The importance of land cover planning on climatic events: evaluation of peatlands' buffer impact on Terceira and Flores islands (Azores, Portugal)

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Abstract. The objective is to estimate the actual and potential hydrological services provided by the peatlands of Flores and Terceira islands. Peatlands were identified through the distribution of *Sphagnum*, obtained by a spectral signature from satellite image analysis. The results show an actual distribution of natural peatlands of 2 766 ha and 2 414 ha, for Terceira and Flores, respectively, which are, even so, quite lower than the potential area estimated as 8 035ha and 5 231 ha, correspondingly. Nowadays, these peatlands have the ability to retain 72 438 317 m^3 of water. Theoretically, if all peatlands were in the natural state, this capacity would increase to 300% of the retained water. The amelioration of naturalness would increase these ecosystems' ability to act better as a buffer in extreme climate events.

Keywords: Naturalness, Spectral signature, *Sphagnum*, Water retention.

1 Introduction

The most extended type of natural peatlands is forest dominated (Mendes, 2010). A considerable area is still occupied by *Sphagnum*-dominated types (Mendes and Dias, 2013). The main threat faced by the peatlands in the Azores is their use as pasture for livestock, leading to the degradation of the peatlands. There is a potential distribution of 35 000 ha of peatlands. Less than 30% currently persists, and of these, more than 50% are under pressure (Mendes and Dias, 2017).The peatlands of Azores have numerous ecological, hydrological and biochemical functions as well as social values. These are extremely important in the regulation of the water cycle, being characterised by water retention structures that release water gradually thus acting as buffers, minimizing the effects of climate events, promoting landscape equilibrium, minimizing the impact of extreme events, such as landslides or floods, and supporting biodiversity. However, owing to peatland depletion and degradation, their natural functions have become narrowed. One of the main future challenges is the establishment of the strategies to minimize the impacts of extreme events, due to climate change, and the Azores islands are no exception. In this context, the goal of this work is to calculate hydrological services from the current distribution of peatlands in Flores and Terceira islands and compare with equal parameters estimation, considering the potential distribution of peatlands in those islands.

2 Methods

Study area: The Azores are located at about 1 400 km W from Europa in the middle of Atlantic Ocean. The archipelago has nine islands, distributed in three groups. The islands selected for this study are Flores (142 km^2, 914 m a.s.l at Morro Alto) and Terceira (402 km^2, 1 023 m a.s.l at Santa Barbara mountain), as these have the largest areas of peatlands (Dias et al., 2004).

Data collection and analysis

Actual distribution of peatlands: For the definition of *Sphagnum* distribution was used: Sentinel-2 images (2018-12-07 for Terceira and 2019-01-22 for Flores) and Rapideye (2017-12-21 for Terceira and 2012-04-16 for Flores), with 2 800 Terceira and 7 500 Flores Ground Truths. The modulation was done in ArcGIS 10.6.1 with a supervised classification with maximum likelihood using 25% and 50% Reject Fraction (RF). For ground truth, ecological field work was done. It was also integrated data from Mendes (2010), Dias et al. (2017), ATLANTIDA©GEVA database and photointerpretation of Planet Scope Images.

Potential distribution of peatlands: The potential distribution was modelled using Rasters (100x100 m) of Aspect E and W orientation, slope (>9º), curvature (<-0.55), TOPEX (Wilson, 1984), endorheic basins, and geomorphology (as alimitation of the model in Terceira). In both situations of *Sphagnum* and forested peatland, water services values from Pereira (2015) were applied, to the extension of the peatlands typology.

For actual and potential cartographic analysis purposes, two types of *Sphagnum* peatlands were assumed: (1) mixed *Sphagnum* peatlands (basin, raised and transition) and (2) hillside *Sphagnum* peatlands (hillside and blanket types) (classification of Mendes and Dias, 2013) and one type of forested and shrubland peatland (in Dias, 1996). Considering naturalness (based in Pereira, 2015 and Mendes, 2010), (1) and (2) were separated into natural (no disturbance), degraded (frequent use as pasture, *Sphagnum* present) and peat soil pasture (corresponding to wet implanted pastures, no *Sphagnum*); forested peatlands were separated in natural and peat soil forested areas (corresponding to forest production).

Hydrological services evaluation: For the actual and potential quantification of hydrological services, reference values were established. To define these reference values for water retention capacity as well as time efflux (considering peatland type and naturalness degree), we studied eight representative peatlands in Terceira island (in Pereira, 2015). These were surveyed with Ground Penetrating Radar for the tri-dimensional modelling of peatlands' internal deep and layer structures. Field coring was done with peat collected by layer for bulk density, water retention capacity and water efflux determination. The obtained reference values were estimated by Pereira (2015) and applied to the different typologies defined in actual and potential peatlands, for the two islands under analysis and the services quantified.

3 Results

3.1 Actual distribution of peatlands

Actual distribution of peatlands: In Terceira island, the area obtained is 909 ha (423 ha using an RF of 0.5 and 486 ha with an RF of 0.25). This distribution in Flores island is 648 ha (290 ha using an RF of 0.5 and 359 ha with an RF of 0.25). The actual distribution of peatlands is presented in Fig.1 and Tab 2. Both in Flores and in Terceira, the dominant type of peatland is *Sphagnum* dominated types (including the degraded forms). However, in potential terms, it would be the forested formations the commonest form of Azorean peatlands.

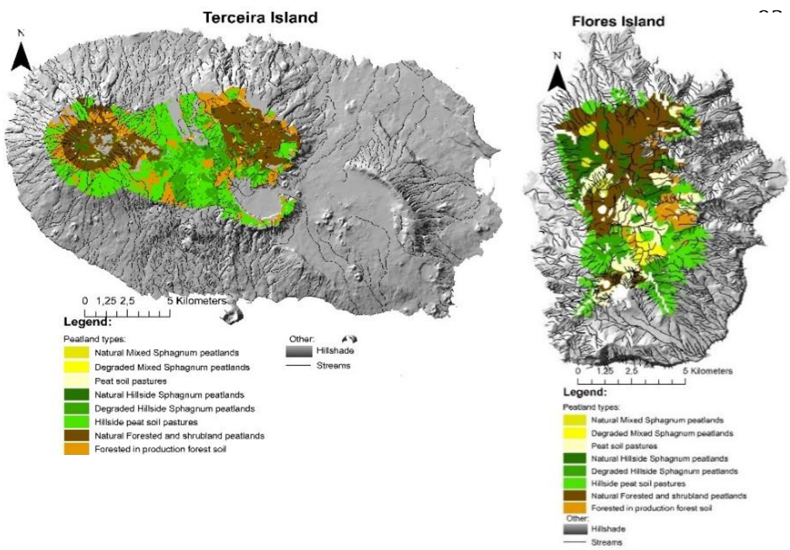

Fig. 1. Actual distribution of peatlands defined for Terceira and Flores islands. Naturalness considered in the type's definition (natural, degraded or peat soil when transformed into pasture or forest production). Modulation in ArcGIS 10.6

3.2 Potential distribution of peatlands

The potential distribution of the peatlands (assumes all formations as natural) is expressed in Fig. 2 and Tab 2. Both in Flores and Terceira, the dominant types of peatlands are forested and shrubland. *Sphagnum* types prevail in endorheic valleys, and *Sphagnum* dominated hillside types monopolise extreme wind sloping areas.

3.3 Hydrological services

Considering the study of the eight reference peatlands, the results showed that hydrologic services, such as water retention as well as water efflux, varied with peat type. However, we found a more relevant relation of these services associated with peat depth

(Fig. 3 and Fig. 4). In terms of disturbances, it was possible to establish a tendency in which more degraded peatlands tend to have lower peat depth, diminishing peatland water services provided. Considering the values obtained for the hydrological services of all types of peatlands (Tab. 1), mixed peatlands show a greater capacity to contain gravitational water, being more important for buffering torrential regimes after large rainfall events. The same type also reveals the greatest capacity for the temporal restraint of gravitational water (efflux), working as accumulation structures.

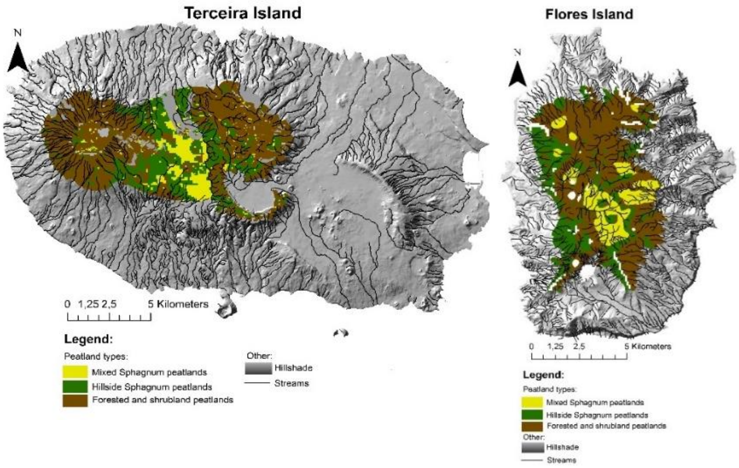

Fig. 2. Simulated potential distribution of peatlands defined for Terceira and Flores islands. Modulation in ArcGIS 10.6.

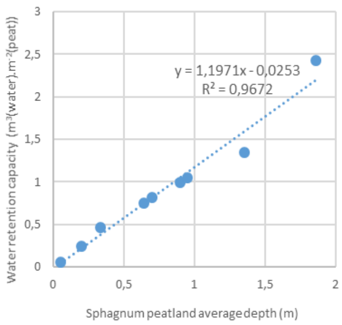

Fig. 3. Relation between *Sphagnum* peatland's depth and water retention capacity. Peat depth obtained by GPR and modulated in GIS. Water retention capacity values obtained in lab as described by Pereira (2015).

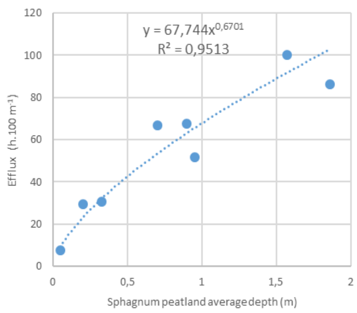

Fig. 4. Relation between *Sphagnum* peatland's depth and water efflux. Peat depth obtained by GPR and modulated in GIS. Time efflux values obtained in lab as described by Pereira (2015).

The results show an actual distribution of natural peatlands of 2 766 ha and 2 414 ha, for Terceira and Flores, respectively, which is even so quite lower than the potential area estimated as 8 079 ha and 5 268 ha, correspondingly. These peatlands currently have the ability to retain 72 438 317 m^3 of water (Tab. 2). Theoretically, if all peatlands were in a natural state, this capacity would increase to 300% of the retained water.

Table 1. Average values of peat depth and hydrological services indicators obtained for Terceira and Flores types of peatlands.

	Nat. Mixed Sphag.	Nat. Hillside Sphag.	Nat. For./shrubland	Deg. Mixed Sphag.	Deg. Hillside Sphag.	For. in production forest soil	Peat soil pastures	Hillside peat soil pastures
Peatland depth (m)	1,65	1,10	0,33	1,15	0,20	0,15	0,10	0,10
Water retention (m^3(water).m^{-3} (peat))	1,10	1,38	0,70	1,18	1,18	0,47	0,45	0,45
Water retention (m^3 (water).m^{-2} (peat))	1,82	1,53	0,23	1,35	0,24	0,07	0,05	0,05
Efflux (h.100 m^{-1})	67,74	30,59	10,26	37,21	29,25	7,00	7,80	7,80
Perlocation velocity ($m.h^{-1}$)	0,11	0,08	0,10	0,18	0,02	0,07	0,08	0,08

Table 2. Values of actual and potential areas of peatland distribution and associated values of water retention capacity obtained for Terceira and Flores types of peatlands.

	TERCEIRA				FLORES			
	Area (ha)		Water storage (m3)		Area (ha)		Water storage (m3)	
	Actual	Potential	Actual	Potential	Actual	Potential	Actual	Potential
Nat. Mixed Sphag.	71	763	1300615	13841653	123	799	2240017	14505886
Nat. Hillside Sphag.	197	2166	3037997	47404912	769	1327	11875007	29031787
Nat. For./shrub.	2497	5150	5775013	11844863	1523	3142	3526759	7226076
Deg. Mixed Sphag.	379		5137043		148		2002912	
Deg. Hillside Sphag.	825		1990130		463		1119573	
For. in production forest soi	1864		843477		376		170264	
Peat soil pastures	1050		738909		684		482185	
Hillside peat soil pastures	1151		520931		1146		519303	
Total	8035	8079	19344115	73091429	5231	5268	21936020	50763749

4 Discussion

Floods accompanied by landslides are quite frequent in Azores and could become more common, associated with climate change. As shown in this study, peatlands are extremely important landscape regulators, which are far below their potential capacity. The potential increase of an average value of 300% in water retention is relevant and can be, theoretically achieved. Additionally, we must highlight that these two islands are the ones characterised by more areas of peatlands and those in a better state of conservation. Large natural areas as Santa Barbara Mountain and Pico Alto Mountain (in Terceira) present lower differences between actual and potential hydrological services, with a 285% increase for Santa Barbara and 237% for Pico Alto. Other areas practically do not present natural peatlands, as the pasture-dominated mosaic between Serra Santa

Barbara and Pico Alto have a potential enormous increase of 1 418% in water retention. The pristine north central plateau of Flores show a potential increase of 132%, contrasting with the 432% potential increase of the southern part of the island being more disturbed. Urgent action is required to protect, sustainably manage and restore peatlands for global biodiversity protection, and it can also play an important role in reducing GHG emissions.

5 Concluding Remarks

Terceira and Flores islands possess a relevant area of peatlands; however, disturbance diminishes their intervention in the hydrologic cycle control of the landscape. Restoration implementation would significantly increase the buffering capacities of peatlands in a scenario of climate change.

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