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Review

Urban green zones and related pollen allergy: A review. Some guidelines for designing spaces with low allergy impact

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ABSTRACT

Urban green spaces are a key element in the planning of today's cities, since they favor the interaction between citizens and the environment, as well as promoting human health. However, lack of planning in the design of urban spaces and in the choice of ornamental species has been among the factors triggering one of the most widespread diseases in urban populations: pollen allergy. In this paper are reviewed the major causes of this extensive allergenicity, including: low species biodiversity at planting; the over-abundance of given species acting as key specific pollen sources; the planting of exotic species prompting new allergies in the population; the choice of male, pollen-producing individuals in dioecious species; the presence of invasive species; inappropriate garden management and maintenance activities; the appearance of cross-reactivity between phylogenetically related species; and the interaction between pollen and air pollutants. The findings of this analysis highlight the clear need for guidelines regarding the design and planning of urban green spaces with a low allergy impact. Proposals include increased biodiversity, careful control when planting exotic species, the use of low pollen producing species, the adoption of appropriate management and maintenance strategies, and active consultation with botanists when selecting the most suitable species for a given green space.

Contents

1. Introduction

Urban green spaces are a key element in the planning of modern cities, in that they foster the interaction between citizens and the environment within an urban context, promote human health, and provide substantial environmental and recreational benefits to urban citizens. Matsouka and Kaplan (2008) aimed to determine what people require from the urban landscape and highlighted two major categories: the need for nature, reflecting the numerous ways in which human needs are met by the natural environment, and the need for human interaction, particularly as promoted by the urban environment. This second need underlines the potential role of urban design in enhancing human conditions: several studies have

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revealed that simply viewing nature through windows reduces the stress of daily urban life (Jackson, 2003); hospital patients with window views of greenery recover faster (Ulrich, 1984); and lower levels of domestic violence are recorded among residents living in areas with trees (Sullivan & Kuo, 1996).

Growing appreciation of the role played by green spaces in regulating the local mesoclimate (Domm et al., 2008) and in the removal of gaseous air pollutants derived from human activities (Nowak et al., 2000) has led many cities to become immersed in a frantic greening process, which has had a direct impact on the citizens' quality of life (Chaphekar, 2009; Chiesura, 2004; Lewis, 1992).

However, despite the undeniable benefits of urban green spaces for human health, they are associated with a number of problems. Urban woodlands may reduce air quality through the emission of biogenic volatile organic compounds involved in ozone formation, which can exacerbate smog problems (Domm et al., 2008). Additionally, trees may harbor hazardous diseases and insect pests and generate fruit/leaf litter. Perhaps the most serious challenge posed by urban green spaces, though, is related to human allergic reactions to the airborne vascular plant pollen released during pollination. Recent data suggest that people living in urban areas are 20% more likely to suffer airborne pollen allergies than people living in rural areas (D'Amato et al., 2007; Ogren, 2002). This situation has emerged due to several factors, chief among which are the uniformity of green spaces, where a small number of species that have proved highly suited to urban environmental conditions are overwhelmingly used, and the interaction of pollen with air pollutants (Cariñanos, Prieto, Galán, & Dominguez, 2004; Cariñanos, Galán, Alcázar, & Dominguez, 2007), which can even prompt an increase in pollen production by certain herbaceous species (Ziska et al., 2003).

Continuous monitoring of airborne pollen has highlighted the major contribution of plants growing in green spaces and urban thoroughfares to the development of allergy symptoms in the local populations in several parts of the world (Cardona-Dahl, 2008), including Japan (Nakae & Baba, 2010), South Africa (Pordman, 1947), Australia (Bass, Delpech, Beard, Bass, & Walls, 2000), North America (Ogren, 2002; White & Bernstein, 2003), South America (Baena-Cagnani et al., 2009), and Europe (D'Amato et al., 2007). The progressive spread of cities with associated changes in architecture and landscaping preferences has not only displaced the ruderal species growing previously in newly urbanized areas but also facilitated the introduction of a growing number of imported and non-native plants (Sneller, Hayes, & Pinnas, 1993) and has also intensified the formation of urban islands in which the city's residents lead most of their daily lives (Cariñanos et al., 2004).

In this report, we examine some of the major causes of the growing allergenicity of ornamental species, particularly trees in urban environments, and review key features of the impact of this phenomenon on local residents. Additionally, guidelines are provided regarding the design and planning of urban green spaces with a low allergy impact.

2. Review of the causes of the growing allergenicity of ornamental species

2.1. Biodiversity

The need for biodiversity in urban ecosystems has become increasingly urgent as more and more people inhabit cities (Savard, Clergeau, & Mennecher, 2000). While species diversity is often positively correlated with the quality of life in cities (Middleton, 1994), the overabundance of some species may have a detrimental effect on local residents, which has been observed in association with many urban green spaces. A study of the tree species lining urban thoroughfares in Mediterranean areas of the Iberian Peninsula focused on the 12 most representative species in each town or city sampled. The results highlighted the limited diversity present: the total list included only 16 species, and the London plane (*Platanus hyspanica*) appeared in almost all of the towns sampled. Additionally, the analysis of the species commonly used as ornamentals in urban areas (Table 1) shows that many of these are anemophilous species producing large amounts of pollen that have a demonstrated allergenic effect on the local population, with more than 500,000 million grains being produced by a single tree in some cases (Piotrowska, 2008; Tormo Molina, Muñoz Rodriguez, Silva Palacios, & Gallardo Lopez, 1996). This category includes all species for which more than one scientific paper has reported a moderate degree of allergenicity in terms of various existing scales (e.g., Ogren Plant-Allergy Scale (OPALS^{TM}, Ogren, 2000), the Allergen Index (Hruska, 2003; Hruska & Staffolani, 2010).

Two Spanish cities provide specific illustrative examples of this phenomenon. Madrid has almost 300,000 roadside trees, which is one of the highest figures for this parameter in the world, of which over 60,000 are *Platanus* × *hispanica* and *P. orientalis*. In Barcelona, these species account for over a third of the 150,000 trees planted in urban areas. *Platanus* species are anemophilous, with an estimated pollen production of 13×10^6 pollen grains per inflorescence (Tormo Molina et al., 1996). Madrid and Barcelona are among the highest ranking Spanish cities in terms of airborne *Platanus* pollen counts during the pollen-producing season (Díaz de la Guardia et al., 1999); not surprisingly, these trees represent one of the main causes of pollen allergies among local people (Gabarra, Belmonte, & Canela, 2002; Sabariego-Ruiz, Gutierrez Bustillo, Cervigon Morales, & Cuesta, 2008).

Members of the Cupressaceae (*Cupressus* spp., *Platycladus* sp., *Calocedrus* sp., *Chamaecyparis* sp., *Juniperus* spp., and *Thuja* spp.) are very common in the city of Granada (southeastern Iberian Peninsula), where they are a key element of the city's famous historic gardens (Casares, 2010) and feature prominently in various districts of the Old Town. There are over 3000 Cupressaceae in the city. Due to the well established allergenic capacity of these species (Charpin, Calleja, Lahoz, Pichot, & Waisel, 2005) and to their exhibiting some of the highest pollen production levels of all anemophilous species, with more than 1100×10^6 pollen grains being produced by each tree (Hidalgo, Galán, & Dominguez, 1999), the incidence of allergic sensitization is estimated at close to 30%. Additionally, *Cryptomeria japonica* (Japanese cedar) is a species of Cupressaceae that is frequently used as a roadside tree along Japanese city streets, and its pollen is one of the main causes of pollen-related disease in these areas (Okuda, 2003).

2.2. Sources of pollen emissions

The low species diversity in many towns and cities is directly linked to the formation of large, concentrated pollen emission sources. The large-scale use of a small number of roadside tree species gives rise to the production of large amounts of monospecific pollen that cannot always be dispersed by air currents. In many cities with a temperate climate, urban green spaces are often characterized by an overabundance of a restricted number of species, particularly poplars (*Populus* spp.), willows (*Salix* spp.), elms (*Ulmus* spp.), cypresses (*Cupressus* spp.), and palm trees (*Phoenix* spp.). All of these species act as chimneys, simultaneously releasing large amounts of pollen into the air during the main pollen season. A good example of this is presented by Elche, an eastern Spanish town with one of the largest palm groves in the Mediterranean area, where the number of pollen-allergy sufferers is among the highest in all of Spain (Fernandez, 1992).

Another factor that generates pollen emission sources of considerable dimensions is the development of living screens, natural

Table 1
List of frequent plant species used as ornamental in urban environments with specification of its allergenicity (indicated as * for monoecious species and ♂ when dioecius), as well as other observations of interest in allergy.

Family	Species frequent in Mediterranean gardens	Allergenicity	Dioecious or female cultivars	Observations
Aceraceae	*Acer campestre*	*		
	Acer negundo	*		
	Acer pseudoplatanus	*		
	Acer platanoides	*		
	Acer opalus	*		
Anacardiaceae	*Cotinus coggygria*			
	Schinus molle	*		
	Schinus therebintifolius	*		
	Pistacia atlantica	♂	*Dioecious*	
	Rhus coriaria, R. tiphyna	♂	*Dioecious*	Female trees can cause contact allergy
Agavaceae	*Agave* spp.			
	Yucca spp.			
Apocynaceae	*Nerium oleander*	*		
Araucariacaceae	*Araucaria* spp.	*		
Arecaceae	*Phoenix dactylifera*	♂	*Dioecious*	
	Phoenix canariensis	♂	*Dioecious*	
	Washingtonia filifera			
	Wasingtonia robusta			
	Trachycarpus fortunei	♂	*Dioecious*	
	Chamaerops humilis	♂	*Dioecious*	
Betulaceas	*Alnus glutinosa*	*		
	Betula spp.	*		
	Carpinus betulus	*		
	Corylus spp.	*		
Bignoniaceae	*Catalpa bignonioides*			
	Jacaranda mimosifolia			
	Thevetia spp.			
Caprifoliaceas	*Sambucus nigra*	*		
Casuarinaceae	*Casuarina equisetifolia*	*		
Cupressaceae	*Calocedrus decurrens*	*		
	Chamaecyparis lawsoniana	*		
	Cupressus arizonica	*		
	Cupressus lusitanica	*		
	Cupressus macrocarpa	*		
	Cupressus sempervirens	*		
	Cupressocyparis × leilandii	*		
	Juniperus spp.	♂	*Dioecious*	
	Platycladus orientalis	*		
	Tetraclinis articulata	*		
	Thuja plicata	*		
Cycadaceae	*Cycas* spp.	♂?	*Dioecious*	
Eleagnaceae	*Eleagnus angustifolia*	*		
Ericaceae	*Arbutus unedo*			
Euphorbiaceae	*Ricinus communis*	*		Poisonous, avoid planting near path or houses, may can cross allergic reaction to latex
Fabaceae	*Acacia bayleyana*	*		
	Acacia cyanophylla	*		
	Acacia dealbata	*		
	Acacia farnesiana	*		
	Albizia julibrissim Bahuinia sp. Ceratonia silicua			
	Cercis siliquastrum		*Polygamous*	
	Erythrina spp.			
	Gleditsia triacanthos	♂	*Polygamous*	Avoid fruitles ♂cultivars as 'Moraine', 'Skycole' and 'Suncole'
	Robinia pseudoacacia	*		
	Robinia hispida			
	Sophora japonica			
	Tipuana tipu			
	Parkinsonia aculeata			
Fagaceae	*Castanea sativa*	*		
	Quercus ilex	*		
	Quercus robur	*		
	Quercus rubra	*		
	Quercus suber	*		

Table 1 (*Continued*)

Family	Species frequent in Mediterranean gardens	Allergenicity	Dioecious or female cultivars	Observations
Ginkgaceae	*Ginkgo biloba*	♂	*Dioecious*	
Hamamelidaceae	*Liquidambar styraciflua*	*		
Hippocastanaceae	*Aesculus hippocastanum*	*		
	Aesculus × carnea			
Lauraceae	*Laurus nobilis*	♂	*Dioecious*	Avoid ♂cultivars as 'Saratoga'. It may cause allergic reaction from contact with the foliage.
	Persea gratissima			
Lythraceae	*Lagerstroemia indica*			
Magnoliaceae	*Magnolia grandiflora*			
	Magnolia soulangeana	*?		All deciduous species may cause allergic reaction
	Liriodendron tulipifera			
Malvaceaae	*Lagunaria patersonii*			Avoid planting near path or houses, may can contact reaction with fruits hairs.
Meliaceae	*Melia azederach*			
Menispermaceae	*Coculus laurifolius*	♂	*Dioecious*	Poisonous bark, frequent in some olds gardens XIX S.
Mirtaceae	*Callistemon* spp.	*		Few capacity of pollen dispersion, avoid planting near path or houses.
	Eucalyptus camaldulensis	*		
	Eucalyptus globulus	*		
	Eucalyptus ficifolia			
	Metroxyderos spp.			
	Myrtus communis			
Moraceae	*Broussonetia papyrifera*	♂	*Dioecious*	
	Ficus spp.			
	Maclura pomifera	♂	*Dioecious*	Avoid ♂ cultivars as 'Double O', 'Fand'arc', 'Altamont'
	Morus alba	♂	*Dioecious*	Avoid ♂ cultivars as 'Fruitless', 'Mapleleaf', 'Urbana'
	Morus nigra	*		
Musaceae	*Musa* spp.			
Oleaceae	*Fraxinus angustifolia*	♂	*Polygamous*	'Flame', 'Moraine' an 'Raywood' are ♀ cultivars
	Fraxinus excelsior	♂	*Polygamous*	Avoid ♂ cultivars as 'Gold Cloud', 'Hesseri', 'Juglandifolia'
	Fraxinus ornus	♂	*Polygamous*	
	Ligustrum lucidum	*		Few capacity of pollen dispersion avoid planting near path or houses
	Ligustrum japonicum	*		Few capacity of pollen dispersion avoid planting near path or houses
	Olea europaea	*		'Swan Hill Olive' and 'Monher' are flowerless cultivars avoid ♂ fruitless cultivars 'Majestic Beauty'and 'Wilson's'
Pinaceae	*Abies alba*			
	Abies pinsapo			
	Cedrus atlantica	*		
	Cedrus deodara	♂		'Repandens' is a ♀ cultivar.
	Picea abies			
	Pinus halepensis			
	Pinus pinaster			
	Pinus pinea			
	Pseudotsuga menziezii			
Platanaceae	*Platanus × hispanica*	*		
Proteaceae	*Grevillea robusta*	*		It may cause skin irritation
Pittosporaceae	*Pittosporum* spp.			
Phytolaccaceae	*Phytolacca dioica*	♂	*Dioecius*	
Punicaecae	*Punica granatum*			
Rhamanaceae	*Rhamnus* spp.	*		
	Zizyphus jujuba			The fruits may cause food allergic reaction

Table 1 (*Continued*)

Family	Species frequent in Mediterranean gardens	Allergenicity	Dioecious or female cultivars	Observations
Rosaceae	*Chaenomeles speciosa*			
	Malus spp.			
	Mespilus germanica			
	Eriobotrya japonica			
	Photinia serrulata			
	Prunus cerasifera			
	Prunus domestica			
	Prunus dulcis	*		
	Prunus laurocerassus	*		
	Prunus serrulata	*		The *flore pleno* varieties are less allergenic
	Pyrus spp.			
	Sorbus spp			
Rutaceae	*Citrus aurantium*			
Salicaceae	*Populus alba*	♂	*Dioecious*	Avoid var *pyramidalis* know as bolleana is ♂. 'Siberia Extremeña' and 'Nivea' are ♀
	Populus × canescens	♂	*Dioecious*	
	Populus × euroamericana	♂	*Dioecious*	'Regenerata' is a ♀. Planting ♀ individuals may contaminate the natural populations of *P. nigra*
	Populus nigra	♂	*Dioecious*	Avoid 'Italica' is a ♂. In landscapping may be replaced by "*Gigantea*", female, or female individuals of *P. × canescens*
	Populus simoni	♂	*Dioecious*	
	Populus tremula	♂	*Dioecious*	Avoid 'Pendula' is a ♂
	Salix alba	♂	*Dioecious*	'Cardinalis' and 'Caerulea' are ♀, avoid 'Crisostela', 'Brizensis', 'Liempde' and 'Tristis' (=S. × sepulcralis) ♂
	Salix babylonica	♂	*Dioecious*	'Crispa'(='Annularis') is ♀
	Salix caprea	♂	*Dioecious*	'Pendula' is ♀ 'Kilmarnock' is ♂
	Salix matsudana	♂	*Dioecious*	'Torulosa' and 'Navajo' are ♀
Simaroubacee	*Ailanthus alisssima*	♂	*Polygamous*	'Erytrocarpa' is ♀
Sterculiaceae	*Brachychiton acerifolium*			
	Brachychiton discolor			The fruits hairs may produce allergic reaction.
	Brachychiton populneum			
	Firmiana simplex			
Strelitziaceae	*Strelitzia* spp.			
Tamaricaceae	*Tamarix* spp.	*		
Taxaceae	*Taxus baccata*	♂	*Dioecious*	'Adpresa', 'Cheshuntensis', 'Fastigiata', 'Fructu-luteo', 'Repandens' and 'Washingtonii' are ♀. Poisonous plant.
Taxodiaceae	*Cryptomeria japonica*	*		
	Metasequoia glyptostroboides			
	Sequoiadendron giganteum			
	Sequoia sempervirens	*		
	Taxodium distichum	*		
Tiliaceae (or Malvaceae)	*Tilia* spp.	*		Few capacity of pollen dispersion avoid planting near path or houses
Ulmaceae	*Celtis Australis*	*?		
	Ulmus minor	*		'Gracilis' is a flowerless cultivar
	Ulmus pumila	*		
	Ulmus glabra	*		'Horizontalis' is a flowerless cultivar
	Zelkova serrata	*		

edges and hedges. In many areas, it is a common practice to use a single constituent species for numerous purposes, such as acting as property boundary walls, lining avenues and open spaces, and the construction of anti-noise barriers. The species that are most used for these purposes include many members of the Cupressaceae and other species that successfully support the development of topiaries, such as privet (*Ligustrum* spp.), boxwood (*Buxus sempervirens*), holly (*Ilex* spp.), yew (*Taxus baccata*) and myrtle (*Myrtus communis*). Although continuous pruning usually diminishes flower production, the high economic cost of this process encourages poor maintenance, which can allow flowers and, consequently, pollen to be produced. This can also be linked to proximity pollinosis, as some of these species can produce flowers almost down to their base (Seitz & Escobedo, 2009), and pollen will, thus, be emitted at human height (Alcázar, Galán, Cariñanos, & Dominguez, 1999).

The microenvironmental conditions found in a given urban district can affect the quality of life of its residents. Comparison of pollen counts in areas with different degrees of urbanization reveals differences in terms of the quantity and number of pollen types recorded (Cariñanos, Sánchez-Mesa, Prieto, López, & Guerra, 2002), daily pollen cycles (Kasprzyk, 2006; Sikoparija, Radisik, Pejak, &

Simié, 2006) and plant growth and productivity (Ziska, Bunce, & Goins, 2004). In a study by Sanchez-Mesa et al. (2005) that related the sale of antihistamines in different districts of a city to the pollen content in each of these urban areas, it was observed that the highest sales figures occurred in the areas where there was also a large presence of ornamental trees.

2.3. Introduction of exotic species

Grouped together under this heading are all of the species growing outside their natural distribution range that have been introduced principally by man. In this section, we consider those species with a primarily ornamental function for which expansion is controlled in urban environments. The introduction of exotic flora for ornamental purposes has been found to have occurred in all ancient societies. The discovery of America and the great explorations of the 18th century gave rise to an unprecedented flow, leading to allergic responses among both New and Old World inhabitants (Selvaggio, 1992). Although some authors have recommended the introduction of exotic plants as a preventive measure to avoid sensitization (Chiesura, 2004), there is evidence showing that the use of some exotic species as ornamentals in towns and cities has eventually given rise to new sources of pollinosis for local residents. The genus *Casuarina* (Australian pine) comprises approximately 60 species that are mainly native to Australia and southern Asia. Some of these species have been used as ornamentals, mainly in coastal cities (Trigo et al., 1999). These wind-pollinated trees produce large amounts of pollen during the main pollen season, which generally occurs during late summer and autumn. As a result, *Casuarina* has become a cause of autumn pollinosis, thus extending the period of symptoms for polysensitized patients (Garcia et al., 1997).

Similar characteristics are reported for a number of *Eucalyptus* species. This highly adaptable Australian genus has been used widely for reforestation, and the pollen counts of these trees are sufficient to cause allergy symptoms (Galdi, Perfetti, Calcagno, Marcotulli, & Moscato, 2003).

Finally, the potential allergenic capacity of *Ginkgo biloba* pollen in the near future should be noted. *Ginkgo biloba* is considered the oldest tree species surviving on earth. It is native to eastern China and was introduced into Europe from China around 1730 and to the USA in 1784 (Cothran, 2004). This living fossil adapts well to urban conditions, and its use to line urban thoroughfares has become fashionable among the Parks and Gardens Departments of many European and American towns and cities. *Gingko biloba* is a dioecious gymnosperm with spectacular fan-shaped leaves that turn gold in autumn. Because its seeds give off an odor of butyric acid, most of the trees planted are male, and on reaching reproductive maturity (at approximately 10 years), they release large amounts of pollen with a demonstrated allergenic capacity (Yun, Si-Hwan, Jung-Won, & Chein-Soo, 2000).

2.4. Botanical sexism

Ogren (2000) attributed the increasing incidence of pollen allergies in the urban environment to botanical sexism in the process of selecting ornamental species for many towns and cities. He correctly noted that "for reasons of convenience, more and more shrubs, trees and other plants are selected for their 'litter-free' characteristics, that is, they are male types and generate few or no seeds or fruits". Some of the species that are commonly used in urban green spaces are dioecious, i.e., individual trees are either wholly male or wholly female. Fruit production (sometimes parthenocarpic) in female plants is associated with a number of problems, including litter, undesirable odor, and slippery ground surfaces. As a result, there has been a marked increase in the use of male trees, which are often selected from asexually propagated clones that are pollen intensive (Ogren, 2002). The dioecious species that are widely planted in warm areas and exhibit pollen with a demonstrated allergenic capacity include *Salix* (Reqi, Xie, & Wei, 2001), *Schinus* (Vargas Correa et al., 1991), *Acer* (Eriksson, 1978), *Morus* (Navarro et al., 1997), *Ginkgo* (Yun et al., 2000), *Juniperus* (Hrabina, Dumur, Sicard, Viatte, & Andre, 2003) and some palms of the genus *Phoenix* (Blanco et al., 1995). Similar problems are also posed by certain polygamous species (Table 1), in which hermaphrodite and monoecious flowers occur on the same tree; some cultivars produce mostly masculine flowers and, thus, behave in practice like dioecious species in terms of pollen output. These include certain species of the genus *Fraxinus*. As this genus belongs to the Oleaceae family, it has a high allergic potential related both to compounds unique to its member (Guerra et al., 1995) and to the presence of allergens common to other Oleaceae (Pajarón et al., 1997). Additionally, a problem is posed by the fact that some commercial varieties are sold as seedless, when in reality they are male or polygamous species. Depending on the sex of the individuals chosen for planting and on the species, the Allergen Index can reach a maximum (*Fraxinus americana*, *F. excelsior*, *F. nigra*, *F. pennsylvanica*, *F. uhdei*, *F. velutina*) or, if only female varieties exist, a minimum (*F. angustifolia*, *F. burgeana*, *F. dipetala*) (Ogren, 2000).

2.5. Invasive species

Invaders are non-native plant species introduced by humans, either accidentally or deliberately, into a given area where they have effectively become naturalized, i.e., populations are maintained and reproduce unaided. The entrance routes for these allochthonous species are numerous, changing over time according to the characteristics of each society. Since the 19th century, two routes have existed that have propitiated the introduction of the vast majority of naturalized species: accidental introduction (such as arvenses in crops) and the utilization of species for ornamental and recreational purposes. This can be illustrated by the case of *Ailanthus altissima* (tree of heaven), which has become popular as a roadside tree in many cities and for which rapid propagation has been observed. Its abundance in some areas has been found to generate pollen sensitization reactions in some patients (Ballero, Ariu, Falagiani, & Piu, 2003). Among the most common invaders are also species belonging to two of the families with the greatest allergenic potential, Poaceae and Asteraceae, which represent an additional source of sensitization for an already overexposed population (Campos Prieto, Herrero Gallastegui, Biurrum, & Loidi, 2004; Mandal, Roy, Chatterjee, & Gupta-Bhattacharya, 2008).

Other less common invaders have also been linked to allergenic potential, including members of the Fabaceae (Radauer & Breiteneder, 2006), Myrtaceae (Boral & Bhattacharya, 2008), Amaranthaceae (Galan et al., 1989), Polygonaceae (Spieksma, Charpin, Nolard, & Stix, 1980) and Zygophyllaceae (Belchí-Hernandez et al., 2001). Some of these species are now used as urban ornamentals, such as *Acacia dealbata*, *Acacia saligna*, *Acer negundo*, *Gleditsia triacanthos*, *Robinia pseudoacacia* and *Parkinsonia aculeata* (Dirr, 1990; Griffith, 1994).

Of more global note is that, in the list of 100 of the World's Worst Invasive Alien Species, published by the IUCN/SSC Invasive Species Specialist Group, a number of species with a high allergenic potential according to some of the existing scales are found in the section on terrestrial plants (Ogren, 2000). These species include *Acacia mearnsii*, *Schinus terebinthifolius* (the most allergenic species of the genus *Schinus*, introduced for its tolerance to drought in many cities with harsh summers), *Cecropia peltata*, *Arundo donax*, *Ligustrum robustum*, *Chromolaena odorata* and *Tamarix ramosissima* (Sellers, Simpson, & Curd-Hetrick, 2010).

2.6. Management and maintenance

The presence of wasteland and neglected garden areas, with sizes that often surpass the conservation capacity of local authorities, provides opportunist species with a chance to make use of the available resources; space, water, and fertilizer thus cease to be limiting factors and encourage the spread of plants with severe pollen-allergy implications. Urticaceae are the main offenders in this respect, particularly *Parietaria* in terms of allergenic potential (Trigo, Fernandez-Gonzalez, Jato, Galan, 2008). This species is also known as lichwort or pellitory-of-the-wall, and its preferred habitat is the walls of old or derelict buildings on highly disturbed, nitrified soil. It responds rapidly to even a minimal water supply and spreads faster than it can be eradicated using routine management and maintenance strategies. Due to its rapid spread and the small size of its pollen grains, *Parietaria* is among the major allergenic pollen types found in the Mediterranean region (D'Amato & Spieksma, 1992).

These problems are exacerbated when species cover the walls of buildings designated as having Cultural Heritage status. In a study carried out on periodic changes detected in the spontaneous flora of the Coliseum in Rome from 1643 until 2001, among more than 200 species inventoried over this period, members of the Asteraceae, Chenopodiaceae/Amaranthaceae, Poaceae, Urticaceae, Plantaginaceae and Poligonaceae families stood out as being among the most abundant. In addition to being indicative of the extraordinary capacity of these plants for colonization and of the difficulty of eradicating them, the abundance of these species can also represent a problem for visitors suffering from allergies who are forced to leave the monument each year (Caneva, Ceschiu, Pacini, & Vinci, 2004).

Intensive urban development has not only changed the landscape and the skyline in many cities, but has also created urban wastelands in the form of building sites that have remained undeveloped, especially in times of crisis, providing marginal plants with a niche that meets their requirements. Species associated with these sites include numerous members of the Amaranthaceae family, some of which are considered among the most detrimental widespread weeds with proven allergenicity (Cariñanos, Galan, Alcazar, & Dominguez, 2000). These sites can be included in the so-called "third landscape" (Clément, 2007), which are residual spaces generated by town planning, agriculture or other anthropic uses of territory and which constitute important refuges of diversity. Rather than seeking to eliminate this spontaneously growing vegetation, management of these sites should be characterized by selective maintenance, encouraging colonization by diverse naturally occurring species and avoiding the establishment of monospecific populations of allergenic species.

2.7. Proximity pollinosis

This term refers to all allergic processes in which proximity to the pollen source plays a decisive role, either through close physical contact with a given plant species or in workplaces or homes close to such sources.

Privets (*Ligustrum* spp.) are a good example of this phenomenon. They are members of the Oleaceae, and therefore, they are closely related to *Olea*, which is the main allergy-causing species found in Mediterranean countries. However, unlike Olea, privets are insect-pollinated. Their pollen grains are large and heavy and their dispersal from the tree after being released is quite limited (Trigo et al., 2008). Another important characteristic of these species is that their flowering period overlaps with the last stages of the flowering period of olive trees. The fact that the two pollen types share common allergens means that there are cross-reactions between them, but, whereas olive pollen can travel long distances from its source (Galan et al., 2008), the allergic reactions prompted by *Ligustrum* appear only close to the source (Cariñanos, Alcázar, Galán, & Dominguez, 2002). Similar findings have been reported for *Phytolacca dioica*, also known as "ombú" or "bella sombra", which is a tree native to the South American Pampas that is widely cultivated in temperate cities throughout the world. Despite being dioecious exhibiting entomophilous pollination (Table 1), cases of patients with rhinoconjunctivitis and wheezing caused by the pollen of this species have been reported (Drago, Pineda de la Losa, & Guspi-Bori, 2007). This characteristic has also been noted for *Pyrus pirifolia* (Karamloo et al., 2001) and *Tilia* (Mur et al., 2001).

2.8. Establishment of cross reactions

The response of the immune system to the inhalation of pollen grains is due to the presence of allergens, usually proteins, which are mostly located on the pollen wall, and these are generally specific (Barber, 2003). The pollen wall also harbors a number of minor allergens that act as panallergens, i.e., that are present in various species and responsible for the appearance of pollen–pollen cross-reactions (Weber, 2003). Knowledge about the patterns of cross-allergenicity between different pollen types is essential for the identification of many allergic symptoms for which there is no apparent cause. Weber (2003) noted that pollen cross-allergenicity is due to interrelationships at two levels: taxonomical and phylogenic; i.e., more closely related plants will have a greater number of shared antigens. This has been clearly demonstrated in numerous plant groups. Studies involving up to 12 different species of Cupressaceae, which include the genera *Juniperus*, *Thuja*, *Cupressus* and *Chamaecyparys*, have found cross-reactivity among all 12, as well as between these species and Pinaceae species, such as *Cedrus deodara* (Schwietz, Goetz, Whisman, & Reid, 2000).

Certain proteins present in Pinaceae pollen grains (*Pinus* spp., *Picea* spp., *Abies* spp., and *Pseudotsuga* spp.) display cross-reactivity with ryegrass (*Lolium perenne*, Poaceae) proteins (Conford, Fountain, & Burr, 1990). A number of studies on grasses, which are species that produce pollen that is a major cause of allergies, have revealed strong cross-reactivity between members of a particular subfamily (Martin, Mansfield, & Nelson, 1985), as well as between members of different subfamilies (Smith, Xu, Swoboda, & Singh, 1997). The most surprising finding with respect to cross-reactivity is an elevated percentage of reaction with oilseed rape, *Brassica napus* (Smith et al., 1997), and almost 44% homology with the major olive allergen Ole e 1 (Asturias et al., 1997).

Olive pollen, which is considered one of the main allergenic pollen types in the Mediterranean region, not only shares common allergens with other Oleaceae species, such as ash, privet and syringa (Martin Orozco et al., 1994) but also shares panallergens with numerous species present in green spaces, including *Eleagnus angustifolia* (Kernerman, McCullough, Green, & Ownby, 1992), castor bean (*Ricinus*) (Vallverdi et al., 1998) and *Plantago* (Castro, Alché, Calabozo, Rodriguez, & Polo, 2007). Some authors have reported homology between Oleaceae, Fagaceae and Betulaceae allergens, thus expanding the potential range of species exhibiting cross-reactivity to include a number of commonly planted genera, such as *Quercus*, *Castanea*, *Juglans*, *Carya*, *Betula*, *Alnus* and *Corylus* (Eriksson, 1978; Niederberger et al., 2002; Valenta et al., 1991). A number of proteins isolated from Betulaceae species harbor allergens similar to those found in other trees, grasses and herbs (Hayek et al., 1998), which indicates the potential scope of allergic sensitization linked to urban ornamental flora.

2.9. Interaction with air pollutants

One environmental factor that clearly distinguishes towns and cities from the rural environment is the considerable presence of air pollutants. Human activities, especially automobile traffic, have created sources of pollution posing a serious threat to health (Kim, Back, Koh, & Cho, 2001). Many authors have reported that urban air pollution is one of the main reasons why there are more allergy sufferers in cities than in rural areas (D'Amato, Liccardi, & D'Amato, 2000). There are also experimental and epidemiological data supporting the association between residential proximity to fine particles and sources of emissions with allergic sensitization and asthma in primary school children (Annesi-Maesano et al., 2007).

Some authors have noted that the allergenic potential of pollen grains may be enhanced by the presence of other air pollutants and that pollen production in species with considerable allergenic potential has actually increased due to the action of gases such as CO_2 (Rodriguez-Rajo, Fernandez-Sevilla, Stach, & Jato, 2010; Ziska et al., 2004). The exposure of pollen grains to agitation by air and air pollutants generates paucimicronic allergen particles measuring less than 2.5 μm, which are capable of penetrating into the lower regions of the respiratory tract (Rantio-Lehtimaki, Viander, & Koivikko, 1994; Spieksma, Nikkels, & Dijkman, 1995). Pollen grains are considered the major biological cause of air quality deterioration because they behave in a similar manner to non-biological airborne contaminants, are associated with high counts, and are damaging to human health (Cariñanos et al., 2004).

A number of reports have highlighted the coadjuvant effect of air pollution on pollen-allergy sufferers: air pollutants lead to a worsening of allergy symptoms (D'Amato, Liccardi, D'Amato, & Cazorla, 2001) and appear to have implications for airborne allergen activity, especially in recent times. In certain situations, pollen grains may carry micrometer-sized particles into the respiratory tract, thus increasing their allergenic potential (Bartra et al., 2007; Kalbande, Dhadse, Chaudhari, & Wate, 2008).

3. Guidelines for designing spaces with a low allergy impact

The effects of the ornamental flora in urban green spaces on the development of pollinosis by city inhabitants is extensively documented in the bibliography, and many of the recommendations that have been put forth for reducing its impact on health are directed toward reducing exposure to pollen, limiting outdoor activities during the pollen season, staying inside during peak pollen periods or wearing a dust mask (Seitz & Escobedo, 2009). The establishment of prevention strategies aimed at the general public is also promoted in the literature, including the dissemination of local aerobiological information, avoidance of contact with allergens, hygiene and prophylaxis measures and relocation away from primary residences to areas with different vegetation at times of maximum pollination (Spanish Aerobiology Network (REA) web page). Only recently have initiatives begun to be implemented with the aim of reducing the impact of transmission sources, e.g., Allergy-free Gardening (Ogren, 2000), and these are most often focused on selecting species with a low or moderate allergenic potential and using females of species with separate sexes, resulting in the so-called "female gardens" (Ogren, 2002). Here, we list some of the key measures that we have concluded should be adopted to reduce the impacts of allergenic plant pollen and alleviate its harmful effects on urban allergy sufferers, as well as provide recommendations on the planning and design of healthy green spaces, as follows (Table 2):

Table 2
Guidelines to design green spaces of low-allergy impact.

(a)	Increase plant biodiversity
(b)	Ensure moderate, controlled introduction of exotic flora
(c)	Control of invasive species
(d)	Avoid massive use of male individuals of dioecious species (avoid botanical sexism)
(e)	Choose species with low-to-moderate pollen production
(f)	Adopt appropriate management, maintenance and gardening strategies to ensure removal of opportunist and spontaneous species
(g)	Avoid forming large focal pollen sources and screens by respecting planting distances
(h)	Obtain expert advice when selecting suitable species for each green area, and avoid fostering cross-reactivity between panallergens
(i)	Establish specific local authority by-laws ensuring that sufficient time is available for the design and planning of urban green spaces

(a) Increase urban biodiversity. This measure has been strongly urged as a priority by a number of specialist groups, including biologists, ecologists, landscape gardeners, and conservationists. Increased biodiversity would reduce the planting of traditional species for which allergenic capacity has been clearly demonstrated; at the same time, it would disperse current large, concentrated monospecific pollen sources, potentially reducing the release of allergenic pollen by up to 30%.

(b) Ensure the moderate, controlled introduction of exotic species. Large-scale planting of exotics has sometimes given rise to new pollinoses; the overuse of exotics and their use as exclusive roadside species should, therefore, be avoided. However, the controlled incorporation of some exotic species can be a valid strategy for increasing floral diversification.

(c) The incorporation of new species must also involve an exhaustive verification that they are not referred to as invasive species in localities of similar ecological characteristics to the intended sites of their planting.

(d) Encourage botanical "gender equality". Replace male individuals of dioecious species with females; this does not alter esthetics and does not always entail fruit-litter problems; for example this could be carried out for *Salix*, *Juniperus*, *Acer*, *Schinus* or *Fraxinus*.

(e) Choose species associated with low-to-moderate pollen production. Not all anemophilous species produce the same amount of pollen. More frequent use of entomophilous species would also help to reduce pollen counts.

(f) Ensure proper management and maintenance of green areas and encourage the presence of "third landscape" sites facilitating the selective colonization of diverse and vagrant species to limit the presence of spontaneous low-diversity populations producing allergenic pollen.

(g) Respect minimum planting distances between trees and minimum distances between trees and buildings, thus limiting the screen effect and the likelihood of proximity pollinosis. Greater knowledge of pollen types will help ensure that allergenic species with a low dispersal capacity (*Ligustrum*, *Tilia*) are planted in areas further away from thoroughfares, homes and offices.

(h) To reduce cross-reactivity between different pollen types, the principle of "resemblance and relatedness" underlying phylogenetic classifications, i.e., members of the same genus and family are very likely to share major allergens and panallergens, should be considered. Species that are not particularly closely related, but that share common phylogenetic ancestors may also share common panallergens.

(i) Ensure that local by-laws establish guidelines for the design of urban green spaces with a low allergy impact; this would improve advanced planning efforts when choosing the species best suited to every green space. It is also essential to involve expert advisers at the planning stage.

4. Conclusion

The analysis carried out in this review of the principal factors that have contributed to the allergenic characteristics of ornamental flora makes it clear that there is a need to implement planning of low impact green zones based on the principles of biodiversity, the prevalence of female varieties and the use of autochthonous species. Only in this way will we be able to achieve sustainable and healthy spaces for all urban inhabitants who suffer from pollen allergies. Additionally, expert participation in the teams involved in the design and planning of green zones is of equal importance.

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