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THE VALUATION OF TREES IN THE URBANIZED AREAS WITH THE COMPENSATION/ REPLACEMENT METHOD AND BENEFITS ANALYSIS (THE CASE OF THE CITY OF GNIEZNO)

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WYCENA WARTOŚCI DRZEW NA TERENACH ZURBANIZOWANYCH METODAMI KOSZTU ODTWORZENIA I ANALIZY KORZYŚCI (PRZYKŁAD MIASTA GNIEZNA)

STRESZCZENIE: Do określenia wartości drzew na terenach zurbanizowanych są stosowane różnorodne metody. W związku z odmienną metodyką, uzyskiwane wyniki są często trudne do porównania. Powoduje to liczne trudności, zarówno w wymiarze teoretycznym, jak i praktycznym. W artykule podejmowana jest próba porównania wyników wyceny wartości drzew uzyskanych dzięki zastosowaniu dwóch metod wyceny – metody kosztu odtworzenia i analizy korzyści. Badaniami objęte zostały drzewa przyuliczne miasta Gniezna.

SŁOWA KLUCZOWE: świadczenia ekosystemów, drzewa, wycena, wartość ekonomiczna

Introduction

The knowledge of the economic value of trees has a significant meaning for managing the stand of trees in the urbanized areas. Information in this area may be unusually useful in investment planning, assessing the impact of the investment on the surrounding natural environment, establishment and development of green areas and their appropriate cultivation. Lack of appropriate information may lead to unplanned and often unrealized losses, transferred into particular quantifications. The cause may be lost benefits because of limited profits coming from the trees, particularly oxygen production, carbon dioxide absorption and water retention.

The estimations of the economic value of the stand of trees were made in the United States and chosen European countries[1]. The estimations were conducted with different methods. In Poland, despite running research on the tree values, the research was rather qualitative than quantitative. So far, no comprehensive economic estimation of the state of trees was conducted for particular spatial unit. It stems from a few reasons: lack of obligation of conducting natural environment valuation in Polish conservancy laws, lack of appropriate, consistent and comprehensive valuation method which would be adopted by the conservancy administration and lack of knowledge and appropriate distribution of already developed methods.

The aim of this article is to present the results of the valuation of street trees in the town of Gniezno. Thanks to the assumed methodology of the research, the obtained results help to compare the value which was determined with the compensation/replacement method and the value determined based on the provided ecosystem services.

Trees as the subject of economic valuation

Trees have specific properties which significantly influence their value. These properties include: the species, age, morphological features, change in time(height, volume increase, shape change),changes concerning the increased vitality in the development process, plants flexibility while adapting to new environmental conditions, location. These features have significant meaning in determining the criteria of tree value estimation[2].

[1] See e.g.: D.J. Nowak, D.E. Crane, J.F. Dwyer, *Compensatory value of urban trees in the United States,* "Journal of Arboriculture" no. 28(4), p. 194-199; G.H. Donovan, D.T. Butry, *Trees in the city. Valuing street trees in Portland, Oregon,* "Landscape and Urban Planning" 2010 no. 94, p. 77-83; M. Giergiczny, J. Kronenberg, *Jak wycenićwartość przyrody w mieście? Wycena drzew przyulicznych w centrum Łodzi,* in: T. Bergier, J. Kronenberg (eds.), *Zrównoważony rozwój – zastosowania,* Kraków 2012, p. 73-89.

[2] H.B. Szczepanowska, A. Latos, *Synteza badań i założenia merytoryczne metody wyceny wartości drzewa dla warunków polskich,* Warszawa 2009.

The compensation/replacement method (CM/RM) is most often used in the cities to estimate the value of trees. This method has been legally recognized in many countries. The cost-benefit analysis (CBA) is frequently used. Hedonic price method (HPM), conditional value method (CVM) and conditional choice method (CEM) are used more rarely.

The compensation/replacement method includes the cost of planting and cultivating the trees, which are the compensation of removed or damaged trees. The variants of this method are used in different way in different countries. In the United States this method was used for the valuation of trees in the New York City and it amounted to USD 5.2 billion (996 dollars per tree), in Jersey City – USD 101 million (USD 742 per tree), in Boston USD 1.3 billion (USD 1058 per tree),and in Oakland USD 757 million (477 dollars per tree). In total, the value for the whole country was estimated at USD 2.4 trillion[3].

The cost-benefit analysis is also used to estimate the economic value of trees. It involves balancing the costs related with maintaining city greenery with expected benefits provided by trees in cities. This method was used in the New York City. The research included 592 000 trees. The analysis showed that trees in the streets of New York bring to its inhabitants the net profit of USD 122 million annually (209 dollars per tree). The following benefits were included in the research: the limitation of energy consumption, CO_2 absorption, pollution absorption, water retention and the impact of trees on the properties. It was estimated that 1 dollar spent on planting and cultivation of trees brings to the city the profits amounting to USD 5.60[4].

Another method which is often applied is the hedonic price method. It is underlined in many conducted research that the natural environment, e.g. trees along the street, impacts the price of a particular property a buyer is willing to pay (particularly in urbanized areas). In Portland, the biggest city of the State of Oregon236,000 trees were inventoried[5]. The research included 2608properties. It was stated that the presence of the trees growing within the distance not exceeding 30.5m from a housecontributed to the increase of the property value of approximatelyUSD 8870(3% of the property value). After rounding this result off, the authors indicated that the trees along the city streets have the value of USD 1.35 billion. It was also stated that the house surrounded by trees growing along the streets were easier to sell. The buyers made the decisions to buy these houseon average 1.7 days earlier. However, it seems that this method is less significant in Poland due to a number of different economic and social conditions[6].

Contingent valuation method involves conducting survey interview. While presenting a hypothetical scenario, the buyers give an answer and quote the price they would be willing to pay for the delivery of particular goods. The plan of

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[3] D.J. Nowak, D.E. Crane, J.F. Dwyer, op. cit.

[4] P.J. Peper et al., *New York City, New York — Municipal forest resource analysis*, Davis 2007.

[5] G.H. Donovan, D.T. Butry, op. cit.

[6] A. Bernaciak, N. Strzelecka, *Natural values as a factor in the location of residential invetsments*, "Economic and Environmental Studies" 2014 no. 14, v. 2, p. 149-162.

the research, conducted in the United States, in 44 cities of the Missouri state, assumed the creation of a fund which would allow for betterkeeping of trees in the cities. The inhabitants expressed their support for establishing the tree fund by paying taxes. In bigger cities, more than half of the inhabitants were willing to paybetweenUSD 14-16 per householdannually[7].

The value of trees in a city may also be estimated with the choice experiment method. Similarly to contingent valuation method, it requires the preparation of hypothetical scenarios of providing services, but the difference is that the respondents have torank these scenarios from the most to the least convenient for them. This method was used in Poland to value the price of street trees in Łódź[8].

The research conducted so far in the economic value of trees allow to draw some conclusions. First of all, there is no one consistent, universal method, which could be applied for economic valuation of trees globally, and consequently could be the legal and formal base for the activities of administration institutions. Secondly, the use of different methods in trees valuation leads to obtaining different results, which may cause significant practical complications. The values obtained in different research conducted with different methods are not comparable to each other. Thirdly, the ecosystem benefits provided by the trees, which are in fact demanded by the society, are not always included in the applied valuation methods.

The compensation/replacement method and benefits analysis – methodological basis of the comparative studies

The valuation of trees with the replacement value, particularly for Polish spatial and environmental conditions was thoroughly developed by Institute of Spatial Management and Housing[9]. The method concerns the cost of the tree replacement by expressing the financial compensation for the potential loss of the tree. The tree circumference of 25 cm was assumed as the limit size of trees which should be reinstated in the form of natural restitution. The cost of a growing tree in this particular circumference was assumed as so called basic value. This value is verified with the application of so calledmaterializing factors.These factors concern the tree condition, its location, species and growth. Depending on the circumference, the calculating formula of the real tree value(RWD) is presented in the following way[10]:

- for the trees of the circumference 20/25 cm: RWD = WP x K x L (1)
- for the trees of the circumference below 20 cm: RWD = WP x M x K x L; (2)
- for the trees of the circumference above 25 cm: RWD = WP x G x P x K x L;(3)

[7] T. Treiman, J. Gartner, *Are residents willing to pay for their community forests? Results of a contingent valuation survey in Missouri, USA,* "Urban Studies" 2006 no. 43 v. 9, p. 1537-1547.
[8] M. Giergiczny, J. Kronenberg, op. cit.
[9] H.B. Szczepanowska (ed.), op. cit.; H.B. Szczepanowska, A. Latos, op. cit.
[10] H.B. Szczepanowska (ed.), op. cit.

where:
WP – basic value in PLN for particular tree species;
K – condition coefficient;
L – location coefficient;
M – coefficient of decreasing the value depending on the tree circumference size;
G – species value coefficient;
P – tree growth coefficient.

The value of services provided to social and economic system by trees (benefits analysis) has been the reference point in this research. Although trees are the source of many benefits included in Common International Classification of Ecosystem Services (CICES)[11], it is suggested only these benefits be included in the valuation whose value can be calculated most precisely. These benefits include:the absorption of carbon dioxide, oxygen productionand water retention. The calculation of the value of these benefits may be made with relatively high precision. It is very difficult to value other benefits. Even if it is possible, the result of such valuation has a significant mistake. It is suggested naming the sum of the values calculated for three types of benefits asthe minimum service value [MWU]. The real value of provided benefits [RWS]is definitely higher than the minimum service value (therefore the denomination ”minimum”), however this value is difficult to calculate,therefore it is not included in quantitative categories.

$$RWD > MWU\ (pd, pt, rw) \tag{4}$$

where:
CWD – the total value of a tree
RWD – the real value of a tree
MWU – the minimum service value
pd – carbon dioxide absorption
pt – oxygen production
rw – water retention

The determination of such value may have significant practical meaning. It allows to relatively easily calculate the value of particular object and confront it with possible consequences of the activities taken on such object(e.g. removal, the decrease of provided benefits). Therefore it may be a useful instrument in local urban planning or the assessment of the environment impact.

The calculation of the provided benefits remains an important issue: the absorption of carbon dioxide (pd), oxygen production (pt)and water retention (rw).

The data concerning the amount of carbon dioxide absorbed by trees was compiledbased on the data available in literature[12]. The data indicates that the

[11] European Environment Agency (EEA), *Common international classification of ecosytsem services* (CICES), 2013, *Consultation on version 4,* www.cices.eu [18-06-2014].
[12] D.J. Nowak, A*tmospheric carbon dioxide reduction by Chicago's Urban Forest,* in: E.G. McPherson, D.J. Nowak, R.A. Rowntree, *Chicago's Urban Forest ecosystem: results of the Chicago, Urban Forest Climate Project,* Forest Service 1994; American Forests 2014, *Tree facts,* www.americanforests.org [18-06-2014]; NCSU, *Tree facts,* www.ncsu.edu [18-06-2014]; AEA (Arbor Environmental Alliance), *Carbon&Tree Facts,* www.arborenvironmentalalliance.com [18-06-2014];

Table 1
The amount of services provided by trees

Tree circumference [cm]	Absorption of carbon dioxide [kg/year]	Oxygen production [kg/year]	Water retention [l/year]
8-25	10.90	2.90	1000.00
26-40	21.60	15.80	1750.00
41-71	48.00	22.60	2125.00
72-99	94.80	45.60	2500.00
100-143	141.50	68.40	3500.00
144-170	235.10	91.10	4500.00
171-239	399.00	110.30	5282.00
Above 240	486.60	118.00	6064.00

Source: own elaboration based on the literature data indicated in the text.

average amount of CO_2 absorbed by a tree amounts to 164.90 kg/year (from 10.90 kg/yearfor the smallest trees to 486.60 kg/year for the biggest ones). Eight classes of the trees' circumferences were established based on the literature. The appropriate amounts of absorbed carbon dioxide were established correspondingly (Table 1).

The price of EUA certificate for the Polish market was assumed in order to determine the value of absorbed carbon dioxide unit. The average monthly prices of carbon dioxide in 2013 varied between 3.57 to 5.22 PLN/CO_2 ton (the average – 4,47 euro/ton). The average annual exchange rate was assumed for currency calculations. After performing the appropriate currency and unit calculations, the price of 1 kilogram of CO_2 in time of performing the analysis amounted to 0,02 PLN/kg.

Similarly, the value of oxygen production was determined based on the literature data[13]. The data analysis indicated that the amount of oxygen delivered by

Urban Forestry Network, www.urbanforestrynetwork.org [18-06-2014]; A.L. Soares et al., *Benefits and costs of street trees in Lisbon, Portugal,* "Urban Forestry & Urban Greening" 2011 no. 10; "Ekspertyza natemat ekonomicznych I ekologicznych zysków wypływających z Programu Lesistości Miasta pod kontem absorpcji CO_2 – Gmina Wrocław"; E.G. McPherson, J.R. Simpson, *Carbon dioxide reduction through urban forestry*. *Guidelines for professional and volunteer tree planters,* Forest Service 1999; D.J. Nowak, D.E. Crane, *Carbon storage and sequestration by urban trees in the USA,* "Environmental Pollution" 2002 no. 116, p. 381-389; *The morton arboretum*, www.mgrieblerdev.devcloud.acquia-sites.com [12-06-2014].

13 D.J. Nowak, R. Hoehn, D.E. Crane, *Oxygen production by urban trees in the United States,* "Arboriculture&Urban Forestry" 2007 no. 33(3), p. 220-226; J. Borowski, 2013, *Dlaczego warto sadzić I pielęgnować drzewa?, www.*sadybamazury.wordpress.com [15-06-2014]; T. Tylkowski, *Drzewa dla terenów zieleni*, „Przegląd Komunalny" 2006 no. 8, www.e-czytelnia.abrys.pl [15-06-2014]; American Forests, *Tree facts,* www.americanforests.org [15-06-2014]; M. McAliney, *Arguments for land conservation: Documentation and information sources for land resources protection*, Sacramento CA 1993; E.G. McPherson, *Benefits of trees, watershed, energy and air,* "Arborist News" 2004 no. 13(6), p. 29-35.

one tree varies between 0.70 and 3500 kg annually and increases proportionally to the tree circumference. Eight ranges of tree circumferences were established along with their corresponding amount of produced oxygen (Table 1).

The value of a produced oxygen unit was established based on the market offer of medical oxygen. During the study, the lowest price of 1 kg of oxygen amounted to 14.00 PLN/kg.

Similar proceedings were assumed for another benefit, the retention of water.The scope of retention was established based on literature data[14].

Assuming that the scope of retention is proportional to the size of a tree and following the available data, the scope of retention was established for eight circumference ranges (Table 1).

The establishment of a coefficient to determine the value of retention in financial categories may be somehow difficult. The following argumentation was assumed. Trees absorb water from the ground and transport it to the leaves through the vascular cambium. Water vapors out of the plant through leaves. This process reminds the functioning of a water pump. The cost of a pump work may be determined based on the electricity used for this purpose. Therefore the value of the service of pumping a particular unit of water can be established based on the costs such as the electricity used for this purpose (other costs, including the costs of purchasing the pump are excluded). To perform the appropriate calculations, the pump with the lowest cost of pumping a unit of water was chosen from the pumps available in the market. Simultaneously, the maximum power consumption of the pump and the lowest price of electricity during the conducted analysis were taken into consideration. Based on these assumptions, the value of pumping 1 m^3 of water was established and it amounted to 0.02 PLN/m^3.

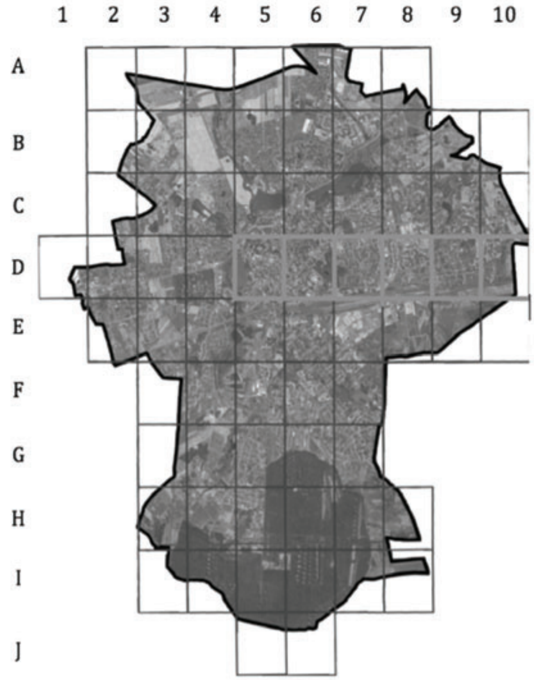
The value of street trees in the town of Gniezno

The research of the economic value of trees was conducted in the town of Gniezno in September 2013. The area of the research was marked with vector numerical map, which divides the city into 68 equal parts. These were placed in the topographic map of Gniezno in 1:50 000 scale. The parts were called sections (figure 1).

The particular sections were marked longitudinally – with the subsequent letters of the alphabet and latitudinally – with the numbers from 1 to 10. The surface of each section is 79.9 ha. Six sections in the longitudinal sequence from D5 to D10 were chosen for the research. The chosen sections start from the suburb area (D10) and end in the city centre (D5). Each section is characterized by different spatial structure. The total area that was researched covered 479.4 ha.

[14] E.G. McPherson, op. cit., p. 29-35; A.L. Soares et al., op. cit.; www.urbanforestrynetwork.org [12-06-2014]; The Morton Arboretum, www.mortonarb.org [12-06-2014].

Figure 1
Division of the town of Gniezno into sections



Source: own elaboration.

5154 trees were inventoried in the researched area including 1619 street trees (31%). Most of the trees were located in D6 section (41% of the total number of trees), where there was the domination of trees accompanying the architectural buildings. The trees were located next to public buildings, schools, churches and in the playground parks. The lowest number of trees was found in D10 section, characterized by the dominating agricultural function (Table 2).

The economic value of trees in the research area, calculated with the compensation/replacement method was estimated at over PLN 50 million. The average value of one tree is over PLN 13.5 thousand. Meanwhile, the value calculated based on the provided ecosystem services is slightly above PLN 2.5 million annually, and the average value of one tree in this case amounts to PLN 560. It must be emphasized that the compensation/replacement method refers to the whole lifecycle of a particular tree. Therefore, the time frames, when the value of the provided services is summed up, should be determined in order to compare the results obtained from these two methods. These time frames can be associated with the average lifespan of a tree in the urban development. The lifespan of 30 years was assumed for the needs of this research. In this period of time the value of trees calculated with the cost analysis method amounted to more than PLN

Table 2
The results of tree inventory in the town of Gniezno, sections D5-D10

Specification	D5	D6	D7	D8	D9	D10	Total
Number of trees in section	1845	2107	892	239	55	16	5154
Including street trees	240	645	513	150	55	16	1619
Number of deciduous trees	1254	1624	762	185	55	16	3896
Number of coniferous trees	591	483	130	54	–	–	1258
Average circumference [cm]	62,25	73,14	74,96	77,85	90,42	104,69	80,55
Average tree condition*	17,85	16,69	17,37	16,77	17,11	18,65	17,41
Tree condition assessment	average	average	average	average	average	good	average
Urban coefficient	1,1	1,1	1,3	1,3	1,3	1,3	1,3
Average value of location coefficient	0,96	1,06	1,09	1,18	1,05	1,2	1,08
The most popular tree species	*Thuja occidentalis*	*Thuja occidentalis*	Small-leaved lime (*Tiliacordata*)	European ash (Fraxinusexcelsior)	European ash (*Fraxinusexcelsior*)	European ash (*Fraxinusexcelsior*)	*Thuja occidentalis*
The most popular street tree species	Norway maple (*Acerplatanoides*)	Small-leaved lime (*Tiliacordata*)	Small-leaved lime (*Tiliacordata*)	European ash (Fraxinusexcelsior)	European ash (*Fraxinusexcelsior*)	European ash (*Fraxinusexcelsior*)	Small-leaved lime (*Tiliacordata*)

* The condition of trees, urban coefficient and location coefficient were determined pursuant to the tree valuation methodology suggested by Szczepanowska [2009]

Source: own elaboration.

Table 3
The value of trees in the town of Gniezno in researched sections [PLN]

Value category [PLN]	Section						
	D5	D6	D7	D8	D9	D10	Ogółem
Total compensation/replacement value	17 286 575,00	20 446 551,12	8 338 116,97	3 787 590,14	607 459,35	277 720,55	50 744 013,13
Average compensation/replacement value	12 595,44	9 726,12	11 612,98	15 847,66	14 126,96	17 357,53	13 544,45
Total value of services annually	772 642,61	1 080 857,92	486 146,10	134 263,19	32 077,56	11 892,94	2 517 880,31
Average value of services annually	418,78	512,98	545,01	561,77	583,23	743,31	560,85
Total value of services in lifecycle (30 years)	23 179 278,24	32 425 737,47	14 584 383,08	4 027 895,57	962 326,72	356 788,25	75 536 409,33
Average value of services in lifecycle (30 years)	12 563,29	15 389,53	16 350,21	16 853,12	17 496,85	22 299,27	16 825,38
Total value of services of carbon dioxide absorption	83 374,32	121 270,56	49 075,80	13 589,58	4 174,32	1 229,04	272 713,62
Total value of services of oxygen production	23 093 490,00	32 301 444,00	14 533 974,00	4 013 940,00	958 062,00	355 530,00	75 256 440,00
Total value of services of water retention	2 407,38	3 022,91	1 333,28	365,99	90,40	29,21	7 249,17

Source: own elaboration.

75.5 milion, and the average value – almost PLN 17 thousand (Table 3). The obtained results are therefore very similar to the results obtained with the compensation/replacement method. However, the previous assumption must be resembled that the value received from summing up the benefits obtained from only three services is treated as the minimum value. The real value, which is not calculated but theoretically assumed, takes into consideration the sum of all provided services. Therefore it is higher than the calculated minimum value.

Conclusions

It is necessary to adopt a homogeneous, universal and precise valuation method so that the tree valuation not only had the theoretical meaning but could serve for the optimization of management processes in environmental protection administration (spatial planning, environmental impact assessment).The more estimated character of the conducted valuation, the lower usefulness of such valuation. Simultaneously, the research progress in the area of ecosystem services and the importance attached to this issue by the European Union ecological policy demand the inclusion of this element in the valuation method.

The inclusion of ecosystem services provided by the trees, at least to the measurable scope expressed in money values, is a significant methodological challenge. It is particularly challenging due to the fact that the economic value of trees has many aspects, it depends on the adopted assumptions and the applied methodology.

The conducted research indicated that two different methods of calculating the trees value lead to obtaining very similar results. The differences between these methods stem from methodological shortages and therefore the necessity of accepting some simplified assumptions. The similar results, however, indicate the possibility of the interchangeable use of these compared methods and the probable use of the results obtained with one method to the analysis conducted with the use of the second method.

There are two problems appearing in relation with the conclusions described herein. These problems would require further research in order to be solved. Firstly, what period of time should be assumed as the average lifespan of particular tree species in urban development while determining the services provided by these trees. This factor significantly impacts the final result of the valuation with the benefit analysis method. Secondly – how to differentiate the value of provided services during the particular stages of tree development. Due to the lack of data in this area, a far reaching simplification was assumed for the needs of this research and no differentiations in the services value were made concerning the age of a tree. Answer to these two questions would allow to make one step towards discovering the real, exact value of trees growing in the urbanized areas.