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OVERVIEW ON ATTENUATION OF INDUSTRIAL AIR POLLUTION BY GREENBELT

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ABSTRACT

Urban air pollution due to industrial emission and vehicular emission due to automobiles has aggravated the problem of environmental pollution. Plants are known to act as sink for air pollutants. Planting of trees and shrubs in the form of greenbelt around the industry is an effective way for abatement of pollution and improvement of environment and is well recognized throughout the world. This article provides a brief review of the history and evolution of work on greenbelt development for pollution attenuation in an industry. It also reviews work on different aspects of greenbelt design and selection of plant species, which can be grown around industrial/urban areas in India. A reported case study carried out at petroleum refinery is discussed. At this plant, green belt of 500m width was found to be 36-40% efficient in removal of SO_2, NOx & SPM and 84-94% efficient in removal of THC, VOC & CO. The future line of work is suggested for collecting data on the potential of greenbelts in attenuating the pollutants.

INTRODUCTION

Air pollution due to industries and increased traffic is becoming an increasingly dominant problem, especially in the developing countries. It is observed that the levels of one or more air pollutants are higher than the permissible limits set by Central Pollution Control Board in many industrialized / urbanized pockets of India (Abbasi, 1998 and Chaulya, 2004). Control of air pollution is possibly by two ways, namely control at source by implementing industrial ecology and by restricting the spread of air pollution through development of greenbelt around industries and plantations in urban areas. Many scientists recommend growing green vegetation in and around the industrial / urban area (Santra, 1995; Thakre, 1995; Shannigrahi and Agrawal, 1996; Sivasamy and Srinivasan, 1996; Khan and Abbasi, 2001; Ghose and Majee, 2001; Shannigrahi and Sharma, 2001; Khan and Abbasi, 2002 and Shannigrahi *et al.* 2003) to check the spread of air pollutants emitted from an industrial complex. A greenbelt development around the site boundary with the suggested plant species would reduce the pollutant dispersion (Chakraborty and Singh, 2001). The capacity of plants to reduce air pollution is well known and has been reported in the literature (Sharma and Roy, 1997; Nowak, 1994 and Nowak *et al.* 2002). Green plants forms a surface capable of sorbing air pollutants and forming sinks for pollutants. Moreover the plants with broader leaves and rough surface act as air filter to filter out dust from air. Leaves with their vast area in the tree crown, sorbs pollutants on their surface. The sorbed gaseous pollutants are incorporated in metabolic stream thus their concentrations in the ambient air is effectively reduced and the air get purified.

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Government of India has made it mandatory to develop a green belt of suitable plants of proper width around industry to attenuate the concentration of air pollutants released by the Industry (Abbasi and Khan, 1999). There is guideline to develop green belts in between residential patches in urban area to improve the aesthetic environment for better public health. Apart from functioning as pollutant sinks and improving aesthetic environment, green belts would provide benefits like providing possible habitats for birds and animals, thus recreating hospitable nature in an otherwise drab urban-industrial scene.

Various aspects of green belt development and the pollution attenuation by green belt are summarized in this article.

History of Green Belt Development

The concept of green belt (GB) as a source of pollution abatement was recognized initially by three nations: The U.S.A., Britain and Kenya (Ruth and William, 1994; Gareth *et al.* 1992; Andy, 1991 and Parsons, 1990) In 1898, a British Social Reformer, Ebenezer Howard, advanced the concept of green belt. A more elaborate plan was created in 1944 by Patrick Abercrombie, who proposed a belt, five or more miles wide, consisting of both public open spaces and private holdings. Concept of greenbelt is little more varying from town to town.

In America, Greenbelt meant a wide band of rural land or open space separating or interrupting urban development. The central goal of Roosevelt's greenbelt programme, was not to create better urban communities, but rather to generate jobs in a declining national economy (Ruth and William, 1994).

In Kenya, greenbelt movement has been started through an agro-forestry project founded and run by women's association. The movement, started and organized by Professor Wangari Maathi, a lecturer in veterinary medicine, aims to plant trees for a variety of reasons: to stabilize soil, for use as fuel, for landscape improvement and as a source of income for the women taking part in the scheme (Andy, C. 1991).

In Germany and The Netherland, there are fixed criteria for the width of GB to be developed around the identified activity zone, depending on the source. Thus, in Germany, the width of GB varies from 100 m around commercial centers to 2000 m around heavy industries. In the Netherlands, the required GB width varies from more than 500 m for heavy industry to 50 m for light and non-polluting industries (Abbasi and Khan, 1999). Netherlands has been a prime country in this field. Following is the green belt criteria followed in Netherlands.

Objectives of Green Belt Development

Objectives of GB development ranges from the micro level air pollution abatement to enhancement of socio-economic status of the region.

(a) The prime objective of GB development is attenuation of air and noise pollution

(b) GB development can serve as a measure, to reduce the soil erosion and aesthetic enhancement of the area

(c) It enhances the socioeconomic status of the region by generating employment avenues and also participates in environmental protection

(d) The width of the GB and the species used for planting varies from industry to industry depending on nature and concentration of air pollutants.

Methodology for Green Belt Design

The design of the GB and its composition may vary from place to place and industry to industry. Just putting some trees around an industry may not serve the purpose of GB. The development of GB, by using pollution tolerant plants for air quality improvement, involves selecting suitable plant species, determining climatic conditions, nature of pollutants to be ameliorated and general landscape of the locality.

Class	Industry	Width of GB (m)
I	Heavy industry with high potential of air pollution	> 500
II	Heavy industry with low potential of air pollution	200 to 500
III A.	Medium heavy industry with high potential of air pollution	100 to 200
B.	Medium heavy industry with low potential of air pollution	100 to 200
IV A.	Light industry with high potential of air pollution	50 to 100
B.	Light industry with low potential of air pollution	50 to 100
V	Service industry	10 to 50
VI	Workshops, handicrafts, etc.	< 10

While selecting the plant species, the characteristics as tolerance, canopy structure, foliage form, average height of the plant and its overall flowering and production potential should take into consideration. In short, a GB development plan and its design mainly depend upon:

i. Nature and extent of pollution load (Nowak, 1994).
ii. Assimilative capacity of the ecosystem to attenuate the pollutants
iii. Climatic conditions of the locality
iv. Soil and water quality of that region
v. Determine the location of greenbelt for optimal pollutant attenuation
vi. Assessment of the appropriate width of greenbelt, density of plantations in it, sequence of planting shrubs and trees, tree height, and the overall shape of the greenbelt
vii. Selection of tree species suitable for different agro-climatic conditions and for different pollutants (Nowak, 1994).
viii. Optimal width of a GB in and around industry is based on pollution attenuation factor of selected plant species (Thakre, *et al.* 1973-1993).
ix. The pollution attenuation factor (Af) for sources releasing at ground level is given by:

$$Af \quad \frac{Qwa}{QB}$$

Af = ratio of mass flux of pollutant reaching at distance X1 and X2 in the absence of GB (Q_{WB}) to the mass flux reaching at the same distance in the presence of the GB (Q_B).

The flowchart of the greenbelt design methodology, based on the pioneering work of Khan and Abbasi (1999), Gupta and Kapoor (1990) and Kapoor and Gupta (1984, 1992) is presented in Fig.1.

Selection of Plant Species for Green Belt

Careful attention could be devoted to the selection of plant species (Beckett *et al.* 1998 and Nowak and Dwyer, 2000). Selection of the appropriate plant species, which are tolerant to the particular pollutants of that area, can be done on the basis of climatological conditions and ecological status of that region. An ideal tree for planting in the GB should have the following characteristics (Sharma *et al.* 1991 and Sharma *et al.* 1994) :

i. Fast growth rate for quick development of canopy (Nowak *et al.* 2002).
ii. Strong branches, thick and durable canopy which can withstand storm
iii. Large leaf size for greater retention of pollutants
iv. Dense foliage for better trapping of pollutants
v. Preferably perennial and evergreen species for extended life of the GB (Beckett, 2000a)
vi. The species should be Indigenous
vii. Resistant to specific air pollutants, diseases and insects
viii. Able to maintain the ecological and hydrological balance of the region (Whitlow and Bassuk, 1988 and Whitlow *et al.* 1992).
ix. Leaves with hairy, resinous, scaly, and coarse surfaces could capture more particles than smooth leaf (Beckett *et al.* 1998; Beckett *et al.* 2000a and Beckett *et al.* 2000b).
x. Species must have the ability to tolerate the unique features of urban soil (Craul, 1994).

In addition to these biological and socioeconomic characters, the Air Pollution Tolerance Index (APTI) of various plant species may be used for the evaluation of the tolerance level of plant species to air pollution for GB development (Singh and Rao, 1983). The four parameters used in deriving the APTI are leaf extract, pH, ascorbic acid, total chlorophyll and relative water content. APTI is calculated as:

$$APTI = \frac{A(T+P)+R}{10}$$

Where, A = ascorbic acid content in mg/g of dry weight, T = total chlorophyll in mg / g of fresh weight, P = pH of leaf extract and R = relative water content (%).

A list of tolerant plant species as a function of pollutants is shown in Table 1 (Chaulya, 2004; Shannigrahi, *et al.* 2004 and Bhattacharya, 1994). A method of classifying plant species as sensitive, intermediate and tolerant may not be entirely satisfactory, since different stages in the life cycle of a plant are likely to differ in their sensitivity or resistance to pollution (Varshaney and Garg, 1979). Nevertheless, such a classification provides a basis for the determination and selection of certain tolerant plant species capable of reducing the impact of air pollution (Shannigrahi & Sharma, 2001; Roy & Sharma, 1997).

Steps for Planting and Management of Green Belt

For planting trees, healthy and established saplings of about 1 m height should be selected in order to avoid mortality. Pits measuring 1 m × 1 m × 1 m are to be dug up at desired points in triangular pattern.

Planting of sapling should be preferably done during rainy season. For planting tall shrubs and dwarf trees 4.5 m spacing between plants and rows is sufficient. While medium and tall trees in middle and rear rows are to be planted 6-7 and 8-10 m apart respectively, depending upon the space available. Close planting is recommended for accommodating more number of trees per unit area resulting in more leaf surface (Abbasi and Khan, 1999).

Dwarf trees with round canopy followed by medium and tall trees with cylindrical canopy are ideal for greenbelts of industrial areas because all plants are exposed to the pollutants (Sharma *et al.* 1994). This helps to divert the emissions upward as plants act as a physical barrier. Trees of the front rows act as absorptive layer while the core area (rear rows) cleans the air.

For designing green belt in urban areas, the pattern of planting should be a little different from industrial areas. Dwarf trees and shrubs in multiple rows should be planted all along the periphery, flanked by medium and tall trees gradually towards center so that all the plants can intercept pollutants from different directions.

Initially for 2-3 yrs, the proper care and maintenance of the saplings is essential. It helps for quick development of canopy, which is very much required for an effective green belt (Sharma *et al.* 1991 and Sharma *et al.* 1994). Sound and intensive management and maintenance, including timely pruning, watering on dry days, and pest monitoring and control, could effectively improve plant health and thus their intensities of photosynthesis and respiration (Yang, 1996), which could increase pollutant absorption.

Recycling of Pollutants by Vegetation

Vegetation act as sinks for gaseous pollutants and also intercept tones of dust and serve as acoustic screens on busy highways and noisy factory areas. Several plants have the capacity to collect the dust suspended in the atmosphere and dilute the concentration of toxic and harmful gases like SO_2, CO_2, etc. Trees have been reported to remove air pollutants like hydrogen fluoride, SO_2, and some compounds of photochemical reactions and collect heavy metals like mercury (Hg) and lead (Pb) from the air (Hill, 1971 and Lin, 1976). After absorbing the air pollutants, trees change them to harmless metabolites through various physiological processes. Of course, each and every plant cannot be an agent of air pollution control; only those which can tolerate pollutants can act as attenuators.

The effectiveness of a green belt (GB) in intercepting and retaining atmospheric pollutants depends on several factors, viz. shape, size, moisture level, surface texture and nature (soluble or insoluble) of both the particulate matter and gas and the intercepting plant parts (Ingold, 1971). Moreover, moist or wet plant surfaces enhance the pollutant removal rate by 10%. Light also has a pronounced effect on the foliar removal of pollutants by stimulating physiological activities and stomatal opening (Mansfield, 1973 and Smith, 1981).

Particulate pollutants are removed from the air by two ways, viz. absorption by the leaves and deposition of particulate matter on leaf surface [25,50-51]. Suspended particles in atmosphere are deposited on plant surfaces by two processes:

i. Sedimentation under the influence of gravity: Sedimentation usually results in the deposition of particles on the upper surfaces of plant parts and is most important with large particles.

ii. Deposition under the influence of precipitation: Deposition is more effective if, the collecting surface is wet, sticky, hairy or otherwise retentive. Interception by fine hairs on vegetation is possibly the most efficient retentive mechanism (Tewari, 1994).

The gaseous pollutants are transferred from the atmosphere to vegetation by the combined forces of diffusion and flowing air movement. Once in contact with plants, gases may be bound or dissolved on exterior surfaces or be taken up by the plants via stomata. Diffusion is very effective if the surface of the plant is wet and the gas is water soluble [52-54]. Plant uptake rate increases as the solubility of the pollutant in water increases. Hydrogen fluoride, sulphur dioxide, nitrogen dioxide and ozone, which are soluble and reactive, are readily sorbed pollutants. Nitric oxide and carbon monoxide, which are very insoluble, are absorbed relatively slowly or not at all by vegetation. During daylight periods when plant leaves are releasing water vapor and taking up carbon dioxide, other gases including trace pollutant gases, in the vicinity of the leaf are also taken up through the stomata (William, 1990).

Vegetation Characteristics for Better Pollution Attenuation

The list of observations based on experimental work and field surveys by numerous authors, on the role of vegetation in attenuating air pollution are given below:

1. The interception and retention of atmospheric

particles by plants is highly variable and is primarily dependent on:

(a) Size, shape, wetness, and surface texture of the particles

(b) Size, shape, wetness and surface texture of the intercepting plant part

2. Generally, greater leaf surface and roughness increases particle capture efficiency.

3. Leaves with complex shapes and large circumference / area ratios collect particles most efficiently.

4. Velocities of deposition on petioles and stems are generally many times greater than velocities of deposition on leaf laminas.

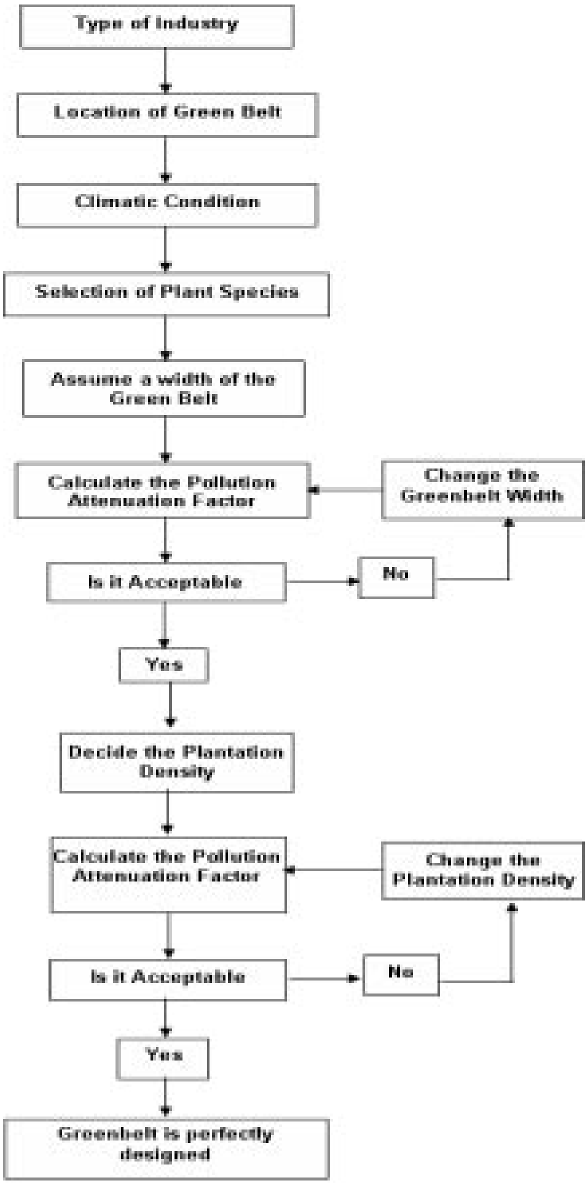


Fig.1 Flow Chart for Green belt Design

5. Collection of atmospheric particles by leafless deciduous species in the winter may remain quite high due to twig and shoot impaction.

Impact of Green Belt on Socio-economic Development

According to IUCN (2007), in addition to the ecological advantages of the green belt, there are a number of socio-economic benefits of green belt to people living in and around the areas proposed to be part of the belt, which include;

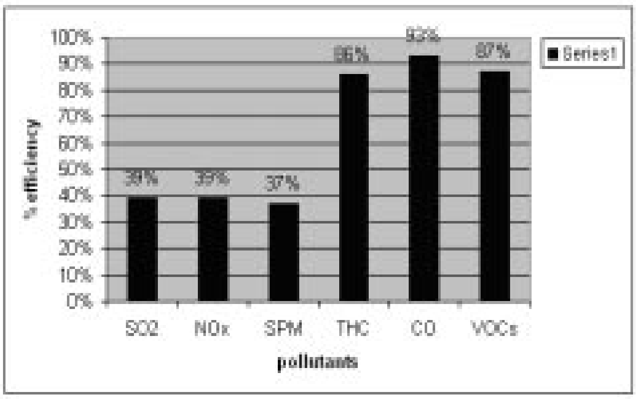
1. Increased development through the provision of funding sources at the European and local level.

2. Green Belt development provides ecosystem services, such as nutrient cycling and water level regulation, which is otherwise very much difficult and costly to reinstate if degraded or replaced with artificial methods.

3. Green Belt development provides sustainable tourism, which would stimulate the support services and provide a market for local products and results into the increased income of that region.

Case Study: Performance Evaluation of a Green Belt in a Petroleum Refinery (Lin, 1976)

A 13.5 MMTPA petroleum refinery on the west coast of India has set up a 500m wide green belt along its periphery based on the model developed by NEERI (1995). About 200,000 mature trees and numerous flowering bushes are a part of its GB and township. Of which 15,000 trees are planted in the 2km corridor area connecting the refinery plant area to the



SO_2 : Sulphur Dioxide, NOx: Oxides of Nitrogen, SPM: Suspended Particulate Matter, THC: Total Hydrocarbons, CO: Carbon Monooxide, VOCs: Volatile Organic Compounds

Fig. 2 Percent Reduction Efficiency of Pollutants by 500m width Greenbelt (Based on data by Rao *et al.* 2004)

Table 1. Tolerant plant species as a function of pollutants for GB development [2,35-38]

Suspended particulate matter (SPM)	Sulphur dioxide (SO_2)	Oxide of nitrogen (NOx)
Acacia nilotica	*Abies grandis*	*Abies grandis*
Achyranthes aspera	*Acacia nilotica*	*Acacia nilotica*
Aegle marmelos	*Accer saccharinum*	*Aegle marmelos*
Ailanthus excelsa	*Accer platanoides*	*Albizzia lebbek*
Albizzia lebbek	*Albizia lebbek*	*Alstonia scholaris*
Alnus viridis	*Aegle marmelos*	*Ailanthus excelsa*
Alstonia macrophylla	*Ailanthus excelsa*	*Alstonia macrophylla*
Alstonia scholaris	*Alstonia macrophylla*	*Anthocephalus cadamba*
Anthocephalus cadamba	*Alstonia scholaris*	*Artocarpus heterophyllus*
Amaranthus graecizans	*Anthocephalus cadamba*	*Azadirachta indica*
Artocarpus heterophylia	*Artocarpus heterophyllus*	Bauhinia variegate
Azadirachta indica	*Azadirachta indica*	*Butea monosperma*
Bougainvillea sp.	Bambusa sp.	*Carissa carandes*
Braya purpurascens	Bauhinia variegata	*Casuarina equisetifolia*
Butea frondosa	*Butea monosperma*	*Citrus medica*
Butea monosperma	*Casuarina equisetifolia*	*Dalbergia sissoo*
Calotropis gigantean	*Cassia siamea*	*Diospyros melanoxylon*
Calotropis procera	*Citrus medica*	*Delonix regia*
Capparis spinosa	*Citrus sinensis*	*Emblica officinalis*
Cassia fistula	*Delonix regia*	*Eucalyptus citriodora*
Cassia siamea	*Dalbergia sissoo*	*Fagus orientalis*
Cassia sophera	*Diospyros melanoxylon*	*Ficus benghalensis*
Casuarina equisetifolia	*Emblica officinalis*	*Ficus infectoria*
Citurs medica	*Eucalyptus citriodora*	*Ficus religiosa*
Clerodendron infortunatum	*Eucalyptus globulus*	*Holoptelia integrifolia*
Cordia oblique	*Ficus benghalensis*	*Leucaena macrophylla*
Croton sparsiflorus	*Ficus infectoria*	*Lagerstroemia indica*
Dalbergia sissoo	*Ficus religiosa*	Lantana camara
Diospyros melanoxylon	*Lagerstroemia indica*	*Madhuca indica*
Eucalyptus citriodora	*Lagerstroemia flosreginae*	Mangifera indica
Eucalyptus citriodora	Lantana camara	*Mimusops elengi*
Ficus benghalensis	*Ligustrum vulgar*	*Moringa oleifera*
Ficus infectoria	*Leucaena macrophylla*	*Phyllanthus distichus*
Ficus religiosa	*Madhuca indica*	*Pithecolobium dulce*
Foloptelea integrifolia	*Mimusops elengi*	*Polyalthia longifolia*
Ipomoea fistulosa	*Moringa oleifera*	*Prosopis juliflora*
Lagerstroemia flosreginae	*Phyllanthus distichus*	*Psidium guajava*
Lantana camara	*Phyllanthus emblica*	*Pterospermum acerifolium*
Leucaena macrophylla	*Picea engelmanni*	*Quercus rubra*
Madhuca indica	*Pithecolobium dulce*	*Robinia pseudocacia*
Mangifera indica	*Platanus accrifolia*	*Sambucus nigra*
Mimusops elengi	*Polyalthia longifolia*	*Spondias mangifera*
Moringa olcifera	*Populus angulata*	*Syzygium cumini*
Murraya exotica	*Populus balsamifera*	*Tamarindus indica*
Nerium odorum	*Prosopis juliflora*	*Ulnus sp*
Peltophorum ferrugineum	*Psidium guajava*	*Zizyphus mauritiana*
Phoenix sylvestris	*Pterospermum acerifolium*	*Zizyphus jujuba*
Phyllanthus distichus	*Quercus alba*	
Phyllanthus emblica	*Quercus palustris*	
Picea sp	*Quercus rubra*	
Pithecolobium dulce	*Quercus virgiana*	
Polyalthia longifolla	*Sesbania aegyptiaca*	
Prosopis juliflora	*Spondias mangifera*	
Psidlum guajava	*Syzygium cumini*	
Punica granatum	*Tamarindus indica*	

Contd.....

Ricinus communis	*Teminalia arjuna*
Salix planifolia	*Teminalia tomentosa*
Shorea robusta	*Thuja occidentalis*
Solanum xanthocarpum	*Thuja plicata*
Spathodiea companulata	*Tilia cordata*
Spondias mangifera	*Zizyphus jujuba*
Streblus asper	*Tabernaemontana coronaria*
Tamarindus indica	*Tecoma stans*
Tecomella undulate	*Tectona grandis*
Thevetia nerifolia	*Vitis sp.*
Zizyphus jujuba	

township. Types of trees planted are indigenous: *Leucaena leucocephala, Albizzia lebbeck, Eucalyptus, Azadirechta indica, Delbergia sisoo, Tamarindus indica*, etc. Percent reduction efficiency of air pollutants due to 500m-width green belt is given in Fig. 2. This clearly shows the effectiveness of Greenbelt in pollution reduction and maintaining the ecological balance of the ecosystem.

The air pollutants are most effectively reduced with an efficiency of about 39% SO_2 & NOx, 37% SPM, 86% THC, 93% CO and 87% VOCs. The noise levels are also reduced to about 33%. Thus, it is concluded that the overall performance of the green belt for reducing / managing the waste generated in the refinery is more than 60%. Over and above, it provides aesthetics and habitat for many flora and fauna.

CONCLUSION

The paper presents the importance of green belt development for reducing air pollution around industries and urban areas and summarizes in detail various aspects of designing and development of green belt. The benefits of green belt viz. improvement of aesthetic environment in residential areas, useful as a means of social development and improvement of habitat conditions for birds and animals is an effective method for biodiversity conservation.

Such studies could strengthen public understanding of the less known benefits of urban trees and provide clues for green space design and management.

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