Solar suitability maps for tropical plants – a decision support tool for botanic gardens

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Abstract

Tropical plants, like every other plant, require certain conditions for a healthy growth. For instance, a certain temperature range, an amount of solar irradiation, either direct or diffuse, and a range of humidity, among other parameters, are typical for a certain species. When the plants must live far away from their natural habitat, as is the case of those in botanical gardens in Europe, a decision must often be taken about the best place in the garden to locate new plant species. Despite the relevance of other ecological factors, such as temperature, humidity and soil characteristics, solar irradiation is a decisive factor in tree growth. However, the interaction from existing trees, shadowing the available ground and changing from spot to spot, along the day and along the year, affects the available sunlight as well as temperature and humidity, both above and below-ground. In this work, using the Tropical Botanic Garden, in Lisbon, as case-study, the yearly global solar irradiation is calculated using the SOL algorithm over LiDAR data, and the Photosynthetically Active Radiation (PAR) is mapped.

Keywords: garden management, tree shadowing, SOL algorithm, PAR.

1 Introduction

Planting new tree species in urban green spaces, such as existent botanical gardens or public gardens requires a thorough planning to meet the space and climatic requirements of the plant the best possible way in a place that does not correspond to the plant's native habitat. Since species require, among other, different temperature, humidity and light ranges to grow, garden management needs decision supporting tools for settling new trees among the existent, considering the conditions in the available ground in the intervals of already standing trees and shrubs. Habitat suitability models have been widely used in biodiversity conservation to support planning and decision making. However, based on digital maps, they miss important features such as the ecological structure. In the last years, the potentialities of LiDAR data in filling this gap are being used to underpin threatened species conservation programmes (Tattoni et al., 2012), and its use in plant conservation is becoming increasingly important.

One of the key factors for plant growth is how much solar irradiation hits the place along the year. This depends on the sun position on its sky path along the year, but also on the local distribution of shadow casting objects (relief, trees, buildings, other man-made constructions) which define, in addition, the local horizon at each spot, limiting the amount of the sky dome seen from the spot (sky view factor – SVF). The global solar irradiation can be modelled as the sum of direct and diffuse radiation. Shadows affect the direct parcel while the SVF affects the diffuse one. Solar irradiation maps of the gardens, or other green spaces, showing yearly global, direct and diffuse irradiation are, therefore, important information from which the Photosynthetically Active Radiation (PAR) can be derived for correlating with plant light needs. PAR maps, considering light requirement classes (from shade-tolerant to shade-intolerant species), can be built, providing fundamental data to decision support in tree species selection. This is particularly important in improving botanical gardens collections where rare and threatened species are frequently preserved, and the best ecological conditions should be ensured.

The present work is part of a wider project aiming a spatial-temporal study of the plant collection in the Tropical Botanical Garden of the University of Lisbon, which presents the particularity of comprising, mainly, tropical and subtropical plants with economic interest and hosting about fifty threatened species in a total area of 70000 square meters.

The Mediterranean climate of Lisbon, Portugal, with mild and rainy winters and warm and sunny summers, is particularly suited to a number of tropical and subtropical species, that can be grown in open-air, providing other factors, specially the low-temperature range limit, are met.

2 Methodology

An aerial LiDAR data set obtained in August 2016, with a density of 12 points/m^2, was the source for the geometric description of the Tropical Botanical Garden. A Digital Surface Model (DSM) with a 0.5m resolution was generated for the area of the garden using ArcMap 10.5.1 LAS dataset tools (ESRI, 2018). A layer with ground points was created for later identification of the study areas of interest, since only ground areas free from tree vegetation come into question.

The solar radiation algorithm SOL (Redweik et al., 2013) was applied to the DSM with a time resolution of one month. Monthly mean values for hourly global and diffuse horizontal irradiation were used, calculated from the Solterm database corresponding to a typical meteorological year (TMY) (Aguiar, 1998). The results consist on maps for yearly global, direct and diffuse solar irradiation of the garden with a spatial resolution of 0.5m as well as a SVF map with the same resolution. PAR maps are derived from the global irradiation maps showing the part of the solar irradiation in the visible range (light) which can be used by plants for photosynthesis. The relation between PAR and global irradiation is not constant since it depends on the sun elevation and cloud amount. Yearly PAR can be calculated summing the daily PAR, *PAR(d)*, along the year, which, in turn, results from equation (1).

$$PAR(d) = G(d) * f(d)_{PARG}$$

$$f(d)_{PARG} = \frac{a + b * \frac{B(d)}{D(d)}}{1 + \frac{B(d)}{D(d)}} \quad (1)$$

where *G(d)* stays for the daily global irradiance (irradiation per square meter) on a surface, *B(d)* for the daily direct irradiance on the surface, *D(d)* for the daily diffuse irradiance on the surface, and *a, b* are empirical parameters with reference values of *a*=0.60 and *b*=0.42 (JRC-IPSC, CRA-CIN,2009). A value of 0.51 was applied as an approximation of the converting factor between yearly PAR and yearly global irradiance. In the future steps of the project, PAR will be calculated hourly and integrated for a year.

PAR classes have been defined for an easier correlation with light requirements of species.

3 Results and future work

Global solar irradiance (Fig. 1), SVF (Fig. 2), and PAR maps (Fig.3) were generated. PAR maps show the available ground areas classified in 4 classes.

These maps can be used to support site selection for species plantation concerning solar irradiation requirements, not only for full sun species but especially for those species that require lower levels of irradiance and some level of shadowing provided by neighbouring trees. In fact, the high number of trees, many of them with very large crown size, that constitute the species collection already existing in the Tropical Botanical Garden (Figs. 2 and 3), makes shade-tolerant species the best candidates for improving the collection.

Figure 1: Yearly global solar irradiance (Wh/m2) in the Lisbon Tropical Botanical Garden. Boundary in green.

Figure 2: SVF in the Lisbon Tropical Botanical Garden; varies from 0 to 1 (completely obstructed to completely unobstructed view of the sky dome, respectively).

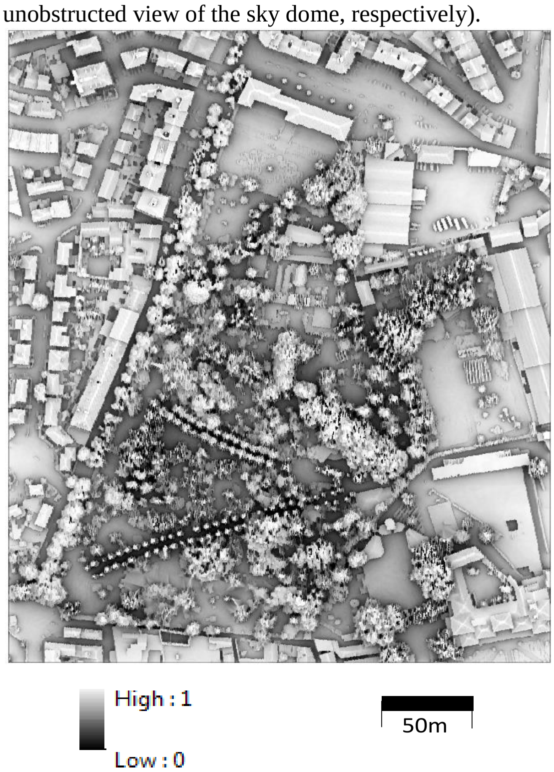
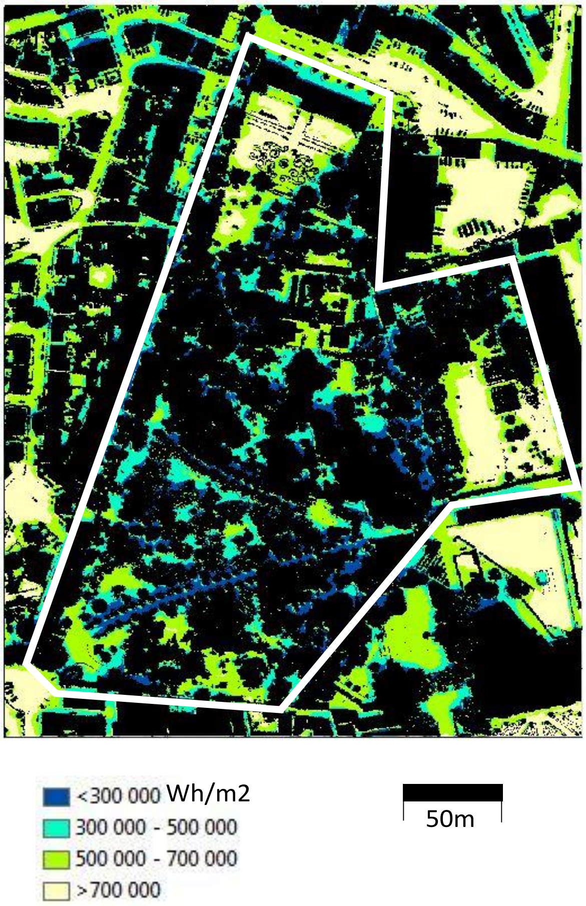


Figure 3: Yearly PAR classes (Wh/m2) in available ground in the Lisbon Tropical Botanical Garden. Boundary in white.



Though a high number of environmental factors (atmospheric and edaphic) are crucial to plant growth, these maps provide an accurate way to establish quantitative classification criteria of both the fraction of sky visible from the ground up and the irradiance/light values otherwise only possible by the empirical experience of garden managers.

Future work will focus on environmental factors, such as the annual solar irradiance variation and the traits of surrounding vegetation (e.g. evergreen vs deciduous plant species) that affect the total amount of PAR in each location and on the extension of the methodology for other growth relevant criteria, like temperature and humidity to improve the knowledge about species suitability and generate maps as tools for management of botanical gardens or other man-made plantations.

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