Planning the Green City of 2050: Species Selection in a Global Change Scenario

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Abstract

The presentation will focused on the technical and practical solutions for the selection of trees that might be the best choice in the urban environments for the next 100 years, given differences in urban sites (infrastructures, climate, soils etc), species attributes, management requirements and climate change. The presentation will be divided in the following parts:

- Trees and climate change in the urban environment (main characteristics of the urban areas. Tree physiology as influenced by typical environmental constraints of urban stands).
- Trees and infrastructure (Improving relations between technical infrastructures and vegetation.
- Selection of planting material in a global change scenario

Presenter Biography

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Scientific activity focused on:

- Impact of plant selection and nursery production practices on root regeneration and tree growth after planting
- Physiological and growth aspects of different species as affected by different cultivation techniques after planting in the urban environment
- Evaluation of morpho-physiological and biochemical parameters to study urban stress tolerance on tree species.
- Evaluation of the ability of shrub and tree species to mitigate the effect of pollution in the urban and periurban environment
- Planning the green city in the global change era: urban tree functions and suitability for predicted future climates (TreeCity)

From 1990 he has published more than 210 scientific and technical papers in Italian (112) and in English (101) in international referred and nationwide journals. He has given more than 100 talks in several international and national congresses.

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Trees and climate change

Climate change is a scientific certainty and cities will be exposed to climate stresses which will involve higher temperature, lower air humidity and soil water availability, as well as higher levels of air pollutants. Effects of climate change are already detectable and will be more evident in the next 40 years. Rapid increases in human population and economic development have led to tremendous urbanization: more than 50% of the world human beings is now living in an urban area and 70% will do that in the year 2050, but urban areas are estimated to be less than a mere 3% of the total land of our planet. As more people's lives are predominantly urban, opportunities for interaction with the natural world decrease, with potentially serious effects for human health and wellbeing. An urban area is a living complex mega-organism, associated with lots of inputs, transformations, and outputs: heat, energy, materials, and others. Urban activities have now become a threat to the global environment. Solving and mitigating problems, including the design of ecologically efficient urban areas, is therefore of prime importance.

Trees are essential in the urban environment not only because of their aesthetic and social values, but also for their effects on air quality. Trees offer double benefits: first by directly sequestering and storing atmospheric C and other pollutants; second, by providing a natural cooling mechanism through evapotranspiration and shade, green space dissipate solar energy that would otherwise be absorbed, so reducing air-conditioning energy needs and avoiding pollutant emissions. These abilities are counteracted by pollutant toxicity and adverse environmental conditions. Urban vegetation is often subjected to more extreme environmental conditions than vegetation of the peri-urban and rural areas. These conditions are related not only to higher atmospheric pollution levels caused by traffic and other anthropogenic emissions, but also to limiting water availability and higher temperatures, typical of the city microclimate.

Due to the negative future prospects for the urban environment caused by global climatic change, there is a need to monitor and manage pro-actively urban greening and peri-urban forests and to gather more basic data about urban trees, and urban green in general. Research projects have shown that, in the short time, the exposition to high CO_2 levels, reduces the stomatal conductance, but increases photosynthesis and growth up to 20-50%, according to the species, plant age and water and nutrients availability. For this reasons, understanding how the increase of temperature will modulate plant responses to increased atmospheric CO_2 has been described as a priority for the research on climate change. The majority of studies concerning the effect of temperature raising on tree growth shows that a 10°C increase in growth temperature resulted in a 1.7-fold increase in total biomass. This has been particularly noted in regions with temperate-cold climate and in the northern part of the distribution range of each species and suggests that plants, at present, live in suboptimal conditions or are able to adapt to a moderate increase temperature. On the other hand, plants which live in the southern portions of the natural distribution area seem to have a lower plasticity of response to temperature increase compared to their counterparts which live the northern regions and, consequently, they have less adaptability to climate change. Similar considerations hold for the species that populate environments characterized by above-optimal temperatures in summer, such as the Mediterranean and the urban one.

According to recent evidences, the urban environment will be the one which will experience the strongest effects of climate change, because of the multiple interaction between water stress, increased temperature (diurnal and nocturnal) and increased atmospheric CO_2. A recent study has shown that *Liquidambar* plants exposed to elevated CO_2 were most affected by drought, despite of the increased in root biomass and of lower stomatal conductance. The interactions between climate change and urban forests include at least two main elements: urban tree contributions and urban tree vulnerability. There are two facets of an adaptation response in an urban forest setting: adjusting the urban forest to change and using urban forests to help cities adapt to change. There are a number of existing stressors on urban trees and challenges to urban forest management that make it difficult to maintain a healthy, multi-age, multi-species forest and make trees more vulnerable to the impacts of climate change. Urban forest management strategies to help improve air quality in future scenarios include: increase the number of healthy trees (increases pollution removal); sustain existing tree cover (maintains pollution removal levels).

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (2007) predicts that the surface air temperature will increase 2-5 °C by the end of this century. The report also predicts significant changes in wind and precipitation patterns. Trees will be affected by this rapid climate change because of their long life spans and the slow rate of genetic adaption. However with a proactive management strategy (i.e. acting in advance of a future situation), vegetation greening and belts of peri-urban forests also have strong potentials to mitigate the impact of global warming such as extreme heat waves. Clear guidance is therefore needed for local authorities and other practitioners on how best to manage public urban green spaces in order to respond to climate change. Therefore, as a proactive measure, urban foresters should consider using species suitable for future climates in current urban greening project.

Trees and infrastructures

Cities have changed and will change in the future and conflicts between trees and infrastructures need to be managed in advance to avoid damages, thus economic losses, and reduced tree growth which results in less benefits. In fact, tree roots can cause severe damage to sewer or septic lines, storm water drains, water supply lines, building foundations, sidewalks, streets, parking lots, curbs, walls and swimming pools, and each year the repair of this damage is a major cost to cities. There is the potential for a range of plant species to cause tree root problems. For example, Italian stone pine (*Pinus pinea* L.), sycamore maple (*Acer pseudoplatanus* L.), Siberian elm (*Ulmus pumila* L.), Dawn redwood (*Metasequoia glyptostroboides* Hu & Cheng) and some species of poplar (*Populus* spp.) are known to interfere with paving and sidewalks. D'Amato et al. (2002) found that the probability to find root growing underneath the sidewalk was different among the genera tested in the research. *Gleditsia* developed the highest number of roots growing beneath the sidewalk, at the smallest trunk diameter, followed by *Zelkova, Koerleuteria* with *Quercu*s which produced the lowest number.

However, it must be stressed that although tree roots are blamed for cracking concrete and invading sewer lines, it is equally valid to point out that these structures fail because they have not been properly engineered to function in a landscape that contains growing trees and their roots. Unfortunately, the main approach in too many cities has been to remove trees rather than to find ways to redesign structures to be compatible with trees.

We have to consider that surface sealing and restricted rooting space lead to insufficient water and oxygen supply (Kopinga 1989; Kjelgren and Clark 1993a). For this reason is important to dig tree pits sufficiently large to allow for healthy tree growth and physical stability of the tree. Under natural conditions, the rooting zone of an individual tree may be approximated to the crown projected surface area (obviously this is different for fastigiated forms). Smaller pits can be tolerated if the trees can penetrate into the soil underneath adjacent paved footpaths and streets. However, this has become increasingly difficult due to sealing by water-impermeable surfaces, heavy compaction and occupation of the space by utilities (Pauleit 2003). Moreover the tree trench/pit should be covered by a surface which allows infiltration of rainwater into the rooting zones and maintains aeration. Where the risk of soil compaction is high, pavements with large gaps or the use of coarse gravel might be a better solution than lawn (Pauleit 2003).

Current practice in European urban areas often falls significantly short of these standards. The size of the planting pits varied between 2 m^3 and 10 m^3 (2,62 – 13,08 y^3) per tree. Even tree pits as small as 0.5*0.5 m (20"*20") have been reported as a standard scheme (Pauleit 2003).

Another thing to consider is that urban soils often have low organic matter content, low and unbalanced nutrient contents and/or low nutrient availability due to a high soil pH (Bradshaw et al. 1995; Balder 1998). Impermeable soil layers can also lead to waterlogging. Tree soils should have good water-holding capacity but drain freely and be well-aerated. Trees need to be supplied with a balanced mix of nutrients. Tree pits should be backfilled with a purpose-designed tree planting mix (Balder 1998).

At the same time we have to think about carefully to the damages that roots can produce to sidewalks or other infrastructure in every cities. A kind of solution could be the root barriers. Numerous researchers have suggested that root barriers are a potential solution to the conflicts between green and gray infrastructure (Hamilton 1984; Coder 1998; Randrup et al. 2001), although this is not universally accepted (Mead 1994). Root barriers are a physical or chemical impediment intended to limit root growth to designated areas away from infrastructure (Morgenroth 2008). There are three main classes of root barrier: traps, inhibitors, and deflectors (Coder 1998).

Traps do not entirely inhibit root growth; they allow root tips to penetrate small holes, but subsequently preclude radial growth by girdling (Morgenroth 2008). They could be made by woven nylon or copper screen, which are permeable and allow for lateral water movement and gas exchange (Coder 1998). But at the same time they severely restrict large root development in one or more directions and may predispose trees to instability (Morgenroth 2008). Inhibitors are used to control root growth by means of chemical intervention. They are composed by a slowly released herbicide, which is considered to have no detrimental environmental impact beyond the root control area (Van Voris et al. 1988).

Deflectors are physical impediments to root growth and are often constructed from plastics. They function by redirecting root growth away from infrastructure and by forcing roots to grow at major depth (Morgenroth 2008). The forces that they exert will dissipate through a larger volume of soil before reaching the sidewalks above. They can be used adjacent to roads or sidewalks; in fact they may impact air and water movement throughout the soil profile.

The barriers can be linear or circular. The firsts are installed in narrow trenches along the edge of a desired protection zone such as a sidewalk or curb; these are more flexible and can be used near new or existing trees. The others are installed around the rootball of a newly planted tree in street pits or other restrictive spaces (Randrup et al. 2001) and they are used only for new plantings.

Research shows that barriers are effective in well-drained, uncompacted soils, which are virtually nonexistent in roadside urban areas and that there are different and often opposing root responses to barriers, this is maybe due to the variability of root growth and its sensitivity to soil conditions (Wagar 1985; Knight et al. 1992; Wagar and Barker 1983; Urban 1995; Barker 1995a, 1995b; Gilman 1996; Costello et al. 1997; Peper 1998; Peper and Mori 1999; Gilman 2006). This points to a species-specific response to root barrier use, a phenomenon noted by Wagar (1985) and Costello et al. (1997).

D'Amato et al. (2002) showed that cracked sidewalks are more likely to favour oxygen dissemination into the soil under the sidewalk and are associated with increased root growth. For example, aggressively rooted species (i.e. *Acer* spp, *Populus* spp, *Pinus pinea*, etc.) planted in older cracked sidewalks would require the earliest intervention to delay sidewalk failure related to tree root growth; instead less aggressively rooted species planted near newer or well-constructed sidewalks with few cracks allow for a delay in preventive measures such as root pruning or root barrier installation.

A recent work from Smiley (2008) compared different methods to reduce sidewalk damage from tree roots. It emerged that minimal sidewalk lifting was associated with the Deep Root barrier, gravel and foam treatments and that the treatments did not affect tree growth.

For the following research is important trying to determine the effect of barrier use on tree health, if they can be used to inhibit root growth or displace roots into deeper, poorer soils like in urban areas. Another aspect is trying to identify tree species that would benefit from delayed root barrier installation and which species should be treated early after planting or may not benefit at all from such treatments.

It's important to improve all aspects about site conditions and how select tree species well-adapted to the urban environment. These need to be based on comprehensive inventories of the urban tree resource and should assess the aesthetic, social, environmental and economic functions of the urban forest.

Selection criteria in a global change scenario

The first step is to analyze the sensitivity of the different species to global change. This aspect has been discussed in a dedicated session of the annual conference of the International Society of Arboriculture held in Providence, RI in 2009. The assessment should identify whether global change could cause significant negative impacts on tree growth and physiology. If a species appears to be not sensitive to climate change, city planners and arborists should move on the next step, that is site assessment and modification (if needed) and planting. If a species appears to be sensitive to climate change, there will be a need to select potential alternative species.

The main selection criteria, other than those technical (B&B or containerized plants, smaller or bigger trees, morphological traits) and aesthetical (deciduous or evergreen species, trunk, leaves and flowers colour, density and texture, growth and habitus uniformity, canopy height and shape in relation to street dimension) are mainly referring to the development of successful tree planting program which takes into account the intrinsic characteristics of the urban environment and the setting up of a regular program for a long-term management.

These criteria can be summarized as follows:

Bioecological (tolerance to anoxia, tolerance to soil compaction, tolerance to drought, disease resistance, low risk to become an invasive species, being a food source for local fauna, tolerance to shade, tolerance to soil pollution and anormalities)

Functional (low maintenance cost, reduced conflicts with human activities and health, growth rate, longevity, improving urban climate and pollutants reduction, tolerance to root manipulation, conflicts with sidewalks, pavements, etc., susceptibility to frequent pruning in relation to possible interferences with traffic and services, branch breakage potential, easy to transplant and to manage).

Physiological: CO_2 sequestration and storage, pollutants removal and inactivation, BVOCs production.

Some of the above mentioned criteria have been already discussed and we therefore briefly review those which are probably more important in a global change scenario and we indicate how these criteria might guide the choices of landscape architects, municipal arborists, city planners and so on.

Disease resistance and stress tolerance
The selection of pest-resistant landscape trees is considered to be the most efficient and long-lasting control method for the insects and diseases that plague trees growing in urban and metropolitan areas (Santamour, 1977). People who work in the field of arboriculture are aware of the uniqueness of tree diseases when the trees are located near large human populations. Already in 1977, Wilson reported that one disruptive force (in our case the climate change or the construction of building and infrastructures) can set into play a chain of successive changes. These changes can proceed to a point where certain species no longer can survive in that ecosystem because it becomes unfit for the existing vegetation. We are becoming aware of air pollutants that may have profound effects on disease and insect problems of urban trees. Possibly the direct air pollutant damage to trees is small compared to the predisposing effects of these disruptive agents to other tree problems and there is an endless array of disease complexes that can be conceived for urban tree diseases. Research is strongly needed all around the world to develop trees that can tolerate these stresses. A breeding and selection program to develop trees for artificial ecosystems needs to take cultural practices into account. Trees can be selected that are compatible with existing cultural practices or that reduce the cost of such practices. According to Shurtleff (1980) we can distinguish five steps to get better trees into an urban landscape: 1) mass field selection to discover sources of resistance. This involves testing of many thousands of individuals collected over a wide geographical area; 2) vegetative propagation of likely candidates. But there is a need to reduce this number quickly to get a breeding program down to a manageable size; 3) trial plantings over a wide area and under highly variable conditions; 4) evaluation of test selections with certification (if feasible) of the best individuals to build up clone numbers; and 5) distribution to commercial growers. This will be money and time consuming, but the results can be beneficial for the future of our cities.

In recent years many cities have planted, especially in Northern Europe not only trees of a selected species, but even a selected clone on street after street. It is obviously nice to see a wide avenue made of identical trees belonging to the same species, but unfortunately, as recently stated by Bassuk et al., (2002) the appeal of same species plantings is ultimately outweighed by disadvantages. Even if aesthetics was the only consideration, the fact that unhealthy or dead trees are unattractive, makes the need to diversify unavoidable. A quick review of disease and pest problems in street tree populations reveals numerous cases of devastation due to over planting or the exclusive planting of a single species throughout a community. Some of the most notable examples include the American elm (Dutch elm disease), American chestnut (chestnut blight), Honey locust (honey locust plant bug), Norway maple (giant tar spot and verticillium wilt) London planetree (canker, anthracnose) and crabapple (scab, fireblight, cedar apple rust, and powdery mildew).

Still, according to what stated by Bassuk et al., (2002) to avoid similar problems in the future, it is clear that uniform plantings of a limited number of species must be avoided. But, is it possible to gain the practical advantages of diversity without giving up the aesthetic advantages of uniformity? Fortunately, the answer is yes. Through careful selection and grouping of plants, communities of trees can be created which, despite their genetic diversity, can satisfy our desire for visual uniformity. By breaking down the visual characteristics that distinguish one species or cultivar from another into basic categories, it is possible to select criteria for putting trees into aesthetically compatible groups.

So the key against adversity is increasing biodiversity and keeping a good species diversity in plantings is always a wise management decision. As new pests and diseases inhabit our woody landscapes, species diversity may be a critical key to minimizing their impact. Ware (1994) suggests to seek out pioneer species meaning those plants that colonize open fields or newly formed land surface left behind such as ex-industrial areas, coal or gravel mines. Pioneer species can change accordingly to the site but, at least in Europe and North America, they generally belong to genera like *Populus, Celtis, Ulmus, Cornus, Crataegus, Salix, Acer, Betula*.

CO_2 and urban trees
The evidence so far suggests that increased CO_2 may result in increased tree growth if other factors (water, temperature, nutrients, etc.) are not limiting, and this effect may be temporary for some species (Johnston, 2004) as it has been underlined by several researchers.
It is also well known that trees sequester carbon in their tissue at different rates and amounts based according to their size at maturity, life span, and growth rate, as well as health state. As underlined by Nowak et al. (2002) at the same time tree care practices release carbon back to the atmosphere based on fossil-fuel emission from maintenance equipment. It is therefore not only necessary to perfectly match the species to the site, but also to choose those species that ask for a minimal maintenance to provide their benefits in CO_2 sequestration and storage. Planting strategies could be adapted to select species which are not only very efficient in sequestering CO_2 but that have shown to have a higher water use efficiency (WUE - ratio between net photosynthesis and transpiration rate). Comparative studies of WUE are important for helping to understand how future climate changes will affect the carbon and energy budget of the different ecosystems including the urban one. So it becomes of paramount importance to test different species in the urban stand in order to select those with a lower transpiration rate for the amount of carbohydrates produced. The efficiency of water use can also be improved by increasing in the density of tree cover and mulches so that little heat reaches the soil surface and evaporation is kept to a minimum. Under this conditions the largest possible portion of the incoming energy can be used in photosynthesis and the most photosynthates produced per unit of water evaporated.

Reduced conflicts with human activities and health
It is well known by people involved in the arboriculture field that trees have their good and bad characteristics. Not always a tree throughout its lifetime satisfy or maintain the objectives

for which it was planted. Trees become larger over time, often outgrowing their original growing space both above and below ground. Some trees also produce fruits or seeds that may be troublesome for the municipality, citizens, car drivers and homeowners.

Therefore trees do not always bring only benefits: in some cases their presence makes the sharing of space and coexistence difficult, in addition to the expenditure of considerable economic resources for their management and maintenance.

Frequently the individual trees that make up an urban arboreal patrimony belong to different species and, as a consequence, there is great variability in shape and size, which leads to problems of varying origin and nature depending on the species and where they are located. The most frequently encountered problems are those linked to the normal cycle of growth and seasonal phenology of the plants. For example there can be problems connected with flower formation (and thus pollen production) which, in addition to the release of allergens, include attraction of insects, production of fleshy fruits and, last but not least, problems related to structural stability of the tree. A list of trees to reconsider before planting, has been published by Clatterbuck and Fare (1998) although written for a specific environment (Tennessee) it gives an idea about the criteria to be followed for selecting tree for urban planting.

As underlined by Sogni (2000), the pollen responsible for the principal allergic reactions comes, fundamentally, from anemophilous species which, in general, produce large quantities of pollen (typically very light and small with a smooth, dry surface; diameters of 20-30 μm are typical with maximums of 150 μm for some coniferous species) and depend on poorly selective diffusion agents such as wind. Entomophilous species are, instead, characterized by pollen which is frequently heavy and spread by insects, and as it is poorly dispersed through the air, it is rarely present in the atmosphere at concentrations sufficient to trigger an allergic reaction. However, there are exceptions such as *Tilia*, an entomophilous genus that often causes an allergic response. In cases such as this, given there is limited air-borne spread of pollen, allergic reactions are noted (at least most violently) with close, direct contact with the producing plant.

The spread of pollen grains in the environment depends not only on the quantity produced but also on climatic events during flowering (e.g. wind, rainfall, atmospheric humidity) and the presence of barriers to their diffusion (e.g. vegetation, buildings, etc.).

The potential for allergic reaction toward a pollen cannot be directly correlated to its dispersability nor to the amount produced. For example, conifers rank first for individual quantity of pollen produced, but they are toward the bottom of a hypothetical ranking of species responsible for allergic reactions (with the exception of *Cupressus sempervirens*); conversely, *Graminaceae* are at the top of the list in terms of allergenity but they are individually modest producers of pollen yet are largely spontaneous and wide-spread in nature and often highly concentrated in large biophytic associations. It is interesting to note that there are some species able to trigger allergic reaction only at elevated spatial concentrations of individuals. This is the case of *Phoenix dactylifera* and *Trachycarpus fortunei*, primary allergic agents in North African countries but of little or no interest in countries at higher latitudes due to their limited presence; or species such as *Fagus sylvatica* and species belonging to the genus *Betula*, to cite only a few examples, which are generally not found in urban landscapes (or are limited to the higher latitudes) but when introduced for ornamental purposes register an increase in importance as allergens with increased diffusion.

Climate change will probably trigger some changes in the species distribution and might enhance pollen production which could, in turn, increase the risk of aggravating allergies. Meteorological factors strongly influence the timing and duration of the pollen season as well as the total pollen count, thus the seasonality of pollen-related disorders such as hay fever may be affected by climate change.

Litter from urban trees is another widespread problem, although it varies in magnitude among trees of many species. Fallen fruits can dirty an environment or give off unpleasant odors (i.e. *Ginkgo biloba*) or, in cases of large or particularly hard fruits (e.g. the cones of the Italian stone pine – *Pinus pinea*), they can cause damage. Even the simple falling of leaves can cause damage, or at least troubles when pavement and asphalt become slippery.

A good review on littering from urban trees was written by Barker (1986). His article closely examined the trees that produce the most litter in the urban environment. For example American sweetgum (*Liquidambar styraciflua*) is sometimes extensively planted along urban streets, yet its fruits are a vexing litter problem. Lavalle hawthorn (*Crataegus x lavallei*) is frequently recommended for street planting (especially in narrow streets) for its stress tolerance, but its fruits can increase the risk of slipping. Full-grown purpleleaf plums (*Prunus cerasifera* 'Pissardi'), are among the most appreciated ornamental trees, but their fruits are an intolerable nuisance, because they litter roads and sidewalks. In general, fleshy fruits are usually messy, but other types of fruit can also be annoying. Other examples are pods of carob (*Ceratonia siliqua*), honeylocust (*Gleditsia triacanthos*), black locust (*Robinia pseudoacacia*) and Japanese pagoda tree (*Styphnolobium japonicum*), nut like those of horsechestnut, acorn (especially some species of oak, like *Quercus rubra*, produce annually a high amount of fruits) or ball-like fruits of plane trees (*Platanus x acerifolia*).

If little can be done to prevent or diminish the problem of fruit litter from existing trees, possibly the best solution, in the long run, is to use non fruiting species and cultivars in newly developed areas when existing trees are replaced (Barker, 1986). In dioecious species (i.e. *Ginkgo biloba*, *Gymnocladus dioicus*) propagation of only male individuals is the easiest way to obtain non fruiting trees. In countries with Mediterranean-like climate the use of olive trees as ornamental plants can be suggested for the undoubted favourable properties of this species; unfortunately in an urban setting olive trees can be messy. Some selections of fruitless olive trees have been patented and their use is suggested over patios, walks, lawns, driveways, and streets and everywhere drought tolerant species are needed.

Sometimes it is not the plant itself which can cause negative interaction with human life but the parasites which attack it. For example, both pine (actually this insect is quite ubiquitary and can be found also on other conifers) and oak processionary moth are spread throughout Europe. These two species are mainly found in central and southern parts of the continent and create "population explosions" in limited areas at time intervals of approximately 20 years, commonly lasting for two or three years. Small stings from these caterpillars contain thaumetopoein, a nettle-poison, from the first stages of the caterpillars and increase until the end of May or beginning of June, but with climate change they start to migrate, especially at lower latitudes already at the end of March-beginning of April. Their small hairs, dispersed in the air, on plants and soil, irritate the skin and mucous membranes of mammals. Attacks of aphids on street trees can determine a strong production of honey dew that makes cars, sidewalk and pavement very sticky and dirt.

It can happen that people, especially children, climb trees and fall out of them; and they may be poisoned by or suffer an allergic reaction to certain trees. Trees with thorns may also present a danger.

Without a doubt, whenever possible, careful selection of species and proper placing of trees can avoid, or at least minimize, these problems (the theory of "the right plant in the right place with the right management). Yet, frequently the arboreal patrimony we find and must manage is the result of plantings that occurred in a time when attention to space and maintenance (in terms of plant dimensions that did not cause conflicts, as well as a different context in terms of resources) presented few problems.

BVOCs production

It is also well-known and documented that plants emit a substantial amount of biogenic volatile organic compounds (BVOCs) such as isoprene and monoterpens. Into the atmosphere BVOCs react with nitrogen oxides (NOx) to form ozone. Although their contribution may be small compared with other sources, BVOC emissions from plants could exacerbate a smog problem. Trees that are well adapted to and thrive in certain environments should not be replaced just because they may be high BVOC emitters. The amount of emissions spent on maintaining a tree that may emit low amounts of BVOCs, but is not well suited to an area, could be considerable and outweigh any possible benefits of low BVOC emission rates. Trees should not be labeled as polluters because their total benefits on air quality and emissions reduction far outweigh the possible consequences of BVOC emissions on ozone concentrations. Emission of BVOCs increase exponentially with temperature. Therefore, higher emissions will occur at higher temperatures. In desert climates, locally native trees adapted to drought conditions emit significantly less BVOCs than plants native to wet regions. As discussed above, the formation of ozone is also temperature dependent. Thus, the best way to slow the production of ozone and emission of BVOCs is to reduce urban temperatures and the effect of the urban heat island. As suggested earlier, the most effective way to lower temperatures is with an increased canopy cover. These effects of the urban forest on ozone production have only recently been discovered by the scientific community, so extensive and conclusive research has not yet been conducted. There have been some studies quantifying the effect of BVOC emissions on the formation of ozone, but none have conclusively measured the effect of the urban forest. As stated by Penuelas and Lluisà (2003) among a variety of proven and unproven BVOC functions in plants and roles in atmospheric processes, recent data intriguingly link emission of these compounds to climate. Ongoing research demonstrates that BVOCs could protect plants against high temperatures. BVOC emissions are probably increasing with warming and with other factors associated to global change, including changes in land cover. These increases in BVOC emissions could contribute in a significant way (via negative and positive feedback) to the complex processes associated with global warming but on this subject there are still many unanswered questions. Not all species of trees, however, emit high quantities of BVOCs. The tree species with the highest isoprene emission rates should be planted with caution: in terms of species choice we should consider that, for instance, most broadleaved species from genera *Eucalyptus, Casuarina* (Beefwood), *Liquidambar, Robinia* (Black locust) *Liriodendron, Populus, Quercus, Nyssa* (Tupelo or Black gum) *Platanus* (Plane), *Salix* and, essentially, all conifers are important emitters of volatile isoprenoids while others such as *Acer* and *Tilia* have low emitting potential (Niinemets and Penuelas, 2008).

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