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Original article

An evaluation of the ecosystem services provided by urban trees: The role of Krasiński Gardens in air quality and human health in Warsaw (Poland)

Zbigniew Szkop

Department of Economic Sciences, University of Warsaw, Długa Str. 44/50, 00-241 Warsaw, Poland
E–mail address: zszkop@wne.uw.edu.pl

ABSTRACT

Trees remove air pollution by the interception of particulate matter on plant surfaces and the absorption of gaseous pollutants through leaf stomata. However, to date, we have rather few empirical studies on the magnitude and value of the effects of trees on air quality and human health, especially especially within the climatic conditions of Central Europe. To investigate the significance of urban trees from the point of view of air pollution removal, an i-Tree Eco model was implemented. The results indicate that the 932 trees in Krasiński Gardens (Warsaw, Poland) absorb 267.12 kg of pollutants per year: 149.9 kg of O_3, 94.4 kg of NO_2, 11.8 kg of SO_2 and 10.9 kg of $PM_{2.5}$. That makes an average removal per tree (calculated by summarizing the values of all of the pollutants) of 0.287 kg/year. Furthermore, health values were used to estimate their pollution removal services in monetary terms. The total benefit of air purification by trees in Krasiński Gardens is estimated at 26250 PLN/year with an average value per tree of: 28 PLN. Although $PM_{2.5}$ removal is the lowest among the four air pollutants analysed, accounting for only 4% of the total mass reduction, it provides 69% of the total economic value. The benefit associated with absorption of O_3 provided 28% of the value, with the absorption of NO_2 and SO_2 at just 3%. The results also show that large tree species (with a crown diameter of 14-15m) can provide around 10 times higher benefits, than small ones (5-6m).

KEY WORDS: economic valuation, benefit transfer method, urban ecosystem services, air pollution removal, Krasiński Gardens

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1. Introduction

Urbanization is increasing on a global scale, creating both opportunities and challenges for improving people's quality of life and managing the transition towards sustainability. Today, the majority of the world's population lives in urban areas, and two-thirds of the earth's inhabitants are expected to be urbanized by 2050 (UNITED NATIONS, 2012). In the context of a rapidly urbanizing world, understanding complexity and managing human–environment interactions within urban areas is vital if we are to balance the interdependent social and ecological goals of sustainability (ASH ET AL., 2008; BETTENCOURT & WEST, 2010; CLARK, 2007). A comprehensive planning approach has the potential to harmonize human–environment interactions and mitigate the harmful impacts of urbanization (ANDERSSON, 2006). Such an approach requires planners to understand and value nature's multiple contributions to the quality of urban life and to capture these values in suitable governance mechanisms (HUBACEK & KRONENBERG, 2013).

One of the most important environmental challenges in urban areas is air quality. Air pollution caused by human activity has been a problem since the beginning of the industrial revolution. With increasing population sizes, industrialization and industrial activities, largely as a result of increasing energy generation, and the use of transport based on fossil fuels, large quantities of pollutants have been produced. The main generators of air pollution and the causes of the presence of these gases in the urban atmosphere are transport, industry, electrical power generation, domestic heating and the incineration of solid urban waste (PAULEIT ET AL., 2000).

In the last few years, various studies have been carried out to confirm that air pollutants have damaging effects on human health (POPE ET AL., 2002, FANN ET AL., 2012). According to a study by Health and Environment Alliance, only in Poland, it is estimated that 45,000 deaths a year are due to pollution (NAJWYŻSZA IZBA KONTROLI, 2014).

Urban vegetation, particularly trees, can affect air quality. There are many studies (for example MCPHERSON & SIMPSON, 1999, YANG ET AL., 2005, NOWAK ET AL., 2006 and ESCOBEDO & NOWAK, 2008) showing that urban vegetation affects air quality at local and regional levels by eliminating air pollutants. For this reason, it is very important to know the ability of urban trees to remove air pollution, as it will help in encouraging investment in urban trees and their planting and proper management in order to achieve environmental improvements.

There are some published results aimed at the comparison of different-aged, differently-managed trees of different species, mainly from the U.S. (MARTIN ET AL., 2012; MCPHERSON, 2003; MCPHERSON & KENDALL, 2014). To date, however, there are rather few empirical studies on the effects of different species selection policies from the point of view of a pollution removal ecosystem service, especially within Central European climatic conditions. Using the methodology proposed in this study, the pollution removal service can be expressed as a monetary value, which can thus help play an important role in the promotion of an ecosystem services approach and its incorporation into decision-making processes. The aim of the research is to provide and discuss the results of an individual-based ecosystem service assessment, based on a complete tree inventory conducted in Krasiński Gardens (Warsaw).

2. Materials and methods

2.1. Study area

The general study area was located in the centre of Warsaw – the capital of Poland. Warsaw's climate is transitional humid continental and oceanic with cold, snowy, cloudy winters and warm, sunny, stormy summers, on the border of an oceanic climate. The average temperature ranges between −2.2°C in January and 18.3°C in July. Mean yearly temperature is 8.2°C. Yearly rainfall averages 531 millimetres, the wettest month being July (NORTHEAST REGIONAL CLIMATE CENTRE, 2012)

Warsaw is the largest city in Poland, with a population of over 1,700,000 inhabitants. Because of its size air pollution is considerable, and this has been studied in detail in previous research (KUCHCIK ET AL., 2014). Krasiński Gardens was the area of study, where the entire stand, composed of 932 trees, was investigated (Fig. 1).

Fig. 1. The surveyed area - Krasiński Gardens (Warsaw, Poland) (source: author's own elaboration)

Krasiński Gardens emerged in the second half of the 17th century, in the area of Jan Dobrogost Krasiński's residence. It was designed by Tylman of Gameren, a prominent architect of the day of King Jan III Sobieski. Today, there are 43 different tree species, from the most common such as Norway maple or Little leaf linden to some ancient tree specimens, including *Ginkgo bilobas* and Turkish hazels.

2.2. Data and materials

The analyses are based on a field-based complete tree inventory. Fieldwork was carried out in the vegetation period of 2010. The general information collected from the field survey included, among other parameters: the identification of species, diameter at breast height (DBH), height of the tree, height to base of live crown, crown base, crown width, percentage of canopy missing (relative to crown volume), percentage canopy dieback, and light exposure of the crown (see NOWAK ET AL., 2008 for a complete list of data measures).

The ratio of canopy missing and ratio of branch dieback in the crown data are used to rate tree condition and to adjust downward leaf area and biomass data, which are calculated with the help of allometric equations (NOWAK ET AL., 2008). The growth of a certain individual is corrected with the crown light exposure (CLE) data (number of sides of the tree receiving sunlight – maximum of five). Listed attributes were recorded for each tree in the study area, if its DBH exceeded 5 cm. The diameter was recorded at 1.4 m (breast height).

In addition, hourly air pollution concentrations, precipitation averages, air temperature and solar radiation data for a complete year were collected. The Regional Inspectorate for Environmental Protection in Warsaw (WIOŚ) provided both precipitation and pollution concentration data from Targówek operational monitoring station. The station is not located in the garden, but overall environmental conditions are typical for this part of the city. Pollution concentration data included: O_3, NO_2, SO_2 and $PM_{2.5}$ (fine particulate matter that is 2.5 microns in diameter and less). Air temperature and solar radiation data for Warsaw were directly retrieved from the US National Climatic Data Centre. As a next step, field data of urban forest structure, air pollution, and meteorological data were processed using i-Tree Eco software (i-Tree Eco v5).

2.3. The i-Tree Eco model

The i-Tree Eco model (i-Tree Eco v5) (NOWAK & CRANE, 2000) uses tools available world-wide. From the tools of the i-Tree suite (i-Tree Canopy, Design, Eco, Landscape, Species, Storm Interface, Storm Template, Streets, Hydro), Eco is the most suitable for international use. The model calculations are based on well-defined allometric relationships between indicators of the relevant ecosystem services (amount of biomass, leaf area) and the measured size parameters of trees. The air pollution removal (dry deposition) calculations are carried out using pollutant concentration datasets of the study area, by calculating deposition velocities, for which detailed meteorological datasets are needed from the study site. The (removed) pollutant flux is calculated as the product of deposition velocity and the pollutant concentration. Deposition velocity is a factor computed from various resistance components (for more details see BALDOCCHI ET AL., 1987; NOWAK & CRANE, 2000; NOWAK ET AL., 2006).

2.4. Valuing ecosystem services

While estimating the value of services provided by a given ecosystem, it is beneficial if analysts, or policy makers, can conduct an empirical study at the location of interest. Unfortunately, in many cases available time and resources are not sufficient to do that. A possible solution is to extrapolate results from another study similar in relevant aspects to the site that is analysed. This method is called "benefit transfer".

One of the most common ways of applying "benefit transfer" is to split a good G into separate components $g_1, g_2, ..., g_n$, and then to identify a value of each component on the basis of a separate assessment exercise. Formally, the approach can be represented by the following formulae (where G stands for good - pollution neutralization, and $g_1, g_2, ..., g_n$ denote specific pollutants. TEV stands for "Total Economic Value" (ŻYLICZ, 2010):

$$G = (g_1, g_2, ..., g_n), \text{ and } TEV(G) = TEV(g_1) + TEV(g_2) + ... + TEV(g_n) \quad (*)$$

In this study the formula (*) was combined with *in situ* valuation studies. For this purpose, an assumption was made that $G = (g_1, g_2, ..., g_n)$, and $I(G) = I(g_1) + I(g_2) + ... + I(g_n)$, where I is the impact of pollution.

An assumption was made that the total impact of pollution reduction is the sum of partial impacts of its components. Consequently, the value of the total impact is the sum of values of the partial impacts (Żylicz, 2010):

$$TEV(I(G)) = TEV(I(g_1)) + TEV(I(g_2)) + ... + TEV(I(g_n)). \ (**)$$

In the valuation of air pollution removal by trees located in the Krasiński Gardens, the approach here corresponds to the combined formula above (**), where impacts are transferred from a study conducted by applying the i-Tree Eco software, and their economic valuation is adopted from the study conducted in the USA by the US Environmental Protection Agency (Nowak, 2014), to estimate the incidence of adverse health effects (i.e., mortality and morbidity) and an associated monetary value that results from changes in NO_2, O_3, $PM_{2.5}$ and SO_2 concentrations due to pollution removal by trees.

The monetary values associated with reduced adverse health effects increases with country population density. The regression equations estimating dollars per tonne (y) based on population density (people per km^2, x) are:

NO_2: $y = 0.7298 + 0.6264x$ ($R^2 = 0.91$)
O_3: $y = 9.4667 + 3.5089x$ ($R^2 = 0.86$)
$PM_{2.5}$: $y = 428.0011 + 121.7864x$ ($R^2 = 0.83$)
SO_2: $y = 0.1442 + 0.1493x$ ($R^2 = 0.86$)

These equations produce average values based on population density, not specific population parameters (e.g. age class distribution) and can give rough estimates of values (Nowak, 2014). As the value of a statistical life (VSL) applied in the model is higher than that recommended by the European Commission or calculated by Giergiczny (Giergiczny, 2008) for Poland, the results may be overestimated and require further studies.

Damages in USD currency units were converted to PLN using purchasing power parity (ppp) exchange rates. The assumption was made that these damages depend linearly on income. As a result, externality values applied to the case study are for NO_2: 8580.034 PLN/t, for $PM_{2.5}$: 1668661.62 PLN/t, for SO_2: 2044.97 PLN/t, and for O_3: 48072.26 PLN/t.

2.5. Comparison between tree types

To compare the effects of different species selection policies from the point of view of a pollution removal ecosystem service and thus to help decision-makers obtain approximate values of pollution neutralization by urban trees, this paper presents the value of that service provided by "typical" tree species, based on research conducted by implementation of the i-Tree Eco software for research carried out in Krasiński Gardens.

To account for differences in the value of ecosystem services of different tree species, the paper reports results for representative mature small (Plum), medium (Black locust), and large (Little leaf linden) deciduous trees (Fig. 2). The selection of these species reflects the fact that they were the most common tree species of each type in the study area. Size of crown diameter of mature tree was used to characterize small, medium, and large trees. The list of potential small, medium and large trees is presented in Annex 1.

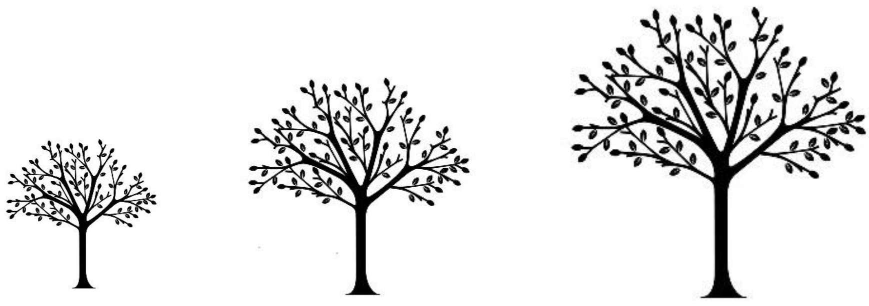


Fig. 2. Tree types
(source: author's own elaboration)

Tree type	Small	Medium	Large
Representative	Plum	Black locust	Littleleaf linden
Mature size crown diameter	5-6 m	9-10 m	14-15 m

3. Results and discussions

3.1. Forest structure

To evaluate the characteristics of ecosystem services provided by different stands, it is necessary to investigate their main structural characteristics. The trees of Krasiński Gardens are characterised by high species richness: 43 species can be found in the area of 9.20 ha. Increased tree species-richness has the potential to minimise the impact, or destruction, of species by specific pathogens and diseases and from climate change. The five most common trees in the study area were Little leaf linden, Norway maple, Horse chestnut, Elm and Plum. The ten most common species amount to 76% of the whole stand (Fig. 3).

Urban trees have to be especially resistant to survive the harsh conditions of living with high exposure to pollutants. Certain species, like *Norway maple* and *Little leaf linden*, are well known for their suitability as urban trees and thus could make up a significant proportion of the trees in Krasiński Gardens (Fig. 2). Overall, 19% of the trees in Krasiński Gardens are in an 'excellent' condition, exhibiting less than 5% crown dieback, with 42% in 'good' and 21% in 'fair' condition. A total of 11% of the trees in Krasiński Gardens are estimated as being in 'critical', 'dying' or 'dead' condition (Fig. 4).

Most of the analysed ecosystem services come from the leaf surface area of the trees, which is mostly dependent on crown size and species of tree (NOWAK, 2007). The majority of trees within Krasiński Gardens are within the large size type (bolded), though most of the trees have not reached their mature size yet (Table 1).

The results clearly show the importance of two species in the Krasiński Gardens: *Norway maple* and *Little leaf linden*. Their abundance, relatively large size, and high leaf area are what makes them important. On the other hand, other species, though not that abundant, generate higher per tree average pollution removal benefits. These are especially: *Horse chestnut*, *Silver maple* and *Ash*.

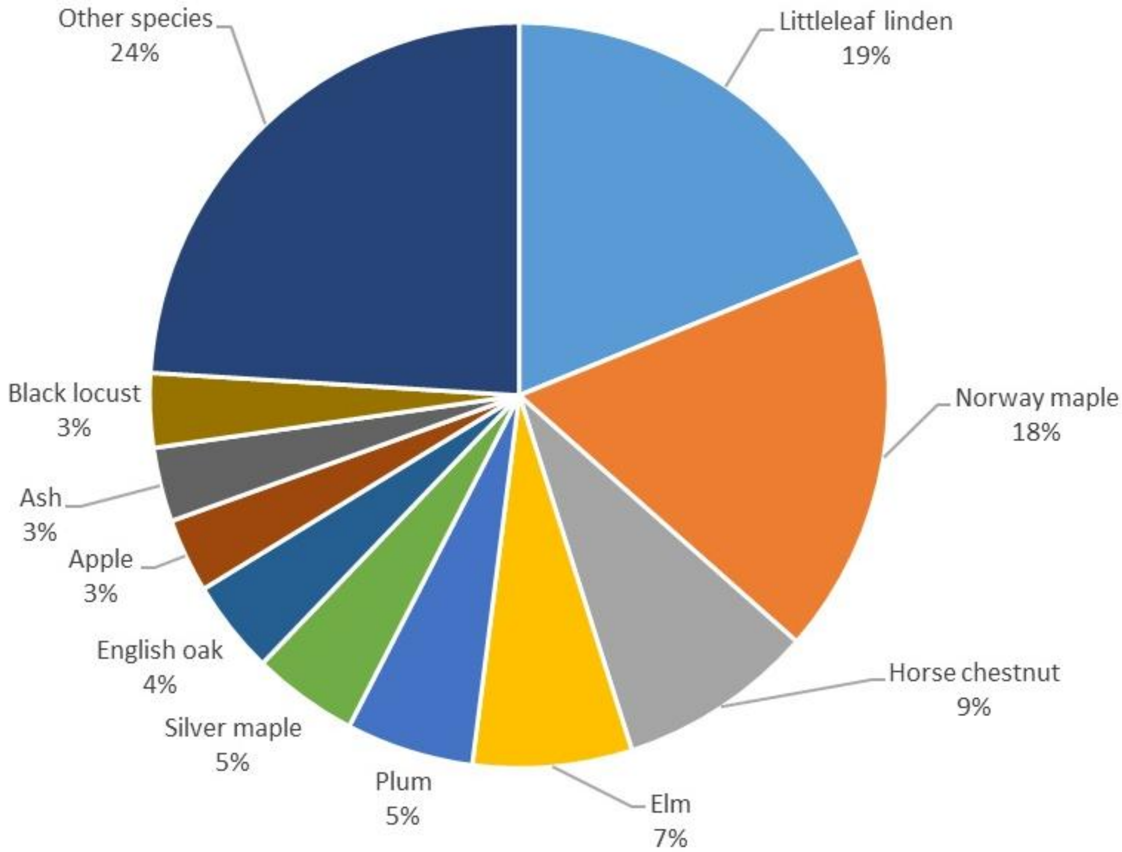


Fig. 3. Relative abundance of tree species in Krasiński Gardens (source: author's own elaboration based on the results of the i-Tree Eco model)

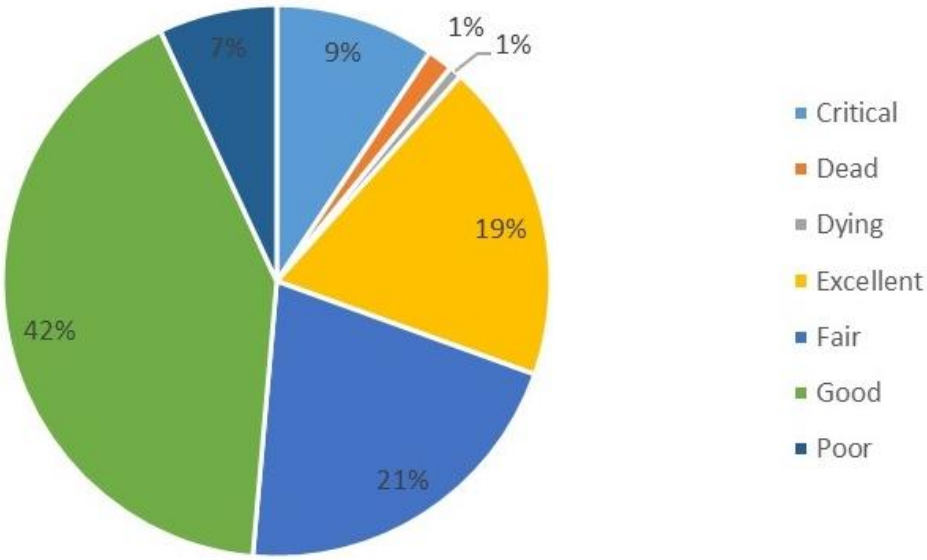


Fig. 4. Tree condition (source: author's own elaboration based on the results of the i-Tree Eco model)

Table 1. Structural characteristics of investigated stands (source: author's own elaboration based on the results of the i-Tree Eco model)

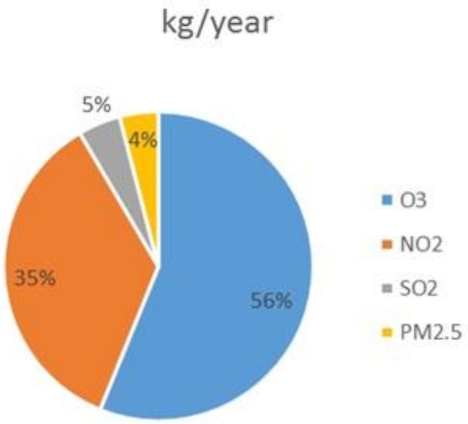
Species name	Number of trees	% of all trees	Avg. DBH [m]	Avg. height [m]	Avg. crown diameter [m]	Aveage value [PLN]
Little leaf linden	**176**	**18.88**	**36.4**	**11.8**	**8.9**	**26.89**
Norway maple	**164**	**17.60**	**48.2**	**17.1**	**9,0**	**28.83**
Horse chestnut	**80**	**8.58**	**58.1**	**15.8**	**9.0**	**49.44**
Elm	**65**	**6.97**	**34.3**	**13.5**	**5.9**	**2025**
Plum	52	5.58	33.5	4.6	4.1	4.54
Silver maple	**43**	**4.61**	**65.1**	**16.7**	**10.0**	**32.83**
English oak	**38**	**4.08**	**44.3**	**15.6**	**8.6**	**29.36**
Apple	30	3.22	37.4	5.2	4.9	6.78
Ash	30	3.22	42.9	15.2	8.2	33.41
Black locust	30	3.22	45.6	10.4	6.2	14.39
All trees	932	100	44.3	13	7.4	28.16

3.2. Air pollution removal in the total tree stand

Total air purification is estimated at 267.12 kg of removed pollutants/year with an economic value of 26245.74 PLN/year. Though $PM_{2.5}$ removal is the lowest among the four air pollutants analysed (NO_2, $PM_{2.5}$, O_3, and SO_2), accounting for only 4% of the total biophysical value (10.91 kg/year), it provides 69% of the total economic value (18203.26 PLN/year) (Fig. 5).

Pollution removal for SO_2, NO_2 and ground-level O_3 were as follows: 11.86 kg, 24 PLN for SO_2; 94.40 kg, 810 PLN for NO_2 and 149.95 kg, 7208 PLN for ground-level O_3 (Table 2).

The average removal per tree (calculated by summarizing the values of all of the pollutants) was 0.287 kg/year (28.16 PLN). These values of pollution removal are higher than have been recorded by studies for sites in: Calgary, Torbay, Morgantown, Syracuse, Toronto, Baltimore, Atlanta Edinburgh, Moorestown, Woodbridge, Washington, Boston, Philadelphia, Jersey City and Minneapolis. Received values are lower though than have been recorded by a few other studies for sites in: New York, Freehold, Udine (Table 3). The differences are due to the greater, or lower, leaf area, which results in more, or less, pollutants being removed. Differences in concentration of pollutants between these sites also impacted the results.



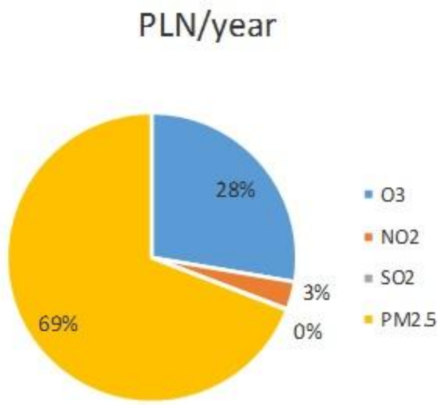


Fig. 5. Annual air pollution removal by air pollutant in kg/year (left) and PLN/year (right)
(source: author's own elaboration based on the results of the i-Tree Eco model and Nowak, 2014)

Table 2. Annual air pollution removal by air pollutant in KG/year (left) and PLN/year (right)
(source: author's own elaboration based on Nowak, 2014)

	O_3	NO_2	SO_2	$PM_{2.5}$
kg/year	149.9461	94.4026	11.8608	10.9089
PLN/year	7208.248	809.9775	24.25492	18203.26

Table 3. Annual air pollution removal - comparison with other cities
(source: *USDA Forest Service, 2003; **Rogers et al., 2013)

Study area	Air pollution removal per tree [kg/year]
Udine, Italy**	0.494
Freehold, NJ*	0.396
New York, NY*	0.292
Warsaw, PL	**0.287**
Minneapolis, MA*	0.283
Jersey City, NJ*	0.272
Philadelphia, PA*	0.248
Boston, MA*	0.218
Washington, DC*	0.197
Woodbridge, DC*	0.194
Moorestown, NJ*	0.184
Atlanta, GA*	0.160
Edinburgh, UK**	0.157
Baltimore, MD*	0.148
Toronto, Canada*	0.146
Syracuse, NY*	0.113
Morgantown, WV*	0.091
Torbay, UK**	0.061
Calgary, Canada**	0.025

3.3. Comparison of different tree types

The differences in air pollution removal between species is strongly visible and basically correlates with the crown diameter, as leaf area is the ecosystem indicator with respect to the quantification of the service. Therefore, the comparisons of the stands are more informative when categorised. In this study all species present in the Krasiński Gardens were categorised based on the size of their mature size crown. These categories, here called "types" are: small (with mature size crown diameter of 5-6 m), medium (9-10 m), and large (14-15 m) (Table 4).

Table 4. Annual benefits at Mature Tree Size for representative small (*Plum*), medium (*Black locust*) and large (*Little leaf linden*) trees (source: author's own elaboration based on the results of the i-Tree Eco model)

Tree type	Pollutant	Amount removed at Mature Tree Size (g)	Value (PLN)	Pollution absorption equation	R^2
Small *(Crown diameter: 5-6 m)*	Ozone	34.4662	1.656868	y = 6.3698x - 0.5677	R^2 = 0.7530
	Nitrogen dioxide	21.70485	0.186228	y = 4.0113x - 0.3573	R^2 = 0.7533
	Sulfur dioxide	2.729	0.005581	y = 0.5044x - 0.0452	R^2 = 0.7524
	Small particulate matter	2.9206	4.873493	y = 0.5402x - 0.0505	R^2 = 0.8575
Medium *(Crown diameter: 9-10 m)*	Ozone	104.8784	5.041742	y = 11.218x - 1.6926	R^2 = 0.8003
	Nitrogen dioxide	67.3216	0.577622	y = 7.1924x - 1.0662	R^2 = 0.8004
	Sulfur dioxide	9.0451	0.018497	y = 0.9662x - 0.1338	R^2 = 0.8002
	Small particulate matter	11.6611	19.45843	y = 1.2462x - 0.1778	R^2 = 0.8610
Large *(Crown diameter: 14-15 m)*	Ozone	428.0895	20.57923	y = 30.261x - 10.695	R^2 = 0.7198
	Nitrogen dioxide	260.4047	2.234281	y = 18.422x - 6.7143	R^2 = 0.7187
	Sulfur dioxide	38.61575	0.078968	y = 2.7283x - 0.9446	R^2 = 0.7118
	Small particulate matter	25.0826	41.85437	y = 1.7794x - 0.7187	R^2 = 0.7809

The total amount of removed pollutants by mature size small trees is only 0.061 kg (with an economic value of 6.7 PLN/year), while the same data for a large tree is 0.75 kg (economic value: 65 PLN/year). The total annual air pollution removal in the case of a mature size medium tree was observed to be 0.19 kg (with an economic value of 25 PLN/year). This indicates, that a large mature size tree (with crown diameter of 14-15 m) can provide around 10 times higher benefit, than a small mature size tree (5-6 m).

4. Conclusions and recommendations

Urban trees can affect local air quality by altering the atmosphere of the urban environment. To investigate the significance of the trees located in Krasiński Gardens from the point of view of air pollution removal, the I-tree Eco model was implemented. The investigation included 932 trees. This stand is characterised by high species richness of 43 species. As a consequence, there is also a high diversity in the impact of ecosystem services provided, owing to the different growth and leaf area production capacities of the different species. The i-Tree Eco model can handle this, as allometric equations for hundreds of species that are native in different continents, are stored in the model's species database. The modules which are used in this analysis (calculations of urban forest structure and air pollution removal) are suitable for use outside the U.S. in different climatic zones, after appropriate model adaptation. Pollutants taken into account in the model were: NO_2, $PM_{2.5}$, O_3, and SO_2. The results indicate that 932 trees in Krasiński Gardens annually absorb 149.9 kg of O_3, 94.4 kg of NO_2, 11.8 kg of SO_2 and 10.9 kg of $PM_{2.5}$. That makes an average removal per tree (calculated by summarizing the values of all of the pollutants) of 0.287 kg/year.

The value of pollution removal can be compared with those that have been recorded by studies for sites in other cities and range from 0.025 kg/year (Calgary, Canada) to 0.494 kg/year (Udine, Italy). The average values for New York (NY) – 0.292 kg/year and Minneapolis (MA) – 0.283 kg/year are very close to the average value for Krasiński Gardens (USDA FOREST SERVICE, 2003; ROGERS ET AL., 2011).

The survey and modelling system has significant potential to inform current and future tree planting and management strategies for improving both the resilience of the tree population, and optimisation of the ecosystem services that trees provide. Further refinement of the approach would allow such predictions to be made.

In the study, health values were used to estimate pollution removal benefits in monetary terms. As a result, the monetary values associated with reduced adverse health effects applied to the case study were for: NO_2: 8580.034 PLN/t, $PM_{2.5}$: 1668661.62 PLN/t, SO_2: 2044.97 PLN/t, and O_3: 48072.26 PLN/t. Mainly because of population density, the values per tonne removed were higher than average pollution removal values per tonne in urban areas in USA (NO_2: 436 $/t; O_3: 2864 $/t; $PM_{2.5}$: 117,106 $/t; SO_2: 148 $/t), but much lower than in New York, where dollar values per tonne removed were the highest in USA (for NO_2: 7200 $/t; for O_3: 63,800 $/t; for $PM_{2.5}$: 3,852,400 $/t; for SO_2: 2600 $/t) (Nowak, 2014).

The main advantage of health valuation is that the outcome varies depending upon population density and gives more realistic results (if there are no people receiving the benefit, then there is no value; the more people the greater the value). On the other hand this approach has its limitations; it does not capture all of the benefits related to pollution removal by trees. Health valuation does not include, for example, damages to crops, materials and biodiversity. An alternative approach is to use general externality values, which include health values and tend to be higher than just health values. The disadvantage of this approach is that to date no one has produced a general ozone externality value. The other problem with general externality valuation is that value ($/t) cannot be related to general income, which makes the results less credible.

As there is no perfect way to value these impacts, the author decided to apply the health valuation, emphasizing that other benefits are beyond the scope of this paper. Using the methodology proposed in this study, the total benefit of air purification of trees in Krasiński Gardens was estimated at 26245.74 PLN/year with an average value per tree of 28.16 PLN. It is worth noting, that though $PM_{2.5}$ removal is the lowest among the four air pollutants analysed, accounting only for 4% of the total mass removed, it provides 69% of the total economic value. The benefit associated with absorption of O_3 provided 28% of the value, when absorption of NO_2 and SO_2 were just 3%.

What is also important to note is that there are strong differences in air pollution removal capacities between tree species of different size. The total amount of removed pollutants by a representative mature size small tree was only 0.061 kg (with an economic value of 6.7 PLN/year), while the same data for a representative large tree was 0.75 kg (economic value: 65 PLN/year).

According to the results of the study, in order to increase the air pollution removal value of trees in Krasiński Gardens in the future, decision makers should consider increasing the number of large type trees, as they generate 10 times higher average pollution removal benefit per tree. The most beneficial species include: *Horse chestnut*, *Silver maple*, *Ash*, *English oak*, *Norway maple* and *Little leaf linden*. However, introducing new species of large, pollutant-tolerant species trees is also recommended, as they will help remove some of the risk associated with relying on a few species to make up most of the park tree population.

Annex 1. The list of potential small, medium and large trees based on their mature tree size (source: author's elaboration based on Senata et al., 2008)

Latin name	Type	Latin name	Type	Latin name	Type
Apple	small	*European beech*	large	*Mountain ash*	medium
Ash	large	*European bird cherry*	medium	*Northern red oak*	large
Basswood	large	*European hornbeam*	large	*Norway maple*	large
Black locust	medium	*European mountain ash*	medium	*Pear*	medium
Black poplar	large	*European white birch*	large	*Plum*	small
Boxelder	medium	*Ginkgo*	large	*Red mulberry*	medium
Butternut	large	*Green ash*	large	*Silver maple*	large
Carolina poplar	large	*Hawthorn*	small	*Sugar maple*	large
Catalpa	medium	*Horse chestnut*	large	*Tulip tree*	large
Cottonwood	large	*Lilac*	small	*Turkish hazelnut*	large
Dogwood	medium	*Littleleaf linden*	large	*White poplar*	large
Elm	large	*Macadamia*	medium		
English oak	large	*Maple*	large		

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