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Short Paper
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Urban Trees in Sync with Urban Climate – Phenology and Microclimate Monitoring using Geocommunication and Citizen Science

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Abstract

In this paper, we demonstrate environmental monitoring in a young citizen science project. The dynamics of urban tree phenology and microclimate regulation throughout the growing season is measured in a cross-city approach, along intra- and inter-urban gradients and for a set of the most common urban tree species. We equipped urban trees in five European cities with beacons that connect via Bluetooth to a tailor-made app. The app is used for phenological monitoring, to display microclimate measurements, and to broadcast information on the trees' microclimate-regulating ecosystem services. The approach and setting are scalable to other citizen-engagement and VGI projects. It fosters an understanding of how urban trees are in sync with urban climate, and deepens our understanding of systemic feedback, which is key for implementing urban tree management. Results show inter-species differences in the length of the growing season as measures of the delivery of regulatory ecosystem services and as responses to urban heat island intensity.

Keywords:

phenology; regulating ecosystem services; beacons; app; microclimate monitoring

1 Introduction

'Smart city' visions usually revolve around smarter and more sustainable technology, lifestyle and consumption, and less around the smart city as a socio-ecological system. Multifunctional green space systems are pivotal for addressing major challenges of urbanization, and public awareness of the societal benefits of urban green spaces should be increased (Pauleit et al., 2018). The provision of urban ecosystem services is an often-unseen information layer, although climate regulation is amongst the most important of ecosystem services at the local and neighbourhood levels (Bolund & Hunhammar, 1999). Climate regulation is usually captured in aggregate metrics, such as carbon sequestration, air filtering and air cooling, on an annual basis. The dynamics of phenology and climate regulation throughout the growing season, along intra- and inter-urban gradients, and comparing the most common urban tree species is a novel approach presented in this paper (cf. Endreny, 2018). To address our research objectives, we used both human observers and technical sensors for geodata collection and geocommunication. Bluetooth beacons and an app were used to embed urban trees, as carriers of ecological processes and functions underlying climate-regulating ecosystem services, in the smart urban fabric. Ultimately, data collected by means of citizen engagement and VGI should help to better understand and improve urban tree management.

We demonstrate an application of environmental monitoring in a young citizen science project. Volunteered geographic information was used to geocommunicate the dynamics of urban trees' ecosystem services in five European cities (Dresden, Mülheim, Salzburg, Szeged and Weer). These cities represent an intra-European, temperate climate gradient from dry continental to sub-Atlantic. The approach and setting are scalable to other citizen-engagement projects, e.g. urban tree stewardship by citizens.

2 Material and methods

Monitoring existing trees in a city is a unique opportunity to gain a better understanding of the mutual influences of urban microclimate and urban trees, and for implementing this understanding in management tools. The environmental education perspective outlined in the Introduction means that monitoring trees is important in addressing major challenges of urbanization. From a research perspective, gaining information about urban trees that are adapted to climate change is valuable for improving urban tree management.

2.1 Tree selection

The urban tree stock is characterized by many individuals of a limited number of species (Morgenroth et al., 2016). And of this limited number of species, few are considered capable of withstanding the projected future urban climate (Roloff, 2016; Vogt et al., 2017). Our objectives were to identify a number of urban tree species that occur frequently in the publicly owned and managed tree stock and are considered to be suitable under urban climate change scenarios. For the preselection of tree species for the study, the tree cadastres of Salzburg, Vienna and Dresden were analysed for frequency of species and age structure (the occurrence of trees of around 20 to 40 years old).

Next, we evaluated the subset of species according to the Citree database planning tool (Vogt et al., 2017) to ensure that these pre-selected tree species are suitable in cities now and for the future. The most important criteria for this suitability are drought tolerance, hardiness, heat tolerance and late frost tolerance.

For the phenological monitoring and microclimate measurements, we selected four species (91 individuals) which grow in at least two of the chosen cities and which, according to the Citree database, are very likely to cope with ongoing climate change (Table 1).

Table 1: Selected tree species for the phenological monitoring.

Species	Drought tolerance	Hardiness	Heat tolerance	Late frost tolerance	Trees	Beacons
Turkish Hazel *(Corylus colurna)*	suitable	very suitable	medium	little	18	16
Little-leaf linden *(Tilia cordata)*	suitable	very suitable	medium	good	32	27
Horse chestnut *(Aesculus hippocastanum)*	not very suitable	suitable	little	medium	16	14
Norway maple *(Acer platanoides)*	suitable	very suitable	medium	good	25	21
Sum					91	78

78 of the trees were equipped with a beacon to run the microclimate measurements and to broadcast information.

2.2 Spatially-enabled web app

A core element for the data collection was phenological monitoring using a web app. To communicate the results in near real time, our smart urban trees were equipped with beacons carrying microclimate sensors and that communicated with the app via Bluetooth. The young citizen scientists used the app to collect data and for geocommunication. As demonstrated by Hof et al. (2018), the app ensured that all data was identified by tree species, tree location (x and y coordinates), and beacon ID. The app was tailor-made and based entirely on open-source software. The front-end is an easy-to-use interface for data collection and website access via mobile devices. Behind is a database designed to store the phenology observations and the microclimate data. Each tree had its own website where content created by the students or the project team (e.g. diagrams, photos or maps) could be presented. The aim here was to create awareness about the local microclimate-regulating ecosystem services of urban trees. The app (currently for Android OS) scans for beacons in the environment and calls the tree websites. App, database and beacons create the technical setting for an innovative citizen science and VGI environment in which urban trees become smart, equipped with sensors that measure their microclimate, and broadcast information on these ecosystem services for display in the app.

2.3 Phenological monitoring

The workflow for the springtime phenological monitoring can be completed in a few minutes of dedicated time. The app replicates the study design described by Wesołowski & Rowiński (2006) and includes looking at ten end buds (randomly selected by the observer) in the southern part of the upper tree crown and keying in a score for the bud development stage. Regulating ecosystem services are provided to the full by the tree as soon as its leaf development is complete. This score on a scale of three levels (0, 1 and 2) is represented by photographs showing the stage of bud development for the specific species. For each of the ten buds selected, the young citizen scientists clicks on the photograph which is closest in appearance to the bud (there are 3 photographs to choose from). The app then calculates the bud development score and sends it to the database (Figure 1). This procedure is repeated every two to three days. Springtime monitoring ends once the sum of all the bud scores for a tree reaches the value of twenty at full foliage stage.

The length of the growing period reflects the inter-species dynamics of regulating ecosystem service provision of the urban tree stock. We hypothesized that these dynamics would show a pattern that was related to urban heat island intensity (cf. Endreny, 2018). To test this, further phenological monitoring was conducted during autumn 2018. Following and adapting the methodology described in the teaching and learning materials of the EU COMENIUS Project BEAGLE (Biodiversity Education and Awareness to Grow a Living Environment) (Batorczak, 2010), 4 scores were used:

(0) All leaves are still green
(1) Leaves are starting to change colour and/or losing first leaves
(2) 50% of the total number of leaves have changed colour and/or 50% have fallen
(3) All leaves have changed colour or all leaves have fallen

The autumn monitoring was done at weekly intervals that started on 13 September 2018 and ended on 27 November 2018.

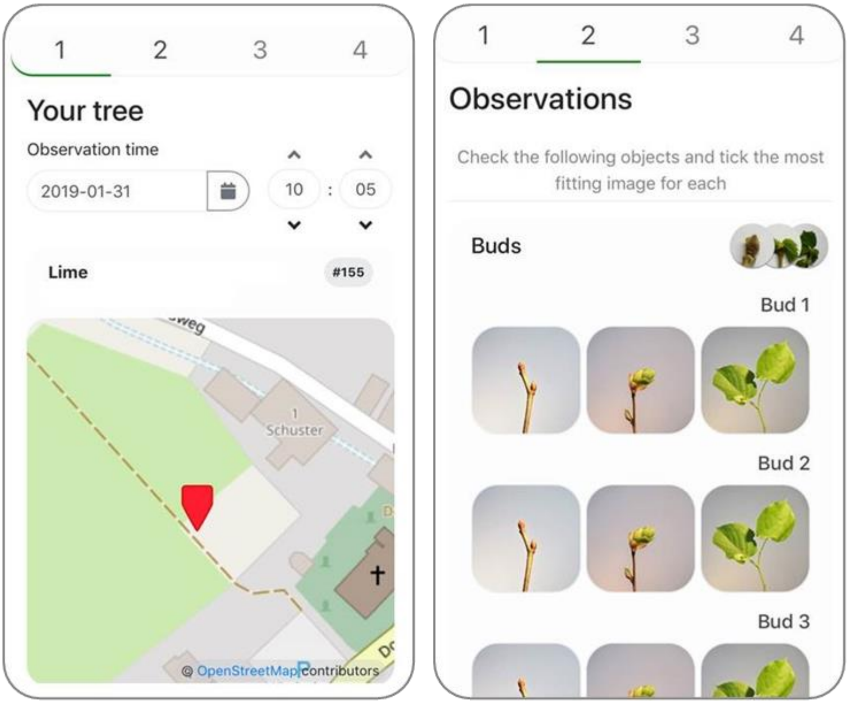

Figure 1: Screenshot of the app implemented for citizen engagement with urban trees and VGI: (left) selection of the urban tree by location, user ID, or species and location; (right) data collection for the phenological monitoring by keying in bud scores represented in the photographs.

3 Results and discussion

The onset and speed of leaf development indicates the reactions of different tree species to urban weather and climate. Geocommunication of the results is implemented as follows. As soon as a mobile device with the app is detected by the beacon hanging in the tree, the app calls the tree website, which in this example, for comparative purposes, includes a diagram showing the leaf-development stages of different urban trees in the project cities.

The diagram in Figure 2 is coupled to a podcast in which a speaker explains what can be seen in the diagram. For this example, the podcast provides the following recorded information:

The diagram shows how different the leaf development of urban trees is, both between different cities and between different tree species. On the Y-axis the investigation period from 28th March until 27th April is shown. From this, the beginning and the duration of the leaf development can be read off. The five different colours represent the five European study cities listed below. On the X-axis four of the tree species investigated are distinguished, namely Norway maple, Horse chestnut, Turkish hazel and Little-leaf linden. Since we did not study the same tree species in each city, not every tree species shows the same number of bars. The length of the bars reflects differences in the duration of the development between tree species or study cities. For example, the bars for Norway maple are approximately the same length. From this we can deduce that the tree species develops equally fast in Mülheim and Salzburg. Also, the start-dates for the development were very close to each other. In contrast, the bars for the Little-leaf linden differ more clearly. Especially in Dresden, leaf development takes a long time – almost a month. In addition, it starts very early. In Mülheim, Salzburg, Szeged and Weer, leaf development begins almost at the same time. However, the trees in Salzburg need 15 days, in Mülheim 12 days, in Weer 10 days, and in Szeged only 7 days to complete their leaf development.

Moreover, the variability in leaf development indicates that an important role is played not only by the local climate but also by further influencing factors, such as exposure to the sun or water supply.

For Salzburg, the phenological observations were analysed from a further perspective. Recent discussions have highlighted the need for more strategic approaches to urban tree stock management to enhance the delivery of ecosystem services that are critical to human wellbeing and biodiversity (Endreny, 2018). Statistical data analysis of phenological observation records for 91 trees carried out in R, a language and environment for statistical computing (R Development Core Team, 2018), revealed significant differences between Turkish hazel (Corylus colurna) and Norway maple (Acer platanoides), as well as between Corylus colurna and Little-leaf linden (Tilia cordata), where the length of their growing periods was concerned. If we take the length of the growing season as a measure of the delivery of climate-regulating ecosystem services, Corylus colurna is a high-performing urban species in Salzburg. The urban heat island intensity in Salzburg has a beneficial impact, indicated by a longer growing period and larger trees, and thus more ecosystem services.

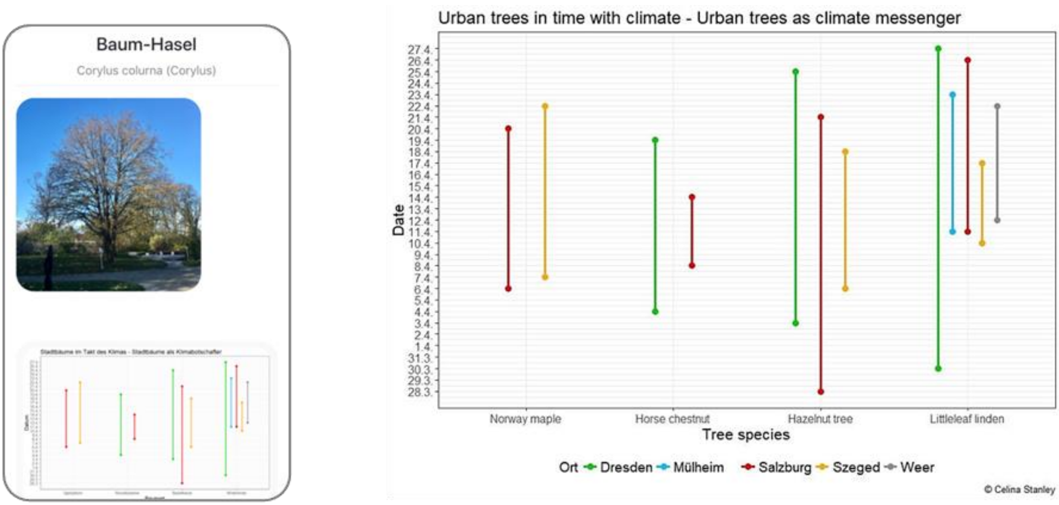

Figure 2: Screenshot of the app implemented for geocommunication: content generated by citizen engagement with urban trees and VGI is broadcast via the beacons with Bluetooth connectivity that are hanging in the trees.

4 Conclusions and outlook

This young citizen science project allows for data collection and analysis and the geocommunication of results on two levels. First, the onset of leaf development and the duration of green foliage as a producer of climate-regulation ecosystem services can be shown across the project cities and for different urban tree species in each individual city. This fosters an understanding of how the phenology and microclimate influences of urban trees happen at the same time and speed – in sync. Second, adaptation of tree species to climate change and potential positive effects of the urban heat island (longer growing seasons, accelerated tree growth and greater ecosystem services) can be analysed (cf. Endreny, 2018). This deepens our understanding of systemic feedback, which is key for implementing appropriate urban tree management.

We have shown results and content that are representative of what can be generated by young citizen scientists and made available for the geocommunication of ecosystem services of urban trees. By repeating the measurements, the incremental growth of records in our database will allow us to extend the analysis on the interrelationship between urban tree species and urban heat island intensity in Salzburg. This will allow us to provide advice on tree-planting sites for particular tree species that reflects estimates of the species' future suitability with respect to the urban heat island intensity in the city.

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