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Green spaces are not all the same for the provision of air purification and climate regulation services: The case of urban parks

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ABSTRACT

The growing human population concentrated in urban areas lead to the increase of road traffic and artificial areas, consequently enhancing air pollution and urban heat island effects, among others. These environmental changes affect citizen's health, causing a high number of premature deaths, with considerable social and economic costs. Nature-based solutions are essential to ameliorate those impacts in urban areas. While the mere presence of urban green spaces is pointed as an overarching solution, the relative importance of specific vegetation structure, composition and management to improve the ecosystem services of air purification and climate regulation are overlooked. This avoids the establishment of optimized planning and management procedures for urban green spaces with high spatial resolution and detail. Our aim was to understand the relative contribution of vegetation structure, composition and management for the provision of ecosystem services of air purification and climate regulation in urban green spaces, in particular the case of urban parks. This work was done in a large urban park with different types of vegetation surrounded by urban areas. As indicators of microclimatic effects and of air pollution levels we selected different metrics: lichen diversity and pollutants accumulation in lichens. Among lichen diversity, functional traits related to nutrient and water requirements were used as surrogates of the capacity of vegetation to filter air pollution and to regulate climate, and provide air purification and climate regulation ecosystem services, respectively. This was also obtained with very high spatial resolution which allows detailed spatial planning for optimization of ecosystem services. We found that vegetation type characterized by a more complex structure (trees, shrubs and herbaceous layers) and by the absence of management (pruning, irrigation and fertilization) had a higher capacity to provide the ecosystems services of air purification and climate regulation. By contrast, lawns, which have a less complex structure and are highly managed, were associated to a lower capacity to provide these services. Tree plantations showed an intermediate effect between the other two types of vegetation. Thus, vegetation structure, composition and management are important to optimize green spaces capacity to purify air and regulate climate. Taking this into account green spaces can be managed at high spatial resolutions to optimize these ecosystem services in urban areas and contribute to improve human well-being.

1. Introduction

Air pollution and the urban heat island effect are two major problems currently affecting urban areas, being mostly caused by road traffic and urban constructions (Heisler and Brazel, 2010; Karagulian et al., 2015). These environmental problems affect citizen's health causing a high number of premature deaths, and considerable social and economic costs (Lai and Cheng, 2010; OECD, 2016). By 2050, the contribution of outdoor air pollution to premature mortality is estimated to double, reaching 6.6 million premature deaths per year around the world (Lelieveld et al., 2015), and 250 000 annual deaths due to the urban heat island effect are expected if no adaptation actions are taken (WHO, 2014). Thus, effective solutions are needed to ameliorate these problems.

Nature-based solutions can be characterized as actions inspired by, supported by or copied from nature. These solutions, can be used to

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ameliorate air pollution and the urban heat island effect impacts in urban areas, being more cost-effective in the long run than other options (European Union, 2015). Some of the nature-based solutions in urban areas are based on blue-green infrastructures that have been extensively associated with numerous benefits, from reduction of air pollution to population well-being (Jansson, 2014; Liu and Shen, 2014; Tzoulas et al., 2007). Nonetheless, green spaces are not all the same. They can vary in their structural aspects, depending on their components in terms of trees, shrubs and/or herbaceous vegetation. The presence of trees in urban green spaces has been related with improvements in air quality due to trees capacity of removing pollutants from the atmosphere (Nowak et al., 2006). This reduction can occur directly by deposition on the tree surface and/or by stomatal uptake of gases (Niinemets et al., 2014). Due to the shading effect trees have on surfaces and/or the cooling effect of the water they transpire, they can also mitigate extreme air temperatures by changing microclimatic conditions on their surroundings (McDonald et al., 2016). Though these contributions to the amelioration of urban environmental problems are known, more information is needed on the exact vegetation structure, composition and management to enhance air purification and climate regulation services of urban green spaces. Understanding the subtle structural differences in green spaces demands a spatially explicit design, with high spatial resolution. This is needed because atmospheric pollutants, such as particulate matter, and the urban heat island effects can vary in different distance including short distances, such as $<$ 500 m (Hall et al., 1996; Llop et al., 2017; Oke, 2011; Pinho et al., 2012). In addition, a high spatial resolution scale is also helpful to manage and plan urban green spaces with enough detail.

To quantify ecosystem services with high spatial resolution, data needs to be collected with high spatial density. This is not possible using classical monitoring stations for atmospheric pollutants and climate, because there are only a few stations available in urban areas. Ecological indicators or surrogates are a useful tool to overcome these problems (Lindenmayer et al., 2015). They have been successfully used to assess the condition of the environment, to monitor its trends over time, to provide early warning signals of change or to diagnose the cause of environmental problems (Branquinho et al., 2015; Dale and Beyeler, 2001; Lindenmayer et al., 2015; Matos et al., 2015). From the ecological indicators, due to its poikilohydric character, epiphytic lichens (living in trees and completely dependent on atmosphere) have often been used as air quality indicator, as well as, micro and macroclimatic indicators (Koch et al., 2016; Llop et al., 2012; Matos et al., 2015; Munzi et al., 2014; Pinho et al., 2011). These features allow them to be used to measure, with high spatial resolution, air quality and micro and macroclimate. If lichens are collected on the same macroclimatic area and with the same background pollution they will reflect differences in air quality and on climate due to forest characteristics (Santos et al., 2017). In this paper, we use lichen diversity metrics and accumulated pollutants between different types of forest structure, composition and management as surrogates of air purification and climate regulation services provided by the vegetation.

Lichen total species richness and functional diversity are two important biodiversity metrics used to understand ecosystem functioning and its response to environmental factors (Matos et al., 2015; Nash et al., 1990). For more than one century, lichen species richness has been used to measure the effects of strong air pollution in urban areas (Davies et al., 2007; Sérgio et al., 2016). Functional diversity metrics are calculated based on functional traits, which are characteristics of an organism considered to be important to its response to the environment and/or its effects on ecosystem functioning (Díaz and Cabido, 2001). In fact, functional diversity metrics have shown to be more adequate in cases of low levels of pollution or where other environmental factors like the urban heat island effect are more pronounced (Pinho et al., 2016). Llop et al. (2012) also found that functional traits associated with growth form and nutrient requirements were indicators of atmospheric pollution in small urban areas, whereas another work (Munzi et al., 2014) suggested that lichen traits associated with water requirements, namely hygrophytic and xerophytic functional groups, are good indicators of the heat island effect. The main type of photobiont can also be a good indicator of micro and macro climatic conditions (Matos et al., 2015; Pinho et al., 2010). The amount of pollutants accumulated over time in lichens is also a metric frequently used to map pollutants deposition, namely by transplanting lichen thallus to the area of interest (Augusto et al., 2016, 2013; Barros et al., 2015; Prasad, 2001).

The bulk of works using lichens in an urban context focused on evaluating ecosystem services provided by very contrasting land-use types (Coffey and Fahrig, 2012; Munzi et al., 2014; Pinho et al., 2016). By contrast, little attention has been paid to the ecosystem services provided by different vegetation structure, composition and management within green spaces. Knowledge of the type of vegetation that optimizes the provision of certain ecosystem services is needed to design better nature-based solutions for specific environmental problems.

The general aim of our work was to quantify the provision of ecosystem services, air purification and climate regulation, given by different vegetation composition, structure and management types. We used lichen diversity and lichen pollutants accumulation as surrogates of those services provided by vegetation since they are good indicators of air quality and of micro and macroclimate. For that, the work focused in a single large green space with different vegetation types. Species richness and functional diversity metrics based on nutrients requirements, water requirements and main type of photobiont traits, and respective functional groups, were used as biodiversity metrics. Understanding which composition, structure and management types of vegetation better provides air purification and climate regulation will help improve and optimize local planning and management of green spaces for these important ecosystem services in an urban context.

2. Material and methods

2.1. Study site

This work was done in the largest urban green space of Almada, a city located on the western coast of Portugal, and with a population of 173298 residents (INE, 2012). It is characterized by a Mediterranean climate, with north and north-western prevailing winds. The green space selected, “Parque da Paz”, comprises a total of 60 ha and was established in 1997. Inside its area, remnants of the original woodland vegetation were kept and around it multiple vegetation types were planted, including areas with varying tree densities, lawns, temporary and permanent lakes and streams and walk-paths.

2.2. Sampling design

A random stratified sampling was performed to select the sites to characterize pollutants accumulation and lichen diversity inside the green space. Stratification was done by vegetation type, taking into account its structure complexity (6 different types of vegetation): original woodland (complex structure), dense plantations (intermediate structure (trees and herbs), high density tree plantation), sparse plantations (intermediate structure (trees and herbs), low density tree plantation), lawns (simple structure (herbs)), allotments and wetland vegetation. This was done ensuring that a minimum of six sites was placed within each vegetation type. Trees were selected as sampling units because we needed trees to sample epiphytic lichen diversity and to place lichen transplants. Within each vegetation type, trees were selected ensuring a minimum distance between sampling sites. A total of 39 sites were selected for lichen transplants. Lichen diversity was assessed in 29 sampling sites on the same location as transplants, ensuring that trees complied with the requirements for standard lichen diversity sampling. The average distance between sampling sites was 45 m (min 11 m, max 120 m) (Fig. 1).

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Fig. 1. Map of the studied green space showing the sampling sites (lichen transplant and lichen diversity sites) and the main vegetation types (allotments, original woodland, dense plantations, sparse plantations, irrigated lawns, wetland vegetation). The surroundings are occupied by urban fabric with different densities and large roads (dark grey).

2.3. Lichen diversity

Lichen diversity was assessed on the trunk of *Quercus* spp. between 50 and 150 cm above ground, following the standard European method (Asta et al., 2002). A grid divided in four squares of 10 cm each was placed on the four main aspects of the trunk (N, E, S, W), and all lichen species occurring inside the quadrats were identified. Lichen samples requiring microscopic identification were collected and identified in the laboratory. Species nomenclature and ecological preferences for water, nutrients and photobiont type, followed Nimis and Martellos (2008). For species absent from this database, the information was retrieved from a lichen flora (Smith et al., 2009). Species frequency was calculated as the number of quadrats each species was present in. Both measures were taken at site level (each tree sampled). Lichen species richness was considered the number of lichen species per sampling site.

Three lichen traits and respective functional groups were selected for this work based on their responsiveness to air pollution and to the urban heat island effect (Llop et al., 2012; Munzi et al., 2014). Response functional groups comprise a set of species belonging to a common trait with either similar responses to the environment or similar effects on major ecosystem processes (Gitay and Noble, 1997). For the three selected traits, lichens classification into functional groups was based on the ecological indicator values available in Nimis and Martellos (2008) using the maximum value given for each species: i) water requirements (hygrophytic - classes 1 and 2, species present in high moisture conditions; xerophytic species - classes 4 and 5, species present in low moisture conditions); ii) nutrients requirement (oligotrophic - classes 1 and 2, species present in low nutrients content; nitrophytic - classes 4 and 5, species present in high nutrients content); iii) main photobiont type (species with green algae or *Trentepohlia*). Functional groups frequency was calculated as the sum of the frequencies of individual species belonging to each functional group. The water requirements and the main photobiont type functional groups were used to assess climate regulation ecosystem service, whereas nutrient requirements functional groups were used to assess air purification.

2.4. Lichen transplants

Lichen transplants were made from a composite sample of 2 g of air-dry *Ramalina canariensis* (J. Steiner) thalli collected from a location without any known sources of pollutants. The lichen samples were placed in mesh bags previously washed and decontaminated (15 × 9 cm). These were hung in tree branches or trunks at approximately 2 m height. After 3 months of exposure, total metal content was determined after acid digestion. Samples were first dried in an oven at 50 °C for 72 h and its dry weight was determined. Approximately 500 mg of lichens were milled and then mineralized in test tubes with 4 ml of HNO_3 (65%, Merck), on a heating plate at 80 °C. The resultant solution was then diluted with deionized water to a final volume of 7 ml. The concentrations of 9 chemical elements were determined by atomic absorption spectrophotometer (Varian Techtron AA59, Australia): nickel (Ni), cadmium (Cd), iron (Fe), copper (Cu), cobalt (Co), lead (Pb), mercury (Hg), manganese (Mn) and chromium (Cr). Standard samples (BCR 482) and transplant controls (lichens samples not exposed in the study area) were simultaneously analysed to serve as reference for the transplant measures.

2.5. Landscape data

Several landscape variables were calculated to characterize sampling sites. Potential solar radiation (Wh/m^2) was used as a surrogate of microclimatic conditions influenced by topography (Pinho et al., 2010). This variable was calculated using the digital elevation model derived from hypsometric curves with 10 m′ interval. Normalized Difference Vegetation Index (NDVI) was used as a proxy of perennial vegetation density and was obtained from summer satellite images (July 2014, when the annual vegetation is entirely senescent) taken from Landsat 8 (30 m resolution). Vegetation types characterization (inside the green space) was based on manual detailed cartography from photo-interpretation. The areas occupied by each vegetation type around sampling sites, namely original woodland, dense plantations, sparse plantations and irrigated lawns, were calculated considering circular buffers of 25 m. Surrounding land-use areas characterization was extracted from the European Urban Atlas considering buffers of 500 m around sampling sites. The following land cover categories were grouped and considered to classify the areas:

a) Urban dense fabric (sum of): Discontinuous Dense Urban Fabric (S.L.: 50% − 80%); Discontinuous Medium Density Urban Fabric (S.L.: 30% − 50%); Discontinuous Low Density Urban Fabric (S.L.: 10% − 30%); Discontinuous Very Low Density Urban Fabric (S.L. < 10%);
b) Continuous urban fabric;
c) Roads (sum of): fast transit roads and associated land; other roads and associated land;
d) Green spaces (sum of): green urban spaces; sports and leisure facilities; agricultural + semi-natural areas + wetlands; forests;
e) Other sites (sum of): mineral extraction and dump sites; construction sites; land without current use.

2.6. Data analysis

Non-metric multidimensional scaling (NMDS) ordination was performed on a matrix of sampling sites per species frequency. Species frequency was relativized prior to the analysis and was used as % of the frequency of the sum of all species in each site. Bray–Curtis distance measure was used in the NMDS analysis because it is one of the most effective measures for species dissimilarities, and the recommended for community data (McCune et al., 2002). The best NMDS solution was selected from 500 runs, each starting randomly (500 iterations per run), and evaluated with a Monte Carlo test (250 runs with randomized data). Lichen community variability represented by the NMDS axes was determined using the coefficients of determination (r^2) between the original plot distances and distances in the final ordination solution (McCune et al., 2002).

To check whether sampling sites would aggregate into distinct vegetation types based on lichen species composition, we used hierarchical, agglomerative cluster analysis with Bray-Curtis distance and flexible beta method (−0.25). This was also performed on the relativized matrix of species frequency per site. The dendrogram was prune into three groups, given that a higher number of groups resulted in groups composed of only one sampling site. The three resulting groups were used to group sampling sites in the NMS ordination.

Site scores of the first NMDS axis were interpolated to obtain a map of its spatial distribution in the study area. The interpolation was done using inverse distance weighing with a circular neighbourhood, and minimum of 8 and maximum of 16 nearby sites.

The relationship of landscape variables with species ordination was assessed using Spearman correlation coefficients. From the set of landscape variables studied, only those significantly correlated to species ordination are discussed (the rest of the results can be viewed in the Supplementary material Table S1). Individual correlations between landscape variables and diversity variables were determined using Spearman correlations. Correlations were considered significant for $p < 0.05$.

A one-way analysis of variance (ANOVA) was performed to determine if the different types of vegetation influenced lichen transplants metal concentration.

Statistical analyses were performed using STATISTICA 11 (StatSoft, Tulsa, OK, USA) and PC-ORD 6.22 (MjM Software, Gleneden Beach, Oregon, U.S. A).

3. Results

Vegetation types in the green space were characterized according to its structure, composition and management (Table 1). Type of vegetation ranged from a simpler structure in lawns (only with an herbaceous layer) to a more complex structure in the original woodland (with several layers composed of trees, shrubs and herbs from natural regeneration).

Pollutants concentration in lichen transplants showed no significant differences between the different vegetation types, suggesting similar levels of air pollution deposition (Supplementary material Table 2.).

The NMDS ordination plot shows sites distribution in the two first axes (Fig. 2). The analysis recommended two axes (the addition of a third one did not significantly reduce minimum stress), with a final stress of 13.2. Minimum stress of the ordination was lower than expected by chance ($P = 0.004$). Axis 1 explained 61% of the variability in lichen community, while the second axis explained only 24.8% (85.8% in total). The cluster analysis aggregated sampling sites into

Table 1
Summary of the characteristics of vegetation types studied in the green space.

Type of vegetation	Characteristics
Original woodlands	Complex structure (trees, shrubs and herbs layer), natural regeneration, unmanaged, old;
Irrigated Lawns	Simple structure (herbs), seeded, managed (watered, fertilized, frequent mowing), with low density tree plantation;
Dense plantations	Intermediate structure (trees and herbs), high density tree plantation, managed (pruned trees, mowing), recent;
Sparse plantations	Intermediate structure (trees and herbs), low density tree plantation, managed (pruned trees, mowing), recent;

Table 2
Summary of Spearman correlations between landscape variables and the first NMDS axis. Original Woodlands - original vegetation type of vegetation (25 m buffer); Irrigated lawns - grasslands with a few scattered trees type of vegetation (25 m buffer); Dense plantations = Dense plantation type of vegetation (25 m buffer); Sparse plantations - Sparse plantation type of vegetation (25 m buffer); Elevation of sampling points; PSR - Potential solar radiation; Roads - Roads surrounding land-use (500 m buffer); Significant correlations are marked: * - $p < 0.05$; ** - at $p < 0.01$; *** - $p < 0.001$. N = 29.

	Landscape variables	Axis 1
Topo-climatic	Elevation	−0.668***
	PSR	0.523**
Surrounding land use	Roads	0.636***
Types of vegetation	Original woodland	−0.766***
	Irrigated Lawns	0.730***
	Dense plantations	0.251
	Sparse plantations	0.043

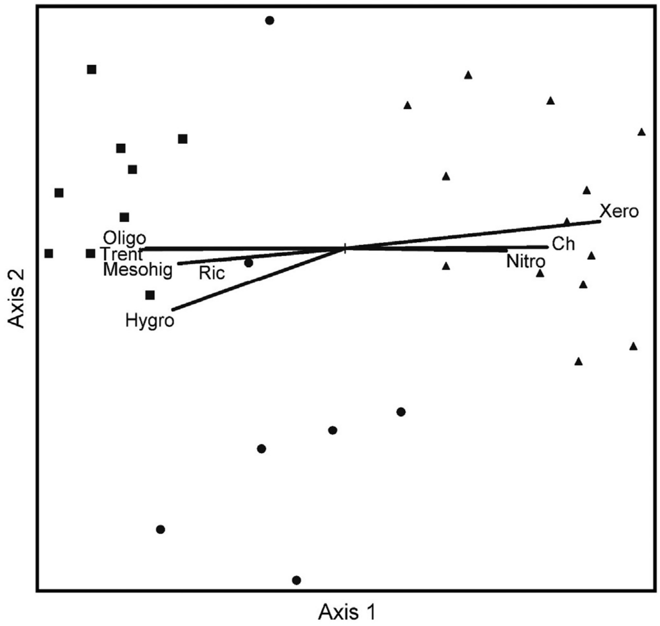

Fig. 2. Non-metric multidimensional scaling (NMDS) analysis of lichen species composition. Only site scores are represented, and different symbols refer to different vegetation types defined by cluster analysis: squares - original woodlands; triangles - irrigated lawns; circles – grouping of sparse and dense plantations. Oligo- Oligotrophic species frequency; Nitro - Nitrophytic species frequency; Hygro - Hygrophytic species frequency; Xero - Xerophytic species frequency; Mesohig - Mesohygrophytic species frequency; Trent – frequency of species with *Trentepohlia* as photobiont; Ch – frequency of species with green algae as photobiont; Ric- Species richness. Final stress of the ordination was 13.2. First axis explains 61% of the variability in lichen community and the second one 24.8%.

three different types of vegetation. These groups were apparent in the NMDS ordination (Fig. 2.), suggesting that the first axis represents a gradient of vegetation complexity with the original woodlands on one extreme and irrigated lawns on the other. Planted woodlands of low and high density represent the intermediate levels along this environmental gradient. Considering that most variability is associated to the first axis, we hereafter assume that this represents the gradient of interest and the second axis will not be interpreted.

All biodiversity metrics were significantly correlated with the first axis of the NMDS. To understand which of these metrics were related to the vegetation complexity gradient driving lichens' community composition differences in the green space, these biodiversity metrics were overlaid in the solution (Fig. 2). Functional groups were clearly separated in terms of their water requirements, nutrients requirements and main type of photobiont. Lichen functional groups with low water and high nutrient requirements (xerophytic, nitrophytic and green algae lichens) were associated with the irrigated lawns, whereas functional groups with high water requirements (hygrophytic), with type of photobiont with *Trentepohlia* (require high moisture conditions to photosynthesize) and low nutrient requirements (oligotrophic) were associated to the opposite side of the gradient in the original woodlands. This was also the side of the gradient associated with higher species richness.

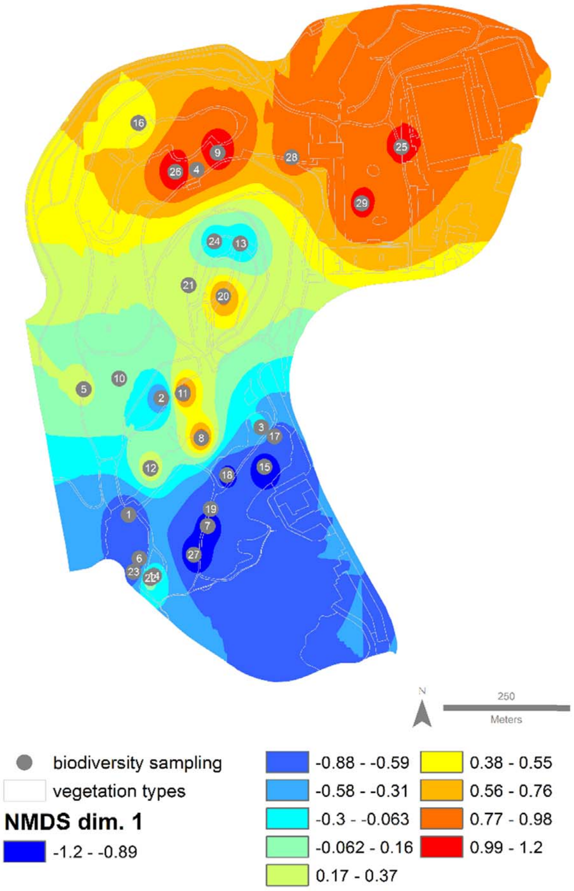

Fig. 3. Interpolation of lichen species non-metric multidimensional scaling first axis site scores. Location of the sampling sites and of different vegetation types are also shown.

Landscape variables were correlated with the first axis ordination scores to identify the main drivers associated with the vegetation complexity gradient reflected by lichen species composition (Table 2). Confirming the results of the cluster analysis, the areas of original woodland and lawns were the types of vegetation significantly correlated with axis scores. The side of the gradient associated with original woodland, was also associated with higher artificial area in the surrounding land-use, and that showing a highest elevation. By contrast, the axis side of the gradient associated with lawns, was more related with areas occupied by roads and exhibiting a higher solar potential radiation.

To facilitate the management of the green space in terms of air purification and climate regulation ecosystem services, the NMDS site scores were interpolated as an integrated representation of these results (Fig. 3.). The map shows clear differences across the green space, distinguishing also spatially lawns from the original woodland areas.

Spearman correlations were calculated to more directly relate landscape variables and the lichen biodiversity metrics (functional groups), enabling a link with air purification and climate ecosystem services (Table 3). Functional groups associated with high nutrient requirements (nitrophytic), low water requirements (xerophytic) and the main type of photobiont (green algae) were positively associated with the area of lawns, with the potential solar radiation (indicator of more xeric microclimatic conditions) and the area of roads occupied in the

Table 3

Summary of Spearman correlations between landscape variables and biodiversity metrics. Oligo - oligotrophic species frequency; Nitro – nitrophytic species frequency; Hygro - hygrophytic species frequency; Xero - xerophytic species frequency; Mesohig - *meso*hygrophytic species frequency; Trent – frequency of lichens with *Trentepohlia* as photobiont; Ch – frequency of lichens with green algae as photobiont; Original Woodlands = original vegetation type of vegetation (25 m buffer); Irrigated lawns - grasslands with a few scattered trees type of vegetation (25 m buffer); Dense plantations - Dense plantation type of vegetation (25 m buffer); Scarse plantations - Scarse plantation type of vegetation (25 m buffer); Elevation of sampling points; PSR - Potential solar radiation; Roads - Roads surrounding land-use (500 m buffer); Significant correlations are marked: * - p < 0.05; ** - p < 0.01; *** - p < 0.001.

		Nutrient requirements		Water requirements		Type of photobiont		Species richness
		Nitro	Oligo	Xero	Hygr	Ch	Tren	-
Topo-climatic	PSR	0,49**	−0,48**	0,46*	ns	0,40*	−0,40*	−0,55**
	Elevation	−0,63***	0,57**	−0,58***	0,52**	−0,55**	0,55**	0,64***
Surrounding land use	Roads	0,41*	−0,46*	0,46*	−0,47**	0,44*	−0,44*	−0,38*
Types of vegetation	Original Woodland	−0,54**	0,66***	−0,65***	0,56**	−0,57**	0,57**	0,46*
	Lawns	0,38*	ns	0,59***	−0,62***	0,65***	−0,65***	−0,58***
	Scarse plantations	ns	ns	ns	ns	ns	ns	ns
	Dense plantations	ns	−0,38*	ns	ns	ns	ns	ns

surrounding land-use. These functional groups exhibited the opposite relation with the area of original woodlands and elevation in the surrounding land-use. By contrast, lichen functional groups associated with low nutrients (oligotrophic), high water requirements (hygrophytic) and with main type of photobiont (*Trentepohlia* algae) were in general positively related with the area of original woodland and elevation. The opposite trend was observed for the area of lawns, potential solar radiation and the area occupied by roads in the surrounding land-use, except for oligotrophic lichens that showed no relationship with lawns. Lichen species richness followed the same general pattern as oligotrophic, hygrophytic and *Trentepohlia* algae lichens. For sparse and dense plantations, there were no significant correlations with the lichen functional diversity metrics, except for low significant negative correlations between dense plantations and oligotrophic species.

4. Discussion

Our results on biodiversity metrics, lichen pollutants accumulation and their relationship with the landscape variables show clearly that green spaces are not all the same and should not be considered homogeneous in terms of the provision of ecosystem services. The structure, composition and management of vegetation in urban green spaces matters for the provision of two ecosystem services: air purification and climate regulation. These services are mainly promoted by patches of original woodland vegetation, already well established, characterized by a complex structure (with trees, shrubs and herbaceous layers), composed of species based on natural regeneration and without any management practices like watering or fertilization.

Lichen traits related to nutrient requirements were used as surrogates of the air purification services that different types of forest provided whereas lichen traits related to water requirements and the main type of photobiont were used as surrogates of climate regulation services. Sites with a higher abundance of epiphytic lichen species with high nutrient requirements and low water requirements were associated with forest that provide lower air purification and climate regulation ecosystem services, respectively. We found that lichen functional groups with low nutrients requirements and high water requirements were associated to the areas of original woodland vegetation, while those more tolerant to high nutrient inputs and to drier conditions were associated with lawns. The original woodland vegetation is characterized by a more complex unmanaged structure, while lawns have a simpler structure and are subjected to management practices such as irrigation and fertilization, suggesting that the complexity, composition and management of vegetation types matters to the provision of ecosystem services. Vegetation types characterized by planted tree species with some management showed an intermediate behaviour between the previous two types of vegetation.

The capacity of climate regulation was also associated with higher densities of trees. However, their positive influence on species more demanding in terms of water requirements and main type of photobiont was only observed in the case of original woodland. Thus, our results agree with previous observation on the capacity of trees to regulate microclimate (Takács et al., 2016; Wang et al., 2015), suggesting that a more mature native and complex vegetation structure, where shrubs and climbers are present is needed to efficiently provide this ecosystem service. Trees have a cooling effect, and this could be the reason for the occurrence of a higher amount of hygrophytic lichen species where tree cover is denser. Also, the presence of lichens with *Trentepohlia* algae in the areas with a more complex vegetation structure supports this conclusion. Trentepohlioid lichens have their optimum photosynthesis in shaded, warm–humid conditions (Nimis and Tretiach, 1995). In fact, a work in the Mediterranean region found this group of species associated to more mesic conditions, namely to less arid areas along an aridity gradient (Matos et al., 2015). The more complex structure in the original woodlands favours more moist conditions, which along with the mild temperatures of the Mediterranean climate promote their development. In addition to the trees role, local orography can also be contributing to climate regulation in original woodlands. Local orography is known to influence vegetation growth, as sites with high potential solar radiation reduce the probability of seed germination and thus the successful establishment of trees and other vegetation (Príncipe et al., 2014). This capacity of local orography to influence climate was also detected in our results, with sites with higher potential solar radiation presenting more lichen species with low water requirements, thus indicating more xeric conditions. In this green space, local orography was in fact rebuilt, except for the original vegetation area. Thus, both the vegetation structure and local orography can be used to optimize the local provision of climate regulation ecosystem services in urban green spaces.

Air purification service was also associated to vegetation types. Lichen functional group with low nutrients requirements was associated to forest areas with a more complex vegetation structure while the ones with high nutrients requirements were associated to lawns. This was also supported by the positive association found between lichen species with high nutrients requirements and the area of nearby fast-transit roads. This is in agreement with previous works that associated this type of lichen functional group to particles and nitrogen enriched dust pollution (Pinho et al., 2008a, 2008b). Total species richness was also negatively associated with fast-traffic roads. Species richness is commonly used as an ecological indicator of high levels of pollution (Llop et al., 2012; Pinho et al., 2004), and in this case, is probably responding to the overall pollutants load. The air purification service observed in our work may be linked with the capacity of trees to reduce pollution loadings (Santos et al., 2017). Though lichen metal concentrations measured in transplants did not significantly differ between vegetation types, a tendency of higher metal deposition in original woodlands and dense plantations was observed. In fact, the presence of trees, whether planted or native, showed always to positively influence the functional groups with low nutrients requirements, given that a layer of dense tree cover was present. This conclusion is supported by other authors observations that trees can reduce air pollutants in urban areas (Mcdonald et al., 2007; Nowak et al., 2014; Santos et al., 2017). This capacity of tree vegetation to remove air pollution particles might also have been enhanced by the green space orography. Despite these results, lichen pollutants concentration had no influence on lichen biodiversity metrics patterns. The concentrations observed in lichen transplants cannot be directly related to law-binding values for health, the values found in our work reflect low concentrations in the atmosphere. In fact, local atmospheric quality stations registered pollutants concentrations well below critical thresholds for human health (Munzi et al., 2014), confirming that background pollution in the city is quite low. Nonetheless, though the pollutants measured showed no relation with lichen biodiversity metrics, other gaseous pollutants from traffic, such as SO_2 or NOx or NH_3, might be responsible from the patterns observed. These pollutants, should arrive mainly from nearby roads surrounding the park, except South (see Fig. 1). Thus, although the different land-cover types are somewhat clustered, any incoming pollution should potentially reach all sites similarly. This is reinforced by the lack of relationship between land-cover types and metals concentration measured in lichens.

4.1. *Main findings*

Overall, we observed that vegetation structure, composition and management matters to the provision of air purification and climate regulation ecosystem services, reinforcing the idea that green spaces cannot be considered homogeneous in the provision of ecosystem services. Managed and less complex vegetation types (lawns and planted woodlands) presented a lower capacity to provide air purification and climate regulation, indicating that the presence of a complex structure is essential to provide these ecosystem services. Vegetation composition and local orography also showed to be important to this provision.

Our work shows very clearly that vegetation structure, composition and management should from now on be used to improve local climate and air quality, thus highlighting the capacity of green spaces to become important nature-based solution to urban heat island effect and air pollution and ultimately improve human well-being.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.envres.2017.10.006.

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