Environmental Pollution 178 (2013) 7–14

Contents lists available at SciVerse ScienceDirect

Environmental Pollution

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

Assessing urban habitat quality using spectral characteristics of *Tilia* leaves

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ARTICLE INFO

Article history:
Received 29 October 2012
Received in revised form
15 February 2013
Accepted 18 February 2013

Keywords:
Urban habitat quality
Bio-monitoring
Linden
Leaf reflectance
Image processing

ABSTRACT

Monitoring environmental quality in urban areas is an important issue offering possibilities to control and improve urban habitat quality as well as to avoid adverse effects on human health. A tree leaf reflectance-based bio-monitoring method was used to assess the urban habitat quality of two contrasting habitat classes in the city of Gent (Belgium). As test trees, two *Tilia* species were selected. Custom made Matlab code is applied to process the measurements of leaf reflectance. This enables the discrimination between polluted and less polluted habitats. The results elicit, that leaf reflectance in the PAR range, as well as the NDAI (Normalised Difference Asymmetry index) are species dependent while Dorsiventral Leaf Reflectance Correlation (DLRC) seems to be independent of species. Therefore the assessment of urban habitat quality is perfectly feasible using leaf reflectance, when taking account of the species specificity of tree leaf physiological and structural responses to habitat quality.

1. Introduction

Urban air pollution is a major hazard for human health, plant growth and development, constitutes a risk in many other environmental domains. The impact of urban pollutants on the health of living organisms at one hand and the growing pressure for action in the policy and management industrial zones to reduce air pollution levels on the other hand, have increased the need to improve methods to monitor urban habitat (i.e. plant, soil, air, water compartment and interaction between them in an urban area) quality both for exposure assessment and for policy support (Briggs et al., 2000; Piraino et al., 2006).

Hence, the assessment of urban air quality is an essential element in the process of risk assessment in environment and public health. The monitoring and quantification of urban habitat pollution is particularly important for the reduction of ecological risks, both in a spatial and cumulative long term perspective.

Over the last three decades different methods have been developed to monitor air quality. Current techniques for the determination and monitoring of air quality generally involve the collection of air samples at particular sites and the analysis of these samples, either in real time or at a later time in the laboratory (Wang et al., 2007; Kardel et al., 2010). However, for the major pollutants measured by air monitoring stations, a pollutant's potential risk is only calculated as a function of its vapour phase concentration. This monitoring approach fails to take into account the multiple interactions which are possible among pollutants and between pollutants and their physicochemical environment; to name a few, exposure time, bioavailability, additive, antagonistic and/or synergistic effects are relevant factors (Lowry, 1995).

Air pollutants lead to a variety of adverse effects and visible injury symptoms of plant leaves (Robinson and Wellburn, 1991; Kammerbauer and Dick, 2000; Gunthard-Goerg et al., 2000; Honour et al., 2009). Few studies however, do demonstrate the interactions between different types of pollutants and plants (Pal et al., 2002; Klumpp et al., 2006; Balasooriya et al., 2009; Kardel et al., 2010). These studies show that different plant species elicit the environmental quality in which they grow by changing their leaf anatomical and physiological properties, and thus changes in leaf properties can be used to provide a reasonably accurate assessment of habitat quality (Falla et al., 2000; Honour et al., 2009). The interaction of a leaf with its environment is not always equally distributed over its area. For example different studies report injury symptoms and leaf colour changes in the leaf edges of certain species (James, 1988; Roh and Lawson, 2009; Hughes et al., 2010). This could be partly attributed to a thinner boundary layer at the leaf's edge (Schuepp, 1993),

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http://dx.doi.org/10.1016/j.envpol.2013.02.021

resulting in a higher interaction between air pollutants and the leaf at these edges.

In contrast to the majority of the physical and chemical methods, methods based on a bio-monitoring, bio-assay or bio-indicator approach, which make use of physiological or anatomical properties of organisms, allow a direct assessment of harmful effects of air pollution on organisms (Piraino et al., 2006), with respect of time and all different pollutants and their effects. Bio-monitoring is useful for the assessment of environmental impacts of pollution on living organisms, including plants as well as animals and humans (Falla et al., 2000). The benefit of using plants as a bio-indicator is their uncomplicated deployment in field campaigns. Moreover monitoring based bio-indicators are cheap compared to the use of physico-chemical methods and monitoring (Falla et al., 2000; Balasooriya et al., 2009). Though the response of plants to air pollutants cannot be extrapolated directly to predictions of human health responses, the findings of plant bioassays can provide an indication for air pollution impacts and hence environmental stress (Romermann et al., 2006).

Considerable sampling effort and laboratory analysis are major disadvantages of bio-monitoring in the sense that costs may still rise unacceptably high. Ways to circumvent this costly aspect is the use of remote sensing technology, or even better the use of optical reflectance measurements. Under certain boundary condition, this technique is a reliable, repeatable, reproducible and cost effective bio-monitoring tool for risk identification and reduction, and it is easy to implement for monitoring long-term and large scale changes in habitat quality.

Optical reflectance techniques have been the subject of extensive studies at the leaf level (Hunt and Rock, 1989; Knapp and Carter, 1998; Mielke et al., 2012), and typically most of them made use of spectro-reflectometry (Woolley, 1971; Carter and Knapp, 2001; Sims and Gamon, 2002; Campbell et al., 2007; Rascher et al., 2010; Nichol and Grace, 2010). Also digital image analysis has been used to quantify plant biophysical parameters and responses to environmental stresses (Price et al., 1993; Ahmad and Reid, 1996; Schaberg et al., 2003). Results from cited authors indicate that digital image analysis is a useful and non-destructive method to quantify biophysical plant reactions. Up to now however, the use of imaging reflectometry in the bio-monitoring of urban habitat quality has hardly been assessed.

Khavanin Zadeh et al. (2012) developed and applied an optical reflectance technique successfully for the bio-monitoring of urban habitat quality with *Carpinus betulus* as indicator species. However, hitherto we do not know whether the technique can also be applied for other species. Also for bio-monitoring purposes we need species that can completely cover the area of interest which is often not the case, a problem which can be overcome by using a combination of species as long as there are co-located sampling points (Kardel et al., 2011, 2012). Therefore, the purpose of this study was to analyse variations in leaf reflectance derived from field level remote sensing of plants growing in two urban land use classes with a contrasting pollution level, i.e. less polluted and polluted habitats. Hereby, the assessment of the potential of the method as an active remote sensing tool to assess urban habitat quality is a specific objective. More specifically, this study focuses on the leaf reflectance characteristics of two kind of *Tilia* sp. used as bio-indicator in Gent city (Belgium). The same study area has been defined as described in Khavanin Zadeh et al. (2012).

2. Material and methods

2.1. Study area

The city of Gent (Belgium) (51° 00′ N, 3° 50′ E), was selected as an urban study area and sampling site. It is one of the most populated cities of Belgium with about 1589 inhabitants per km^2. The city is composed of contrasting habitats with respect to environmental pollution (Balasooriya et al., 2009; Kardel et al., 2010). These habitats include, industrial zones, e.g., a harbour connected to the north with the Schelde river and the North Sea, associated industrial activities, waste deposit zones and densely populated areas in the South. On the other hand, urban green and semi-natural areas as well, are located in the East and West of the city. Several plant-based biomonitoring campaigns have been conducted in the past in this city by e.g. Balasooriya et al. (2009) and Kardel et al. (2010, 2012).

During 2009, a bio-monitoring was organized, wherein average concentrations of NO, NO_2, SO_2, O_3, PM_{10} and $PM_{2.5}$ (Particle Matter) were obtained from the Flemish Environmental Agency, for the city centre of Gent. They amounted to 10, 34, 4, 36, 35 and 20 μg m^{-3}, respectively. During the sampling period the O_3 concentration was higher than the annual mean, and amounted to 43.5 μg m^{-3}, which was 21% above the annual mean, while the other parameters dropped below the annual mean. Therefore air pollutant concentrations at Gent city show low-moderate degree of pollution in the urban. There are 3 monitoring stations in the study area. One of these monitoring stations can be considered as being representative for the less polluted areas (LP; sub urban area), while both others represent the polluted areas (P; urban and industrial area) (Table 1).

The climate condition of the city of Gent is influenced by a temperate, Atlantic Ocean climate, with its highest air temperatures (18 °C) in July/August and its lowest temperatures (4 °C) in January/February. Rainfall is sheer equally distributed throughout the year. The predominant wind direction is from southwest to northeast. In 2009, total rainfall amounted to 835 mm, and the average air temperature, wind speed and relative humidity respectively were 11.9 °C, 3.7 m s^{-1} and 81%, for the central area of Belgium (www.kmi.be). Traffic density varies largely over the study area, from a high traffic intensity varying between 600 and 2500 vehicles per hour in the urban, highway and industrial sites in the polluted habitats, to less than 25 vehicles per hour in green areas representing the less polluted habitat (Kardel et al., 2012).

Two urban habitat types with contrasting pollution levels (Balasooriya et al., 2009; Kardel et al., 2011) were identified. The industrial area was selected as a polluted habitat (P) and the urban green areas were selected as a less polluted habitat (LP). For each habitat, two types of *Tilia* species were selected, i.e. Hairy *Tilia* sp. (HT) and Non-Hairy *Tilia* sp. (NHT). Hairy and non-hairy referred to the presence or absence of trichomes on the leaf surfaces, respectively. According to Kardel et al. (2011) 7–8 trees were selected in each habitat, and of each tree, 3 to 4 leaves were sampled from different branches. Leaf sampling was performed at the sunny and street-exposed canopy sides at heights between 1.5 and 2.5 m above ground level during August 2009.

2.2. Anatomical-morphological and physiological leaf characteristic measurements

Relative chlorophyll content (RCC) of the leaves for HT and NHT sampled in P and LP, was measured using a chlorophyll content metre (CCM 200, Optic-Sciences, Hudson, USA). The measurements with CCM were performed near the main leaf vein at four points at each leaf side. Leaf Area (LA in cm^2) was determined by scanning of the leaves using a leaf area metre (Li-300 leaf area metre, Li-COR, Lincoln, Nebraska).

In the following step, scanned leaves were dried in an oven at 45 °C during 5–6 days and subsequently weighted using an electronic balance with an accuracy of 1 mg (B310 S, Sartorius, Göttingen, Germany) to obtain Leaf Dry Mass (LDM). Finally, Specific Leaf Area (SLA) (cm^2 g^{-1}) was calculated by dividing LA with LDM.

2.3. Leaf reflectance measurements

The field level leaf reflectance measurements were performed under standard illumination conditions using a field illumination set up as described by Khavanin Zadeh et al. (2012). A reflex camera was used and mounted on the field illumination setup. The inner side of the setup is coated with non-reflecting black paint, intended to avoid indirect illumination (stray light) of the target as much as possible, thus avoiding multiple scattering conditions as much as possible. The height of the camera with respect to the leaf surface is chosen as such, that an image pixel approximately matches the size of an epidermal leaf cell. The camera is locked on top of the leaf reflectance measurement setup with a camera mounting cylinder. The setup allows keeping the distance between the camera objective and the target leaf surface constant throughout all measurements. In setup, the illumination of a leaf is performed with two warm-white LED light sources (Lexon Star

Table 1
Mean annual pollutants concentration (μg/m^3) in both the less polluted (LP) and polluted (P) habitats.

Pollutant	Habitat					
	No	No_2	O_3	SO_2	PM_{10}	$PM_{2.5}$
LP	9.7	27.1	37.1	2.8	24.5	13.4
P	10.2	33.4	43.6	9.5	27.8	17.3