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

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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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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,

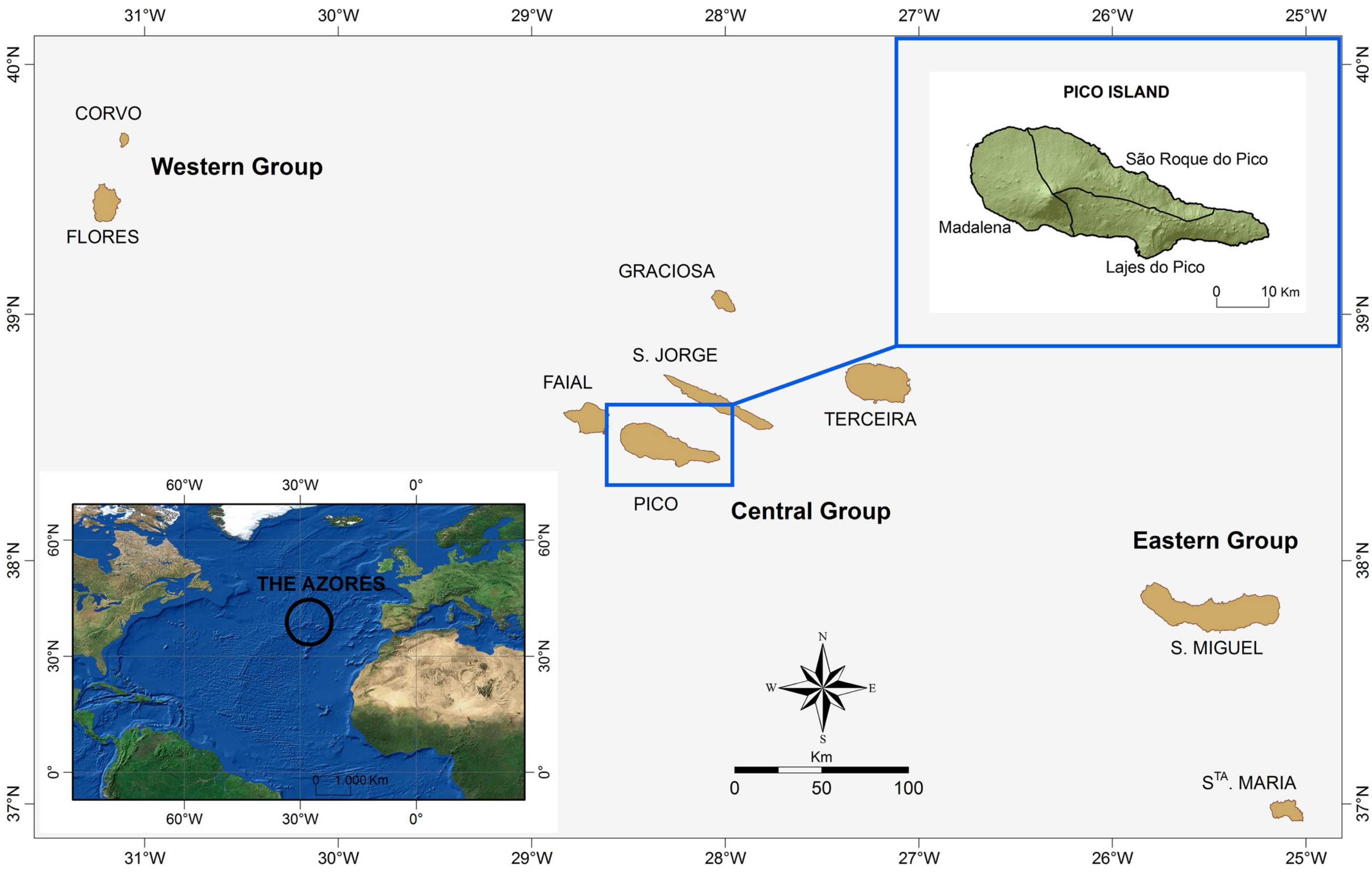


Fig. 1. Location of the Azores archipelago (Portugal) and Pico Island (administrative municipalities' boundaries).

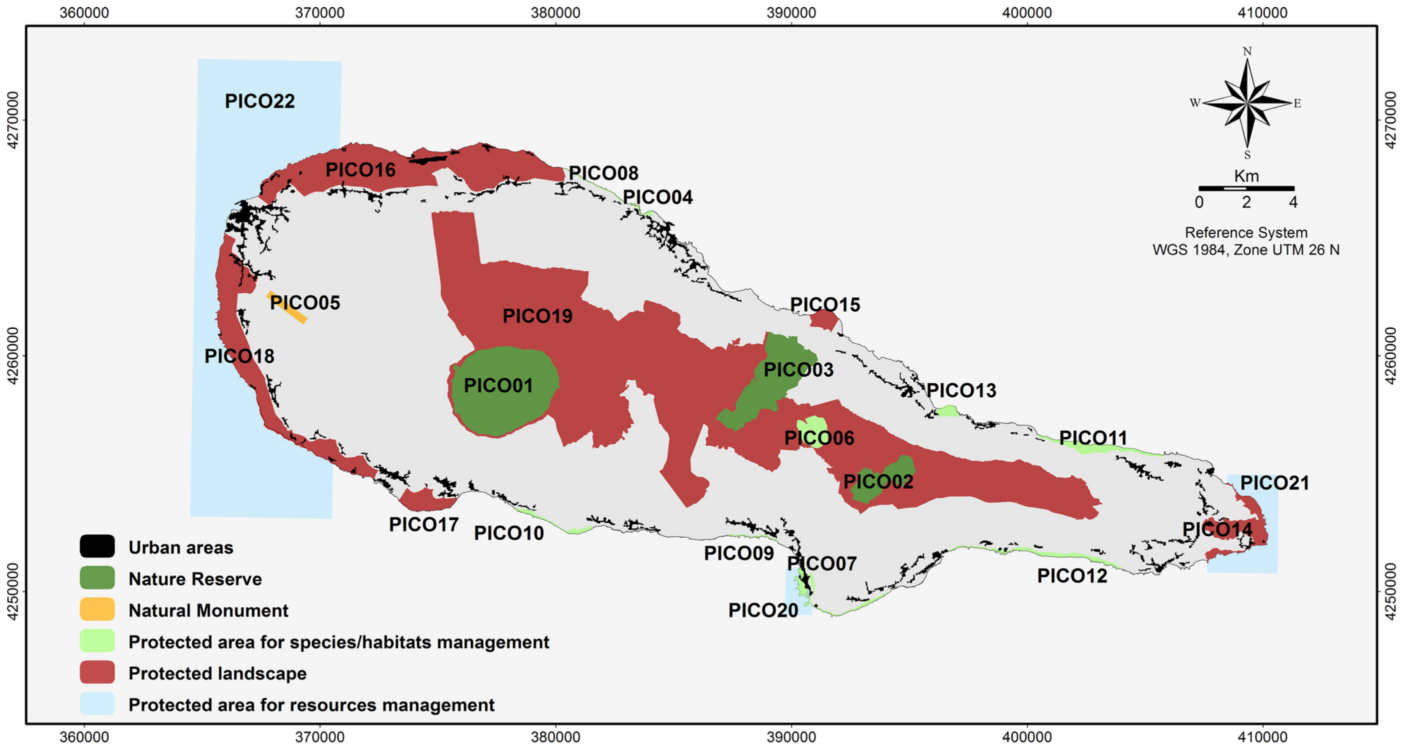
mainly due to their dependence on the sea as the most important communication route and to the geological, geomorphologic, and climatic constraints of the island (Porteiro et al., 2005). The current economy is mainly dependent on crops, cattle, fisheries, and tourism (Calado et al., 2014a). Agricultural areas include a traditional viticultural area with a strong socio-cultural identity classified as a UNESCO world heritage site – Landscape of the Pico Island Vineyard Culture. The middle crown of the island (Calado et al., 2014b) is dominated by pastures, forests of *Cryptomeria japonica* and *Eucalyptus globulus* (hereafter cryptomeria and eucalyptus, respectively), and semi-natural vegetation. The development of these monocultural landscapes for pastures and forests increased the fragmentation of natural ecosystems and facilitated the establishment of invasive species (Silva and Smith, 2006). *Pittosporum undulatum* (hereafter pittosporum), classified as the 8th most invasive of 195 species evaluated (Silva et al., 2008), is the most problematic invasive species in the Azores. Pittosporum was first used in the Azores in the 19th century as living fences around fruit orchards for wind protection, but has since invaded coastal areas to an altitude of 600 m (the limit of suitable conditions), progressively replacing native species, especially *Myrica faya* (Hortal et al., 2010). Large pastures and natural areas predominate in central areas of the island, where the majority of protected areas (PAs), rich in endemic species, are also located (Fig. 2).

2.1.1. *Pico's Island Natural Park*

Island Natural Park (INP) is currently the main entity in the Azorean PA network, one INP in each island (established in the Regional Legislative Decree No. 15/2012/A), which was formed by the standardization of the previous heterogeneous classification into a new homogeneous management system (Calado et al., 2009) based on categories of the International Union for Conservation of Nature. The category assigned to each area depends on its management goals and generally represents a gradation of naturalness (Dudley, 2008). The entire island of Pico was categorized by this approach, although its INP contain different classes of PAs.

The Regional Legislative Decree No. 15/2012/A states that (i) 'nature reserves' are mainly for preserving natural and semi-natural habitats and species of fauna and flora, for maintaining the natural or semi-natural condition of the area and for restoring or correcting its ecological balance, (ii) 'natural monuments' should conserve and maintain the integrity of natural features, (iii) 'protected areas for habitat and species management' are mainly for recovering natural and semi-natural habitats and species of fauna and flora, (iv) 'protected landscapes' are for preserving landscapes with natural or semi-natural scenic value and for maintaining and promoting economic activities compatible with the current value, and (v) 'protected areas for resources management' should preserve natural or semi-natural habitats and species and are subject to management measures for the sustainable use of resources compatible with the maintenance of their ecological quality.

As stated, each Azorean island constitutes an INP. Pico Island has the most classified area, covering around 35% of the terrestrial territory of the island and containing 19 terrestrial and three marine PAs (Fig. 2): four nature reserves, one natural monument, eight protected areas for habitat/species management, six protected landscapes, and three protected areas for resource management (all three are coastal and marine areas). No coherent global management plan has been implemented yet (Botelho, 2013), despite the establishment of goals for each category of PA.



PICO01 - Nature Reserve of Montanha do Pico
PICO02 - Nature Reserve of Caveiro
PICO03 - Nature Reserve of Mistério da Prainha
PICO04 - Nature Reserve of Furnas de Santo António
PICO05 - Natural Monument of Gruta das Torres
PICO06 - Protected Area for Species/Habitats Management of Caiado
PICO07 - Protected Area for Species/Habitats Management of Lajes do Pico
PICO08 - Protected Area for Species/Habitats Management of Furnas de Santo António
PICO09 - Protected Area for Species/Habitats Management of Silveira
PICO10 - Protected Area for Species/Habitats Management of Mistério de São João
PICO11 - Protected Area for Species/Habitats Management of Terra Alta
PICO12 - Protected Area for Species/Habitats Management of Ribeiras
PICO13 - Protected Area for Species/Habitats Management of Zona do Morro
PICO14 - Protected Landscape for Vineyard Culture – Ponta da Ilha
PICO15 - Protected Landscape for Vineyard Culture – Ponta do Mistério
PICO16 - Protected Landscape for Vineyard Culture – Zona Norte
PICO17 - Protected Landscape for Vineyard Culture – São Mateus/São Caetano
PICO18 - Protected Landscape for Vineyard Culture – Zona Oeste
PICO19 - Protected Landscape of Zona Central
PICO20 - Protected Area for Resources Management of Porto das Lajes
PICO21 - Protected Area for Resources Management of Ponta da ilha
PICO22 - Protected Area for Resources Management of Canal Faial-Pico/sector Pico

Fig. 2. Pico Island Natural Park.

2.2. *Assessment of changes in carbon storage between 1998 and 2013*

The amount of carbon stored in the study area was assessed using the InVEST Carbon Storage and Sequestration model (version 3.1.2 × 86) (NCP, 2015). This model aggregates the biophysical amount of carbon stored in four carbon pools (aboveground living biomass, belowground living biomass, soil, and dead organic matter) based on the 2013 LULC map available from Moreira (2013) and Fernandes et al. (2014) containing 18 LULC categories (Table 1). The 1998 LULC map was produced by the photo-interpretation of real-color orthophotomaps from 1998. The InVEST model requires a raster format for both maps. The same LULC categories at the same resolution (25 m^2 per pixel) (as Moreira, 2013) were used to produce comparable maps.

The Carbon Storage and Sequestration model requires carbon values for each LULC category and each carbon pool. Only three studies (Abreu 2011; Mendonça, 2012; Calado et al., 2015) have evaluated the amount of carbon in Azorean vegetation. Calado et al. (2015) did a preliminary assessment only for the Ponta Delgada municipality, using carbon values derived from studies from Japan (for cryptomeria) and mainland Portugal. Therefore, a review of the literature to gather carbon values for each LULC category was performed, focusing on studies in areas with climatic and geomorphological conditions as similar as possible to those in the Azores. To avoid overestimating carbon storage, a value of zero was applied to categories for which an appropriate value could not be found (Table 1).

Mendonça (2012) provided values only for aboveground carbon in the Azorean endemic Macaronesian heath. The Portuguese National Forest Inventory (AFN, 2010) provided aboveground values for the available woody species: pittosporum, acacia, and *Myrica faya*. Data from Ordonez et al. (2008) was used whose study area, despite being at lower latitude in the physiographic province of the Transversal Volcanic System, or the Neovolcanic Mountains (Mexico), was dominated by Andosol soil, which is also predominant in the Azores (DROTRH/IA, 2001; SRAM, 2008). FIVS (2008) was used because it has specific values for vineyards. Alonso et al. (2012) provided estimates of carbon values for heathlands in England, which were used because no preferable values were found. Carbon values reported for northern Spain by Onaindia et al. (2013) were used for eucalyptus. Abreu (2011) provided carbon values of cryptomeria in the Azores. Carbon values reported by Tsui et al. (2013) were used because they also refer, as in the Azores, to soils of volcanic origin, and no preferable values were found. Carbon values of a “warm temperate moist” climate from IPCC (2006) were used, because the climate of Pico Island is classified as warm temperate with humid and warm summers (Cfb) (AEMET-IM, n.d.).

The InVEST model was first run separately for both the 1998 and 2013 LULC maps to assess the changes in carbon storage between 1998 and 2013. The results gave the total surface (number of pixels) for each LULC category in 1998 and 2013 and the general amounts of stored carbon (tonnes). The value of carbon storage for each LULC in

Table 1
Carbon stocks (t/ha) by category of land use/land cover (LULC) used as inputs to the InVEST model (a value of zero was used when no data were available).

LULC	Carbon stock				Classification in Moreira (2013)
	Aboveground	Belowground	Soil	Dead organic matter	
Endemic Macaronesian heath	239.17 (Mendonça, 2012)	0	89.2 (Tsui et al., 2013)	0	Habitat
Pittosporum	79 (AFN, 2010)	0	89.2 (Tsui et al., 2013)	13 (IPCC, 2006)	Threat
Agriculture	0.31 (Ordonez et al., 2008)	0.2 (Ordonez et al., 2008)	81.6 (Ordonez et al., 2008)	0.6 (Ordonez et al., 2008)	Threat
Pine	100.81 (Ordonez et al., 2008)	26 (Ordonez et al., 2008)	93.1 (Ordonez et al., 2008)	3 (Ordonez et al., 2008)	Threat
Vineyard	50 (FIVS, 2008)	12.5 (FIVS, 2008)	89.2 (Tsui et al., 2013)	0	Neutral
Acacia	126.1 (AFN, 2010)	0	89.2 (Tsui et al., 2013)	0	Threat
Hiking trail	0	0	89.2 (Tsui et al., 2013)	0	Threat
Urban	0	0	0	0	Threat
Alpine and boreal heath	2 (Alonso et al., 2012)	0	88 (Alonso et al., 2012)	0	Habitat
Water body	0	0	0	0	Neutral
Rocky shore	0	0	0	0	Habitat
Bog	0	0	658 (Cannell et al., 1993)	0	Habitat
Road	0	0	0	0	Threat
Myrica faya	79 (AFN, 2010)	0	89.2 (Tsui et al., 2013)	13 (IPCC, 2006)	Habitat
Bare soil	0	0	89.2 (Tsui et al., 2013)	0	Neutral
Eucalyptus	61 (Onaindia et al., 2013)	0	65 (Onaindia et al., 2013)	13 (IPCC, 2006)	Threat
Grassland	0.23 (Ordonez et al.2008)	0.02 (Ordonez et al., 2008)	89.9 (Ordonez et al., 2008)	0.7 (Ordonez et al., 2008)	Threat
Cryptomeria	206.4 (Abreu, 2011)	51.9 (Abreu, 2011)	89.2 (Tsui et al., 2013)	22 (IPCC, 2006)	Neutral

1998 and 2013 was then obtained by multiplying these two values. The total amount of stored carbon for each year was the sum of all LULC carbon-storage values. The change in carbon storage between 1998 and 2013 was determined by subtracting the total carbon-storage values for 1998 from those for 2013.

Blue carbon is "the carbon stored, sequestered or released from coastal ecosystems of tidal marshes, mangroves and seagrass meadows" (Herr et al., 2012). InVEST also has a Blue Carbon model, but it was not used due to a lack of data. Future studies and assessments of coastal and maritime habitats will allow a more complete analysis of blue-carbon storage in the Azorean islands.

Furthermore, the IDRISI Selva Land Change Modeller (Eastman, 2012) was used with the same LULC maps to corroborate the changes in land use. This modeller allowed a more detailed analysis of LULC transitions between 1998 and 2013, providing information for the contributors to the net change for each land use and the global net surface increase/decrease of each land use between the two dates, detailing the amount of surface gained and lost and the net value of surface change.

2.3. *Carbon storage and habitat quality in 2013*

The 2013 carbon-storage map produced by the InVEST model was overlaid with the map of habitat quality by Moreira (2013) and Fernandes et al. (2014) for comparison. The latter assessed the quality of the natural habitats on Pico Island. The methodology classified LULC categories as threats, neutral areas, or habitats (Table 1). The quality depended on the threats to which the habitats were exposed and their sensitivity towards them.

Only natural habitats were comparatively analyzed, because the study of Moreira (2013) was limited to these areas. The carbon-storage values were classified in 10 classes ("equal intervals" tool) to allow comparisons between carbon-storage and habitat-quality maps, similarly to Moreira (2013), thereby creating an identical general-level scale for both carbon storage and habitat quality. The correlation between the two variables was calculated using the ArcGIS "band collection statistics" tool to assess possible relationships. All tools were from ArcGIS (version 10.3), which was also used for the remaining cartographic analysis.

3. Results

3.1. *Assessment of changes in carbon storage between 1998 and 2013*

The highest carbon storage values occurred in bogs (658 t/ha), cryptomeria (369.5 t/ha), and endemic Macaronesian heath (328.37 t/ha) (Table 2 and Fig. 3), mainly in the inner part of the island (darker patches in Fig. 3A and B). Values for *Pinus pinaster* (hereafter pine) (222.91 t/ha) near coastal areas, pittosporum (181.20 t/ha), and *Acacia melanoxylon* (hereafter acacia) (215.30 t/ha) were intermediate, and the remaining LULC categories had lower values. Urban areas, roads, rocky shores, and water bodies were assigned a value of zero, because no information about carbon pools were available for these LULCs.

A total of approximately 40796 t of stored carbon was lost on the island between 1998 and 2013, corresponding to a decrease of 0.6% (Fig. 3C and Table 2). An analysis of the changes in LULC (Fig. 3C) indicated that most INP areas changed little, resulting in relatively stable carbon storage over time, but the LULCs changed in about 26% of the area inside the INP (Table 3).

The percentage increase of area change was highest for forestry LULCs (Fig. 4): area covered with eucalyptus and cryptomeria increased by 89 and 39%, respectively. This high increase in area for

Table 2
Assessment of carbon storage changes in 1998 and 2013 by category of land use/land cover (LULC).

LULC	Carbon (t/ha)	Area 1998 (ha)	Area 2013 (ha)	Change in area (ha)	Carbon 1998 (t)	Carbon 2013 (t)	Carbon-storage change (t)
Endemic Macaronesian heath	328.37	5028.52	4620.76	−407.76	1651214.29	1517318.14	−133896.15
Pittosporum	181.20	11730.88	11416.22	−314.66	2125635.00	2068619.06	−57015.94
Agriculture	82.71	3368.59	2943.01	−425.58	278615.87	243416.56	−35199.31
Pine	222.91	642.00	560.03	−81.96	143107.11	124836.84	−18270.26
Vineyard	151.70	1563.34	1520.66	−42.68	237159.06	230684.50	−6474.56
Acacia	215.30	514.44	496.44	−18.00	110757.86	106882.46	−3875.40
Hiking trail	89.20	29.25	29.20	−0.05	2608.65	2604.19	−4.46
Urban	0.00	574.98	729.50	154.52	0.00	0.00	0.00
Alpine and boreal heath	90.00	26.85	26.85	0.00	2416.28	2416.28	0.00
Water body	0.00	23.36	23.36	0.00	0.00	0.00	0.00
Rocky shore	0.00	523.95	524.58	0.63	0.00	0.00	0.00
Bog	658.00	31.76	31.76	0.00	20896.44	20896.44	0.00
Road	0.00	346.59	349.28	2.69	0.00	0.00	0.00
Myricafaia	181.20	1000.40	1006.18	5.78	181272.48	182318.91	1046.43
Bare soil	89.20	1350.77	1502.67	151.90	120488.24	134037.72	13549.48
Eucalyptus	139.00	19.13	182.10	162.98	2658.38	25312.25	22653.87
Grassland	90.85	17131.46	17574.37	442.90	1556393.37	1596631.06	40237.69
Cryptomeria	369.50	573.53	942.82	369.29	211917.49	348370.14	136452.66
TOTAL		**44479.77**	**44479.77**		**6645140.50**	**6604344.55**	**−40795.95**

Table 3
Areas corresponding to carbon-storage losses/gains on the entire island, inside and outside the Island Natural Park (INP) (absolute values and percentages) (LULC: land use/land change).

		Carbon loss	Carbon gain	LULC change
Island	(ha)	2208.02	2119.80	4327.82
Inside INP	(ha)	581.69	553.53	1135.21
	(%)	26.34	26.11	26.23
Outside INP	(ha)	1626.33	1566.28	3192.61
	(%)	73.66	73.89	73.77

eucalyptus was due to plantations established by a mainland company of paper production that uses areas in the Azores because of its high average rainfall. Eucalyptus growth requires high amounts of water and so can have an important environmental impact in mainland Portugal.

Due to the combination of their surface change and amount of carbon storage, four LULCs were most responsible for the changes in total carbon storage: endemic Macaronesian heath, pittosporum, grassland, and cryptomeria (Table 2). Most of the area of carbon storage was lost from the endemic Macaronesian heath (328.37 t/ha) and pittosporum (181.20 t/ha), losing 410 and 315 ha, respectively, mainly to grassland (90.85 t/ha), resulting in a carbon storage at least twice as low as the original LULC. The second source of loss of carbon storage on the island was due to the replacement of 443 ha of endemic Macaronesian heaths (328.37 t/ha) (arrow 1 in the central INP in Fig. 3C) and pittosporum (181.20 t/ha) in coastal areas by grasslands (90.85 t/ha). Cryptomeria (369.50 t/ha) was responsible for the highest gain in carbon storage, 369 ha, half from grassland (90.85 t/ha) (arrow 2 in the eastern part of central INP in Fig. 3C), a quarter from pittosporum (181.20 t/ha), and a quarter from endemic Macaronesian heath (328.37 t/ha).

3.2. *Carbon storage and habitat quality in 2013*

Both habitat quality (Fig. 5A) and carbon storage (Fig. 5B) were highest in the central zone of the island and lowest near the coast. Color intensity differed between the maps because most of the values represented the higher classes of habitat quality and no values were found for classes 4, 6, 7, 8, and 9 of carbon storage; the two highest values for carbon storage (658 t/ha for bogs and 328 t/ha for endemic Macaronesian heath) differed considerably from each other.

The main differences between habitat quality and carbon storage were for rocky shores, which had average values for habitat quality but zero carbon storage. Notably, habitat quality, but not carbon storage, generally decreased from the center of the island towards the coastal areas; the values for carbon storage are at the land-use scale, whereas the values for habitat quality depend on the relative impact of each threat and their corresponding impact across space and on the sensitivities of the habitats to each threat (Moreira, 2013). In addition, habitat quality was highest but carbon storage was low in the area of alpine and boreal heaths at the top of Pico Mountain.

The losses of carbon storage from endemic Macaronesian heath and pittosporum represent an important loss of high-quality natural habitat, because most of the values for the endemic Macaronesian heath were in the three highest classes of habitat quality. Additionally, Moreira (2013) considered grassland a threat to natural habitats, which increased the negative impact of this LULC change. Despite its net surface loss, pittosporum gained area from agriculture and vineyards in coastal areas.

4. Discussion

Carbon stocks decreased by 0.6% (about 40,800 t) on Pico Island between 1998 and 2013, with a moderate relationship between areas of high natural habitat quality and high carbon storage. This correlation was also reported by Strassburg et al. (2010). These authors used data sets on terrestrial biodiversity and carbon storage to map and investigate potential synergies between carbon and biodiversity-oriented conservation. They found a strong association between carbon stocks and species richness, supporting the results of the present study. Little information, however, is available about some variables and carbon-storage values (especially for carbon stocks of belowground and dead organic matter) for the Azores, and for this field in general. This limitation should be overcome with further studies that specifically assess the amount of carbon storage in the Azores, which would help to improve the accuracy of the results.

Despite the relationship between both variables, the low positive correlation from the analysis suggests exercising caution for a management plan protecting and/or increasing areas of high carbon storage, because it could neglect considerable areas that might be essential to biodiversity or even have a negative impact on them. If priority is given to measures fostering only carbon storage, some areas with low storage but high biodiversity (e.g. rocky shores) could be neglected, and neutral areas (e.g. cryptomeria) or threats (e.g. invasive alien plants) with high storage would increase, or at least be maintained, with potential negative impacts on bio-

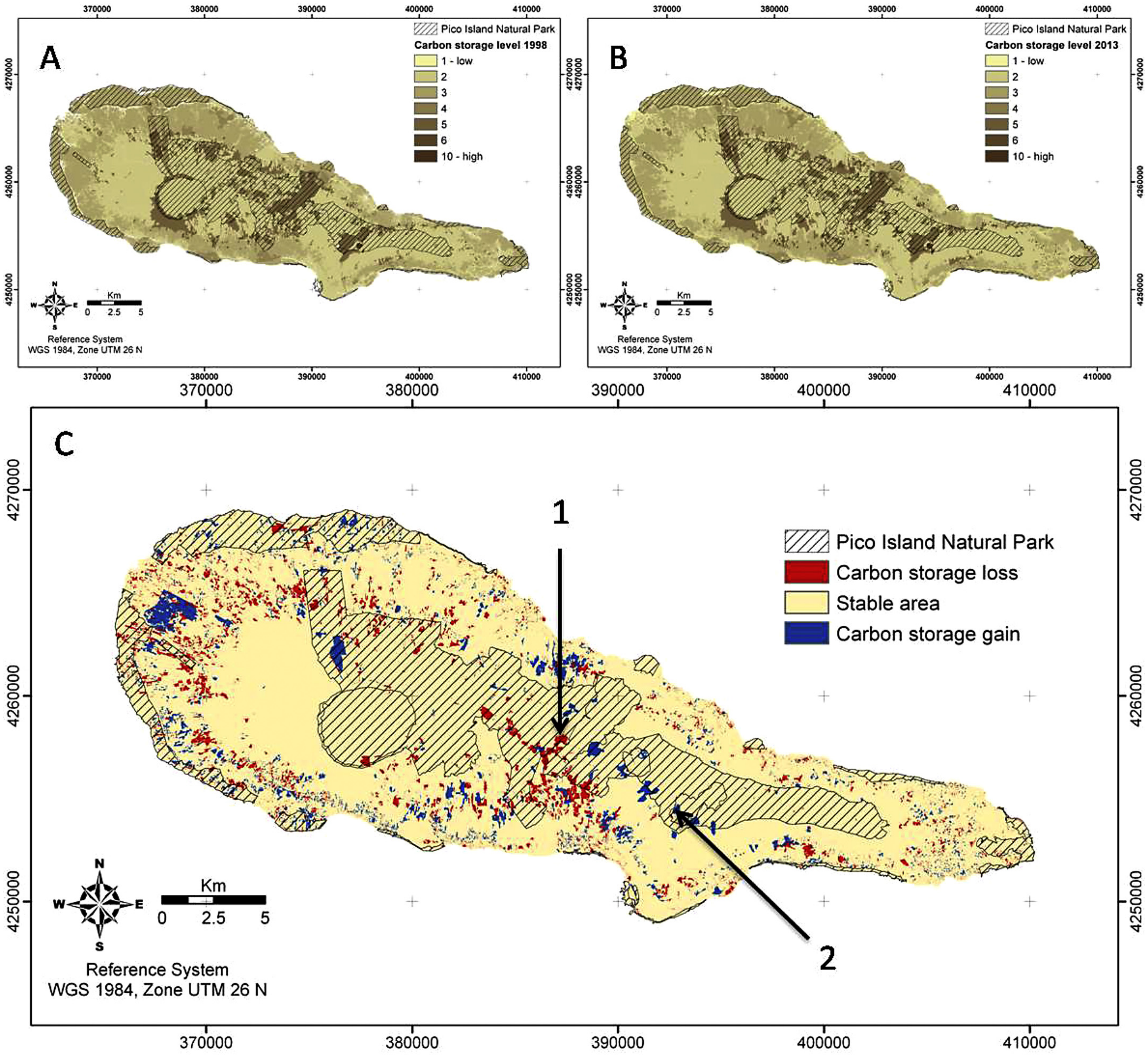


Fig. 3. Carbon storage in 1998 (A) and 2013 (B) and the changes in carbon storage between 1998 and 2013 (C). Arrow 1: LULC change from endemic Macaronesian heath to grassland (red spots). Arrow 2: LULC change from grassland to cryptomeria (blue spots). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

diversity. Areas with higher carbon stocks but lower biodiversity or habitat quality should be increased with care, because critical areas of biodiversity may be lost. Solutions that also contribute to increasing carbon stocks, however, should be favoured if the objective is to conserve biodiversity. Compromises between changes in land use might decrease the tradeoffs between conservation and human activities. Maximizing carbon stock (economical benefit) and biodiversity (environmental benefit) is then possible, but the levels of both variables should be maintained.

Strassburg et al. (2010) and Paoli et al. (2010) reported similar results. Strassburg et al. (2010) stated that many areas of high value for biodiversity could benefit from carbon-based conservation, but others could come under increased pressure. Their results suggest "that additional gains for biodiversity conservation are possible, without compromising the effectiveness for climate change mitigation, if REDD takes biodiversity distribution into account". Paoli et al. (2010) addressed the possibility of co-benefits between the conservation of biodiversity and the reduction of global greenhouse gas emissions by reducing deforestation in tropical areas. These authors argued that a regulatory framework, that balances interventions to reduce emissions with targets that co-benefit biodiversity, is required to avoid undermining long-term prospects for biodiversity conservation in the tropics.

Costa et al. (2012) reported that roughly half of the area occupied by pittosporum on Pico Island could be moderately or highly effectively replaced by *Myrica faya*. Pico is thus one of the most favorable islands for *Myrica faya* reforestation. These results can be used to determine where *Myrica faya* should be first established or restored if it is still present in the area. The decrease in area covered with pittosporum between 1998 and 2013 (315 ha) was mainly due

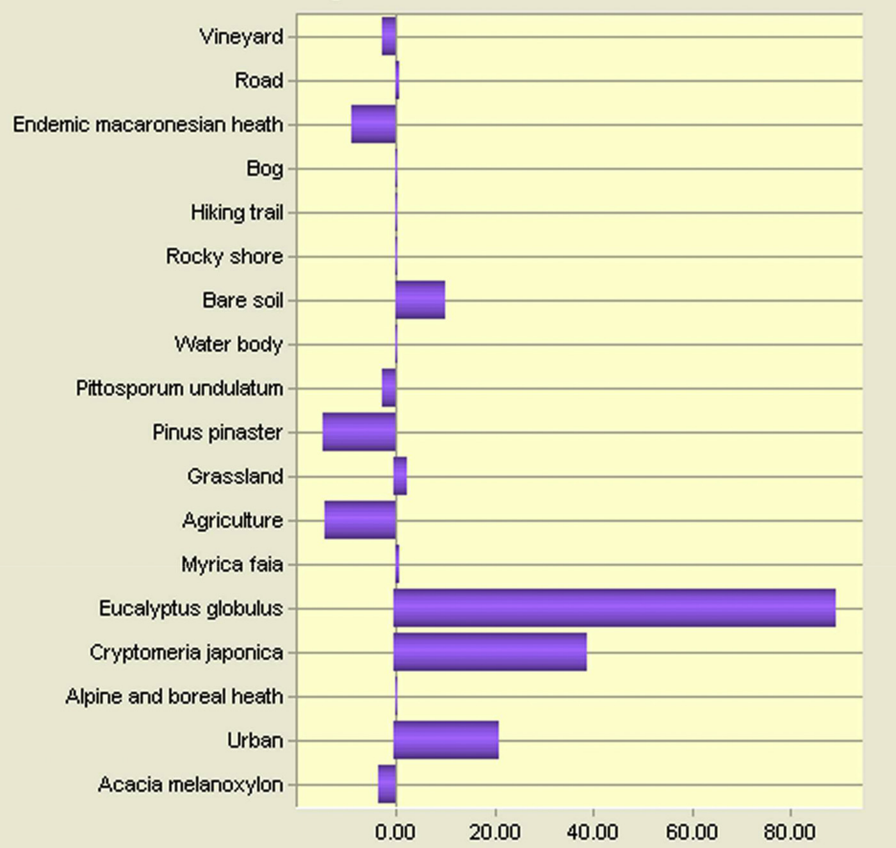


Fig. 4. Percentage of area change for each land use/land cover (LULC) between 1998 and 2013.

to conversion to grassland. Further research would determine the effect of giving funds to private owners to control invasive plants. Effectively controlling or eradicating such a robust invasive species would, nevertheless, likely require an integrated island strategy applied to wider areas. The invasive power of pittosporum, despite its general decrease in area, is still visible where it replaced vineyards and other agricultural land in small patches throughout the coastal area.

Pittosporum is currently not being used for any important private or public economic activity despite its estimated biomass production of 150–60,000 Mg, depending on the Azorean island (highest value on Pico). Pittosporum is only used as a source of composting material for pineapple plantations in greenhouses on São Miguel and for the small-scale production of honey in association with other plants (Lourenço et al., 2011). This indifference might change in the near future, because a regional company, whose target is to develop and produce biofuels, is currently developing projects to build three factories for the recovery of energy from forest biomass in the Azores. The Azorean Regional Government has already recognized these as 'Regional Interest Projects' in 2012, and the company is currently seeking ENplus certification for the production of pellets. Certification requires low emissions and trouble-free heating with a high-energy value, and is already in use in several European countries and the United States (AEBIOM, n.d.). The three factories will produce pellets for local, national, or international consumption for industries, district heating, and/or domestic clients. One factory will be on Pico Island (the others on São Miguel and Terceira Islands) and will contribute 31% of the total production (100,000 t of pellets/year). Fifty percent of this production is likely to be exported to help the regional economy.

The characteristics of pittosporum wood make it a good candidate for combustion or gasification (Lourenço et al., 2011). Research studies to identify other potentially interesting species for pellet production are under development, as is research on the long-term replacement of alien with native species, such as *Myrica faya* (NaturalReason, 2012). Invasive plants could be used to produce pellets (pittosporum and perhaps acacia), followed by non-invasive species. Pico has large areas invaded by pittosporum, so this activity could economically use the invasive alien plants while gradually replacing them with native species. The restoration and revegetation of endemic plants and the release of space for pastures and forestry would then help the regional economy and nature conservation. The emission of greenhouse gases from pellet combustion would be balanced by the growth of new vegetation for storing carbon in the same area. A lower dependence of the Azores on fossil fuels would be another benefit of this activity (Lourenço et al., 2011). Further research on carbon storage and emission of greenhouse gases by this activity especially applied to the Azores will confirm the ecological sustainability of such measures.

Bogs by far stored the most carbon per hectare. Their role in global biodiversity and importance for endangered species (fauna and flora) has drawn increasing attention during recent decades (Strack, 2008). Restoring and extending them would be ideal, because they represent a key option for increasing carbon storage. Restoration projects are currently being tested in several locations in Europe and the United States (Strack, 2008). Their effectiveness cannot yet be evaluated due to the long time (25–30 years) needed to restore, when possible, the original conditions. Preliminary results, however, are encouraging, and additional research and fieldwork will allow an evaluation of the feasibility of increasing bog areas beyond their current natural limits without any restoration purpose. Several areas of bogs in the Azores, though, have already been drained to increase grasslands (Cruz and Benedicto,

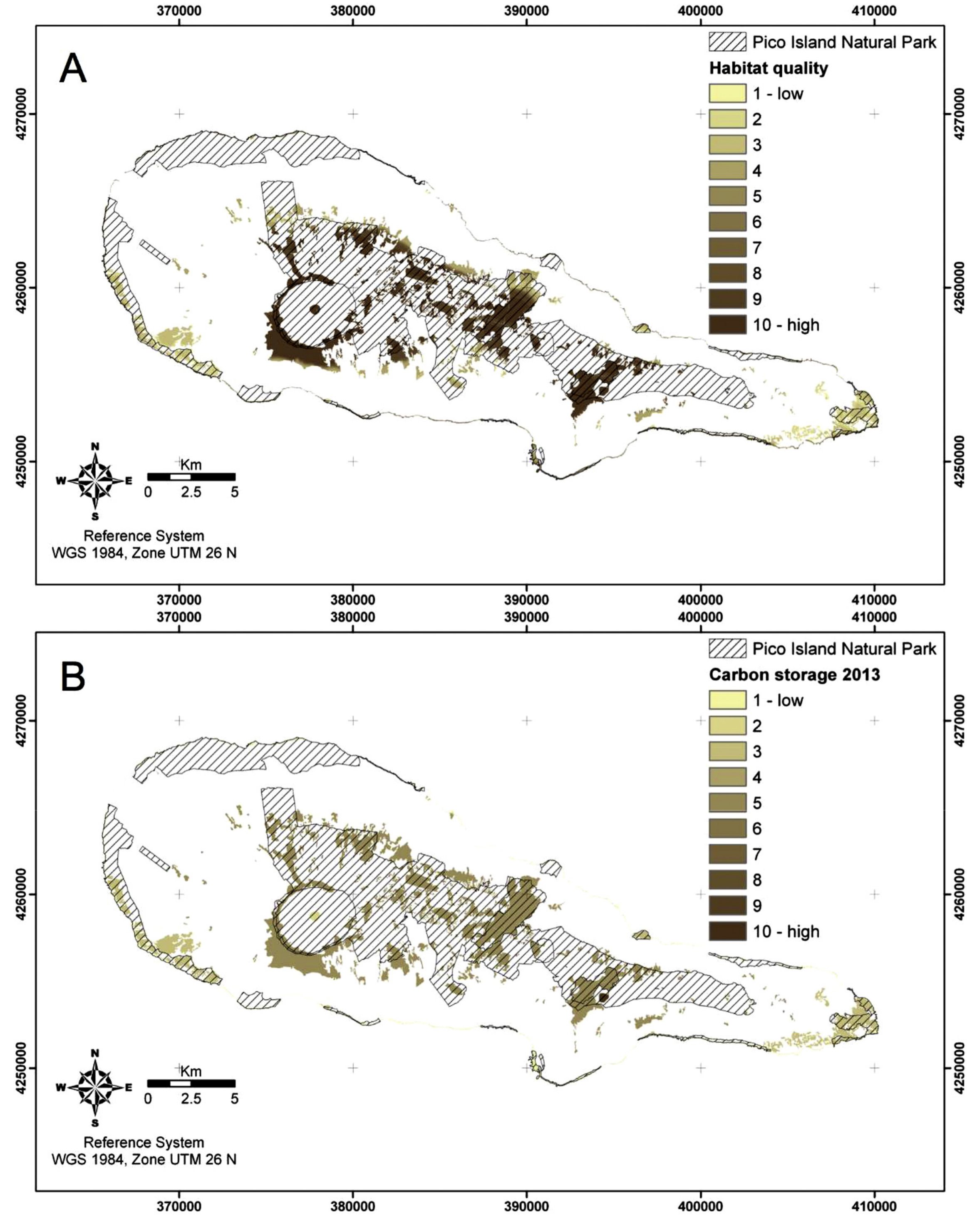


Fig. 5. Natural habitat quality (A) and carbon storage (B) in natural habitats (Fig. 5A was adapted from Moreira (2013)).

2009), potentially leading to large losses of both carbon storage and biodiversity.

The endemic Macaronesian heaths (second highest carbon storage in natural habitats) grow slowly but store carbon for long periods of time. Restorative actions could extend them to higher altitudes, replacing grasslands that would have to be relocated to lower altitudes in coastal areas. This option and its associated trade-offs need to be carefully weighed. Most urban areas and human activities are concentrated along the coast, and some exist in PAs (mainly protected landscape for vineyard culture). These zones also contain heather (*Erica azorica*) that cannot be removed due to its status of legal protection. All these constraints and competing uses in coastal areas hinder the decision to replace grasslands, which would need to be based on a solid compromise between all stakeholders involved.

Demand for grassland areas on Pico Island is currently high (Pereira et al., 2014). The areas of endemic Macaronesian heath that were converted to grassland between 1998 and 2013 in the central INP illustrate this pressure. Large areas on Pico do not have adequate soil productivity to support grassland: they can be sensitive (especially wetlands) and have high risks of erosion if pastures and grazing intensity are not effectively managed (Fernandes et al., 2015).

Coastal areas recovered from invasive alien species could also be used for forestry, which would represent an important economic income for the archipelago. The most important forests, those of cryptomeria, generate about 1.8 million Euros/year for forest owners in the Azores and about 10.9 million Euros for the entire sector in the Azores (data for 2009, DRRF n.d.). The increase between 1998 and 2013 in areas covered with cryptomeria (+39%) and eucalyptus (+89%) reflects the importance of this economic sector. The endemic vegetation unfortunately requires too much maintenance (10 years versus 3–5 years for cryptomeria) to be cost effective in the forestry sector. If forestry wood is used for the production of long-lived goods (such as in construction or furniture), retaining carbon during its lifetime, forestry wood could also represent a carbon sink (ESA, 2000). The InVEST model can also be run with a fifth optional pool, harvested wood products, to account for the amount of carbon not entering the atmosphere due to a long-lived product, such as house timbers or furniture (NCP, 2015). The input data requested by the model, however, is not available for the Azores: the amount of biomass, in terms of carbon, removed per harvest, the frequency of harvests, and rate of degradation of products that contain carbon. Future availability of these data will allow a more detailed and/or accurate assessment of carbon sequestration in the archipelago (NCP, 2015).

4.1. Land-management recommendations and conditions for their implementation

Results led to the proposal of recommendations for managing the island territory with two specific goals. The first goal is to decrease the area covered by invasive alien species, and the second goal is to protect natural habitats (or enlarge them when possible) and to relocate grasslands and forestry areas. Natural habitats are the primary focus, with high values of carbon storage (bogs, endemic Macaronesian heaths, and *Myrica faya* heaths). Fostering these carbon-rich native Azorean habitats is focused on simultaneously increasing carbon storage and biodiversity. Alpine and boreal heaths were assumed to be near their optimal extent and should not be enlarged, because they have maximum habitat quality (i.e. they do not suffer from any threat) and their values of carbon storage were not as high as those of other habitats.

All these LULC changes would require the participation of island stakeholders and the establishment of soil studies to develop a plan describing and justifying the best location of grasslands, forestry areas, and *Myrica faya* heaths to replace invasive alien plants. The proportion to which each LULC should be implemented and which surface should be kept for *Myrica faya* preservation will require discussion. The long-term reduction in the supply of freshwater is one of the most important current challenges in the Azores (Calado et al., 2011), so mapping crucial areas for water maintenance would help the discussion of new LULC allocations, depending on their impact on water supply. Studying the changes in island carbon storage with potential future LULC modifications will provide information about the evolution of carbon stocks in the region, which might also help to determine the proportions of the LULCs that should be established to increase carbon stocks. Connecting fragmented habitats between the coastal areas and the inner part of the island should also be recommended when allocating new LULCs (Calado et al., 2014b).

Efforts of land management to increase carbon storage in the Azores could benefit the regional economy if the LULUCF system is incorporated into the EU's future climatic policies. As an example, the allocation of carbon credits could allow companies that buy credits through the European Emission Trading System to decrease their expenses. This particular example could be beneficial, for example, for SATA airlines and EDA – Electricidade dos Açores (EDA – Electricity of the Azores).

4.2. Relationships with INP

Moreira (2013) reported that 64% of the natural-habitat areas were in Pico's INP and that areas with the lowest quality were not. Low habitat quality is mainly due to the occurrence of invasive alien species, so their (mainly pittosporum) progressive decrease in area will lead to lower threat values and allow higher habitat quality, even if they are outside INP. These changes could then improve the natural habitats outside INP, with a supplementary effect on INP for biodiversity protection in the region, demonstrating that conservation needs to be established at the island scale and not only inside INP (Calado et al., 2014a; Fernandes et al., 2015; Moreira 2013).

Including the proposed recommendations in future plans to manage INP at the island scale could protect biodiversity, progressively increase carbon storage, control invasive alien species, and extend forestry areas. The careful management of land should be able to increase the economic and environmental value of the region with reduced tradeoffs.

5. Conclusions

This study analyzed the storage of carbon on Pico Island in several land-use classes and their changes between 1998 and 2013. Carbon storage for 2013 was also compared to associated biodiversity and habitat quality.

This study supports the strategies that promote the potential of the conservation of biodiversity to promote the mitigation of climate change. Maximizing carbon storage and biodiversity without major tradeoffs is possible, but the value of either variable should not be reduced. Proposed recommendations are not only oriented towards biodiversity conservation but also recognize the importance of economic activities for the subsistence of the inhabitants.

Small islands, specifically those of the Macaronesia Biogeographic Region, have similar features (such as volcanic origin and remnant areas of native laurel forest), so the methods used in this study can be extrapolated with adequate adaptation. The proposed management guidelines can be equally applied to other Macaronesian islands and, with local adaptations, to other outermost regions.

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References

AEBIOM, n.d. ENpluspellets, European Biomass Association. http://www.enplus-pellets.eu (accessed 2.07.15).

AEMET-IM, n.d. Climate atlas of the archipelagos of the Canary Islands, Madeira and the Azores–Air temperature and precipitation (1971–2000), State Meteorological Agency of Spain and Institute of Meteorology of Portugal. https://www.ipma.pt/export/sites/ipma/bin/docs/publicacoes/atlas.clima.ilhas.iberico.2011.pdf.

AFN, 2010. Inventário Florestal Nacional. Autoridade Florestal Nacional, Lisboa, Portugal, ISBN: 978-972-8097-76-9.

Abreu, P.M.R., 2011. Contributo da Criptoméria para o sequestro de carbono nos Açores, PhD Dissertation. University of Aveiro, Portugal, 104p.

Alonso, I., Weston, K., Gregg, R., Morecroft, M., 2012. Carbon storage by habitat: Review of the evidence of the impacts of management decisions and condition of carbon stores and sources, Natural England Research Reports, Number NERR043. http://publications.naturalengland.org.uk/publication/1412347.

Azevedo, E.B., 1996. Modelação do clima insular à escala local. Modelo CIELO aplicado à ilha Terceira, PhD Dissertation. University of Azores, Portugal, 247p.

Borges, P.J.S.A., 2003. Ambientes litorais nos Grupos Central e Oriental do arquipélago dos Açores—Conteúdos e Dinâmica de Microescala, PhD Dissertation. University of the Azores, Portugal.

Botelho, C.S.F., 2013. Contributo dos instrumentos de gestão territorial para a sustentabilidade do parque natural de ilha do Pico, Master Dissertation. University of Lisbon, Portugal, 92p http://run.unl.pt/handle/10362/10828.

Calado H., Lopes C., Porteiro J., Paramio L., Monteiro P., 2009. Legal and technical framework of Azorean protected areas. Journal of Coastal Research SI 56, Proceedings of the 10th International Coastal Symposium, Lisbon, Portugal, pp. 1179–1183. ISSN 0749-0258. http://e-geo.fcsh.unl.pt/ICS2009/_docs/ICS2009_Volume_II/1179.1183_H.Calado_ICS2009.pdf.

Calado, H., Ng, K., Borges, P., Alves, F., Sousa, L., 2011. Climate change and coastal tourism in the Azores Archipelago. In: Jones, A., Philips, M. (Eds.), Disappearing Destinations, Climate Change and Future Challenges for Coastal Tourism. CABI, Wallingford, Oxfordshire, Cambridge, pp. 111–122, http://dx.doi.org/10.1079/9781845935481.0111.

Calado, H., Vergílio, M., Fonseca, C., Gil, A., Moniz, F., Silva, S.F., Moreira, M., Bragagnolo, C., Silva, C., Pereira, M., 2014a. Developing a planning and management system for protected areas on small islands (the Azores Archipelago, Portugal): the SMARTPARKS project. J. Integr. Coast. Zone Manage. 14 (No. 2), 335–344 http://www.aprh.pt/rgci/pdf/rgci-496_Calado.pdf.

Calado, H., Bragagnolo, C., Silva, S.F., Pereira, M., 2014. A multi-scale analysis to support the implementation of a regional conservation policy in a small-island archipelago—the Azores, Portugal. Journal of Coastal Research SI 70, Proceedings 13th International Coastal Symposium, Durban, South Africa, pp. 485–489. http://www.jcronline.org/doi/pdf/10.2112/SI70-082.1.

Calado, H., Braga, A., Moniz, F., Gil, A., Vergílio, M., 2015. Spatial planning and resource use in the Azores. Mitig. Adapt. Strateg. Global Change 20 (7), 1079–1095, http://dx.doi.org/10.1007/s11027-013-9519-2.

Cannell, M.G.R., Dewar, R.C., Pyatt, D.G., 1993. Conifer plantations on drained peatlands in Britain: a net gain or loss of carbon? Forestry 66 (No. 4), 353–369, http://dx.doi.org/10.1093/forestry/66.4.353.

ClimAdaPT.Local, 2015. Municipalities and Climate Change—EMAAC—Municipal Strategies for Adaptation to Climate Change. FCUL (Coord.). Financed by EEA Grants/Agência Portuguesa do Ambiente (APA). http://climadapt-local.pt/en/project/ (in Portuguese).

Condé, S., Richard, D., 2002. Biogeographical regions in Europe. The Macaronesian region–volcanic islands in the ocean. In: EEA Report No 1/2002 – Europe's biodiversity – biogeographical regions and seas. European Environment Agency http://www.eea.europa.eu/publications/report_2002_0524_154909/biogeographical-regions-in-europe/MacaronesiaReg.pdf.

Costa, H., Aranda, S.C., Lourenço, P., Medeiros, V., Azevedo, E.B., Silva, L., 2012. Predicting successful replacement of forest invaders by native species using species distribution models: the case of Pittosporum undulatum and Morella faya in the Azores. For. Ecol. Manage. 279, 90–96, http://dx.doi.org/10.1016/j.foreco.2012.05.022.

Cruz, A., Benedicto, J., 2009. Assessing Socio-economic Benefits of Natura 2000—a Case Study on the ecosystem service provided by SPA Pico da Vara/Ribeira do Guilherme. Output of the project Financing Natura 2000: Cost estimate and benefits of Natura 2000 (Contract No.: 070307/2007/484403/MAR/B2), p 43. http://ec.europa.eu/environment/nature/natura2000/financing/docs/azores_case_study.pdf.

Cruz, J.V., Silva, M.O., 2000. Groundwater salinization in Pico Island (Azores, Portugal): origin and mechanisms. Environ. Geol. 39 (No. 10), 1181–1189, http://dx.doi.org/10.1007/s002540000109.

DROTRH/IA, 2001. Plano Regional da Água—Relatório técnico (Versão para Consulta Pública). Direcção Regional do Ordenamento do Território e dos Recursos Hídricos/Secretaria Regional do Ambiente. Ponta Delgada, Portugal.

DRRF, n.d. Direçao Regional dos Recursos Florestais. http://drrf-srrn.azores.gov.pt/Paginas/Home.aspx (accessed 14.07.15).

De Groot, R.S., Wilson, M., Boumans, R., 2002. A typology for the description, classification and valuation of ecosystem functions, goods services. Ecol. Econ. 41 (No. 3), 393–408, http://dx.doi.org/10.1016/S0921-8009(02)00089-7.

De Groot, R.S., 1992. Functions of nature: evaluation of nature in environmental planning, management and decision making. Polar Rec. 29, http://dx.doi.org/10.1017/S0032247400023779, 162–162.

Decision No 529/2013/EU of the European Parliament and of the Council of 21 May 2013 on accounting rules on greenhouse gas emissions and removals resulting from activities relating to land use, land-use change and forestry and on information concerning actions relating to those activities.http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32013D0529.

Dias, E., Elias, R.B., Nunes, V., 2004. Vegetation mapping and nature conservation: a case study in Terceira Island (Azores). Biodivers. Conserv. 13 (8), 1519–1539, http://dx.doi.org/10.1023/B:BIOC.0000021326.50170.66.

Dudley, N. (Ed.), 2008. Guidelines for Applying Protected Area Management Categories. IUCN, Switzerland.

Dwivedi, P., Khanna, M., Sharma, A., Susaeta, A., 2016. Efficacy of carbon and bioenergy markets in mitigating carbon emissions on reforested lands: a case study from Southern United States. Forest Policy Econ. 67, 1–9, http://dx.doi.org/10.1016/j.forpol.2016.03.002.

EFI, 2014. What is REDD+? EUREDD Facility. European Forest Institute. http://www.euredd.efi.int/redd (accessed August 2015).

ESA, 2000. Carbon Sequestration in Soils. Ecological Society of America, http://www.esa.org/esa/wp-content/uploads/2012/12/carbonsequestrationinsoils.pdf (accessed June 2015).

EU, 2015. The EU Emissions Trading System (EU ETS). European Commission, European Union, http://ec.europa.eu/clima/policies/ets/index_en.htm (accessed August 2015).

Eastman, J.R., 2012. IDRISI Selva. Clark University, Worcester, http://www.clarklabs.org/products/land-change-modeler.cfm (accessed April 2015).

FIVS, 2008. International Wine Carbon Calculator Protocol. Version 1.2. Fédération Internationale des Vins et Spiritueux, http://www.wineinstitute.org/files/International%20Wine%20Carbon%20Calculator%20Protocol%20V1.2.pdf (accessed November 2013).

Fernandes, J.P., Guiomar, N., Freire, M., Gil, A., 2014. Applying an integrated landscape characterization and evaluation tool to small islands (Pico, Azores, Portugal). J. Integr. Coast. Zone Manage./Revista de Gestão Costeira Integrada 14, 243–266, http://dx.doi.org/10.5894/rgci473.

Fernandes, J.P., Guiomar, N., Gil, A., 2015. Strategies for conservation planning and management of terrestrial ecosystems in small islands (exemplified for the Macaronesian islands). Environ. Sci. Policy 51, 1–22, http://dx.doi.org/10.1016/j.envsci.2015.03.006.

Guo, L.B., Gifford, R.M., 2002. Soil carbon stocks and land use change: a meta analysis. Global Change Biol. 8, 345–360, http://dx.doi.org/10.1046/j.1354-1013.2002.00486.x.

Gao, C., Knorr, K., Yu, Z., He, J., Zhang, S., Lu, X., Wang, G., 2016. Black carbon deposition and storage in peat soils of the Changbai Mountain, China. Geoderma 273, 98–105, http://dx.doi.org/10.1016/j.geoderma.2016.03.021.

Herr, D., Pidgeon, E., Laffoley, D. (Eds.), 2012. Blue Carbon Policy Framework: Based on the Discussion of the International Blue Carbon Policy Working Group. International Union for Conservation of Nature, Gland, Switzerland and Conservation International, Arlington, Virginia.

Hortal, J., Borges, P.A.V., Jiménez-Valverde, A., Azevedo, E.B., Silva, L., 2010. Assessing the areas under risk of invasion within islands through potential distribution modelling: the case of Pittosporum undulatum in São Miguel, Azores. J. Nat. Conserv. 18, 247–257, http://dx.doi.org/10.1016/j.jnc.2009.11.002.

IPCC, 2000. Land Use, Land-Use Change and Forestry (Summary for Policymakers). Cambridge University Press, Cambridge, http://www.ipcc.ch/ipccreports/sres/land_use/index.php?idp=3 (accessed 01.06.16).

IPCC, 2001. Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the 3rd Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York http://www.grida.no/publications/other/ipcc_tar/.

IPCC, 2006. Generic methodologies applicable to multiple land-Use categories. In: Eggleston, S., Buendia, L., Miwa, K., Ngara, T., Tanaben, K. (Eds.), IPCC Guidelines for National Greenhouse Gas Inventories. Agriculture, Forestry and Other Land Use, Vol. 4. IGES, Japan http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_02_Ch2_Generic.pdf.

Lagabrielle, E., Rouget, M., Payet, K., Wistebaar, N., Durieux, L., Baret, S., Lombard, A., Strasberg, D., 2009. Identifying and mapping biodiversity processes for conservation planning in islands: a case study in Réunion Island (Western Indian Ocean). Biol. Conserv. 142 (No. 7), 1523–1535, http://dx.doi.org/10.1016/j.biocon.2009.02.022.

Lourenço, P., Medeiros, V., Gil, A., Silva, L., 2011. Distribution, habitat and biomass of Pittosporum undulatum, the most important woody plant invader in the Azores Archipelago. For. Ecol. Manage. 262 (No. 2), 178–187, http://dx.doi.org/10.1016/j.foreco.2011.03.021.

Mendonça, F.E.P., 2012. Serviços dos Ecossistemas na Ilha Terceira: estudo preliminar com ênfase no sequestro de carbono e na biodiversidade. PhD Dissertation. University of Azores, Portugal, 147p.

Miranda, P.M.A., Valente, M.A., Tomé, A.R., Trigo, R., Coelho, M.F., Aguiar, A., Azevedo, E.B., 2006. O clima de Portugal nos séculos XX e XXI. In: Santos, F.D., Miranda, P.M.A. (Eds.), Alterações climáticas em Portugal: cenários, impactos e medidas de adaptação (Projecto SIAM II). Gradiva, Lisbon, pp. 47–113 (in Portuguese).

Moreira, M., 2013. Valoração da biodiversidade no Parque Natural de Ilha do Pico através da metodologia InVEST, Technical report developed under the SMARTPARKS Project –Spatial planning and management of Protected Areas in small islands (PTDC/AAC-AMB/098786/2008). University of the Azores, Ponta Delgada Portugal, 37p.

NCP, 2015. Natural Capital Project, http://www.naturalcapitalproject.org (accessed 15.05.15).

NaturalReason, 2012. http://www.naturalreason.pt/pages/projectos.php (accessed 19.07.15).

Ng, K., Phillips, M.R., Borges, P., Thomas, T., August, P., Calado, H., Veloso-Gomes, F., 2014. Maintaining a way of life for São Miguel Island (the Azores archipelago, Portugal): an assessment of coastal processes and protection. Sci. Total Environ. 481, 142–156, http://dx.doi.org/10.1016/j.scitotenv.2014.01.067.

Nurse, L.A., McLean, R.F., Agard, J., Briguglio, L.P., Duvat-Magnan, V., Pelesikoti, N., Tompkins, E., Webb, A., 2014. Small islands. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of

Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1613–1654 http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap29_FINAL.pdf.

Onaindia, M., Manuel, B.F., Madariaga, I., Rodríguez-Loinaz, G., 2013. Co-benefits and trade-offs between biodiversity, carbon storage and water flow regulation. For. Ecol. Manage. 289, 1–9, http://dx.doi.org/10.1016/j.foreco.2012.10.010.

Ordonez, J.A.B., Jong, B.H.J., García-Oliva, F., Aviña, F.L., Pérez, J.V., Guerrero, G., Martínez, R., Masera, O., 2008. Carbon content in vegetation, litter, and soil under 10 different land-use and land-cover classes in the Central Highlands of Michoacan, Mexico. For. Ecol. Manage. 255, 2074–2084, http://dx.doi.org/10.1016/j.foreco.2007.12.024.

Paoli, G.D., Wells, P.L., Meijaard, E., Struebig, M.J., Marshall, A.J., Obidzinski, K., Tan, A., Rafiastanto, A., Yaap, B., Slik, J.W.F., Morel, A., Perumal, B., Wielaard, N., Husson, S., D'Arcy, L., 2010. Biodiversity conservation in the REDD. Carbon Balance Manage. 5, 7 http://www.cbmjournal.com/content/5/1/7.

Pereira, M., Bragagnolo, C., Calado, H., Fonseca, C., 2014. Conflitos territoriais em áreas protegidas de pequenas ilhas: a ilha montanha do Pico (Açores −Portugal). Revista de Geografia e Ordenamento do Território (GOT) 5, 207–231 http://cegot.org/ojs/index.php/GOT/article/viewFile/2014.5.009/82.

Petit, J., Prudent, G., 2010. Climate Change and Biodiversity in the European Union Overseas Entities. IUCN, Gland, Switzerland and Brussels, Belgium.

Porteiro, J., Calado, H., Monteiro, P., Medeiros, A., Botelho, A., Paramio, L., Lacerda, S., Santos, M., Cadete, J., Moreira, A., 2005. XII Scientific Expedition of the Department of Biology Pico Island, Reports and Communications of the Department of Biology, University of the Azores21–35 https://repositorio.uac.pt/bitstream/10400.3/726/1/Sistema%20de%20informa%C3%A7%C3%A3o%20geogr%C3%A1fica%20das%20zonas%20balneares%20da%20ilha%20do%20Pico%20%28A%C3%A7ores%29.pdf.

Regional Legislative Decree No. 15/2012/A of April 2. Establishes the Legal Regime of Nature Conservation and Biodiversity Protection. http://dre.pt/pdf1sdip/2012/04/06600/0162501713.pdf.

Rietbergen, S., Hammond, T., Sayehg, C., Mooney, K., 2008. Island voices – island choices: developing strategies for living with rapid ecosystem change in small islands. In: Ecosystem Management Series, 6th ed. IUCN, Gland, p. 40 https://portals.iucn.org/library/efiles/edocs/CEM-006.pdf.

Rubenstein, M., 2011. Sea Level Rise and Climate Change: Impacts on Small Island States. State of the Planet, Earth Institute, Columbia University, http://blogs.ei.columbia.edu/2011/12/15/a-changing-climate-for-small-island-states/ (accessed 31.05.16).

SRAM, 2008. Plano de Ordenamento das Bacias Hidrográficas das Lagoas Caiado, Capitão, Paul, Peixinho e Rosada Fase A Caracterização/Diagnóstico Prospectivo. Governo dos Açores, Secretaria Regional do Ambiente e do Mar.

SREA, 2010. Séries Estatísticas 1998–2008. Serviço Regional de Estatística dos Açores, http://estatistica.azores.gov.pt/ (accessed April 2015).

Santos, F.D., Valente, M.A., Miranda, P.M.A., Aguiar, A., Azevedo, E.B., Tomé, A.R., Coelho, F., 2004. Climate change scenarios in the Azores and Madeira Islands. World Resour. Rev. 16, 473–491.

Silva, L., Smith, C.W., 2006. A quantitative approach to the study of non-indigenous plants: an example from the Azores archipelago. Biodivers. Conserv. 15, 1661–1679, http://dx.doi.org/10.1007/s10531-004-5015-z.

Silva, L., Ojeda, E.L., Luengo, J.L.R. (Eds.), 2008, 546p http://cita.angra.uac.pt/ficheiros/publicacoes/1258549928.pdf.

Strack, M. (Ed.), 2008. Peatlands and Climate Change. International Peat Society, Finland, 223p http://www.peatsociety.org/sites/default/files/files/PeatlandsandClimateChangeBookIPS2008.pdf.

Strassburg, B.B.N., Kelly, A., Belmfort, A., Davies, R.G., Gibbs, H.K., Lovett, A., Miles, L., Orme, C.D.L., Price, J., Turner, R.K., Rodrigues, A.S.L., 2010. Global congruence of carbon storage and biodiversity in terrestrial ecosystems. Conserv. Lett. 3, 98–105, http://dx.doi.org/10.1111/j.1755-263X.2009.00092.x.

Tsui, C.C., Tsai, C.C., Chen, Z.S., 2013. Soil organic carbon stocks in relation to elevation gradients in volcanic ash soils of Taiwan. Geoderma 209–210, 119–127, http://dx.doi.org/10.1016/j.geoderma.2013.06.013.

UNEP, 2014. Emerging Issues for Small Island Developing States. Results of the UNEP Foresight Process. United Nations Environment Programme (UNEP), Nairobi, Kenya http://www.unep.org/pdf/Emerging_issues_for_small_island_developing_states.pdf.

Watson, R.T., Noble, I.R., Bolin, B., Ravindranath, N.H., Verardo, D.J., Dokken, D.J., 2000. Land use, land use change and forestry: a special report of the intergovernmental Panel of Climate Change. 388p. http://www.ipcc.ch/ipccreports/sres/land_use/.