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Consistency of the presentation of forests on topographic maps

Abstract
This article analyses the accuracy of the presentation of forests on Polish topographic maps. Four test polygons were selected, differing in forest coverage and spatial distribution of forest areas in order to improve the objectivity of the study. All the polygons were located in Roztocze. Four maps were tested: System 1965 (1:50 000), GUGIK80 (1:100 000), PUWG92 (1:10 000), and VMap L2 (1:50 000). The forest areas from the maps and aerial photographs were vectorised; then the photographs were converted into an orthophotomap that constituted the reference material. All materials were coherent in terms of content validity. After vectorising the range of the forests, sampling was conducted within the hexagonal fields. A comparison of the obtained values provided the basis for maps that presented the errors. The analysis permitted several conclusions to be drawn, generally stating that the credibility of maps within the scope of presenting forest areas depends on the scale and purpose of the map, and that any analyses based on these maps should assume that the results should have higher tolerance levels.

Keywords
Topographic maps • change in forest coverage • forests • Roztocze

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Introduction

Users of topographic maps usually consider them a credible and accurate source of information about the geographic environment. This assumption provides the basis for the many different comparative studies of situations concerning different maps. The results of these studies allow the processes occurring in the geographic space, such as changes in forest coverage, to be understood. Conclusions resulting from a direct analysis of map content are used in assessing the direction and rate of changes, and can be used in research at both the micro- and macroscale. For example, knowledge about changes in land cover permit the identification and reconstruction of the course of historical events, such as, for instance, battles. Tracing the directions of changes allow them to be assessed and their effects forecasted. Analyses concerning larger areas can be used in shaping spatial planning policies. The consequences of such activities can, therefore, be far-reaching. In both the above examples, the credibility of the results of the analyses should be at a high level. This will largely depend on the correct choice and assessment of the source materials providing the basis for the analyses. Therefore, it is worth empirically verifying the thesis concerning the high accuracy of the representation of environmental components on topographic maps.

Objective and justification

The primary objective of the study described in this paper is to determine the scope to which the representation of forests on different topographic maps corresponds with the reality. Topographic maps covering the territory of Poland prepared after World War II are known to have different scales and follow different editorial guidelines. This results in a varied level of generalisation resulting not only from the scale of the map, but also from its purpose. This affects considerably the manner in which the forests on the map are presented. The obtained results suggest conclusions that would outline a framework of comparability for cartographic studies. This would provide an answer to the question concerning the level of credibility that can be given to analyses based on the comparison of situations using topographic maps. From this perspective, the research is pioneering.

Study methodology

Verifying the credibility of the presentation of forest areas on topographic maps involved referring to aerial photographs that had been rectified. The resulting orthophotomap constituted the reference material and provided the basis for comparisons and the assessment of the situation on the maps. For pragmatic reasons the pixel size was limited to 1x1m. The validity of the compared topographic maps obviously refers to the same period as the aerial photographs. In practice, the analyses can only be fully conducted after the vectorisation of the image of the forests on the orthophotomap. This task only appears easy; in fact the interpretation of the aerial photograph is itself problematic: it covers forest nurseries, young trees, and other forms of land cover, which may or may not be categorised as forest areas. At this stage a generally accepted forest definition is useful and can be found in official national documents. Pursuant to the definition, a forest is a compact area of at least 0.1 ha that is overgrown with trees, bushes, and forest floor (Journal of Laws

Vol. 24 • No. 4 • 2020 • pp. 202-217 • ISSN: 2084-6118 • DOI: 10.2478/mgrsd-2020-0024

of 2015, item 2100). It is a simple and unambiguous solution, however, topographic maps have adopted different forest definitions (Olenderek 2011). This brief definition was expanded for the purposes of this paper, and assumed that a forest covers a compact area overgrown by trees, but also includes areas that will become one of these in the near future. Therefore, the range of forests also covered young forests (groves). The situation is analogous to the case of topographic maps. Ranges of forests were vectorised, and these included sparse forests, groves, and young forests. The same measure also concerned the content of large-scale maps, because smaller-scale maps presented forests as one type of range even if they were made up of the aforementioned separate designations. Therefore, the meaning of *forest* was used in its broadest sense, and was applied to topographic maps at the smallest scales.

Forests were marked in accordance with the course of their boundaries. If a road, path, or power line ran through a forest, these areas were included in the forest area. The exception to this rule was the occurrence of wider non-forested belts, either marked on a map, or observed in the aerial photographs. When a forest boundary overlapped the course of a road or river, the delineated boundary ran along their axis. Forest areas excluded areas not classified as forest (e.g. a single field within a forest). Vectorization of the forests was carried out under the same conditions to maintain the native geometric accuracy of the source.

The vectorised ranges of forests from the orthophotomap, together with the topographic maps were used to conduct the analyses. The measurements were conducted in primary fields, in a hexagonal shape having an area of 1 km^2. Such a layout of primary fields is optimal (Mościbroda 1999) and is being applied more frequently. The fields were overlaid with the study area in order to cover it completely. The forest coverage was calculated for both photographs and topographic maps within the resulting primary fields. The next stage was to compare these calculated values on the maps to those obtained from measurements on the orthophotomaps. The result of this comparison is a set of errors in the presentation of forest coverage that can be expressed in a relative form (amount of deviation from the reference area, calculated as a percentage), and absolute form (specified in units of surface area). The results of the analysis were presented in the form of a synthetic maps prepared by means of the isoline method, suggestively presenting the spatial variability of the error index in the form of a continuous statistical surface (Cebrykow 2004).

Research material and its range

This desk study covers the area of Roztocze, which is characterised by high variability in the forest cover index and high variability in the compactness of forest areas. The priority was to provide a diversity of geographic environments in the test polygons in order to improve the objective character of the study. It was equally important to analyse maps from the point of view of different editorial styles, different political and technological periods, and civil and military purposes. The selection of the areas was also largely determined by the availability of image data, in the form of aerial photographs and topographic maps, that were valid for the same point in time. The material review resulted in designating four test polygons, labelled with the letters A, B, C, and D (Fig. 1).

For polygons A and B, a set of documents was collected that was composed of aerial photographs, and topographic maps at a scale of 1:50 000 in the 1965 standard, and 1:100 000 in the GUGIK-80 standard. The aerial photographs were taken in 1964. The validity of the map at the 1:50 000 scale is also dated for 1964. The map at the 1:100 000 scale shows the state as of 1967. Despite the difference in date, the map was included in the comparison because the material review provided no better possibilities for selecting research materials, and the three year difference was not disqualifying.

The polygons marked C and D used research material from 2001 and 2002. The reference layer resulted from the vectorisation of forests from an archival orthophotomap available at Geoportal 2 through the WMS service. The comparison employed maps at a scale of 1:10 000 in the PWUG 92 standard, and 1:50 000 prepared in the Vmap L2 standard. Unfortunately, Roztocze is not covered by a map at the 1:50 000 scale in the PWUG 92 standard because the preparation of maps in this standard were abandoned during the period of interest (Kowalski & Siwek 2013).

Analysis of the presentation of forests

First, the analysis focused on polygon A, with a surface area of approximately 6 thousand ha, covering the northern fragment of the Roztocze National Park. It is characterised by a total forest coverage of approximately 70%. The forests constitute an area that is compact in the centre, with straight-line or ragged boundaries. In the first stage, the vectorised range of forests from the topographic map at 1:50 000 in the 1965 standard was overlapped with the delineation of the range of forests from the photograph. This resulted in a map of differences (Fig. 2).

The next stage was quantifying the differences in forest surface areas between the photograph and the map within the primary fields with a surface area of 1 km^2. The result was two maps: one expressing errors in a relative scale, in percent; and the second in an absolute scale in units of surface area, namely hectares (Fig. 3 and 4).

The analysis of the relative error for the presentation of forest coverage (Fig. 3) reveals minimum index values in the centre of the map. Higher values of errors are observed only in areas not completely covered by forest. Negative values reach 100%, and are related to a complete lack of forest being presented on the topographic map within the primary field. All areas with a negative index are related to relatively small forest areas not being presented.

Excess forest areas in the form of relative errors with a positive value reach a level of 240%. Maximum error values are related to marginal fields that in certain conditions show higher deviations. This is often caused by the fragmentary representation of the study polygon within the primary field. The full presentation of the distribution of errors will be possible after the analysis of the distribution of absolute errors. The total image of relative deviations confirms their low value.

Errors expressed in the underestimated or overestimated map of forest coverage (Fig. 4) are in the range of -2 to 8 ha. The total error involves an overestimation of forest coverage by 56.43 ha (1.38%). The highest values are observed in the boundary belts of the compact forest complex where error values are positive, averaging approximately 3 ha. The values are seemingly low, but referencing them to the surface area of 100 ha (1 km^2) of the sampled primary field shows that 3% of its surface was incorrectly defined. The tendency for overestimation of forest coverage is evident.

Within polygon A, the analysis also covered the situation on the 1:100 000, GUGIK 80 map. In the first stage, a map of differences was prepared with reference ranges from the aerial photograph (Fig. 5).

A visual assessment already permits the characteristic distribution of positive and negative errors to be observed, arranged along the forest edge along an axis from south-west to north-east. Positive errors occur to the south-east, and negative to the north-west. Such an arrangement suggests that the forests

Vol. 24 • No. 4 • 2020 • pp. 202-217 • ISSN: 2084-6118 • DOI: 10.2478/mgrsd-2020-0024

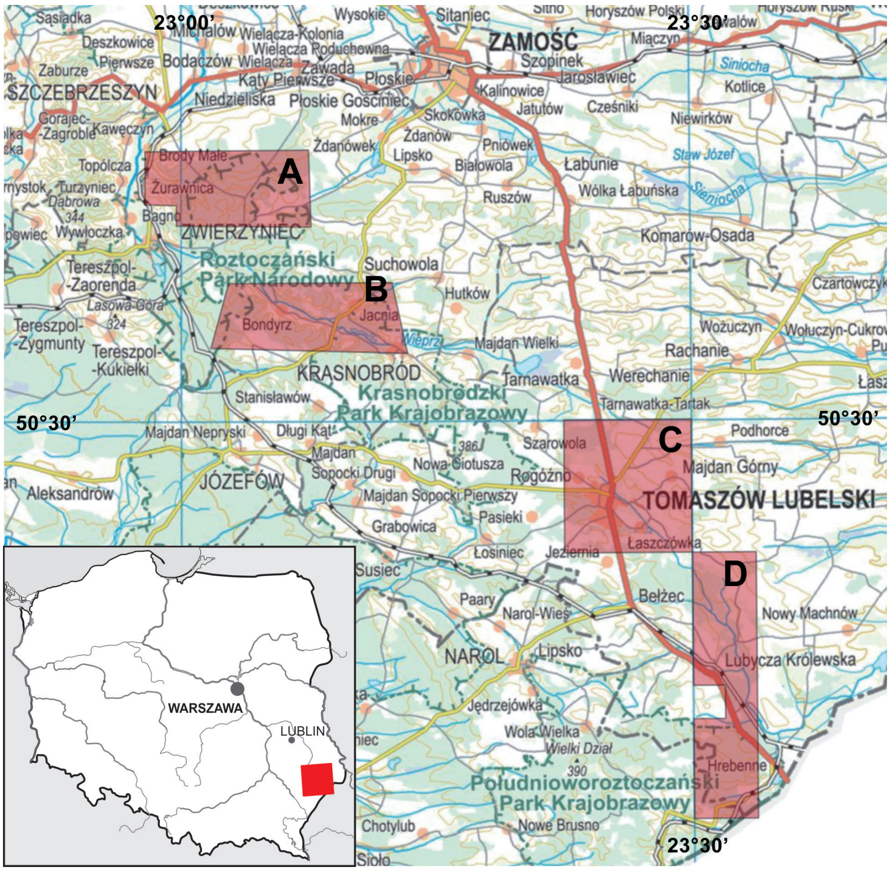

Figure 1. Range of test polygons A, B, C, and D
Source: Own work based on the 1:250 000 map from the website – Geoportal 2

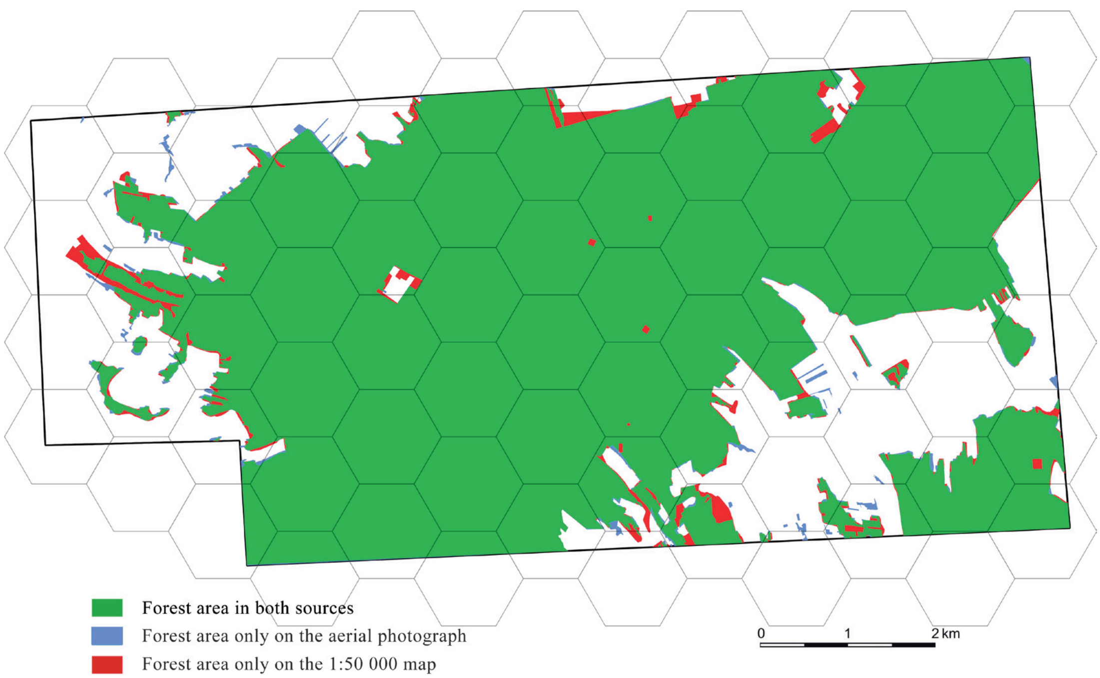

Figure 2. Test polygon A, map of the differences in forests coverage between the aerial photograph and the 1:50 000 GUGIK 65 map
Source: Own work

Vol. 24 • No. 4 • 2020 • pp. 202-217 • ISSN: 2084-6118 • DOI: 10.2478/mgrsd-2020-0024

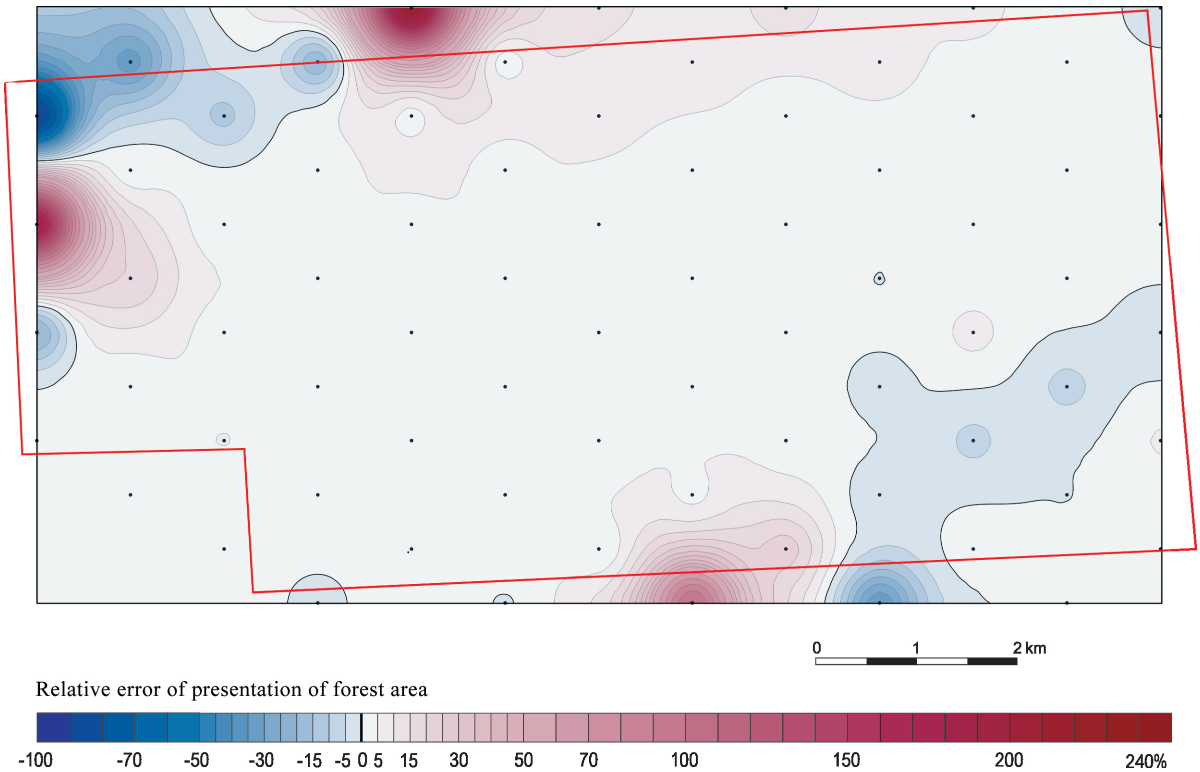

Figure 3. Study polygon A, relative errors for the 1:50 000 GUGIK 65 map
Source: Own work

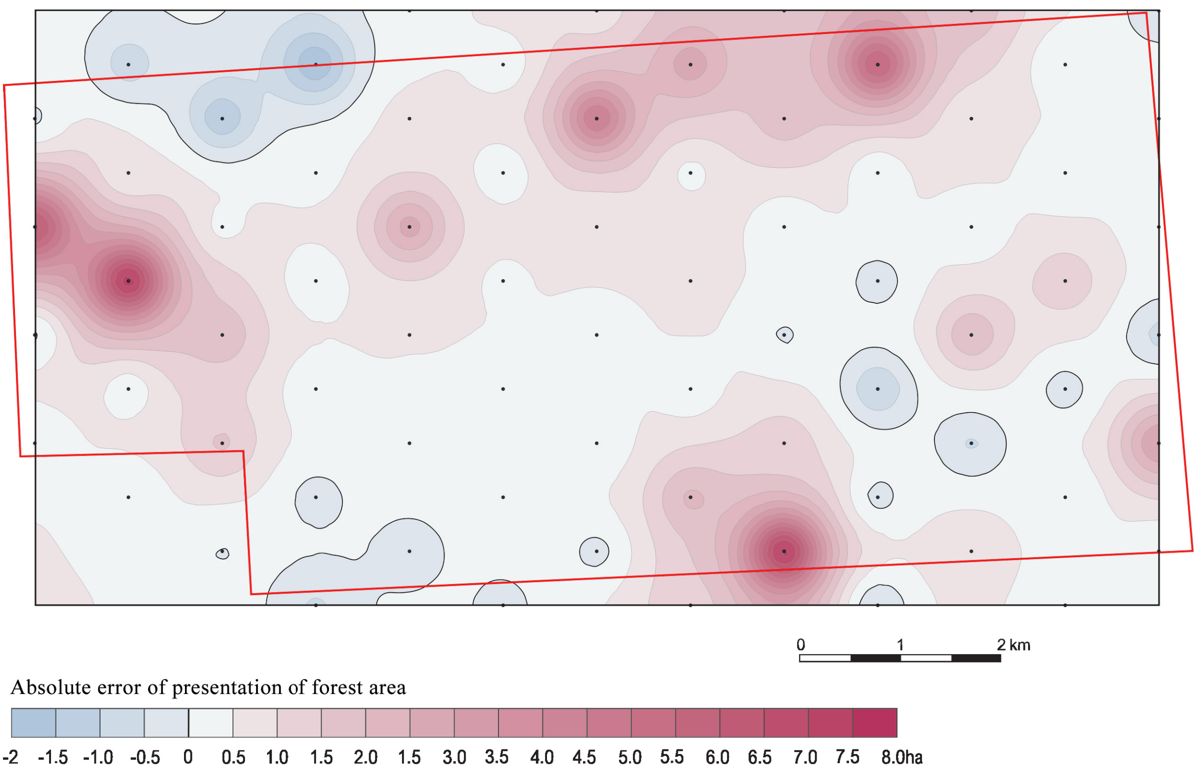

Figure 4. Test polygon A, absolute errors for the 1:50 000 GUGIK 65 map
Source: Own work

Vol. 24 • No. 4 • 2020 • pp. 202-217 • ISSN: 2084-6118 • DOI: 10.2478/mgrsd-2020-0024

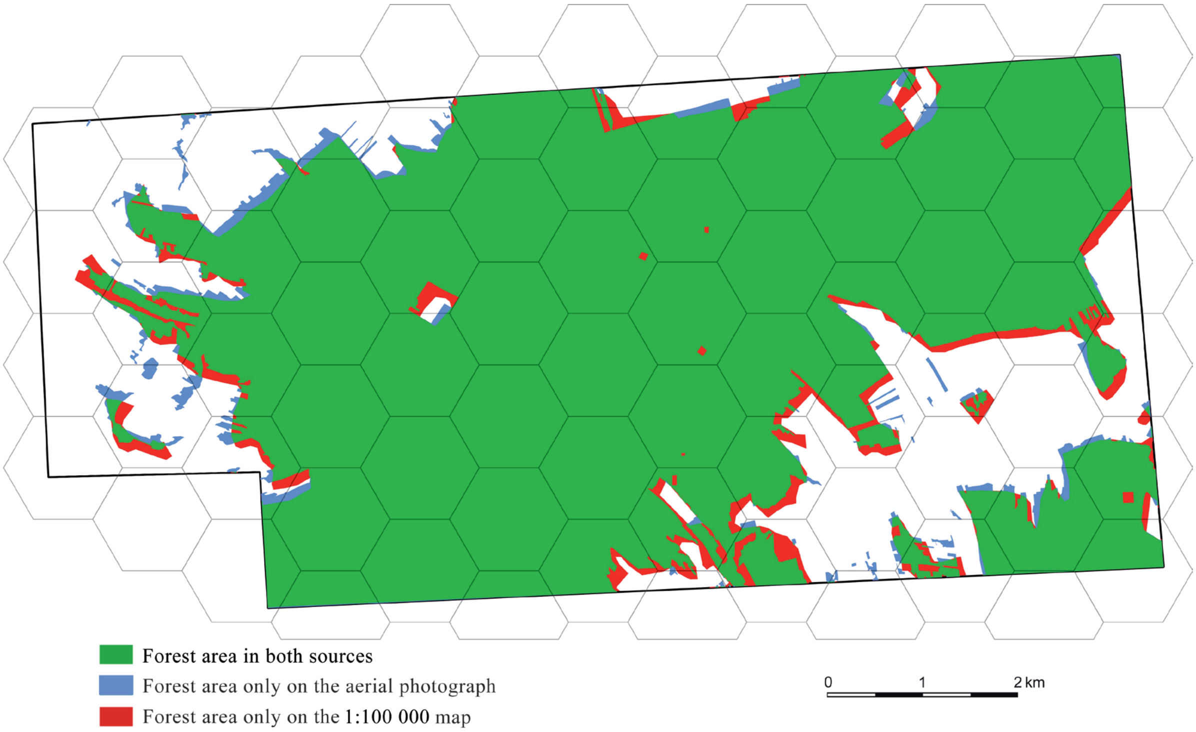

Figure 5. Test polygon A, map of the differences in forest coverage between the aerial photograph and the 1:100 000 GUGIK 80 map
Source: Own work

on the GUGIK 80 map had shifted towards the situation on the aerial photograph. The shift oscillates around a value of 100 m in the field, and is probably caused by intentional distortion resulting from editorial assumptions (Stankiewicz & Głażewski 2000; Krukowski & Łoboda 2015). The consequence of such a situation is shown in the distribution of errors on the quantitative maps (Fig. 6 and 7). Relative errors are within the range of 100% to 154.4%. The causes of obtaining such values are analogous to those of the analysis of the 1:50 000 map. Absolute deviations have values in the range of 8.2 to 12.7 ha. A general prevalence for positive errors is observed. There is an additional 78.5 ha in comparison to the reference surface area, constituting an overestimation of 1.9%.

The next stage of the study was an analysis of the previously tested types of topographic maps within the polygon, characterised by a different forest distribution character. Test polygon B (Fig. 8) has forest cover of approximately 50%, and a surface area of more than 6,700 ha.

The presented maps (Fig. 9 and 10) show the differences between the reference surface area of forests read from the aerial photographs, and that presented on the 1965 map at a scale of 1:50 000. Figure 9 shows the deviations on a relative scale. The values are within the range of -51.4% to more than 500%. The highest positive error values are observed in the marginal zone outside the study area. Such high values do not correspond with high absolute errors, and result from the lack of small forest areas within the sampled primary polygons that are almost devoid of forest. The maximum positive error values reach approximately 100%. The tendency to overestimate forest coverage is prevalent throughout the area and results in an overestimation of 125 ha in total, corresponding to a relative value of 4.2%. In absolute terms, the errors are in the range of -4.0 to 12 ha.

A strong tendency for overestimating forest coverage is observed on the GUGIK80 map at a scale of 1:100 000 (Fig. 11). The forest generally has a surface area higher than the reference material throughout the test polygon. Its total excess is 362 ha, corresponding to a 12% overestimation. Within the test polygons, the values are in the range of -4 ha to almost 20 ha. In percentage values, the deviations are in the range of -100% to 285%, although within polygon B, errors show lower values: from -50% to 100%. As in the previous analyses, the highest values of absolute errors are distributed on the margins of the isoline map (Fig. 12 and 13).

Moving on to test polygon C, the set of maps was changed. Test polygon C covers an area of 8,236 ha with an average forest coverage of approximately 25%. The analysis covers the 1:10 000 map in the 92 standard, and the 1:50 000 map in the VMap Level2 standard. First, a map of the differences between the range of forests on the map at the 1:10 000 scale and the orthophotomap was prepared. The next stage involved the comparison of the 1:50 000 map (Fig. 14).

Even a visual analysis of the surface area of forests provides the basis for its underestimation on both maps compared to the reference material. In the case of the 92 standard map, a smaller range of 94 ha is presented, corresponding to a total underestimation of -4.6%. For the VMap Level2 map, the forest surface area is smaller by 204 ha, i.e., -9.9%. The differences primarily concern small ranges, generalised on maps based on the criterion of minimum area subject to presentation.

Local errors on the 92 standard map are in the range of -100 to 100%, and when expressed in surface area units, they vary from -10 to 4 ha. The areas in which the maximum errors occur are not the same in all cases, although a pattern showing an increase in area of forests within compact, larger forest complexes is observed. Moreover, the areas include smaller errors in the range of -5 to 5%. Underestimation errors are recorded in areas almost devoid of forest, or those in which forests have small surface areas and strongly developed boundaries (Fig. 15 and 16).

Vol. 24 • No. 4 • 2020 • pp. 202-217 • ISSN: 2084-6118 • DOI: 10.2478/mgrsd-2020-0024

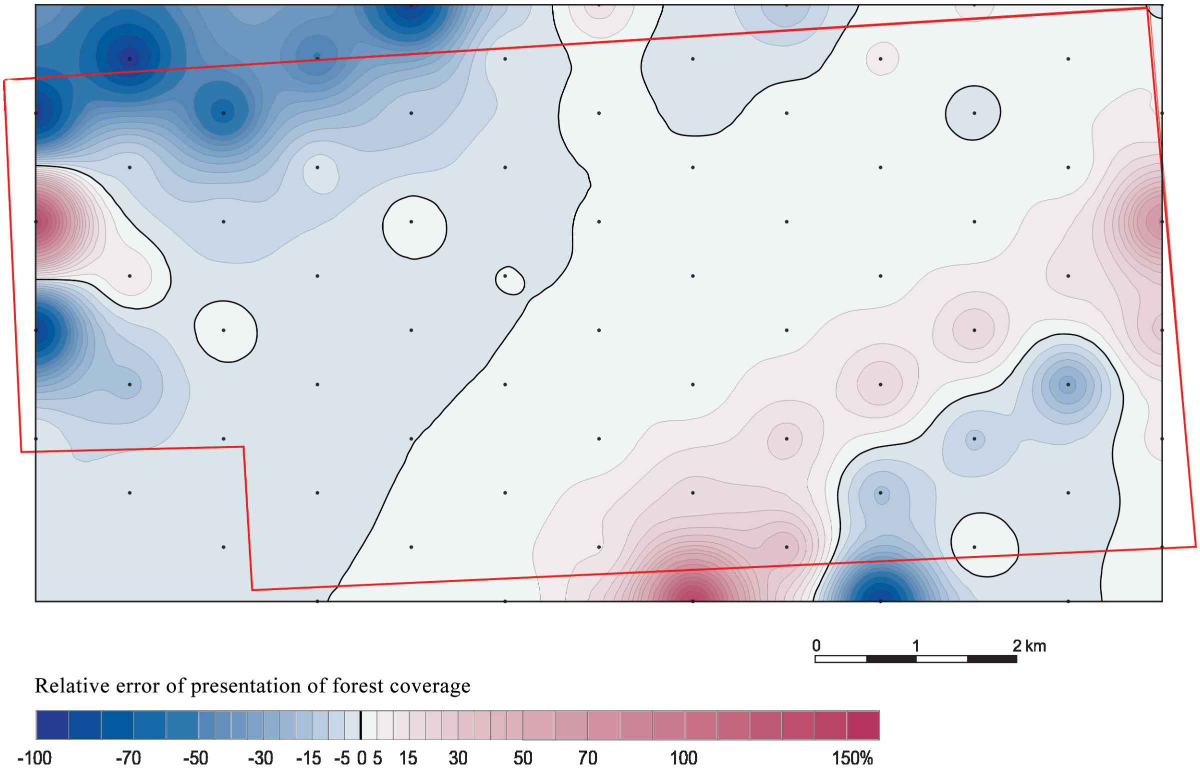

Figure 6. Test polygon A, relative errors for the 1:100 000 GUGIK 80 map
Source: Own work

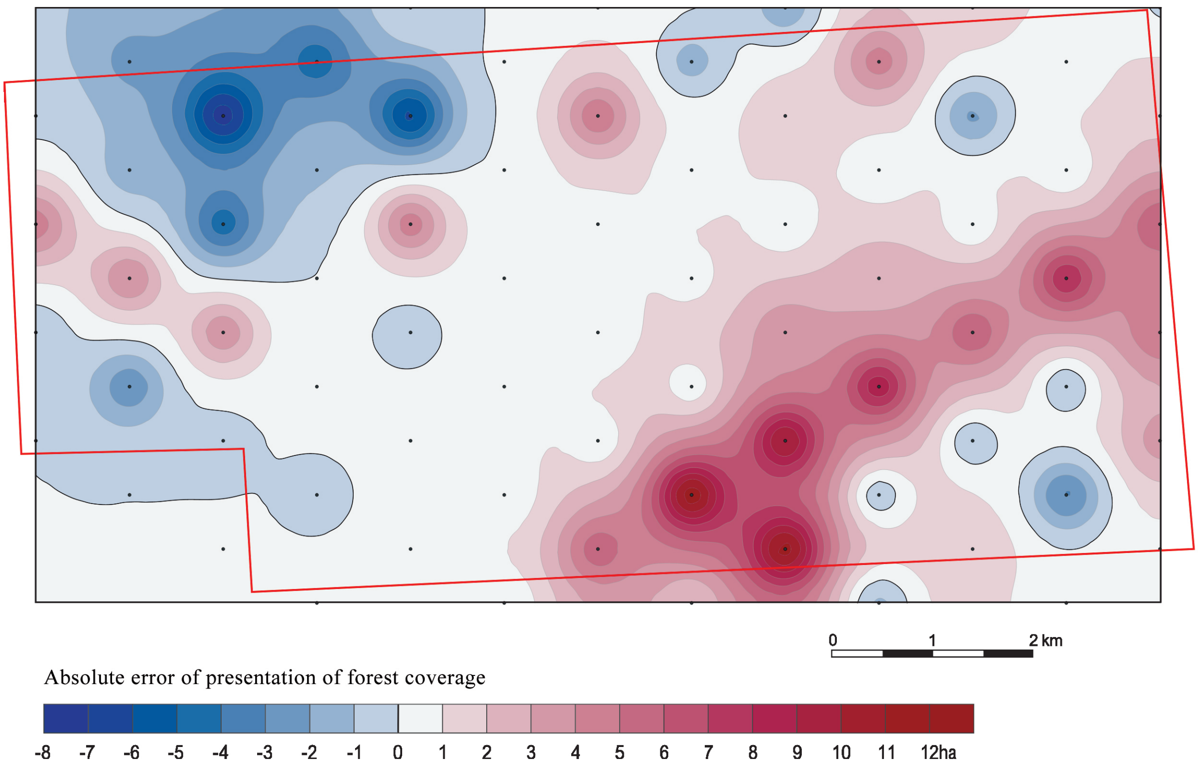

Figure 7. Test polygon A, absolute errors for the 1:100 000 GUGIK 80 map
Source: Own work

Vol. 24 • No. 4 • 2020 • pp. 202-217 • ISSN: 2084-6118 • DOI: 10.2478/mgrsd-2020-0024

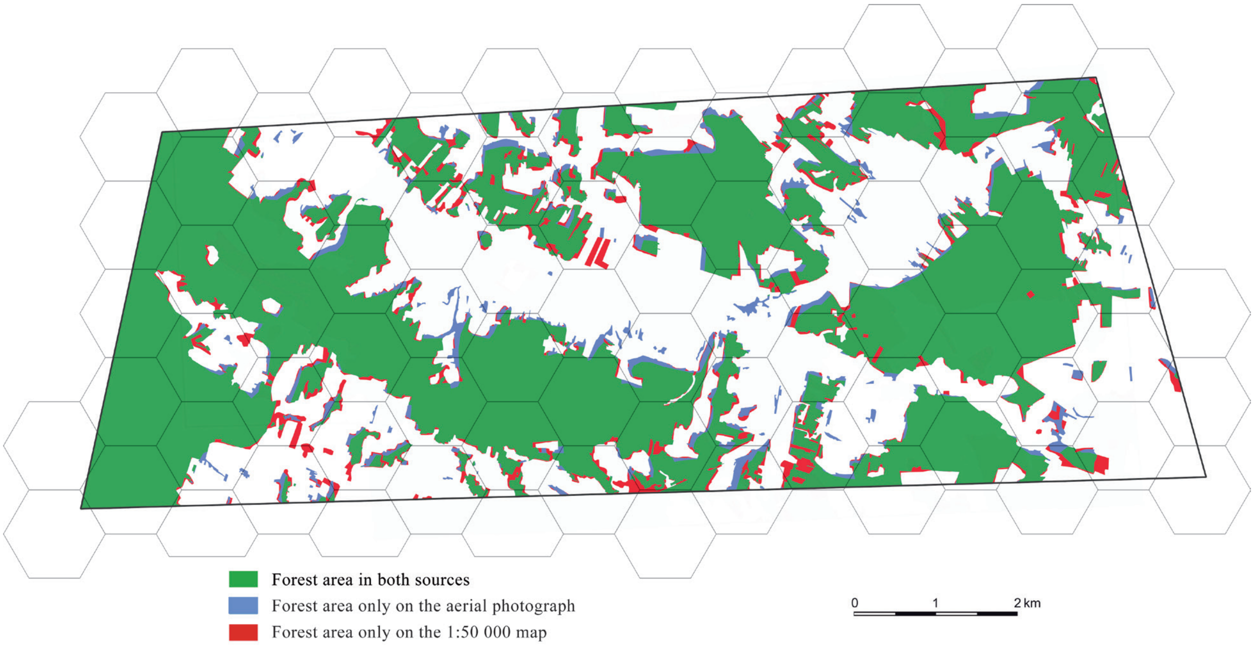

Figure 8. Test polygon B, map of the differences in forest coverage between the aerial photograph and the 1:50 000 GUGIK 65 map
Source: Own work

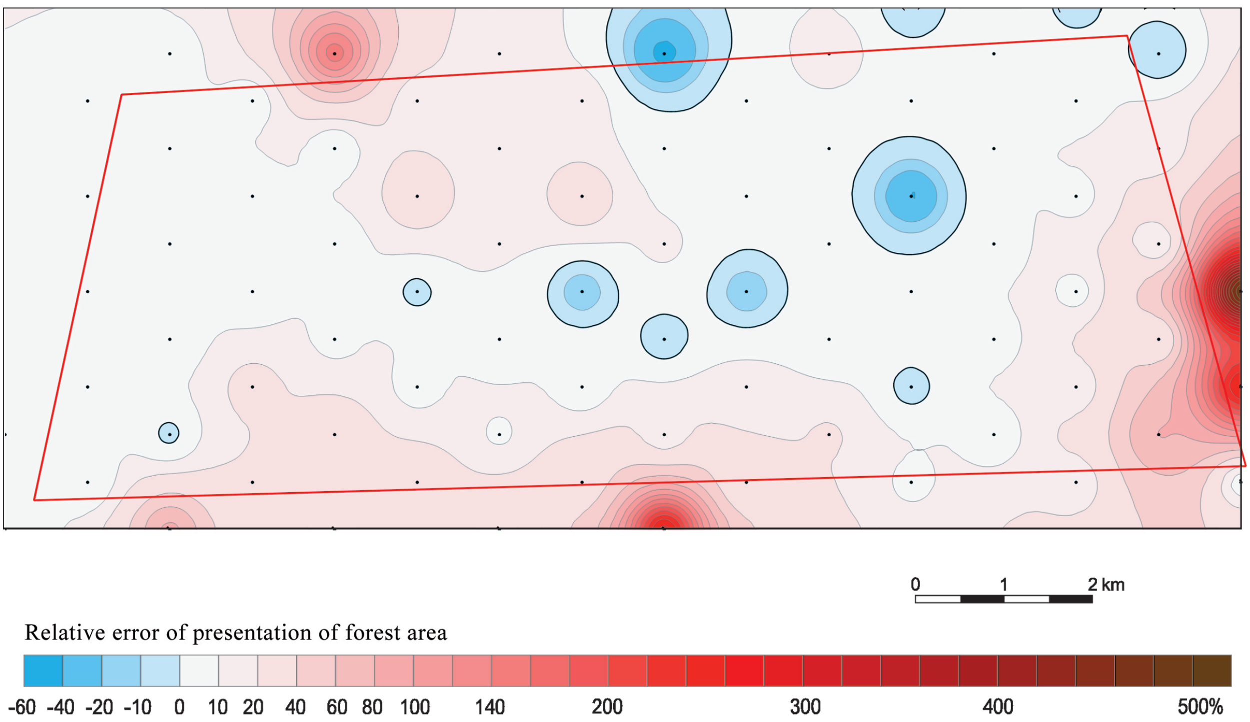

Figure 9. Test polygon B, relative errors for the 1:50 000 GUGIK 65 map
Source: Own work

Vol. 24 • No. 4 • 2020 • pp. 202-217 • ISSN: 2084-6118 • DOI: 10.2478/mgrsd-2020-0024

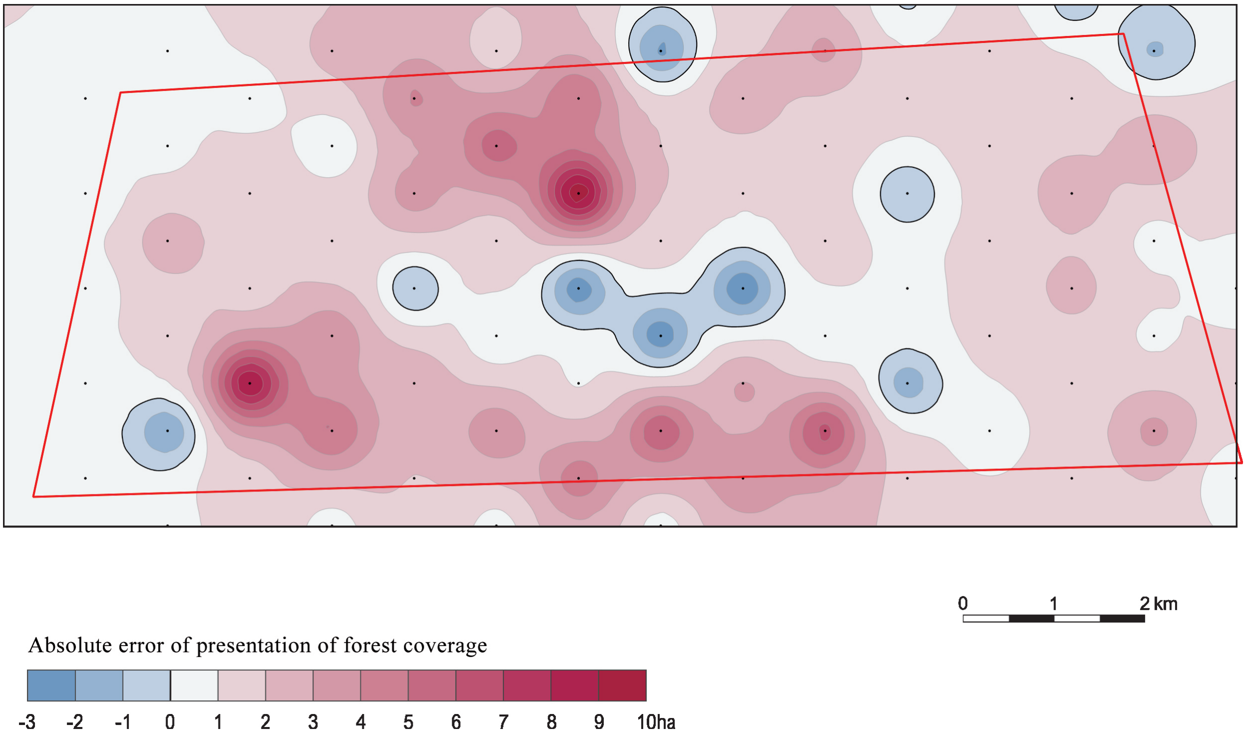

Figure 10. Test polygon B, absolute errors for the 1:50 000 GUGIK 65 map
Source: Own work

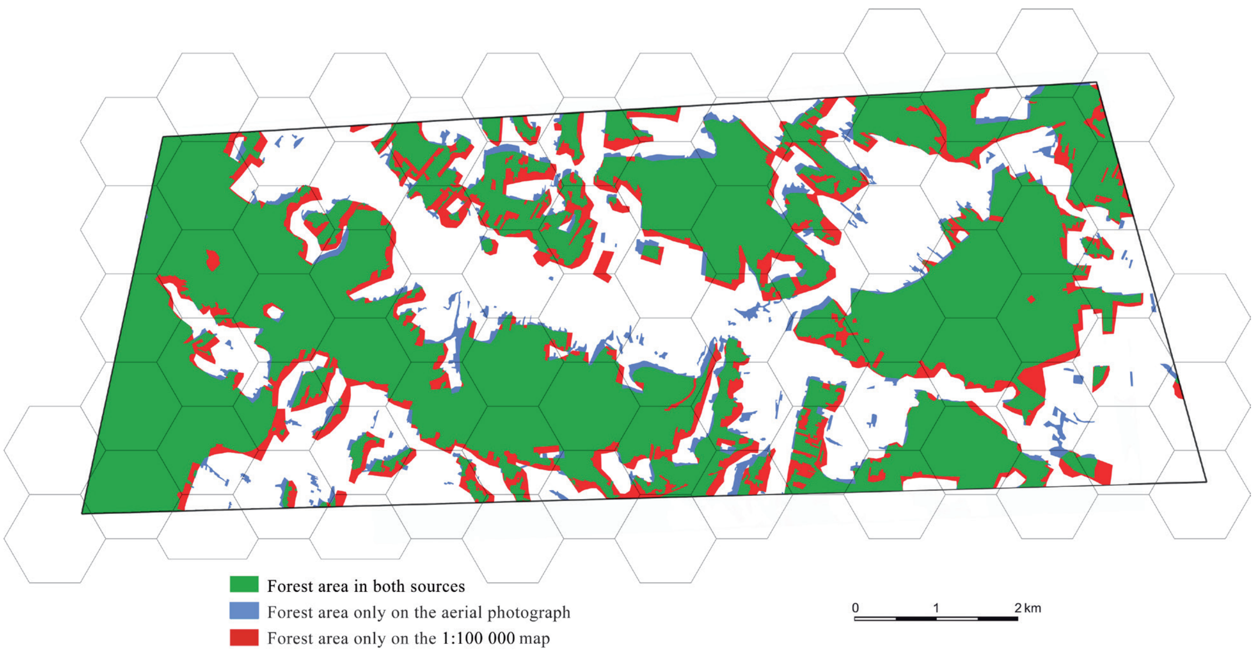

Figure 11. Test polygon B, map of the differences in forest coverage between the aerial photograph and the1:100 000 GUGIK 80 map
Source: Own work

Vol. 24 • No. 4 • 2020 • pp. 202-217 • ISSN: 2084-6118 • DOI: 10.2478/mgrsd-2020-0024

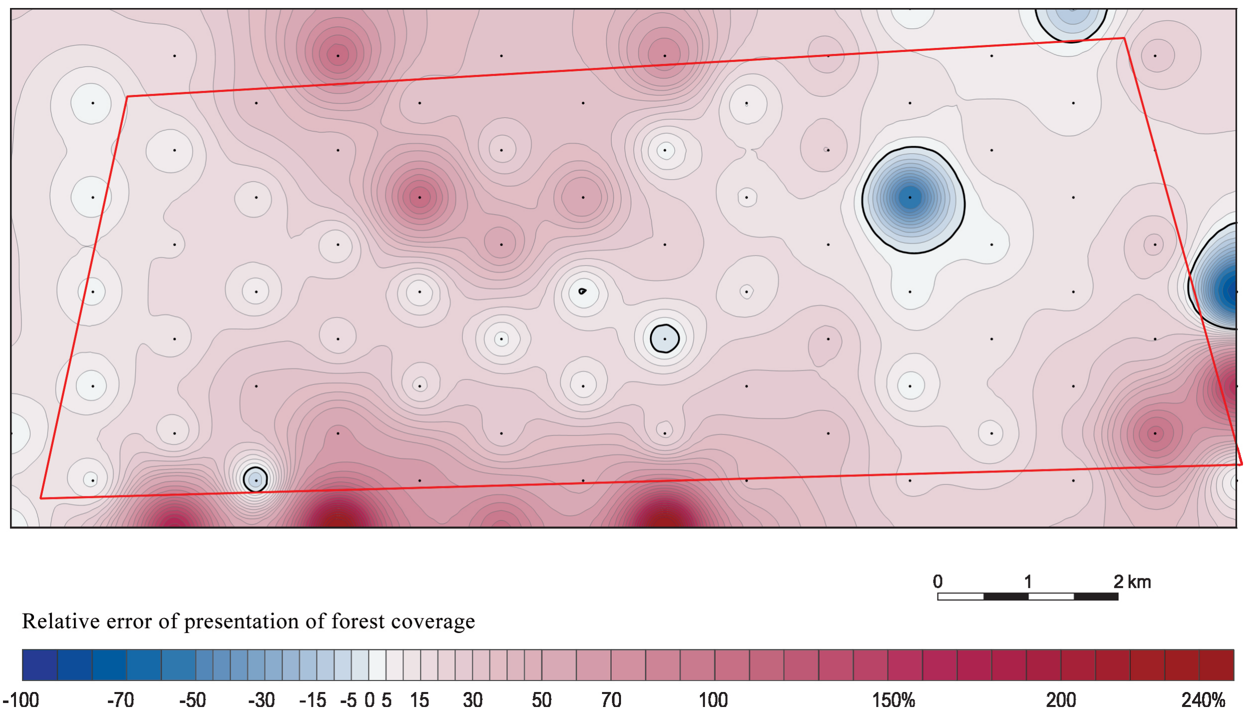

Figure 12. Test polygon B, relative errors for the 1:100 000 GUGIK 80 map
Source: Own work

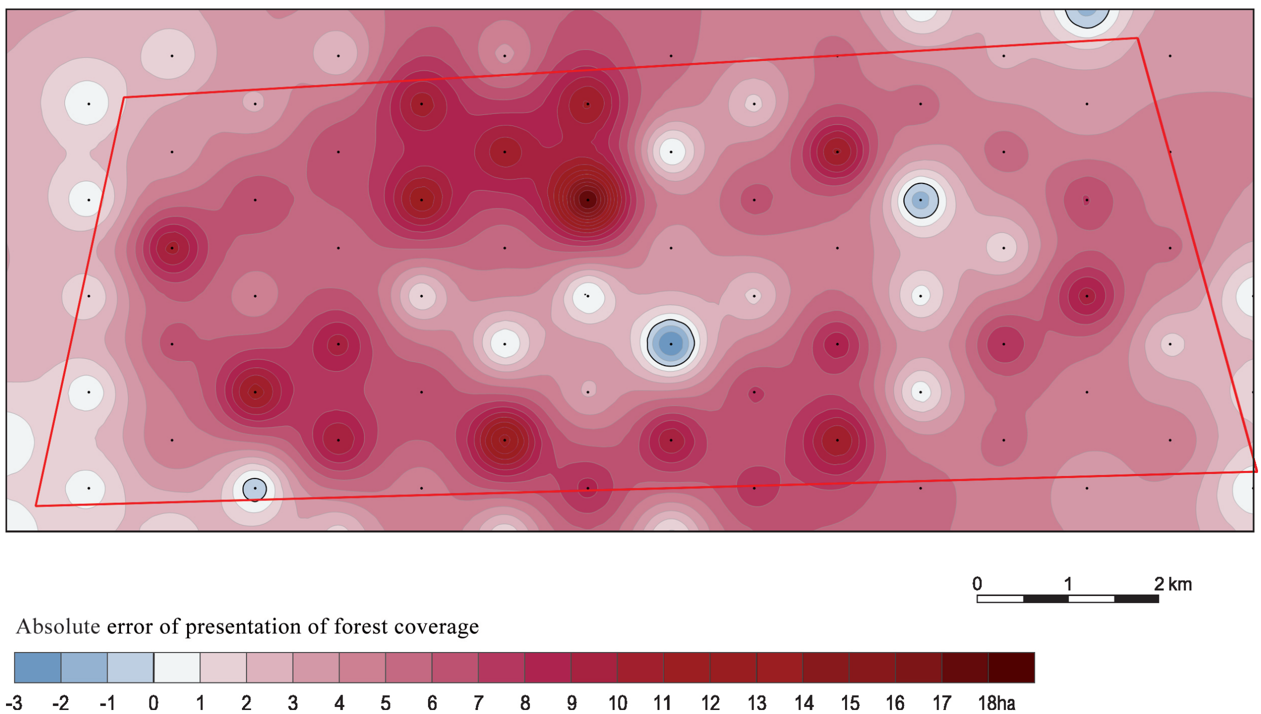

Figure 13. Test polygon B, absolute errors for the 1:100 000 GUGIK 80 map
Source: Own work

Vol. 24 • No. 4 • 2020 • pp. 202-217 • ISSN: 2084-6118 • DOI: 10.2478/mgrsd-2020-0024

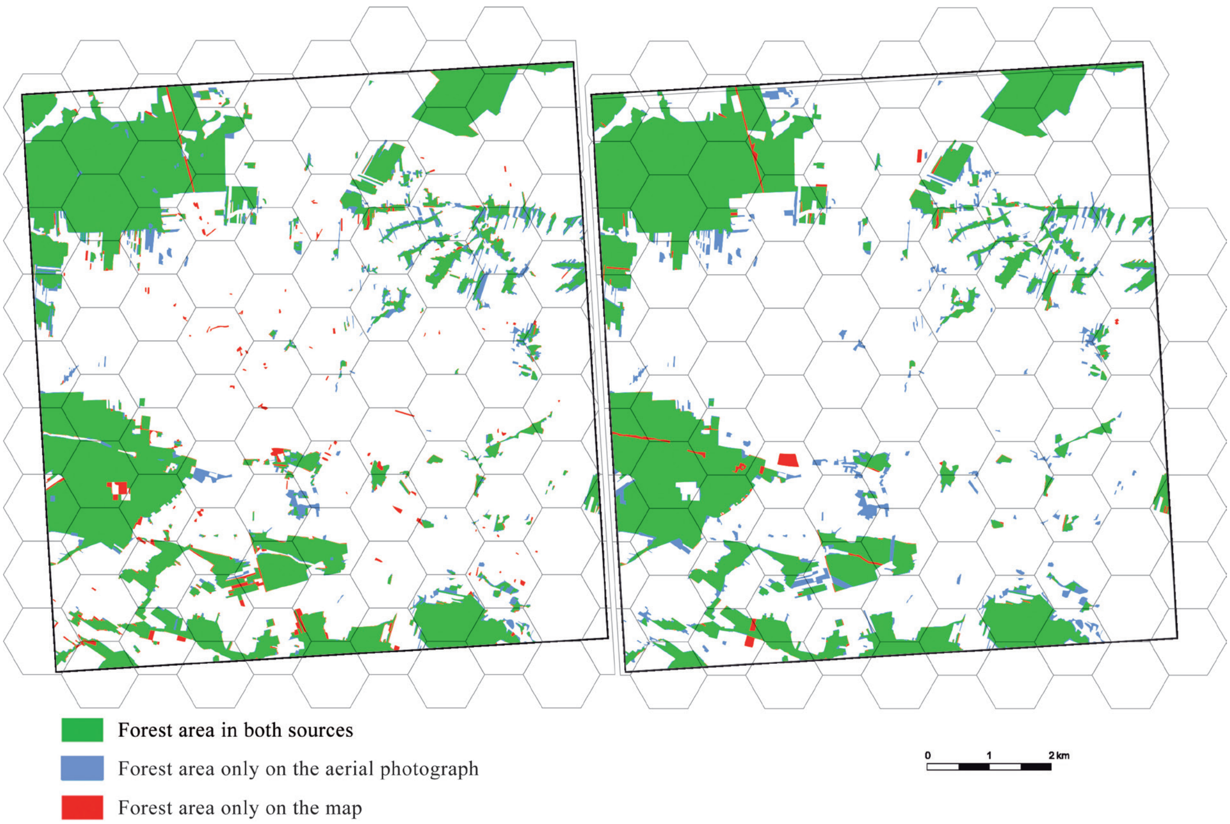

Figure 14. Test polygon C, differences in the forest coverage between the aerial photograph and topographic maps: to the left the 92 1:10 000 map, and to the right the 1:50 000 VMap Level2 map
Source: Own work

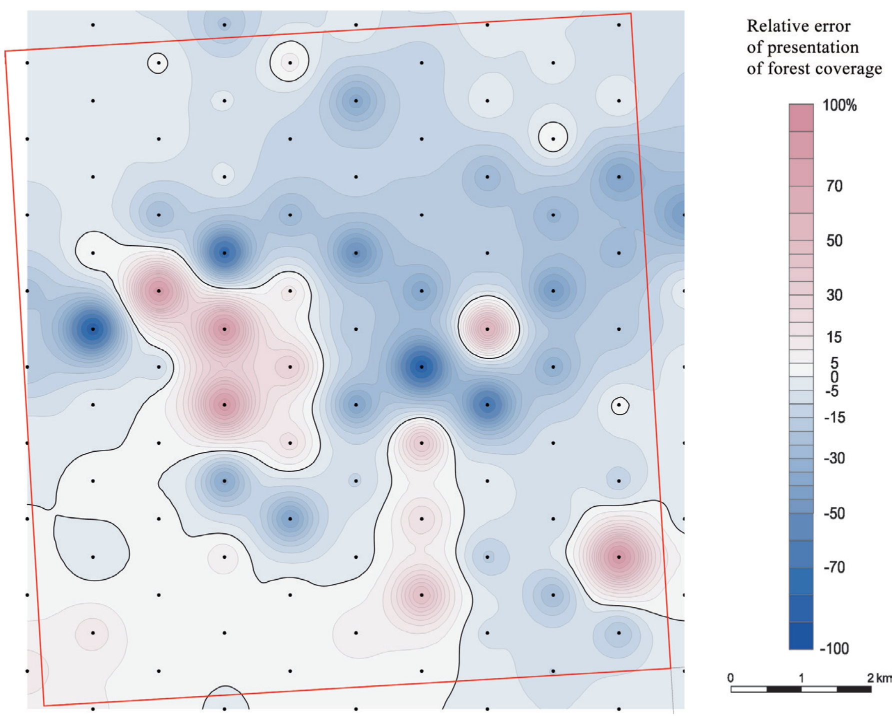

Figure 15. Test polygon C, relative errors for the 1:10 000 in the 92 standard map
Source: Own work

Vol. 24 • No. 4 • 2020 • pp. 202-217 • ISSN: 2084-6118 • DOI: 10.2478/mgrsd-2020-0024

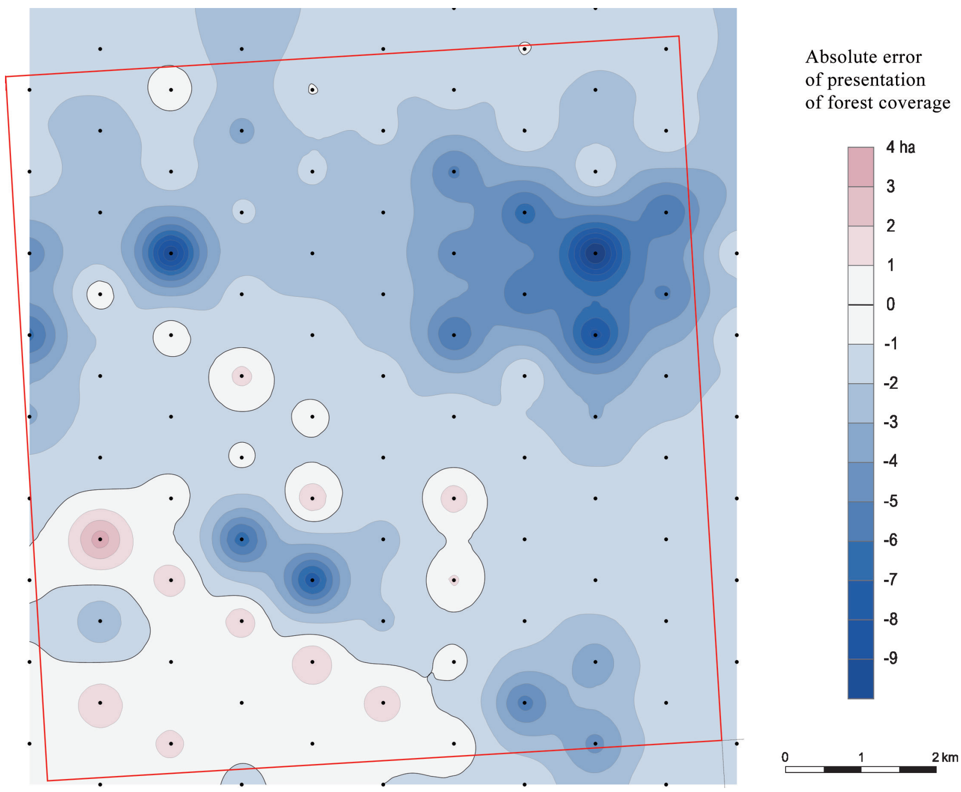

Figure 16. Test polygon C, absolute errors for the 1:10 000 in the 92 standard map
Source: Own work

For the VMap L2, 1:50 000 map, the tendency for underestimation of forest coverage is even stronger than in the case of the 1:10 000 map (Fig. 17). The percentage index has a value in the range of -100 to 20%, whereas positive values are only recorded in 5% of the sampled primary fields. Differences compared to the reference material, expressed in surface area units, cover almost -13 ha, and add less than 4 ha (Fig. 18).

The fourth test polygon, D, is located south-east of polygon C, and occupies 7,739.3 ha, with 55% forest coverage. In comparison to test polygon C, the forest areas are compact and develop large complexes, particularly in the southern part of the test polygon (Fig. 19). The group of maps used in the analysis was the same as in the case for test polygon C.

First, the ranges of the forests were analysed for the 1:10 000 scale map, and compared to the situation on the orthophotomap. Over the major part of polygon D, relative errors are in the range of -10% to 10%. Extreme values reach -100%, and more than 100%. These concern characteristic primary fields, however, they are almost devoid of forest – in this case, omitting very small forest fragments resulted in reaching an error level of -100%. The overestimation error of forest coverage is also related to fields with a similar character. Adding a small forest area into an area devoid of forest creates enormous relative error values. This is confirmed by the low absolute error recorded in the area, not exceeding 1 ha (Fig. 20).

Absolute errors in polygon D reach values in the range of -9 to 11 ha. A tendency for the underestimation of forest coverage is observed here. Such a situation concerns approximately three-fourths of the area of the test polygon. Overestimation of forest coverage occurs in the central and southern part of the area. The correlation between the statistical surfaces on maps of relative and absolute errors is low.

The consistency of the presentation of statistical surfaces is higher in the visualisation of errors for the VMap map at a scale of 1:50 000 (Fig. 21). Both the relative and absolute error maps show an evident prevalence for negative errors, with several minor areas having overestimated forest coverage. This is confirmed by a total error for the test polygon equal to -116 ha, corresponding to a -2.6% underestimation of forest coverage. The relative error recorded in primary fields was in the range of -100% to 50% excess. For the absolute measure, the underestimation error is approximated to -10 ha, and the overestimation reaches more than 7 ha. It should be emphasised that 69 out of 110 primary fields had an error value below ±1 ha, and 31 fields showed zero error.

Conclusions

The analyses of errors in the presentation of forest coverage on Polish topographic maps was performed using a limited sample. In the authors' opinion, however, it permits several direct and broader conclusions to be drawn, which are related to their use as a source of data for environmental studies. The presentation of forest coverage and its adequacy are related to the scale of the map and its purpose. Larger scales present the ranges more accurately, while smaller scales show the effect of generalisation, simplified forest boundaries, and the elimination of forest patches that have the smallest surface area. This results from the generalisation criteria included in the preparation manuals for these maps (Saliszczew 1998). Interestingly, in modern studies (the 92 standard and VMap L2), a tendency for underestimation of forest areas is observed, whereas older maps (1965 and GUGIK-80) overestimated when compared to the reference material (Table 1). The total overestimation of forest coverage in the test polygons reached 1.4% for the 1965

Vol. 24 • No. 4 • 2020 • pp. 202-217 • ISSN: 2084-6118 • DOI: 10.2478/mgrsd-2020-0024

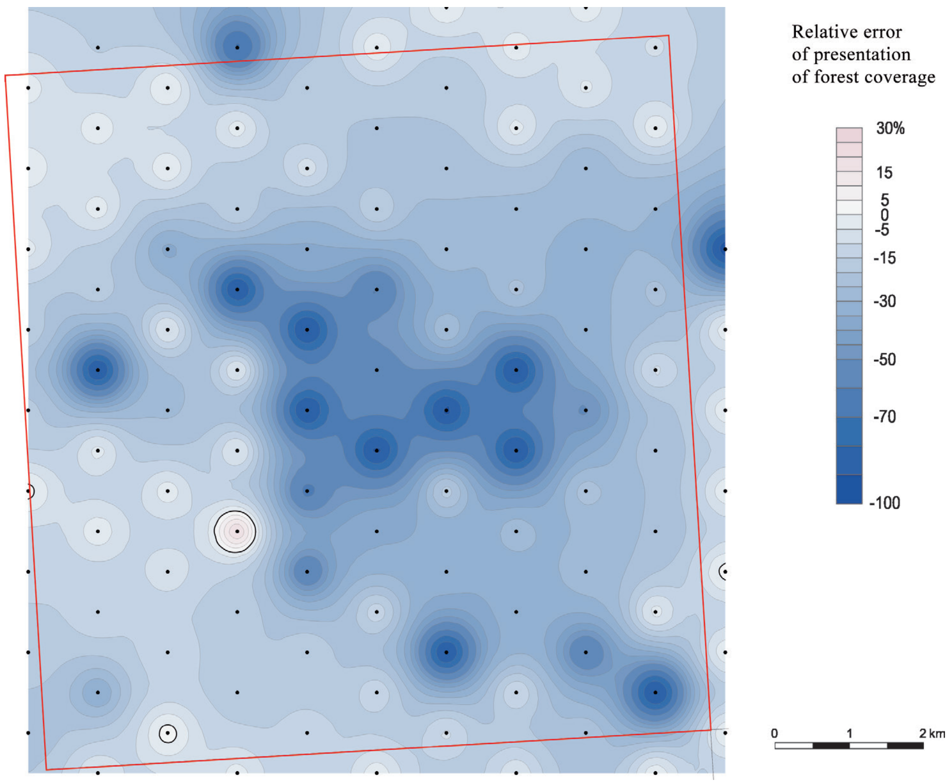

Figure 17. Test polygon C, relative errors for the VMap L2 1:50 000 map
Source: Own work

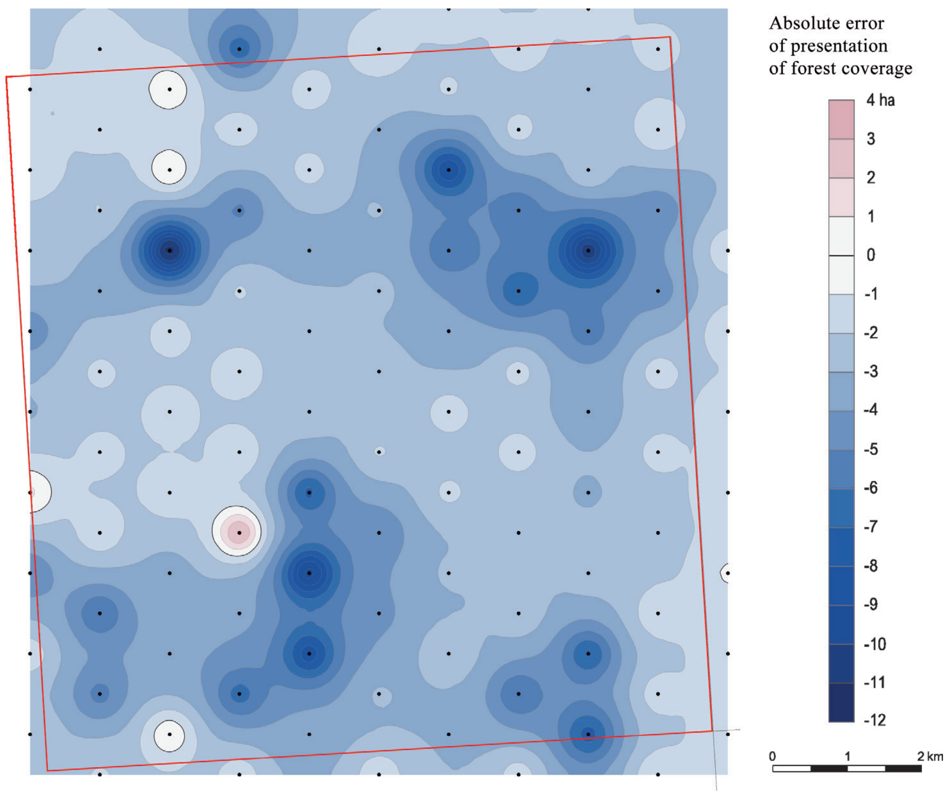

Figure 18. Test polygon C, absolute errors for the VMap L2 1:50 000 map
Source: Own work

Vol. 24 • No. 4 • 2020 • pp. 202-217 • ISSN: 2084-6118 • DOI: 10.2478/mgrsd-2020-0024

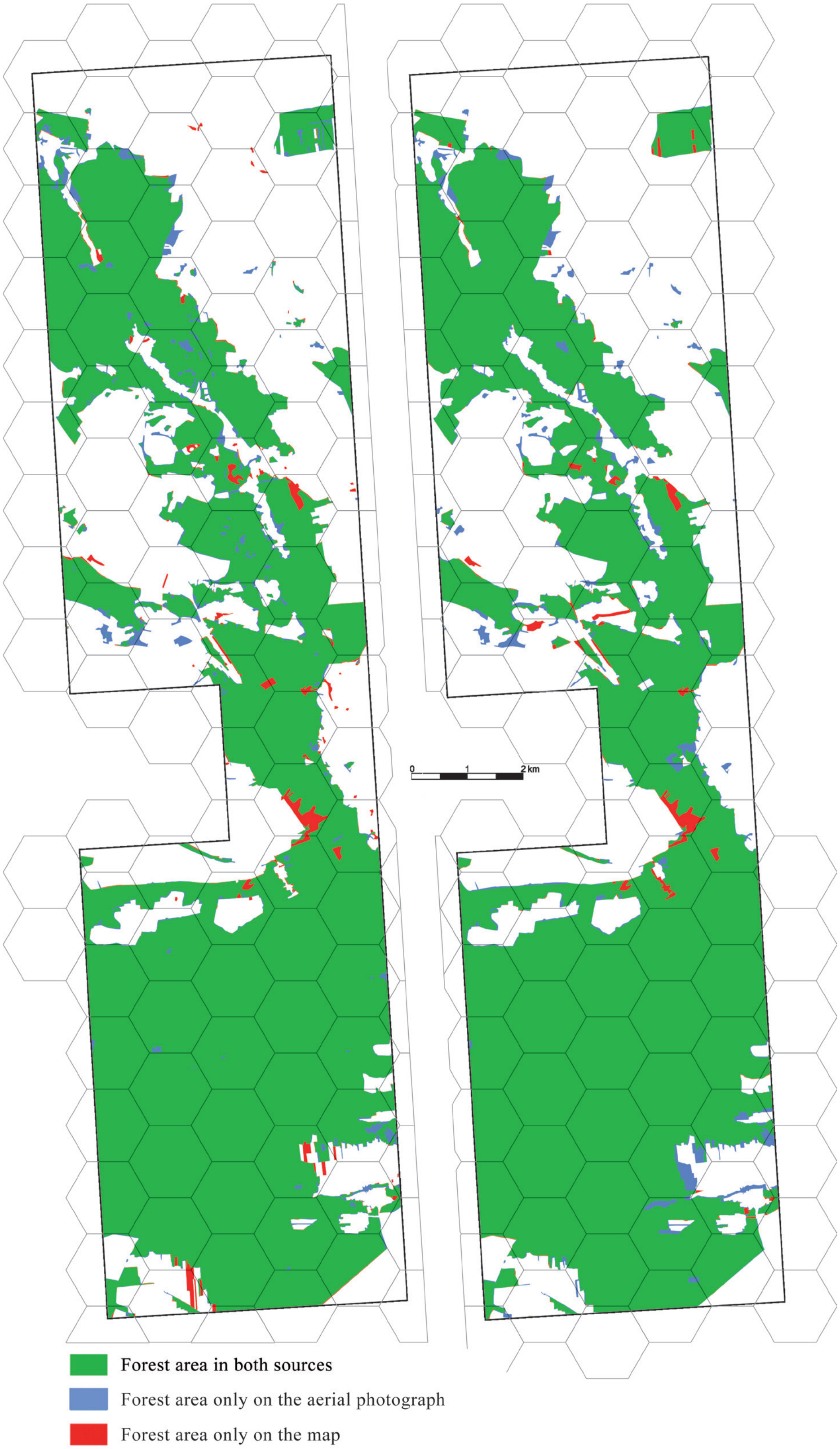

Figure 19. Test polygon D, differences in the forest coverage between the aerial photograph and topographic maps: the 92 1:10 000 map to the left, and the 1:50 000 VMap Level2 map to the right
Source: Own work

Vol. 24 • No. 4 • 2020 • pp. 202-217 • ISSN: 2084-6118 • DOI: 10.2478/mgrsd-2020-0024

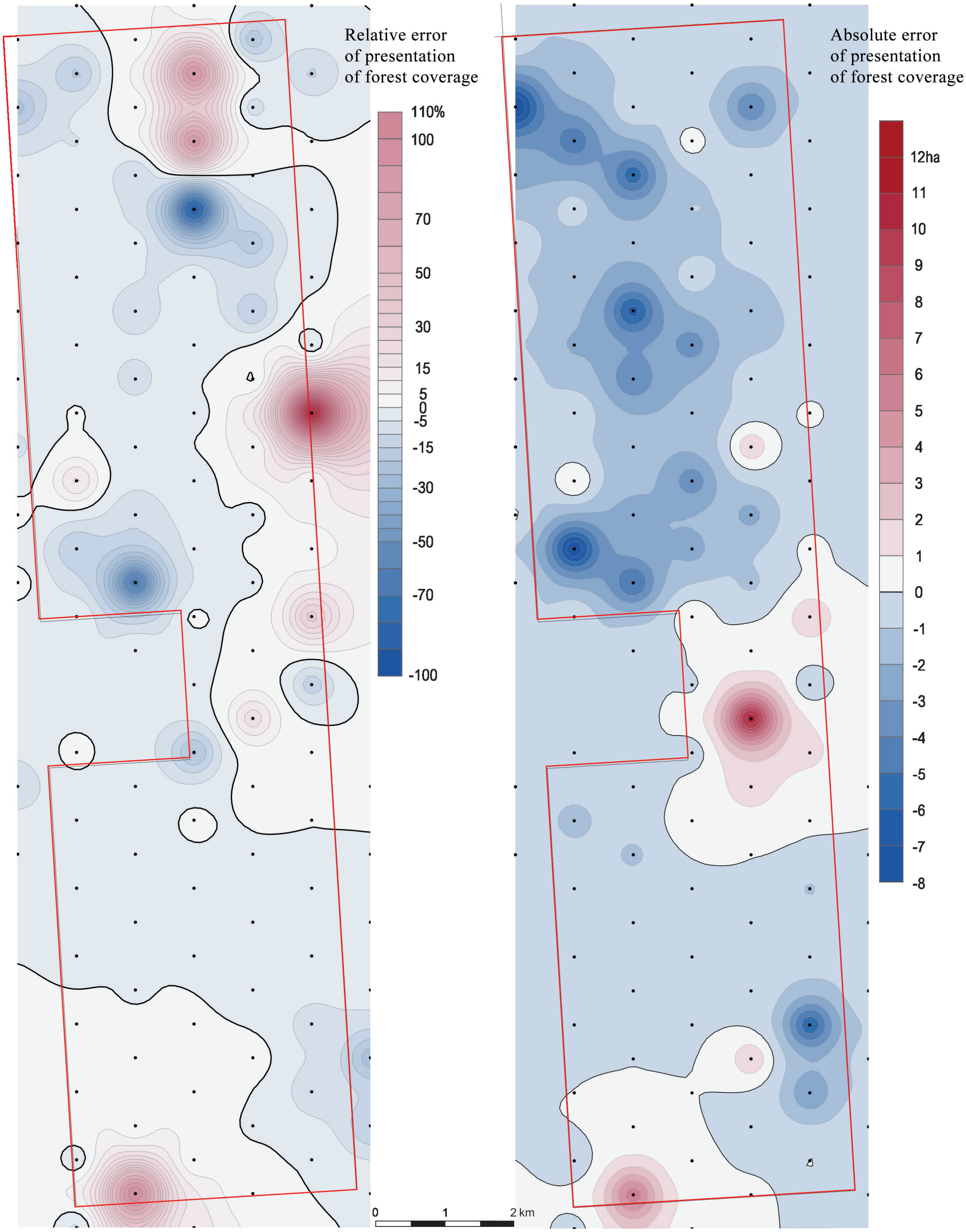

Figure 20. Test polygon D, errors for the 1:10 000 in 92 map system: map of relative errors to the left, map of absolute errors to the right
Source: Own work

Vol. 24 • No. 4 • 2020 • pp. 202-217 • ISSN: 2084-6118 • DOI: 10.2478/mgrsd-2020-0024

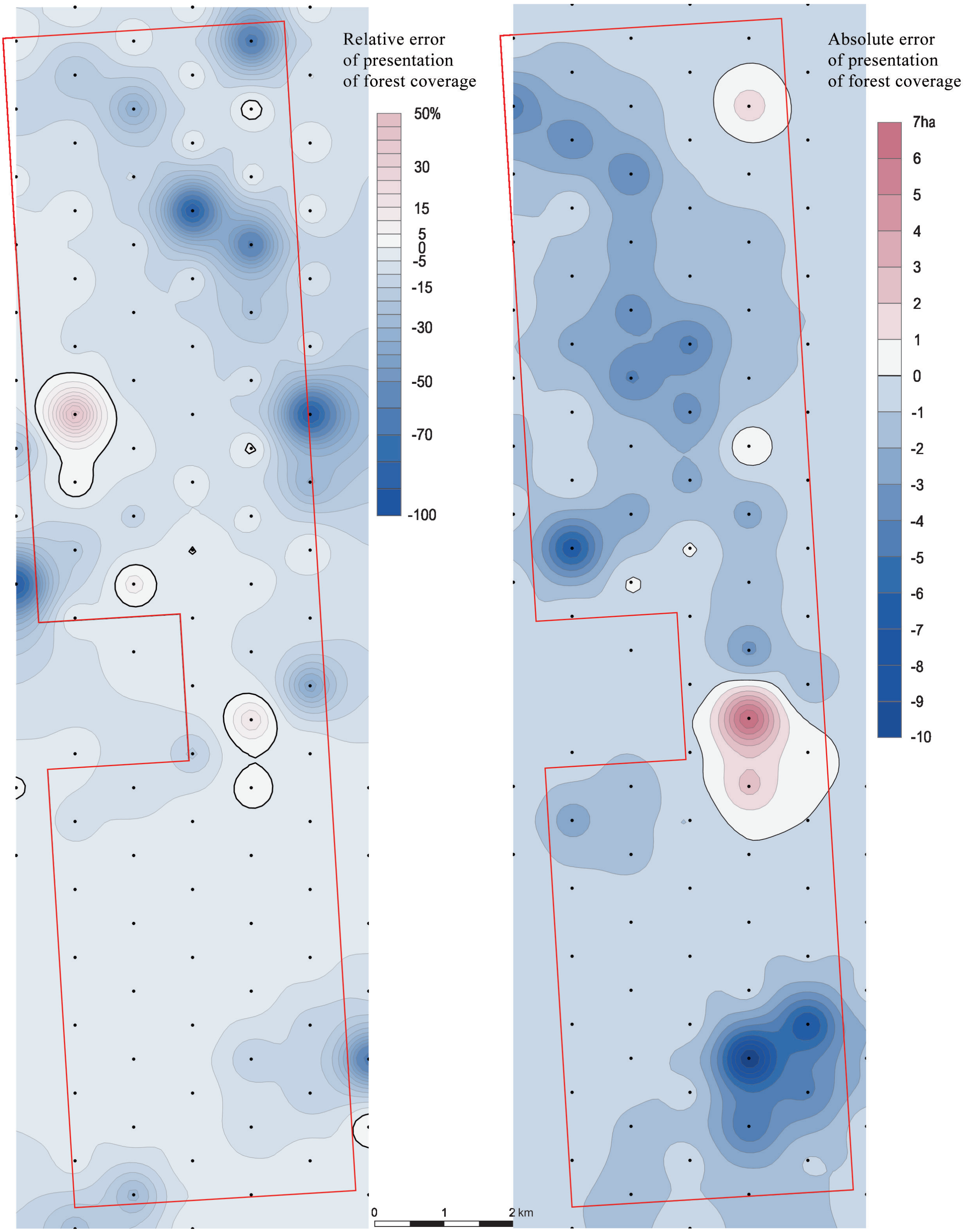

Figure 21. Test polygon D, errors for the VMap L2 1:50 000 map: map of relative errors to the left, map of absolute errors to the right
Source: Own work

Vol. 24 • No. 4 • 2020 • pp. 202-217 • ISSN: 2084-6118 • DOI: 10.2478/mgrsd-2020-0024

Table 1. Total errors in the test polygons for the analysed maps (Source: Own work)

Map	Polygon A		Polygon B		Polygon C		Polygon D	
	%	ha	%	ha	%	ha	%	ha
Standard 65	1.38	56.42	4.17	125.76	-	-	-	-
GUGIK 80	1.92	78.50	9.85	362.97	-	-	-	-
Standard 92	-	-	-	-	-4.9	-100.36	-1.64	-72.27
VMap L2	-	-	-	-	-9.85	-201.93	-2.64	-116.22

map, and almost 2% in the case of the GUGIK-80 map. These values are relatively low, but they concern an area with large and compact forest complexes. The errors increase in areas with lower forest coverage and more complex forest range boundaries. In polygon B, the errors increased to 4.17% (1965), and to as much as 12.12%. In maps from the other group (Standard 92 map and VMap L2), a similar tendency is observed, whereas the errors are negative. In polygon C, with its lower forest coverage and higher indicator for the development of forest boundaries for the Standard 92 map, the underestimation reached a value of -4.9%, and for VMap, -9.85%. In the case of areas with higher forest coverage and high contribution of forest complexes, errors decrease to values of -1.64% and -2.64%. The provided figures affect the assessment of the credibility of the presentation of forests on maps. Unfortunately, the study results show that the accuracy of presentation of their surface areas is specified with an error tolerance of several percent. The tolerance value will increase with decreasing map scale. This conclusion is not innovative, but it justifies a frequently forgotten rule concerning the comparison of maps with a similar scale and purpose, and therefore a similar degree of content generalisation.

The presented analysis focuses on the differences in presented forest coverage between maps and reference material, in the form of orthophotomaps. The obtained results, however, provide the basis for broader conclusions. This is exemplified by diachronic studies for which maps are frequently one of the basic sources of information. In the context of the obtained results, the accuracy of such studies can, presumably, be limited, and although modern GIS technology offers highly precise results, they should be provided in a way that takes into consideration a certain level of tolerance.

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Ustawa z dnia 28 września 1991 r. o lasach: Dz.U. 2015, poz. 2100 [*Act of 28 September 1991 concerning forests*: Journal of Laws 2015, item 2100].

List of maps

Układ 65, 1:50 000: Zamość Południe (156.2)
GUGIK80 1:100 000: Biłgoraj (86.04.2), Zamość (86.05.1).
Układ 92 1:10 000: Dęby (M-34-72-A-a-1), Lubycza Królewska (M-34-60-C-c-3), Żurawce (M-34-60-C-c-1), Łaszczówka (M-34-59-D-b-2), Tomaszów Lubelski (M-34-59-D-b-3), Majdan Górny (M-34-59-D-b-4), Rogóźno (M-34-59-D-b-1), Siedliska (M-34-72-A-a-3).
VMap L2, 1:50 000: M-34-59-C,D, M-34-60-C,D, M-34-72-A, B