Land Use Policy 58 (2016) 196–207

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Carbon stocks and biodiversity conservation on a small island: Pico (the Azores, Portugal)

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ARTICLE INFO

Article history:
Received 31 March 2016
Received in revised form 9 June 2016
Accepted 18 July 2016

Keywords:
Carbon stock
Biodiversity
Conservation
Land management
InVEST
Small island

ABSTRACT

The loss of carbon storage and sequestration capacity has been increasingly assessed and analyzed worldwide as among the factors causing or amplifying climate change. Solutions that contribute to decreasing the release of carbon and increasing its sequestration, without compromising currently threatened ecosystems, are required, especially for small territories. This study focuses on the strategies to increase the resilience of small islands to these losses, including spatial management to prevent and adapt to climate change while preserving biodiversity. Changes in carbon storage on Pico Island (Azores, Portugal) between 1998 and 2013 were assessed using the InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) Carbon Storage and Sequestration model. Changes in carbon stocks caused by changes in land use during this period, and the stocks' relationships with protected areas and the quality of natural habitats on Pico Island, were analyzed. Bogs and Azorean endemic Macaronesian heaths store more carbon per ha. Alien species are invading natural areas, and their carbon values need to be carefully addressed. Results, however, indicated that simultaneously increasing carbon stocks (economical value) and protecting biodiversity (environmental value) is possible by adapted and discussed management actions. This study supports the strategies that promote the potential of the conservation of biodiversity for mitigating climate change. The proposed management guidelines can be applied to other Macaronesian islands and, with local adaptations, to other outermost regions.

1. Introduction

Carbon stored in terrestrial ecosystems plays an important role in the global carbon cycle (Watson et al., 2000). Carbon accumulated in live biomass, in decomposing organic matter, and in soil is naturally exchanged with the atmosphere through photosynthesis, respiration, decomposition, and combustion. Anthropogenic activities, especially those responsible for changes in land use (e.g. conversion of scrubland to grassland), can alter the ratio of carbon in those systems by promoting the release or storage of carbon in various carbon pools (IPCC, 2000). In addition to their impact on climate, anthropogenic pressures, such as land-use dynamics and an increasing demand for fresh water and other natural resources, are among the main threats to the conservation of biodiversity, especially in vulnerable island ecosystems (Lagabrielle et al., 2009; UNEP 2014).

The ecosystems of small islands are fragile due to specific conditions such as remoteness, isolation, smallness, closed systems, limited physical space, and limited natural resources. For example, most settlements and human activities are near the coast (due to the high ratio of coastline to land area for small islands), which potentiates the impacts of coastal erosion on the economies and societies of islands (Rubenstein, 2011). Small islands are thus more sensitive to climatic variability and changes, invasive exotic species, natural hazards, and overexploitation of natural resources. The lower adaptive capacity of small islands also aggravates their vulnerability, leading to challenging management, especially for environmental conservation and sustainability (Rietbergen et al., 2008; Nurse et al., 2014; UNEP 2014).

Ecosystemic functions are defined as "the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly" (De Groot, 1992). Each function is the product of the natural processes of the entire ecological sub-system of which it is part, so the conservation of each level

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http://dx.doi.org/10.1016/j.landusepol.2016.07.020
0264-8377/

of the ecosystem is very important (De Groot et al., 2002). These authors defined four main types of ecosystemic functions: (i) regulation of essential ecological processes and life-support systems, (ii) refuge and reproduction habitat for wild plants and animals, (iii) production of ecosystemic goods for human consumption, and (iv) information function corresponding to opportunities for reflection, spiritual enrichment, cognitive development, recreation, and aesthetic experience. Islands, especially those that have never been connected to a continent, have high levels of animal and plant endemism (Petit and Prudent, 2010). The particular features of small islands also enable singular natural habitats to fulfill specific ecosystemic functions (Condé and Richard, 2002). This study addresses one of the ecosystemic functions that regulate essential ecological processes and life-support systems, the storage of carbon as part of the carbon cycle, by preliminarily assessing the amount of carbon in all systems of an entire island.

The study of the impacts of climate change in the Azores has begun only recently (e.g. Santos et al., 2004; Miranda et al., 2006; Calado et al., 2011; ClimAdaPT.Local 2015). Groundwater, which is currently the main source of freshwater in the Azores, is increasing in salinity due to the association of low hydraulic gradients of the basal aquifer system and the use of drilled wells for water extraction (Cruz and Silva, 2000). The future rise in sea level (Ng et al., 2014) together with an increase in the pumping of water during the summer, due to less precipitation, could increase the problem of saltwater intrusion. In a scenario of growing tourism, as in the Azores, alternative freshwater supplies need to be considered. Increasing coastal erosion and the hazards of landslides are other effects of climate change in the Azores with potential impacts on the daily lives of communities and the growth of tourism (Calado et al., 2011).

Carbon has been studied worldwide (e.g. Guo and Gifford 2002; Strassburg et al., 2010; Dwivedi et al., 2016; Gao et al., 2016), but, to the best of our knowledge, only two studies have investigated carbon storage in the Azores: Mendonça (2012) and Calado et al. (2015). This study focuses on the Azores archipelago and more specifically on Pico Island (Azores, Portugal). The main objective was to develop a preliminary and integrated assessment of carbon stocks on Pico Island, based on different categories of land use/land cover (LULC) (Moreira 2013; Fernandes et al., 2014). Changes in carbon storage on Pico Island between 1998 and 2013 were assessed using the InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) Carbon Storage and Sequestration model. Changes in carbon stocks caused by changes in land use during this period, and the stocks' relationships with protected areas and the quality of natural habitats on Pico Island, were also analyzed. Proposals for possible ways to manage the territory based on carbon storage and the importance of biodiversity are discussed. The analysis is in line with Strassburg et al. (2010), who recognizes that climate change and the loss of biodiversity (two crises of global magnitude) should be addressed together.

1.1. Legal framework

Policies adopted by the world's governments for establishing a path to a low-carbon future and limiting climate change below 2 °C rely largely on 'the invisible hand' of the market. Under a 'cap-and-trade' system, governments or intergovernmental bodies trade licenses, known as 'carbon permits', to major emitters, namely industrial plants and power stations. Emitters can trade these permits with others who might make 'equivalent' changes at a lower cost. Over time, the cap is tightened to achieve higher targets for emission reductions. This approach is guiding the European Union's Emissions Trading System, the world's largest carbon market, which governs almost half of Europe's total carbon emissions (EFI, 2014; EU, 2015).

Forests store 80 and 40% of the Earth's above and belowground terrestrial carbon, respectively, so preserving forests is one of the most cost-effective actions for mitigating climate change (IPCC, 2001). REDD, a carbon market mechanism supported by the EU, was originally created to reduce emissions from deforestation and forest degradation in Global South countries. REDD was later extended (REDD+) to include the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks (EFI, 2014).

The European Union is willing to incorporate the land use, land-use change, and forestry (LULUCF) sector in its target to reduce the emission of greenhouse gases by 20% by 2020 (Decision No 529/2013/EU). LULUCF has been partly taken into account for the EU's quantified commitments for emission limitation and reduction following Article 3(3) of the Kyoto Protocol to the United Nations Framework Convention on Climate Change. Harmonized EU-wide rules for emission accounting and common objectives, however, have not yet been established. Member States should also provide information about their LULUCF efforts to limit or reduce emissions, and to maintain or increase removals of greenhouse gases (Decision No 529/2013/EU).

2. Methodology

2.1. Study area

The Azores archipelago is a European Outermost region and an Autonomous Region of Portugal, with political and administrative autonomy. It is composed of nine islands of volcanic origin in the North Atlantic Ocean between 37 and 40°N and 25 and 31°W, approximately 1500 km from the Portuguese mainland and 3900 km from the east coast of North America (Fig. 1). The islands are geographically divided into three main groups: Western Group (Flores and Corvo), Central Group (Graciosa, São Jorge, Faial, Pico, and Terceira), and Eastern Group (São Miguel and Santa Maria).

The Azorean climate is temperate oceanic with a mean annual temperature of 17 °C at sea level, low thermal amplitude, high mean relative humidity, persistent wind, and rainfall ranging from 800 to 3000 mm/m^2, increasing with altitude (Azevedo, 1996). The Azores are characterized by low and rocky coastlines and coastal cliffs (Borges, 2003), prominent river valleys in eroded volcanic rocks, vast lava flows, and active volcanoes (Condé and Richard, 2002). The association between the physiography and climatic regime contributes to the small diversity of water resources (ephemeral and torrential brooks or creeks, lagoons, small ponds, coastal waters, and groundwater) and small watersheds (usually < 30 km^2) (DROTRH/IA, 2001). The Azores are part of the Macaronesia Biogeographic Region, along with Madeira (Portugal), the Canary Islands (Spain), and Cape Verde (Portugal), one of Europe's most unique regions for its biodiversity (Condé and Richard, 2002). Some of the most common natural habitats are the *Juniperus-Ilex* forests (with *Juniperus brevifolia*, *Ilex perado* subsp. *azorica*, and *Laurus azorica*) and several types of mires, bogs, fens, and forested peat bogs (e.g. *Sphagnum* sp.) (Dias et al., 2004), with high values for conservation.

The present study focused on Pico Island of the Central Group, the second largest and most recent of the archipelago, covering an area of 447 km^2 with 152 km of coastline (Fig. 1). Its most striking feature is the homonymous volcano, Pico Mountain, with an altitude of 2351 m (the highest in Portugal), in the western portion of the island and contributing to its unique landscape.

Pico Island has a population density of approximately 32.8 people/km^2, is essentially a rural territory (SREA, 2010), and is divided into three municipalities: Madalena, São Roque do Pico, and Lajes do Pico (Fig. 1). Settlements, transportation infrastructures, and economic activities are concentrated in the coastal zone,