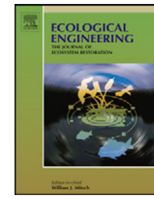
Ecological Engineering 37 (2011) 914–919

Contents lists available at ScienceDirect

Ecological Engineering

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



An index based on silvicultural knowledge for tree stability assessment and improved ecological function in urban ecosystems

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ARTICLE INFO

Article history:
Received 14 September 2010
Received in revised form 5 January 2011
Accepted 23 January 2011
Available online 18 February 2011

Keywords:
Urban forestry
Silvicultural characteristics
Tree stability index
Crown asymmetry index
Wind load

ABSTRACT

Trees in the city not only have an ornamental function but also a role in improving the ecological function in urban ecosystems that has been substantially disturbed by human activities such as environmental pollution. Today the ecological role of urban greenery is clearer than ever and is included in the new scientific field of ecological engineering, which is the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both. Trees in an urban environment show many difficulties in surviving in it because the ecological conditions that exist in the cities are worse than these of the nature. One of these seems to be the heavy wind loads. But even though rough surfaces slow down the wind speed, tall buildings can cause wind tunnel effects that stress a tree as much or even more than if it was positioned in an exposed, unprotected site. An urban tree must be able to endure all the damages and loads from the wind throughout its life. The ability of a tree to withstand wind loads of gale forces depends on its shape and its dimensions. The objective of this paper is the evaluation of tree stability based on the aboveground silvicultural characteristics in order to create an empirical index which can correlate tree stability with these features. Silvicultural characteristics that play the greatest role on tree stability are crown ratio (CR), crown asymmetry index (CAI), and tree height (*H*). Consequently, tree stability index (TSI) is formed by them. According to TSI values, tree stability was classified in three categories (classes): high, moderate and crucial stability. The limits of the transition from one class to another, as the classes themselves are depended on the number of variables that represent silvicultural characteristics.

1. Introduction

The urban ecosystem consists of both the "grey" and the "green" infrastructure. The "grey" element is the result of human impact and includes every possible infrastructure as buildings, roads, etc. The "green" element includes urban greening and peri-urban forests. Green zones are a basic element of ecological engineering affecting city planning. Vegetation in the city not only has an ornamental function but also a role in regulating the environmental function: it retains atmospheric water, contributes to evapo-transpiration, represents a filter against pollution and an excellent regulator of the air, heat and damp with the urban surroundings. Today the ecological role of urban greenery is clearer than ever. Urban greening contributes to increase the quality of life for many communities and their residents (Hauer and Johnson, 1992; Gomez et al., 1998; Dafis, 2001).

In some countries, town planning teams consist mainly of architects, thus leaving the team with little ecological knowledge of urban greenery and how to use it properly (both as regards the quantity and the right plant species). This matter falls within the sphere of ecological engineering and we feel it is of fundamental importance for environmental guarantees and urban ecology. As it is referred to by Rosemond and Anderson (2003) one goal of ecological engineering should be to shift human impacts on ecosystems to a more natural response that takes into account local, native conditions. In addition, techniques used in the study of non-human species, particularly in quantifying their effects on ecosystem processes and other populations could be employed in ecological engineering studies. Also, the goal of ecological engineering is to better integrate society with its supporting environment (Bergen et al., 2001). Creating integrated urban and other built environments is a potential application for ecological engineering. Increasing calls for 'greening' urban environments, allowing for more of a connection between place and nature in

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0925-8574/$ – see front matter
doi:10.1016/j.ecoleng.2011.01.015

built environment, will require design that includes ecology and engineering. Traditional landscape architecture, and urban horticulture approaches can be augmented by ecological engineering. And deals with the new scientific field of ecological engineering which is the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both (Mitsch, 1998).

For the last 50 years there has been a growing realization that the solutions to most of environmental problems reside in making cities more efficient in their consumption of energy and materials and disposing of waste products, and in altering patterns of urban development to reduce the amount of impervious "grey" infrastructure and to increase the amount of "green" infrastructure, particularly trees (Carreiro, 2006). This realization has been expressed in the concepts of the eco-cities movement, adopted by many environmentalists and urban designers throughout the world (Register, 2002; Carreiro, 2006). According these it is adopted the perception that the accomplishment of healthy ecosystems is possible only if urban vegetation is included in the procedure of urban design (Moll et al., 1995; Kuchelmeister, 1998; Tsitsoni et al., 2007). The goal of the vegetation ecological approach is to create real green environments as the basis of human existence (Miyawaki, 1998).

Within current engineering practice the tendency is to use ecology as an indicator or assessment tool in such broad scale practices as watershed management, ecosystem management, integrated natural resource management and urban planning and development (Gattie et al., 2003).

For most people each tree is a given, static, permanent feature of urban environment. However, trees, whether long-lived or not, will inevitably collapse and decompose, and no trace will remain from their existence. Trees, that are not adapted to the conditions of an urban ecosystem, can die from causes such as a disease or insect attack, drought, uprooting, and catastrophic stem failure in high winds, or from combinations of factors working together (Hauer and Johnson, 1992). Furthermore, effuse and without planning pruning could drive in that direction.

An urban tree must be able to endure all the damages and loads, from gravity, snow or from the wind throughout its life. For nearly all trees, the greatest load is from the wind that comes as gusts of rapid, periodic, dynamic events. In terrestrial environments forces caused by wind are the most ubiquitous and important cause of dynamic loading (Grace, 1977) on the trees. Wind is the most persistent of the harmful natural forces to which any individual tree or forest stand is subjected (Jacobs, 1936; James et al., 2006).

Considerable research into the interaction between wind and tree movement has been contacted in order to better understand the mechanics of wind damage and wind-induce physiological responses (Gardiner, 1995; Kerzenmacher and Gardiner, 1998; Moore and Maguire, 2004).

The result of storm winds are forces twisting and bending tree parts causing either the part to fail or the supporting soil to fail. Trees sense structural stress and attempt to minimize failures through reactive growth. Trees modify their structure over time as they are challenged by wind. Trees are biologically designed to sustain average wind loads (Coder, 2007). Although the relationship between wind loading and tree has been studied, a detailed understanding of the effect of wind loading and tree weight on the internal wood structure and reactions has not been developed yet (Horacek, 2003).

Trees in an urban environment seem to be protected from heavy wind loads. But although rough surfaces slow down the wind speed, tall buildings can cause wind tunnel effects that stress a tree as much or even more than if it were positioned in an exposed, unprotected site on a field (Hirtz, 1981; Grey and Daneke, 1986; Stathopoulos and Storms, 1986; Brudi and van Wassenaer, 2002; Dafis, 2001).

The ability of a tree to withstand wind loads of gale forces is calculated by including the shape of the load – bearing structure (trunk and crown), the properties of green wood and the forces that occur in a gale – force wind gust (Brudi and van Wassenaer, 2002). When trees are healthy, without any trace of decay and knowing that the main cause of failure is a wind speed > 30 m/s (Kane, 2008), the aboveground silvicultural characteristics play the greatest role on tree stability.

Taking into account that tree failure by wind poses risks for the urban environment, the humans' safety and their property, the determination of tree stability and the evaluation of tree risk are imperative.

The objective of this paper is the assessment of tree stability by their aboveground silvicultural characteristics in order to create an empirical model which can correlate tree stability with these features.

2. Materials and methods

2.1. Research area

The city of Thessaloniki extends in an area with elevation between 0 and 350 m. The climate is Mediterranean, with an obvious continental impact through the seasons. Wind conditions diverse through the year. In winter, the northern wind named Vardaris that comes from the valley of Axios River prevails. In spring, the presence of southern-west sea breezes is more frequent. In summer, prevailing winds are northern and also south western, decreasing in September, and from November northern and western winds are dominating (Tsitsoni and Zagas, 2001).

2.2. Data collection and analysis

The research took place on the street trees of three representative roads in the centre of the city of Thessaloniki, which are orientated to wind direction Vardaris. The number of the trees that were measured are presented in Table 1.

According to literature (Stathers et al., 1994; Wessolly, 1995, 1996; Peltola et al., 2000; Brudi and van Wassenaer, 2002; Horacek, 2003; Kolařik, 2003; Sterken, 2005; James et al., 2006; Coder, 2007), tree stability is directly related to the aboveground silvicultural characteristics of each individual. Thus, in order to try an empirical estimation of tree stability and the construction of a mathematical model as well, the measurements that have been recorded for each individual are: Tree species, breast height diameter (D), tree height (H), height at crown base and the radius of the crown R_1, R_2, R_3, R_4, which were used to calculate two crown diameters $CD_1 = R_1 + R_2$ and $CD_2 = R_3 + R_4$.

Based on the above measurements, the horizontal and vertical dimensions of the crown were calculated and estimated as they are referred by Assmann (1970): crown length (CL), crown ratio (CR), live crown ratio (LCR), crown width (diameter) ratio or crown index (CWR or CDR), crown fullness ratio (CFR), degree of spread (DS), and crown projection ratio (CPR).

Table 1
Total number of street trees and number of trees in the sample per avenue and per species.

Name of the avenue	Species	Number of trees
Nikis' Avenue	*Platanus orientalis*	81
Egnatias' Avenue	*Celtis australis*	76
	Albizia julibrissin	37
Karamanlis' Avenue	*Populus × euramericana cv. 'I-45/51'*	28