

TRANSFORMATION OF THE LANDSCAPE STRUCTURE OF THE SELECTED TESTING GROUNDS IN THE TRI-CITY AGGLOMERATION IN THE YEARS 1985–2012

BARBARA KORWEL-LEJKOWSKA 

Institute of Geography, University of Gdańsk, Poland

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ABSTRACT: The aim of the research was to define the scale and directions of transformation of the selected forms of land cover in the surroundings of the intra-urban areas of the Tri-city Agglomeration (Poland), combined with simultaneous testing of the usefulness of the index of convergence of structures for analysing changes in the structure of land use. The analysis was made on the basis of data from topographic maps on a scale of 1:10,000 and digital data from BDOT10k for a period of 28 years. In the areas of major changes, the scale and directions of changes between particular types of land cover were determined. Negative natural effects expressed, among other things, by the deteriorating proportion between the biologically active and built-up areas were indicated.

KEYWORDS: land cover structure, suburbanisation, Tri-city Agglomeration, Poland

Corresponding author: Barbara Korwel-Lejkowska, Institute of Geography, University of Gdańsk, ul. Bażyńskiego 4, 80-309 Gdańsk, Poland; e-mail: barbara.korwel-lejkowska@ug.edu.pl

Introduction

Progressive functional changes in suburban and rural areas generate settlement and landscape changes. Suburbanisation processes are one of the main reasons for these changes. The development of the Tri-city Agglomeration (Poland) occurs, immensely, in areas far away from the central residential and service complex of compact development, causing negative natural effects expressed, among other things, by the deteriorating proportion between the biologically active and built-up areas. As a result, the landscape surrounding the intra-urban areas of the Tri-city agglomeration loses its open rural character,

taking on the features of a suburban landscape, and sometimes even an urban landscape. The aim of the research was to define the scale and directions of transformation of the selected forms of land cover in the vicinity of the central service band of the Tri-city Agglomeration, combined with simultaneous testing of the usefulness of the index of convergence of structures for analysing changes in the structure of land use.

The causes and effects of suburbanisation have been repeatedly analysed and described in literature, both on the global arena, for example: Antrop (2004); Biolek, Andráško, Malý, Zrůstová (2017); Burdack, Hesse (2007); Duany, Plater-Zyberk (2008); Dylewski (2006); Jackson

(1985); Mieszkowski, Mills (1993); Rontos, Mavroudis, Salvati (2011); Soule (ed.) (2006), as well as in Polish terms and conditions, including: Degórska (2012); Gałka, Warych-Juras (2018); Lisowski, Grochowski (2008); Lorens (ed.) (2005); Łowicki (2008); Parysek (2002); Przewoźniak (2005); Raszka (2006). With respect to the suburbanisation processes related to the Tri-city Agglomeration, the studies of Kistowski (2008), Lorens (2015), Sagan et al. (2006) and Sołtys (2006) are worth mentioning.

Political and related administrative and legal changes in spatial development have been an important factor of landscape transformation in Poland since the late 1980s. Therefore, the period of 28 years selected for analysis (1985–2012) can be divided into two significant periods characterised by different intensity of changes (Korwel-Lejkowska, Nadratowska 2018). The first period (1985–2000) is characterised by the decline of the functioning of State Farms and the takeover of property by the Agricultural Property Agency of the State Treasury, which was associated with the gradual transformation of large-area agricultural monocultures into a more fragmented land with various farming profiles, set-aside as part of fields and the degradation or rebranding of farm buildings. In the second period (2001–2012), Poland's accession to the European Union facilitated infrastructural development, which was impossible to achieve in previous years; agriculture in zones located nearest to the city centres ceased to play any significant role, and in its place, new large-size objects appeared in space, such as shopping malls and business centres as well as warehouse complexes. Single-family houses on private plots and multiple-family developer housing estates have also appeared on a larger scale, with their scale and architectural form not always matching with the surroundings and traditions of the region.

Methods

The work focuses on the analysis of types of land cover, which is one of the elements of the landscape structure. Structural landscape analysis partly authorises the formulation of conclusions regarding its functioning, despite the fact that landscape analysis based on the land use

structure uses a limited resource of environmental data (Łowicki 2008). The analysis of changes in the spatial development and land cover structure in the years coinciding with the period of the preparation of maps and digital data (in the scale 1:10,000): the year 1985 (according to the topographic maps in the 1965 datum), 2000 (according to the topographic maps in the 1992 datum) and 2012 (according to the digital data from BDOT10k) was made. Comparative analysis of cartographic materials concerned the area of the selected forms of land cover: forests, grasslands, waters and built-up areas in the adopted time periods (1985–2000, 2001–2012). The area of development was considered as the area actually occupied by buildings that resulted in the possibility of depicting the actual state of development, which is not possible with analyses based on statistical data concerning issued decisions on building regulations or permits. Analyses were carried out using the MapInfo Professional software. For each element, a cartogram presenting the percentage share of the area of a given type of land cover in the adopted basic field in the years 1985, 2000 and 2012, the size of the area of selected land cover, which were created or disappeared in the years 1985–2000 and 2001–2012, and a balance of changes in the land use pattern in both time periods, was prepared. Based on these, maps of the intensity of changes in space were prepared. A square base area of 0.25 km² was adopted as a reference unit.

The created vector net consists of 4,597 square basic fields. For the analysis of the intensity of changes, an indicator of structural convergence (similarity) (c) was chosen:

$$c = \cos \infty = \frac{\sum_{j=1}^m \overline{W}_{j(t_0)} \times \overline{W}_{j(t_1)}}{\left[\sum_{j=1}^m \overline{W}_{j(t_0)}^2 \right]^{\frac{1}{2}} \times \left[\sum_{j=1}^m \overline{W}_{j(t_1)}^2 \right]^{\frac{1}{2}}}$$

where: $\overline{W}_{j(t_0)}$ and $\overline{W}_{j(t_1)}$ are indicators of the branch structure of the phenomenon in the initial year (1985) (t_0) and the final year (2012) (t_1) respectively.

The analysis included the values of changes in forest, grassland, water and built-up areas in 1985 and 2012 for each basic field. The matrix of these categories was subsequently created, then the indices of the branch structure of the phenomenon were calculated, constituting the basis

for determining the coefficient of structural convergence c . The range of index values obtained was divided on the basis of main points of breaking the distribution curve into six compartments (Table 1).

Table 1. Distinguished ranges of changes according to the value of the structural convergence index.

Structural convergence index (c)	Range of changes
0.000	total changes
0.001; 0.399	great
0.400; 0.849	average
0.850; 0.974	small
0.975; 0.999	very small
1.000	no changes

Source: own study.

The co-existence of fields with the value of the “ c ” index indicating the biggest changes and the total area exceeding 10 km² was the basis for the selection of the **testing grounds**. Four testing grounds (A–D) were determined, located within the boundaries of rural communes, excluding other areas with much greater changes, due to their location almost entirely within the boundaries of Gdańsk. An analysis of the changes in particular types of land cover was carried out on the basis of detailed maps and the scale and directions of transformations between particular types of land cover within the boundaries of testing grounds were determined. Special attention was paid to situations in which new buildings were built on forest or grassland areas (with grassland functions). The potential possibilities of transformations are presented in Table 2. Not all potentially possible systems of changes of one type of land cover were equally present: changes of built-up areas into underwater areas (and vice versa) occurred incidentally.

For detailed analyses of transformations of land cover in the adopted time intervals, the surface of plots where new buildings occurred was used. It was assumed that due to the construction of new buildings, the area of the entire plot,

according to the geodetic division, has changed the type of use. In individual situations, when the area of the plot according to the surveying division was many times larger than the actual area of the buildings, the area of transformation was reduced by using the course of roads and the building line on the adjacent plots. For this purpose, aerial photographs obtained from the Geoportal¹ service and a local inspection were used.

Research area

The study area is located entirely within the Pomeranian Voivodeship (Poland), including parts of urban communes: Wejherowo, Reda, Rumia, Gdynia, Gdańsk, Pruszcz Gdański, Żukowo and rural communes: Kosakowo, Puck, Wejherowo, Luzino, Szemud, Przodkowo, Żukowo, Kolbudy, Pruszcz Gdański, Trąbki Wielkie, Pszczółki, Suchy Dąb and Cedry Wielkie (Fig. 1). To the east, the research area borders on the compact building area of Gdańsk, Sopot and Gdynia. The central service bands of these cities, as well as Rumia, Reda, Wejherowo and partially Pruszcz Gdański, with dense buildings, usually of a downtown character, were omitted from the analysis, as they focused on the zones, which, since the 1980s, have been subject to increasingly strong suburbanisation. It was decided to delimitate the research area referring to the spatial structure of the environment, mostly independent of administrative boundaries. The borders of the research area were drawn along natural or semi-natural borders, which constitute a barrier to the development of urbanisation: the bank of the Gulf of Gdańsk, the eastern bank of the Vistula River Śmiała, the western bank of the Vistula, the borders of forest complexes, river valleys, the western bank of Lake Wycztok; in the Żuławy area the borders were adopted in

¹ <http://mapy.geoportal.gov.pl/imap/>

Table 2. Potential possibilities of transformation of the land cover options considered.

	Forests (F.)	Grasslands (G.)	Surface waters (W.)	Built-up areas (B.)
Forests (F.)		F. → G.	F. → W.	F. → B.
Grasslands (G.)	G. → F.		G. → W.	G. → B.
Surface waters (W.)	W. → F.	W. → G.		W. → B.
Built-up areas (B.)	B. → F.	B. → G.	B. → W.	

Source: own study.

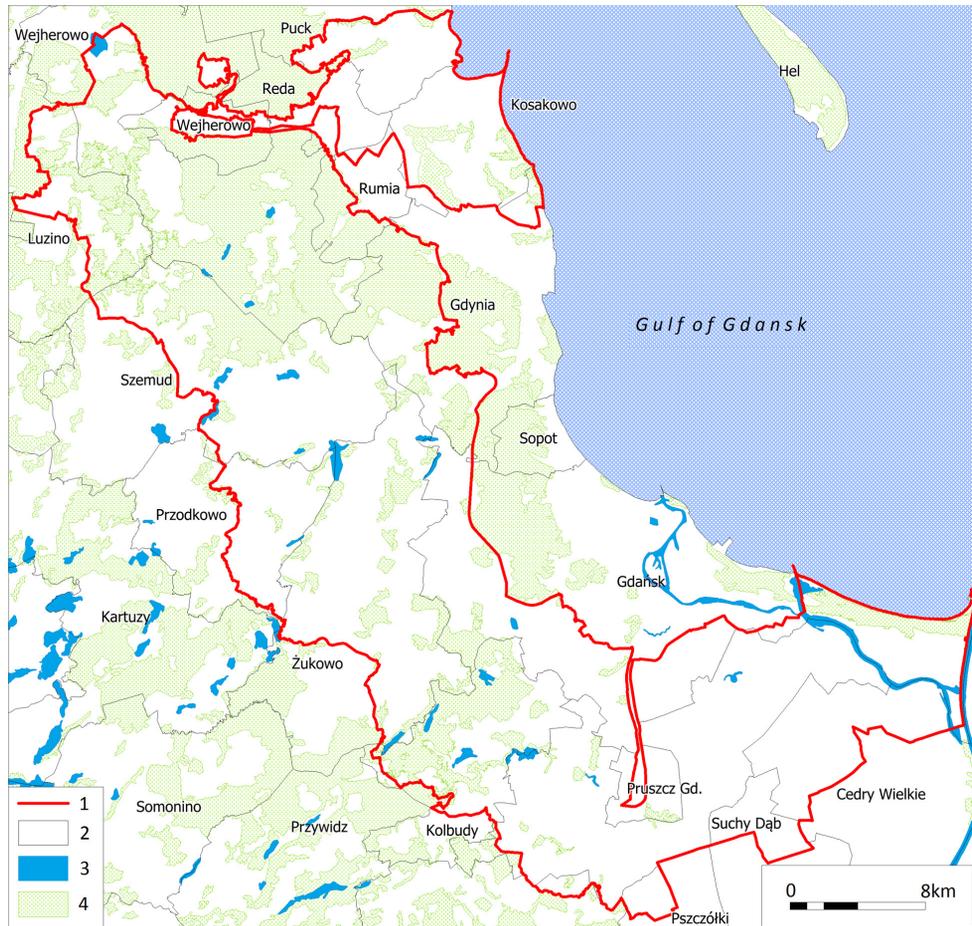


Fig. 1. Location of the research area on the background of the administration division of the Pomeranian Voivodeship.

1 – border of the study area, 2 – communes, 3 – surface waters, 4 – forests.

Source: own study.

accordance with the course of water sections, often carried out with the crowns of the main flood embankments. The total area of the research is 1040.5 km².

Results

The basic characteristics of testing grounds A–D are presented in Table 3, and their location within the boundaries of the study area is shown in Fig. 2. In the years 1985, 2000 and 2012, each testing ground had a different percentage of coverage with the analysed forms of land cover (Fig. 3).

The low share of built-up areas results from the adopted method of building development analysis (only the area beneath the buildings was counted). The general trend was an increase in the built-up area in all types of testing grounds,

slight fluctuations in water surface and an increase in forest areas (except for testing ground D, where in the first period there was an increase in afforestation and then a decrease). The changes in grassland areas were characterised by a constant increase in testing grounds B and C, whereas the area in testing grounds A and D decreased in the first period and then increased. These changes are the result of the spatial processes of the disappearance of a part of forests, grasslands, waters or built-up areas with the simultaneous formation of new areas of the analysed forms of land cover in other places. Therefore, they constitute a balance of the areas under discussion. An example of changes in the land cover in the years 1985, 2000 and 2012 is presented in Fig. 4 (testing ground D).

When considering land cover changes on the selected testing grounds, the following things have been taken into account: the area of land

Table 3. Characteristics of surface area, location and land cover of the selected testing grounds.

Location of research area*	Characteristics
A - Area: 10.5 km ² Mesoregion: Pobrzeże Kaszubskie (Kashubian Coast) Microregions: Pradolina Kaszubska (Kashubian Glacial Valley); Kępa Rekowska (fragment).	The testing ground includes a fragment of the Reda valley, the so-called Mostowe Błota, between Rekowo Dolne and Reda-Ciechocino in the west, the Polchowo area in the north and the Łyski Channel in the south. The testing ground has an agricultural character.
B - Area: 12 km ² Mesoregion: Pojezierze Kaszubskie (Kashubian Lake District). Microregions: Wysoczyzna (Upland) Gniewowsko-Bieszkowicka; the Valley of Zagórska Struga; Wysoczyzna Łężycko-Chwaszczyńska.	The relief is very dynamic and the main natural axis is Zagórska Struga. There are numerous small natural water reservoirs. The landscape of the testing ground changes its character from agricultural to residential and recreational.
C - Area: 17.25 km ² Mesoregion: Pojezierze Kaszubskie (Kashubian Lake District). Microregions: Wysoczyzna Gdańska; the Valley of the Radunia River; Wysoczyzna Arciszewsko-Jagatowska	The Radunia valley, which constitutes the entire testing ground, is characterised by strong dynamics of relief formation processes due to its steep slopes. The development of the testing ground has a residential and recreational character.
D - Area: 17.25 km ² Mesoregions: Pojezierze Kaszubskie (Kashubian Lake District); Żuławy Wiślane. Microregions: Wysoczyzna Arciszewsko-Jagatowska; the Valley of the Kłodawa River (fragment).	The area includes a fragment of Żuławy on the border with Gdańsk Upland. The development is connected with the southern part of the city of Pruszcz Gdański (mainly industrial and warehousing) and the villages of Rusocin and Cieplewo (residential). The eastern part still plays an agricultural role, while the north-eastern part is occupied by a military airport.

Source: mesoregions according to Solon et al. 2018, microregions according to Przewoźniak 1985.

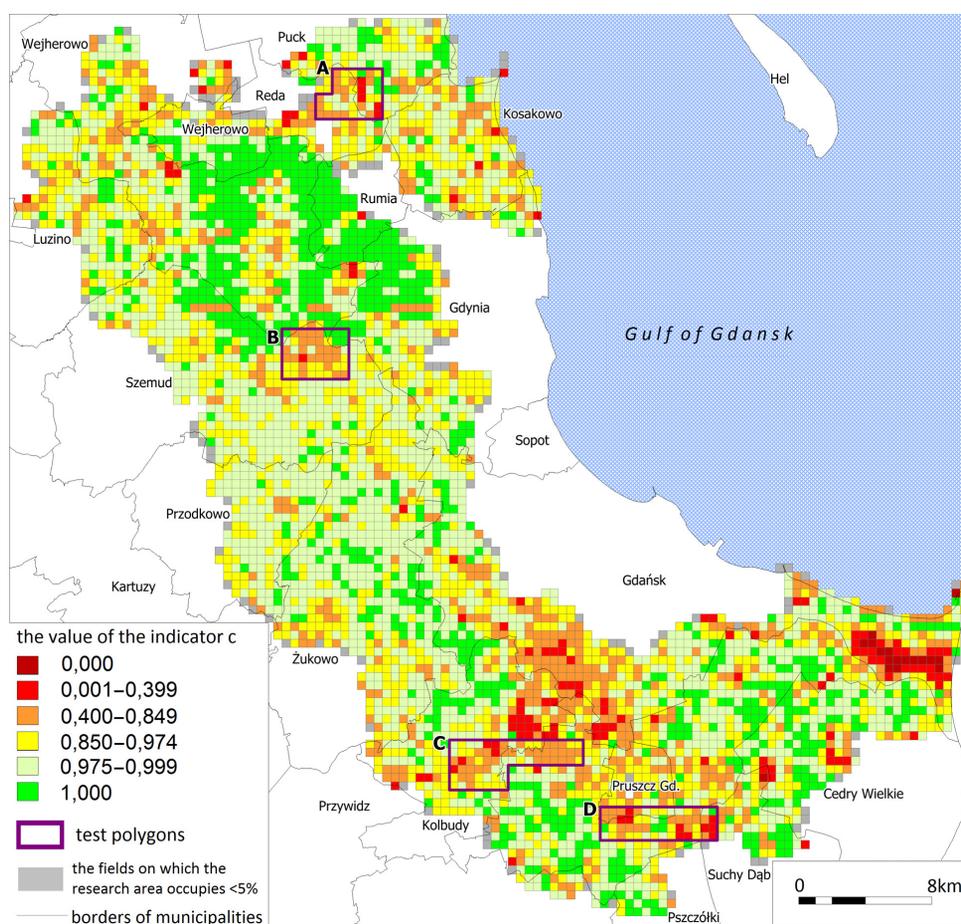


Fig. 2. Spatial distribution of indicator c and location of the testing grounds within the research area.
Source: own study.

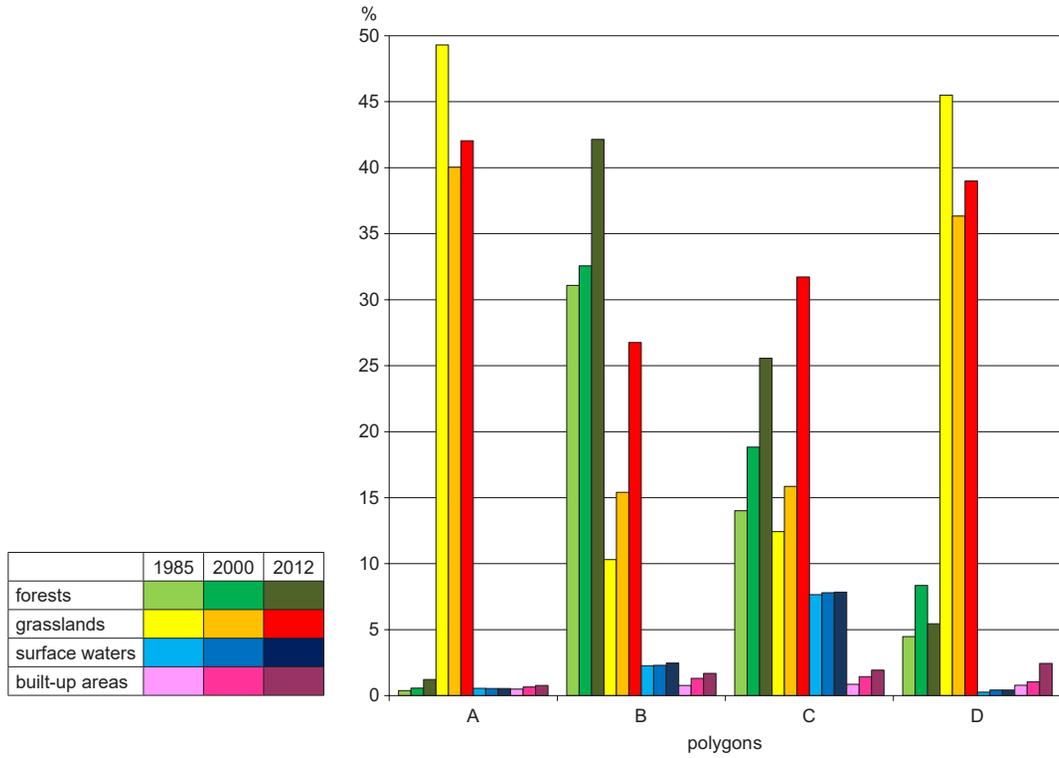


Fig. 3. Percentage of area occupied by selected forms of land cover in testing grounds in 1985, 2000 and 2012. Source: own study.

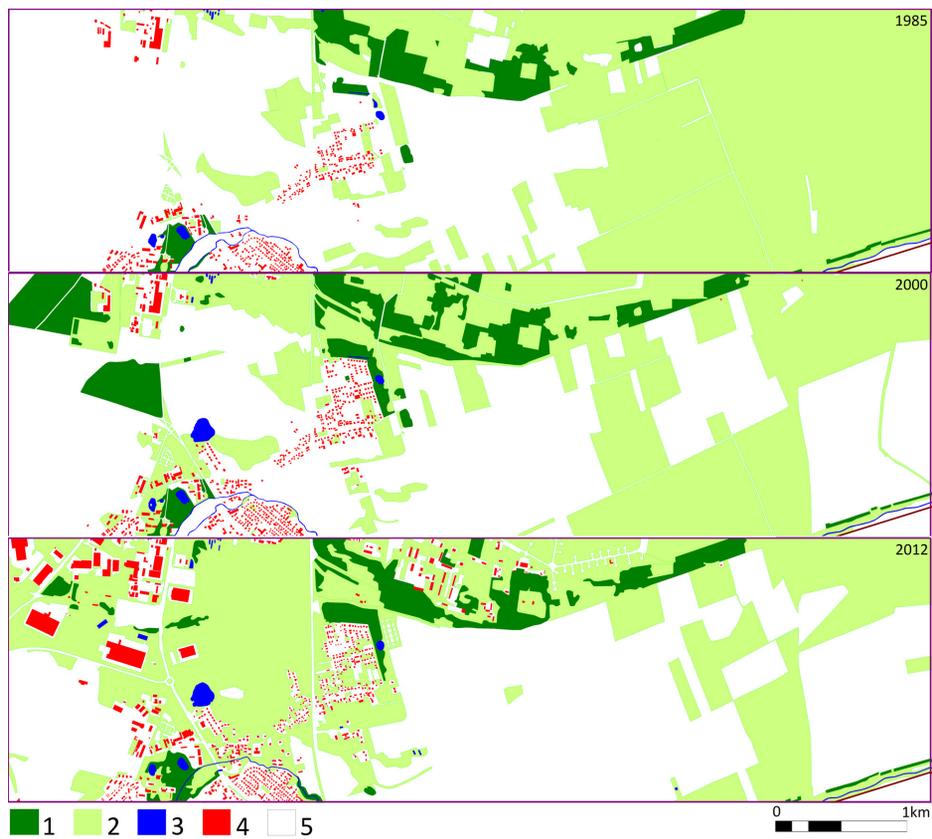


Fig. 4. State of the coverage of testing ground D in 1985, 2000 and 2012. 1 - forests, 2 - grasslands, 3 - surface waters, 4 - built-up areas, 5 - other land cover forms. Source: own study.

cover forms, which have been eliminated and the percentage of the area subsequently afforested on these sites, area changed into the green lands, built-up, permanently flooded or intended for other uses in the years 1985–2000 and 2001–2012. In all testing grounds, surface area changes in grasslands dominated; for instance, in testing grounds B and C, even several times higher in the second period, compared to the first one.

On testing ground D, a slightly smaller loss of their surface area was recorded in the years 2001–2012 than in the first period. The forest area loss in all the testing grounds was significantly higher after 2000 and most pronounced in testing ground D (almost 60 ha), where it was associated with the creation of a warehouse and logistics zone (between nationwide roads nos. 1 and 6) near the south-western border of the city of Pruszcz Gdański. More than 10 ha of forest were eliminated in the years 2001–2012 and similarly in testing ground C (24.6 ha). The smallest area changes concerned water loss (from 0.04 ha on testing ground A in the second period of analysis to 2.7 ha on testing ground C in the second period) and built-up areas (from 0.44 ha on testing ground B in the first period of analysis to almost 3.5 ha on testing ground C in the second period). These two methods of land cover decrease the surface area more in the second period of the study in all testing grounds. The discussed losses refer only to the change of a given form of land cover to another one, because the share of all four land cover forms in relation to the whole research area increased (mainly at the expense of arable land) during the 28-year period under analysis.

The areas of different types of land cover, which in both periods of time were designated for different uses, differ significantly between the testing grounds and results in percentage shares of new types of use (Fig. 5) also differ in terms of size. These differences in the two periods are shown, in total, on the graphs for each type of land cover considered. The changes in the direction of development, as unfavourable from the natural point of view, have been analysed in more detail.

The change of forests to a different type of use was the first of the analysed phenomena. In the first period of analysis, the diversity of changes was less than in the second period (Fig. 5a). Loss of forests – except for testing ground A – was associated with the transformation into grassland

(up to 90% in testing ground D). In the years 1985–2000, only in testing ground C, the forest loss was related to the appearance of water in the space. In the years 2001–2012, a part of the forests, in all testing ground, was intended for:

- development: from 4.3% on testing ground C to almost 32% on testing ground D. However, as can be seen from Fig. 5a, the changes were very small in the surface area;
- grassland: at least 50% of the previously forested areas, except for testing ground A, where the change covered 31% of the area under discussion;
- waters (except for testing ground A) – the changes were small in percentage: from 0.13% (on testing ground C) to 0.76% (on testing ground B).

The largest number of grassland areas disappeared in testing grounds A and D (in both periods). In testing grounds B and C, the losses in both periods were similar in size (Fig. 5b), and the share of new land uses was also similar. In the second period, there was more than a double increase in afforestation in previous grasslands, and at the same time, the area of eliminated grassland increased (10 times in testing ground B and 4 times in testing ground C). It was a positive change from the point of view of the functioning of the environment and the quality of human life. Similarly, as in the case of forest loss, over 97% of the grassland area, which was eliminated in testing ground A, was transformed in both periods, mainly, into arable land. These areas were several dozen times larger than in the case of forests. In testing ground D, 35 ha of less grassland was lost after 2000 than in the last 15 years of the 20th century, while in both periods a similar percentage of these areas was afforested (6.4–6.9%), and the share of areas intended for development increased as much as 21 times.

The example of changes is presented in Fig. 6. This applies to a large extent to areas excluded from agricultural production and ultimately intended for development.

Water is one of the leading components of the environment, hence reducing its surface area may adversely affect the environment, unless it concerns natural processes of overgrowing or peat-forming. On the selected testing grounds, this loss was largely insignificant or very small (Fig. 5c). A six times larger water loss in testing



Fig. 5. Loss [ha] of forest (a), grassland (b), water (c) and built-up areas (d) in testing grounds A-D and the share of [%] types of land cover, which in the years 1985-2000 and 2001-2012 were transformed into: 1 - forests, 2 - grassland, 3 - water, 4 - built-up areas, 5 - other type of cover.
 Source: own study.

ground C in the second period (in relation to the first period) can be described as a relatively large change, with a simultaneous change in the directions of these changes: in the years 1985–2000, a small water loss was reported as there was one case of backfilling a small water reservoir (0.07

ha) intended for industrial and warehouse buildings, whereas in the years 2001–2012, 12 small water reservoirs disappeared and overgrew with forest and 20 others with grass plants and, finally, one was backfilled in order to set up commercial and service buildings. In the first period, the



Fig. 6. Change of grasslands into detached houses near Kielno (testing ground B) in 2004, 2007 and 2019. Source: photos taken by P. Baszanowski.

previous underwater land in testing grounds B and D was designated primarily for afforestation and, to a small extent, for grassland – which, to a certain extent, resulted from natural processes. In the years 2001–2012, the share of water area in testing ground B decreased (although the number of such places increased), and the percentage of areas covered with turf increased significantly. Apart from these natural processes, there were also two cases of buildings erected in the area of earlier waters: one was a farm building and the other a single-family building. At testing ground D, the transformation scenario was almost identical in both periods as regards the surface area, number of reservoirs and directions of changes.

Apart from the situation in the years 2001–2012, at testing ground C, the decommissioned buildings did not cover more than 1.5 ha in each of the study periods (Fig. 5d). The smallest number of buildings was liquidated in testing ground A (due to the agricultural character of the Reda valley) and these places were allocated for agricultural production. In the years 2001–2012, almost half of them were grasslands (18 plots of an average area of 204 m², located in the western part of the testing ground). In the first period, there was only one such situation. The appearance of the forest in the place of former built-up areas in the first period concerned only testing ground C, however, in the second period, it concerned testing grounds B, C and D. The greatest changes in the area and the share of built-up areas took place in testing ground B, especially the loss of summer housing in the vicinity of Lake Marchowo.

Along with the increase in the area of the liquidated built-up area, the percentage occupied by new grasslands in the particular test ranges also increased. Changes of buildings into other types of land cover and changes in the area of forests, grasslands and waters into built-up areas, occurred on a larger scale in the second period of research, when the area of transformation of forests and built-up areas increased 7-fold (Table 4).

In relation to the transformations taking place on the testing grounds, the following directions of changes should be emphasised:

- flat valley bottom, with fertile soils and shallow groundwater level, unfavourable development, remained under agricultural use and characterised by similar transformations: grassland to arable land and vice versa, with negligible share of built-up areas (example: testing ground A and the eastern part of testing ground D);
- the strongest suburbanisation processes (including the chaotic development of buildings) take place here around the intra-urban area of the agglomeration. They are characterised by changes related to the abandonment of agriculture in the direction of year-round development, with an increased share of grasslands waiting for development. There has also been an example of the entry of large-format buildings accompanying the surroundings of the agglomeration, to areas previously uninvested (example: eastern part of testing ground B and western part of testing ground D);
- forested parts of the plateau, with lakes and rivers, are characterised by changes related to the development of the recreational function and the formation of summer housing (example: eastern part of polygons B and C).

Conclusions

The analysis of changes taking place in the space surrounding the Tri-City has been conducted since the 1980s. It concerned, among others, the natural environment – within the limits of geocomplexes (Przewoźniak 1985) or socio-economic features, including demographic and infrastructural features in administrative units (Lorens 2015; Masik 2010). The approach used in the research allowed for the analysis of changes independent of administrative boundaries

Table 4. Loss of selected forms of land cover in the years 1985–2000 and 2001–2012.

Losses [km ²]	1985–2000	2001–2012	Multiple of losses in second period in relation to first period
Forests	1.5963	10.6659	×6.7
Grasslands	33.4734	66.8310	×2.0
Surface waters	0.7859	1.1892	×1.5
Built-up areas	0.7295	5.1754	×7.0

Source: own study.

crossing the natural structures. The method also allows further monitoring of changes, including updating data from BDOT10k. Using the index of convergence of structures, you can compare changes in the intensity of transformation processes in various areas for any time intervals.

Summarising the discussed transformations for the whole area and individual testing grounds, the following regularities should be pointed out:

- The increase in the area of all the discussed forms of land cover around the Tri-city Agglomeration took place mainly at the expense of arable land; reducing their acreage is associated with a decrease in the number of people working in agriculture, and thus, the need for re-education. It is also associated with an increase in the mobility of residents; landscape transformation, associated with a change in the structure of land cover (especially with new, often chaotic buildings), also causes changes in its perception and identification of residents with the new landscape; hence, the need to sociological depth studies in this field.
- The entry of buildings into areas of earlier arable land, grassland or forests entails the need for utilities, which financially burden new residents and local governments, obliged to provide appropriate installations; the chaotic distribution of new buildings in relation to the mosaic of forests and grasslands causes the weakening of ecological corridors in many places (an example of excessive investment in the Radunia valley – testing ground C); particular attention should be paid to the development of buildings in protected areas, including landscape parks and protected landscape areas, due to the prohibition on locating buildings within 100 m from river banks, lakes and other natural water reservoirs (Article 24.1. p. 8, The Nature Conservation Act).
- In spite of the increase in the area of forests, grasslands and – to a lesser extent – water, the spread of buildings is the most intensive process, and the proportion of these two groups of areas (biologically active and built-up) has decreased, which proves that the structure of land cover has deteriorated towards the conditions reducing the possibilities of maintaining the natural balance; the size of changes in the area of selected types of land cover in relation to 1985 indicates the highest relative growth of land under buildings, which confirms the progressing spread of buildings. Any changes in biologically active areas into built-up areas are unfavourable from the natural point of view; the increase in built-up areas in the western part of Gdańsk and Gdynia causes an increase in flood risk in the eastern parts of cities, by reducing the possibility of water retention in drainage basins flowing from the plateau into the Gulf of Gdańsk.
- The biggest changes by acreage took place in the grasslands. Due to the changes taking place in these areas, the analysed test areas can be divided into two groups: 1) testing grounds in which the grassland area first decreased (1985–2000) and then increased (2001–2012): A and D, 2) testing grounds where, in both periods the grassland area increased, whereas in the years 2001–2012 it was higher than in the first period: B and C; the increase in the grassland area in the second period was not always associated with the use of these areas as meadows or pastures. Some of them are wastelands, which are often intended for development.
- The transformation of built-up areas into other types of land use included small areas and concerned mainly old summer buildings located most often in the forest, farm buildings, including the areas of former State Agricultural Farms and individual old single-family buildings, the liquidation of which was associated with poor technical condition. Transformation of buildings into forests, grasslands or water is a positive change due to the functioning of the environment, resulting, among other things, in an increase in water retention due to the appearance of small reservoirs and afforestation.
- During the preparation of data for analysis, many objects were removed, because they were incorrectly classified in BDOT10k to the category “grasslands”, which results in the need to verify data from BDOT10k based on other sources, including mapping in the field.
- The method used allows indicating specific places of changes within communes, regardless of statistical data collected for entire administrative units.

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