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Spatial diversity of a coastal seascape: Characterization, analysis and application for conservation

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ABSTRACT

Recent conservation approaches have focused on the landscape as either a conservation target or a mechanism by which conservation can be achieved. A seascape is a spatially heterogeneous surface that is generally represented as a mosaic of patches (homogeneous units of natural vegetation) with spatial and functional relationships that are organized as puzzle pieces, which represent one or several ecosystems. Spatial analysis using a landscape ecology approach offers a wide range of tools to study, monitor, manage, and conserve these areas. The objective of this study was to identify the benthic community and spatially characterize the submarine habitats of the shallow coast along the Yucatan, Mexico, to identify priority conservation areas. The study area was divided into 3 zones based on their environmental qualities, and a total of 290 sampling sites were defined from a stratified random sample based on the unsupervised classification of Landsat ETM+ images. For each site, a video was taken; the substrate type was identified; and the organisms present were identified to the lowest possible taxonomic level. Training groups were defined by ordination analysis for the supervised classification of spectral bands and bathymetric modeling to obtain maps of the seascape, and the composition and configuration of the seascape were analyzed using spatial diversity metrics and indices. A total of 40 benthic morphotypes, predominantly brown algae and seagrass, were identified. Seven habitat types were defined along the coast based on the arrangement and spatial organization of the benthic community: bare substrate (A), sand with seagrass (B), seagrass meadow (C), seagrass with macroalgae (D), macroalgae on sand (E), flagstone with macroalgae (F), and macroalgal forest (G). The spatial configuration of the coastal seascape reflected the geomorphological characteristics of the study area and was significantly different among the three zones. Habitats G and F were present everywhere along the coast and dominated the seascape, whereas habitat C only occurred in Zone 3. Due to their structural complexity and biological richness, habitats C, D, F, and G are potentially critical for turtle, grouper, octopus, and lobster species, so these habitats are suggested as priority conservation areas to promote the conservation of these species as well as the productivity and functionality of these ecosystems.

1. Introduction

Since the 1990's, conservation perspectives have focused on landscapes either as conservation goals or as the mechanisms by which conservation can be achieved (Franklin, 1993). This new approach has stimulated awareness of the importance of surface heterogeneity, spatial patterns, and large-scale disturbances (Noss, 1983; Redford et al., 2003). The idea has been transformed from "conserve species" to "conserve spaces" with the aim of maintaining biological richness by promoting the conservation of space (Noss, 1990; Roff and Evans, 2002).

The landscape concept refers to a mosaic of elements (patches, corridors and a matrix) arranged in a given proportion, number, shape, location and area that characterize a particular territory (Morera et al., 2007) and represent natural habitats, cover types or land uses. This concept arose as a result of the interactions between abiotic conditions (i.e., climate, topography, and soils), biotic conditions, anthropogenic activities and the dynamics of natural disturbances that could be observed and evaluated from any scale (Forman, 1995).

The patches in marine landscapes (seascape) contain spatial

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variations in substrate types, nutrients, depths, and natural disturbances (McGarigal and Cushman, 2005; Pittman et al., 2011). According to Boström et al. (2011), the seascape configuration is a mosaic of patches where submerged aquatic vegetation is distributed as islands embedded in a matrix (Patch-matrix model), as a collection of patches of different types where the interaction of the parts influences the ecological function of the entire mosaic (Patch-mosaic model) (Wiens et al., 1997; Collinge et al., 2003) or as a continuum of patches without distinguishable boundaries, based on a projection of the morphological characteristics of the underwater territory (Gradient model) (Cushman and McGarigal, 2003; Pittman et al., 2009).

Heterogeneity and complexity are two key concepts in the study of landscapes. Heterogeneity represents horizontal variation in the physiognomy of habitats present in a given area, and complexity describes the development of vertical strata within a particular habitat (Mac Arthur and Wilson, 1967; August, 1983). In any natural landscape, heterogeneity and structural complexity are based on factors such as geomorphology, hydrology, and climate (Lugo-Hubp et al., 1992; Solleiro-Rebolledo et al., 2011) and can be used to define the distribution of ecosystems, the regulation of matter and energy flows, and the distribution of species and environmental services (Bradley and Maher, 2001; Rodríguez-Loinaz, 2004; Vila Subirós et al., 2006).

According to Gratwicke and Speight (2005) and other authors, complexity is positively related to wildlife diversity. Structurally complex habitats provide a greater number of niches and resources that increase biodiversity (McCoy and Bell, 1991; Tews et al., 2004). Thus, biodiversity is always linked to a habitat (Walz and Syrbe, 2013), which is the space with biotic and abiotic properties where an organism, population, or community lives. Habitats are differentiated according to their biotic and structural compositions (McCoy and Bell, 1991).

In the context of the landscape, heterogeneity represents the horizontal variation in the physiognomy of the habitats present in an area (Mac Arthur and Wilson, 1967; August, 1983), and a heterogeneous region is characterized by its high richness (number of habitats) and abundance (patches per habitat) (Gratwicke and Speight, 2005). In this sense, habitat heterogeneity in this study refers to the extent (area in km^2) and diversity (number) of habitat types.

On a global scale, the effects of anthropogenic activities and processes can bring about changes in habitat structures, decreases in habitat complexity and as a result, changes in the population structure and community composition (Thompson, 2005). Coastal environments do not escape the effects of anthropogenic activities. These environments are very important for secondary productivity, the transfer of matter and energy in the food web, and coastal biodiversity; however, many of the environments are located in the vicinity of densely populated regions (Weslawski et al., 2004; Lotze et al., 2006) and as a result are subject to stressors, such as eutrophication, dredging and overfishing, which generate a loss of diversity and a decrease in the quality of ecosystem services (Hughes et al., 2009; Boström et al., 2011; Watson et al., 2014).

The Aichi Biodiversity Targets for 2020 include the incorporation of at least 17% more protected terrestrial areas; 10% more inland, coastal, and marine water areas; and the restoration of at least 15% of degraded ecosystems (Convention on Biological Diversity, 2010). For 2014, approximately 10.1 million km2 (3% of the total area) of marine environments around the world were estimated to be located within protected natural areas, of which approximately 6.6% were in exclusive economic zones (Watson et al., 2014).

This situation has generated a growing need to identify the constituent factors of heterogeneity and complexity that influence species richness and abundance (Mörtberg et al., 2007; Pittman et al., 2009; Jörgensen et al., 2015). Therefore, one of the goals and objectives of environmental programs and plans is to promote the sustainable use of resources without jeopardizing biodiversity while maintaining habitat integrity (Hole et al., 2009). Key pieces include identifying the composition and distribution of communities and the characterization of the space where they are distributed (i.e., their habitats) (Steltzenmüller et al., 2013) to enable protected areas to be managed as a coherent network and not as isolated islands.

The Shallow Yucatan Coast of Mexico (SYC) is bordered entirely by environments of high ecological value (García-Frapolli et al., 2009). More than 60% of the coastal territory is included within the two Biosphere Reserves (Celestún and Ría Lagartos) and two state jurisdiction Protected Natural Areas (El Palmar and Bocas de Dzilam) (García de Fuentes et al., 2011); all four environments are recognized by the Convention on Wetlands of International Importance (RAMSAR).

Approximately 20% of the marine coast and lagoons of the State are associated with anthropogenic activities. Urban development and resource extraction exert strong pressures on biotic elements, resulting in changes in the structure and composition of the flora and fauna communities of the coastal seabeds and the functions of the ecosystems (Gobierno del Estado de Yucatán, 2007; Herrera-Silveira et al., 2010).

Considering the biological and scenic richness of sites such as the SYC, sustainable and objective management strategies that ensure the maintenance of marine diversity and ecosystem services are urgently needed. Therefore, the objectives of this work were to identify the benthic community, characterize the submerged habitats, and distinguish priority areas for conservation.

2. Materials and methods

2.1. Study area

The SYC is delimited as a polygon that is 198 km in length with variable amplitudes up to 13 m in depth and a total surface area of 464,432.75 Ha (Fig. 1).

Three regions were distinguished based on the environmental quality of the SYC (Herrera-Silveira and Morales-Ojeda, 2009): to the west, from the town of Celestún to the village of Sisal; the central portion, from Sisal to Telchac Puerto; and to the east, from Telchac Puerto to the town of Dzilam de Bravo; these regions are designated as Zone 1, Zone 2 and Zone 3, respectively, in this study (Fig. 1).

The SYC is located on a plain along a wide continental shelf with a gentle slope; it is shallow and composed of marine deposits of biogenic carbonate origin (Capurro et al., 2002). The SYC lacks major topographical features (Lugo-Hubp et al., 1992) and surface rivers (Solleiro-Rebolledo et al., 2011). It receives nutrients and freshwater by groundwater discharges, coastal lagoons and springs related to the “ring of wells” associated with the Chicxulub Crater (Pacheco-Martínez and Alonzo-Salomon, 2003).

The marine portion has low-energy waves, dominant surface currents from East to West (Enríquez et al., 2010) and potential sediment transport in the same direction (Appendini et al., 2012). Hurricane season (August-November) overlaps the rainy and windy seasons (Álvarez-Góngora and Herrera-Silveira, 2006) with winds up to 10 ms^{-1} (Enríquez et al., 2010), which increases the intensity of coastal processes that cause significant changes in coastal morphology (Capurro et al., 2002; Cuevas-Jiménez and Euán-Avila, 2009).

In September of 2002, hurricane Isidore, which was a Category 3 hurricane on the Saffir-Simpson scale, impacted the coastal zone of