The distribution and naturalness of peatland on Terceira Island (Azores): instruments to define priority areas for conservation and restoration

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SUMMARY

The study reported here used spatial analysis to assess the effectiveness of the legal nature protection framework in supporting the conservation of peatlands on Terceira Island (Azores archipelago, Portugal) and identify potential improvements. Terceira has 3011 ha of peatland, of which 44 % is forested. Bogs and fens account for 14 % and 3 % of this area, respectively, while 39 % has been classified as degraded peatland. Overall, 46 % of the peatland is still in natural condition and 80 % of this is concentrated in two 'wild' areas known as Santa Barbara and Pico Alto, which are separated by an intervening expanse of land with mainly disturbed mires. Most of the peatland lies within a Natural Park (82 %) and a Special Conservation Area (SCA; 67 %). The wildest peatland (70 %) is in Ramsar and public forestry areas. A management zonation to define priority areas for protection and restoration is proposed. This includes three reserve areas and six buffer areas, in which controlled management to inhibit potential direct impacts on the wildest peatland should be implemented. This model includes a corridor between the two major reserves to promote connectivity. Nowadays the local extent of peatland is less than the potential area. Moreover, an assessment of peatland condition indicates a need for development of strategies to conserve wild peatland and implement restoration to improve the naturalness of disturbed peatland, as well as the ecological connectivity between the two major mire-rich natural protected areas on the island.

KEY WORDS: cartography, classification, natural park, peatland management zonation model, public areas, Ramsar, Special Conservation Area (SCA)

INTRODUCTION

Historically, peatlands covered nearly 100 million hectares of Europe, which is 20 % of the land area (Lappalainen 1996). Owing to a long history of high population and climatic suitability for agriculture, Europe has experienced one of the largest losses of mires in the world (Rochefort & Lode 2006). Peat accumulation has ceased on more than 50 % of European mires and almost 20 % of the original mire area is no longer peatland. In many countries, only 1 % or less of the original resource remains (Joosten & Clarke 2002). Raeymaekers (1998) reports that European Union (EU) countries have lost more than 70 % of their original mire area. The occurrence of mires in Portugal is not considered to be representative of Europe as a whole, but Portuguese mires are extremely important within the region and unique in a global context (Montanarella *et al*. 2006). Raeymaekers (1998) states that Portugal has 1 km^2 of mire, representing only 1 % of the original mire area; whereas Joosten & Clarke (2002) report that the country has 20 km^2 of peatland (including 2 km^2 of active mire), of which 1 km^2 is in the Azores archipelago. Contemporary and subsequent studies (e.g. Dias 1996, Dias & Mendes 2007, Mendes 2010, Mendes & Dias 2013) have suggested that this is an under-estimate of the area of Azorean peatland. *Sphagnum* ecosystems in the Azores have also been studied in some detail during the last 20 years (Dias 1996, Mendes 1998, Dias *et al*. 2004, Mendes & Dias 2009, Mendes & Dias 2010, Mendes 2010, Mendes & Dias 2013, Pereira 2015, Mendes & Dias 2017 and Mendes 2017). The latest and most accurate data (Mendes & Dias 2017, Mendes 2017, Tanneberger *et al.* 2017) indicate that the original area of peatland in the Azores may have been 350 km^2; that less than 30 % of this area persists nowadays; and that more than 50 % of the remaining peatland is under pressure, mainly due to its use as pasture for livestock.

There is still a large area of peatland on Terceira Island (Figure 1), but a substantial part of it is disturbed by human activities, necessitating measures to safeguard peatland habitats. The most important areas for biodiversity conservation on Terceira Island are the Santa Barbara Mountain / Pico Alto Natura

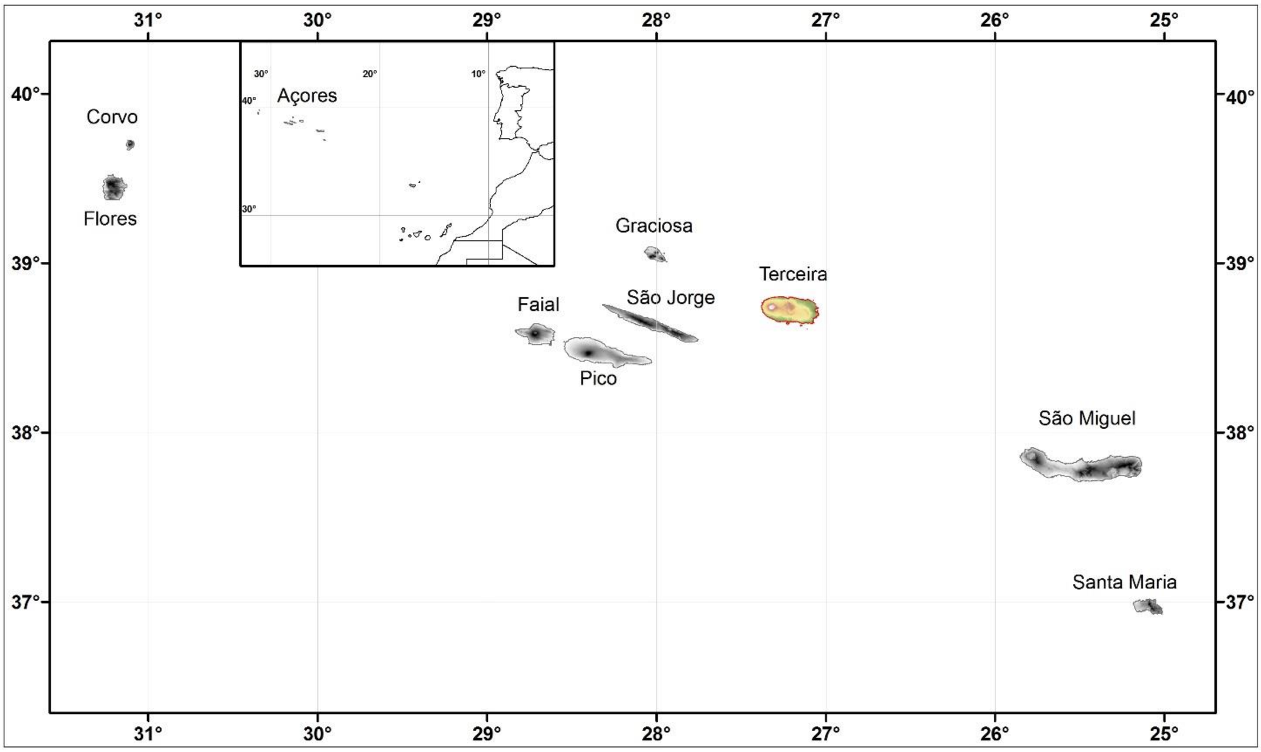

Figure 1. Map showing the Azores archipelago and its location within the North Atlantic region (inset). Terceira is the island studied here.

2000 Special Conservation Area (SCA; code PTTER0017, created December 2001) (Figure 2A) and the Natural Park (DLR 15/2007/A, approved 24 June 2007) (Figure 2B). Terceira also has two Ramsar sites, one of which is focused on peatlands (Figure 2D). Additional areas that should be considered in this context are public areas (Figure 2C) under the jurisdiction of the environmental and forestry services which, at least in priority key locations, could be managed for nature conservation. However, all of the legal frameworks (SCA, Natural Park, Ramsar site) lack management plans for the conservation of elements that are protected under the EU Habitats Directive, as well as action plans for the restoration of relevant disturbed habitats. It is urgent that strategies are established to safeguard natural mire areas, as well as to restore the neighbouring land and processes upon which they depend.

Protecting natural ecosystems is always the first choice in nature conservation but, when this is not possible, restoration can be used to complement conservation efforts. Surviving natural mires must be protected because, as mentioned by Rochefort & Lode (2006), it would be unwise to rely only on restored peatlands as a conservation strategy for a given geographical region. To ensure the maintenance of regional peatland biodiversity, it is important to maintain natural mires in the landscape and to preserve undisturbed fragments adjacent to disturbed areas. Artificial divisions have been imposed between restoration ecology and conservation biology by differences in language and in the interpretation of concepts such as invasiveness and naturalness (Davis *et al*. 2011). Generally speaking, the goals of conservation and habitat restoration are the same, but the methods differ. Conservation tends to focus on protecting remaining areas of high-quality habitat, whereas restoration operates on degraded land. As degraded land has increasingly come to dominate the earth's surface, restoration has become an important strategy for biodiversity conservation (Dobson *et al*. 1999). Ecological processes and flows may be restored by actively restoring natural landscape conditions and removing barriers in the matrix of land through which organisms move. Maintaining landscape flows is a goal in which restoration and conservation are highly complementary (Noss *et al*. 2006); ideally, both approaches should be employed in a coordinated strategy for the conservation of biodiversity and ecological processes.

In 2010 the Convention on Biological Diversity (CBD) agreed an ambitious global target to restore at least 15 % of degraded ecosystems by 2020 (Target 15; http://www.cbd.int/sp/). The EU adopted this policy in 2015 (Target 2; http://eur-lex.europa.eu\

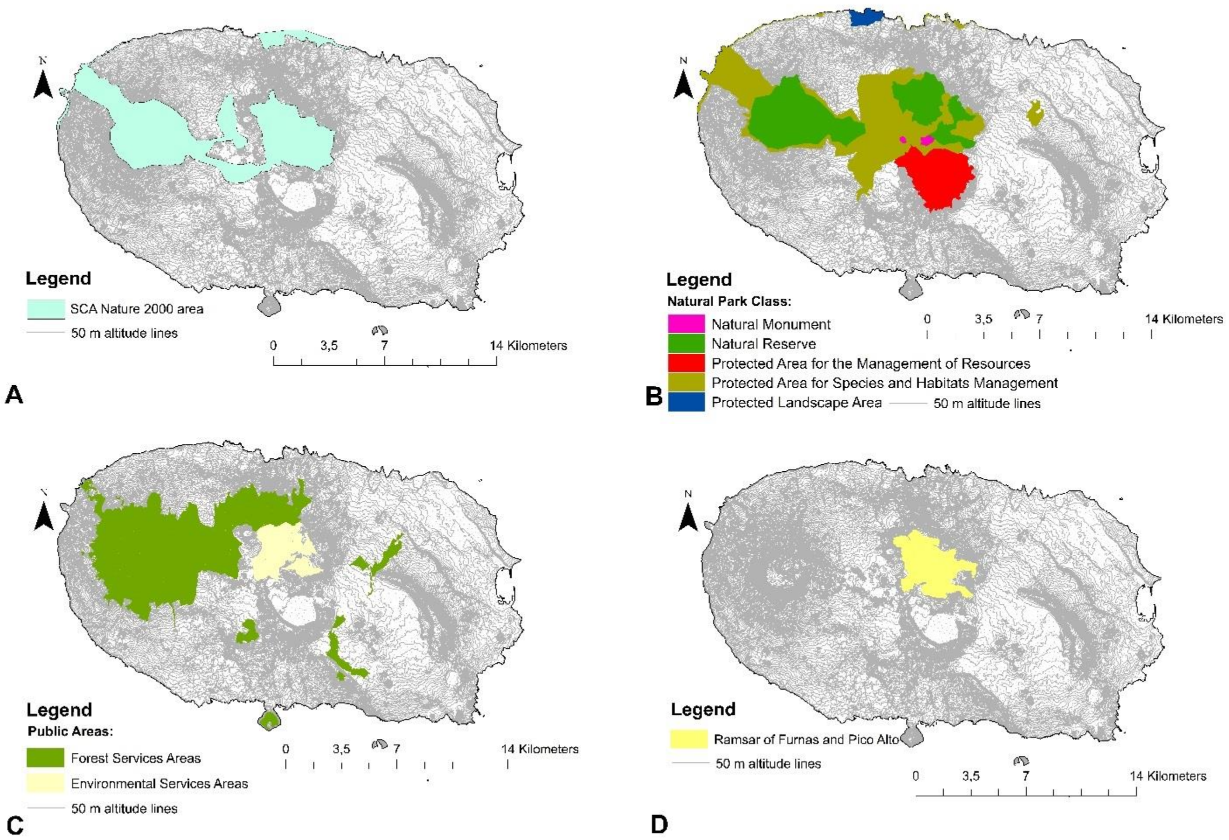

Figure 2. Classified and public areas on Terceira. A: Natura 2000 SCA (Special Conservation Area); B: Terceira Natural Park Areas and their classes, accessed 10 Jun 2016 at http://www.azores.gov.pt/Gra/srrn-natureza/conteudos/livres/Parque+Natural+da+Ilha+Terceira.htm; C: Terceira public area, accessed 10 Jun 2016 at http://ot.azores.gov.pt/Perimetros-Florestais.aspx#igt-ter. Images were georeferenced in ArcGIS 10; D: Terceira Ramsar classified area of Furnas and Pico Alto, accessed 10 Jun 2016 at https://rsis.ramsar.org/ris/1805.

legal-content/EN/TXT/?=CELEX:52011DC0244). The over-arching goal is to help with halting biodiversity loss and the degradation of ecosystem services (Kotiaho & Moilanen 2015).

The objectives of nature conservation have evolved over the last few decades, from placing emphasis on the protection of emblematic species, unique landscapes, biodiversity and habitats towards the conservation of ecological processes and processes relating to operation of the landscape (Franklin 1993, Regier 1993, Montes 1995). The intention is not only to conserve the wealth of species, but also to maintain their natural dynamics in a sustainable manner (Kupfer 1995), for example by conserving their habitats and the ecological processes they require to survive. The conservation networks aim to conserve not only the unique spatial integration of protected natural areas and ecological connectivity between landscape elements, but also all of the ecological processes operating in the landscape as well as environmental goods and services.

This study is a contribution to implementation of these international restoration targets. Its objectives are to: (1) define the distribution of peatland habitats within Terceira Island using GIS and classify them in terms of naturalness; (2) determine which of the protected and public spaces encloses the largest area of peatland, taking into account both distribution and naturalness; and (3) establish a theoretical spatial model to define priority areas for conservation and restoration on Terceira Island, and explore its potential and constraints.

This study is important in the context of establishing reference information for future peatland studies and will form a basis for future management plans. Combining distribution and naturalness provides a conceptual framework for the selection of peatlands for conservation as well as for defining priority areas for restoration. More generally, we hope it will provide a useful contribution to knowledge about the distribution and ecology of the world's peatlands.

STUDY AREA

Ecological conditions

The study area for GIS mapping of peatland was the whole of Terceira Island, which is one of the nine islands of the Azores archipelago (Figure 1). The Azores (36° 56' N – 39° 42' N, 25° 5' W – 31° 12' W) is the northernmost Macaronesian archipelago, located about 1400 km from continental Europe (the distance from Santa Maria Island to Lisbon) and 1900 km from the American continent (the distance from Flores Island to St John's Newfoundland, the most easterly city in North America). The area of Terceira Island is about 402 km^2 and it rises from sea level to 1023 m a.s.l. at the summit of its highest mountain, Santa Bárbara volcano, which is located in the western part of the island. Climate and topography at this altitude are highly favourable for the development of wet vegetation complexes. With some exceptions like lava domes (Dias 1996, Elias & Dias 2003, Dias *et al*. 2004), the majority of the plant communities are mire vegetation or directly dependent on mires. The predominant soil types of Terceira are Andosols with placic (indurated subsoil horizons of cemented iron and magnesium), developed from volcanic pyroclastic material under a wet, temperate Atlantic climate (Pinheiro 1990, Madruga 1995). However, in our study area, the major soils type are Histosols which have formed in places where poor drainage inhibits the decomposition of plant remains, allowing the accumulation of organic material. In the Azores, precipitation easily reaches 4000 mm year^{-1} on the highest islands (see Azevedo 2003 for detailed climate information). According to Dias (1996), annual precipitation (direct and horizontal) ranges from 4109 mm at 600 m a.s.l. to 13054 mm at 980 m a.s.l. The presence of placic in the soils limits drainage and this combines with high precipitation to create ideal conditions for the occurrence of mires, mainly above 500 m a.s.l. (Mendes 2010).

Historical landscape changes on Terceira Island

In continental Europe, landscape is the result of a long interaction process between humans and the environment. Such interaction has occurred only rather recently in the Azores, which were uninhabited until the middle of the 15th century AD. According to Dias (1996), much of the original vegetation of Terceira was dense evergreen forest (Laurisilva, Tertiary remnants of European forests), heathlands in naturally disturbed habitats and peatlands on high plateaux. Since the arrival of people, the landscape of Terceira and all other Azorean islands has changed drastically. The first Portuguese colony appeared on Santa Maria in 1439 and was followed by Flemish colonies on Faial (from 1466) and Flores (from 1472) (Connor *et al*. 2012). People arrived on Terceira between 1450 and 1487 (Leite 2012). According to Dias (1996), human impact on the vegetation occurred in three phases, which are described below.

(1) A pre-colonisation phase, in which a wide variety of domestic animals were released on the islands to sustain the anticipated human population; thus, according to this description, grazing was the first human-related activity that disturbed the natural condition of the Azores. The fact that the released animals reproduced implies that there were natural grasslands, as mentioned by Dias (2007, based on descriptions by Gaspar Frutuoso), and possibly some fens.

(2) An early extractive phase in which forests were felled for construction, ship-building and charcoal production. Only a few years after colonisation, the human impacts are described as follows: "what nature created during so many years, was so quickly destroyed, by fire and plowing and almost everything consumed, so, bare lands were conquered by wind taking land powder back to sea" (Frutuoso 1978). In this phase, forest was the type of vegetation most affected. Intensive use of wood led to the extinction of species on some islands (e.g. *Juniperus brevifolia* on Santa Maria Island, as mentioned by Dias (2007)).

(3) A later, transformative phase during which the Azorean landscape was deforested and turned over to the production of exotic monocultures.

Other key moments in Terceira's history that affected nature were the Black Death and the Second World War, which were periods of extreme poverty that drove local people to intensively exploit natural resources in order to survive (Rezendes 2008). Other historical landscape change is associated with the accession of Portugal to the EU (in the 1980s). Prior to EU accession, the land was used extensively with activities restricted to the best areas. When financial support from Europe became available, farmers explored new areas (including fens, bogs and some forested peatlands) and the intensification of agriculture through fertilisation and frequent sowings. Another activity that promoted changes in land use was the introduction of the exotic Japanese cedar *Cryptomeria japonica*. Because of these severe human interventions, little native vegetation survives on the islands today and introduced plant species outnumber native species by a factor of three to one (Schäfer 2005). Nonetheless, although drastically changed, Terceira still has wild areas with extremely high value for rare species and habitats.

More recently, the development of a global environmental conscience within European, national and regional authorities combined with increasing public awareness has given rise to legislation to protect rare habitats and species as well as pristine areas, which has been applied to critical parts of Terceira (and indeed all of the Azores islands). This includes European Directives such as the Habitats Directive, the designation of Azorean Natura 2000 areas, the definition of Regional classified parks and other framework areas and - very important for peatlands - Ramsar sites (the most important ones are described by Mendes & Dias (2017) and Mendes (2017)). In this scenario, the recognition of peatland values as well as the losses that have occurred creates conditions that promote studies focused on these habitats, including restoration.

METHODS

Data collection and distribution mapping

The distribution of peatlands on Terceira Island was described in the study of Mendes & Dias (2013). The information about fens, degraded bogs and forested bogs was subsequently adjusted on the basis of data from Mendes (2017). In the first phase of these surveys, the vegetation was defined from aerial photographs flown in 2006. Images from Google Earth were used to acquire more recent (2013) information and to deduce peatland types on the basis of physiognomy and colour. In a second phase the boundaries of areas assigned to different peatland types were confirmed through field survey, and other patches that had not been identified from aerial photographs were registered. Mapping was conducted (Figure 3) in the ArcGIS environment. During the field surveys, 97 inventories were made in fens, forested peatlands and degraded peatlands. The inventories were conducted on square plots measuring 10 m ×10 m (the minimum inventory area for forested peatlands according to Mueller-Dombois & Ellenberg (1974)) located in the central part of each of the peatlands visited. Another 99 inventories from the Atlântida© Database were used to complete the floristic information. Definitions of peatland types in the distribution map (Figure 3) were based on Mendes & Dias (2013) for bogs and Mendes (2017) for other peatland types, although they were improved in this study.

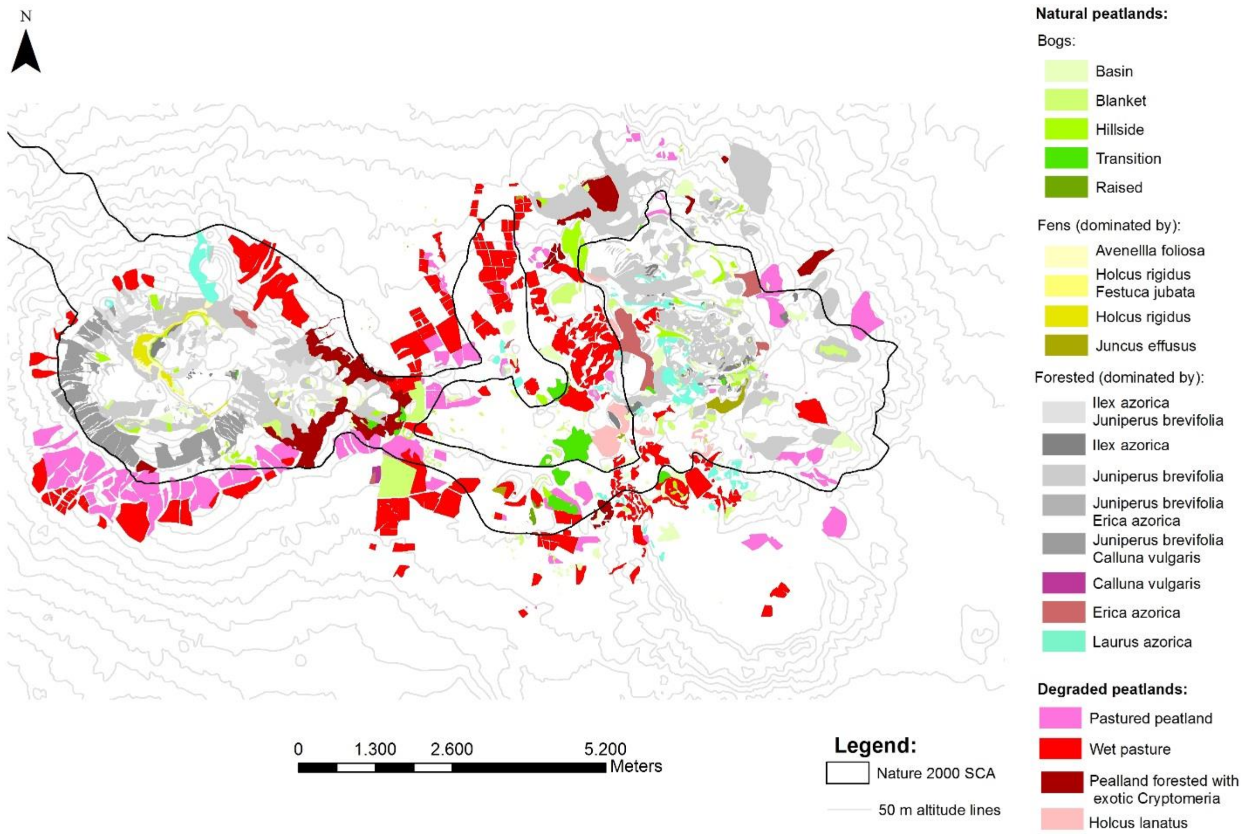

Figure 3. The distribution of peatland on Terceira Island, which is largely coincident with the St. Bárbara / Pico Alto Natura 2000 area (SCA). Natural peatland types identified in this study are distinguished; degraded peatlands are placed in a single group regardless of type. Digital base map: Military Map 1:25000. Projection System: U.T.M. Local Data: Graciosa base SW 1948 Zone 26S. Font: IGEOE.

Degree of naturalness

The naturalness of peatlands is of major interest, as they are often the last surviving terrestrial wilderness areas, both regionally and globally (Joosten & Clarke 2002). According to Joosten & Clarke (2002), naturalness is the quality of not having been deliberately influenced by human beings. Conservation has used two different but related facets of the concept of naturalness: (1) as a conservation value; and (2) as a property or state descriptor of ecosystems (Machado 2004). The same term is used in both cases, generating some confusion (Grumbine 1994). The intention here is to classify peatland naturalness as a state descriptor; however, the ecological expression of naturalness within each patch is used globally to understand its conservation value. Angermeier (2000) mentioned that degree of naturalness is mandatory information for conservation strategies.

Building on the notion of ecosystem health (Machado 2004), we define the degree of naturalness - adapted from Dias *et al*. (2004) and Melo (2008) - of peatland in terms of the level of human interference, reflecting deviation from the wild state. To define degree of naturalness, expressed in Figure 4, four classes are distinguished: (1) disturbed - existing disturbance factors significantly affect the dynamics, structure and composition of the peatland, which is already occupied by non-natural plant communities, but it is still possible to identify some elements of the natural system such as typical peatland species (e.g. *Sphagnum* spp.), high wetness and the presence of peat (possibly fertilised or ploughed in the past, grazed with some frequency); (2) altered - existing disturbance factors slightly affect the peatland causing alteration of its natural dynamics so that anthropic plant communities may dominate, but at least 40 % of the area is occupied by natural species (not fertilised but may have been ploughed in the past, grazed with some frequency); (3) conserved - at least one factor negatively affects the natural dynamics, structure and composition of the peatland (low cover of exotic species (< 20 %), no grazing or low-frequency grazing); and (4) wild - natural plant community.

Degree of threat

This criterion was adapted from Dias *et al*. (2004) and aims to encapsulate the pressures acting on peatlands. It is related to naturalness, in this case expressed on a temporal scale, and describes the peatland in terms of the actual pressures acting on it and the probability of their affecting its extent, structure, floristics and dynamics, now or in the

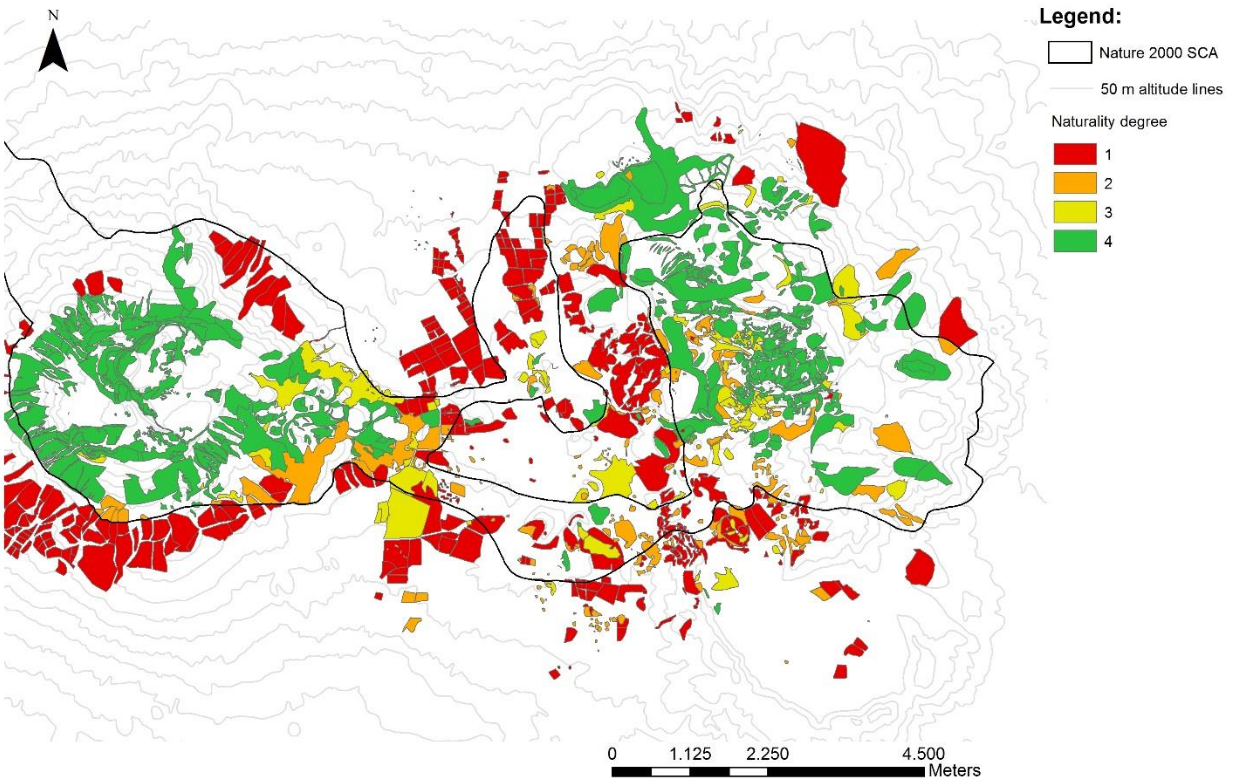

Figure 4. Naturalness map of Terceira Island peatlands. This map distinguishes naturalness classes for peatlands: 1 = disturbed; 2 = altered; 3 = conserved; 4 = wild. Digital base map: Military Map 1:25000. Projection System: U.T.M. Local Data: Graciosa base SW 1948 Zone 26S. Font: IGEOE.

future. Each polygon defined in the cartography was classified as: (1) no risk - peatland is integrated into a completely wild landscape and not affected by any pressures; (2) minimal risk - peatland is integrated into an ecologically functional natural multi-habitat system and subject to no immediate natural or anthropic threats, but adjacent areas are disturbed (Classes 1 and 2 do not need any intervention); (3) potential risk - pressures affecting the peatland are low or with minor impact, but the presence of low-resilience vegetation or any increase in the level of disturbance should be taken to indicate a need for monitoring to evaluate any effects; (4) actual risk - the peatland is threatened by factors which are already affecting its floristics and structure or natural dynamics, so there is an immediate need to eliminate the activities causing the disturbance and effect regeneration of the peatland; and (5) immediate risk - strongly threatened by disturbance which is seriously affecting the peatland and promoting its degradation.

In this study, the degree of threat was recorded as complementary information and used in assembling the characterisation of each area classified (see Figure 6 later).

Definition of zonation

In this study, we analysed the relationship between the distributions of peatland and protected areas, as well as public area boundaries, to evaluate which contained more peatlands. The study was conducted for SCA, Natural Park and Ramsar sites, plus public areas in which management is by governmental forestry and environmental service departments, as areas where there would be fewer constraints on the implementation of any recommended interventions.

Given the distribution and naturalness of peatlands on the island, as well as the boundaries of protected/public areas, a landscape zonation (nomenclature based on Noss 1994) was established to define priority areas for active conservation and restoration. First, reserves were defined to include most wild peatlands considering the framework boundary of protection, although additional areas were included if relevant. The area of the reserve was defined with a circular form so that the interior was farther from the edge effect (Franklin 1992, Noss 1994). Noss (1994) stated that external influences extend across reserve boundaries, so it is necessary to define buffers. An inner buffer was established to define strictly protected areas, and this was surrounded by an outer buffer where a wider range of human uses would be compatible with nature conservation. The inner buffer was drawn assuming peatland naturalness. Therefore, an inner buffer of 500 m and an outer buffer of 750 m were defined.

In addition, a corridor was established to promote connectivity between the main reserves. In this study, a corridor was defined and embedded in a dissimilar matrix to connect larger blocks of habitats, and was proposed for conservation on the grounds that it would enhance or maintain the viability of specific wildlife populations in the habitat blocks (Beier & Noss 1998). The minimal width defined for plants was around 30 m and for birds 60 m (USDA 2016). However, other authors have adopted much higher values, mentioning that the optimal width of wetland ecological corridors is 1298 m (Kong *et al.* 2009). In this case, the area drawn was based on peatland naturalness and the existence of classified areas, considering a minimum width of 650 m and an outer buffer of 200 m. Several small reserves were established within the corridor. An inter-regional corridor to connect the system to other kinds of habitats is quite important, but was not defined in this study because the analysis depended on the presence of peatland.

RESULTS

Distribution

On Terceira Island, peatlands occur mainly on the central plateau at altitudes above 500 m a.s.l. (Mendes 2010) (Figure 3). However, the lowest-altitude peatland identified (in the north-eastern part of the island) was at 320 m a.s.l., indicating that the extent of peatland was greater in the past and has been reduced by land use changes. Our distribution study identified 3011 ha of peatland of which 44 % was forested, 14 % was bog and 3 % was fen. The remaining 39 % was occupied by degraded examples of these habitats.

Azorean bogs were classified as basin, transitional, raised, valleyside and blanket types, described in Mendes and Dias (2013). Fens and forested peatland types were classified on the basis of structuring dominant species (Dias 1996, Mendes 2010). The main natural peatland type on Terceira Island was forested (Figure 3), located in the wildest parts of the island, mainly within Natura 2000 areas in Santa Bárbara and Pico Alto.

Degree of naturalness

The degree of naturalness map (Figure 4) shows clearly that natural (Class 4) peatlands are concentrated within the island’s two most important wild sites, Serra de Santa Bárbara and Pico Alto (Nature 2000 SCA areas). Peatlands lying between these two areas are highly disturbed, mainly by agricultural use. It is important to characterise peatland ecosystems located between the two natural patches and eventually create conditions to establish connectivity between them by peatland restoration.

Within the external boundary of the Terceira Island Natura 2000 area, peatlands are mainly classified as conserved (Class 3), altered (Class 2) or disturbed (Class 1). However, Terceira still has an important resource of natural and almost untouched peatlands (46 %), most of them protected by European and regional legislation, that should be actively conserved.

The wildest group of Azorean peatlands is the forested one. Most of the examples identified were placed in the class of maximum naturalness. Both bogs and fens are more variable in this classification. As expected, degraded peatlands are mostly classified as 1 or 2 for naturalness. However, some patches of peatland planted with *Cryptomeria* were placed in Class 4 because they correspond to old plantations with less cover of *Cryptomeria*, no actual disturbance and a high percentage of natural flora.

Several maps showing the distribution of peatlands and their naturalness inside protected and public areas are presented, first globally (Figures 3 and 4) and then as the intersection of peatland with each type of area considered (Natura 2000 SCA, Natural Park, Ramsar or public area) in Figure 5. Natural Park includes the most relevant area of peatland (82 % of the total area), but because it includes several disturbed and degraded peatlands, its general naturalness decreases. SCA possesses 67 % of the total area of peatland (Figures 5 and 6), including most of the wild mires; however, the limit of the protected area is coincident with the limit of the wild peatlands. Ramsar and environmental public areas present a lower occupancy of peatlands, both around 25 %. However, these two areas contain a higher proportion of wild peatland (69 % in environmental areas and 73 % in Ramsar) and less threatened peatland. Public forestry areas represent an important zone for the preservation of peatlands; these developed areas contain more than half of the island's peatlands.

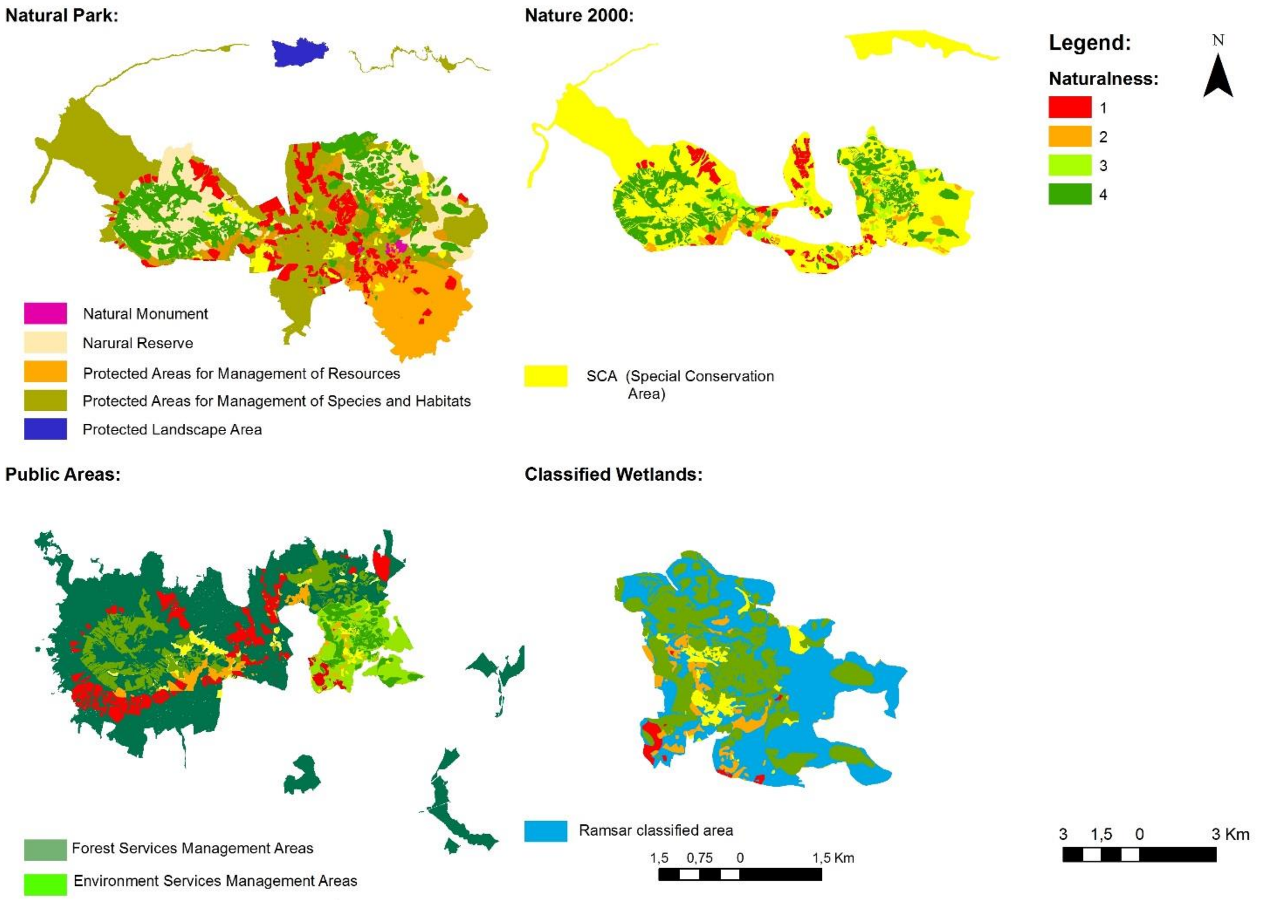

Figure 5. Intersection of peatland classes (1 = disturbed; 2 = altered; 3 = conserved; 4 = wild) with protected areas designated for the preservation of natural entities: Natural Park, Natura 2000 SCA, Ramsar Wetlands of International Importance and public areas under Forestry Services and Environmental Services responsibility. Digital base map: Military Map 1:25000. Projection System: U.T.M. Local Data: Graciosa base SW 1948 Zone 26S. Font: IGEOE.

Proposal of a management zonation model for Terceira Island peatlands

The zonation defined for preservation of peatlands (Figure 7) includes two major reserves (R1, R2) containing more than 80 % of the wild peat habitats of the island, and thus representing the most important area for peatland conservation. Santa Barbara Reserve has an area of 713 ha and Pico Alto Reserve extends to 606 ha (Table 1). The reserves are completely integrated with other legal protection frameworks (Figure 8).

The inner buffer of Santa Barbara (IB1 in Figures 7 and 8) was already partially outside the SCA and Natural Park but was included in the forestry public area and has an area of 551 ha. The outer buffer (OB1) has an area of 1122 ha and its boundary corresponds to the boundary of the forestry area, representing residual private area.

The inner buffer of Pico Alto (IB2 - 514 ha) was mostly included in the Natural Park exhibiting residual private area (Figure 8). The outer buffer of Pico Alto (OB2 - 1066 ha) included some private area, but most of the buffer lay within areas managed for forestry.

The corridor (including R3, IB3 and OB3) defined to connect R1 and R2 is wider in the area closest to Santa Barbara, because this zone contains important sections of peatland and corresponds to public forestry areas. The corridor width varies between 2700 m in the connection to Santa Barbara and 650 m in the centre of the corridor. When possible, the definition of the corridor considers public and/or classified areas to reduce private domain constraints on intervention. However, the connection between the corridor and the outer buffer of Pico Alto was placed in private areas, although this area was still inside Natural Park and partially included in SCA areas. In the corridor, several small reserves (R3) were defined to increase the stepping-stone effect, with the intention that they would be restored to increase rare components typical of extremely wild areas which are presently non-existent in the corridor area. Ecological corridors and stepping-stones are structures that facilitate connectivity.

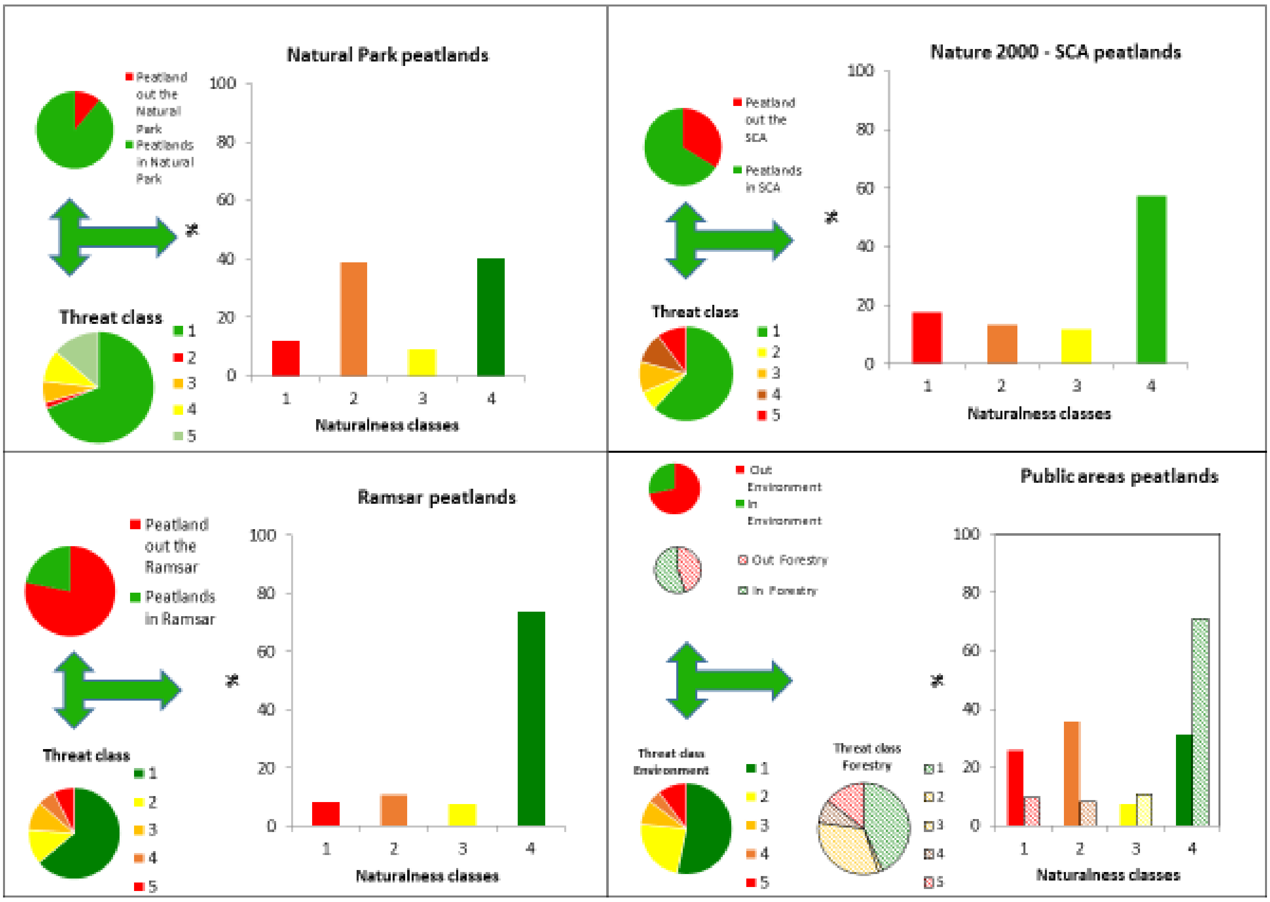

Figure 6. Proportion of peatland within and outwith each type of area considered (Natural Park, SCA, Ramsar, public areas). Peatland naturalness and threat classes are identified in each case. Classes of naturalness: 1 = disturbed; 2 = altered; 3 = conserved; 4 = wild. Classes of threat: 1 = no risk; 2 = minimal risk; 3 = potential risk; 4 = actual risk; 5 = immediate risk.

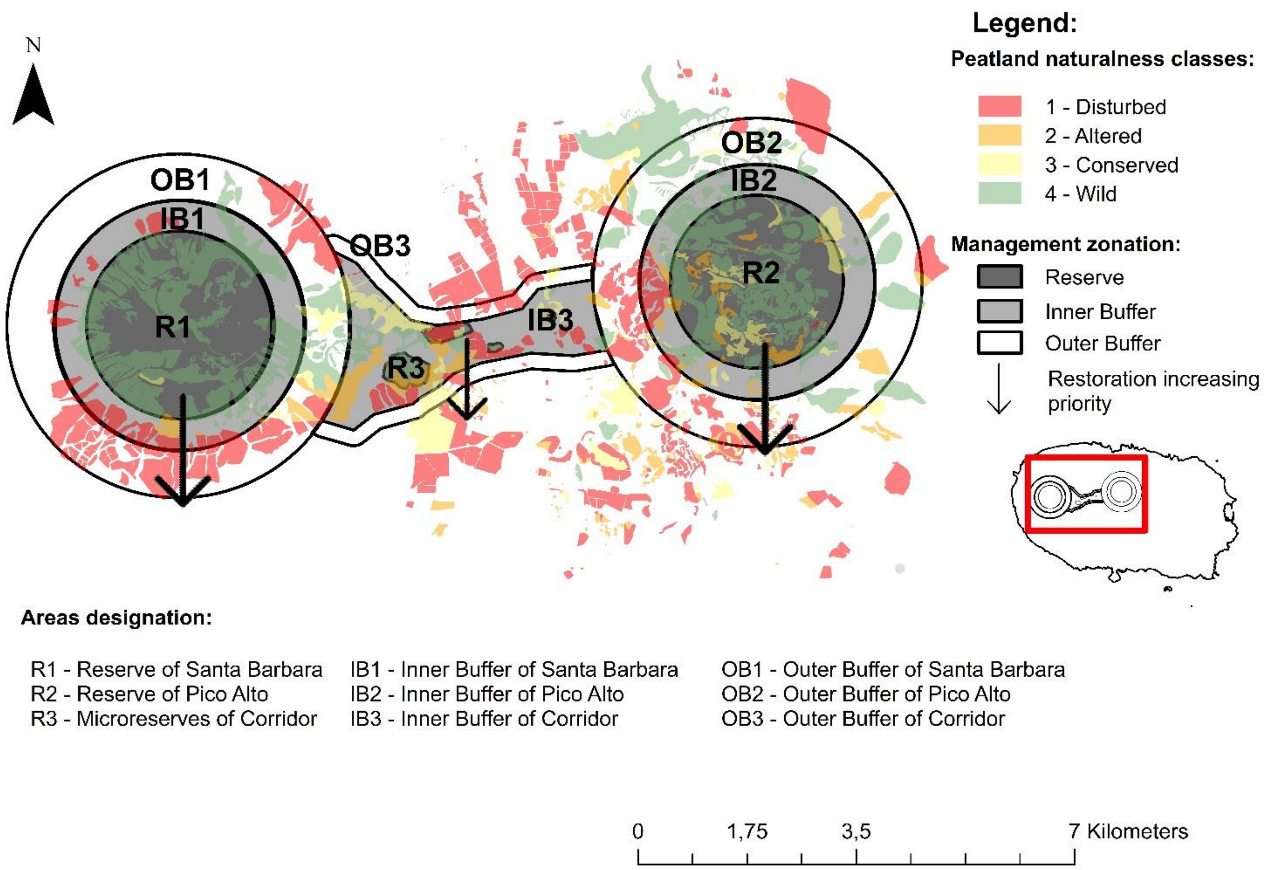

Figure 7. Definition of a theoretical management zonation model for Terceira peatlands, with the definition of three classes: reserve, inner buffer and outer buffer. This model is intended to define priority areas for restoration, expanding from the reserve into the outer buffer. Digital base map: Military Map 1:25000. Projection System: U.T.M. Local Data: Graciosa base SW 1948 Zone 26S. Font: IGEOE.

Table 1. Data for the areas defined in the management proposal established for Terceira peatlands.

Code	Designation	Management proposal	Area (ha)	Naturalness 4 (%)
R1	Reserve of Santa Barbara	Conservation/no economic activities/limited access	713	98
R2	Reserve of Pico Alto		606	77
R3	Microreserves of Corridor	Conservation /restoration/ gradual removal of land use activities /authorised access	49	33
IB1	Inner Buffer of Santa Barbara		551	55
IB2	Inner Buffer of Pico Alto		514	54
IB3	Inner Buffer of Corridor		518	22
OB1	Outer Buffer of Santa Barbara	Conservation/land use compatible with nature conservation/authorised access	1122	21
OB2	Outer Buffer of Pico Alto		1066	41
OB3	Outer Buffer Corridor		247	0

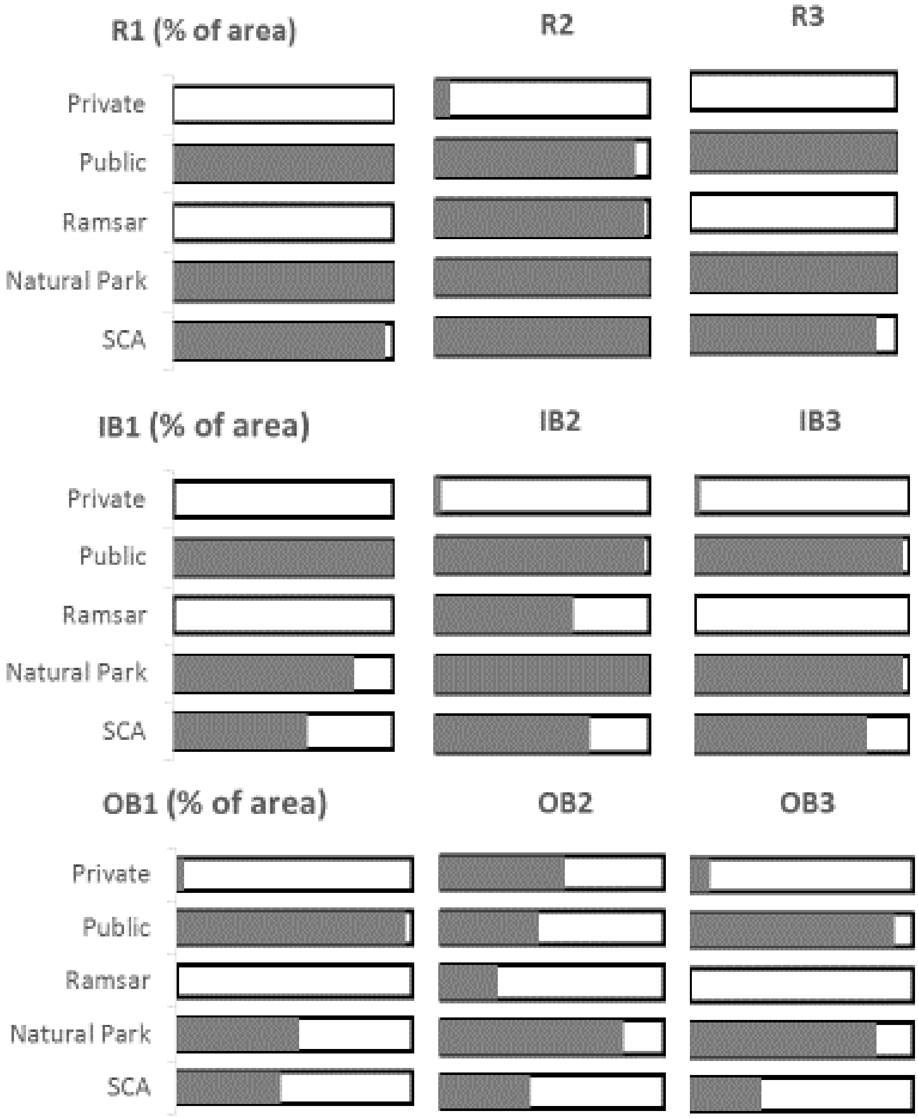

Figure 8. Spatial analysis of the reserve (R), inner buffer (IB) and outer buffer (OB) zones in terms of % of area classified as private/public, Ramsar, Natural Park and SCA (Natura 2000 Special Conservation Area).

DISCUSSION

Distribution

On Terceira Island, peatlands are mainly located above 500 m a.s.l. (Mendes 2010). However, their actual distribution is the result of five centuries of land transformation and not necessarily due to any ecological restriction on the development of mires. Dias (1996), as well as Mendes (1998), reported that the water supply from precipitation and water sub-superficial retention (due to the presence of placic horizon) was the main environmental factor for the development of peatlands. Placic horizon, which is important for peatland formation because it limits drainage, was mentioned for Terceira at altitudes above 400 m (Madruga 1995). However, several direct observations showed the existence of a placic horizon below this altitude. A spatial relationship between land above 400 m and peatland distribution, established in this study, included almost all peatlands; however, some small patches were excluded. Considering an altitude threshold of 300 m, all peatlands were included in the limits. In terms of precipitation (direct precipitation) obtained from Azevedo (2003), the lowest value associated with the presence of a peatland was 1500 mm per year. These environmental relationships, associated with historical characterisations, indicate that the actual area of peatlands is quite reduced. Besides, forested peatlands have been most affected. We believe that this peatland type was more widely distributed across the island in the past. The results of Connor *et al.* (2012) indicate this possibility, showing a post-human-impact explosion of *Sphagnum* spores coinciding with a decrease in the endemic shrub *Juniperus brevifolia*, which is a key species of forested peatlands in the Azores (Elias & Dias 2008). *Juniperus* appears to have declined in the landscape because it has been used massively for various purposes including merchant ships and house construction since people colonised the Azores (Dias 1996) and, more recently, the use of forested areas as pasture has been detrimental due to both grazing and trampling.

Degree of naturalness

In terms of landscape-level changes in peatlands, the distribution of *Sphagnum* bogs - mainly blanket and hillside bogs - increased after the arrival of humans. These two bog types have increased in area since people colonised the island as a result of the global degradation of forested peatland (Mendes 2017). Sjögren (1973) described how widespread deforestation and burning on the islands has led to a rapid expansion of *Sphagnum* blanket peat (our classification includes blanket and hillside bogs). This was also confirmed for other oceanic islands by Lawson *et al.* (2007), where pollen record studies indicated that birch woodland was replaced by acidophilic taxa (namely *Sphagnum*) and may reflect a general trend initiated by hydrological changes, fire, deforestation, grazing and loss of soil fertility. Sjörs (1980) reported that nearly all sloping peatlands (in Eurasia and North America) were formed by paludification in post-glacial periods and were once covered by woodland or, in some cases, grassland. Thus, it is possible that hillside and blanket bog formations in the Azores are the regenerative result of forested peatland degradation in past times, as well as more recent extensive use of the territory.

The main threat to Azorean peatlands is the inappropriate use of land, mainly for pasture and/or exotic forest production (Mendes 2017). A large extent of these habitats should be formally protected nowadays, if they are located in classified areas, but there is a large gap between theory and reality because: (1) defined management plans for Azorean classified areas are lacking; (2) the enforcement of laws is still poor and, due to lack of awareness or for other reasons, landowners / land users are still damaging peatlands (e.g. by illegally moving soil and/or planting); (3) there is still a lack of knowledge and capacity for identification (e.g. fens are often treated as pastures in agricultural projects); (4) existing laws address only the area of a peatland, neglecting the fact that the future of the peatland depends on landscape processes (water movement, seed banks etc.) and thus also on the management of the whole hydrological catchment. Degraded patches are important elements of Terceira Island's peatlands. Most of these need intervention to increase their naturalness. However, it is necessary to define objectives and priority locations for intervention.

Proposal for management of peatlands on Terceira Island

Due to human interference and landscape transformation, habitats including peatland have become extremely fragmented on Azorean islands. Fragmentation is the process of breaking up continuous habitats and thereby causing habitat loss, patch isolation and edge effects (Bogaert 2000). It is imperative to define strategies and implement measures to conserve and restore biodiversity in the Azores, including peatlands, the target habitat type of this study. The zoning defined in this study is designed to constrain land use activities in and around reserve areas and make them more compatible with conservation goals. Through a carefully planned zoning approach, a conservation reserve system allows habitat or species protection, experimental field research, human habitation and development and limited use of resources (Noss 1994, Baldwin *et al*. 2010).

The zonation for peatland conservation on Terceira incorporates the results of an analysis of peatland distribution and naturalness but also considers the boundaries of protected and public areas. Thus, there are two priority areas, defined as reserves, namely: Santa Barbara Mountain in the west and the mountain Pico Alto in the east. Both reserves are inside the Natura 2000 SCA and the Natural Park (Pico Alto reserve is also included in the Ramsar area). For reserves we propose the prohibition of any economic activity, limitation of access and that they should be regarded as priority areas for the implementation of protection measures.

The inner buffer for Santa Barbara Mountain is partially outside the SCA and Natural Park but is included in the forestry public area and is mainly occupied by poor-quality pastures and *Cryptomeria japonica* forest. There should be an integrated approach by environmental services (the regional service responsible for nature conservation) with participation of the forestry services to implement measures in the inner buffer, including the abandonment of pasture use and a gradual replacement of *Cryptomeria* forest by native forest species. According to Governo dos Açores (2014), associated with the certification of wood production in the region, the definition of forestry strategies includes revitalisation of natural forests, highlighting a possible integrated solution. The inner buffer in Serra de Santa Barbara corresponds to a priority area for restoration, where it could be possible to gradually increase naturalness from the wild centre of the reserve to its margins.

The inner buffer of Pico Alto presents areas of more-natural peatlands that are potentially easier to recover but the implementation of any measures would need to overcome the impediment that some of the peatlands are privately owned. This may make the task more difficult but it should still be considered. Even for private land, the rules defined for use of the area are embedded in the regional position on conservation of peatlands. Purchase of some areas or compensation of landowners for abandonment of some activities will have to be considered. The same situation is found in the outer buffer of Pico Alto, where the land is mainly private. Outer buffer and corridor areas should be studied and divided into areas with possible economic use (agriculture and forestry), areas of limited use (e.g. extensive farming, restrict mowing areas, etc.) and areas for natural habitats restoration.

The area between these two major reserves and their buffers is a predominantly agricultural area where the only vegetation types are pastures and (mostly degraded) peatlands. It includes several lava fields with very low value as pasture. The remaining wetlands are extremely important to promote the connection between the two reserves. The presence of wetlands attracts birds, which are important mediators for seed dispersal (Amezaga *et al*. 2002). Among the abiotic connections, those related to flow and quality of water are, perhaps, the most important. It is important to note the possibility that the biological and genetic connection between the two wild areas might be interrupted or at least constrained by intervening highly disturbed areas. There is currently discussion on the negative effects of corridors (Noss 1987, Simberloff *et al*. 1992). Still, in this study, we consider that movements between landscape elements and exchanges between ecological systems are key components in our comprehension of ecological processes, at the individual as well as the population level (as mentioned by Wiens 1997 and Baldwin *et al*. 2012). In this context a corridor between the two reserves is planned. The creation of a reserve (R3) inside the corridor assumes its restoration to a wilder state to promote the development of rare communities that are found mainly in natural areas such as Santa Barbara and Pico Alto. Besides promoting an increase in biodiversity, this would allow a stepping-stone dynamic between the natural reserves.

As mentioned before, it is necessary to find alternatives to imposing restrictive uses in the defined area and as possible implementations of restoration measures, not only of peatlands, but also for other potential wetlands such as lakes and forests. We stress the need to think beyond isolated protected areas to a 'whole-landscape' vision of many land parcels under various tenures and jurisdictions contributing to an integrated approach to conservation.

For the inner buffers we propose that direct land use activities should be gradually removed, access to these areas (e.g. controlled tourism activities as well as environmental education) allowed, and that they should be regarded as priority areas for the implementation of restoration programmes. For the outer buffers we propose that land uses should be compatible with nature conservation, that landowner access and tourism should be allowed, and that they should be considered as important areas for the implementation of restoration programmes.

In this context, the priority areas for conservation action are the reserves. In terms of restoration, the priority areas fall within Naturalness Classes 2 and 3, and Class 1 when located adjacent to natural areas, increasing naturalness from the wild centre to the margins (Figure 7).

Improving this area's degree of naturalness will improve the wildness of peatlands and increase the connectivity between the most important natural areas of Terceira. It is interesting that a public area (occupied by degraded peatlands due to decades of pasture use) was recently assigned for the implementation of experiments in regenerative succession, as well as several restoration activities, to improve our knowledge of restoration techniques for Azorean pastured peatland. This area was included in the corridor, within a micro reserve.

This study concluded that the most representative area, in terms of peatland distribution, is the Natural Park, which hosts 82 % of the total area of peatlands. Ramsar and environmental areas had the highest naturalness peatland classes. This integration is often taken as synonymous with conservation, but this is not so because all protected areas in the Azores lack management plans for the conservation of biodiversity. The SCA and the Natural Park area include important areas of peatland and this must be reflected in the management plans for these areas. The development and implementation of management plans is urgent, not only to respond to nature conservation demands but also, in the near future, to fulfil European requirements associated with improvement of the status of protected entities, such as several types of peatlands. The management zonation defined in this study for peatlands could be integrated into island management plans for nature conservation.

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AUTHOR CONTRIBUTIONS

CM and ED conceived and designed the research; CM performed the investigations, analysed the data and wrote the manuscript; AM and MP helped with fieldwork; CM, ED and LR edited the manuscript; all authors commented on all versions of the manuscript.

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