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Identification and analysis of ecosystem services associated with biodiversity of saltworks

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ABSTRACT

Saltworks are artificial ecosystems that are exploited for salt production. These extreme environments create particular habitats for a diversity of species. In "extreme" environments organisms must adapt to stressful environmental conditions. Saltworks are particularly influenced by biotic factors, such as biodiversity and its interspecific interactions, which are linked to abiotic factors. The large variation of abiotic factors in extreme ecosystems helps explain the causal relationships between them, as well as the structure of the communities that inhabit them. Species that live in these habitats develop adaption strategies in order to survive and reproduce. Despite the important role of saltwork communities, especially regarding the ecological aspects of the biota of high saline environments that remain poorly understood, few studies have been carried out in these ecosystems. In this context saltworks are a particularly interesting type of study given that they contain a large diversity of species and environments. Many ecosystems are found around Salinor, such as: mangroves, flooded areas and Caatinga vegetation fragments. Based on existing literature, we were able to identify 13 types of services, of which one pertained to support services, two pertained to regulation services, five pertained to provision services and four pertained to cultural services. Most of the studies we consulted were classified as support services (36.36%), whereas biodiversity maintenance was present in 100% of these studies. The second category corresponded to provision services (22.73%). With respect to regulation services, five studies examined water quality maintenance (62.50%), one study examined climate regulation (12.50%), and the other two examined pest and disease control (25%). The studies that focused on cultural services examined tourism (41.67%), cultural and historical values (25%) and scientific research (33.33%). With respect to the study carried out in Salinor, we were able to identify a considerable number of ecosystem services. From our analysis of the biodiversity found in this saltwork, we were able to identify a total of 42 ecosystem services generated by the different habitats (mangroves, flooded areas, Caatinga, evaporation and crystallizer ponds). Although it is considered to be an artificial ecosystem, Salinor and its surroundings preserve natural characteristics, therefore demonstrating great potential to supply of ecosystem services. These ecosystem services consist of four types of ecosystem functions, such as food supply, biodiversity maintenance, carbon sequestration, research and ecotourism.

1. Introduction

An ecosystem is defined by its structural components (biota) and functional processes (interaction between biota and abiotic factors). This definition, however, does not distinguish between natural and artificial ecosystems, such as saltworks, which are a result of human activity. Regardless of their origin, saltworks have developed trophic characteristics that progressively and predictably change as the level of salinity increases (Ladhar et al., 2015; Oren, 2009; Sadoul et al., 1998). Hypersaline environments are important natural resources of considerable economic, ecological and cultural value. These ecosystems cover large areas throughout the world, not only in salt productions areas (saltworks), but also in natural lakes and tide pools (Javor, 1989). The biochemical processes that occur in these ecosystems hold considerable environmental, social and economic value (Shadrin, 2009).

Saltworks are high interest ecosystems given their ecological and economic importance (Rodrigues et al., 2011). They represent refuges for diverse organisms such as migratory birds and other animals that

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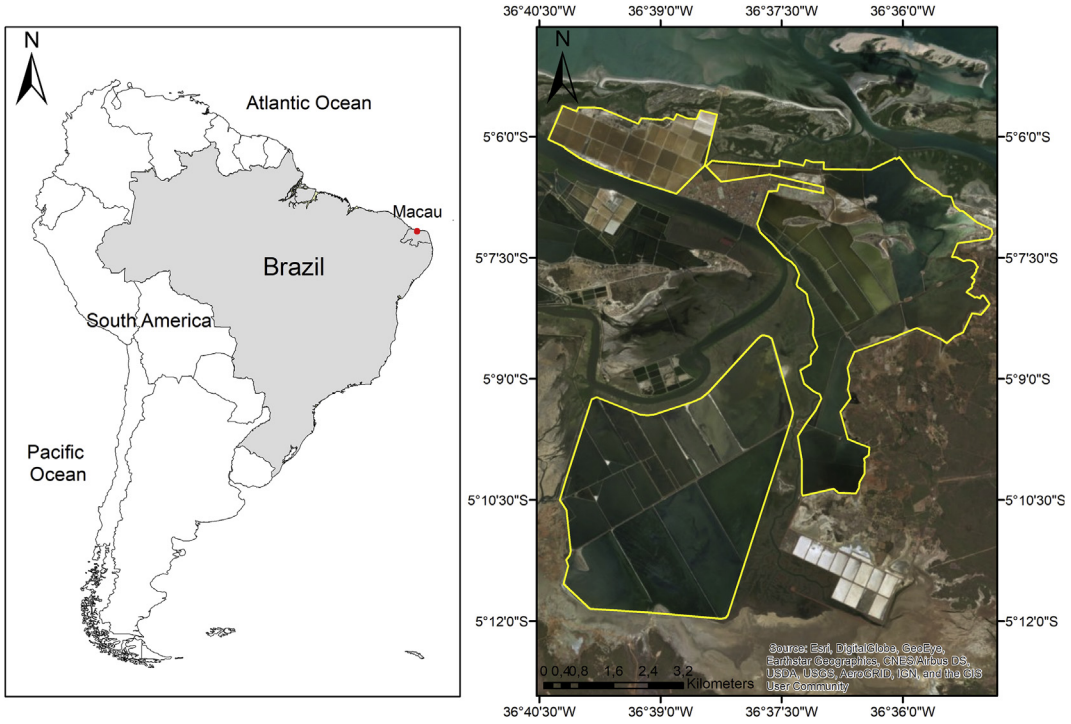

Fig. 1. Map showing the location of the Salinor saltwork.

reside in their surrounding areas. These environments, considered to be extreme, are transition areas located between the mainland and the sea.

Saltworks are composed of a series of interconnected shallow ponds, through which seawater flows evaporates up to saturation. The ponds with the lowest salinity (35–100 PSU) present similar biotic characteristics to estuaries or coastal lagoons (Evagelopoulos and Koutsoubas, 2008). Variations in salinity strongly influence community dynamics, chemical compositions, and genetic structures. Sea exchanges, hydrology, salinity, and nutrients play important roles in developing biological communities in these ecosystems.

In the ponds of the saltworks, biological systems composed of planktonic and benthic communities develop (Davis, 2000). In the first ponds, where the water enters from the estuary, the diversity of organisms, including microorganisms suspended on the water column, such as microalgae, cyanobacteria, flagellates, and protozoa, is similar to nearby marine plankton species. Microalgae, macroalgae, seagrass, fish, crustaceans and other marine species are also found in this pond. In the subsequent ponds, salinity increases gradually and the lower salinity species die and release nutrients for the succession of higher salinity tolerant organisms (Davis, 2000).

The successive process inside the ponds repeats as the water becomes more saline. At salinity levels of between 100 and 210 PSU diatom and dinoflagellate plankton communities decrease and are progressively replaced by cyanobacteria. Fishes also disappear and *Artemia* populations self-recruit. The sequence finishes with the halophilic bacteria in the highly salinized and crystallizing ponds (Davis, 2000).

Saltwork habitats are characteristically heterogeneous depending on their degree of salinity. In addition to salinity changes in the ponds, brine evaporation also contributes to changes in the biological aspects of the tank circuit (Ladhar et al., 2015). Thus, the fauna and flora species in each tank are determined by salinity and other abiotic factors such as temperature and nutrient availability (Coleman, 2009). These conditions are tolerated by aquatic communities with complex cycles and by species that are highly specialized for life in this environment (López et al., 2010). Given that they are highly productive, these environments provide habitat, shelter and nursery for an infinite number of arthropods, fishes and crustaceans, which serve as an important food source for predators (birds and small mammals). In addition to sustaining resident populations, saltworks are very important for migratory birds that use these ecosystems for refuge and feeding.

Diverse salt tolerant plant species that are adapted to this extreme environment surround the saltworks. In these areas the plants that survive are either tolerant or require a high concentration of salt for their growth. The mangrove vegetation that has adapted to these environmental conditions, such as salinity, soft substrate, and subjected to tidal regimes, is essential for supporting life. This unique ecosystem provides diverse niches and refuges for numerous fauna species (autochthones and allochthones), and is important for water quality (retaining sediments), shoreline stability, and nutrient cycling (Costa et al., 2015a; Crisman et al., 2009; Davis, 2000; Davis and Giordano, 1995). The mangrove is characterized by fauna consisting primarily of microphages; however, diverse animals enjoy this environment, from microscopic forms to reptiles and mammals. Mollusks (oysters, mussels, and shellfish), crustaceans (shrimp, crab) and diverse fish species are commonly found in this environment. Moreover, the shallow areas of the mangrove ecosystem are privileged feeding areas for shorebirds.

A transition zone, known as flooded areas, is connected to the mangrove, which forms part of the mangrove's natural sequence. This zone is primarily characterized by herbaceous plants, which are able to survive in these highly saline conditions by using several survival, adaptation, physiological, and biochemical defense mechanisms. A large number of these plants have been used for food and traditional medicine (Rodrigues et al., 2011).

Saline environments have both important ecological and economic functions, such as providing habitats for biodiversity and providing diverse ecosystem services for humans (Rocha et al., 2012). Ecosystem services are the benefits that people obtain from ecosystems. According to the Millennium Ecosystem Assessment, environmental services fall into one of four categories: provisioning services (raw materials used by humans), supporting services (nutrient cycling, primary production, and oxygen production), regulating services (climate, water quality), and cultural services (leisure, spirituality and knowledge generation). Despite providing a number of services, humid and saline areas face