Gómez-Orea [17,18] and Cendrero [19] developed a methodology for the planning and management of coastal zones in Spain. In Mexico, official proposals have emanated from the federal government and are basically oriented to terrestrial areas [20–22].

The philosophy of these proposals is oriented towards protecting landscape sustainability within an integrated approach where regional and local biophysical and socio-cultural information is considered. Their methods identify the capacity of the territory to sustain environmental policies and to face the challenge of integrating development with the environment [8,23,24].

In an environmental planning scheme, zonification facilitates identifying geographical areas with a combination of unique physical, biological, human, terrestrial or marine characteristics that can be interpreted in terms of objectives outlined by the managing authorities [25]. In the case of marine protected areas in the coastal zone (MPACZ), the use of zonification schemes allows a gradual implementation of actions with different degrees of protection. To achieve a gradient in the intensity of use and protection of different zones, specific policies and rules must be dictated for each zone, thus attempting to create a management plan for a heterogeneous place such as a MPACZ.

Two types of problems arise when creating MPACZ zonification schemes for management and conservation purposes: firstly, significant scientific information to provide a detailed description of the biological aspects of these reserves is lacking [26,27]; and secondly, the environmental processes that describe the intrinsic heterogeneity of the coastal area, principally the marine component, are scarcely known [27,28].

In this study, we used the ecological marine framework for the conservation of biodiversity proposed by Zacharias and Roff [29], taking as reference the ecosystem's structural and functional abiotic attributes, in order to describe the intrinsic heterogeneity of the MPACZ, generating what we presently term ecosystemic zonification (EZ). This zonification scheme is being used in the process of developing the Sistema Arrecifal Veracruzano National Park (PNSAV) management program; however, the present work does not describe this process, but only the ecosystem-based zoning scheme.

The EZ is based on the fact that, in marine ecosystems, abiotic characteristics importantly mold and define the presence of biologically lower hierarchical level communities and populations [29–31]. These abiotic attributes are observable phenomena

* Corresponding author. Tel.: +52 646 174 5925; fax: +52 646 174 4560.
E-mail address: iespejel@gmail.com (I. Espejel).

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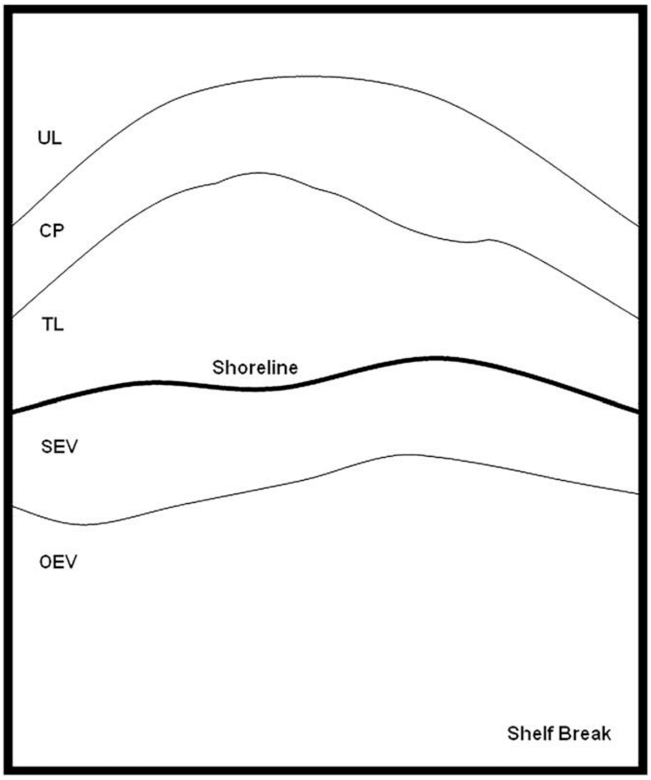

Fig. 1. Coastal zone ecotones. UL: uplands, CP: coastal plains, TL: tide lands, SEV: shoreface entrainment volume (at inner shelf), OEV: offshore entrainment volume (at outer shelf) [31,33,42].

employed to understand and monitor marine biodiversity. They also reveal the heterogeneity of these systems [28] because they characterize different ecotones of the marine environment [32,33].

The fundamental difference between terrestrial and marine systems lies in the predominance of the aquatic environment, where water properties have profound effects on the biological and physical characteristics of the environment [26,29]. MPACZ management must consider the three dimensions of the marine environment, in addition to the regional connection created by the exchange of water masses [26,34]. In contrast with the terrestrial natural protected areas, it is almost impossible to establish physical limits in MPACZs that define the flow of material and energy. Marine areas thus behave as extremely open systems and are dependent on this exchange with neighboring areas, a situation that increases their vulnerability in terms of human activity [35,36].

To undertake the zonification of a MPACZ from the perspective of the ecosystem, it is necessary to identify the factors that determine the heterogeneity of its coastal areas. Firstly, those related to the coastal zone *per se* must be understood. Multiple approaches exist for defining geographical limits in coastal and marine zones [30,37–40]. However, all these definitions take into account a terrestrial and a marine component, as well as a transition zone, where these two components come into contact. The presence of these components illustrates the marked heterogeneity of coastal systems that can also be observed in terms of the previously mentioned concept of ecotones [32].

Escofet [31] describes a number of frontiers or ecotones that generally run parallel to the coast [33] (Fig. 1), which serve to understand the functional character of the coastal area. Energy flows can be observed between these ecotones, particularly regarding differential movements of sediments and water currents [41]. This approach facilitates the understanding of the functional relationships between the components of the coastal area [31,42,43].

1.1. MPACZ zonification in Mexico

In Mexico, with the aim of preserving marine resources and coastlines, and to safeguard the genetic diversity of wild species and their ecosystems, the federal government has created marine reserves, which dictate different levels of protection. Up until 2006, 30 MPACZs have been decreed, with protection and management policies that rely on administrative programs, which are in turn based on different activities and intensities of use of the MPACZ. Their central aim is to preserve the biodiversity of the protected environment.

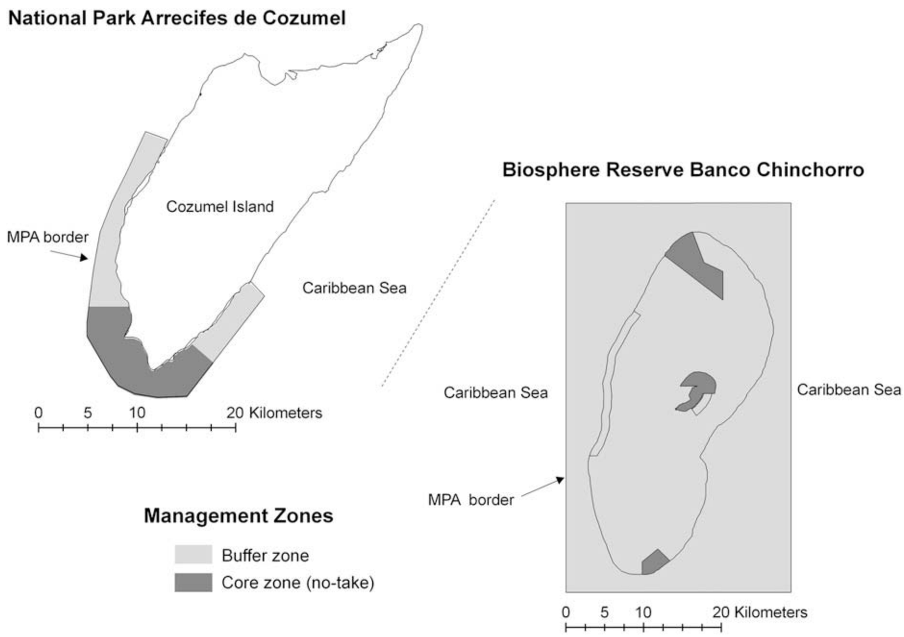

Fig. 2. Zonification schemes for the MPACZ in the Mexican Caribbean. Source: National Commission for Natural Protected Areas, Mexico.

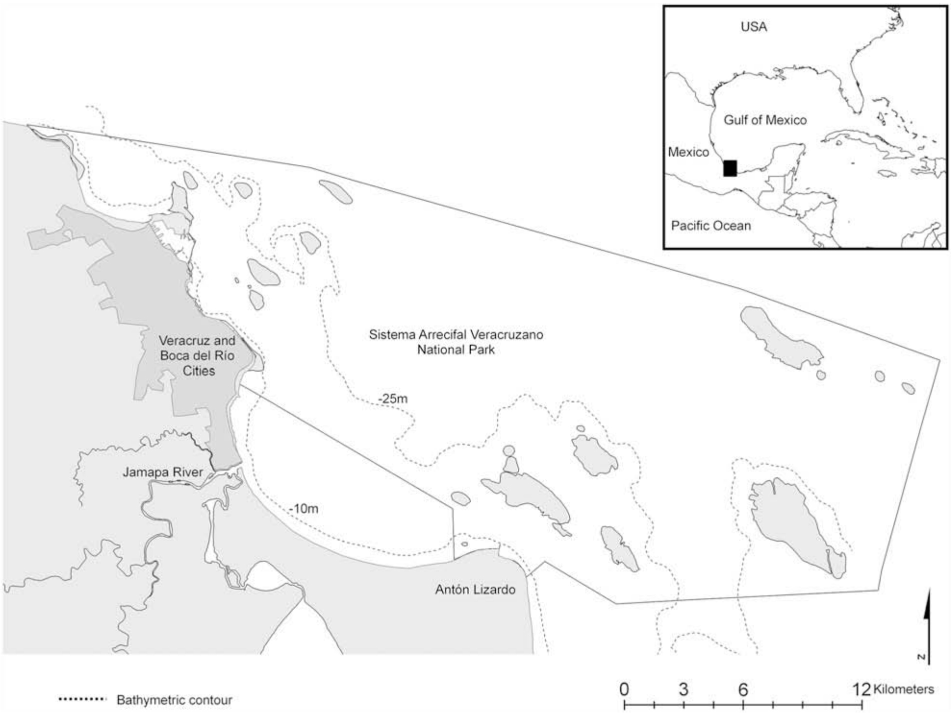

Fig. 3. The Sistema Arrecifal Veracruzano National Park (PNSAV).

In the Mexican General Law for Ecological Balance and Protection of the Environment (LGEEPA for its initials in Spanish), zonification is defined as "*a technical planning instrument which can be used to establish Natural Protected Areas (NPA), allowing to organize the territory in terms of its conservation and the representativeness of its ecosystems, taking into account the natural vocation of the land and its current and potential use, in conformity with the objectives outlined in this declaration.*" In addition, the LGEEPA mentions sub-zoning as a technical and dynamic planning instrument that must be incorporated into the respective management plan of an NPA, with the aim of organizing the core and buffer zones defined in the corresponding reserve decree.

At present, MPACZ zonification depends on the identification of required levels of conservation within the reserve, which must establish stricter zones (core zone) and more relaxed zones that allow human activities (buffer zones) within a plan of sustainable development (Fig. 2). This zonification system, which has been successfully applied to terrestrial NPAs, however, is not necessarily the most appropriate for the protection of coastal areas, including marine and terrestrial ecosystems, because of the above-mentioned structural and functional differences between these two types of environment [26,29].

In the light of the fact that sustainable management may be more successful when based on ecosystem functioning [30,44–46], the present project aim was to outline an approach for an MPACZ ecosystemic zonification, using a Mexican example, the Sistema Arrecifal Veracruzano National Park (PNSAV for its acronym in Spanish). This example incorporates the functions of the coastal areas, to produce guidelines that indicate the most appropriate management and conservation efforts.

The PNSAV is a coral reef protected area located on the Gulf of Mexico east coast, in front of the city and port of Veracruz (Fig. 3). The PNSAV consists of 23 coral structures, including six islands, which formed in an area where coral formations are limited by the incoming waters of the Antigua, Jamapa and Papaloapan rivers [47], and the strong winter winds called "*nortes*". It is an important system of the central Gulf of Mexico region, and together with the coral reef systems of the north of Veracruz (Tuxpan), these may act as a reservoir, bridge and species dissemination point between the Caribbean and Florida coral reefs [48]. A number of fisheries of commercial importance exist within the PNSAV [49] as well as extraction sites for arts and crafts purposes [50], ornamental fish, and aquatic tourism activities, especially scuba diving.

In 1992, the Sistema Arrecifal Veracruzano (SAV) was declared a natural protected area, and the marine park was converted into a national park. The National Commission of Knowledge and Use of Biodiversity (CONABIO for its acronym in Spanish) declared it a priority marine region in Mexico, and the International Coral Reef Initiative defined it as an important conservation zone. In 2004, it was classified as a RAMSAR site and in 2006 it was declared a biosphere reserve by UNESCO. This has recently caused it to become a greatly studied coral reef area [49,51,52].

Table 1
Criteria for identifying heterogeneity factors in the PNSAV.

Hierarchical level	Criteria
Subsystem	Morphology of the PNSAV, presence of the Jamapa river (northern, central and southern components)
Seascape	Strips parallel to the coast: bathymetry and currents (littoral fringe, inner shelf and outer shelf)
Environmental unit	Presence of coral reefs (individual or coalescent)

2. Methods

The zonification proposal for the PNSAV ecosystem was based on a hierarchical landscape nested scale [3,31], that helped to identify the subsystems, seascapes and environmental units comprising it (Table 1). To identify the PNSAV internal heterogeneity, current physical characteristics of the area were considered, which, according to Zacharias and Roff [29], provide a general definition of the ecosystems structure and function.

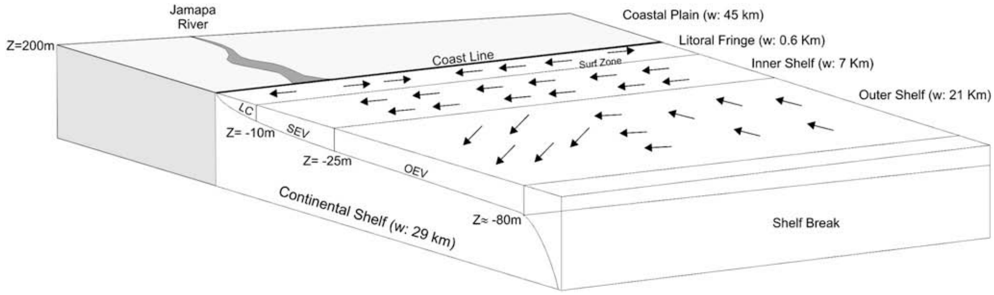

Fig. 4. Ecotones of the coastal zone related to the PNSAV. LC: littoral currents; SEV: shoreface entrainment volume; OEV: offshore entrainment volume; W: width; Z: elevation with respect to sea level. Arrows indicate the direction of the currents.

In the subsystem scale, the physiographic characteristics of the PNSAV were evaluated with maps of 1:250,000 scale (large scale) taking into account shoreline contour, presence of river outflows and coral reef geographic distribution. In the seascape scale, a bathymetric model of the area was obtained from S.M. 822 (Veracruz and Puerto de Alvarado) and S.M. 823 (Veracruz and the surrounding area) maps from the Ministry of the Mexican Armed Marines.

This information together with data on current patterns and water masses circulation revealed bathymetric discontinuities, associated with flow variations of water masses that circulate in the protected area [52]. Finally, different environmental units were identified on a local scale. These were delimited by the isolated or coalescent coral reefs that form the PNSAV.

3. Results

The most evident physiognomic feature of the PNSAV on a large scale (1:250,000) is the natural division of the system into two subsystems, separated by the Jamapa river outflow; the subsystems correspond to the northern coral reef opposite Veracruz city and the southern coral reef opposite Anton Lizardo town (Fig. 3).

On the seascape scale, the PNSAV was divided into three large areas, associated with the contours of depth and the water currents (Fig. 4): littoral fringe (LF), inner shelf (IS) and outer shelf (OS). The LF corresponds with the littoral zone, and in this study, the area is located between 0 m and the 10 m isobathic contour. Littoral currents move parallel to the coast along this fringe with latitudinal and seasonal variations [53] (Table 2).

The second section, known as the inner shelf (IS), was defined by the presence of marine currents that move parallel to the coast, and these are referred to as shelf-water parallel to the coast [31], or *shoreface entrainment volume* [33]. In the studied zone, these currents generally move along the fringe located between the LF and the 25 m isobathic contour, with seasonal variations [52,54].

The outer shelf (OS) includes the waters free from the shelf (WFS) [31] or *offshore entrainment volume* [33]. In contrast with the other divisions, this is a zone where the water currents present a local movement, not parallel to the coast, and generally move at depths greater than 25 m up to the limit of the continental shelf and present seasonal variations [54,55].

Within the following hierarchical scale, i.e. the scale of environmental units, the presence of coral reefs was considered within each seascape. It was determined whether coral structures were isolated (individual) or if they were joined to other coral constructions (coalescent). Following these criteria, we identified three subsystems, eight seascapes and 14 environmental units (Fig. 5).

Table 2
Characteristics that define the seascapes of the PNSAV within the zonification process.

Seascapes (strips parallel to the coast)	Bathymetric characteristics (structure)	Hydrological characteristics
1. Littoral	0 m–10 m	Littoral current, displacement parallel to the coast with geographical and seasonal variations
2. Inner shelf	10 m–25 m	Water currents moving parallel to the coast, with seasonal variations regarding direction [31,55,68]
3. Outer shelf	More than 25 m	Water currents free from the shelf, average displacement is not parallel to the coast, and presents strong seasonal and geographical variations [31,54,55]

4. Discussion

Although whether NPAs can really accomplish their aims is still being discussed at present [56,57], the generation of zonification schemes constitutes a first step to create management programs that will be consistent with the MPACZ aims. Laffoley [58] states that the zonification procedure provides a mechanism to explain management process to the broad public in an understandable format. In this context, Kelleher [59] indicates that zonification is the best way to assure strict protection for the core zone that forms part of a larger protected area with multiple uses. Zonification has been the cornerstone for the management of important marine parks, such as the Great Barrier Reef [60], which has exceptional dimensions (345,000 km^2).

Zonification based on the biological attributes of the MPACZ has been applied to coral reef areas, taking the structure of the coral communities as reference, and the damage caused to them by deep-sea diving activities [61]. In addition, there are zonification viewpoints which integrate multi-criteria analysis, taking into account the environmental characteristics or the resources, as well as users and decision makers opinions [58,62]. These factors have proved effective to understand coastal and marine environments.

However, in spite of the fact that in several protected marine areas the criterion of an ecosystemic approximation to conservation is manifest [63], it is not reflected in their zonification, which is the basic instrument for the application of rules and conservation policies. Therefore, the creation of an ecosystemic zonification such as that presented herein, does not only consider the structure and function of marine ecosystems for protection purposes in terms of their heterogeneity [28], but it also facilitates the understanding and evaluation of natural aspects, as well as internal and external human factors that threaten it [42].

For example, the division of the PNSAV into three strips according to bathymetry and marine currents (marine seascapes) allows to identify a strip which is deemed as having a poor capacity

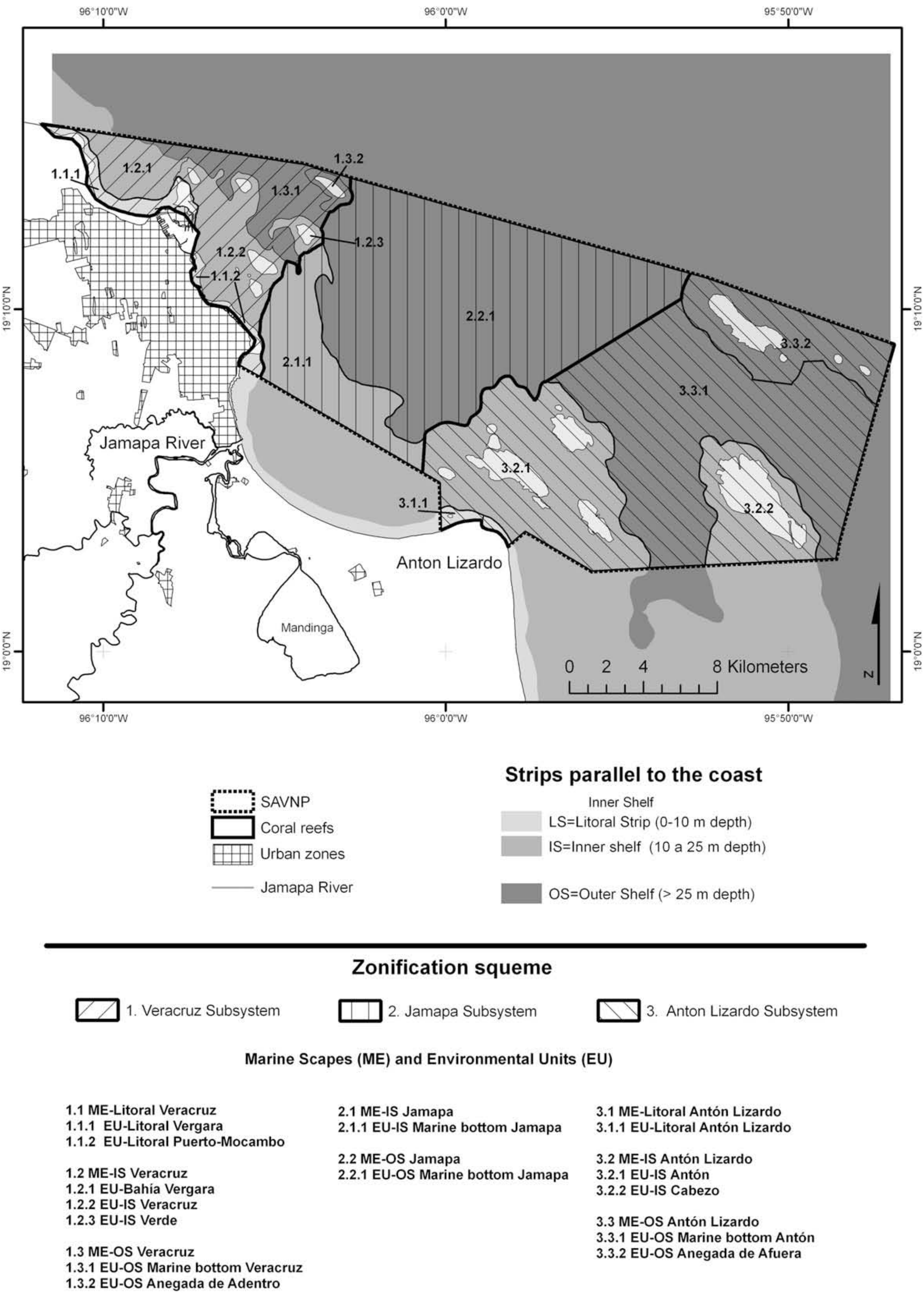

Fig. 5. Ecosystemic zonification of the PNSAV.

for cleanliness (LS) and one with a greater capacity for cleanliness (OS). Thus, the shelves located within each one of the seascapes show a different impact caused by the outflow of sewage from Veracruz city (greater impact in the LS and less in the OS) [64]. This example is also applicable to other shelf systems such as the Australian Great Barrier Reef where the effects of coral whitening are greater in reefs situated close to the coast, than in those further away [65].

Table 3
Advantages and disadvantages of ecosystemic zonification compared with zonification based on resource use.

Ecosystemic zonification	Zonification according to use
Ecosystemic abiotic parameters	Communities and populations Biotic parameters
Meso scale	Micro scale
Guided by the ecosystemic functioning of the NPA	Guided by interests of users These must be conceived by consensus in a plenary meeting
Uses concepts less easily understood by users and managers	Easily understood by users and managers
Allows to incorporate external areas, making it possible to predict their behavior	Focuses exclusively on the interior of the reserve, without considering external factors
Quick, requires little information and measurements in situ	Slow, requires much information and measurements in situ
Cannot be modified in short time scales	Updated every 5–10 years
Integrates with macroscale management tools, such as ecological marine and land regulations, because it links to other procedures of broad scale	Limited only to the interior of the reserve. It considers a zone of influence due to the adjacent and neighboring areas, but does not include them in the zonification itself

The approach presented here is also according to the international criteria for elaboration of integrated management schemes of coastal areas [66], where coherent management units are identified, representing functional geographical areas that provide the basis for administrative policies. Table 3 compares the EZ and the traditional zonification scheme that includes human usage of the protected area.

5. Conclusion

The present work considers that the efforts in several MPACZs to establish zonification schemes should have an ecosystemic focus, which can easily establish a sub-zonification where social and economic aspects relating to the areas under protection can be incorporated. This combination of approaches would incorporate environmental heterogeneity as well as structural and functional aspects of marine ecosystems (these being factors that determine the survival of organisms within these areas). This proposal is therefore relevant to conservation activities and offers clear and objective indicators that can be periodically evaluated, indicating the effectiveness of policies implemented for the preservation of these environments [42] and, as Rappaport [67] mentions, is best from a practical point of view.

Work concerning the types, classifications and schemes for zonification of MPACZs is still necessary in order to make them adequate regarding their sea or coastal aptitude or vocation (local essence), habitats, physiography and oceanic dynamics, as well as different types of activities that can be carried out there. In the case of the PNSAV, the present proposal is being directly used in the management program in progress.

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