

## Long-term monitoring across elevational gradients (III): vascular plants on Terceira Island (Azores) transect

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Anthropogenic disturbance often drives habitat loss, ecological fragmentation and a decrease in biodiversity. This is especially problematic in islands, which are bounded and isolated systems. In the Azores, human settlement led to a significant contraction of the archipelago's original native forested areas, which nowadays occupy only small patches and are additionally threatened by the spread of invasive species. Focusing on Terceira Island, this study aimed to assess the composition of vascular plant communities, and the abundance and distribution patterns of vascular plant species in permanent 100 m<sup>2</sup> plots set up in the best preserved vegetation patches along an elevational gradient (from 40 to 1000 m a.s.l.). Sampling yielded a total of 50 species, of which 41 are indigenous and nine are exotic. The richest and best preserved communities were found between 600 m and 1000 m, corresponding to *Juniperus-Ilex* montane forest and *Calluna-Juniperus* altimontane scrubland formations. Nonetheless, exotic species were prevalent between 200 m and 400 m, with *Pittosporum undulatum* clearly dominating the canopy. These results support the high ecological and conservation value of the vegetation formations found in the island's upper half, while calling attention to the biological invasions and homogenization processes occurring at its lower half. Long-term monitoring in these plots will further reveal direction and rates of change in community composition, allowing for more informed management and conservation strategies in the island.

Key words: disturbances, elevation, *Ilex perado* subsp. *azorica*, *Juniperus brevifolia*, *Laurus azorica*, native vegetation, permanent plots, *Pittosporum undulatum*

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### INTRODUCTION

Islands tend to be less diverse than mainland areas of similar size (Whittaker & Fernández-Palacios 2007), but it also seems that, being

discrete and isolated entities, they are hotspots for many rare species with restricted distributions (Kier et al. 2009). Focusing on insular floras, islands shelter exclusively about one quarter of all known plant taxa (Kreft et al. 2008). Nonetheless,

anthropogenic pressure on these fragile ecosystems is leading to a decrease in the number of endemics and an increase in the number of introduced and invasive species (Sax et al. 2002). In the Azores, five centuries of human occupation led to a decrease estimated between 87% (Monteiro et al. 2008) and 95% in the area occupied by native vegetation (Triantis et al. 2010; Gaspar et al. 2011), seriously threatening the continued existence of the remaining vascular species endemic to the archipelago (around 35% of the total native vascular plant richness) (Silva et al. 2010). Additionally, introduced species already comprise around 80% of the archipelago's vascular flora (Silva et al. 2010), with biological invasions and habitat destruction thus converging to create a bleak scenario for the future of the Azorean vegetation.

In this context, this is the third paper on the series "Long-term monitoring across elevational gradients", which aims to identify, characterize and monitor the vascular plant diversity of some of the remaining fragments of native flora in several Azorean islands, using elevational transects with a 200 m step. In order to do so, a standardized methodology, thoroughly explained in the first paper of the series (Gabriel et al. 2014), was applied to Terceira Island during the winter of 2012 and the spring of 2013.

The main purpose of this paper is to identify and characterize native vegetation patches in Terceira, concerning their composition of flowering plants, ferns and the richness of habitats for bryophytes. We also determine a) if the floristic composition of these plots is representative of the island's indigenous vascular diversity, b) if the vascular communities in the transect show signs of elevation zonation, c) if taxonomy and origin correlates with species distribution patterns and d) how Terceira's results compare to Pico's. This analysis may contribute with information to research and conservation topics of interest, such as the effectiveness of the native biodiversity protection measures (associated with Terceira's Natural Park areas) or the identification of elevational zonation patterns associated with differences in environmental variables in the island.

#### CHARACTERIZATION OF TERCEIRA ISLAND

Located at the coordinates 27°19' W, 38°71' N, in the Central Group of the Azores archipelago, Terceira is the third largest (402 km<sup>2</sup>) of the nine Azorean islands (Borges et al. 2009). It reaches 1021 m a.s.l. of maximum elevation in the Santa Bárbara Volcanic Complex (Forjaz 2004), the youngest of the four stratovolcanos that shape the island. According to Calvert et al. (2006), two of these volcanoes have collapsed and are believed to be extinct (Guilherme Moniz and Cinco Picos) but the other two are still considered active (Pico Alto and Santa Bárbara). Terceira is thus mostly formed by trachytes and pyroclastic material (cinders, ashes, pumices, tuffs) of trachyte composition (Madeira et al. 2007).

Human settlement in Terceira was strongly influenced by the geomorphology of the territory. As a major part of the island's interior is occupied by volcanic cones and stratovolcanos, most communities were forced to establish along the coastal lowlands and river-valleys (Agostinho 1942), and most of them are still located below 250 m a.s.l. (review in Silveira 2013). Presently, Terceira's main economic activity is the rising of livestock and the production of dairy-based products (INE 2011) and most of the natural vegetation that originally covered the island's lower areas was destroyed in order to create pastureland, used for rotational crops and grazing dairy cattle (Silveira 2013).

The climate in Terceira can be considered mild, with high relative humidity values, regular rainfall and strong wind regimes (Azevedo et al. 2004). According to the observations registered in the Meteorological Station of Angra do Heroísmo, the mean temperature values (at 74 meters a.s.l.) oscillate between 25° C in August and 15° C in February. Mean rainfall peaks in January, at approximately 130 mm and it's the lowest in July, at circa 30 mm. At higher elevations, the model CIELO projects a mean annual rainfall of more than 2800 mm and minimum and maximum temperatures of, respectively, less than 6° C and 13 to 14° C for the Santa Bárbara Mountain. The wind is most likely to come from the SE and NW sectors (Azevedo et al. 2004).

According to Silva et al. (2010) there are 1109 vascular plant taxa in the Azores, 61% of which occur in Terceira (N = 674). Only about a quarter of these species are endemic or native (N = 164; 24%) but they represent almost 78% of the 210 indigenous vascular plants known for the Azores. As recently described by Elias et al. (2016), Terceira island has six natural vegetation belts: *Erica-Morella* coastal woodlands; *Picconia-Morella* lowland forests; *Laurus* submontane forests; *Juniperus-Ilex* montane forests; *Juniperus* montane woodlands and *Calluna-Juniperus* altimontane scrublands. Taking into account their potential distribution on the island, coastal woodlands are more likely to occur in the coastal areas of the south, east and central north, from the coast up to 100 m a.s.l. Lowland forests are found usually between 100 m and 300 m a.s.l., but sometimes near the coast, and they could occupy around 38% of the island. The potential area of occupation of *Laurus* submontane forests is the interior of the island, between 300 and 600 m a.s.l. Lowland and submontane forests comprise the Azorean Laurel forests, the potentially dominant vegetation type in the Azores (Elias et al. 2016). Unfortunately, as in the other islands, these have declined dramatically in Terceira and only a few patches remain. The best preserved vegetation patches are found in the mountainous areas of the central and western parts of the island. Here, *Juniperus-Ilex* montane forest is the dominant vegetation, still occupying relatively large areas in Terra Brava, Pico Alto and Santa Bárbara natural reserves. *Juniperus* montane woodlands and *Calluna-Juniperus* altimontane scrublands occur in the western part of the island, mainly in the Santa Bárbara Natural reserve, a part of Terceira Island Natural Park (Regional Legislative Decree no. 11/2011/A, of April 20). With a total extent of 95.78 km<sup>2</sup>, distributed among 20 terrestrial and marine areas, the Park encompasses 88.35 km<sup>2</sup> of the island's landmass, which adds up to about one fifth (22%) of its total (Figure 1).

#### VEGETATION STUDIES IN TERCEIRA ISLAND

A review of the history of vegetation zonation studies in the Azores is featured in the second paper of this series (Coelho et al. 2016). Pico Island, with its mountain standing as the highest

in Portugal has, understandingly, been the focus of most elevational vegetation works.

Nonetheless, Terceira Island has also served as a stage for botanical research in the archipelago. Some works set on the island focus on the mapping and description of the native or endemic vegetation (Dias 1989; Dias et al. 2004; Melo 2008), stressing the sensitivity of the region's endemic species to anthropogenic disturbances and the high conservation value of the Santa Bárbara Mountain. Approaching the subject from a different angle, other studies explore the patterns and consequences of the spread of exotic species in Terceira's protected areas (Silveira 2011; Goulart 2014), accentuating the negative effects of species such as *Cryptomeria japonica* (Japanese red cedar), *Hedychium gardnerianum* (Kahili ginger), *Hydrangea macrophylla* and *Pittosporum undulatum* (Incenso tree) on the island's native vegetation.

## MATERIAL AND METHODS

### STUDY SITE AND SAMPLING DATES

A transect was set up entirely inside the limits of the Natural Park of Terceira (Regional Legislative Decree no. 11/2011/A, of April 20) along the western side of the island (Figure 1); the Natural Park of Terceira aims to contain the best preserved native vegetation areas and avoid highly disturbed and modified areas. Thus, the selected transect encompasses not only one of the best preserved areas of the island, but the only protected area going continuously from the coast to the summit. At each elevation, sites of homogeneous vegetation were sought after and two plots (10 m x 10 m) were set up inside those areas. The fieldwork was carried out in two stages. The first took place between the 26<sup>th</sup> and 28<sup>th</sup> of September 2012 and served the purpose of setting the 12 permanent plots in six elevations, from 40 m (Serreta lighthouse) to 1000 m (Santa Bárbara Mountain) at a 200 m elevational step (Figure 1), collect bryophytes and perform a preliminary assessment of the vascular species present in each plot. This dataset was later complemented with information on the vascular species cover, during a second phase in May 2013.

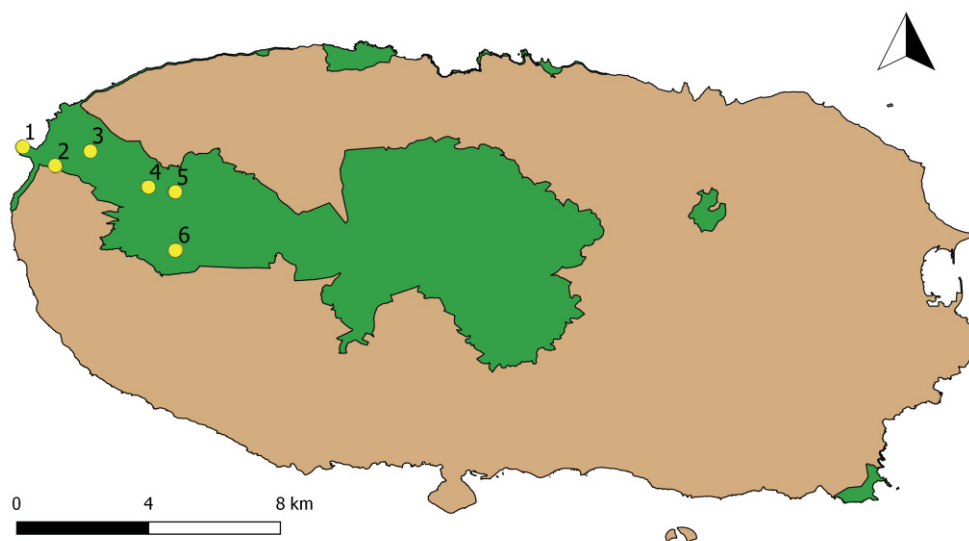


Fig. 1. Terceira Island transect, with the location of the six sampled elevational sites (1 – 40 m; 2 – 200 m; 3 – 400 m; 4 – 600 m; 5 – 800 m; 6 – 1000 m) and the delimitation of Terceira's Natural Park protected areas.

#### SAMPLING METHODOLOGY

The sampling methodology followed the standardized BRYOLAT protocol (Ah-Peng et al. 2012, adapted by Gabriel et al. 2014) for the collection of bryophytes and small ferns along environmental gradients, thoroughly described in the first paper of this series (Gabriel et al. 2014). Despite focusing on cryptogams, this methodology also includes the characterization of several aspects of the surrounding vascular flora, such as presence, cover, height and diameter at breast height of the largest trees. It was possible to identify the plants in the field and only a few voucher specimens were taken and deposited in AZU (Herbarium of the University of the Azores, Angra do Heroísmo).

Nomenclature and taxonomy of the vascular flora, as well as species origin, follows Silva et al. (2010). Regarding the latter, species are divided 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 casual species (CAS).

#### CLIMATE DATA IN THE MOVECLIM TRANSECT

Climate data was derived from the CIELO Model (Azevedo 1996; Azevedo et al. 1999a,b), a physically based model created to dynamically simulate the local climate in islands using information from a reference meteorological station. The variables we considered for this work were total annual precipitation, average annual relative humidity and average annual temperature, derived from estimates for the last 30 years (Table 1).

#### DATA ANALYSIS

Vascular species richness and cover were determined for each plot. The occurrence of a Mid Domain Effect (MDE) (Colwell & Hurtt 1994; Colwell & Lees 2000) was also assessed, both for indigenous and total richness of vascular plants. When the MDE occurs in bounded domains (such as islands), species distribution ranges overlap more near the middle of the elevational gradient, producing a hump-shaped richness pattern.

The disturbance index (D) (Cardoso et al. 2013) was determined for each plot. This index

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Table 1. Brief characterization of the six sampled sites [12 Plots] in Terceira Island: Geographic data, climatic 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)]. Site codes: standard elevation (a.s.l.) and plot number.

Site name	Site codes	Geographic data					Climatic data			Biological data					Disturbance index (D)	
		Coordinates (N)		Coordinates (W)		Elevation (m)	Slope (°)	Exposure (°)	Rain (mm)	Relative humidity (%)	Temperature (°C)	Endemic AZ	Endemic MAC	Native		Naturalized
1. Serreta lighthouse	0040P1	38°45'59.7"	27°22'31.4"	31	10	270 W	1091	87	18	3	3	3				35,6
	0040P2	38°45'59.5"	27°22'30.5"	38	10	100 W	1091	87	18	1	2	1				
2. Canada das Covas, Serreta	0200P1	38°45'35.3"	27°21'49.1"	243	45	215 SW	1361	92	17	7	4	4	1		47,5	
	0200P2	38°45'36.2"	27°21'50.1"	229	20	360 N	1361	92	17	8	3	4	1			
3. Carneiro Peak	0400P1	38°45'54.8"	27°21'05.9"	387	45	320 NW	1620	95	15	5	7	4			35,2	
	0400P2	38°45'54.1"	27°21'05.84"	381	15	330 N	1620	95	15	6	6	4				
4. Lagoinha Peak	0600P1	38°45'09.3"	27°19'53.9"	675	40	150 S	3065	97	14	10	1	8	2		24,6	
	0600P2	38°45'09.1"	27°19'52.9"	675	15	0 N	3065	97	14	8	1	7	2			
5. Lagoa do Pinheiro trail	0800P1	38°45'03.0"	27°19'20.0"	824	20	180 S	3179	99	13	9	1	10	1		16,7	
	0800P2	38°45'03.1"	27°19'19.3"	827	5	90 E	3188	98	13	7	1	9	1			
6. Santa Bárbara Mountain	1000P1	38°43'49.7"	27°19'19.4"	988	10	20 N	3185	100	12	8	10				16,1	
	1000P2	38°43'50.3"	27°19'17.9"	990	30	75 E	3254	100	12	10	11					

takes into account landscape configuration and defines an anthropogenic disturbance gradient that varies from 0 (no disturbance at all, indicating the presence of pristine natural forests) to 100 (maximum possible disturbance, indicating a prevalence of urban/industrial uses) (Table 1).

## RESULTS

### PLOT DESCRIPTION

A total of 12 plots were sampled in Terceira Island, set along six elevational sites. Rainfall and relative humidity increase along the gradient, while temperature decreases, as well as the disturbance index (Table 1).

The list of vascular plant species present in each plot together with their average percentage cover may be observed in Table 2. In order to characterize the vegetation communities, a brief description of the six sampled sites is presented in the following section; with the plots illustrated on Figure 2.

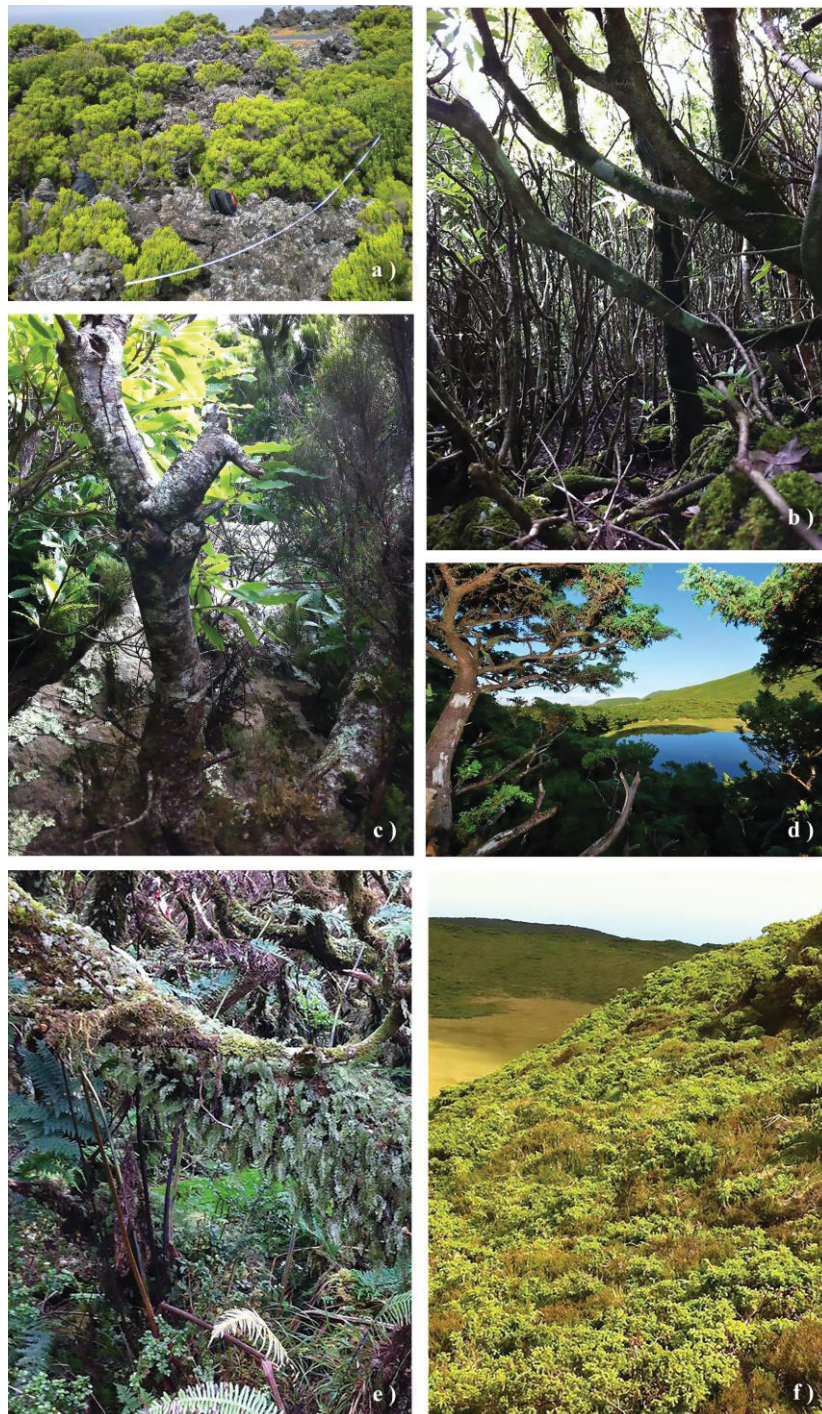


Fig. 2. Vegetation appearance along the altitudinal gradient set up in Terceira Island: a) 40 m; b) 200 m; c) 400 m; d) 600 m; e) 800 m; f) 1000 m.



Division	Class	Order	Family	Species	Col.	Site codes												
						0040P1	0040P2	0200P1	0200P2	0400P1	0400P2	0600P1	0600P2	0800P1	0800P2	1000P1	1000P2	
Pinophyta	Polypodiaceae	Pinales		<i>*Dryopteris azorica</i> (Christ) Alston	END			1	<1	7	5	12	2	12	3	9	1	
				<i>Elaphoglossum semicylindricum</i> (Bowdich) Benl	MAC								3	2	2	1		
				<i>Polypodium azoricum</i> (Vase) R. Fern.	END		2	<1										
Magnoliophyta	Cupressaceae	Pinales		<i>Cryptomeria japonica</i> (L. fil.) D. Don	NATU				<1	2								
				<i>*Juniperus brevifolia</i> (Seub.) Antoine	END		3	19	29	23	57	88	57	88	81			
Asparagales	Orchidaceae	Poales		<i>Platanthera pollostantha</i> R.M.Bateman & M.Moura	END									<1			<1	
				<i>Carex echinata</i> Murray	N													
Poaceae	Juncaceae	Poales		<i>Carex hochstetteriana</i> Gay ex Seub.	END					<1								
				<i>Carex pilulifera</i> L. subsp. <i>azorica</i> (Gay) Franco & Rocha Afonso	END											1	3	
				<i>Carex</i> sp.	END								9					
				<i>Eleocharis multicaulis</i> (Sm.) Desv.	N												1	6
Poaceae	Juncaceae	Poales		<i>Luzula purpureosplendens</i> Seub.	END									3	2	15	24	
				<i>Agrostis</i> sp.	END													1

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Division	Class	Order	Family	Species	Col.	Site codes												
						0040P1	0040P2	0200P1	0200P2	0400P1	0400P2	0600P1	0600P2	0800P1	0800P2	1000P1	1000P2	
				<i>Deschampsia foliosa</i> Hack.	END									3			7	22
				<i>Festuca petraea</i> Guthn. ex Seub.	END <1													
				<i>Holcus rigidus</i> Hochst.	END												2	3
				<i>Hordeum murinum</i> L. subsp. <i>leporinum</i> (Link) Asch. & Graebn.	NATU <1													
		<b>Zingiberales</b>																
		Zingiberaceae		<i>Hedychium gardnerianum</i> Sheppard ex Ker-Gawl.	NATU-1			1	3	6	12	2	<1					
		<b>Magnoliopsida</b>																
		<b>Apiales</b>																
		Araliaceae		<i>Hedera azorica</i> Carrière	END				<1				3					
		Pittosporaceae		<i>Pittosporum undulatum</i> Vent.	NATU-1			4	60	67	72	63						
		<b>Aquifoliales</b>																
		Aquifoliaceae		* <i>Ilex perado</i> Aiton subsp. <i>azorica</i> (Loes.) Tutin	END			9	4				44	22	8	29		
		<b>Boraginales</b>																
		Boraginaceae		<i>Myosotis maritima</i> Hochst. ex Seub.	END								1					
		<b>Caryophyllales</b>																
		Caryophyllaceae		<i>Sagina maritima</i> G. Don fil.	N								<1					
		<b>Dipsacales</b>																
		Adoxaceae		<i>Viburnum treleasei</i> Gand.	END								<1	2				

Division	Class	Order	Family	Species	Site codes												
					Col.	0040P1	0040P2	0200P1	0200P2	0400P1	0400P2	0600P1	0600P2	0800P1	0800P2	1000P1	1000P2
<b>Ericales</b>			Ericaceae	<i>Calluna vulgaris</i> (L.) Hull	N			1		9	19					14	17
				* <i>Erica azorica</i> Hochst. ex Seub.	END	54	84	34	24	30	34	14					<1
				* <i>Vaccinium cylindraceum</i> Sm.	END					11	6	13	22	8	16	5	3
			Myrsinaceae	* <i>Myrsine africana</i> L.	N					30	14	18	21	7	36	5	<1
			Primulaceae	<i>Lysimachia azorica</i> Hornem. ex Hook.	END							11	10	3	1	2	4
<b>Fagales</b>																	
			Myricaceae	<i>Morella faya</i> (Aiton) Wilbur	N	14	24	14	24	19	22						
<b>Gentianales</b>																	
			Gentianaceae	<i>Centaurium scilloides</i> (L. fil.) Samp.	N												<1
<b>Lamiales</b>																	
			Oleaceae	<i>Picconia azorica</i> (Tutin) Knobl.	END			14	23								
			Plantaginaceae	<i>Plantago lanceolata</i> L.	NATU	<1											
			Scrophulariaceae	<i>Sibthorpia europaea</i> L.	N												1
<b>Laurales</b>																	
			Lauraceae	* <i>Laurus azorica</i> (Seub.) Franco	END			16	<1	9	41	27	8	14			
				<i>Persea indica</i> (L.) C. K. Sprengel	NATU				<1								
<b>Malpighiales</b>																	
			Hypericaceae	<i>Hypericum foliosum</i> Aiton	END												<1
<b>Myrtales</b>																	

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Division	Class	Order	Family	Species	Col.	Site codes										
						0040P1	0040P2	0200P1	0200P2	0400P1	0400P2	0600P1	0600P2	0800P1	0800P2	1000P1
			Myrtaceae	<i>*Metrosideros excelsa</i> Sol. ex P. Gaertn.	NATU	<1	16	11	3	5	2	19	9	19		
				<i>Psidium littorale</i> Raddi	CAS	<1	<1									
		<b>Rosales</b>														
		Rhamnaceae		<i>Frangula azorica</i> V. Grubov	END				1	<1						
		Rosaceae		<i>Potentilla anglica</i> Laich.	N								1		1	1
				<i>Rubus ulmifolius</i> Schott	NATU		<1									
		<b>Saxifragales</b>														
		Crassulaceae		<i>Umbilicus horizontalis</i> (Guss.) DC.	N	<1	<1									
				<i>Umbilicus rupestris</i> (Salisb.) Dandy	N		<1				9	1				

Site 1 (~40 m) – Serreta lighthouse – Both plots consist of coastal vegetation including monostratified and poor floristic communities, composed almost entirely of *Erica azorica* (around 69% mean cover) (Table 2) and, in a smaller percentage, *Morella faya* (ca. 19%). A few other species, namely *Festuca petraea*, *Hordeum murinum*, *Pittosporum undulatum*, *Myosotis maritima*, *Sagina maritima*, *Metrosideros excelsa*, *Plantago lanceolata* and *Umbilicus horizontalis* are also present, despite covering a minimal percentage of the plots (around 1%). The vegetation has a relatively low stature and the maximum canopy height registered in the plots is 3 m, corresponding to several *E. azorica* specimens.

Site 2 (~200 m) – Canada das Covas, Serreta – These communities are dominated by the exotic *P. undulatum* (64% mean cover), accompanied by *E. azorica*, *M. faya* and *Picconia azorica*. Other tree species such as *Metrosideros excelsa*, *Laurus azorica* and *Ilex perado* subsp. *azorica* are also present in the uppermost vegetation layer. The understory scrub vegetation is quite sparse (around 8%) but also dominated by an exotic species, *Hedychium gardnerianum*, with 2% mean cover. Nevertheless, the ferns *Asplenium onopteris*, *Pteridium aquilinum*, *Dryopteris azorica* and *Polypodium azoricum* are also present, each one covering about 1% of the plots. Plot 2 included a specimen of *Juniperus brevifolia*, a new record for the island at this elevation. Maximum canopy height was 5.6 m.

Site 3 (~400 m) – Carneiro Peak – As in the previous site (site 2, Canada das Covas, Serreta), both plots at this elevation show clear signs of disturbance, with an even higher percentage of *P. undulatum* (68%) dominating the canopy, along with smaller percentages of the indigenous *E. azorica*, *J. brevifolia*, *Morella faya*, *Vaccinium cylindraceum* and the exotic *Metrosideros excelsa* (8%). In the understory, the plots are covered by *Myrsine africana*, *Calluna vulgaris*, *H. gardnerianum* and the pteridophytes *P. aquilinum* and *D. azorica*. In Plot 1 we also registered the presence of *Selaginella kraussiana* (19%). The canopies reached 6.6 m.

Site 4 (~600 m) – Lagoinha Peak – These floristically diverse communities are dominated by *J. brevifolia* (40%), *L. azorica* (34%), *Ilex*

*perado* subsp. *azorica* (33%) and *V. cylindraceum* (18%). *Ilex* specimens reach up to 8 m high in the emergent canopy layer. The most abundant species in both plots' understory layers are *M. africana*, *Lysimachia azorica* and the pteridophytes *Calcuta macrocarpa*, *P. aquilinum* and *Hymenophyllum tunbrigense*. Plot 1 shows a higher taxonomic diversity in the understory, with the presence of five species absent from plot 2. The only species present in plot 2 and absent from plot 1 is *E. azorica*, with 14% total cover.

Site 5 (~800 m) – Lagoa do Pinheiro trail – In both plots, *J. brevifolia* dominates the landscape (73% cover) accompanied by *I. perado* subsp. *azorica*, *V. cylindraceum* and *L. azorica*, completing the canopy line with a maximum height of 4 m. Below the tree line, the main species present are *M. africana*, *L. purpureosplendens* and the ferns *Hymenophyllum wilsonii*, *H. tunbrigense* and *C. macrocarpa*. Plot 1 proved to be more diverse than Plot 2, with three more species, including the Azorean endemic orchid *Platanthera pollostantha* (Bateman et al. 2013).

Site 6 (~1000 m) – Santa Bárbara Mountain – Vegetation is composed almost exclusively by dwarfed, semi-prostrate *J. brevifolia* specimens (occupying around 85% of the plots), growing in dense patches with a maximum height of 1.6 m. Also present in the scrub patches are *C. vulgaris*, *V. cylindraceum* and *M. africana*. The herbaceous layer is mainly composed by *L. purpureosplendens*, *Deschampsia foliosa* and the pteridophytes *C. macrocarpa*, *H. wilsonii* and *Blechnum spicant*. Plot 2 proved to be more diverse than plot 1, containing five more species, with emphasis for the presence of *P. micrantha*. This was the only site in our transect where no exotic species were found, being entirely composed by indigenous taxa.

#### PATTERNS OF RICHNESS AND DISTRIBUTION OF VASCULAR PLANTS

The six elevational sites surveyed resulted in a list of 52 taxa — 2 identified only to the genus level — representing around 8% of all vascular taxa reported for the island. From the 50 species identified, 41 were indigenous species (21 END, 1 MAC and 19 N) and nine were exotic.

There are 11 species present in four or more

elevations along the gradient (Table 2, species marked with an asterisk), showing a broader distribution range than the remaining taxa and accounting for c. one fifth of the total vascular richness along the transect. Six of these 11 species are Azorean endemics (the trees *J. brevifolia*, *I. perado* subsp. *azorica*, *E. azorica*, *L. azorica*, *V. cylindraceum* and the fern *D. azorica*), and four are native to the archipelago (the ferns *B. spicant*, *C. macrocarpa*, and *P. aquilinum*, as well as the shrub *M. africana*) (Silva et al. 2010). Concurrently, there are ten species occurring solely in the gradient's last 200 m, all of which are indigenous, five being endemic. One is the Polypodiopsida *H. wilsonii* and the remaining are all herbaceous Liliopsida, (*Platanthera micrantha*, *Carex echinata*, *C. pilulifera* subsp. *azorica*, *Eleocharis multicaulis*, *Deschampsia foliosa*, *Holcus rigidus*, *Centaureum scilloides*, *Sibthorpia europaea* and *Potentilla anglica*). On the opposite extreme, there are 13 species restricted to the first 200 m, five of which are exotics. However, notwithstanding these clear signs of disturbance, this lower elevational strip exclusively features the endemic "Pau-branco" (*Picconia azorica*), a regionally common but endangered species due to clear-cuts and grazing cattle (Schäfer 2005).

The most diverse plant group along the transect corresponds to the Division Magnoliophyta (the flowering plants or Angiosperms), represented by two Classes: Liliopsida and Magnoliopsida, both present in all sites. Liliopsida's highest diversity is attained at 1000 m (N = 8). Magnoliopsida is the main component of the vascular flora, being more diverse than any other Class in all levels. Maximum diversity is attained at 200 m, with 13 species present (Figure 3).

In the Division Lycopodiophyta (the oldest extant vascular plant division, at around 410 million years old) (Schooley 1997), the Class

Selaginellopsida is represented by only one species (*S. kraussiana*), present between 400 m and 800 m. In the Division Pteridophyta (the ferns), the Class Polypodiopsida is present in all levels except in the lowest (40 m). The highest number of species is attained at 600 m and 800 m, with seven and eight species present, respectively. The Division Pinophyta (the conifers) and its Class Pinopsida have two representatives in this transect (*J. brevifolia* and *C. japonica*). The first one is present from 200 m until the summit of Santa Bárbara mountain and the second one was only identified at 400 m but is not indigenous (Table 2; Figure 3).

As expected, since we selected a priori only native vegetation patches, there is a higher diversity of indigenous (END, MAC and N), rather than exotic (NATU, CAS) species all throughout the transect. In our plots, exotic species richness reaches its maximum at 200 m, being almost negligible (less than 1%) in the remaining elevations and completely absent at 1000 m. Indigenous species are present at every elevation, although their maximum relative richness peak occurs at the highest end of the gradient, between 600 m and 1000 m, where greater number of endemics (both from the Azores and Macaronesia) were found (Table 1; Figure 4).

Indigenous species richness is lowest between 200 m and 400 m, increasing and reaching a plateau in the highest three sites. This pattern does not conform to the existence of a Mid-Domain Effect (MDE) (Figure 5), with the richness peak occurring above the middle of the gradient and the number of species in the 200 m and 400 m sites being quite lower than a fit to the model would require. Similar results were obtained for all the species taken together, including exotics (not shown).

Vascular plants on Terceira Island transect

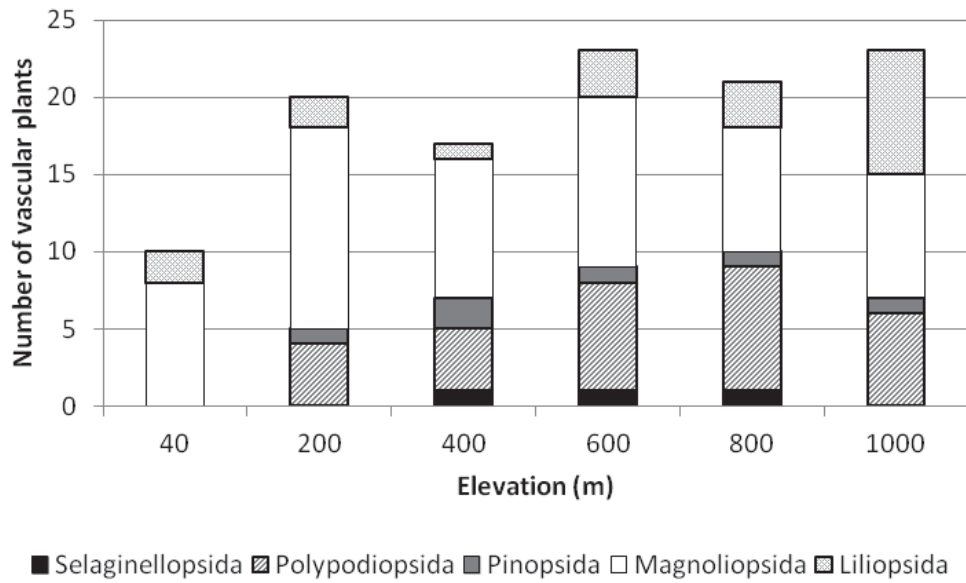


Fig. 3. Number of vascular plants per class at each studied standard elevation.

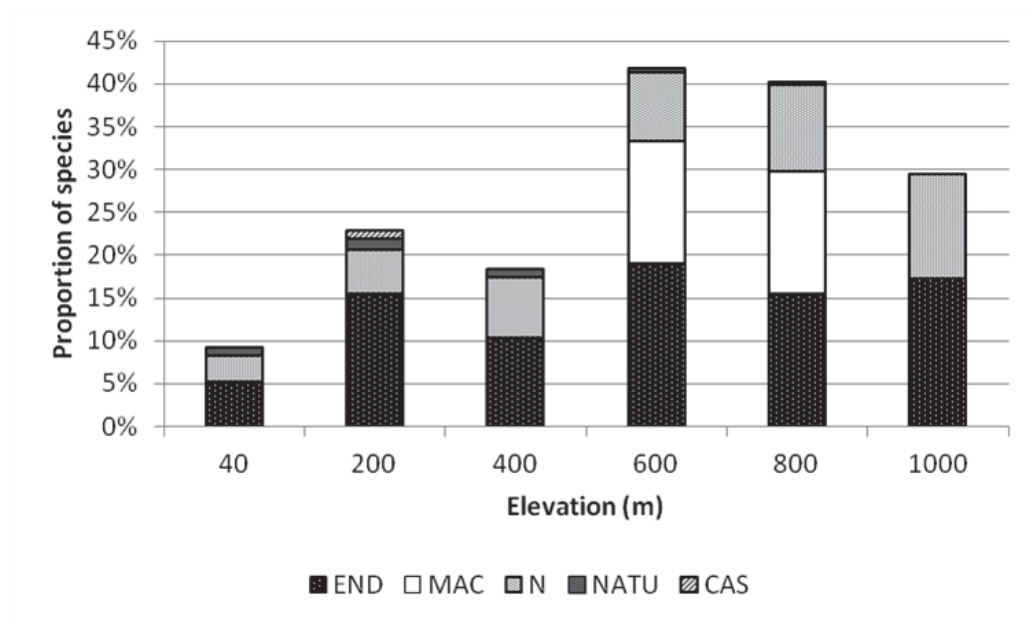


Fig. 4. Proportion of species: indigenous (END, endemic species to Azores; MAC, endemic species to Macaronesia; N, native species); exotic (NATU, naturalized species; CAS, casual species) along the Terceira transect.

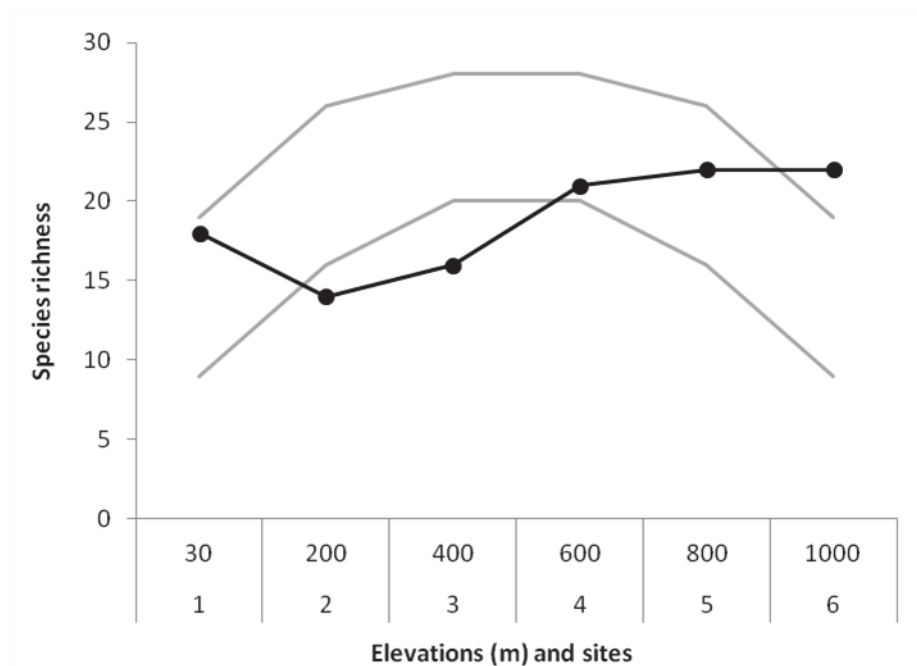


Fig. 5. Mid Domain Effect (MDE) test for the distribution of indigenous species on the Terceira Island transect. The dotted black line represents the observed species richness and the grey lines delimit the 95% confidence interval.

## DISCUSSION

The main objective of this paper was to describe some areas of native vegetation in Terceira with respect to their vascular flora, ascertaining the current richness and distribution patterns of these taxa along the island's elevational gradient. Since environmental trends in elevation are usually reflected in changes in the structure, composition and diversity of the vegetation, it would be expected to find distinct zones along the transect as a response to the increasing elevation. Accordingly, these vascular plants show clear signs of elevational zonation, with a natural layering of various vegetation types occurring at different elevations due to vertical differences in environmental conditions (particularly temperature and precipitation).

The sampled coastal vegetation of Serreta lighthouse (station 1, 40 m a.s.l.) belongs to the *Erica-Morella* Coastal Woodland vegetation belt, as proposed by Elias et al. (2016). Nevertheless,

plot 1 probably corresponds to a coastal scrubland (like the ones described by Dias, 1996) typical of the transition zone between the terrestrial and marine ecosystems (Elias et al. 2016). Plot 2 has a higher canopy height and *Morella faya* becomes more abundant, so this community is more similar to the typical *Erica-Morella* woodlands. Only ten vascular plant species were found among those *Erica* bushes, (the lowest richness value along the gradient), and they also represent one of the lowest heights of the vegetation, possibly as a result of their exposure to the sea winds (cf. Dias et al., 2005). More than a third of the species identified at this elevation are exotic (*H. murinum*, *P. undulatum*, *P. lanceolata* and *M. excelsa*), but are present in fairly low abundances, suggesting this is a somewhat well preserved patch of coastal indigenous vegetation.

At 200 m the vegetation resembles that of highly degraded *Picconia-Morella* Lowland Forest (Elias et al. 2016) dominated by the exotic *P. undulatum*. In fact, besides the presence of *M.*

*faya*, this is the only site where *Picconia azorica* is present in our transect. The species *M. faya*, *P. azorica*, *E. azorica* and *L. azorica* are equally abundant in the landscape, with approximately 20% cover each. At 400 m, we find trees of *E. azorica* and *M. faya* and shrubs of *M. africana* and *C. vulgaris* each occupying around a fifth of the area of each plot. This site is in the *Laurus* submontane forest belt, but nowadays Laurel forests are very rare in their pristine state (Dias 1996, Elias et al. 2016), due not only to the invasion of introduced species (as demonstrated in our plots by *P. undulatum*, *M. excelsa* and *H. gardnerianum*) but also by the conversion of forest to pastureland.

At 600 m, in Lagoinha Peak, we find what seems to be a transition area between the *Laurus* submontane forest and *Juniperus-Ilex* montane forest belts. In fact, according to Elias et al. (2016), this is usually the altitudinal limit between submontane and montane forests. Both kinds of vegetation co-occur in areas of high atmospheric humidity and rainfall with a high degree of soil saturation. In the *Laurus* forests this saturation is sporadic (although moisture content in the soil is permanent), while in the *Juniperus-Ilex* forests the forest floor is often formed by Sphagnum moss carpets, which is more or less constantly saturated (Dias et al. 2005; Gabriel & Bates 2005). *Juniperus-Ilex* Montane Forests are confined to areas of high cloud cover and extremely high humidity, which in most islands can be found above 500 m, whilst *Laurus* Submontane Forests predominate immediately below the permanent clouds (Silva 2007). The vegetation, despite showing signs of transition, can be classified as a *Juniperus-Ilex* formation at its lowest elevational limit. It is represented by *I. perado* subsp. *azorica* trees emerging up to 8 m high above a canopy dominated by *J. brevifolia* and *V. cylindraceum*. The herbaceous ground layer is largely dominated by pteridophytes and, as with all cloud forests, the epiphytic flora is well developed. *Laurus* Submontane Forest vegetation is sparsely represented by *L. azorica* in the canopy and *H. azorica*, *D. azorica* and *D. aemula* in the undergrowth.

At 800 m, alongside the trail to Lagoa do Pinheiro, the vegetation is now fully inside the

*Juniperus-Ilex* Montane Forest belt (Elias et al. 2016) but seems to be an azonal community (probably determined by the presence of thick pumice downfall deposits in the geological substrate and exposure to the westerlies) clearly dominated by *J. brevifolia*. This kind of formation is confined to areas of extreme wetness and strong winds, typically occurring on mountainous areas, where *J. brevifolia* forms a continuous layer (Dias et al. 2005). The epiphytic flora is well developed and bryophytes were found to completely envelop most juniper branches. Finally, in Santa Bárbara mountain, at 1000 m, we find *Calluna-Juniperus* montane scrublands (sensu Dias, 1996) that belong to the *Calluna-Juniperus* altimontane scrubland belt (Elias et al. 2016) with *J. brevifolia* and *C. vulgaris* dominating a superbly well-preserved landscape, with no exotic species. This kind of formation appears on mountain ridges with high amounts of rainfall and strong winds, that force the vegetation to be dwarfed and semi-prostrate (Dias et al. 2005).

This transect, which was intended specifically to cover the best preserved areas of indigenous vegetation in the island for each of the six sampled elevations, managed to encompass 22 endemics (21 species endemic to the Azores and one to Macaronesia) and 19 non-endemic natives, bringing the indigenous richness of vascular plants along the transect to a total of 41 species. Given that the indigenous vascular flora of Terceira adds up to a total of 164 taxa, 58 of which (35%) are endemic to the Azores and seven to Macaronesia (Silva et al. 2010), we managed to sample 25% of the island's indigenous vascular flora in an area corresponding to less than 1% of the island's total surface. Furthermore, only nine exotic species were found, two of them with invasive behaviour (*Hedychium gardnerianum* and *Pittosporum undulatum*), both classified as problematic invasive species in Macaronesia (Silva et al. 2008).

Overall, vascular plant richness increases with elevation up to 600 m and then reaches a plateau in the last three sites (Figure 3). This constant pattern at high elevations is quite rare in the literature. To our knowledge, it was only reported once, for terrestrial ferns in the last 1600 m of a 2600 m elevational gradient in Costa Rica

(Watkins Jr. et al. 2006), showing no significant correlation to any of the explanatory variables examined. In our study, which is based on very few non-randomly selected plots, it might be an artefact of the sampling methodology and disappear with denser sampling.

As expected, the flowering plants, the largest and most diverse group within the kingdom *plantae* (Mauseth 2014) were predominant all throughout the transect, being present at all elevations. Class Magnoliopsida constitutes the majority of the overstory vegetation along the gradient and presents its richness maximum at 200 m (Figure 3). This coincides with the presence of exotic species found in our plots exclusively at this elevation (*Psidium littorale*, *Rubus ulmifolius* and *Persea indica*) on highly disturbed vegetation patches, due to the high degree of human intervention on the landscape. Liliopsida, mostly herbs and grasses, constitute, along with the ferns (Polypodiopsida), most of the understory vegetation of the plots.

Polypodiopsida are more numerous between 600-800 m in the transect, where the high and closed canopies provide their ideal shade and moisture conditions. The same is true for *S. kraussiana* (Lycopodiophyta), also common to wet and shady places, except coastal regions (Schäfer 2005) and present in our transect between 400-800 m.

As for variation in species richness patterns according to their origin, it is worth noticing that more than half (N = 6) of the wider ranged species along the gradient are Azorean endemics (Table 2, species marked with an asterisk). According to Schäfer (2005), many Azorean endemics are characterized by a wide ecological and elevational range and in our transect, all of these show elevational ranges equal to or broader than 600 m, testifying in favour of Schäfer's hypothesis. Nevertheless, their presence is by no means abundant within the island, mostly due to the competition with invasive species like the Himalayan *H. gardnerianum* and the Australian *P. undulatum*.

In comparison with the Pico island transect (Coelho et al. 2016) the Terceira transect captured a lower percentage of the island's indigenous vascular plant diversity (35% for Pico, 25% for Terceira). Bearing in mind that Terceira's

elevational gradient is half the length of Pico's, this difference might be partly due to the fact that Pico's gradient manages to cover a broader set of vegetation types and thus potentially capture more diversity. For example, sub-alpine and alpine scrublands, found in Pico Mountain above 1200 m included two indigenous species (*Daboecia azorica* and *Thymus caespititius*) that were absent from lower elevations. Nonetheless, both transects capture only a small part of the whole indigenous flora (a quarter to a third), which begs for caution against the generalization of the resulting patterns. To complement our findings, we suggest the future establishment of more than one permanent transect per island, which would result in a more comprehensive native vegetation sample.

Also, contrary to Pico's clear richness maximum at 600 m, Terceira's transect yields a richness plateau between 600 m and 1000 m. Despite some composition similarities between the two islands at 600 m (co-dominance of *L. azorica* and *L. perado* subsp. *azorica*, both falling in the *Juniperus-Ilex* montane forests category), Pico's 600 m site has a lower disturbance index than Terceira's (15% against 25%), appearing to be better preserved. Furthermore, comparing both islands, the considerably higher cover of *J. brevifolia* at this elevation in Terceira further supports our assessment that the 600 m site in Terceira is in a transition area between *Laurus* Submontane Forest and the *Juniperus-Ilex* Montane Forest found at 800 m, which could explain the less abrupt decline in richness between 600 m and 800 m when compared with Pico's.

These results support the fact that Terceira's mid-high elevation vegetation patches (from 600 m to 1000 m), much like Pico's (Coelho et al. 2016), are important reservoirs of endemic vascular species richness and are still relatively well preserved. From the coast up to 400 m we find very few remnants of native vegetation due to habitat destruction (caused by human disturbance and forest conversion to pasturelands) and the ones that prevail are being severely modified by the invasion of exotic species. Considering that all our plots fall within the boundaries of Terceira island Natural Park, it is important to keep monitoring vegetation

composition in these areas and take current and future trends into account when evaluating and redefining management and conservation strategies.

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