Original Research

Assessment of Road Transport Environmental Impact as Illustrated by a Metropolitan Area

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Abstract

The article deals with issues of road transport influence on the natural environment. The research was carried out with regard to the Poznań agglomeration, where there are many valuable natural areas. In order to assess natural environment quality, negative road transport influence levels, and range, and in order to identify the conflicts between communication routes and the natural environment within the Poznań agglomeration, the LATINO model modified and adjusted to Polish local conditions was used. The conducted analyses demonstrate that the fundamental problem is the fragmentation of valuable natural areas caused by abundance of high-traffic roads, which leads to conflicts of at least mediocre importance covering almost 55% of the Poznań agglomeration area.

Keywords: Poznań agglomeration, road transport, environmental impact, man-environment conflict, impact assessment

Introduction

Roads are one of the main types of human activity affecting the environment in a significant way. The decrease in environmental quality under the influence of roads is important for the development of transport infrastructure plans at various levels of planning [1]. Therefore, there has been a growing interest in the influence of roads on ecosystems and landscapes over recent years [2-8]. An extensive overview of works devoted to the impact of transport traffic on the various aspects of the environment can be found in Spellerberg [9], Spellerberg and Morrison [10], and Daigle [11]. Research on the effects of roads on wildlife and plants on selected aspects of the environment [3, 12-20], such as air, soil [21-33], and the fragmentation of habitats [34-43] as well as biodiversity in particular valuable natural areas is particularly numerous [5, 44-50]. Significantly fewer studies are devoted to comprehensive impact of roads on the environment [2, 3, 6, 8, 34, 51-56].

Despite abundant literature on various aspects of the impact of roads on the environment, the assessment methods of the impact of roads applied in practice are developed poorly, especially in strategic impact assessment as a part of landscape planning [57]. There is a need for a better and comprehensive understanding of the environmental impact of roads, forecasting its effects and counteracting them [8, 34, 54, 58-59]. The application of modeling of the impact of roads on the basis of GIS software gives new opportunities [1, 45, 57, 60].

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The main objective of this research was to determine the scope and the range of road transport impact on the environment within the Poznań agglomeration and to assess the conflicts caused by the road transport with the environment using GIS technology.

Study Area

The Poznań agglomeration (understood as the city of Poznań and the districts constituting the county of Poznań) is situated in a central part of Wielkopolska province. The agglomeration covers an area of 2,163 km^2, 12% of which is occupied by Poznań, and 88% by the county of Poznań. As of 2009 its total population is 873,479, 63% of which is occupied by Poznań, and 37% by the county of Poznań [61]. The most dense area are the cities of Poznań (2,117 people on km^2) and Luboń (2,147 people on km^2).

Total length of the national roads[1] within the analyzed area is almost 41 km, 214 km province roads, 982 km county roads, and almost 3,000 km district roads. More roads are to be built. High population density generates considerable transport needs. According to the Central Statistical Office in 2009 there are 642 vehicles (including 507 cars) per 1,000 inhabitants of Poznań, whereas in the county of Poznań there are 676 cars per 1,000 inhabitants (for comparison the national average is 432 cars) [61]. Most inhabitants as a mode of transport choose a private car. According to the last extensive traffic survey, private car trips represent 53% of all trips registered in the city, while public transport modes correspond to 23%, and pedestrians and cycling 10%. On average, during the day there were about 2.1 million trips taken in the urban area (1.9 million trips were realized by urban inhabitants). Daily, every inhabitant made on average 1.99 trips by public means of transport. 88% of all registered traffic was connected with Poznań, only 12% represent transit traffic. Within the county of Poznań, on the other hand, there were 440,000 trips registered daily. On average, an inhabitant took 1.44 trips during the day using different modes of transport [62].

There are numerous legally protected areas within the Poznań agglomeration: Wielkopolska National Park, 12 sites of Natura 2000 network, 15 nature reserves, 4 landscape parks, and 11 protected landscape areas, not to mention individual forms of nature conservation.

Methods

In order to determine the areas that can be affected by a considerable quality decrease resulting from road transport influence, a research procedure consisting of three stages was proposed (Fig. 1). The three stages are as follows:

- stage 1 – an assessment of the natural environment quality within the Poznań agglomeration,
- stage 2 – an assessment of negative road transport influence level and range within the study area,
- stage 3 – a comparison of both aforementioned assessments and identification of the most crucial conflicts between the main communication routes and the natural environment occurring within the Poznań agglomeration.

The first stage required that the principles of geographical space assessment with regard to natural resources quality were defined. The assessment of natural space with regard to natural resources quality is not a simple task. Many authors have attempted to determine both valuable natural and deteriorated areas [63-65]. Nevertheless, every space evaluation methodology is based on subjective choices and grounds. The key issue is to choose the representative – according to the author – features and also to determine their number. An interesting attempt of the assessment of natural potential of the selected areas is the research procedure proposed by a scientific team led by Garcia-Montero [57]. The team assessed the quality of natural space within Spain. The proposed LATINO model assumes an aggregation of features determining the condition of several natural environment components. Based on methodology proposed by the Spanish team, there was an attempt to determine the quality of the natural environment within the Poznań agglomeration. For the purposes of our study there was the adapted LATINO model, which aggregates different characteristics representing the natural environment quality components or illustrates influence on these components. The modification in relation to the original version of the model resulted from a different scale of the study (the original – national level, the present work – local level), and also from different access to specific data about the natural environment in Poland and in Spain. The following elements were considered to be of vital importance for natural environmental quality: forest areas, legally protected areas (into consideration were taken these areas which are legally obliged to make protection plans or protection assignments plans, namely: national parks, nature reserves, landscape parks and areas of Natura 2000 network), water basins, river network density, soil quality (according to soil quality class in different geodesy districts), distance from forest areas, distance from surface water and distance from areas that are under active legal protection (Table 1). Some of these characteristics agree with the characteristics used in LATINO model. The remaining were chosen from the literature dealing with the natural environment condition assessment [64, 66]. The stage when the characteristics were chosen was the first one and, at the same time, the most crucial stage of building the model as it determines the quality of the results and the aptness of the proposed conclusions.

[1] Roads in Poland are classified in accordance with the Act of 21 March 1985 on public roads into: national roads (numbered with one or two digits, e.g. 1, 12, which can be preceded by the letter "A" corresponding to roads of motorway class, or by the letter "S" to represent roads of expressway class (A1, S2); province roads (three-digit number, e.g. 101), county roads (four-digit number followed by a letter, which represents the province, e.g. 1990 D), and district roads (four-digit number and a letter representing the province, e.g. 106651 B). Roads also are classified according to their class (the Ordinance of the Minister of Transportation and Maritime Economy dated 2 March 1999) into: motorways (A), expressways (S), main high-speed roads (trunk roads) (GP), main roads (G), service roads (Z), local roads (L), and access roads (D).

Table 1. The features used to build the model of the natural environment quality assessment.

Code Letter	Type of feature	Type of variable	Significant influence on			
			Atmosphere	Biosphere	Hydrosphere	Litho/pedosphere
A	Protected areas	stimulant	+	+	+	+
B	Water basins area	stimulant		+	+	
C	Forest area	stimulant	+	+		
D	Distance from protected areas	nonstimulant		+		
E	Distance from surface water	nonstimulant		+	+	
F	Distance from from areas	nonstimulant	+	+		
G	Soil quality	nonstimulant				+
H	River network density	stimulant		+	+	

The statistical analysis and the aggregation of the selected features were possible thanks to the application of ArcGIS software (version 9.3). Good quality of raster pictures allowed a very detailed assessment with the use of previously gathered extensive data [67]. The area of the Poznań agglomeration was divided into 854,902 cells (pixels) of 50 m × 50 m each. Each cell was attributed 8 numerical values corresponding to the values of features chosen for the purpose of this analysis. Next, values of the individual features were normalized using so-called "min-max normalization" according to the following formulas:

- for a stimulant:

$$Xn = \left(\frac{x - \min(x)}{\max(x) - \min(x)} \right)$$

- for a nonstimulant:

$$Xn = \left(\frac{\max(x) - x}{\max(x) - \min(x)} \right)$$

Thanks to normalization the values of all eight characteristics became comparable assuming values from 0 to 1 (Fig. 2). It was possible then to aggregate all the characteristics within one indicator.

During analysis it was decided to use a method of building a synthetic indicator of natural environmental quality. All analyzed features are considered to be equivalent to each other (an alternative would be to assign subjective weights to all individual characteristics). A synthetic indicator (v_s) integrating all chosen for the model and standard-

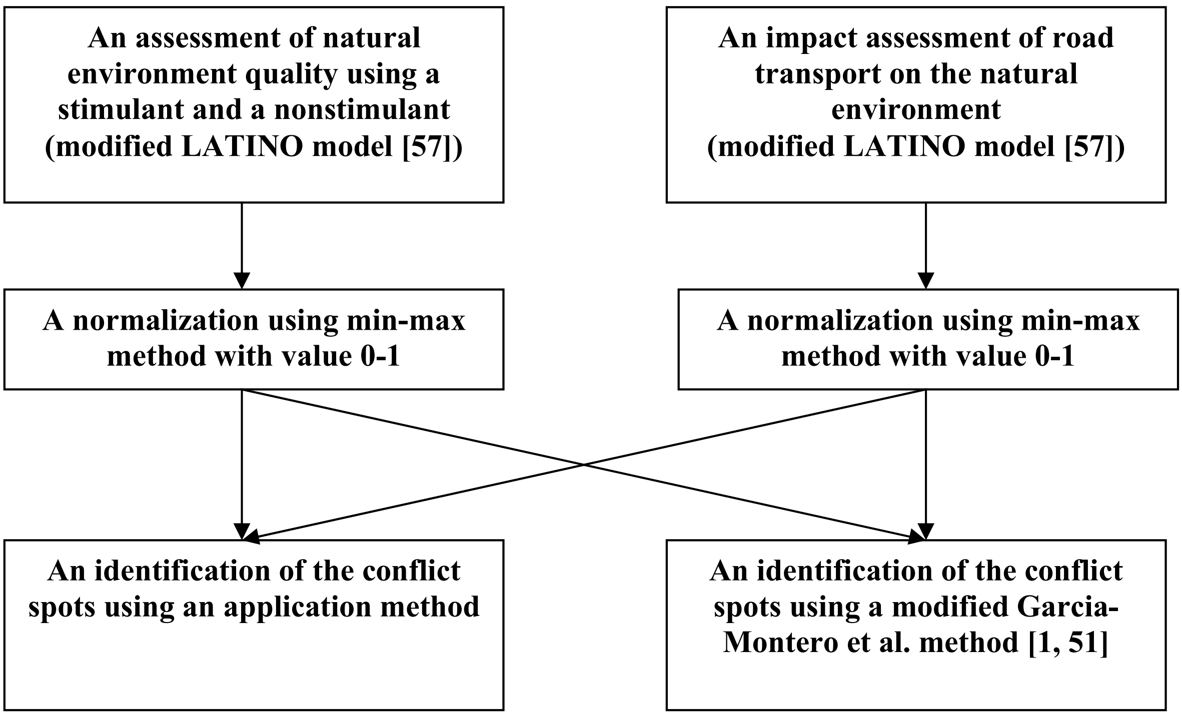

Fig. 1. The research procedure scheme.

ized features (v_i) was calculated for each pixel according to the following formula:

$$v_S = \sqrt{v_1^2 + v_2^2 + \ldots + v_i^2} \qquad i = 1,2,\ldots,8$$

By that means for every cell there was a value received, which can be interpreted as natural environmental quality.

During the second stage, similarly, the features characteristic of negative road transport influence for the aforementioned 854,902 cells were aggregated, thus finding one common synthetic indicator. Five features concerning various traffic and road network characteristics were chosen [6, 68-69] (Table 2).

All these features were then normalized using a "min-max" method in order to obtain comparable values. An integration of all characteristics into one common synthetic indicator was received by calculating the root of the sum of squared values of individual characteristics:

$$v_T = \sqrt{v_1^2 + v_2^2 + \ldots + v_j^2} \qquad j = 1,2,\ldots,5$$

The third stage consisted of an identification of the conflict spots using application method with reference to previously obtained cartographic analyses: the natural environment quality and negative road transport influence. There was a hierarchy of "hot spots" categories proposed, where categories were ranked according to risk degree of road transport influence. It was also assumed that the higher the value of both indicators, the greater the interaction between traffic and the natural environment. There were three classes of areas of different risk degree of conflict situation occurrence proposed:

Table 2. The features used for the model of transport influence on the environment.

Code Letter	Feature	Type of variable
A	Traffic intensity/density	stimulant
B	Distance from roads	nonstimulant
C	Distance from roads with high traffic intensity	nonstimulant
D	Traffic-flow density	stimulant
E	Traffic-node density	stimulant

- An area of very-high-risk degree – if both indicator values were higher than 0.5
- An area of high-risk degree – if both indicator values were equal to or lower than 0.5 and higher than 0.4
- An area of average risk degree – if both indicator values were equal to or lower than 0.4 and higher than 0.3.

Areas where at least one of the indicator values was lower than or equal to 0.3 were considered unthreatened or threatened only to a small degree with conflict situation occurrence.

The other quite simple way to identify conflict spots of high road transport impact on the natural environment is a method used by Garcia-Montero et al. [1, 51]. The method involves mapping out the buffer zones – the "corridors" around the roads of the utmost importance (at the same time characterized by the highest traffic). Spaces where valuable natural areas (or areas of high environment quality) are found are considered to be "hot spots." The method's authors

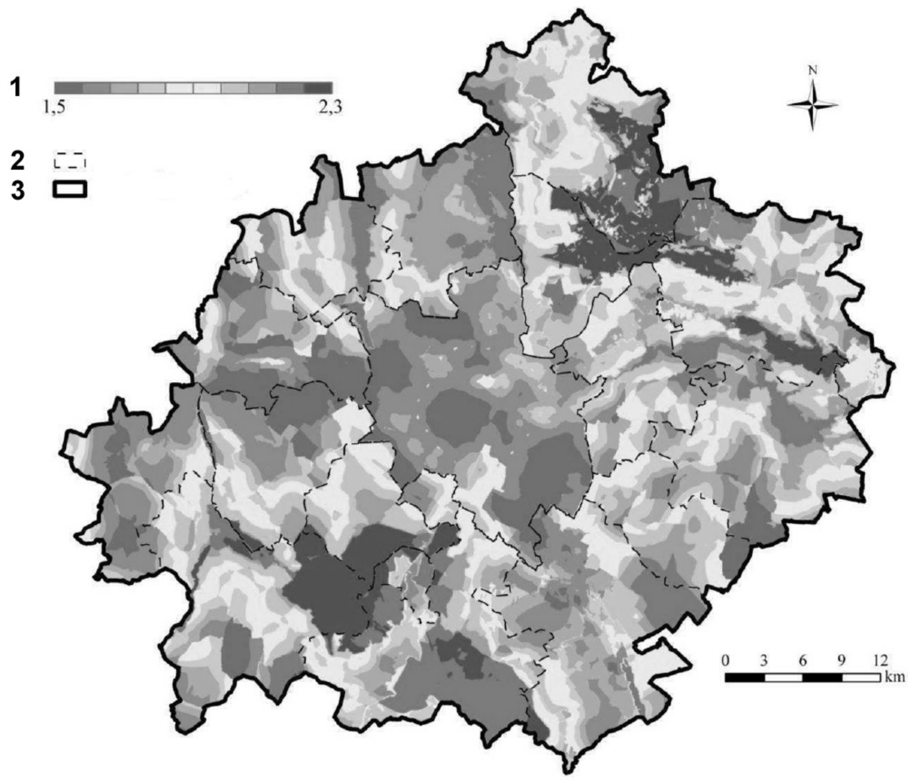

Fig. 2. The assessment of natural environmental quality within the Poznań agglomeration (without min-max method normalization). 1 – Indicator's value, 2 – District boundaries, 3 – Agglomeration boundaries.

in the work concerning the whole country (Spain) proposed that such "corridors" should be outlined within the distance of 2 km from the axis of the road. It seems though to be exaggerated when our study concerning a much smaller area is considered. For the purposes of this work it was assumed that the most important impact can occur within 500 m from the axis of the road [6, 69], so the corridor's width was narrowed to 1 km. At the same time the above-mentioned "corridors" where negative road transport impact on the natural environment may occur were mapped out around the national roads and province roads within the Poznań agglomeration, since these are the roads of the heaviest traffic (for example: A2 motorway – almost 37,000 vehicles a day, S11 expressway – about 33,000 vehicles a day, some province roads 10,000 vehicles a day, sometimes reaching even 15,000 vehicles a day – data for 2010 [70]). Next, a cartographic image with the corridors was applied on a map of the natural environment quality, thus revealing conflict places of various risk degrees.

Results

The Assessment of Environmental Value of Individual Areas

The results obtained from a study generate values from 1.51 (the lowest quality) to 2.31 (the highest quality). The median was 1.79 and the standard deviation was 0.13. The areas with the highest values primarily cluster around two areas – in the northeast and in the south. The areas of high environmental values in the northeastern part of the agglomeration are as follows: Natura 2000 area (Biedrusko) with the Protected Landscape Area Biedrusko, the Warta and the Główna valleys, and the major forest complex in Pobiedziska and Kostrzyn dictricts. In the south, on the other hand, there are forests of Wielkopolska National Park and Rogalin Landscape Park with areas of Natura 2000 network, and also the Warta Valley and the system of postglacial channels with lakes: Strykowskie, Niepruszewskie, Dymaczewskie, and Witobelskie. These areas on account of occurrence of vast compact forest complexes may be regarded as the "green lungs" of the Poznań agglomeration (Fig. 2). Then the lowest values are characteristic of centrally located Poznań and the remaining towns of the agglomeration, especially Tarnowo Podgórne and Buk.

The Assessment of Negative Road Transport Influence

Fig. 3 shows that negative road transport influence focuses primarily within Poznań. The obtained results confined in the set of numbers from 0.3 (the minimal influence) to 2.2 (the greatest influence). The median was 1.28 and the mean standard deviation was 0.2. The main reason for this state of affairs is high population density and connected with it is the great number of vehicles used. The second reason is the shape of the communication layout of the Poznań agglomeration – a good many national and provincial roads meet within Poznań. The increased traffic level within Poznań also is determined by the concentration of service

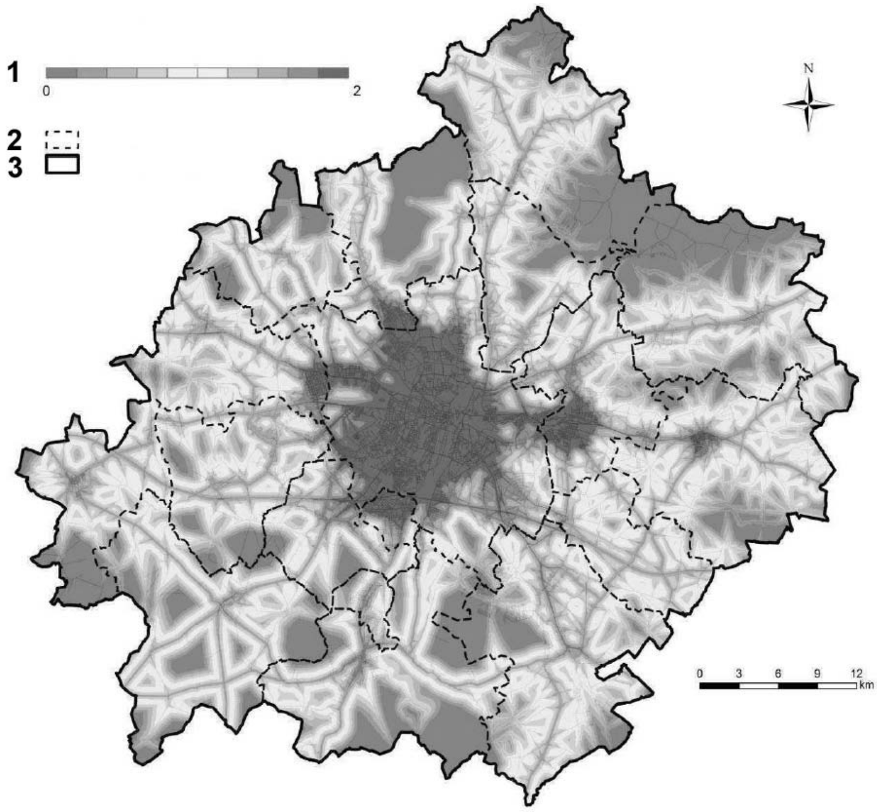

Fig. 3. The assessment of road transport influence on the natural environment within the Poznań agglomeration.
1 – Indicator's value, 2 – District boundaries, 3 – Agglomeration boundaries.

sector of translocal character (administrative, cultural, educational) as well as the concentration of production plants and service centers, where many employees live outside the city limits and commute on a daily basis. The high values of the indicator are characteristic also of other intensely urbanized and centrally located centers, such as: Stęszew, Kórnik, Kostrzyn, and Mosina.

An Identification of Conflict Spots

In order to identify the conflict spots, two previously generated cartographic studies were used – a map of natural environment quality and a map of negative road transport influence. Both factors creating the graphic image were reduced to the range 0-1 (by means of min-max normalization) in order to obtain their comparability, and then the maps were applied one on another, revealing conflict areas of different risk degree.

The areas attributed 'very high' risk represent only a small proportion of the Poznań agglomeration – only 3.7% (wherein only about 0.1% were the areas where both indicators reached values above 0.6). The area category to which areas of 'high' risk degree belong covers 19.2% of the whole agglomeration area, while areas with 'average' risk degree cover 31.8%.

In the second case in order to identify the conflict spots where there is considerable influence of road transport on the natural environment (Fig. 5) the method developed by Garcia-Mantero's et al. [1, 51] was followed. The areas that run the most risk of being exposed to negative road transport influence in the Poznań agglomeration are as follows:

- forests of the Puszcza Zielonka (Żywiec Dziewięciolistny Nature Reserve, Uroczyska Puszczy Zielonki Natura 2000 Site, Puszcza Zielonka Landscape Park)
- forests and the lakes of Wielkopolska National Park and Rogalin Landscape Park within the Natura 2000 network
- forests and the Główna and Cybina valleys in Swarzędz, Kostrzyn, and Pobiedziska communities (Ostoja koło Promna Natura 2000 site, Promno Landscape Park)
- the Warta Valley and the forests of Biedrusko lying between Biedrusko village and Poznań
- Kierskie Lake together with nearby meadows and forests.

Discussion

The great and still growing number of trips (especially car trips) cause increases in troublesome emissions to the natural environment [21, 71]. Especially dangerous is the process of uncontrolled suburbanization, connected with chaotic building development on valuable natural areas, thus provoking the necessity to build technical infrastructure such as roads and the sewage system [72]. The devel-

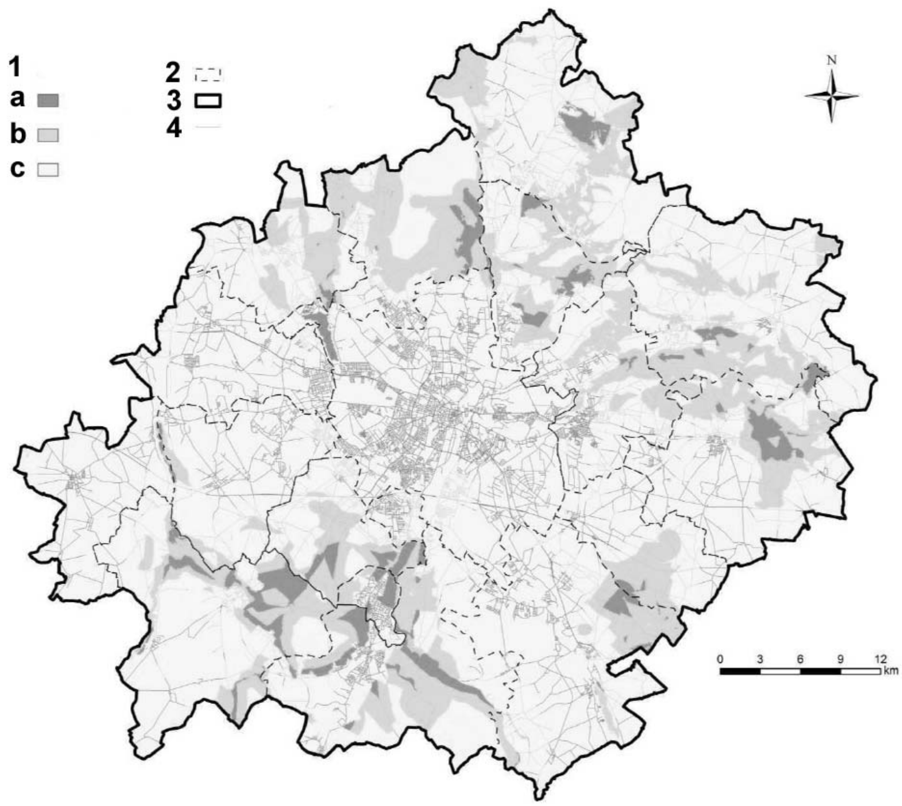

Fig. 4. The Poznań agglomeration areas subjected to risk of conflict situation occurrence as far as road transport influence on the natural environment is concerned.

1 – Risk degree: a – very high, b – high, c – average, unthreatened or threatened to a small degree; 2 – District boundaries; 3 – Agglomeration boundaries; 4 – Roads.

oping agglomeration constantly needs new building land, first of all for new motorways and expressways bypassing Poznań and also for ring roads around other smaller towns and cities. The new roads cause the fragmentation of valuable natural areas and forests to a large extent [2, 5, 8, 34, 73]. In the end such areas, surface water (the Warta River, its tributaries, and the lakes of postglacial origins) or soils (the highest quality soils in Kleszczewo gmina and Rokietnica gmina) are exposed to degradation. In addition, the roads intersecting valuable natural areas cause increased human access to wildlife habitats [2-3, 6, 8-9, 34, 46, 74], as well as contributing to the intensification of land use and urbanization processes [12, 75].

It came as no surprise that the most negative road transport influence on the natural environment occurs on areas with high population density. 54.7% of the Poznań agglomeration area (primarily in districts bordering on Poznań) is affected by at least "average" negative road transport influence on the natural environment, which causes a considerable risk of degradation to the natural environment, especially within high-quality areas. The location of potential conflict spots where the natural environment and road transport interact shows that their occurrence is characteristic of places of high environmental values near which human activity is rapidly developed. These areas, although often legally protected, are subjected to enormous road transport influence. The increase in risks to the valuable natural areas arises primarily due to two phenomena. On the one hand it is considerable traffic on national and provincial roads, where besides local traffic also transit traffic takes place, including goods transport (operated by lorries) which is very troublesome to the environment. Taking into account that the rail transport is not a satisfactory alternative to road transport, it can be predicted that traffic intensity will increase together with the economic development of the region. On the other hand, the cause for conflicts to arise results from the phenomenon of urban sprawl and from the population growth in suburban areas, which in turn creates a need for communications infrastructure development within these areas. In the end the communications pressure on the natural environment increases within the areas where recently no such problems occurred. Scientific literature dealing with the migration phenomenon within urban agglomerations describes negative influence connected with increased traffic as one of the elements that leads inhabitants to take decisions to move to country areas (near urban centers) [76-78]. In the Poznań agglomeration this phenomenon is primarily manifested by the increase in the areas of residential buildings, and also areas of detached houses (with houses occupied by one or a few families) of high standards near valuable natural areas [75, 79]. It can be concluded that the negative effects connected with road transport influence inhabitants' behavior and decisions.

The reduction of the negative environmental impact should be one of the primary objectives of local transport policy implementing the principles of sustainable transport. In accordance with these principles the development of the transportation system and meeting the needs of residents cannot take place at the expense of the environment. Owing to the methods of the roads' environmental impact assessment applied in this article, it is possible to determine the areas of conflict, which already require actions neutralizing

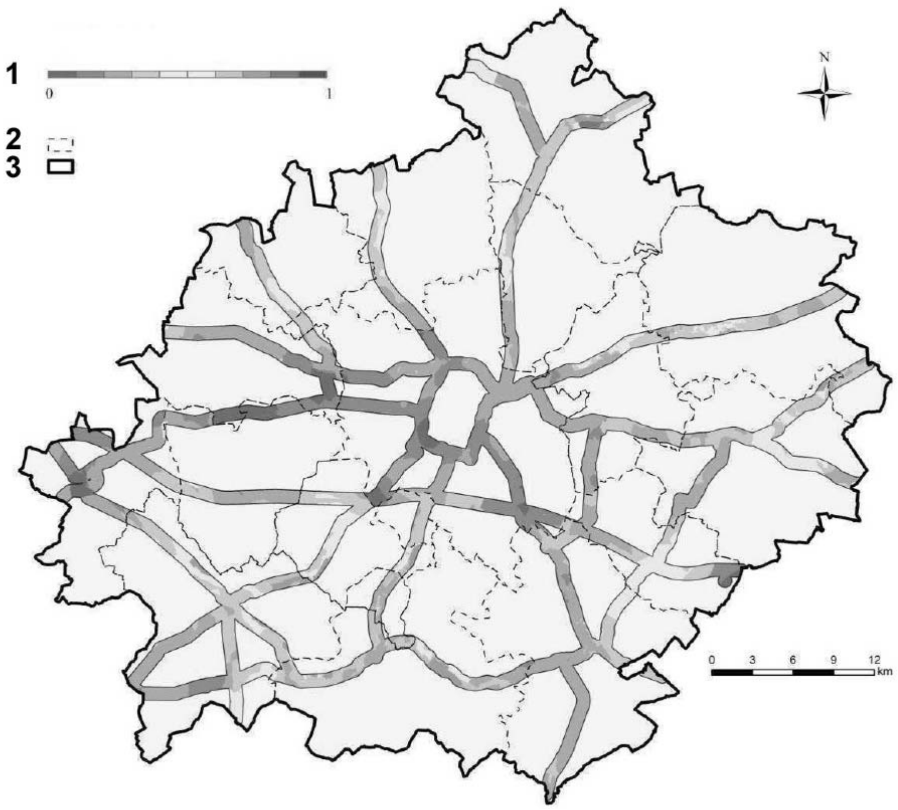

Fig. 5. The identification of the conflict spots in the "corridors" of national and provincial roads.
1 – Indicator's value, 2 – District boundaries, 3 – Agglomeration boundaries.

the negative environmental impact of roads. These sites must be subject to environmental and biotic monitoring, the results of which should be the basis for such actions. To basic actions to reduce the impact of transport on the environment, particularly in naturally valuable areas, should include: the development of plans for sustainable development of transport systems, the necessity of performing environmental impact assessment in the planning of new roads, anticipation of conflicts and appropriate location of new roads, restoration of degraded natural values (including the planting of trees and shrubs, restoration of hydrographic conditions) and their continuity, construction of safety meshes and animal crossings, the change of transport-related behaviors of people, and an increase in the role of public consultations in decision-making processes, including consideration of amendments and comments on plans submitted by citizens and ecological organizations.

Conclusions

The used methodology is a new approach in Poland and can have multiple practical applications. It can be used to assess current and future effects of communications investments or prepared plans and strategies with regard to communications in urban centres and agglomerations.

The suggested list of characteristics chosen for the purpose of this analysis is not an exhaustive set including all elements that determine the natural environment values (the model can be supplemented with other more detailed characteristics in the future). It seems though that the list, including features of components of biosphere, hydrosphere, pedosphere, and indirectly also components of the atmosphere and lithosphere, is an adequate list for the purposes of this work.

The carried out analyses show that the key problem is the fragmentation of valuable natural areas and the route of the high-traffic intensity roads through and nearby to these areas, causing conflicts of at least average importance. The most negative communications influence occurs in the agglomeration centre, where the quality of the environment is already low. These are the areas that require actions in the first place, actions which will improve the quality of individual environmental components, at the same time improving living conditions. The examples of such actions may be as follows: reducing traffic intensity by better use and the increase in the availability of public transport, the use of city buses with hybrid drive systems, the implementation of fees and limited parking zones, an increase in the fluidity of traffic, the use of special low-noise road pavements, building of noise barriers, and restricting the development of residential areas near roads with high traffic intensity.

The presented research methodology allows us to use the parametric perspective to the issue of conflicts caused by the interaction between road transport and the natural environment, although some questions require further complex research. The applied research procedure, as well as the approach toward communications issue within agglomeration, may serve as an inspiration and a starting point for further studies dealing with communications system development, transport influence on the natural environment or for specific urban planning. Let us hope that the issues presented in this article will grow in importance in the following years and that the communications policy and strategies realized within urban areas will assure both social needs and economic development and will not lead to natural environment deterioration.

References

1. GARCIA-MONTERO L., LÓPEZ E., MONZÓN A., OTERO PASTOR I. Environmental screening tools for assessment of infrastructure plans based on biodiversity preservation and global warming (PEIT, Spain). Environ. Impact Asses. **30**, (3), 158, **2010**.
2. SPELLERBERG I.F. Ecological effects of Road, Science Publishers Inc., Enfield, NH, USA, pp. 260, **2002**.
3. TROMBULAK S.C., FRISSELL C.A. Review of ecological effects of roads on terrestrial and aquatic communities. Conserv. Biol. **14**, (1), 18, **2000**.
4. CARR L.W., FAHRIG L., POPE S.E. Impacts of landscape transformation by roads. In: Gutzwiller K.J. (Ed.) Applying Landscape Ecology in Biological Conservation. Springer-Verlag, New York, 225, **2002**.
5. FORMAN R.T.T., ALEXANDER L.E. Roads and their major ecological effects. Annu. Rev. Ecol. Syst. **29**, 207, **1998**.
6. FORMAN, R.T.T., SPERLING D., BISSONETTE J.A., CLEVENGER A.P., CUTSHAL C.D., DALE V.H., FAHRIG L., FRANCE R., GOLDMAN C.R., HAENUE K., JONES J.A., SWANSON F.J., TURRENTINE T., WINTER T.C. Road Ecology: Science and Solutions. Island Press, Washington, D.C., USA, pp. 504, **2002**.
7. HAVLICK D.G. No Place Distant: Roads and Motorized Recreation on America's Public Lands. Island Press, Washington, USA, pp. 253, **2002**.
8. COFFIN A.W. From roadkill to road ecology: A review of the ecological effects of roads. Journal of Transport Geography **15**, 396, **2007**.
9. SPELLERBERG I.F. Ecological effects of roads and traffic: a literature review. Global Ecol. Biogeogr. **7**, 317, **1998**.
10. SPELLERBERG I.F., MORRISON T. The ecological effects of new roads – a literature review. Science for Conservation, **84**, Wellington, N.Z., pp. 55, **1998**.
11. DAIGLE P. A summary of the environmental impacts of roads, management responses, and research gaps: A literature review. BC J. of Ecosystems and Manage. **10**, (3), 65, **2010**.
12. UNDERHILL J.E., ANGOLD P.G. Effects of roads on wildlife in an intensively modified landscape. Environmental Review **8**, 21, **2000**.
13. RIITTERS K.H., WICKHAM J.D. How far to the nearest road? Front. Ecol. Environ. **1**, (3), 125, **2003**.
14. ORŁOWSKI G., NOWAK L. Factors influencing mammal roadkills in the agricultural landscape of South-Western Poland. Pol. J. Ecol. **54**, 283, **2006**.
15. WRÓBEL M., TOMASZEWICZ T., CHUDECKA J. Floristic diversity and spatial distribution of roadside halophytes along forest and field roads in Szczecin lowland (West Poland). Pol. J. Ecol. **54**, 303, **2006**.
16. STRASBURG J.L. Conservation biology: Roads and genetic connectivity. Nature **440**, 875, **2006**.

17. CHRISTEN D., MATLACK G. The role of roadsides in plant invasions: a demographic approach. Conserv. Biol. **20**, (2), 385, **2006**.
18. EIGENBROD F., HECNAR S.J., FAHRIG L. The relative effects of road traffic and forest cover on anuran populations. Biological Conservation **141**, 35, **2008**.
19. ŠERA B. Road vegetation in Central Europe – an example from the Czech Republic. Biologia, **63**, (6), 1085, **2008**.
20. BARTHELMESS E.L., BROOKS M.S. The influence of body-size and diet on road-kill trends in mammals. Biodivers. Conserv. **19**, 1611, **2010**.
21. VAN GENT H.A., RIETVELD, P. Road transport and the environment in Europe. Sci. Total Environ. **129**, 205, **1993**.
22. HEWITT C.N., RASHED M.B. Removal rates of selected pollutants in the runoff waters from a major rural highway. Water Res. **26**, 311, **1992**.
23. LEGRET M., PAGOTTO C. Evaluation of pollutant loadings in the runoff waters from a major rural highway. Sci. Total Environ. **235**, 143, **1999**.
24. ANDRÉ M., HAMMARSTRÖM U. Driving speeds in Europe for pollutant emissions estimation. Transport Res. D-Tr. E. **5**, 321, **2000**.
25. POLKOWSKA Ż., GRYNKIEWICZ M., ZABIEGAŁA B., NAMIEŚNIK J. Levels of pollutants in runoff water from roads with high traffic intensity in the city of Gdansk, Poland. Pol. J. Environ. Stud. **10**, (5), 351, **2001**.
26. ZACHARIADIS T., KOUVARITAKIS N. Long-term outlook of energy use and CO_2 emissions from transport in central and eastern Europe. Energ. Policy **31**, 759, **2003**.
27. BIGNAL K., ASHMORE M., POWER S. The ecological effects of diffuse air pollution from road transport, English Nature Research Reports, 580, Peterborough, UK, pp. 97, **2004**.
28. GRIGALAVIČIENE I., RUTKOVIENE V., MAROZAS V. The Accumulation of Heavy Metals Pb, Cu and Cd at Roadside Forest Soil, Pol. J. Environ. Stud. **14**, (1), 109, **2005**.
29. MANGANI G., BERLONI A., BELLUCCI F., TATANO F., MAIONE M. Evaluation of the pollutant content in road runoff first flush waters. Water Air Soil Poll. **160**, 213, **2005**.
30. KRZYZANOWSKI M., KUNA-DIBBERT B., SCHNEIDER J. (Eds). Health effects of transport-related air pollution. World Health Organization – Regional Office for Europe, Copenhagen, Denmark, pp. 205, **2005**.
31. KLIMASZEWSKA K., POLKOWSKA Ż., NAMIEŚNIK J. Influence of Mobile Sources on Pollution of Runoff Waters from Roads with High Traffic Intensity, Pol. J. Environ. Stud. **16**, (6), 889, **2007**.
32. POLKOWSKA Ż., SKARŻYŃSKA K., DUBIELLA–JACKOWSKA A., STASZEK W., NAMIEŚNIK J. Evaluation of pollutant loading in the runoff waters from a major urban highway (Gdansk beltway, Poland). Global NEST Journal **9**, (3), 269, **2007**.
33. ŚWIETLIK R., STRZELECKA M., TROJANOWSKA M. Evaluation of Traffic-Related Heavy Metals Emissions Using Noise Barrier Road Dust Analysis. Pol. J. Environ. Stud. **22**, (2), 561, **2013**.
34. SEILER A. Ecological effects of roads. A review. Introductory Research Essay, **9**, Uppsala, pp. 40, **2001**.
35. HEILMAN Jr. G.E., STRITTHOLT J.R., SLOSSER N.C., DELLASALA D.A. Forest fragmentation of the conterminous United States: assessing forest intactness through road density and spatial characteristics. Bioscience **52**, 411, **2002**.
36. SAUNDERS S.C., MISLIVETS M.R., CHEN J., CLELAND D.T. Effects of roads on landscape structure within nested ecological units of the Northern Great Lakes Region, USA. Biological Conservation **103**, 209, **2002**.
37. HAWBAKER T.J., RADELOFF V.C. Roads and landscape pattern in Northern Wisconsin based on a comparison of four road data sources. Conserv. Biol. **18**, 1233, **2004**.
38. DONALDSON A., BENNETT A. Ecological effects of roads: Implications for the internal fragmentation of Australian parks and reserves Parks Victoria Technical Series, 12, Parks Victoria, Melbourne, pp. 74, **2004**.
39. JAEGER J.A.G. Effects of the Configuration of Road Networks on Landscape Connectivity. In: Leroy I.C., Nelson D., McDermott K.P. (Eds) Proceedings of the 2007 International Conference on Ecology and Transportation, Center for Transportation and the Environment, North Carolina State University, Raleigh, NC, 267, **2007**.
40. JAEGER J.A.G., SCHWARZ-VON RAUMER H.-G., ESSWEIN H., MÜLLER M., SCHMIDT-LÜTTMANN M. Time series of landscape fragmentation caused by transportation infrastructure and urban development: a case study from Baden-Württemberg (Germany). Ecology and Society **12**, (1), 28, **2007**.
41. JAEGER J.A.G., BERTILLER R., SCHWICK C., MÜLLER K., STEINMEIER C., EWALD K.C., GHAZOUL J. Implementing landscape fragmentation as an indicator in the Swiss Monitoring System of Sustainable Development (MONET). J. Environ. Manage. **88**, (4), 737, **2008**.
42. BENÍTEZ-ĽOPEZ A., ALKEMADE R., VERWEIJ P.A. The impacts of roads and other infrastructure on mammal and bird populations: a meta-analysis. Biological Conservation **143**, 1307, **2010**.
43. BATA T., MEZŐSI G. Assessing landscape sensitivity based on fragmentation caused by the artificial barriers in Hungary, J. Environ. Geog. **6**, (1-2), 37, **2013**.
44. TREWEEK J.R., HANKARD P., ROY D.B., ARNOLD H., THOMPSON S., Scope for strategic ecological assessment of trunkroad development in England with respect to potential impacts on lowland heathland, the Dartford warbler *Sylvia undata* and the sand lizard Lacerta agilis. J. Environ. Manage. **53**, 147, **1998**.
45. GENELETTI D. Ecological evaluation for environmental impact assessment. Netherlands Geographical Studies, NGS, Utrecht, The Netherlands, pp. 219, **2000**.
46. GENELETTI D. Biodiversity Impact Assessment of roads: an approach based on ecosystem rarity. Environ. Impact Assessment Review, **23**, 343, **2003**.
47. BYRON H.J. Biodiversity issues in road environmental impact assessments: Guidance and case studies. In: Evink G.L, Garrett P., Zeigler D. (Eds) Proceedings of the Third International Conference on Wildlife Ecology and Transportation, Florida Department of Transportation, Tallahassee, pp. 211-220, **1999**.
48. BYRON H.J., TREWEEK J., VEITCH N., SHEATE W.R., THOMPSON S. Road developments in the UK: an analysis of ecological assessment in environmental impact statements produced between 1993 and 1997. J. Environ. Plan. Manage. **43**, 71, **2000**.
49. SHERWOOD B., CUTLER D.F., BURTON J.A. Wildlife and roads: the ecological impact. Imperial College Press, pp. 299, **2003**.
50. VOTSI N.E, MAZARIS A.D., KALLIMANIS A.S., ZOMENI M.S., VOGIATZAKIS I.N., SGARDELIS S.P., PANTIS J.D. Road effects on habitat richness of the Greek Natura 2000 network. Nature Conservation **1**, 53, **2012**.
51. GARCÍA-MONTERO L.G., OTERO I., MANCEBO QUINTANA S., CASERMEIRO M.A. An environmental screening tool for assessment of land use plans covering large geographic areas. Environ. Sci. Policy **11**, 285, **2008**.

52. FORMAN R.T.T., DEBLINGER R.D. The ecological road-effect zone of a Massachusetts (U.S.A.) suburban highway. Conserv. Biol. **14,** 36, **2000**.
53. FORMAN R.T.T. Estimate of the area affected ecologically by the road system in the United States. Conserv. Biol. **14**, (1), 31, **2000**.
54. FORMAN R.T.T., ALEXANDER L.E. Roads and their major ecological effects. Annu. Rev. Ecol. Syst. **29**, 207, **1998**.
55. SOUTHERLAND M.T. Conserving biodiversity in highway development projects. The Environmental Professional **17**, 226, **1995**.
56. Environmental Impact Assessment of Roads. Road Transport Research, Organization for Economic Co-operation and Development, OECD Scientific Expert Group, Paris, France, pp. 186, **1994**.
57. GARCÍA-MONTERO L., MANCEBO QUINTANA S., CASERMEIRO M., OTERO PASTOR I., MONZÓN DE CÁCERES A. A GIS raster model for assessing the environmental quality of Spainfocused on SEA and infrastructure planning procedures (LATINO model). Highway and Urban Environment **17**, (1), 31, **2010**.
58. TREWEEK J.S., THOMPSON N.V., JAPP C. Ecological assessment of road developments. A review of environmental statements. J. Environ. Plan. Manage. **36**, 295, **1993**.
59. HOANG T., DURAND C., VENTURA A., JULLIEN A., LAURENT G. A global tool for environmental assessment of roads – Application to transport for road building. European Conference of Transport Research Institutes, Hague, Available to download at: http://www.ectri.org/YRS05/Papiers/Session-3bis/ventura.pdf, pp. 9, **2005**.
60. LI X., WANG W., LI F., DENG X. GIS based map overlay method for comprehensive assessment of road environmental impact. Transportation Research Part D **4**, 147, **1999**.
61. Central Statistical Office, Warsaw, Poland. www.stat.gov.pl.
62. Comprehensive traffic research, Biuro Inżynierii Transportu, Poznań, **2000** [In Polish].
63. KISTOWSKI M. The concept of environmental diagnosis for spatial management purposes on a national and regional scale. In: Ratajczak W., Stachowiak K. (Eds) Spatial management to society, Bogucki Wydawnictwo Naukowe, Poznań, pp. 304, **2010** [In Polish].
64. ROO-ZIELIŃSKA E., SOLON J., DEGÓRSKI M. The assessment of the natural environment condition and changes on the basis of geobotanical, landscape and soil indicators. IGiPZ PAN, Warszawa, pp. 320, **2007** [In Polish].
65. WARSZYŃSKA J., The assessment of the natural environment reserves for touristic purposes (case study – the Kraków Province). Zeszyty Naukowe UJ, CCCL, Prace Geogr., **36**, pp. 135, Warszawa, **1974** [In Polish].
66. SOLON J. The landscape diversity assessment on the basis of flora spatial structure analysis. Prace Geograficzne IGiPZ PAN, **185**, pp. 232, **2002** [In Polish].
67. POLICHTCHOUK Y. Geoinformation systems and regional environmental prediction. Safety Sci., **30**, 63, **2000**.
68. GRONOWICZ J. Land transport and the environment protection. Wydawnictwo Instytutu Technologii Eksploatacji, Radom, pp. 371, **2004** [In Polish].
69. MAZUR E. Transport and the natural environment of Poland. Wydawnictwo Naukowe Uniwersytetu Szczecińskiego, Szczecin, pp. 206, **1998** [In Polish].
70. The study of spatial development determinants of the Poznań agglomeration. Kaczmarek T. (Ed.), CBM, Poznań, pp. 270, **2012** [In Polish].
71. BANISTER D. Transport Policy and the Environment, Spon, London, pp. 360, **1998**.
72. SESSA C. Achieving sustainable cities with integrated land use and transport strategies. In: Marshall S., Banister D. (Eds) Land use and transport. Elsevier, Oxford, pp. 37-70, **2007**.
73. FORMAN R.T., GORDON M. Landscape Ecology, John Willey & Sons, New York, pp. 619, **1986**.
74. GRAHAM K., BOULANGER J., DUVAL J., STENHOUSE G. Spatial and temporal use of roads by grizzly bears in west-central Alberta. Ursus **21**, 43-56, **2010**.
75. LAURANCE W.F., COCHRANE M.A. Introduction. Conserv. Biol. **15**, 1488, **2001**.
76. KONECKA-SZYDŁOWSKA B. Socio-economic situation of Poznań suburban cities in the period of transformation. In: Słodczyk J., Klimek R. (Eds) Transformations of urban and suburban areas. Uniwersytet Opolski, Wydział Ekonomiczny, Opole, pp. 113-127, **2006** [In Polish].
77. BAŃSKI J. The suburbs – not a city anymore, not country yet. In: Jezierska-Thole A., Kozłowski L. (Eds) Spatial management in a zone of urban-rural continuum in Poland, Wydawnictwo Naukowe UMK, Toruń, pp. 29-43, **2008** [In Polish].
78. BEIM M. Modelling of suburbanization process within the Poznań agglomeration with the use of artificial neural networks and cellular automata, Bogucki Wydawnictwo Naukowe, Poznań, pp. 268, **2008** [In Polish].
79. BRZEZICKA D. The influence of Poznań on social-economic situation of suburban districts in the opinion of their authorities. In: Kaczmarek T., Mizgajski A. (Eds) Poznań county. The spatial and life quality, Bogucki Wydawnictwo Naukowe, Poznań, pp. 361-368, **2008** [In Polish].