



UNIVERSITY OF WARSAW
FACULTY OF ECONOMIC SCIENCES

WORKING PAPERS

No. 21/2017 (250)

THE PROBLEM OF NON-OPTIMAL MANAGEMENT OF URBAN GREEN AREAS IN WARSAW

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WARSAW 2017



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Abstract

In his paper the author looks at management of urban green areas in Warsaw as a principal agent problem. In the study the principal is the City Mayor, while the agent is institution responsible for managing street trees in Warsaw (ZOM). While the City Mayor is interested in enhancing the welfare of their constituency, the lower level officers do not have to be preoccupied with the same concerns - they are interested in maximizing their utility subject to some constraints imposed by their bosses. This is a standard hierarchical agency theory model. As the agent's contract is not incentive compatible, the theoretical "residual claimancy" condition does not hold, and the species composition is different from what it would have been if the principal-agent model implemented was incentive compatible.

Keywords:

Principal-agent models, urban trees, ecosystem services

JEL:

H49, Q53, Q57, R59

Acknowledgements

The article is funded by National Science Centre in Poland under the project no. 2016/23/N/HS4/0367 – “The role of ecosystem services provided by trees in urban planning and management”.

DOI:

<https://doi.org/10.26405/WP/WNE/2017/250/021>

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1. Introduction

Trees make a difference to the urban living conditions by providing a number of ecosystem services. Street trees play a special role in this respect as they have an effect on the quality of the environment in those most polluted areas and contribute to the reduction of rainwater flow into the municipal sewage system. As demonstrated in a recent study [Szkop, 2017], by absorbing selected pollutants, street trees in Warsaw provide benefits of over PLN 600,000 a year. Besides, they help reduce the rainwater flow into the municipal sewage system, which generates benefits of nearly PLN 400,000 a year. The study further showed that mature trees of large-sized species can provide a benefit stream which is several times larger than provided by trees of smaller-sized species and that stream is mainly determined by their leaf area. The growing awareness of the role of trees in the urban structures raises a question whether it is possible to increase the stream of ecosystem services provided by street trees in Warsaw.

The urban greenery management system in Poland's capital is hierarchical, with the Environmental Protection Office of the Municipal Office of Capital City of Warsaw (BOŚ) in the principal position on behalf of the City Mayor.

Responsibilities of the Environmental Protection Office include¹:

- Managing the matters of environmental management of the Capital City of Warsaw in line with the principles of sustainable development by designing and reviewing projects of environmental protection plans and schemes;
- Handling the matters of conservation, including maintenance, protection and development of green areas and supervision over the tree stand management in the Capital City of Warsaw;
- Initiating development of draft legal regulations and systemic solutions to ensure efficient green area management, including defining guidelines, schemes and concepts for upgrading and renewing green areas;
- Supervising and supporting activities of the organizational units of the Capital City of Warsaw handling the collection, update and processing of greenery inventory data within the citywide green area database.

Therefore, BOŚ provides the management function but is not involved in the decision-making in relation to planting specific species. The decision-making agencies reporting to BOŚ and deciding on the planting activities in specific locations are²:

- ZOM: street greenery along the streets managed by ZDM³ (trunk roads, regional roads and district roads) and certain parks;
- Environmental Protection Departments of the individual Boroughs of Warsaw (WOŚ): local street greenery in the Boroughs and certain parks, garden squares and green spaces;
- ZTP: greenery within the Borough of Muranów, including a portion of local street trees (the streets are listed on the authority's website⁴);
- ZPTP: certain street trees, parks, garden squares and green spaces within the Borough of Praga Północ;

¹ https://bip.warszawa.pl/Menu_podmiotowe/biura_urzedu/OS/default.htm. Accessed August 2017.

² Wrzesień, M., 2017. BOŚ, Warsaw (email communication).

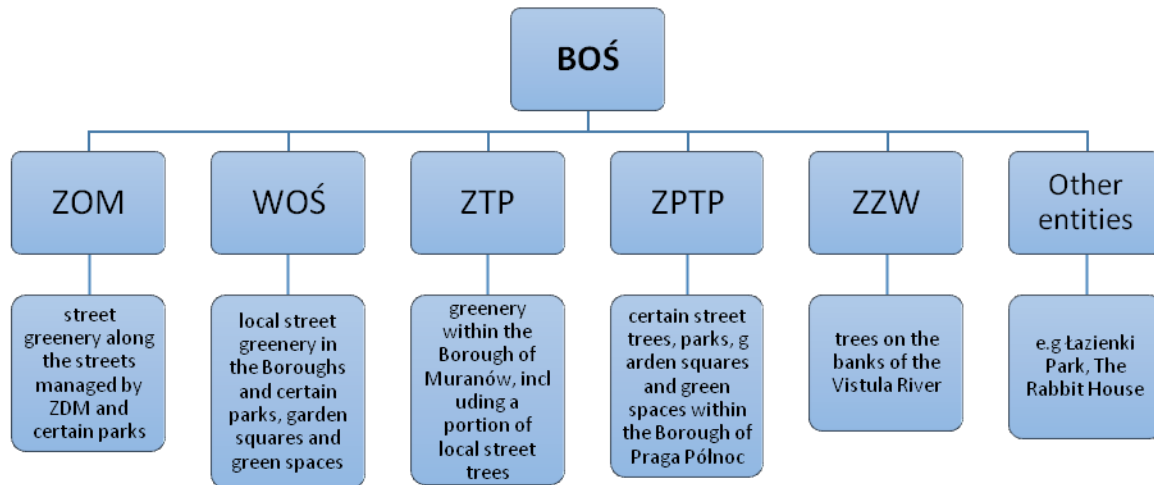
³ ZDM (Polish: *Zarząd Dróg Miejskich*) means the Warsaw City Road Authority.

⁴ <http://ztp.waw.pl/> Accessed August 2017.

- Warsaw Greenery Authority (ZZW): trees on the banks of the Vistula River (intended to gradually take over the management of the most of the urban greenery).

The urban greenery management system chart is presented in the figure below (Figure 1):

Figure 1: Warsaw urban greenery management system chart



Source: Wrzesień, M., 2017. BOŚ, Warsaw (email communication)

where:

ZOM (Polish: *Zarząd Oczyszczania Miasta*) means the City Cleaning Authority;

WOŚ (Polish: *Wydział Ochrony Środowiska*) means the Environmental Protection Departments of the individual Boroughs of Warsaw;

ZTP (Polish: *Zarząd Terenów Publicznych*) means the Public Areas Authority;

ZPTP (Polish: *Zarząd Praskich Terenów Publicznych*) means Praga Public Areas Authority; and

ZZW (Polish: *Zarząd Zieleni Warszawy*) means Warsaw Greenery Authority.

A major challenge facing the agencies responsible for urban greenery in Warsaw is the poor condition of street trees. Street tree mortality in Warsaw is not a new problem but the scale of the process is alarming, as illustrated by the following facts:

- For 1973–87, tree losses are estimated to be 26,000 tree specimens [Dmuchowski, Bandurek, 2001; Szczepanowska 2001];
- In 1982–2006, around half of the trees along the main city streets were cut down [Borowski, Latocha, 2006]; and
- Hundreds of prematurely dying trees along the roads managed by ZDM are removed every year [unpublished data of the City Cleaning Authority Greenery Department in Warsaw, 2017].

Street trees, especially those planted along busy roads, have the greatest exposure to the pressures of the urban environment but, on the other hand, they have the greatest potential for providing regulating ecosystem services, of all existing urban greenery. For this reason, it is essential to gain an understanding of the factors that lead to their fast dying. Numerous authors insist that one contributor to street tree mortality in Warsaw, alongside the fundamental degradation of the habitat, is the misguided tree selection. The tree selection models advocated so far tend to ignore the specific features of street habitats [Bugala *et al.*, 1984; Siewniak, Czekalski, 2001; Borowski J., Latocha P., 2006]. Having recognized the issue, BOS developed a document entitled “Standardy kształtowania zieleni Warszawy”(Standards of Warsaw Greenery Development) in 2016. Those standards aim at supporting the work of the municipal administration bodies in managing the greenery development in Warsaw. Until that time, except for some piecemeal guidance, there had been no comprehensive guide covering that issue. Adopting common standards in Warsaw, where several bodies share responsibility for greenery maintenance, seems in all respects a necessity. Such directives have already been implemented in many cities across Europe, and in Poland, Kraków and Wrocław have done so. In Warsaw, the various institutions dealing with urban greenery have so far largely relied on the experience of a small group of their employees for the selection of appropriate species for planting. This has been the case with ZOM, the primary decision-making body in charge of determining the species composition for planting along the trunk, regional and district roads. Those decisions have been mostly based on the experience of the entity’s highly qualified experts.

The 2016 document notes that *“an appropriate selection of trees, in particular for the hard plant growing conditions of the city, is key to their successful cultivation”*.The document identifies those aspects of the habitat and space settings that may affect the tree condition. However, it states that *“an appropriate selection depends on the specific habitat and spatial conditions. Plants must be selected according to their preferences for the type, humidity and content of the soil and their light and space requirements so as to avoid future conflicts with other trees or the urban infrastructure.”*The importance of the regulating ecosystem services is also stressed. The document argues that *“the location and selection of trees must factor in the phytoremediation properties of the trees”* and that *“infiltration could be increased by planting trees of large-sized species”*.The role of biodiversity is also recognized. There is a clear statement that *“the selection of trees should be sufficiently broad to avoid planting urban monocultures”*.The document names examples of species recommended for planting directly on the sides of streets with heavy vehicle traffic, with a special focus on the following four criteria:

- Tree tolerance for excess salinity;
- Tree tolerance for drought;
- Site and the tree light requirements; and
- Phytoremediation properties of trees (removal of particulate matter, nitric oxides and ozone from the air).

However, arguably, the document has not changed the landscape of urban greenery management in Warsaw. First, experts responsible for urban greenery can be expected to already have the knowledge provided in the document, as confirmed by their qualifications in the field. Second, the document is provided for advisory purposes only and the ultimate decisions on the selection of specific species to be planted in a particular location continue to be taken by persons responsible for planting activities at the relevant agency. One reason is that although some trees are generally recommended for street planting (e.g. *Ginkgo biloba* or *Platanus x hispanica*), they

should not be planted in specific habitat conditions (e.g. windy areas). Therefore, it is expected that final decisions on the species composition will continue to be made based on the experience and expertise of a small group of employees of each individual agency reporting to BOŚ.

However, as appears from the analysis of the document, the city authorities (BOŚ) are keen to have an urban tree species composition that will be distinguished by high healthiness and potential for providing the regulating ecosystem services, while sustaining a considerable level of biodiversity to mitigate the risk of mass tree deaths. This is a typical behaviour of a hierarchically managed city where the top management is generally interested in enhancing the welfare of their constituency. Nevertheless, lower-level officials do not necessarily share the same preferences; they are interested in maximizing their own utility, subject to some constraints imposed by their superiors. This is a standard hierarchical model of the agency theory. In this study, the author looks at the issue of optimal urban green area management in Warsaw at two layers: as a direct representative of the Mayor of the City of Warsaw, BOŚ (principal) exerts control over one of the executive branches: the City Cleaning Authority, or ZOM (agent), who is responsible for street greenery. While the City Mayor is interested in having street greenery that facilitates the welfare of residents, the ZOM management is not necessarily so. In addition, the issue of asymmetric information is also at play. The ZOM management has the experience and expertise allowing to increase the stream of ecosystem services provided by street trees, the knowledge that the City Mayor (BOŚ) does not have. By employing the notation typical for the principal-agent models [Mas-Colell *et al.*, 1995], it can be stated that BOŚ (principal) wants to maximize the following formula:

$$B(x)-s(x)$$

where:

$B(x)$ stands for net benefits provided by urban greenery;

$s(x)$ stands for the salary of the ZOM management; and

x is the level of effort put into the urban greenery enhancement/maintenance activities;

while the ZOM management wants to maximize the following formula:

$$s(x)-c(x)$$

where:

$c(x)$ stands for the cost of the effort subject to the constraint:

$$s(x)-c(x) \geq u^0$$

where:

u^0 is an (unknown) ZOM aspiration level.

Under the standard convexity assumptions, an incentive compatible contract requires that the greenery manager (agent) is the residual claimant, i.e. $\partial B/\partial x = \partial c/\partial x$. This is not the case in Warsaw. The salary of the agent (in particular the pay received by the ZOM management) is in no way determined by the stream of ecosystem services provided by urban trees, or even by the very number of trees. Such conditions are not conducive to maximizing the effort put into urban greenery enhancement/maintenance activities. As a result, this could lead to a non-optimal value

of stream of ecosystem services provided by street trees in Warsaw from the perspective of social welfare.

As far as the author is aware, there are no economic studies into the issue of urban greenery management using the principal-agent approach. There is a recent paper that uses this framework [Hotte *et al.*, 2016], but the study generally addresses land-use problems rather than planting trees in cities. Many contributions apply the agent-based modelling [Guzy *et al.*, 2008], but they do not investigate a potential conflict of incentives between the entities in the management structure. Kronenberg [2015] identifies institutional barriers that may affect the efficiency of urban greenery management other than the principal-agent problem.

2. Materials and methods

Benefits provided by living and healthy trees are undisputable. However, the fact that a portion of trees dies before reaching maturity or is characterized by high dieback levels is a problem. Trees along the main Warsaw roads provide a valid example: approximately one thousand trees are planted every year by ZOM, of which part survives to maturity, but a considerable portion dies early.

There are a number of reasons why street trees die. Planting non-native species that are unsuitable for Poland's climatic zone is one of them. Consequently, without special and expensive protection agents, a tree will die of harsh climate conditions, pest infestation or other causes. Secondly, some trees might have been planted the wrong way failing to meet the requirements of the particular species for normal growth. Thirdly, some trees might not have been properly tended to, especially in the first years after planting. For instance, they might have been insufficiently watered. Fourthly, trees might have been exposed to environmental pollutants, e.g. chlorides [Nowocin, 2017].

In many cases, the mortality and dieback rates of urban trees in Warsaw could be potentially improved by selecting tree species that perform better in Poland's climate and are less demanding in terms of their habitat conditions and more resistant to the urban pressures (including air pollution) and also require low maintenance.

The study has investigated whether ZOM officials factor in the following parameters in their selection of species for planting (i.e. if there is a significant statistical correlation between the number of trees of a given species planted and the relevant parameter):

1. Potential capacity of providing ecosystem services by the trees;
2. Tree mortality rate;
3. Tree dieback rate;
4. Cost of tree purchase and planting; and
5. Species composition of early dying trees.

The study uses calculations based on i-Tree Eco modelling [Szkop, 2017] as well as data on tree species planted by ZOM in 2012–2016 [Nowocin, 2017].

Re. item 1.:

The trees' capacity of providing ecosystem services is determined by their leaf area (LA).

The potential (100% alive) leaf area (equal to the potential capacity of providing ecosystem services) of a specimen of a tree species aged 40 years ($LA_{max_{1-40}}$) can be written as a total of net leaf area increments using the following formula:

$$LA_{max_{1-40}} = LA_{max_1} + LA_{max_2} + LA_{max_3} + \dots + LA_{max_{39}} + LA_{max_{40}}$$

where:

LA_{max_i} stands for the maximum net leaf area increment in a specimen of a tree species aged between $i-1$ and i .

The study has examined if there is a correlation between the number of trees planted and the potential leaf area of a specimen of a tree species aged 40 years. For the purposes of this analysis, the age of 40 years is used as it is considered a representative age of an average mature street tree in Warsaw. Theoretically, most trees can live to a much older age but given the generally poor condition and high mortality of trees growing in the urban environment, the lifespan of 40 years seems realistic, and officials deciding to plant a tree may be reasonably expected to assume that the tree will survive to that age. To make sure that the results obtained are not sensitive to the adopted timespan, i.e. that the correlation between the number of trees planted and their size also exists for those trees which are younger and older than 40 years, it has been additionally examined if there is a correlation between the number of trees of a given species planted and their leaf area at the age of 10 to 100 years ($LA_{max_{1-10}}$, $LA_{max_{1-20}}$... $LA_{max_{1-100}}$).

Re. items 2. and 3.:

The dieback and mortality rates have been calculated for each species separately, broken down into two age groups:

- Trees aged 0 to 10 years; and
- Trees aged 10 to 40 years.

The breakdown into two age groups intends to capture the fact that in their early years trees show a (slightly) higher dieback level and a (significantly) higher mortality, which rates stabilize after the first several years.

The dieback rate (D) has been defined as a mean observable dieback of living trees of a given species in the specific age group: $D = (d_1 + d_2 + d_3 + \dots + d_n) / n$

where:

d_i stands for the observable dieback of a tree; and

n is the total number of trees of a given species.

The mortality rate (M) has been calculated for each tree species as $M = nd / N$

where:

nd stands for the number of dead trees ($D=100\%$) in the specific age group; and

N stands for all trees of a given species in the specific age group.

Re. item 4.:

The cost of tree purchase and planting has been determined from the data received from ZOM in relation to tree purchase and planting prices for standard form trees of a given species.

Re. item 5.:

The species composition of early dying trees has been determined on the basis of street trees identified as dead (100% dieback) during the tree inventory carried out in 2011. To exclude natural death of a tree, only trees aged up to 40 years have been considered.

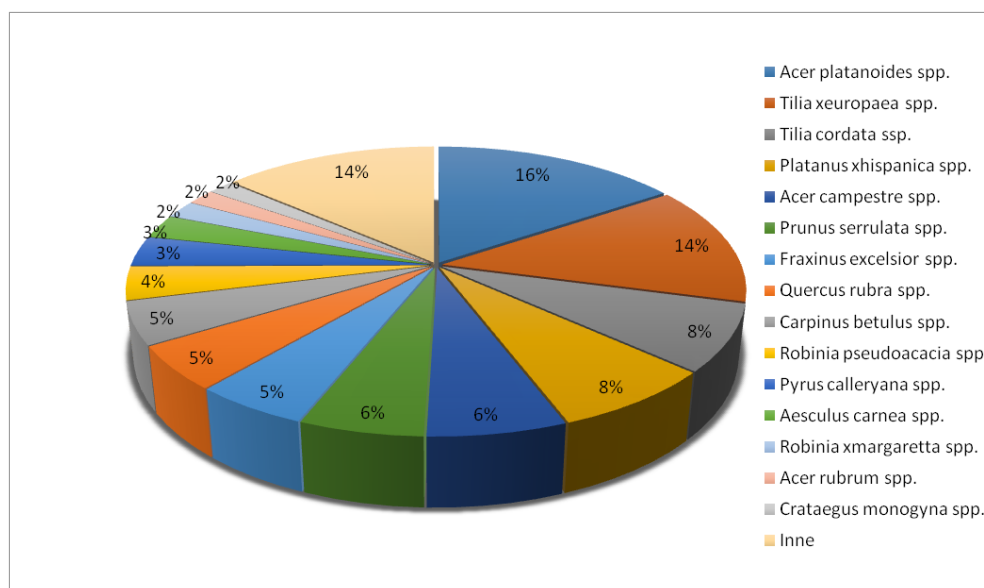
The next stage of the study was to use the empirical data to compare selected tree species of different potential and real (controlling for the mortality and dieback rates) streams of ecosystem services in order to demonstrate that it is possible to improve the efficiency of urban greenery management in Warsaw.

3. Results

3.1 Species composition

In 2012 to 2016, ZOM commissioned planting 3,874 street trees. The most common tree species planted were: *Acer platanoides* spp. (Norway maple) (589 trees), *Tilia xeuropaea* spp. (common lime) (514 trees), *Tilia cordata* spp. (small-leaved lime) (286 trees), *Platanus xhispanica* (London plane) (284 trees) and *Acer campestre* spp. (field maple) (237 trees). These five species accounted for over a half of all trees planted. All these species are large-sized at maturity. The percentage share of individual species is shown in the figure below⁵:

Figure 2. Species composition of trees planted by ZOM in 2012–2016.



Source: Nowocin, K., 2017. ZOM, Warsaw (electronic data).

Factors assumed to have been potentially considered by ZOM in selecting the species for planting along the main Warsaw roads have been examined. Those factors are as follows:

- Potential capacity of providing ecosystem services by the trees;
- Tree mortality rate;
- Tree dieback rate;
- Cost of tree purchase and planting;
- Species composition of early dying trees.

⁵For the full list of species commissioned for planting by ZOM in 2012–2016, please refer to the table in Annex I.

3.2 Potential capacity of providing ecosystem services by the trees

The value of the ecosystem services provided is directly related to the leaf area (LA) of a tree, which makes that index the most convenient parameter for comparing the potential of various trees for providing ecosystem services.

As demonstrated in the regression analysis, if LA is increased by one unit, namely if the leaf area is expanded by one square metre, then the average amount of absorbed pollution in Warsaw will increase by: 1.08 g for O₃; 0.53g for NO₂; 0.08g for SO₂; and 0.04g for PM_{2,5}, and the rainwater flow will be reduced by 2.01L of rainwater (Table 1)⁶. The values are provided in units of measurement where g stands for a gram; L stands for a litre; and R is the correlation ratio.

Table 1. Effect of the LA size on the volume of ecosystem services provided

Ecosystem Service	Value (g or L)	R	R ²
O ₃ (g)	1.08	0.997	0.995
NO ₂ (g)	0.53	0.875	0.766
SO ₂ (g)	0.08	0.990	0.980
PM _{2,5} (g)	0.04	0.984	0.968
Flow reduction (L)	2.01	0.999	0.998

Source: Own calculations based on i-Tree Eco modelling

An analysis of the correlation ratio suggests that there is a virtually full correlation between the size of the leaf area and the volume of O₃, SO₂ and PM_{2,5} absorption and rainwater retention, respectively, and a strong correlation between the size of the leaf area and the volume of NO₂ absorption, NO₂ concentrations being the most varied within the city. The size of the leaf area explains 77% to almost 100% of the variability (variance) in the capacity of trees to provide ecosystem services. All variables are statistically significant.

The potential of a healthy tree to provide ecosystem services at the age of 40 is shown in Table 2.

Table 2: Potential of healthy trees of various species to provide ecosystem services at the age of 40 (leaf area in sq. m)

Gatunek	Number of trees	LA ₁₋₄₀ [m ²]
<i>Acer platanoides</i> spp.	589	165,36
<i>Tilia xeuropaea</i> spp.	514	179,79
<i>Tilia cordata</i> ssp.	286	182,69
<i>Platanus xhispanica</i> spp.	284	158,15
<i>Acer campestre</i> spp.	237	98,71

⁶See Annex III: Results of linear regression analysis (1)–(5).

<i>Prunus serrulata</i> spp.	212	56,47
<i>Fraxinus excelsior</i> spp.	196	141,30
<i>Quercus rubra</i> spp.	189	124,83
<i>Carpinus betulus</i> spp.	183	77,83
<i>Robinia pseudoacacia</i> spp.	144	110,80
<i>Pyrus calleryana</i> spp.	130	48,11
<i>Aesculus carnea</i> spp.	102	253,88
<i>Robinia x margaretta</i> spp.	76	102,49
<i>Acer rubrum</i> spp.	67	143,32
<i>Crataegus monogyna</i> spp.	60	36,95
<i>Fraxinus pennsylvanica</i> spp.	59	135,88
<i>Tilia tomentosa</i> spp.	58	181,46
<i>Quercus robur</i> spp.	53	84,57
<i>Ulmus hollandica</i> spp.	46	186,59
<i>Acer pseudoplatanus</i> spp.	38	151,74
<i>Populus tremula</i> spp.	37	337,47
<i>Ginkgo biloba</i> spp.	35	54,00
<i>Sorbus aucuparia</i> spp.	33	68,45
<i>Betula pendula</i> spp.	27	59,24
<i>Prunus virginiana</i> spp.	22	56,69
<i>Malus x moerlandsii</i> spp.	20	58,62
<i>Crataegus x media</i> spp.	17	42,93
<i>Sorbus aria</i> spp.	13	57,48
<i>Prunus calleriana</i> spp.	9	56,69
<i>Quercus frainetto</i> spp.	9	77,25
<i>Betula utilis</i> spp.	8	61,35

<i>Prunus eminens</i> spp.	7	56,69
<i>Sorbus intermedia</i> spp.	6	71,33
<i>Quercus palustris</i> spp.	5	77,99
<i>Crataegus xlavallei</i> spp.	4	36,37
<i>Quercus xbimundorum</i> spp.	4	77,04
<i>Quercus xwarei</i> spp.	3	78,01
<i>Catalpa bignonioides</i> spp.	2	82,57

Source: Own calculations based on i-Tree Eco modelling

There is a moderate positive correlation ($R=0.35$) between the number of trees of a given species planted and their size (leaf area at the age of 40). This is a statistically significant correlation ($p=0.03$)⁷. Evidence for a similar correlation across different timespans for trees aged 10 to 100 years has also been verified (Table 3).

Table 3: Potential of healthy trees of various species to provide ecosystem services according to their age (LAmax stands for the leaf area in sq. m)

Species	Number of trees	LA max ₁₋₁₀	LA max ₁₋₂₀	LA max ₁₋₃₀	LA max ₁₋₅₀	LA max ₁₋₆₀	LA max ₁₋₇₀	LA max ₁₋₈₀	LA max ₁₋₉₀	LA max ₁₋₁₀₀
Acer platanoides spp.	589	37,94	78,29	121,82	195,48	235,06	265,18	296,41	333,77	365,00
Tilia xeuropaea spp.	514	41,95	85,69	132,74	215,06	258,43	293,70	327,59	368,77	402,66
Tilia cordata spp.	286	41,63	86,40	134,54	218,78	263,16	299,25	333,93	376,07	410,75
Platanus xhispanica spp.	284	34,63	73,75	115,95	187,35	225,71	254,91	285,18	321,39	351,67
Acer campestre spp.	237	22,49	47,31	73,01	132,23	159,14	192,66	212,89	239,79	260,01
Prunus serrulata spp.	212	15,27	27,86	42,17	68,23	81,34	93,09	129,78	145,67	182,36
Fraxinus	196	34,57	66,76	104,03	174,10	208,44	241,25	264,66	297,45	320,87

⁷See Annex III: Results of linear regression analysis (6).

excelsior spp.										
Quercus rubra spp.	189	25,69	55,59	90,21	155,30	187,20	217,67	239,42	269,88	291,63
Carpinus betulus spp.	183	21,72	38,87	58,35	93,83	111,68	127,69	177,65	199,29	249,25
Robinia pseudoacacia spp.	144	30,96	57,58	84,19	135,94	162,26	187,39	209,61	235,27	257,49
Pyrus calleryana spp.	130	8,87	20,86	34,49	59,31	71,79	82,99	117,93	133,06	168,00
Aesculus carnea spp.	102	64,80	132,87	193,37	313,99	377,44	437,55	481,78	542,41	586,65
Robinia xmaregata spp.	76	28,90	53,43	77,96	125,66	149,92	173,09	193,58	217,23	237,71
Acer rubrum spp.	67	34,31	68,83	106,08	169,09	202,95	228,72	255,44	287,40	314,12
Crataegus monogyna spp.	60	10,16	18,34	27,65	44,60	53,12	60,77	84,62	94,96	118,82
Fraxinus pennsylvanica spp.	59	28,88	61,15	98,51	168,76	203,20	236,08	259,56	292,43	315,91
Tilia tomentosa spp.	58	40,76	85,41	133,44	217,46	261,73	297,73	332,32	374,35	408,95
Quercus robur spp.	53	17,30	39,20	61,88	114,14	137,89	167,47	185,33	209,07	226,92
Ulmus hollandica spp.	46	52,52	91,11	138,85	230,18	277,08	320,67	367,51	413,99	460,84
Acer pseudoplatanus spp.	38	35,23	72,12	111,93	179,28	215,46	243,00	271,56	305,71	334,27
Populus tremula spp.	37	80,99	166,49	251,98	372,80	448,26	483,59	512,66	577,31	606,39

Ginkgo biloba spp.	35	9,95	23,41	38,70	66,57	80,58	93,15	132,38	149,36	188,59
Sorbus aucuparia spp.	33	19,04	35,13	51,79	90,18	107,63	129,36	142,47	159,91	173,03
Betula pendula spp.	27	14,69	28,80	44,02	80,24	96,17	117,16	132,32	148,79	163,94
Prunus virginiana spp.	22	16,43	28,73	42,71	68,18	80,99	92,48	128,33	143,86	179,71
Malus xmoerlandsii spp.	20	16,43	29,32	43,97	70,66	84,08	96,12	133,69	149,96	187,54
Crataegus xmedia spp.	17	12,28	21,65	32,29	51,68	61,43	70,18	97,47	109,29	136,59
Sorbus aria spp.	13	14,02	27,30	42,39	69,88	83,71	96,11	134,81	151,56	190,26
Prunus calleriana spp.	9	16,43	28,73	42,71	68,18	80,99	92,48	128,33	143,86	179,71
Quercus frainetto spp.	9	17,20	36,75	57,00	103,65	124,86	151,26	167,20	188,39	204,33
Betula utilis spp.	8	13,79	28,85	45,10	83,77	100,77	123,19	139,37	156,95	173,13
Prunus eminens spp.	7	16,43	28,73	42,71	68,18	80,99	92,48	128,33	143,86	179,71
Sorbus intermedia spp.	6	17,67	35,14	53,24	94,93	113,88	137,48	151,72	170,67	184,91
Quercus palustris spp.	5	18,32	37,75	57,87	104,23	125,30	151,54	167,37	188,43	204,27
Crataegus xlaivallei spp.	4	10,15	18,16	4,33	43,85	52,19	59,67	83,02	93,13	116,47
Quercus xbimundorum spp.	4	16,23	36,03	56,54	103,79	125,26	152,00	168,14	189,60	205,74
Quercus xwarei spp.	3	16,21	37,80	57,90	104,22	125,27	151,49	167,31	188,35	204,18

Catalpa bignonioides spp.	2	15,67	30,08	56,33	109,33	136,09	162,86	184,47	206,08	227,70
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Source: Own calculations based on i-Tree Eco modelling

A regression analysis of two variables where the response variable is the number of trees of a given species planted and the explanatory variable is the potential leaf area of a tree (aged 10 to 100 years) has confirmed the existence of a statistically significant correlation (from $p=0.049$ for trees aged 10 years to $p=0.019$ for trees aged 100 years)⁸ between the number of trees planted and their potential leaf area, equal to the potential of providing ecosystem services, regardless of their age. This is a moderately strong correlation ($0.32 < R < 0.38$).

Therefore, the ZOM management can be assumed to consider their potential capacity of providing ecosystem services in selecting the tree species for planting in Warsaw in favour of those trees that have a greater leaf area (LA).

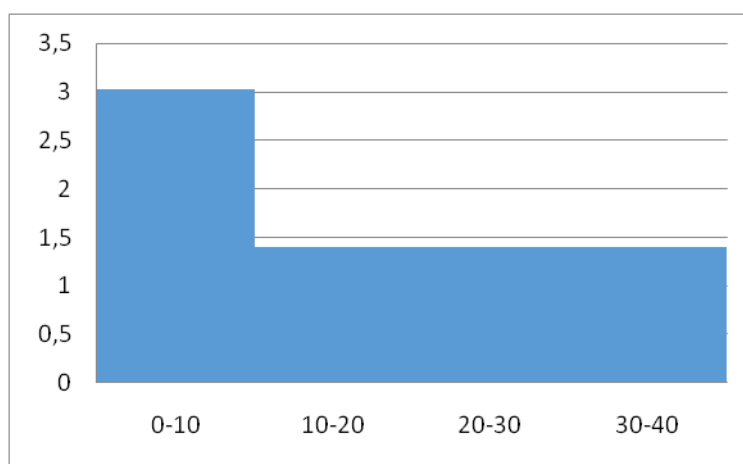
3.3 Tree mortality rate

The mortality rate for urban trees is among the key performance indicators of tree asset management. The street tree mortality is usually captured within the following threshold values [McPherson, 2014]:

- a) low mortality (1% annually during the first five years and 0.5% within the subsequent 30 years); and
- b) high mortality (5% annually during the first five years and 2% within the subsequent 30 years).

A high mortality rate dramatically reduces the number of trees growing to reach maturity and considerably undercuts the effects of management. The mortality of street trees in Warsaw has been calculated separately for trees aged up to 10 years and for those aged between 10 and 40 years. The results are shown in the figure below.

Figure 2. Mortality of street trees in Warsaw



Source: Own compilation based on information received from BOŚ

⁸See Annex III: Results of linear regression analysis (7)–(16).

The mean mortality of street trees in Warsaw aged up to 10 years is quite high at 3.02%. At 1.40%, the mean mortality of trees aged 10 to 40 years is quite high as well. However, the mortality rates vary significantly by individual tree species. The details are provided in Table 4.

Table 4. Mortality (%) of street trees in Warsaw by species

Species	Number of trees	Mortality ₀₋₁₀	Mortality ₁₀₋₄₀
<i>Acer campestre</i> spp.	589	1,78	1,42
<i>Acer platanoides</i> spp.	514	1,97	1,37
<i>Acer pseudoplatanus</i> spp.	286	3,67	1,77
<i>Acer rubrum</i> spp.	284	1,99	1,28
<i>Aesculus carnea</i> spp.	237	4,04	0,73
<i>Betula pendula</i> spp.	212	3,36	0,53
<i>Betula utilis</i> spp.	196	3,89	0,90
<i>Carpinus betulus</i> spp.	189	0,60	1,21
<i>Catalpa bignonioides</i> spp.	183	1,71	1,67
<i>Crataegus xlavallei</i> spp.	144	2,48	1,45
<i>Crataegus xmedia</i> spp.	130	2,48	1,45
<i>Crataegus monogyna</i> spp.	102	2,48	0,94
<i>Fraxinus excelsior</i> spp.	76	2,49	1,49
<i>Fraxinus pennsylvanica</i> spp.	67	1,00	0,98
<i>Ginkgo biloba</i> spp.	60	7,20	0,66
<i>Malus xmoerlandsii</i> spp.	59	1,13	0,68
<i>Platanus xhispanica</i> spp.	58	6,57	1,96
<i>Populus tremula</i> spp.	53	1,46	1,39
<i>Prunus calleriana</i> spp.	46	2,85	2,77
<i>Prunus eminens</i> spp.	38	2,44	2,10
<i>Prunus serrulata</i> spp.	37	2,72	2,57
<i>Prunus virginiana</i> spp.	35	2,44	2,77

<i>Pyrus calleryana</i> spp.	33	0,82	0,72
<i>Quercus xwarei</i> spp.	27	5,92	1,24
<i>Quercus frainetto</i> spp.	22	5,92	1,24
<i>Quercus palustris</i> spp.	20	5,91	1,24
<i>Quercus robur</i> spp.	17	4,96	1,23
<i>Quercus rubra</i> spp.	13	6,73	2,00
<i>Quercus xbimundorum</i> spp.	9	4,08	1,24
<i>Robinia pseudoacacia</i> spp.	9	2,17	0,74
<i>Robinia xmargaretta</i> spp.	8	2,47	1,26
<i>Sorbus aria</i> spp.	7	2,02	1,74
<i>Sorbus aucuparia</i> spp.	6	2,20	2,31
<i>Sorbus intermedia</i> spp.	5	0,58	1,80
<i>Tilia cordata</i> ssp.	4	2,00	0,88
<i>Tilia tomentosa</i> spp.	4	1,89	0,51
<i>Tilia xeuropaea</i> spp.	3	2,13	1,01
<i>Ulmus hollandica</i> spp.	2	4,17	2,09

Source: Own compilation based on information received from BOŠ

Mortality varies greatly species to species. The lowest mortality rate of trees aged up to 10 years can be observed for *Sorbus intermedia* spp. (Swedish whitebeam) and is 0.58%, which is very low. Relatively low annual mortality rates (<2%) at the age of 10 years or less can also be seen for species such as:

- *Acer campestre* spp.
- *Acer platanoides* spp.
- *Acer rubrum* spp.
- *Carpinus betulus* spp.
- *Catalpa bignonioides* spp.
- *Fraxinus pennsylvanica* spp.
- *Malus xmoerlandsii* spp.
- *Populus tremula* spp.
- *Pyrus calleryana* spp.
- *Tilia tomentosa* spp.

The highest mortality rate at the age of 10 years or less is observable for *Ginkgo biloba* spp.(maidenhair tree); at as much as 7.20% annually it is indeed very high. High mortality rates (>4%) at the age of 10 years or less are also found for species such as:

- *Aesculus carnea* spp.
- *Platanus xhispanica* spp.
- *Quercus xwarei* spp.
- *Quercus frainetto* spp.
- *Quercus palustris* spp.
- *Quercus robur* spp.
- *Quercus rubra* spp.
- *Quercus xbimundorum* spp.

For trees aged between 10 and 40 years, *Tilia tomentosa* spp. (silver lime) has the lowest mortality rate at 0.51, which is low. Relatively low annual mortality rates (<1%) at the age between 10 and 40 years can also be seen for species such as:

- *Aesculus carnea* spp.
- *Betula pendula* spp.
- *Betula utilis* spp.
- *Crataegus monogyna* spp.
- *Fraxinus pennsylvanica* spp.
- *Ginkgo biloba* spp.
- *Malus xmoerlandsii* spp.
- *Pyrus calleryana* spp.
- *Robinia pseudoacacia* spp.
- *Tilia cordata* ssp.

For trees aged between 10 and 40 years, *Pyrus calleryana* spp.(Callery pear) shows the highest mortality rate at 2.77%, which is high. High annual mortality rates (>2%) at the age between 10 and 40 years are also found for species such as:

- *Prunus eminens* spp.
- *Prunus serrulata* spp.
- *Prunus virginiana* spp.
- *Quercus rubra* spp.
- *Sorbus aucuparia* spp.

The analysis leads to a conclusion that:

- Some species are plagued by high mortality in the early years after planting (0–10 years of age) and in their older years (10 to 40 years of age) (e.g.*Quercus rubra* spp.);
- Some species are plagued by high mortality in the early years after planting (0 to 10 years of age) but if they can survive through that period, they demonstrate low mortality rates in their older years (10 to 40 years of age) (e.g.*Aesculus carnea* spp.);
- Some species are distinguished by low mortality rates both in the early years after planting (0 to 10 years of age) and in their older age (10 to 40 years of age) (e.g. *Fraxinus pennsylvanica* spp.); and

- Some species are distinguished by low mortality rates in the early years after planting (0 to 10 years of age) but demonstrate higher mortality rates in their older ages (10 to 40 years of age) (e.g. *Carpinus betulus* spp.).

An analysis of the correlation ratio allows to see that there is only a faint correlation between the mortality of species at the age of 0 to 10 years and the frequency of planting of the species ($R=0.10$) and it further decreases for trees aged 10 to 40 years ($R=0.065$). The regression analysis has provided no grounds for concluding with statistically significant probability that ZOM has indeed considered annual mortality rates at the ages of 0 to 10 years or 10 to 40 years in their decision-taking related to the selection of species for planting. The probability of obtaining the same results as those observed or even results that suggest a stronger correlation is as much as 52% ($p=0.516$) for trees aged 10 years or less and 70% ($p=0.698$) for trees of 10 to 40 years of age, assuming that the null hypothesis stating that there is no correlation between the variables concerned is true.⁹

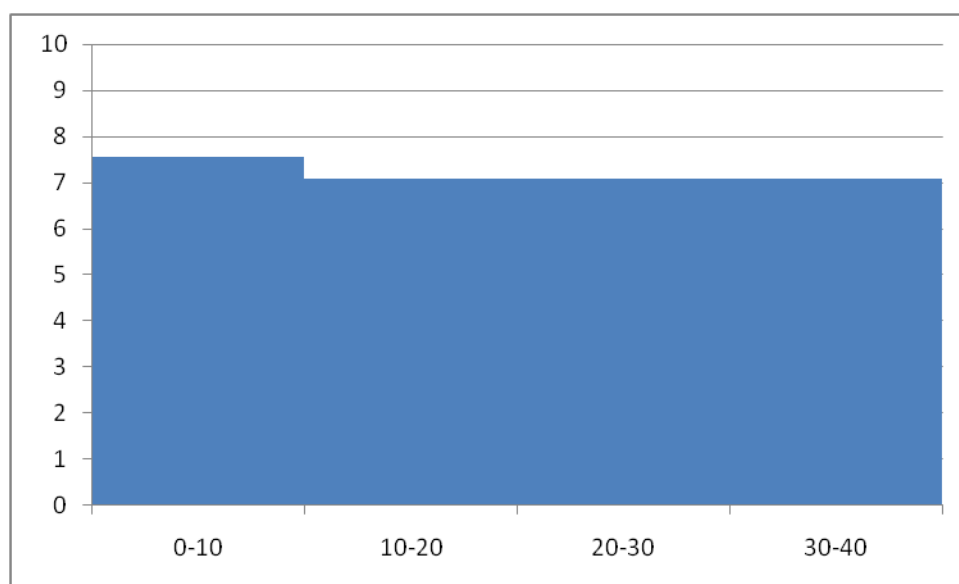
3.4 Tree dieback rate

Even if a tree does survive to a certain age, this does not mean that it provides the potential stream of ecosystem services expected at that age. This is because a tree may show signs of dieback. Dieback refers to the process of tree decline quantified as a percentage of a standing, dying (1–99%) or eventually dead (100%) tree.

The occurrence of dieback has the same root causes as tree deaths, i.e. planting unsuitable non-native species, planting trees the wrong way, maintenance deficiencies, especially in the first years after planting, exposure to excessive environmental pollution or the tree's approaching the age of natural death [Nowocin, 2017; Molenda, 1980].

The mean dieback rate of street trees in Warsaw is 7.19%. It is only slightly higher for trees up to 10 years of age (7.56%) than for trees aged 10 to 40 years (7.07%) (Figure 3).

Figure 3. Mean dieback rate of street trees in Warsaw



Source: Own compilation based on the information received from BOŚ

⁹ See Annex III: Results of linear regression analysis (17),(18).

Even though the mean dieback rate of trees in Warsaw is slightly higher for young trees than for trees aged over 10 years, it varies significantly by individual tree species as shown in Table 5.

Table 5. Dieback rate(%) of street trees in Warsaw by species

Species	Number of trees	Dieback ₀₋₁₀	Dieback ₁₀₋₄₀
<i>Acer platanoides</i> spp.	589	5,99	5,63
<i>Tilia xeuropaea</i> spp.	514	6,11	6,57
<i>Tilia cordata</i> ssp.	286	6,85	6,85
<i>Platanus xhispanica</i> spp.	284	16,82	5,66
<i>Acer campestre</i> spp.	237	8,10	5,59
<i>Prunus serrulata</i> spp.	212	6,48	8,45
<i>Fraxinus excelsior</i> spp.	196	11,92	6,73
<i>Quercus rubra</i> spp.	189	8,11	6,44
<i>Carpinus betulus</i> spp.	183	3,13	4,69
<i>Robinia pseudoacacia</i> spp.	144	4,63	5,91
<i>Pyrus calleryana</i> spp.	130	6,50	7,77
<i>Aesculus carnea</i> spp.	102	6,40	6,92
<i>Robinia xmargaretta</i> spp.	76	6,18	8,84
<i>Acer rubrum</i> spp.	67	7,68	6,94
<i>Crataegus monogyna</i> spp.	60	8,44	5,61
<i>Fraxinus pennsylvanica</i> spp.	59	3,52	6,86
<i>Tilia tomentosa</i> spp.	58	4,91	5,87
<i>Quercus robur</i> spp.	53	9,36	6,02
<i>Ulmus hollandica</i> spp.	46	6,95	7,52
<i>Acer pseudoplatanus</i> spp.	38	11,86	8,59
<i>Populus tremula</i> spp.	37	13,06	8,91
<i>Ginkgo biloba</i> spp.	35	4,64	4,04

<i>Sorbus aucuparia</i> spp.	33	9,75	7,47
<i>Betula pendula</i> spp.	27	7,94	15,87
<i>Prunus virginiana</i> spp.	22	6,20	8,19
<i>Malus xmoerlandsii</i> spp.	20	7,49	6,75
<i>Crataegus xmedia</i> spp.	17	9,79	6,54
<i>Sorbus aria</i> spp.	13	8,65	6,59
<i>Prunus calleriana</i> spp.	9	6,20	8,19
<i>Quercus frainetto</i> spp.	9	7,71	7,96
<i>Betula utilis</i> spp.	8	10,82	15,04
<i>Prunus eminens</i> spp.	7	6,20	8,19
<i>Sorbus intermedia</i> spp.	6	0,82	4,29
<i>Quercus palustris</i> spp.	5	8,24	6,19
<i>Crataegus xlaivallei</i> spp.	4	10,32	6,29
<i>Quercus xbimundorum</i> spp.	4	8,24	6,19
<i>Quercus xwarei</i> spp.	3	8,24	6,19
<i>Catalpa bignonioides</i> spp.	2	2,97	4,29

Source: Own compilation based on the information received from BOŚ

The dieback rate varies greatly species to species. For trees aged up to 10 years, the lowest dieback rate is observed for *Sorbus intermedia* spp. (Swedish whitebeam) at 0.82. Relatively low dieback rates (<5%) at the age of 10 years or less can also be seen for species such as:

- *Catalpa bignonioides* spp.
- *Tilia tomentosa* spp.
- *Fraxinus pennsylvanica* spp.
- *Robinia pseudoacacia* spp.
- *Catalpa bignonioides* spp.

The highest dieback rate at the age of 10 years or less is noted for *Platanus xhispanica* spp. (London plane); at as much as 16.82% it is indeed very high. High dieback rates (>10%) at the age of 10 years or less are also found for species such as:

- *Fraxinus excelsior* spp.
- *Acer pseudoplatanus* spp.
- *Populus tremula* spp.

- *Betula utilis* spp.
- *Crataegus ×lavalleyi* spp.

For trees between 10 and 40 years of age, the lowest dieback rate is observed for *Ginkgo biloba* spp. (maidenhair tree) at 4.04, which is low. Relatively low annual mortality rate (<5%) at the age of 10 to 40 years can also be seen for species such as:

- *Catalpa bignonioides* spp.
- *Sorbus intermedia* spp.
- *Carpinus betulus* spp.

For trees aged 10 to 40 years, the highest dieback rate is observed for *Betula pendula* spp. (silver birch) at 15.87%, which is high. High dieback rates(>8.5%) at the age of 10 to 40 years are also found for species such as:

- *Robinia x margaretta* spp.
- *Acer pseudoplatanus* spp.
- *Populus tremula* spp.
- *Betula utilis* spp.

The analysis leads to a conclusion that:

- Some species are plagued by high dieback levels in the early years after planting (0–10 years of age) and in their older years (10 to 40 years of age) (e.g. *Betula utilis* spp.);
- Some species are plagued by high dieback rates in the early years after planting (0 to 10 years) but demonstrate lower dieback rates in their older years (10 to 40 years of age) (e.g. *Platanus x hispanica* spp.);
- Some species are distinguished by low dieback rates both in the early years after planting (0 to 10 years of age) and in their older age (10 to 40 years of age) (e.g. *Sorbus intermedia* spp.); and
- Some species are distinguished by lower than average dieback rates in the early years after planting (0 to 10 years of age) but demonstrate higher rates in their older ages (10 to 40 years of age) (e.g. *Robinia x margaretta* spp.).

An analysis of the correlation ratio between two variables (where the response variable is the number of trees planted and the explanatory variable is the dieback rate) allows to see that there is no correlation between the dieback rate of species at the age of 0 to 10 years and the frequency of planting of the species ($R=0.007$) and a very faint correlation for trees aged 10 to 40 years ($R=0.19$). The regression analysis has provided no grounds for concluding with statistically significant probability that ZOM has indeed considered dieback rates in their decision-taking related to the selection of species for planting. The probability of obtaining the same results as those observed or even results that suggest a stronger correlation is as much as 97% ($p=0.97$) for trees aged 10 years or less and 24% ($p=0.24$) for trees of 10 to 40 years of age, assuming that the null hypothesis stating that there is no correlation between the variables concerned is true.¹⁰

3.5 Cost of tree purchase and planting

Trees of various species have different prices. The price is a product of many factors, including whether the tree is of a native or non-native species, whether it is easy to grow and how much

¹⁰ See Annex III: Results of linear regression analysis (19), (20).

time it takes for the tree to reach the size expected by the buyer and also whether it is readily available in the local market. ZOM purchases trees through public procurement. The number of contracts awarded for purchase and planting of street trees was 21 in 2012–2016. The table below (Table 6) shows the average price paid by ZOM in the above period for the purchase and planting per tree of a given species.

Table 6. Cost of purchase and planting of street trees in Warsaw

Species	Number of trees	Average purchase price
<i>Acer campestre</i> spp.	237	505
<i>Acer platanoides</i> spp.	589	520
<i>Acer pseudoplatanus</i> spp.	38	549
<i>Acer rubrum</i> spp.	67	559
<i>Aesculus carnea</i> spp.	102	666
<i>Betula pendula</i> spp.	27	492
<i>Betula utilis</i> spp.	8	496
<i>Carpinus betulus</i> spp.	183	517
<i>Catalpa bignonioides</i> spp.	2	544
<i>Crataegus x lavalleyi</i> spp.	4	518
<i>Crataegus x media</i> spp.	17	559
<i>Crataegus monogyna</i> spp.	60	519
<i>Fraxinus excelsior</i> spp.	196	502
<i>Fraxinus pennsylvanica</i> spp.	59	514
<i>Ginkgo biloba</i> spp.	35	616
<i>Malus x moerlandsii</i> spp.	20	554
<i>Platanus x hispanica</i> spp.	284	489
<i>Populus tremula</i> spp.	37	657
<i>Prunus calleryana</i> spp.	9	466
<i>Prunus eminens</i> spp.	7	517
<i>Prunus serrulata</i> spp.	212	500

<i>Prunus virginiana</i> spp.	22	537
<i>Pyrus calleryana</i> spp.	130	528
<i>Quercus xwarei</i> spp.	3	566
<i>Quercus frainetto</i> spp.	9	869
<i>Quercus palustris</i> spp.	5	579
<i>Quercus robur</i> spp.	53	559
<i>Quercus rubra</i> spp.	189	591
<i>Quercus xbimundorum</i> spp.	4	495
<i>Robinia pseudoacacia</i> spp.	144	483
<i>Robinia xmargaretta</i> spp.	76	739
<i>Sorbus aria</i> spp.	13	446
<i>Sorbus aucuparia</i> spp.	33	578
<i>Sorbus intermedia</i> spp.	6	486
<i>Tilia cordata</i> ssp.	286	488
<i>Tilia tomentosa</i> spp.	58	539
<i>Tilia xeuropaea</i> spp.	514	500
<i>Ulmus hollandica</i> spp.	46	645

Source: Nowocin, K., 2017. ZOM, Warsaw (electronic data).

The average purchase price of street trees in Warsaw was PLN 550 PLN (PLN 460–869) in 2012–2016. As appears from the regression analysis, there is a faint negative correlation ($R=-0.21$) between the following attributes: the number of trees planted and the cost of tree purchase and planting, which could imply that the ZOM personnel does consider, if only to a very limited extent, the cost of tree purchase and planting in their decision-taking related to the selection of species for planting, and preference is given to cheaper species. Nevertheless, assuming no correlation between the variables concerned, it is possible to obtain those results or results suggesting an even stronger correlation in 20% of all observations as a result of a random sampling error ($p=0.20$)¹¹. As the probability of obtaining the same results as those observed or even results that suggest a stronger correlation is as much as 20%, assuming that the null hypothesis stating that there is no correlation between the variables concerned is true, there are no grounds to reject it.

¹¹See Annex III: Results of linear regression analysis (21).

3.6 Species composition of early dying trees

Where a tree of a given species in a specific location dies for reasons other than natural causes, decision-makers can:

- Plant a tree of the same species in the same place thinking that the tree death was not related to the qualities of the species; or
- Identify the root cause of the tree death and select a species that would be more resistant to the specific adverse factor; or
- Decide that the specific site is unsuitable for planting trees and choose another landscaping option (e.g. planting bushes or shrubs).

Intuitively, the first option requires the least effort and could be preferred by decision-makers.

The table below (Table 7) contains the details of the number of trees of the given species planted by ZOM in 2012–2016 and the number of trees aged 1 to 40 years identified as dead (100% dieback) during an inventory count of trees in the locations managed by ZOM which was carried out in 2011.

Table7. Species composition of early dying trees

Species	Number of trees of the given species planted by ZOM in 2012–2016	Number of trees aged 1 to 40 years identified as dead in 2011
<i>Acer campestre</i> spp.	237	11
<i>Acer platanoides</i> spp.	589	128
<i>Acer pseudoplatanus</i> spp.	38	28
<i>Acer rubrum</i> spp.	67	1
<i>Aesculus carnea</i> spp.	102	4
<i>Betula pendula</i> spp.	27	37
<i>Betula utilis</i> spp.	8	0
<i>Carpinus betulus</i> spp.	183	1
<i>Catalpa bignonioides</i> spp.	2	0
<i>Crataegus xlavallei</i> spp.	4	0
<i>Crataegus xmedia</i> spp.	17	0
<i>Crataegus monogyna</i> spp.	60	1
<i>Fraxinus excelsior</i> spp.	196	44

<i>Fraxinus pennsylvanica</i> spp.	59	3
<i>Ginkgo biloba</i> spp.	35	8
<i>Malus xmoerlandsii</i> spp.	20	1
<i>Platanus xhispanica</i> spp.	284	40
<i>Populus tremula</i> spp.	37	11
<i>Prunus calleriana</i> spp.	9	0
<i>Prunus eminens</i> spp.	7	0
<i>Prunus serrulata</i> spp.	212	6
<i>Prunus virginiana</i> spp.	22	0
<i>Pyrus calleryana</i> spp.	130	2
<i>Quercus xwarei</i> spp.	3	0
<i>Quercus frainetto</i> spp.	9	0
<i>Quercus palustris</i> spp.	5	0
<i>Quercus robur</i> spp.	53	24
<i>Quercus rubra</i> spp.	189	87
<i>Quercus xbimundorum</i> spp.	4	0
<i>Robinia pseudoacacia</i> spp.	144	13
<i>Robinia xmargaretta</i> spp.	76	0
<i>Sorbus aria</i> spp.	13	2
<i>Sorbus aucuparia</i> spp.	33	21
<i>Sorbus intermedia</i> spp.	6	8
<i>Tilia cordata</i> ssp.	286	95
<i>Tilia tomentosa</i> spp.	58	0
<i>Tilia xeuropaea</i> spp.	514	108
<i>Ulmus hollandica</i> spp.	46	0

Source: Own compilation based on the information received from BOŚ

All trees of the above species can potentially live much longer than 40 years and, therefore, their death must be assumed to be caused by reasons other than natural causes. A regression analysis shows a very high correlation ($R=0.86$) between the decisions on planting new species and the species composition of trees that die for reasons other than natural causes. The correlation is statistically significant ($p=7.13E-12$), which allows to reject the null hypothesis stating that there is no correlation between those attributes¹². The result implies that ZOM usually decides to plant the same tree species in replacement of the removed dead trees. However, those trees often represent species that are not the most suitable for a specific location.

4 Discussion of results

The study demonstrates that in the selection of species for planting city officials in Warsaw base their decision-making on the trees' potential capacity of providing ecosystem services as well as the species composition of dying trees which already exist in the city. Those officials, however, tend to see urban trees as assets rather than living things, expecting them to provide a steady stream of benefits for some time after planting, which is usually at least several decades. Thereby, they assume that the tree survival rate and condition index will be close to 100%. Still the reality shows that for some tree species those indicators assume much lower values.

If the potential volume of benefits provided by a tree of a given species at the age of n years (potential size of the leaf area) is written as:

$$LA_{max1-n}$$

where:

n is the tree age,

then from the perspective of social welfare, considering that only living trees with a healthy leaf area provide benefits, a more realistic formula describing the volume of benefits provided by that tree will look as follows:

$$LA_{real*1-n} = LA_{max1-n} \theta$$

where:

θ stands for the mean dieback rate of the given tree species.

Additionally, in order to estimate the leaf area of a tree at a specific age for a tree being planted now (dynamic analysis), the probability of its survival to the relevant age must be controlled for. Then, the formula would be as follows:

$$LA_{real1-n} = LA_{max1-n} \theta \Omega_n$$

where:

Ω_n stands for the probability of survival to n years.

Moreover, the dynamic potential and real values must both take into account a discount rate. However, it is contingently ignored in the calculations for the sake of simplification because the discount rate for a several-decade-long period of analysis is debatable. Interestingly, the discount rate for the adopted period would reduce the value of the potential and real leaf area by the same percentage for each species, whereby the proportion between them would remain unchanged.

¹²See Annex III: Results of linear regression analysis (22).

Both the potential and the real stream of benefits provided by trees of various species aged 40 (potential and real leaf area) for trees being planted now are shown in the table below (Table 8).

Table 8. Comparison of the potential and real leaf surface for trees of various species aged 40

Species	Number of trees	L _{max1-40} [m ²]	L _{real1-40} [m ²]	Difference [%]
<i>Acer platanoides</i> spp.	589	165,36	84,63	51,18
<i>Tilia xeuropaea</i> spp.	514	179,79	121,19	67,41
<i>Tilia cordata</i> ssp.	286	182,69	106,51	58,30
<i>Platanus xhispanica</i> spp.	284	158,15	41,74	26,39
<i>Acer campestre</i> spp.	237	98,71	50,74	51,41
<i>Prunus serrulata</i> spp.	212	56,47	17,97	31,83
<i>Fraxinus excelsior</i> spp.	196	141,30	65,22	46,16
<i>Quercus rubra</i> spp.	189	124,83	31,73	25,42
<i>Carpinus betulus</i> spp.	183	77,83	48,51	62,33
<i>Robinia pseudoacacia</i> spp.	144	110,80	67,05	60,52
<i>Pyrus calleryana</i> spp.	130	48,11	32,87	68,31
<i>Aesculus carnea</i> spp.	102	253,88	125,75	49,53
<i>Robinia xmargaretta</i> spp.	76	102,49	49,79	48,58
<i>Acer rubrum</i> spp.	67	143,32	74,07	51,68
<i>Crataegus monogyna</i> spp.	60	36,95	17,31	46,85
<i>Fraxinus pennsylvanica</i> spp.	59	135,88	85,12	62,65
<i>Tilia tomentosa</i> spp.	58	181,46	99,95	55,08
<i>Quercus robur</i> spp.	53	84,57	32,93	38,93
<i>Ulmus hollandica</i> spp.	46	186,59	59,76	32,03
<i>Acer pseudoplatanus</i> spp.	38	151,74	55,92	36,85
<i>Populus tremula</i> spp.	37	337,47	174,47	51,70
<i>Ginkgo biloba</i> spp.	35	54,00	20,12	37,25

<i>Sorbus aucuparia</i> spp.	33	68,45	25,13	36,72
<i>Betula pendula</i> spp.	27	59,24	30,17	50,92
<i>Prunus virginiana</i> spp.	22	56,69	17,49	30,86
<i>Malus xmoerlandsii</i> spp.	20	58,62	39,74	67,79
<i>Crataegus xmedia</i> spp.	17	42,93	20,43	47,59
<i>Sorbus aria</i> spp.	13	57,48	25,88	45,02
<i>Prunus calleriana</i> spp.	9	56,69	16,78	29,59
<i>Quercus frainetto</i> spp.	9	77,25	26,59	34,42
<i>Betula utilis</i> spp.	8	61,35	26,76	43,62
<i>Prunus eminens</i> spp.	7	56,69	21,49	37,91
<i>Sorbus intermedia</i> spp.	6	71,33	37,32	52,32
<i>Quercus palustris</i> spp.	5	77,99	27,36	35,08
<i>Crataegus xlavallei</i> spp.	4	36,37	17,11	47,04
<i>Quercus xbimundorum</i> spp.	4	77,04	32,81	42,58
<i>Quercus xwarei</i> spp.	3	78,01	27,37	35,08
<i>Catalpa bignonioides</i> spp.	2	82,57	40,17	48,65

Source: Own calculations based on i-Tree Eco modelling

The differences between $L_{Amax_{1-40}}$ and $L_{Areal_{1-40}}$ are considerable. The real leaf area accounts for 46% of the potential area on average (potential means not controlling for the mortality or dieback rate). There are also significant differences between species: from little over 25% for *Quercus rubra* spp. (red oak) to over 68% for *Pyrus calleryana* spp. (Callery pear).

Those differences have their implications for how urban greenery is managed in Warsaw. The graphs below show possibilities of making improvements by changing the species composition on the example of selected tree species existing in Warsaw. The field below the graphs can be interpreted as the aggregate total leaf area of trees over 40 years (from the 1st to the 40th year of life), however, it must be kept in mind that the discount rate is not controlled for. If the discount rate was controlled for, values more distant in time would be significantly lower.

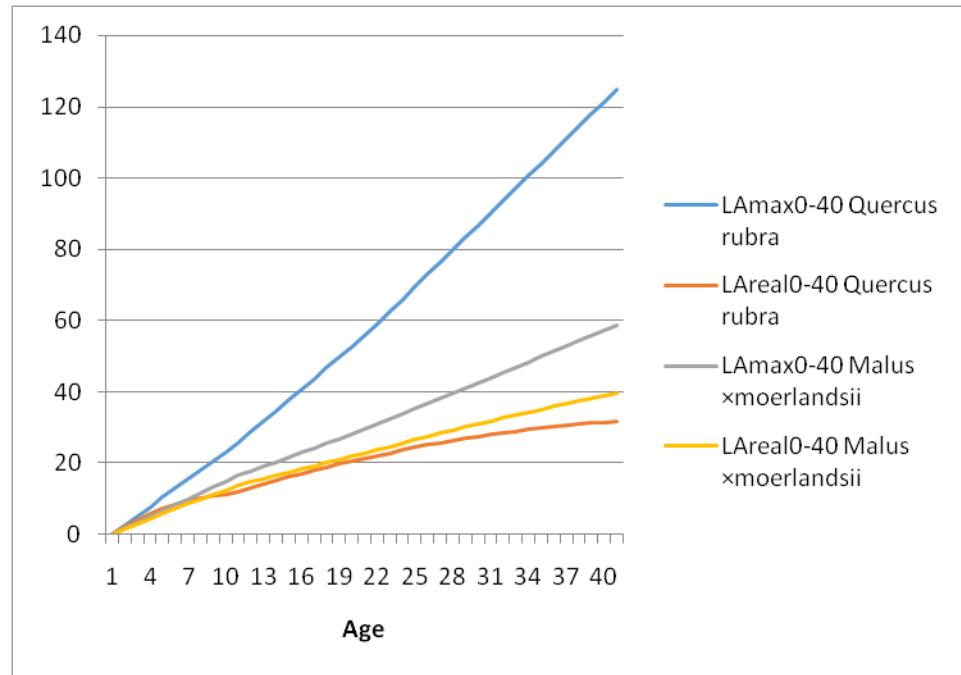
- *Quercus rubra* spp. (red oak), *Malus xmoerlandsii* spp. ('Profusion' crab apple)

Quercus rubra spp. is a popular species as a street tree in Warsaw, being the ninth most commonly occurring species (2,661 trees)¹³. *Malus xmoerandsii* is definitely less popular and

¹³ Trunk, regional and district roads.

ranks 58th (122 trees). That difference is also apparent from the trees planted by ZOM in 2012–2016. During that period, 189 trees of the *Quercus rubra* species and only 20 trees of the *Malus xmoerlandsii* species were planted. The difference between the potential ($L_{Amax1-40}$) and the real ($L_{Areal1-40}$) total leaf areas of both species at the age of 40 years or less is shown in the figure below (Figure 4).

Figure 4. Comparison of L_{Amax} and L_{Areal} totals for two species (*Quercus rubra*, *Malus xmoerlandsii*) aged up to 40



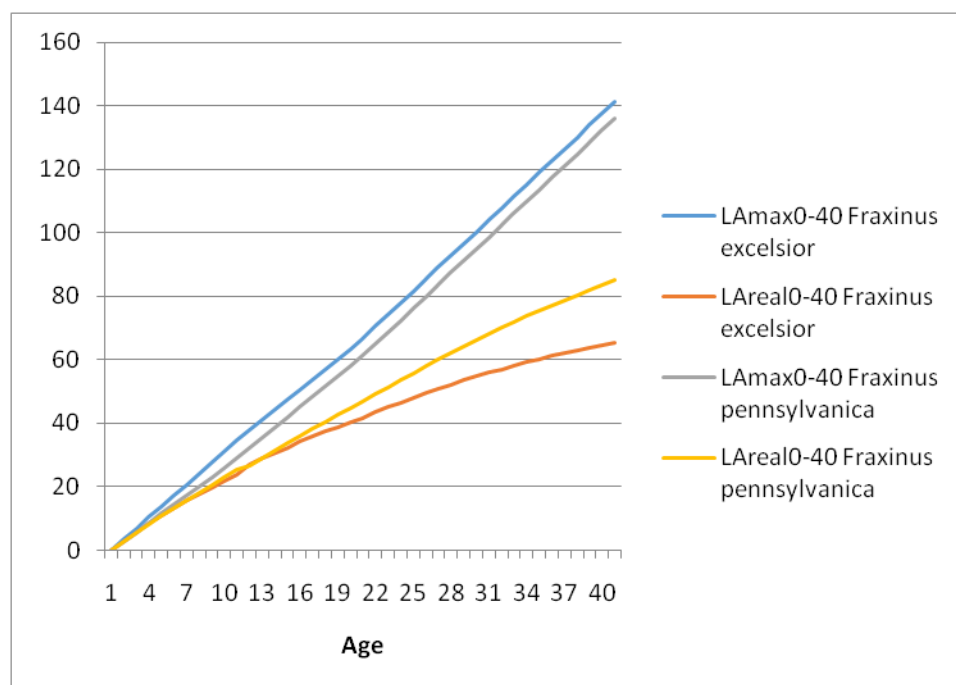
Source: Own calculations based on i-Tree Eco modelling

Such a large disproportion is warranted by the comparison of the potential total leaf area of trees of both species aged up to 40 years. For *Quercus rubra* the value is over 2,394sq. m whereas for *Malus xmorlandsii* it is little less than 1,215sq. m. However, if the mortality and dieback rates are controlled for in relation to both species, *Malus xmorlandsii* appears to have a greater real total leaf area (907sq. m) than *Quercus rubra* (810sq. m).

- *Fraxinus excelsior* spp. (common ash), *Fraxinus pennsylvanica* spp. (green ash)

Fraxinus excelsior and *Fraxinus pennsylvanica* are related species. Both species are very common throughout Poland. *Fraxinus excelsior* is usually slightly larger than *Fraxinus pennsylvanica*. They differ in their prevalence in the streets of Warsaw. *Fraxinus excelsior* is the fourth most common street tree species in Warsaw (3,776). *Fraxinus pennsylvanica* takes only the 14th place (1,138trees). A comparison of the potential and real total leaf areas ($L_{Amax1-40}$ and $L_{Areal1-40}$) of both species at the age of 40 years or less is shown in Figure 5.

Figure 5. Comparison of L_{Amax} and L_{Areal} totals for two species (*Fraxinus excelsior*, *Fraxinus pennsylvanica*) aged up to 40



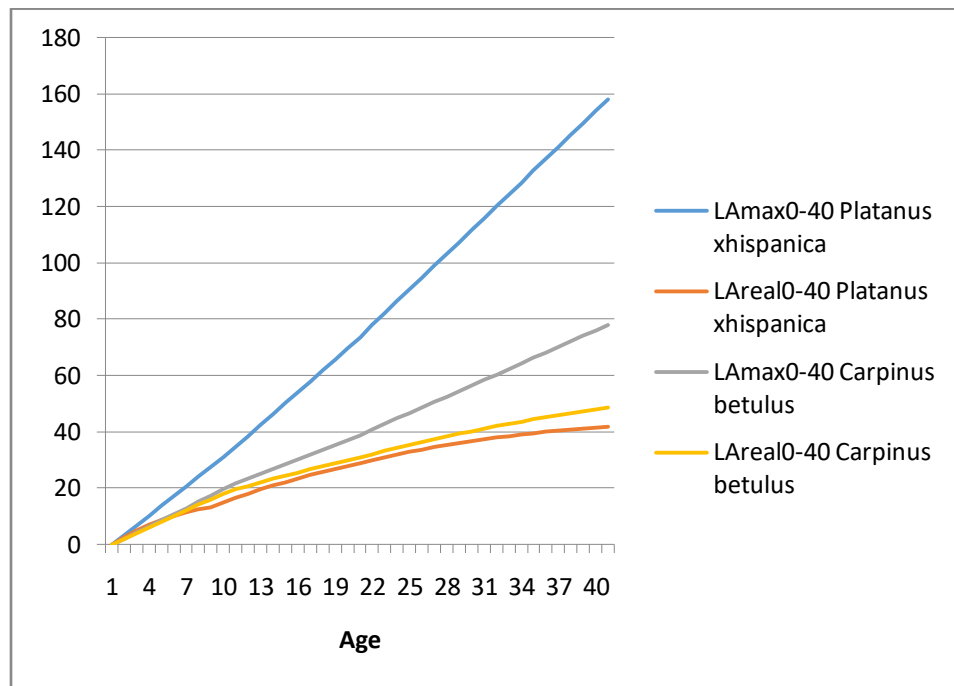
Source: Own calculation based on i-Tree Eco modelling

If the potential capacity of providing ecosystem services expressed as the potential total leaf area of both species is compared, *Fraxinus excelsior* performs better in comparison (2,820sq. m) than *Fraxinus pennsylvanica* (2,624sq. m). The picture is different where the mortality and dieback rates are controlled for and is in favour of *Fraxinus pennsylvanica*, for which the real total leaf area is then 1,880sq. m whereas the real total leaf area of *Fraxinus excelsior* is 1,599sq. m.

- *Platanus xhispanica* spp. (London plane), *Carpinus betulus* spp. (European hornbeam)

Platanus xhispanica is a relatively large-sized tree species occurring in fair numbers along the roads of Warsaw (798). On the other hand, *Carpinus betulus* is a medium-sized species and more than one half less common (346). Comparisons of the potential and real total leaf areas (L_{Amax}₁₋₄₀ and L_{Areal}₁₋₄₀) of both species at the age of 40 years or less are shown in Figure 6.

Figure 6. Comparison of LA_{max} and LA_{real} totals for two species (*Platanus xhispanica*, *Carpinus betulus*) aged up to 40



Source: Own calculations based on i-Tree Eco modelling

The difference in their size is clearly reflected in their potential capacity of providing ecosystem services, where the aggregated leaf area of *Platanus xhispanica* is nearly one-half larger (3,103 sq. m) than that of *Carpinus betulus* (1,611sq. m). However, the real capacity of providing those services is entirely different. *Carpinus betulus* has an aggregated leaf area of 1,192sq. m whereas for *Platanus xhispanica* it is 1,078sq. m.

5 Conclusion

The main conclusion from the study is that the species composition preferred by the ZOM management differs from that preferred by BOŚ (representing the Mayor of the Capital City of Warsaw), which follows from the fact that the ZOM management does not take sufficient account of the mortality and dieback rates in their planting activities. This is a consequence of the incentive incompatibility of the principal-agent contract. In order to develop an effective incentive system, it must be ensured that the greenery manager (agent) is the residual claimant the agent is the residual claimant.

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Annex I

Species	Number of trees
<i>Acer platanoides</i> spp.	589
<i>Tilia xeuropaea</i> spp.	514
<i>Tilia cordata</i> ssp.	286
<i>Platanus xhispanica</i> spp.	284
<i>Acer campestre</i> spp.	237
<i>Prunus serrulata</i> spp.	212
<i>Fraxinus excelsior</i> spp.	196
<i>Quercus rubra</i> spp.	189
<i>Carpinus betulus</i> spp.	183
<i>Robinia pseudoacacia</i> spp.	144
<i>Pyrus calleryana</i> spp.	130
<i>Aesculus carnea</i> spp.	102
<i>Robinia xmargaretta</i> spp.	76
<i>Acer rubrum</i> spp.	67
<i>Crataegus monogyna</i> spp.	60
<i>Fraxinus pennsylvanica</i> spp.	59
<i>Tilia tomentosa</i> spp.	58
<i>Quercus robur</i> spp.	53
<i>Ulmus hollandica</i> spp.	46
<i>Acer pseudoplatanus</i> spp.	38
<i>Populus tremula</i> spp.	37
<i>Ginkgo biloba</i> spp.	35
<i>Sorbus aucuparia</i> spp.	33
<i>Betula pendula</i> spp.	27

<i>Prunus virginiana</i> spp.	22
<i>Malus</i> × <i>moerlandsii</i> spp.	20
<i>Crataegus</i> × <i>media</i> spp.	17
<i>Sorbus aria</i> spp.	13
<i>Prunus calleriana</i> spp.	9
<i>Quercus frainetto</i> spp.	9
<i>Betula utilis</i> spp.	8
<i>Prunus eminens</i> spp.	7
<i>Sorbus intermedia</i> spp.	6
<i>Quercus palustris</i> spp.	5
<i>Crataegus</i> × <i>lavalleyi</i> spp.	4
<i>Quercus xbimundorum</i> spp.	4
<i>Quercus</i> × <i>warei</i> spp.	3
<i>Catalpa bignonioides</i> spp.	2
Sum	3784

Annex II

Trees growing among roads of I,II and III category		
Species	Number of trees	%
<i>Tilia cordata</i> spp.	12511	16,392
<i>Acer platanoides</i> spp.	9997	13,099
<i>Acer negundo</i> spp.	5666	7,424
<i>Fraxinus excelsior</i> spp.	3776	4,948
<i>Acer saccharinum</i> spp.	3396	4,451
<i>Tilia platyphyllos</i> spp.	3203	4,197
<i>Populus nigra</i> spp.	3145	4,122
<i>Quercus robur</i> spp.	3145	4,122
<i>Quercus rubra</i> spp.	2661	3,488
<i>Acer pseudoplatanus</i> spp.	2613	3,424
<i>Robinia pseudoacacia</i> spp.	2470	3,237
<i>Betula pendula</i> spp.	2461	3,225
<i>Aesculus hippocastanum</i> spp.	1833	2,402
<i>Fraxinus pennsylvanica</i> spp.	1138	1,492
<i>Sorbus intermedia</i> spp.	1109	1,454
<i>Populus simonii</i> spp.	1089	1,427
<i>Sorbus aucuparia</i> spp.	1001	1,312
<i>Pinus sylvestris</i> spp.	954	1,251
<i>Platanus xhispanica</i> spp.	798	1,046
<i>Prunus domestica</i> spp.	660	0,866
<i>Prunus cerasifera</i> spp.	652	0,855
<i>Populus alba</i> spp.	646	0,848

<i>Acer campestre</i> spp.	506	0,664
<i>Ulmus laevis</i> spp.	501	0,657
<i>Acer tataricum</i> spp.	495	0,649
<i>Crataegus monogyna</i> spp.	490	0,643
<i>Pyrus calleryana</i> spp.	489	0,641
<i>Rhus typhina</i> spp.	454	0,596
<i>Prunus cerasus</i> spp.	401	0,526
<i>Tilia xeuropaea</i> spp.	363	0,476
<i>Carpinus betulus</i> spp.	346	0,453
<i>Populus xcanescens</i> spp.	333	0,437
<i>Populus tremula</i> spp.	331	0,434
<i>Tilia euchlora</i> spp.	327	0,429
<i>Prunus avium</i> spp.	290	0,381
<i>Picea abies</i> spp.	288	0,378
<i>Juglans regia</i> spp.	266	0,349
<i>Populus maximowiczii</i> spp.	243	0,318
<i>Picea pungens</i> spp.	234	0,308
<i>Ginkgo biloba</i> spp.	233	0,306
<i>Pyrus pyraister</i> spp.	224	0,294
<i>Salix alba</i> spp.	212	0,279
<i>Alnus glutinosa</i> spp.	208	0,273
<i>Malus sylvestris</i> spp.	208	0,273
<i>Salix fragilis</i> spp.	178	0,234
<i>Sambucus nigra</i> spp.	177	0,232
<i>Populus xberolinensis</i> spp.	175	0,230

<i>Tilia tomentosa</i> spp.	171	0,224
<i>Elaeagnus angustifolia</i> spp.	159	0,209
<i>Sorbus aria</i> spp.	152	0,200
<i>Populus x canadensis</i> spp.	150	0,197
<i>Padus avium</i> spp.	146	0,193
<i>Thuja occidentalis</i> spp.	146	0,193
<i>Larix decidua</i> spp.	142	0,187
<i>Sorbus torminalis</i> spp.	141	0,185
<i>Quercus petraea</i> spp.	140	0,183
<i>Fraxinus ornus</i> spp.	133	0,174
<i>Malus xmoerlandsii</i> spp.	122	0,161
<i>Pinus nigra</i> spp.	119	0,156
<i>Malus domestica</i> spp.	118	0,155
<i>Prunus serrulata</i> spp.	116	0,153
<i>Aesculus xcarnea</i> spp.	107	0,141
<i>Corylus colurna</i> spp.	105	0,138
<i>Crataegus laevigata</i> spp.	105	0,138
<i>Prunus serotina</i> spp.	79	0,105
<i>Caragana arborescens</i> spp.	74	0,097
<i>Fagus sylvatica</i> spp.	74	0,097
<i>Ulmus minor</i> spp.	74	0,097
<i>Abies alba</i> spp.	55	0,073
<i>Malus xpurpurea</i> spp.	52	0,068
<i>Acer rubrum</i> spp.	49	0,065
<i>Morus alba</i> spp.	46	0,061
<i>Prunus spinosa</i> spp.	42	0,056

<i>Syringa vulgaris</i> spp.	41	0,055
<i>Salix xsepulcralis</i> spp.	39	0,052
<i>Ulmus glabra</i> spp.	38	0,050
<i>Robinia hispida</i> spp.	35	0,047
<i>Salix caprea</i> spp.	31	0,041
<i>Pinus strobus</i> spp.	28	0,038
<i>Laburnum anagyroides</i> spp.	25	0,033
<i>Hippophae rhamnoides</i> spp.	23	0,030
<i>Prunus padus</i> spp.	23	0,030
<i>Catalpa bignonioides</i> spp.	19	0,026
<i>Taxus baccata</i> spp.	19	0,026
<i>Picea omorika</i> spp.	16	0,021
<i>Salix babylonica</i> spp.	16	0,021
<i>Pinus rigida</i> spp.	15	0,020
<i>Betula papyrifera</i> spp.	13	0,018
<i>Abies concolor</i> spp.	12	0,017
<i>Prunus armeniaca</i> spp.	12	0,017
<i>Acer pensylvanicum</i> spp.	10	0,014
<i>Gleditsia triacanthos</i> spp.	10	0,014
<i>Abies grandis</i> spp.	9	0,012
<i>Acer saccharum</i> spp.	9	0,012
<i>Juglans nigra</i> spp.	9	0,012
<i>Corylus avellana</i> spp.	8	0,011
<i>Abies koreana</i> spp.	6	0,009
<i>Juniperus communis</i> spp.	6	0,009
<i>Crataegus macracantha</i> spp.	5	0,008

<i>Malus floribunda</i> spp.	5	0,008
<i>Prunus xeminens</i> spp.	5	0,008
<i>Picea glauca</i> spp.	4	0,006
<i>Picea orientalis</i> spp.	4	0,006
<i>Prunus triloba</i> spp.	4	0,006
<i>Pseudotsuga menziesii</i> spp.	4	0,006
<i>Crataegus punctata</i> spp.	3	0,005
<i>Juniperus virginiana</i> spp.	3	0,005
<i>Prunus persica</i> spp.	3	0,005
<i>Ptelea trifoliata</i> spp.	3	0,005
<i>Ailanthus altissima</i> spp.	2	0,003
<i>Cercidiphyllum japonicum</i> spp.	2	0,003
<i>Chamaecyparis pisifera</i> spp.	2	0,003
<i>Larix xmarschlinsii</i> spp.	2	0,003
<i>Liriodendron tulipifera</i> spp.	2	0,003
<i>Malus xscheideckeri</i> spp.	2	0,003
<i>Pinus mugo</i> spp.	2	0,003
<i>Pinus ponderosa</i> spp.	2	0,003
<i>Pterocarya fraxinifolia</i> spp.	2	0,003

<i>Rhamnus cathartica</i> spp.	2	0,003
<i>Ulmus pumila</i> spp.	2	0,003
<i>Abies nordmanniana</i> spp.	1	0,002
<i>Alnus incana</i> spp.	1	0,002
<i>Catalpa speciosa</i> spp.	1	0,002
<i>Celtis</i> spp.	1	0,002
<i>Chamaecyparis nootkatensis</i> spp.	1	0,002
<i>Fraxinus angustifolia</i> spp.	1	0,002
<i>Juglans cinerea</i> spp.	1	0,002
<i>Larix kaempferi</i> spp.	1	0,002
<i>Malus royalty</i> spp.	1	0,002
<i>Prunus mahaleb</i> spp.	1	0,002
<i>Sambucus racemosa</i> spp.	1	0,002
<i>Sophora japonica</i> spp.	1	0,002
<i>Tilia americana</i> spp.	1	0,002
Sum	76263	100

Annex III – results of linear regression analysis

(1)

SUMMARY OUTPUT - O3 by LA

Regression Statistics	
Multiple R	0,9977013
R Square	0,9954079
Adjusted R Square	0,9954078
Standard Error	9,1826845
Observations	162466

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	2969491777	2969491777	4E+07	0
Residual	162464	13699239,9	84,32169529		
Total	162465	2983191017			

	Coefficient	Standard Error	t Stat	p-value	Lower 95%	Upper 95%	Lower 95,0%	Upper 95,0%
Intercept	0,3281027	0,032238167	10,17746022	3E-24	0,264916551	0,391289	0,264917	0,391289
X Variable 1	1,0892546	0,000183552	5934,325977	0	1,088894804	1,089614	1,088895	1,089614

(2)

SUMMARY OUTPUT - NO2 by LA

Regression Statistics	
Multiple R	0,8752755
R Square	0,7661072
Adjusted R Square	0,7661058
Standard Error	36,200981
Observations	162466

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	697381639,5	697381639,5	532145	0
Residual	162464	212910865,1	1310,511037		
Total	162465	910292504,6			

	Coefficient	Standard Error	t Stat	p-value	Lower 95%	Upper 95%	Lower 95,0%	Upper 95,0%
Intercept	-3,080586	0,127092822	-24,23886891	1E-129	-3,329685459	-2,83149	-3,32969	-2,83149
X Variable 1	0,5278659	0,000723617	729,4825594	0	0,526447591	0,529284	0,526448	0,529284

(3)

SUMMARY OUTPUT - SO2 by LA

Regression Statistics	
Multiple R	0,989598
R Square	0,9793042
Adjusted R Square	0,9793041
Standard Error	1,4307134
Observations	162466

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	157361115,58	157361115,58	8E+06	0
Residual	162464	332554,1853	2,04694077		
Total	162465	16068669,76			

	Coefficient	Standard Error	t Stat	p-value	Lower 95%	Upper 95%	Lower 95,0%	Upper 95,0%
Intercept	0,202922	0,005022886	40,39947784	0	0,193077222	0,212767	0,193077	0,212767
X Variable 1	0,0792934	2,85983E-05	2772,656892	0	0,079237357	0,079349	0,079237	0,079349

(4)

SUMMARY OUTPUT - PM2,5 by LA

Regression Statistics								
Multiple R	0,9838271							
R Square	0,9679158							
Adjusted R Square	0,9679156							
Standard Error	0,8781294							
Observations	162466							

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	3779381,066	3779381,066	5E+06	0
Residual	162464	125277,8174	0,771111246		
Total	162465	3904658,884			

	Coefficient	Standard Error	t Stat	p-value	Lower 95%	Upper 95%	ower 95,0%	pper 95,0%
Intercept	-0,250975	0,003082898	-81,40883873	0	-0,257017586	-0,24493	-0,25702	-0,24493
X Variable 1	0,0388596	1,75528E-05	2213,868511	0	0,038825227	0,038894	0,038825	0,038894

(5)

SUMMARY OUTPUT - AR by LA

Regression Statistics								
Multiple R	0,9990687							
R Square	0,9981382							
Adjusted R Square	0,9981382							
Standard Error	0,0107789							
Observations	162466							

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	10119,87084	10119,87084	9E+07	0
Residual	162464	18,87592983	0,000116185		
Total	162465	10138,74677			

	Coefficient	Standard Error	t Stat	p-value	Lower 95%	Upper 95%	ower 95,0%	pper 95,0%
Intercept	0,0012014	3,78422E-05	31,74893892	2E-220	0,00112728	0,001276	0,001127	0,001276
X Variable 1	0,0020108	2,15459E-07	9332,798272	0	0,00201041	0,002011	0,00201	0,002011

(6)

SUMMARY OUTPUT - LP by LA max40

Regression Statistics								
Multiple R	0,3575537							
R Square	0,1278446							
Adjusted R Square	0,1036181							
Standard Error	128,98722							
Observations	38							

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	87797,9759	87797,9759	5,277	0,027530601
Residual	36	598957,2873	16637,70242		
Total	37	686755,2632			

	Coefficient	Standard Error	t Stat	p-value	Lower 95%	Upper 95%	ower 95,0%	pper 95,0%
Intercept	20,274066	40,36890936	0,502219807	0,6186	-61,59787647	102,146	-61,5979	102,146
X Variable 1	0,7475864	0,325436151	2,297182905	0,0275	0,087571262	1,407601	0,087571	1,407601

(7)

Statystyki regresji	
Wielokrotność R	0,321674042
R kwadrat	0,103474189
Dopasowany R kwadrat	0,078570694
Błąd standardowy	130,7769326
Observacje	38

ANALIZA WARIANCJI

	df	SS	MS	F	Istotność F
Regresja	1	71061,44396	71061,44396	4,155006763	0,048908753
Resztkowy	36	615693,8192	17102,60609		
Razem	37	686755,2632			

	Współczynniki	Błąd standardowy	t Stat	Wartość-p	Dolne 95%	Górne 95%	Dolne 95,0%	Górne 95,0%
Przecięcie	28,71205016	40,72786591	0,704973107	0,485363377	-53,8878898	111,3119901	-53,8878898	111,3119901
Zmienna X 1	2,774854527	1,361301592	2,03838337	0,048908753	0,014006954	5,535702101	0,014006954	5,535702101

(8)

SUMMARY OUTPUT - LP by LA max20

Regression Statistics	
Multiple R	0,3383482
R Square	0,1144795
Adjusted R Square	0,0898817
Standard Error	129,97178
Observations	38

ANOVA

	df	SS	MS	F	Significance F
Regression	1	78619,40077	78619,40077	4,6541	0,037730687
Residual	36	608135,8624	16892,66284		
Total	37	686755,2632			

	Coefficient	Standard Error	t Stat	p-value	Lower 95%	Upper 95%	Lower 95,0%	Upper 95,0%
Intercept	26,586035	39,8665795	0,666875237	0,5091	-54,2671355	107,4392	-54,2671	107,4392
X Variable 1	1,4295835	0,662664524	2,157326149	0,0377	0,085637569	2,773529	0,085638	2,773529

(9)

SUMMARY OUTPUT - LP by LA max30

Regression Statistics	
Multiple R	0,3547115
R Square	0,1258203
Adjusted R Square	0,1015375
Standard Error	129,13683
Observations	38

ANOVA

	df	SS	MS	F	Significance F
Regression	1	86407,73345	86407,73345	5,1815	0,028877762
Residual	36	600347,5297	16676,32027		
Total	37	686755,2632			

	Coefficient	Standard Error	t Stat	p-value	Lower 95%	Upper 95%	Lower 95,0%	Upper 95,0%
Intercept	23,37891	39,49011956	0,592019219	0,5575	-56,71076426	103,4686	-56,7108	103,4686
X Variable 1	0,9773446	0,429359926	2,276282676	0,0289	0,106562277	1,848127	0,106562	1,848127

(10)

SUMMARY OUTPUT - LP by LA max40

Regression Statistics	
Multiple R	0,3575537
R Square	0,1278446
Adjusted R Square	0,1036181
Standard Error	128,98722
Observations	38

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	87797,9759	87797,9759	5,277	0,027530601
Residual	36	598957,2873	16637,70242		
Total	37	686755,2632			

	Coefficient	Standard Error	t Stat	p-value	Lower 95%	Upper 95%	ower 95,0%	pper 95,0%
Intercept	20,274066	40,36890936	0,502219807	0,6186	-61,59787647	102,146	-61,5979	102,146
X Variable 1	0,7475864	0,325436151	2,297182905	0,0275	0,087571262	1,407601	0,087571	1,407601

(11)

SUMMARY OUTPUT - LP by LA max50

Regression Statistics	
Multiple R	0,357711
R Square	0,1279572
Adjusted R Square	0,1037337
Standard Error	128,9789
Observations	38

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	87875,24684	87875,24684	5,2824	0,027457581
Residual	36	598880,0163	16635,55601		
Total	37	686755,2632			

	Coefficient	Standard Error	t Stat	p-value	Lower 95%	Upper 95%	ower 95,0%	pper 95,0%
Intercept	14,383901	42,56545586	0,337924274	0,7374	-71,9428443	100,7106	-71,9428	100,7106
X Variable 1	0,6536174	0,284386513	2,298341815	0,0275	0,076854838	1,23038	0,076855	1,23038

(12)

SUMMARY OUTPUT - LP by LA max60

Regression Statistics	
Multiple R	0,3567552
R Square	0,1272743
Adjusted R Square	0,1030319
Standard Error	129,02939
Observations	38

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	87406,2733	87406,2733	5,2501	0,027903728
Residual	36	599348,9899	16648,58305		
Total	37	686755,2632			

	Coefficient	Standard Error	t Stat	p-value	Lower 95%	Upper 95%	ower 95,0%	pper 95,0%
Intercept	14,801911	42,50978459	0,348200097	0,7297	-71,4119274	101,0157	-71,4119	101,0157
X Variable 1	0,5412997	0,236240897	2,291303737	0,0279	0,062180908	1,020418	0,062181	1,020418

(13)

SUMMARY OUTPUT - LP by LA max70

Regression Statistics	
Multiple R	0,3553443
R Square	0,1262696
Adjusted R Square	0,1019993
Standard Error	129,10364
Observations	38

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	86716,30828	86716,30828	5,2026	0,028573212
Residual	36	600038,9549	16667,74875		
Total	37	686755,2632			

	Coefficient	Standard Error	t Stat	p-value	Lower 95%	Upper 95%	ower 95,0%	pper 95,0%
Intercept	11,695171	43,85397047	0,266684419	0,7912	-77,24480316	100,6351	-77,2448	100,6351
X Variable 1	0,4858672	0,213012778	2,280929792	0,0286	0,053857257	0,917877	0,053857	0,917877

(14)

SUMMARY OUTPUT - LP by LA max80

Regression Statistics	
Multiple R	0,3694606
R Square	0,1365011
Adjusted R Square	0,1125151
Standard Error	128,3455
Observations	38

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	93742,87354	93742,87354	5,6908	0,022438109
Residual	36	593012,3896	16472,56638		
Total	37	686755,2632			

	Coefficient	Standard Error	t Stat	p-value	Lower 95%	Upper 95%	ower 95,0%	pper 95,0%
Intercept	-3,298116	47,88801902	-0,068871418	0,9455	-100,4195192	93,82329	-100,42	93,82329
X Variable 1	0,4932172	0,206751998	2,385549859	0,0224	0,073904716	0,91253	0,073905	0,91253

(15)

SUMMARY OUTPUT - LP by LA max90

Regression Statistics	
Multiple R	0,3696336
R Square	0,136629
Adjusted R Square	0,1126465
Standard Error	128,33599
Observations	38

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	93830,67629	93830,67629	5,697	0,022370347
Residual	36	592924,5869	16470,12741		
Total	37	686755,2632			

	Coefficient	Standard Error	t Stat	p-value	Lower 95%	Upper 95%	ower 95,0%	pper 95,0%
Intercept	-3,145088	47,80857796	-0,065785014	0,9479	-100,1053774	93,8152	-100,105	93,8152
X Variable 1	0,4377453	0,183399262	2,386843498	0,0224	0,065794396	0,809696	0,065794	0,809696

(16)

SUMMARY OUTPUT - LP by LA max100

Regression Statistics	
Multiple R	0,3789652
R Square	0,1436146
Adjusted R Square	0,1198261
Standard Error	127,81575
Observations	38

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	98628,09578	98628,09578	6,0371	0,018959127
Residual	36	588127,1674	16336,86576		
Total	37	686755,2632			

	Coefficient	Standard Error	t Stat	p-value	Lower 95%	Upper 95%	Lower 95,0%	Upper 95,0%
Intercept	-14,95326	51,01701263	-0,293103423	0,7711	-118,4205576	88,51404	-118,421	88,51404
X Variable 1	0,43653	0,17766345	2,457061087	0,019	0,076211775	0,796848	0,076212	0,796848

(17)

SUMMARY OUTPUT - LP by Mortality0-10

Regression Statistics	
Multiple R	0,1086887
R Square	0,0118132
Adjusted R Square	-0,015636
Standard Error	137,2996
Observations	38

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	8112,792915	8112,792915	0,4304	0,515983612
Residual	36	678642,4702	18851,17973		
Total	37	686755,2632			

	Coefficient	Standard Error	t Stat	p-value	Lower 95%	Upper 95%	Lower 95,0%	Upper 95,0%
Intercept	124,66252	44,25022113	2,81721799	0,0078	34,91891164	214,4061	34,91891	214,4061
X Variable 1	-8,307675	12,66378614	-0,65601826	0,516	-33,99102347	17,37567	-33,991	17,37567

(18)

SUMMARY OUTPUT - LP by Mortality10-40

Regression Statistics	
Multiple R	0,0650378
R Square	0,0042299
Adjusted R Square	-0,02343
Standard Error	137,82541
Observations	38

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	2904,919352	2904,919352	0,1529	0,698061538
Residual	36	683850,3438	18995,84288		
Total	37	686755,2632			

	Coefficient	Standard Error	t Stat	p-value	Lower 95%	Upper 95%	Lower 95,0%	Upper 95,0%
Intercept	120,29385	57,49703089	2,092175058	0,0435	3,684471317	236,9032	3,684471	236,9032
X Variable 1	-14,76265	37,75084359	-0,391054921	0,6981	-91,32491203	61,79961	-91,3249	61,79961

(19)

SUMMARY OUTPUT - LP by Dieback0-10

Regression Statistics	
Multiple R	0,0067813
R Square	4,599E-05
Adjusted R Square	-0,027731
Standard Error	138,11465
Observations	38

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	31,58072832	31,58072832	0,0017	0,967769082
Residual	36	686723,6824	19075,65785		
Total	37	686755,2632			

	Coefficient	Standard Error	t Stat	p-value	Lower 95%	Upper 95%	Lower 95,0%	Upper 95,0%
Intercept	97,24771	61,51978532	1,580755033	0,1227	-27,52019638	222,0156	-27,5202	222,0156
X Variable 1	0,308402	7,579592385	0,040688465	0,9678	-15,06372376	15,68053	-15,0637	15,68053

(20)

SUMMARY OUTPUT - LP by Dieback10-40

Regression Statistics	
Multiple R	0,1934214
R Square	0,0374119
Adjusted R Square	0,0106733
Standard Error	135,50958
Observations	38

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	25692,78933	25692,78933	1,3992	0,244615425
Residual	36	661062,4738	18362,8465		
Total	37	686755,2632			

	Coefficient	Standard Error	t Stat	p-value	Lower 95%	Upper 95%	Lower 95,0%	Upper 95,0%
Intercept	179,49654	71,04890367	2,52638019	0,0161	35,40268842	323,5904	35,40269	323,5904
X Variable 1	-11,22135	9,486579242	-1,182866211	0,2446	-30,46102836	8,01832	-30,461	8,01832

(21)

SUMMARY OUTPUT - LP by Price

Regression Statistics	
Multiple R	0,2476592
R Square	0,0579168
Adjusted R Square	0,0317479
Standard Error	134,0585
Observations	38

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	39774,69171	39774,69171	2,2132	0,145543325
Residual	36	646980,5715	17971,68254		
Total	37	686755,2632			

	Coefficient	Standard Error	t Stat	p-value	Lower 95%	Upper 95%	Lower 95,0%	Upper 95,0%
Intercept	375,71017	186,8818352	2,010415661	0,0519	-3,303757996	754,7241	-3,30376	754,7241
X Variable 1	-0,291068	0,195652228	-1,487678347	0,1955	-0,687868692	0,105734	-0,68787	0,105734

(22)

SUMMARY OUTPUT - LP by LP of Dead Trees

<i>Regression Statistics</i>	
Multiple R	0,8563125
R Square	0,7332712
Adjusted R Square	0,725862
Standard Error	71,332056
Observations	38

<i>ANOVA</i>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	503577,8226	503577,8226	98,96852778	7,134E-12
Residual	36	183177,4405	5088,262237		
Total	37	686755,2632			

	<i>Coefficient</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>p-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95,0%</i>	<i>Upper 95,0%</i>
Intercept	35,287963	13,25389487	2,66245987	0,011523106	8,407818726	62,16811	8,407819	62,16811
X Variable 1	1,4951392	0,150291031	9,948292707	7,13E-12	1,19033483	1,799944	1,190335	1,799944



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