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Research Paper

Assessing how green space types affect ecosystem services delivery in Porto, Portugal

Marisa Graça[a,b,*], Paulo Alves[a], João Gonçalves[a,b], David J. Nowak[c], Robert Hoehn[c], Paulo Farinha-Marques[a,b], Mario Cunha[b,d]

[a] Research Center in Biodiversity and Genetic Resources (CIBIO/InBIO), University of Porto, Campus Agrário de Vairão, Rua Padre Armando Quintas, n° 7, 4485-661 Vairão, Portugal

[b] Faculty of Sciences of the University of Porto, Rua do Campo Alegre, s/n, 4169-007 Porto, Portugal

[c] Northern Research Station, USDA Forest Service, 5 Moon Library, SUNY-ESF, Syracuse, NY 13210, USA

[d] Centre for the Research and Technology of Agro-Environmental and Biological Sciences, Campus Agrário de Vairão, Polo do Porto, Rua Padre Armando Quintas, n° 7, 4485-661 Vairão, Portugal

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ABSTRACT

Significant advances have been made in identifying, quantifying and valuing multiple urban ecosystem services (UES), yet this knowledge remains poorly implemented in urban planning and management. One of the reasons for this low implementation is the insufficient thematic and spatial detail in UES research to provide guidance for urban planners and managers. Acknowledging how patterns of UES delivery are related with vegetation structure and composition in urban green areas could help these stakeholders to target structural variables that increase UES provision. This investigation explored how different types of urban green spaces influence UES delivery in Porto, a Portuguese city, and how this variation is affected by a socioeconomic gradient. A stepwise approach was developed using two stratification schemes and a modelling tool to estimate urban forest structure and UES provision. This approach mapped explicit cold and hotspots of UES provision and discriminated the urban forest structural variables that influence UES at the local scale. Results revealed that different types of green spaces affect UES delivery as a direct result of the influence of structural variables of the urban forest. Furthermore, the uneven distribution of green spaces types across socioeconomic strata alters UES delivery across the city. This case study illustrates how a methodology adaptable to other geographic contexts can be used to map and analyze coupled social and ecological patterns, offering novel insights that are simple to understand and apply by urban planners and managers.

1. Introduction

Recent research has highlighted the capacity of urban ecosystems to provide critical benefits for human wellbeing, and the need to take them into account in urban planning (Gomez-Baggethun & Barton, 2013; Haase et al., 2014). The ecosystem services (ES) concept emerged as a holistic approach that explicitly recognizes these benefits, while integrating the management of biodiversity, natural resources and human needs (Haines-Young & Potschin, 2010). As such, various authors have adopted the ES framework in urban studies to provide relevant insights for urban planning and policy strategies (Ahern, Cilliers, & Niemelä, 2014; McPhearson, Hamstead, & Kremer, 2014). Addressing the local delivery of ES is particularly important in adaptive urban planning, as some benefits crucial for human wellbeing are locally derived, such as rainwater drainage, microclimate regulation, improvement of air quality through pollution removal, noise reduction and recreation (Bolund & Hunhammar, 1999). Urban green areas provide many of these ES, and thus their potential to contribute to human wellbeing in cities is being increasingly acknowledged (De Vries, van Dillen, Groenewegen, & Spreeuwenberg, 2013; Tzoulas et al., 2007).

Several examples illustrate how multiple urban ecosystem services (UES) have been identified, quantified and valuated to inform stakeholders and support decision-making processes (Derkzen, Teeffelen, & Verburg, 2015; Kabisch, 2015; McPhearson, Kremer, & Hamstead, 2013). However, this growing body of knowledge remains poorly implemented in actual urban planning and management (Haase et al.,

* Corresponding author at: Research Center in Biodiversity and Genetic Resources (CIBIO/InBIO), University of Porto, Campus Agrário de Vairão, Rua Padre Armando Quintas, n° 7, 4485-661 Vairão, Portugal.

E-mail addresses: graca.marisa@fc.up.pt (M. Graça), paulo.alves@fc.up.pt (P. Alves), jfgoncalves@fc.up.pt (J. Gonçalves), dnowak@fs.fed.us (D.J. Nowak), rhoehn@fs.fed.us (R. Hoehn), pfmarque@fc.up.pt (P. Farinha-Marques), mcunha@mail.icav.up.pt (M. Cunha).

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2014; Kabisch, 2015; Kremer et al., 2016). One of the issues contributing to this gap is the lack of sufficient thematic and spatial detail in UES research to provide guidance for urban planning and design (Derkzen et al., 2015). Furthermore, there is a scarcity of studies aiming to analyze urban ecosystems at finer scales, addressing for example, variations in type and function of existing urban green areas (Haase et al., 2014), though some exceptions should be noted (e.g. Derkzen et al., 2015). Yet, different types of urban green areas such as public parks, domestic gardens or wasteland are heterogeneous and reflect diverse social needs and values that affect their performance in terms of UES delivery. These social needs and values are displayed through personal preferences of landowners and other stakeholders in the design and management of private green spaces, as well as strategies and policies defined by public institutions (Andersson, Barthel, & Ahrne, 2007). Selection and maintenance of vegetation in cities mirrors this human influence conspicuously, given its relevance as a major component in the design of urban green spaces (Grove et al., 2006).

Several studies have also exposed links between the spatial variability of UES delivery within the urban fabric and environmental inequity (Escobedo et al., 2006; Escobedo, Clerici, Staudhammer, & Corzo, 2015; Graça et al., 2017; Jenerette, Harlan, Stefanov, & Martin, 2011; Pedlowski, Da Silva, Adell, & Heynen, 2002), even if sometimes authors do not explicitly use the ES framework (Romero et al., 2012). To our knowledge, it remains largely unexplored how such environmental injustice can be mitigated through the proper planning of green spaces. Moreover, Luederitz et al. (2015) highlight as a key challenge for UES research the low transferability of data between contexts, especially in complex urban settings with heterogeneous socioeconomic and ecological backgrounds. This issue adds to the difficulties in providing orientations for urban planners and managers, and underlines the need to develop methodologies that can address local specific conditions and processes. Such process based knowledge is crucial to reveal unique patterns of UES delivery, as well as more generalizable trends already observed in other cross-city comparisons, both of which can contribute to effectively unravel drivers of ecosystem structure, functioning and dynamics (Kremer et al., 2016).

As a key provider of UES, vegetation holds a great potential to enhance urban resilience (Bolund & Hunhammar, 1999; Weber, 2013; Yapp, Walker, & Thackway, 2010). It is, however, necessary to better understand the ecological impacts of vegetation type and structure in cities. Previous research has shown, for example, that species assemblage and functional characteristics of vegetation affect ES provision (e.g. Lundholm, MacIvor, MacDougall, & Ranalli, 2010). In addition, structural variables of the urban forest such as tree density, size and condition impact ecosystem functions such as air pollution removal, carbon sequestration and rainfall interception, thus influencing UES supply (Nowak & Dwyer, 2007). However, trees also emit biogenic volatile organic compounds (BVOC) that can contribute to the formation of ozone (O_3). Some species emit more BVOC than others and their emission rate can be further increased by higher temperatures, potentially degrading air quality especially in an urban heat island context (Calfapietra et al., 2013). Controversy persists regarding the real effect of trees in air quality (Setälä, Viippola, Rantalainen, Pennanen, & Yli-Pelkonen, 2013), supporting the need for more research. Some authors argue, for example that trees reduce air circulation in street canyons, consequently trapping pollutants and decreasing air quality (e.g. Vos, Maiheu, Vankerkom, & Janssen, 2013), while others suggest beneficial effects of trees for mitigation of air pollution (e.g. Irga, Burchett, & Torpy, 2015). Nevertheless, vegetation type and design seem to have a significant role in determining the effect in air quality (Gromke & Ruck, 2007; Janhäll, 2015).

Trees influence microclimate through evapotranspiration, shading, modified air movements and heat exchange, which also affect the urban atmosphere; moreover, urban vegetation intercepts rainfall and reduces water runoff and floods, which avoids stormwater treatment costs and damages (Nowak & Dwyer, 2007). These benefits rely on the structure and composition of vegetation, and are crucial for regulating the urban environment. Thus, acknowledging how vegetation structure and composition in urban green areas affect delivery of regulating UES could help urban planners and managers to target structural variables that enhance their provision. Adaptive design and management of urban green areas could therefore be addressed to explicitly enhance the provision of these UES and help in the implementation of the EU Strategy for Green Infrastructure (European Commission, 2013), as well as to tackle environmental inequities and to promote urban resilience.

However, few studies exist on how choices regarding vegetation use may affect the supply of regulating UES (though some exceptions should be noted, such as Hayek, Neuenschwander, Halatsch, & Grêt-Regamey, 2010; Hunter, 2011; Morani, Nowak, Hirabayashi, & Calfapietra, 2011). Likewise, comparative research concerning UES distribution within the urban fabric has not yet focused upon a full suite of designed types of urban space rather than vegetation types such as trees, shrubs and herbaceous (e.g. Derkzen et al., 2015). This paper aims to explore how different types of urban green spaces influence delivery of regulating UES in Porto, Portugal. The research was designed to answer the following questions:

- How are urban green types distributed in Porto in relation to socioeconomic patterns, and how does this distribution affect UES provision?
- Which structural variables of the vegetation differentiate the urban green types, and how do they impact UES delivery?

The purpose of the research was to assess social-ecological patterns affecting UES provision, with the central objective of identifying key variables that could be targeted through urban planning, planting design and management of green spaces to enhance UES.

2. Methods

2.1. Study area

The municipal limits of Porto, a major urban center of Portugal, were used to define the study area in this research (Fig. 1). This municipality covers 41.4 km^2 with 237 591 inhabitants in 2011 (INE, 2011), and it is the nucleus of a metropolitan area comprised of 17 municipalities with 1 759 524 inhabitants in the same year (INE, 2014). Porto is bordered by the Atlantic Ocean at west, and Douro River flowing through the southern limit of the city. The climate is Mediterranean (Csb climate, according to Köppen-Geiger classification), with mild seasons (temperatures typically oscillate between 5.0–16.8 °C in winter and 13.8–25.0 °C in summer) and annual precipitation that averages 1 254 mm (usually occurring from October to April) (IM, 2011). The study area contains a variety of fragmented and discontinuous green areas dispersed throughout the built-up matrix, which reflect the intensity of urban sprawl in the last century (Madureira, Andresen, & Monteiro, 2011). Yet, the singular combination of climate and geographic context have contributed to the establishment of a rich native and non-native flora.

2.2. Classification and distribution of urban green typologies in Porto

In this investigation, green spaces refer to urban areas with more than 35% of vegetated area, including patches with a minimum threshold of 800 m^2, and alignments of street trees (see Appendix A for a synthesis of criteria used for this classification). The classification of green areas was developed by adapting an existing survey and criteria from Farinha-Marques et al. (2011, 2012) to obtain a spatially explicit representation of the eight categories of green spaces found in Porto: *Agricultural areas*, *Allotments & urbanizations*, *Civic & institutional*, *Motorways & tree-lined streets, Private gardens & backyards*, *Parks, public*