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## Variability and sustainability of the Southern Subarea of the Caribbean Sea large marine ecosystem

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## ABSTRACT

The Southern Subarea of the Caribbean Sea Large Marine Ecosystem encompasses most of the continental and island coasts of Venezuela, as well as Trinidad, Tobago, Bonaire, Curacao, Aruba and the northeastern continental coast of Colombia in the Caribbean. The subarea is the only area of the Caribbean Sea LME (CSLME) with an important upwelling process that determines its very high productivity, especially in the eastern region of Venezuela. It generates a big impact over the ecological conditions of the rest of the Caribbean Sea LME, mainly over the biological productivity. However, extreme changes of climatic conditions have weakened upwelling in several years during the last two decades, with severe consequences in the total fish production of Venezuela and the Southern Subarea of the Caribbean Sea Large Marine Ecosystem. The crisis of the sardine in Venezuela is perhaps the clearest example of it. Another contribution of the Southern Subarea of the Caribbean Sea LME is the high biodiversity of marine fauna and flora that appears in numerous coral reefs, seagrass meadows and mangroves in the region. Unfortunately, several factors threaten the health and population sizes of some taxonomic groups. The corals are among the most affected, with losses of significant live coral coverage at all the reefs of the Southern Subarea, similar to the rest of the Caribbean region. Even when the governance of the Southern Subarea of the Caribbean Sea LME has many environmental laws and institutions that are charged with applying these laws, the latter are not appropriately enforced. If this situation does not change, the sustainability of the Southern Subarea will be at risk.

### 1. Introduction

Large Marine Ecosystems (LMEs) are “relatively large regions on the order of 200,000 km<sup>2</sup> or greater, characterized by distinct: (1) bathymetry, (2) hydrography, (3) productivity, and (4) trophically dependent populations” ([www.lme.noaa.gov/Portal/](http://www.lme.noaa.gov/Portal/)). LMEs are largely conceived as units for the practical application of transboundary management issues (including fish and fisheries, pollution and ecosystem health, habitat restoration, productivity, socioeconomics and governance) (Sherman and Duda, 1999). The LME system focuses on productivity and oceanographic processes (Spalding et al., 2007). There are 66 LMEs in the world (Sherman and Hamukuaya, 2016).

According to Spalding et al. (2007), the Greater Caribbean is part of the Tropical Atlantic Realm and the Tropical Northwestern Atlantic Province, which comprises nine ecoregions: Western Caribbean; Southwestern Caribbean; Eastern Caribbean; South

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**Fig. 1.** The Southern Caribbean Sea Large Marine Ecosystem subarea along the coast of Venezuela depicting the countries of Aruba, Curacao, Bonaire and Trinidad. (Modified from Garmin MapSource).

Caribbean; Greater Antilles; Bermuda; Bahamian; Southern Gulf of Mexico; and Floridian. The main goal of this paper is to describe the main physical and bio-ecological characteristics of the Southern Subarea of the Caribbean Sea Large Marine Ecosystem with regard to spatial variability, degree of conservation and some of the measures taken to ensure its sustainability. The Southern Subarea encompasses most of the continental and island coasts of Venezuela, as well as Trinidad, Tobago, Bonaire, Curacao, Aruba and the northeastern continental coast of Colombia (Fig. 1). This article will focus on Venezuela, mainly because the country plays an important role in the water mass productivity in the whole Caribbean, and because of its high contribution to both the marine biodiversity of the Southern Caribbean Ecoregion and the Southern Caribbean Sea Large Marine Ecosystem subarea.

## 2. Borders of the caribbean sea large marine ecosystem and the Southern Subarea of the Caribbean Sea LME

The Caribbean Sea LME (CSLME) is a semi-enclosed tropical sea of about 3.3 million km<sup>2</sup> bordered to the north by the Bahamas and the Florida Keys, to the west by Central America, to the south by South America, and to the east by the Lesser and Greater Antilles Island chain. The CSLME is also bordered by the Gulf of Mexico LME to the northwest and the North Brazil Shelf LME to the south (CARSEA, 2007). This large marine ecosystem is comprised of four deep basins: the Venezuelan Basin in the east; the Colombian Basin in the west; the Cayman Trough in the northwest; and the Yucatan Basin in the north. Two continental countries border the south of the Caribbean, Venezuela with 2722 km of coastline and Colombia with approximately 1760 km of coastline (the last includes the Southern and Southwestern Caribbean Ecoregions and the Southern Subarea of the Caribbean Sea Large Marine Ecosystem). The marine area of Venezuela covers 500,000 km<sup>2</sup>, including its territorial sea, contiguous zone and the projection of its exclusive economic zone (García et al., 2011). The marine area of Colombia in the Caribbean Sea covers approximately 540,876 km<sup>2</sup>, with a coastline that extends from Cabo Tiburón in the frontier with Panamá to the Peninsula de la Guajira in the frontier with Venezuela (Lozano-Duque et al., 2010). The Colombian coastline and its associated marine areas from the Peninsula de la Guajira to Tayrona are included in the Southern Caribbean bioregion and the Southern Caribbean Sea subarea; the rest of the coastline belongs to the Southwestern Caribbean. The hydrographic and climatic conditions of the CSLME are not homogeneous. Some zones are usually impacted by storms and hurricanes, especially to the northeast, north and west of the region. Even in zones at approximately the same latitude, such as Venezuela and Colombia, particular coastal geomorphology and hydrographic conditions determine the presence and level of development of some benthic or pelagic communities (i.e., coral reefs, pelagic fishes). For example, the upwelling condition and the river discharge are determinants in this sense (ecological drivers) because of cooler, turbid and nutrient-rich waters. These are conditions that can limit and even damage the corals and other biological components of the coral reefs.

## 3. Productivity of the Southern Subarea of the Caribbean Sea large marine ecosystem: the upwelling cycle

The role of the Southern Subarea over the aquatic productivity of the whole Caribbean is a topic of relevant importance. The CSLME is considered a Class III (< 150 g C/m<sup>2</sup>-yr) low productivity ecosystem, according to SeaWiFS global primary productivity estimates (O'Reilly and Sherman, 2016). However, the upwelling along the northern coast of Venezuela contributes to relatively high productivity in the region. Another factor contributing to the greater productivity of South America's northern coast is the nutrient input from rivers and estuaries. The remaining area of this LME is mostly comprised of clear, nutrient-poor waters. Key components of the shallow water areas are the coral reefs of the Caribbean Sea (NOAA, 2004); their efficient recycling of nutrients and high degree of structural complexity are some of the reasons explaining the enormous biological diversity they host. In the study by Rueda-Roa and Muller-Karger (2012), which included the analysis of sixteen years of SST imagery (January 1994–December 2009),

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