Environmental Research 160 (2018) 306–313

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

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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ARTICLE INFO

Keywords:
Environmental management
Air pollution
Urban heat island effect
Cities
Lichen traits

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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http://dx.doi.org/10.1016/j.envres.2017.10.006
Received 7 December 2016; Received in revised form 22 August 2017; Accepted 4 October 2017
Available online 15 October 2017

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).