Long–term monitoring across elevational gradients (II): vascular plants on Pico Island (Azores) transect

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Coelho, M.C.M., R.B. Elias, J. Kluge, F. Pereira, D.S.G. Henriques, S.C. Aranda, P.A.V. Borges, C. Ah-Peng & R. Gabriel 2016. Long–term monitoring across elevational gradients (II): vascular plants on Pico Island (Azores) transect. *Arquipelago*. Life and Marine Sciences 33: 21 – 44.

Pico Island remains one of the last remnants of natural vegetation in the Azores, including the largest natural protected area; nevertheless, habitat change and the spread of exotic plants are visible, especially in those areas where human presence prevails. Currently, the lowlands are vastly occupied by pastures dominated by exotic herbs/grasses and most forests are dominated by *Pittosporum undulatum*. This paper aims to: i) review previous botanical studies related to elevational gradients; ii) investigate vascular plants composition and abundance in native vegetation, following an elevational transect (from 10 to 2200 m); and iii) investigate some patterns of the recorded diversity and distribution of vascular plants. Methodology follows a standardized protocol with observations in 100 m^2 plots. A total of 88 species were recorded, representing 35% of the indigenous but only 5% of the exotic species previously known from Pico. The richest areas were found between 600 and 1000 m and the areas with the lowest proportion of indigenous species occurred between 1800 and 2200 m. The recorded composition and richness values of endemic and native vascular plants support the high ecological and conservation value of the studied areas and constitute a good basis for long–term monitoring projects.

Key words: elevation, exotic species, indigenous vegetation, monitoring, vascular plants

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INTRODUCTION

The Azores archipelago, in the middle North Atlantic, is formed by nine isolated islands, colonized since the 15th century and currently bearing a small fraction of their original primary forest habitats (estimated at less than 3%; Triantis et al. 2010; Gaspar et al. 2011). Even if about a fifth (21%) of the Azores terrestrial territory is currently under some level of protection, native forest communities are restricted to much smaller fragments, more consentaneous with the areas categorized as natural reserves (8%) and the islands of Terceira, Pico and Flores are the largest contributors to that percentage (PNA [cited 2016]).

In the Azores, the known vascular flora comprises 1110 species and subspecies: 881 exotic (79%) (including 328 casuals); 73 endemic (7%) and 136 (12%) native non–endemic plants to the archipelago (Silva et al. 2010); the remaining 20 species have a doubtful/undetermined origin. The proportion of endemic vascular plants in the Azores is low, if compared with other archipelagos of Macaronesia, as Madeira (154/1204) (Borges et al. 2008) and Canary Islands (539/2091) (Arechavaleta et al. 2010), but relatively high if compared with most European regions, such as mainland Portugal (150/3314) (Menezes de Sequeira et al. 2012). If only indigenous species are considered, the endemism rate of Azorean flora, reaches about one third (35%), a value higher than in Madeira (20%). Moreover, there is a recent recognition that current number of endemic angiosperms in Azores is underestimated (Schäfer et al. 2011). Within this context, of high level of both exotic/invasive species, and endemic biodiversity, it is important to monitor the remaining fragments of native vegetation, to be able to evaluate the trends of habitat and climate change, invasion by exotics and the success of conservation programs (Gabriel et al. 2014).

Characterization of Pico Island

Pico Island is located between the coordinates 38°33'57" and 38°33'44" N of latitude and 28°01'39" and 28°32'33" W of longitude (França et al. 2003). With a surface of 445 km^2 and a coastal perimeter of 126 km (Forjaz 2004), it is the largest of the five islands of the Central Group. Pico is shaped roughly as an oval, elongated in the WNW–ESE axis (45 to 50 km from "Madalena" to "Ponta da Ilha"), with a maximum width in the NNE–SSW axis (16 km from "Arcos" to "Ponta de S. Mateus") (Zbyszewski et al. 1963).

This is the youngest of the nine Azorean islands, holding the highest mountain of Portugal (2351 m a.s.l.), an active stratovolcano that created the island 250 000 years ago (França et al. 2003). Its cone rises abruptly from the sea, with a wide base that narrows from 1200 m elevation and terminates in a shallow caldera (*c.* 3 km wide), from the centre of which a secondary cone, called "Piquinho" rises over 60 m (Forjaz 2004, França et al. 2014). Due to its volcanic origin, Pico Island is mostly formed by basaltic rocks (basalts, mugearite, hawaiite) and pyroclastic materials of basaltic composition (Madeira et al. 2007). Unlike other Azorean islands, such as São Jorge, the coastal areas have almost no high cliffs, and are characterized by the low lava flows and a few sandy beaches of basaltic origin (Nunes 1999).

Pico Island is quite near its neighbouring islands, Faial and São Jorge, separated only by two narrow channels, the first with 6 km width and 95 m of depth, and the second with 18 km width and 1200 m of depth (Nunes 1999). During the last glacial maximum (20 000 years ago) Pico and Faial Islands were connected (Rijsdijk et al. 2014) which may have been of great biological value allowing the exchange of several species.

Pico Island has a very low urban density (32 inhabitants/km^2) compared with the islands of Terceira (141 inhabitants/km^2) and São Miguel (185 inhabitants/km^2) (INE [cited 2015]).

Pastures for dairy cattle (40%) and exotic forests (33%) of *Cryptomeria japonica*, *Pinus pinaster* and *Acacia melanoxylon* dominate the land use of Pico Island (Cruz et al. 2007), while agriculture (8%; including viticulture and maize), is much less predominant. The economy of the island is mainly based on livestock (with an important production of cheese), fishery, agriculture (mainly winery), and tourism (Lima et al. 2014; Silva 2015).

The climate of Pico Island is considered humid mesothermal with oceanic characteristics. Annual precipitation varies between 974 mm at low elevations and 4834 mm at 1200 m, and decreases for 2025 mm at summit (Azevedo 1996; Azevedo et al. 1999a,b). The average air temperature of February (the coldest month) ranges from 15º C (in the coastal areas) to 6º C (in the top of the mountain) and in August (the warmest month) from 23º C to 13º C, respectively (Azevedo et al. 2004; Barceló & Nunes 2011). This island is the only that presents snowfall in its higher lands, persisting for more or less extended periods of time, during the winter months (Azevedo et al. 2004). The annual relative air humidity in Pico is below 80% along the coastal areas, increasing in the remaining elevations (80–100%) (Azevedo et al. 2004). However, exceptional conditions of air dryness occur, with the relative humidity reaching values lower than 10% at the summit of Pico Mountain (França et al. 2014). The annual average wind speed in coastal areas, during winter months, reaches 20 km/h but gusts commonly attain speeds of 100 km/h; in summer months the wind velocity values decrease to under 10 km/h (França et al. 2014).

Pico's Natural Park is the largest of the archipelago, covering more than one third of the island's area, and aiming to shelter the endemic fauna and flora of the Azores, including their unique subalpine and alpine habitats (Leuschner 1996). However, land categorized as Strict Nature Reserve (IUCN category Ia) covers only 5,2% of the island, including the mountain of Pico, "Caveiro", "Mistério da Prainha" and "Furnas de Santo António" (DLR 20/2008/A).

The island hosts more than four fifths of all indigenous vascular plants found in the Azores (N=173; 83%) (Silva et al. 2010) but, among its 616 *taxa*, it also includes 430 exotic *taxa* (naturalized and casual), that are considered introduced and 13 *taxa* with doubtful colonization status (Borges et al. 2010; Silva et al 2010). The invasive *Pittosporum undulatum* Vent. has been occupying large areas of Azorean forest, about a third of all forest surface of the nine islands (Silva et al. 2008c), but that increase is more prominent in Pico Island since that species occupies 61% of all forest surface (REAA 2014). However, the climatic optimum of this species is at mid–altitudes being unable to live in the colder and much more humid altitudes (Hortal et al. 2010).

VEGETATION ZONATION STUDIES IN PICO ISLAND

Since the settlement of Portuguese in the Azores, the vegetation suffered significant alterations, mainly due to land–use change and the introduction of exotic species. In the 16th century, Gaspar Frutuoso (1998), in the series "Saudades da Terra" described the Azorean vegetation as composed of "tall and dense forests", without mentioning any particular stratification according to elevation. Among the woody species assigned to Pico Island by that author, it is possible to recognize *Juniperus brevifolia* (Seub.) Antoine ("Zimbro, Cedro"/Azorean cedar), *Taxus baccata* L. ("Teixo"/Yew), *Erica azorica* Hochst. ex Seub. ("Urze"/Azorean Heather), *Frangula azorica* V. Grubov ("Sanguinho"/Buckthorn), *Laurus azorica* (Seub.) Franco ("Louro"/Azorean sweet bay), *Morella faya* (Aiton) Wilbur ("Faia"/Firetree), *Myrsine africana* L. ("Tamujo"/Cape myrtle), *Picconia azorica* (Tutin) Knobl. ("Pau–branco"), and *Viburnum treleasei* Gand. ("Folhado"/Azorean laurustinus) (Frutuoso 1998).

Much later, several botanists attempted to describe the Azorean vegetation. Many of these early endeavours used different elevation belts and focused on the highest island of the archipelago (*cf.* Table 1). In fact, its wide range of elevations (more than twice the elevation of the second highest point in the Azores — São Miguel, 1105 m elevation [Forjaz 2004]) allows the presence of more vegetation belts and comparisons with other mountain regions, either in Macaronesia or elsewhere.

Table 1, adapted and updated from Lüpnitz (1975), summarizes the works of previous authors that explicitly used elevation as an important descriptive variable in the delimitation of vegetation belts in the Azores, such as Seubert & Hochstetter (1843), Morelet (1860), Guppy (1917), Allorge & Allorge (1946), Marler & Boatman (1952), Tutin (1953), Dansereau (1966), Lüpnitz (1975), Purvis et al. (1994, 1995). However, other very important works, namely by Sjögren (1973, 1978), Dias (1996), Elias (2001, 2007), Dias et al. (2004) and Elias et al. (2011) followed a different approach to describe Azorean plant communities, the first by using a phytosociological perspective, the others a more quantitative multivariate analysis, focusing on the communities without restricting their analysis to the finding of elevation belts.

Since the pioneer work by Seubert & Hochstetter (1843), more than 150 years separate these visions of the Azorean vegetation, and this was a dynamic period regarding land use (*e.g.* Triantis et al. 2010; Silveira 2013), with massive loss of native habitats.

Considering Table 1 (in the following page), it is possible to recognize some consensus towards a vegetation change around 500–600 m and another around 1500 m, but the descriptions of the

Table 1. Summary of different systems attempting to describe Azorean vegetation, using different elevational belts (adapted and updated from Lüpnitz 1975; see details in text)

Elevational belt (m)	Seubert & Hochstetter (1843)	Morelet (1860)	Guppy (1917)	Allorge & Allorge (1946)	Marler & Boatman (1952)		Tutin (1953)	Dansereau (1970)		Purvis et al. (1994:upper elevations; 1995: lower elevations)	
1-100	Cultivated or Mediterranean zone (0 m - 500 m)	Zone of cultivation (0 m - 500 m)	Lower woods or *Faya* zone (0 m – 610 [800] m)	Littoral, Mediterranean or *Riccia* region (0 m - 200 [300] m)	Rocky slopes (0 m - 50 [100] m)		Coastal vegetation (0 m - 100 m)	*Morella faya* (0 m - 300 m)			
100-200					Cleared woodland with *Pinus pinaster* (50 m - 150 m)		Laurel forest (broad-leaved evergreen trees) (100 m - 600 m)				
200-300				*Myrica faya* or *Echinodium* and *Neckera* region (200 [300] m - 600 m)	*Pittosporum undulatum* woodland (150 m - 500 m)						
300-400								*Laurus azorica* (300 m – 650 m)			
400-500									*Juniperus brevifolia* (450 m – 1100 m)		
500-600	Canarian zone or belt of laurel wood (500 m - 850 m)	Zone of woods: laurels and other evergreen trees and shrubs (500 m - 1500 m)			*Myrica faya* and *Persea azorica* (500 m - 1000 m)						
600-700			Upper woods or *Juniper* zone (610 m - 1237 m)	*Sphagnum* region (*Juniperrus brevifolia* and *Persea indica* forests) (600 m -700 [800] m)			*Ericetum azoricae* (*Erica azorica* and *Juniperus brevifolia*) (600 m - 1500 m)	*Erica azorica* (650 m-1600 m)			
700-800										Mid-elevation lichen-rich forest (700 m - 900 m)	
800-900				*Juniperus brevifolia* region (*Adelanthus decipiens* and *Daltonia stenophylla*) (800 [900] m - 1400 [1500] m)							
900-1000	Azorean zone or region of shrubs (850 m - 1500 m)									Mid-elevation wet bryophyte-rich forest (900 m -1000 m)	
1000-1100					Calluna vulgaris heath grasslands and wet hollows (1000 m - 1500 m)	Mixed *Erica azorica* –*Juniperus brevifolia* scrub (1000 m - 1200 m)				Upper elevation lichen-rich forest (1050 m - 1150 m)	
1100-1200											
1200-1300			Shrubs or *Juniper* zone (1237 m - 1676 m)			*Juniperus brevifolia* scrub (1200 m - 1400 m)				*Juniperion brevifolii* (1200m-1300m)	
1300-1400										*Calluna vulgaris* - *Daboecia azorica* heath land; *Erica* - sparse (1340 m - 1500 m)	
1400-1500											
1500-1600	Bush or scrub zone (1500 m - 1700 m)	Upper zone: more pastures and heaths (1500 m - 2351 m)		Subalpine or *Andreaea rupestris* region (1500 m - 2351 m)	Barren screes on the volcanic cone (>1500 m)		*Callunetum* (bushes of *Erica* and *Calluna*) (>1500 m)			*Calluna/Thymus* heath (scattered, dwarf *Erica* clumps) (1520 m - 1600 m)	
1600-1700								*Calluna vulgaris* (1600 m – 2200 m)			
1700-1800	Summit zone (1700 m - 2351 m)		*Calluna*, *Menziesia* and *Thymus* zone (1676 m - 2351 m)								
1800-1900											
1900-2000											Prostrate mats of Calluna/Thymus with Racomitrium (>1900 m)
2000-2100										Stunted assemblage of Stereocaulon (2000 m - 2300 m)	
2100-2200											
2200-2300								Lichens (2200m-2350m)			
2300-2351										At least 50 % of bare rock (2300 m - 2351 m)	

communities differ considerably among the authors. Nevertheless, Guppy (1917), Allorge & Allorge (1946), Tutin (1953), Dansereau (1966) and Lüpnitz (1975) separate the lower elevation vegetation belts, dominated by broadleaf species (generally below 600 m), from the higher elevation *Juniperus* zone.

From 600 to 1500 m, Tutin (1953) described *Ericetum azoricae*. However, it is the endemic conifer *Juniperus brevifolia* that is generally recognized as the main architect species in the Azores montane vegetation. Guppy (1917) described forests of *Juniperus brevifolia* and *Laurus azorica* (832–1485 m), while Allorge & Allorge (1946) mentioned pure stands of *Juniperus brevifolia* between 850 and 1500 m. Sjögren (1973), divided the plant communities of the Azores into four alliances, defining the broad alliance *Juniperion* around the presence of *Juniperus brevifolia*; the importance of this gymnosperm is lately emphasized by Elias (2007).

It seems to be consensual that *Calluna vulgaris* (L.) Hull and *Thymus caespititius* Brot. dominate the vegetation above 1500 m, but Purvis and colleagues (1994, 1995), working with lichens, were able to describe a zonation, even above that elevation. It is worth mentioning that the *Callunetum* put forward by Tutin (1953) was later questioned by Sjögren (1973), who proposed an impoverished *Juniperion* for all the mountainous area of Pico.

The strong influence of the human presence was already noted in the 19th century by Seubert & Hochstetter (1843), which referred an "area of cultures" to the elevations below 500 m. That same idea is reinforced by Marler & Boatman (1952), who introduced *Pittosporum undulatum* as a differential species of *Pittosporetum*, a phytosociological association, claiming that "the vegetation of the northern slopes of Pico has been affected by the recently assumed dominance of an introduced tree *Pittosporum undulatum*", with the consequent disappearance of natural vegetation (1952, p. 143–144).

This is the second paper on the series "Long–term monitoring across elevational gradients" that aims to identify and characterize the biodiversity of native flora in several Azorean islands along an elevational transect. This paper presents the results of the MOVECLIM field study concerning the vascular flora of Pico Island (further details in Gabriel et al. 2014). The main goals of this work are to i) review previous botanical studies related to elevational gradients — focusing on Pico Island, since it has the widest elevational range; ii) investigate vascular plants composition and abundance in key areas of native vegetation, following an elevational transect (from 10 to 2200 m); and iii) investigate some patterns of the recorded diversity and distribution of vascular plants.

METHODS

STUDY SITE AND SAMPLING DATES

Up to 1000 m, the Pico Island's transect was set up along the eastern side of the island (Fig. 1a) in order to encompass the best preserved native vegetation and avoiding as much as possible areas with exotic species. From 1200 to 2200 m the transect roughly followed the mountain trail on the south declivity of the main volcanic cone (Fig. 1b). All sites, except the one studied at 400 m, were placed inside the limits of the island's Natural Park, namely in Nature Reserves areas as Pico mountain, "Caveiro" and "Mistério da Prainha". There were three field study phases: 1st) 4–12 September 2012, with the purpose to setting the permanent plots in 12 sites, along an elevational gradient, from 10 to 2200 m, using a 200 m elevational step (Fig. 1) and conduct a preliminary survey of the vascular species present in each of the plots; 2nd) 5–11 May 2013, the vascular species cover was obtained on the same plots; and 3rd) 28 July to 4 August 2013, the sites were revisited to gather pteridophyte data.

SAMPLING METHOD

The sampling methodology mainly followed the standardized protocol BRYOLAT (Kessler et al. 2011; Ah–Peng et al. 2012), and was thoroughly described in the first paper of this series (Gabriel et al. 2014). This methodology has been designed for the study of bryophyte and fern diversity and distribution along environmental gradients in the tropics and subtropics, but it also allows the characterization of vascular flora by recording the presence and cover, as well as the heights and diameter at breast height (dbh) of the largest trees.

Fig. 1. Location of Pico Island (a) and of the transect, showing 12 sites, sampled with 200 m elevational steps (b, c). (b) Lower elevation sites, from 10 to 1000 m and (c) Mountainous sites, from 1200 to 2200 m (surveys in 2012 and 2013).

Vascular plants were identified and cover percentage visually estimated in two 100m^2 plots per each site (species identified to genera did not have reproductive structures available in the field to assist in further identification). The taxonomical classification of the vascular flora follows Silva et al. (2010).

CLIMATE DATA IN THE MOVECLIM TRANSECT

Climate data was obtained from the CIELO Model (Azevedo 1996, Azevedo et al. 1999a,b). CIELO is a physically based model that simulates the climatic variables on an island using data from the synoptic reference of a meteorological site. For this work, the used variables were: precipitation (total annual), relative humidity (maximum and minimum) and temperature (maximum and minimum), obtained from an estimate of the values from the previous 30 years (Table 2).

DATA ANALYSIS

Species richness and cover–abundance were analysed for each plot. The occurrence of a Mid Domain Effect (MDE) (Colwell & Hurtt 1994; Colwell & Lees 2000) was tested, using indigenous and total richness of vascular plants. When the MDE is confirmed, species distribution ranges overlap more towards the middle of the elevational gradient, due to topographical and/or geographical constraints.

The disturbance index (D) (Cardoso et al. 2013) was obtained to determinate the landscape disturbance accounting specifically for landscape composition and configuration. This index reflects an anthropogenic disturbance gradient, ranging from zero (no disturbance at all) to 100 (maximum possible disturbance, like an urban/industrial area) (Table 2).

Table 2. Geographic data, climate data [Rain (total annual); Relative humidity (average annual) and Temperature (average annual) (Azevedo 1996; Azevedo et al. 1999a,b)], biological data and disturbance index [minimum 0; maximum 100 (Cardoso et al. 2013)], for the 12 sites (24 plots) in Pico Island. Site codes: standard elevation (a.s.l.) and plot number.

		Geographic data					Climate data			Biological data					
Site name	**Site codes**	**Coordinates (N)**	**Coordinates (W)**	**Elevation (m)**	**Slope (°)**	**Exposure (°)**	**Rain (mm)**	**Relative humidity (%)**	**Temperature (⁰ C)**	**Endemic AZ**	**Endemic MAC**	**Native**	**Naturalized**	**Doubtful**	**Disturbance index (D)**
1."Manhenha"	0010P1	38°24'49.5"	28°01'47.3"	17	5	205	974	86	19	6		4	4		38
	0010P2	38°24'49.5"	28°01'47.8"	14	10	300				5		3	6		
2."Cabeço da Hera"	0200P1	38°25'05.5"	28°03'14.2"	224	50	270	1014	93	17	3		5	6		47
	0200P2	38°25'05.4"	28°03'13.1"	226	50	60				3		6	8		
3."Fetais, Piedade"	0400P1	38°25'32.8"	28°05'15.5"	365	5	140	1292	94	16	10		4	3		57
	0400P2	38°25'33.3"	28°05'14.5"	364	5	25				8		5	4		
4."Caminho dos Burros, Chão Verde"	0600P1	38°28'7.85"	28°16'34.3"	621	10	180	3066	96	14	19	1	15	4		15
	0600P2	38°28'7.73"	28°16'33.4"	623	15	225				18	1	15	4		
5."Caiado"	0800P1	38°27'20.8"	28°15'26.2"	809	5	320	3513	98	13	12	1	9	1		27
	0800P2	38°27'20.4"	28°15'26.1"	813	5	110				13	1	8	2		
6."Caveiro"	1000P1	38°26'13.8"	28°12'46.9"	952	25	20	3812	99	12	14	1	7	2		23
	1000P2	38°26'13.8"	28°12'46.1"	947	25	350				17	2	9			
7.Pico Mountain	1200P1	38°28'13.3"	28°25'30.9"	1261	5	320	4834	98	11	11		9	6	2	25
	1200P2	38°28'14.3"	28°25'30.1"	1261	5	300				11		7		1	
8.Pico Mountain	1400P1	38°28'10.5"	28°25'16.9"	1418	20	70	4653	98	10	8		4		1	24
	1400P2	38°28'09.5"	28°25'16.5"	1407	15	95				8		4	2	1	
9.Pico Mountain	1600P1	38°27'57.5"	28°24'59.5"	1601	30	95	4047	98	9	9		8	2		24
	1600P2	38°27'55.7"	28°24'59.7"	1588	25	100				10		8	2		
10.Pico Mountain	1800P1	38°27'57.9"	28°24'45.2"	1805	35	70	3613	98	8	3		3			24
	1800P2	38°27'57.4"	28°24'45.0"	1802	35	70				3		3			
11.Pico Mountain	2000P1	38°27'56.6"	28°24'30.0"	2003	40	90	2723	99	7	1		2			23
	2000P2	38°27'56.1"	28°24'29.2"	2009	40	120				1		2			
12.Pico Mountain	2200P1	38°27'58.9"	28°23'57.2"	2239	10	320	2025	99	6	1		2			23
	2200P2	38°28'00.2"	28°23'57.9"	2242	15	320				1		2			

RESULTS

PLOT DESCRIPTION

Twelve elevation sites were sampled on Pico Island, comprising 24 plots (Fig. 1, 2 and 3; Table 2). Climate becomes harsher along the elevational gradient. Around 1600 m there is a clear change of conditions (inversion layer), where precipitation values decrease (Table 2).

The list of vascular plant species registered in each plot, and their average percentage cover may be observed in Table 3. Regarding the species origin (indigenous or exotic), the vascular flora present in these plots fall into five categories: Azores endemic (END), Macaronesia endemic (MAC), native non–endemic (N) (which, together, are the indigenous species), naturalized species (NATU) (including exotic and invasive species) and some species with doubtful colonization status (D) (Silva et al. 2010).

In order to characterize the vegetation communities a brief description of the 12 sampled sites is presented in the following section; the plots are illustrated on Figure 2 (sites 1–6) and Figure 3 (sites 7–12).

Site 1 (~10 m) — "Ponta da Ilha, Manhenha" — Coastal scrubland around the lighthouse of "Manhenha", near "Piedade" village. A lava field divided by some stone walls, probably, the area was earlier used for orchards, which were abandoned from the middle of the 20th century. Presently, the plots are dominated by *Morella faya* which reached a cover of 75% (Table 3) and, at the herbaceous level, by *Pteridium aquilinum* (average about 60%). Among others, the endemic species *Erica azorica*, *Picconia azorica*, *Juniperus brevifolia*, *Euphorbia azorica* were also registered in the area. *M. faya* was the tallest tree registered on the plots, reached almost 6 m (height=580 cm; dbh=22 cm). The naturalized *Salpichroa origanifolia* (Lam.) Baill. (Silva et al. 2008d), was registered for Plot 2, and is now documented in the entire archipelago except in Corvo Island (Silva et al. 2010).

Site 2 (~200 m) — "Cabeço da Hera" — lowland forest located near "Piedade" village. The surrounding area of "Cabeço da Hera" is occupied by a quarry, pastures for cattle, and farmland with some maize cultivation. Both plots had a very steep slope, of about 50º (Table 2). More than a third of all species (N=9; 39%) were exotic, and *Pittosporum undulatum* exhibited the highest cover (Table 3); this is in line with the Disturbance Index, which presents the second highest value observed in the transect (D=47; Table 2). Nevertheless, the tallest trees recorded on site were the endemics *Picconia azorica* (height=600 cm; dbh=11 cm) and *Morella faya* (height=590 cm; dbh=20 cm).

Site 3 (~400 m) — "Fetais, Piedade" — forest. The plots are close to a secondary road, and grasslands, interspersed with forested hills covered with *Morella faya, Laurus azorica* and *Pittosporum undulatum* dominate the surrounding area. These plots proved to be the most affected by anthropogenic influence, presenting also the highest Disturbance Index of the transect (D=57; Table 2). In fact this site is dominated by the presence of *Pittosporum undulatum* (*c.* 80%) (Table 3) reaching more than 8 m height (dbh=18 cm), but endemic species such as *Picconia azorica, Laurus azorica, Erica azorica, Ilex perado* subsp. *azorica* and the orchid *Platanthera micrantha* (Hochst. ex Seub.) Schlecht. were also present. And for other plant groups, the very rare endemic moss *Echinodium renauldii* (Cardot) Broth. was also found in this site (Coelho et al. 2013a).

Site 4 (~600 m) — "Caminho dos Burros, Chão Verde" — *Laurus azorica* and *Ilex perado* subsp. *azorica* dominate the vegetation (*c.* 50%). A specimen of *Erica azorica* was the tallest tree in the plots (height=640 cm; dbh=12 cm) and a specimen of *Laurus azorica* presented the largest diameter (dbh=18 cm). These plots showed the lowest Disturbance Index (D=15) of the entire gradient (Table 2). With 42 plant species (four naturalized), this is the richest site of the elevational gradient. It is possible to observe 23 out of the 25 differential species of the alliance *Juniperion brevifolii* Sjögren (1973), including: the ferns *Culcita macrocarpa* C. Presl, *Dryopteris aemula* (Aiton) O. Kuntze, *Hymenophyllum tunbrigense* (L.) Sm; the shrubs *Vaccinium cylindraceum* Sm., *Myrsine africana*; and the plant rarities *Platanthera micrantha* and *Sanicula azorica* Guthn. ex Seub.

Fig 2. Illustration of plots at different standard elevations in Pico Island (a) 10 m [P2]; b) 200 m [P1]; c) 400 m [entrance]; d) 600 m [P1]; e) 800 m [entrance]; f) 1000 m [P1]).

Fig. 3. Illustration of plots at different standard elevations in Pico Island. Pico Mountain: (a) 1200 m [P1]; b) 1400 m [P2]; c) 1600 m [P1]; d) 1800 m [P2]; e) 2000 m [P1]; f) 2200 m [P2]).

Table 3. List of vascular plant species registered in each of the 24 plots of Pico Island and their average percentage cover. Species marked with an asterisk (*) occur in five or more sites. Nomenclature and colonization status (Col.) are according to Silva et al. (2010) (N, native non–endemic species; END, endemic species to Azores; MAC, endemic species to Macaronesia; D, doubtful colonization status; NATU, naturalized species [1–4, most to least noxious invasive species according to Silva et al. 2008a]). (Site codes according to Table 2).

						Site codes																							
Division	**Class**	**Order**	**Family**	**Species**	**Col.**	**0010P1**	**0010P2**	**0200P1**	**0200P2**	**0400P1**	**0400P2**	**0600P1**	**0600P2**	**0800P1**	**0800P2**	**1000P1**	**1000P2**	**1200P1**	**1200P2**	**1400P1**	**1400P2**	**1600P1**	**1600P2**	**1800P1**	**1800P2**	**2000P1**	**2000P2**	**2200P1**	**2200P2**
Lycopodiophyta																													
	Lycopodiopsida																												
		Lycopodiales																											
			Lycopodiaceae	*Huperzia suberecta* (Lowe) Tardieu	MAC												<1												
	Selaginellopsida																												
		Selaginellales																											
			Selaginellaceae	**Selaginella kraussiana* (Kunze) A. Braun	N						<1	5	7	<1	<1	2	<1	<1											
Pteridophyta																													
	Polypodiopsida																												
		Osmundales																											
			Osmundaceae	*Osmunda regalis* L.	N							<1	<1																
		Hymenophyllales																											
			Hymenophyllaceae	*Hymenophyllum tunbrigense* (L.) Sm.	N							1	2	<1	14	17	8												
				Trichomanes speciosum Willd.	N								<1				1												
		Cyatheales																											
			Culcitaceae	*Culcita macrocarpa* C. Presl	N							29	9	38	19	57	63												
		Polypodiales																											
			Aspleniaceae	*Asplenium marinum* L.	N	<1	1	1	1																				
				Asplenium obovatum Viv. subsp. *lanceolatum* (Fiori) P. Silva	N				<1																				
			Blechnaceae	**Blechnum spicant* (L.) Sm.	N							4	9	9	2	8	4	40	24	6	8	13	20	4	2				
			Dennstaedtiaceae	**Pteridium aquilinum* (L.) Kuhn	N	88	30	1	<1	1	<1	<1	<1	1	3			9	4										
			Thelypteridaceae	**Christella dentata* (Forssk.) Brownsey & Jermy	NATU			1				4	9		<1	<1		<1					<1						
				**Dryopteris aemula* (Aiton) O. Kuntze	N							1	<1	1	<1	4	2	2	<1			<1	<1						
				**Dryopteris azorica* (Christ) Alston	END					<1	1	8	16	54	31	44	33	<1					1						
				**Dryopteris crispifolia* Rasbach, Reichstein & Vida	END					<1		9	38	19	63	38	19	19	<1			<1	1						

Division	Class	Order	Family	Species	Col.	Site codes																							
						0010P1	0010P2	0200P1	0200P2	0400P1	0400P2	0600P1	0600P2	0800P1	0800P2	1000P1	1000P2	1200P1	1200P2	1400P1	1400P2	1600P1	1600P2	1800P1	1800P2	2000P1	2000P2	2200P1	2200P2
				Dryopteris sp.					1	<1	1																		
				Elaphoglossum semicylindricum (Bowdich) Benl	MAC							2	4	1	13	1	2												
				Polystichum setiferum (Forssk.) T. Moore ex Woyn.	N			1		<1	<1	<1										1	1						
			Polypodiaceae	*Polypodium azoricum* (Vasc) R. Fern.	END	<1			<1	<1	<1	<1	1																
				Anthoxanthum odoratum L.	NATU													7											
				Oreopteris limbosperma (All.) Holub	N					<1		<1	<1	<1															
				Stegnogramma pozoi (Lag.) K. Iwats.	N			9																					
				Cerastium fontanum Baumg. subsp. *vulgare* (Hartm.) Greuter & Burd.	NATU																1								
				Diplazium caudatum (Cav.) Jermy	N				<1	19	<1																		
Pinophyta																													
	Pinopsida																												
		Pinales																											
				Juniperus brevifolia (Seub.) Antoine	END	17	1					3	14	13	18	35	41	<1	11										
Magnoliophyta																													
	Magnoliopsida																												
		Laurales																											
			Lauraceae	*Laurus azorica* (Seub.) Franco	END					18	15	60	36	7	4	6	7												
		Ranunculales																											
			Dryopteridaceae	*Cyrtomium falcatum* (L. fil.) C. Presl	NATU-1	1	<1	<1	1																				
		Fagales																											
			Myricaceae	*Morella faya* (Aiton) Wilbur	N	75	76	41	37			<1	4																
		Rosales																											
			Rhamnaceae	*Frangula azorica* V. Grubov	END							9	2		1														
			Woodsiaceae	*Deparia petersenii* (Kunze) M. Kato	NATU-3						<1																		
				Fragaria vesca L.	D													1											
				Potentilla anglica Laich.	N													3	<1	10	20	<1	4						

Division	Class	Order	Family	Species	Col.	Site codes																							
						0010P1	0010P2	0200P1	0200P2	0400P1	0400P2	0600P1	0600P2	0800P1	0800P2	1000P1	1000P2	1200P1	1200P2	1400P1	1400P2	1600P1	1600P2	1800P1	1800P2	2000P1	2000P2	2200P1	2200P2
				Rubus hochstetterorum Seub.	END							<1	3																
			Rosaceae	*Duchesnea indica* (Andr.) Focke	NATU-4													2				2	4						
		Malpighiales																											
			Euphorbiaceae	*Euphorbia azorica* Seub.	END	2																							
				Euphorbia stygiana H. C. Watson subsp. *stygiana*	END									37	9														
			Hypericaceae	*Hypericum foliosum* Aiton	END				1			<1					1												
			Papaveraceae	*Fumaria muralis* Sonder ex Koch subsp. *muralis*	NATU		<1																						
				Viola palustris L. subsp. *juresii* (Link ex K. Wein) Cout.	N													<1											
		Malvales																											
			Thymelaeaceae	*Daphne laureola* L.	N							<1	<1					1											
		Myrtales																											
		Saxifragales																											
			Crassulaceae	*Umbilicus horizontalis* (Guss.) DC.	N	<1																							
				Umbilicus rupestris (Salisb.) Dandy	N				1		<1																		
		Santalales																											
			Santalaceae	*Arceuthobium azoricum* Wiens & F.G. Hawksworth	END							<1				2	2												
		Caryophyllales																											
			Caryophyllaceae	*Cerastium* sp.																		1	2						
			Zingiberaceae	*Hedychium gardnerianum* Sheppard ex Ker-Gawl.	NATU-1			<1	1	4	2	1	1	2	4														
				Silene uniflora Roth subsp. *cratericola* (Franco) Franco	END																							1	<1
				Holcus lanatus L.	NATU																	4							
			Solanaceae	*Physalis peruviana* L.	NATU			<1	<1																				
		Ericales																											
			Ericaceae	**Calluna vulgaris* (L.) Hull	N													11	22	50	57	50	66	84	81	84	81	31	36
				**Daboecia azorica* Tutin & Warb.	END														<1	<1	2	3	3	11	25	4	7		
				**Erica azorica* Hochst. ex Seub.	END	28	33			14	19	9	2	18	15			57	38	26	27	41	54						

Division	Class	Order	Family	Species	Col.	0010P1	0010P2	0200P1	0200P2	0400P1	0400P2	0600P1	0600P2	0800P1	0800P2	1000P1	1000P2	1200P1	1200P2	1400P1	1400P2	1600P1	1600P2	1800P1	1800P2	2000P1	2000P2	2200P1	2200P2
				**Vaccinium cylindraceum* Sm.	END					4	1	21	29	19	27	31	13	12	13	2	4	4	2						
			Myrsinaceae	*Myrsine africana* L.	N							33	19	15	16	7	7												
			Primulaceae	**Lysimachia azorica* Hornem. ex Hook.	END							3	3	<1	<1	4	2	3	1	3	2	1	2	4	1				
		Gentianales																											
			Rubiaceae	**Rubia agostinhoi* Dans. & P. Silva	N							8	5	1	3	5	6	2	1			4	1						
		Lamiales																											
			Lamiaceae	**Thymus caespititius* Brot.	N															3	6	3	4	23	25	12	24	2	4
			Oleaceae	*Picconia azorica* (Tutin) Knobl.	END	19	6	12	35	19	11																		
			Phytolaccaceae	*Phytolacca americana* L.	NATU-3	19	4																						
				Plantago sp.											1														
			Scrophulariaceae	*Sibthorpia europaea* L.	N							<1	<1				<1		<1			<1	9						
		Solanales																											
			Pittosporaceae	*Pittosporum undulatum* Vent.	NATU-1	9	11	81	73	75	84	<1	<1																
			Plantaginaceae	*Plantago lanceolata* L.	NATU													1											
			Polygonaceae	*Polygonum aviculare* L.	NATU				20																				
		Boraginales																											
		Aquifoliales																											
			Aquifoliaceae	**Ilex perado* Aiton subsp. *azorica* (Loes.) Tutin	END					8		36	57	44	69	50	51	17	11			<1	1						
		Asterales																											
			Asteraceae	*Bellis azorica* Hochst. ex Seub.	END												1												
				Leontodon saxatilis Lam. subsp. *longirostris* (Finch & P. D. Sell) P. Silva	D													2	2	2	2								
				Rubus ulmifolius Schott	NATU				2	<1	2	1	4																
				**Tolpis azorica* (Nutt.) P. Silva	END								<1				14	3	6	1	<1	<1							
		Dipsacales																											
			Adoxaceae	*Viburnum treleasei* Gand.	END							1	3																
		Apiales																											

Division	Class	Order	Family	Species	Col.	Site codes																							
						0010P1	0010P2	0200P1	0200P2	0400P1	0400P2	0600P1	0600P2	0800P1	0800P2	1000P1	1000P2	1200P1	1200P2	1400P1	1400P2	1600P1	1600P2	1800P1	1800P2	2000P1	2000P2	2200P1	2200P2
			Apiaceae	*Angelica lignescens* Reduron & Danton	END												1												
				Sanicula azorica Guthn. ex Seub.	END							<1	<1																
			Araliaceae	**Hedera azorica* Carrière	END	1	2	<1		2	6	2	4	4	3	<1	3												
				Salpichroa origanifolia (Lam.) Baill.	NATU-1		<1																						
	Liliopsida																												
		Alismatales																											
				Solanum nigrum L.	NATU		9																						
		Liliales																											
			Smilacaceae	*Smilax azorica* H. Schaef. & P. Schoenfelder	END								<1			9	1												
		Asparagales																											
			Orchidaceae	*Platanthera micrantha* (Hochst. ex Seub.) Schlecht.	END					<1		<1		<1	<1														
		Poales																											
				Carex hochstetteriana Gay ex Seub.	END		2	1			<1																		
				Carex peregrina Link	N							<1	<1																
				Carex sp.											4														
				Carex vulcani Hochst. ex Seub.	END							<1	2			4	10												
			Juncaceae	**Luzula purpureosplendens* Seub.	END							<1	2	5	2	16	15	4	3	3	3	12	6						
			Poaceae	*Agrostis* sp.														9		4		<1	2	2	1			<1	<1
				Sonchus oleraceus L.	NATU													2			2								
				Deschampsia foliosa Hack.	END											2	1												
				Festuca francoi Fern. Prieto, C. Aguiar, E. Dias & M. I. Gut	END													2	16	13	20		4						
			Commelinaceae	*Tradescantia fluminensis* Vell.	NATU-2				1																				
				**Holcus rigidus* Hochst.	END											<1		6	6	16	10	12	2	1	2				
		Zingiberales																											
			Violaceae	*Viola odorata* L.	NATU													<1											
		Commelinales																											
			Araceae	*Zantedeschia aethiopica* (L.) Spreng.	NATU	<1		2	<1							9													

Site 5 (~800 m) — "Caiado" — Forest dominated by *Ilex perado* subsp. *azorica* (Table 3) where it reaches the highest height and dbh values (height=480 cm; dbh=16 cm). Among the tree species there are also *Juniperus brevifolia* and *Laurus azorica* while *Euphorbia stygiana* is distinguished by its large size, reaching heights of 270 cm. The ferns *Dryopteris crispifolia* Rasbach, Reichstein & Vida, *D. azorica* (Christ) Alston (*c.* 40% cover) and *Culcita macrocarpa* are also quite frequent. Surrounding this area, there is a lagoon, "Lagoa do Caiado", forest areas (production, protection, recreation) and low intensity pastures (DROTRH 2008).

Site 6 (~1000 m) — "Caveiro" — Mountain cloud forest; system dominated by *Ilex perado* subsp. *azorica* and *Juniperus brevifolia* (Table 3). *Ilex perado* subsp. *azorica* was the tallest tree (height=370 cm) and *Juniperus brevifolia* the broadest one (dbh=17 cm); both species had high percentage covers (average 50% and 38%, respectively). Many other plants are considered differential species in the alliance *Juniperion brevifolii* (Sjögren 1973). The fern *Culcita macrocarpa* reached the highest abundance (60% cover). This site is part of the Natural Reserve of "Caveiro", which includes both forests and bogs, but the presence of cattle is notorious in the semi–natural pastures surrounding the plots.

Sites 7 to 9 (~1200 to ~1600 m) — Pico Mountain — from this point on, the transect follows the mountain trail, which starts around 1200 m and extends up to the crater of Pico Mountain. Plants reaching more than 2 m were not present in the trail. The first site (site 7) is covered by an *Erica* scrub (*c.* 50% cover) reaching up to 200 cm. The fern *Blechnum spicant* (L.) Sm. occupied about a third of the area of the plot but *Calluna vulgaris*, *Ilex perado* subsp. *azorica* and *Vaccinium cylindraceum* did not reached 15% of cover. At 1400 m (site 8), vegetation stature is lower, with the tallest species reaching up to 75 cm high; *Calluna vulgaris* dominates the vegetation (> 50% cover) while short shrubs of *Erica azorica* cover about a quarter of the area and the endemic *Holcus rigidus* about a tenth (Table 3). At 1600 m (site 9) *Calluna vulgaris* (*c.* 60% cover) and *Erica azorica* (*c.* 50% cover) predominated, the latter reaching a canopy's maximum height of 120 cm.

Site 10 to 12 (~1800 to ~2200 m) — Pico Mountain — these last three sites are dominated mainly by *C. vulgaris,* but *Daboecia azorica* and *Thymus caespititius* (Table 3) are also present. These plots present a low number of species, and no naturalized plants were recorded. At 1800 m (site 10), the canopy's maximum height was 29 cm, in the remaining elevations, the species were even shorter, reaching up to 12–22 cm height. The endemic species, *Silene uniflora* Roth *subsp. cratericola* (Franco) Franco described from the crater of the mountain was recorded at 2200 m (site 12).

Patterns of richness and distribution of vascular plants

The twelve elevational sites surveyed resulted in a list of 88 *taxa* — one species new to the flora of the island and five identified only to the genus level — which represent circa 14% of all vascular *taxa* present in this island. A total of 60 indigenous species (32 END, 2 MAC and 26 N), 21 exotic species, two species with doubtful colonization status and five species identified to genera were found in the surveyed sites.

About a fifth of the species (N=20; 23%) presented a broad distribution range and were present in five or more elevations (Table 3, species marked with an asterisk): six ferns, the Azorean cedar, 10 Magnoliopsida, two Liliopsida and one Selaginellopsida. Except for the fern *Christella dentata*, all species were indigenous. Most of the species (N=51; 58%) occur up to 1000 m, while about a fifth (N=18; 21%) were only recorded above that altitude, including *Calluna vulgaris*, *Daboecia azorica*, *Thymus caespititius, Festuca francoi* Fern. Prieto, C. Aguiar, E. Dias & M. I. Gut and *Silene uniflora* subsp. *cratericola* (Table 3).

In the transect, eudicotyledons' richness (Class Magnoliopsida) is irregularly distributed among the different elevations surveyed, ranging from three to 20 species, with the highest sites (1800 to 2200 m) showing fewer species (Table 3; Fig. 4). Maximum diversity is achieved by Magnoliopsida at 600 and 1200 m, with the presence of 20 and 18 species, respectively. Monocotyledons' richness (Class Liliopsida) ranges between one to six species. Liliopsidas' highest diversity is reached at 600 and 1000 m

(Fig. 4). The only gymnosperm found in the transect, the endemic species *Juniperus brevifolia* (Division Pinophyta, Class Pinopsida), occurs in both plots of five sites (10, 600, 800, 1000 and 1200 m) (Table 3). Ferns' richness (Class Polypodiopsida) reaches 14 species at 600 m and 10 species at 200 and 800 m (Fig. 4). *Huperzia suberecta* and *Selaginella kraussiana* are the two representatives of the Classes Lycopodiopsida and Selaginallopsida, respectively; the first is present only at 1000 m while the second is common between 400 and 1200 m (Table 3; Fig. 4).

The number of indigenous species (END, MAC and N) was always higher than the number of exotic species (NATU). The maximum relative richness of indigenous species was recorded around the middle of the elevational gradient at 600, 800 and 1000 m (Fig. 5). These altitudes correspond to the most complex forests present in the transect, including the trees *Laurus azorica*, *Ilex perado* subsp. *azorica* and *Juniperus brevifolia* and many other woody species. Exotic species richness reaches its maximum value at 10 and 200 m. At the remaining elevation levels the relative richness of exotic species is minimal, less than 2%, and they are completely absent in the highest elevations, between 1800 and 2200 m (Table 2; Fig. 5).

The distribution of species richness seems to follow a parabolic pattern (Fig. 4 and 5). Nevertheless, the indigenous vascular plant species distribution does not fit the Mid Domain Effect (MDE) (Fig. 6), since both the peak of richness is reached below the middle of the gradient and the number of species in the highest elevations is lower than expected. Similar results were obtained for all the species including exotics (not shown).

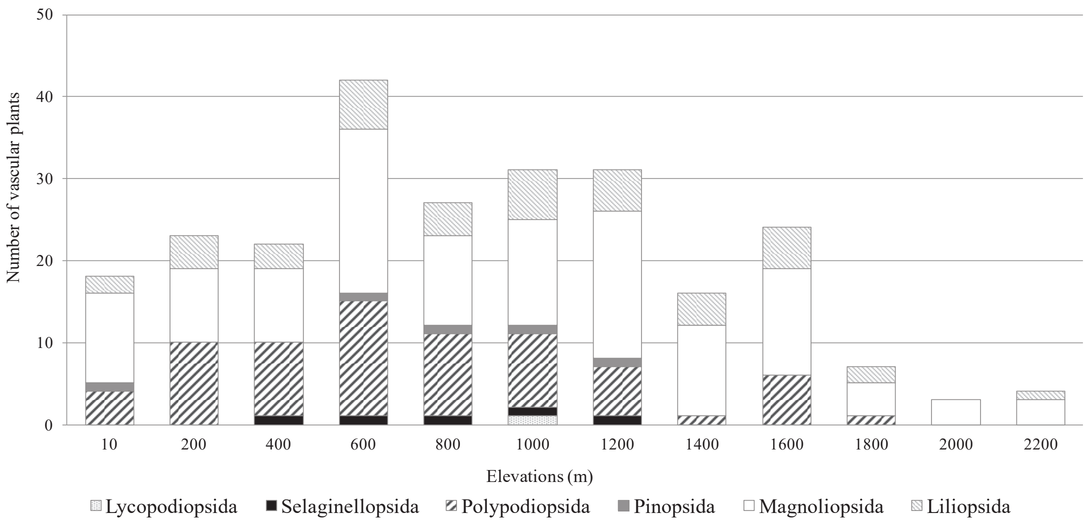

Fig. 4. Number of vascular plants per class at each studied standard elevation.

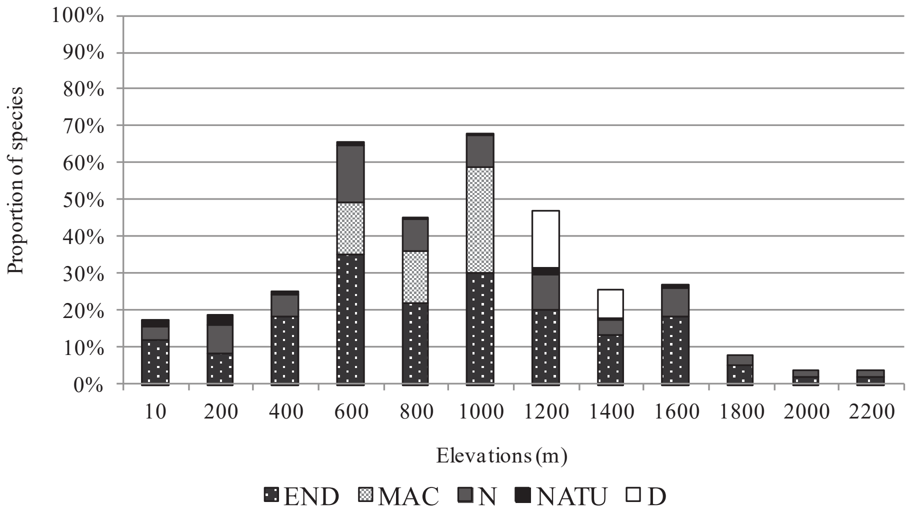

Fig. 5. Proportion of species: indigenous (END, endemic species to Azores; MAC, endemic species to Macaronesia; N, native species); exotic (NATU, naturalized species); and with doubtful colonization status (D) along the Pico transect.

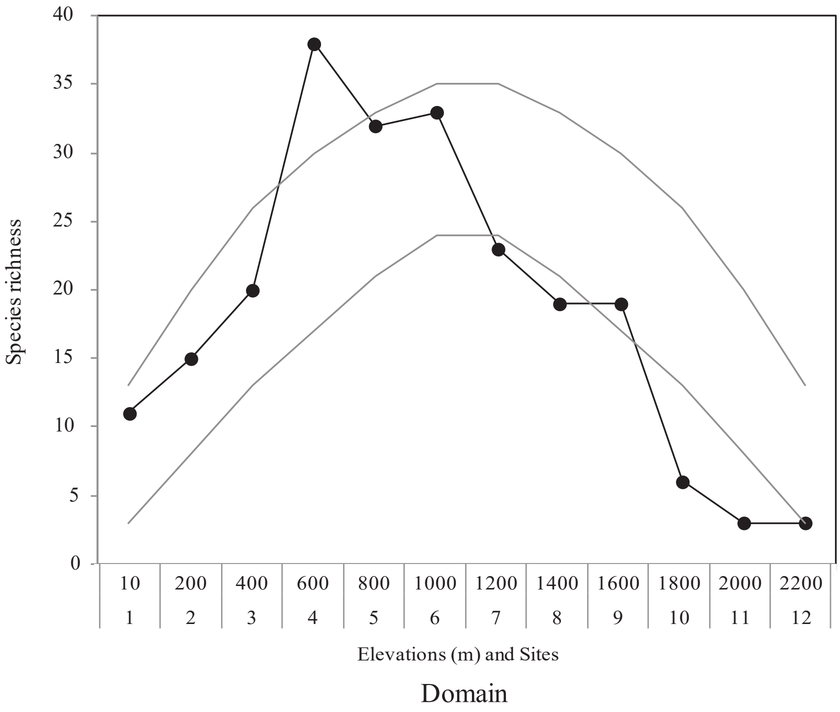

Fig. 6. Mid Domain Effect (MDE) test for indigenous species distribution on the Pico Island transect.

DISCUSSION

Among the classification systems describing the Azorean vegetation, many used elevation to explain biodiversity patterns (see Table 1 and references therein). This is understandable since not only does biodiversity respond to elevation in a number of ways (Rahbek 1995) but, in general, it is also considered a good surrogate of habitat diversity and climatic variables, i.e. "environmental heterogeneity" (*e.g.* Hortal et al. 2009; Kessler et al. 2011; Ah–Peng et al. 2012; Gabriel et al. 2014). In the Azores, some authors have proposed exposure to winds and soil's humidity as the main factors explaining the distribution of plant communities (*e.g.* Dias 1996; Dias et al. 2005), nevertheless, the elevational approach used in this study, analysing only a minimum fraction of the available area of the island (24 plots of 100 m^2), resulted in a list of more than a third of the indigenous species (N=60; 35%), although intermixed with some of the exotic species (N=21; 5%) present in Pico Island. This transect and the permanent marked plots, thus represents a good start for future monitoring studies.

The composition found in the surveyed plots roughly agrees with the studies of Dansereau (1966), since this author places a prominent value on species such as *Morella faya* (0–300 m), *Laurus azorica* (300–650 m) and *Juniperus brevifolia* (450–1100 m). There are also striking resemblances with the Alliance *Juniperion brevifolii* described by Sjögren (1973), since a large number of differential species was also retrieved within the plots, especially above 400 m, where the proportion of species belonging to *J. brevifolii* and their average cover is always higher than the species with no differential value (data not shown).

The richness of species steadily rises from the coast (N=18: 11 indigenous and 7 exotic) until the 600 m (N=42: 38 indigenous and 4 exotic) where it peaks, declining afterwards to a very low number of species inside the caldera of Pico Mountain (Table 2; Fig. 5). Although the species distribution resembles a normal curve, it does not support the Mid Domain Effect hypothesis (Fig. 6), since the peak of richness appears much lower than the middle of the domain (1200 m). A similar deviation from the predictions was also found with the epiphytic bryophytes of Réunion Island–Mascarene archipelago (Ah–Peng et al. 2012).

Many Azorean endemic plants are characterised by a wide ecological and elevational range (*e.g.* Sjögren 1973; Schäfer 2005; Table 1) and these modern times' observations are also corroborated by palaeoclimatic studies (Connor et al. 2012, 2013). In fact, the Pico stratified sampling showed 20 species with ranges equal or higher than 1000 m (Table 3); the widest range belongs to *Erica azorica* (*c.* 1600 m range), a species considered as a cornerstone of the Azorean native vegetation (*e.g.* Ribeiro & Borges 2010). Other endemics species, such as *Juniperus brevifolia,* still present a wide range (*c.* 1200 m), but was missing from the sites of 200–400 m. This means that some species are becoming rarer, and that the indigenous communities are fragmented which agrees with the idea put forward by many authors (Table 1), for instance Purvis & James (1993: 2) who stated that in the Azores "virtually no natural forests with native trees exist below 500 m, having been replaced almost completely by the exotic *Pittosporum undulatum* (…)". Indeed the sites surveyed at lower elevations (200 and 400 m), were impoverished and fragmented, dominated by *P. undulatum* (Table 3).

In fact, invasion pressure continues in the Azores, as is exemplified by the new record for Pico Island of the naturalized *Salpichroa origanifolia* (10 m site), a species considered among the Top 100 invasive species of Macaronesia (Silva et al. 2008d).

As expected (*e.g.* Silva et al. 2005) exotic species richness was higher in the sites where human action is dominant. Nevertheless, it was possible to find eight exotic plant species along the mountain trail (1200–1600 m), all presenting low covers (below 5% except *A. Odoratum* L., with 7%) (Table 3) and only one (*D. Indica* (Andr.) Focke) currently considered invasive (Fernandes et al. 2008). Although these species were introduced a long time ago in the Azores (*cf.* Schäfer 2003), and the nature of invasive species promote their installation, its presence above 1000 m could be exacerbated by the intensity of visitors arriving in the lowland, ready to hike to the top of the mountain, stepping into the natural vegetation and accidentally transporting propagules of exotic species (it is possible to find seedlings or young trees of apple, peach and apricot along the trail up to the Pico summit, clearly indicating that visitors do have an effect in vegetation). Similarly to other touristic areas (*e.g.* Huiskes et al. 2014), this ecotourism pressure may promote the spread of additional invasive species to higher altitudes in Pico, calling to urgent measures of tourists self–regulation or special measures of education by the park rangers in order to reduce propagule transfer of plants.

Invasions and habitat loss (Martín et al. 2008) are serious threats to the indigenous flora (*e.g.* Schäfer 2005; Heleno 2008; Silva et al. 2008a, 2009), hindering both natural evolutionary processes and ecosystem services. Besides, changes in the dynamics of the vegetation from the Azores may be reinforced by the foreseen climatic changes (Harter et al. 2015).

Notwithstanding it is worth reinforcing that forests at medium–higher elevations (600–1000 m) harbour an impressive number of endemic vascular plant species (Table 2, Fig. 5) establishing native communities similar to the ones described in the past (*e.g.* Seubert & Hochstetter 1843; Morelet 1860; Tutin 1953; Dansereau 1966; Sjögren 1973; Dias 1996). This richness was also confirmed for other plant groups, such as bryophytes (Coelho et al. 2013b). At the lower altitude sites, and in spite of their obvious alterations, it was possible to list a relatively high number of woody endemic species along with *Platanthera micrantha* and endemic ferns, while the disturbance index of subalpine and alpine habitats remains quite low.

Currently, the native vegetation of Pico Island remains very rich and important for conservation and, although all sites but one (400 m) are well within the boundaries of the Pico Natural Park, it is necessary to monitor them to validate and/or adjust eventual conservation measures, such as the control of invasive species — PRECEFIAS Program for Control or Eradication of Invasive Plants in Sensitive Areas (Silva et al. 2008b) — or the restauration of habitats using local species to better guarantee the survival of populations and preserve their evolutionary potential (*e.g.* Rumeu et al. 2011). Monitoring and management of these sites will be very important to prevent future threats to native areas. Furthermore the ongoing fragmentation (REAA 2005) and degradation of habitats due to trampling (*e.g.* Silva et al. 2005), expansion of exotic flora (*e.g.* Silva et al. 2008b) and replacement of indigenous vegetation by grasslands or plantation of non–endemic trees (*e.g.* Triantis et al. 2010) are threats to the Azorean biodiversity (Borges et al. 2009) that may change the quality of the studied ecosystems in the near future.

ACKNOWLEDGMENTS

The authors would like to acknowledge the financial support granted by the research project MOVECLIM (M2.1.2/F/04/2011/NET) and also by projects ISLANDBIODIV (NETBIOME/0003 /2011), IMPACTBIO (DRCT–M2.1.2/I/005/ 2011) and ATLANTISMAR (DRCT–M2.1.2 /I/027/2011). Besides, MCMC and DSGH were funded by Ph.D. grants M3.1.2/F/051/2011 and M3.1.2/F/051/2011, from the "Fundo Regional Ciência e Tecnologia", Regional Government of the Azores and PROEMPREGO. The team are grateful to the Director of the Natural Park of Pico Island, Dr. Paulino Costa, and to the Director of the research group CITA–A — "Centro de Investigação e Tecnologias Agrárias–Açores", Doutor João Madruga, for logistic assistance. The authors wish to thank Pedro Cardoso for estimating disturbance data for each site and the referees, Hanno Schäfer and Mónica Moura, for their valuable comments on an earlier version of the manuscript.

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Received 13 Nov 2015, Accepted 19 Feb 2016, Published online 28 July 2016