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# FOREST COVER CHANGE OR MISINTERPRETATION? ON DEPENDENT AND INDEPENDENT VECTORISATION APPROACHES

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*Abstract*: The paper compares the influence of dependent and independent vectorisation approaches on forest cover change analysis, with a hypothesis that the former reduces the number and area of sliver polygons. Independent vectorisation is based on separate creation of the vector layer for each period in the time series, while the dependent is based on modification of the successive vector layers. The comparison is based on three map sets – the second Austrian military survey (1861/1862), a Polish military map (1936) and a Polish topographic map (1979) and carried out in Szczawnica commune located in the Polish Carpathians. The results show that the overall differences between the two vectorisation approaches are low at the commune level, but the local differences, within the grids 500×500 m might be up to 30–40%. Statistical analysis did not indicate any considered variable directly responsible for the differences, confirming that it is a randomly distributed phenomenon. The results show also that the dependent vectorisation cannot eliminate the existence of sliver polygons, but their number may be limited when compared to the independent approach. As the dependent vectorisation is much more time efficient, we conclude that it might be a better solution in the situation when manual vectorisation is the most appropriate method of land use data acquisition from historical maps.

*Keywords*: vectorisation, backdating, sliver polygons, historical maps, forest cover change, uncertainty

## Introduction

Historical land use information is a key element of any long-term land change analysis. It might be acquired from a wide range of data including historical statistics, cadastral records, repeat photography and historical maps (Bürgi *et al.*

2007; Harvey *et al.* 2014; Yang *et al.* 2014). One important advantage of historical maps as compared to other sources is that they allow a spatially explicit presentation of land use with exact boundaries between classes. This advantage makes historical land use reconstructions based on historical maps much more reliable than those based on proximate data and converted in a spatially explicit manner using advanced modelling procedures (Fuchs *et al.* 2015). Using historical maps is, however, always connected to some degree of uncertainty (Plewe 2002; Leyk *et al.* 2005; Kaim *et al.* 2014). Leyk *et al.* (2005) define three main domains of uncertainty in land use change research: production-oriented uncertainty (inherent in historical data creation), transformation-oriented uncertainty (caused by data processing, especially in Geographic Information Systems) and application-oriented uncertainty (connected to differences in meaning of notions on historical and current materials). Current data acquisition from historical maps is closely related to transformation-oriented uncertainty. This domain is often understood by authors as errors (Goodchild 1991).

The techniques of data acquisition from historical maps differ, depending on map quality, type of information acquired and finally the size of study area. For relatively small areas and high quality maps, procedures of automatic feature extraction seem to perform well (Leyk *et al.* 2006; Iwanowski, Kozak 2012; Herrault *et al.* 2013). They give satisfactory results when the class we want to extract is easily detectable and contrasted from neighbouring classes. This is not always true in the case of black and white sheets of historical maps. For larger areas, frequent significant differences in quality of map sheets exclude automatic extraction procedures in many cases except for more recent maps (Ostafin *et al.* in review). For analysing series of historical maps for broad scale applications (both in time and space), using a regular sample of points with land use attributes seems to be a time efficient and reasonable solution (Munteanu *et al.* 2015; Loran *et al.* 2016) giving results comparable to much more time consuming manual vectorisation (Kaim *et al.* 2016). This procedure is not suitable, however, for relatively small areas, where assigning land use to a dense point grid needs a similar amount of work as manual vectorisation. Therefore, when it comes to the analysis of relatively small areas using low quality historical maps, it seems that manual land use vectorisation is still the most appropriate solution. In general, two approaches can be distinguished when using this procedure. The first one is based on independent vectorisation of maps representing each period to produce vector layers. This procedure is usually called independent vectorisation (Feranec *et al.* 2007). The other approach relies on modifying the original vector layer using older map information (backdating) or later map information (updating) called dependent vectorisation (Feranec *et al.* 2007; Linke *et al.* 2008). In this approach, the interpreter focuses only on changes between the two considered time steps. Although both vectorisation approaches are commonly used in land use reconstructions, the impact of choosing either of them on the final land change map is unknown. What matters here is not only the subjective nature of human vectorisation, but for instance, also differences in subsequent map symbologies, or map geometric errors. The aim of this paper was to compare the results of a dependent and independent forest vectorisation procedure on the set of historical maps and to assess its impact on long term forest cover change estimates in the Polish Carpathians. More specifically we wanted to conduct the comparison in the relatively difficult conditions of a fragmented mountain landscape with detailed (1: 25 000), but very different map series, resulting in different land cover layers.

## Materials and methods

### Study area

Our procedure was tested in Szczawnica commune (87.8 $km^2$) located in the central part of the Polish Carpathians. In the 19th century the eastern part of the study area was inhabited by Ruthens, who were expelled from their villages after World War II (Kwiek 1998). Before this, the region was one of the most intensively exploited agriculturally in the Carpathian region. The arable lands were located even above 900 m, remarkably high in the Carpathian conditions (Reinfuss 1947). After the depopulation, the area faced sudden and dynamic changes in land use leading to a substantial increase in forest cover on agricultural lands (Kaim 2009). The western part of the study area is located close to the town of Szczawnica – one of the oldest and most popular spa resorts in the Polish Carpathians, stimulating the development of settlements and tourist infrastructure nearby (Dec *et al.* 2009). Currently the area of the municipality is mostly covered by forests (70.7%, based on Baza Danych Obiektów Topograficznych BDOT10k, 2014) with settlements located in the valleys. Dynamic changes in the forest cover over time make the study area appropriate to conduct our testing procedure.

### Materials

The availability of historical maps of the study area is relatively good as compared to other parts of the Polish Carpathians (Kaim 2010). That is why we were able to use several cartographic sources from different periods, characterised by a similar scale. Information about forest cover in the mid-19th century was obtained from the second Austrian military survey maps 1: 28 800, published for the area in 1861/1862 (Timár *et al.* 2010). A forest mask from the interwar period was extracted from the

Polish military map 1: 25 000 published in 1936 (Krassowski 1974). For the 1970s, a set of Polish topographic maps (1: 25 000) published in 1974 and 1979 by the Head Office of Geodesy and Cartography (Główny Urząd Geodezji i Kartografii, GUGIK) was used (Fig. 1). The elevation and slope information used in the analysis was based on the Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM) (Farr *et al.* 2007), resampled to 50 m resolution.

## Initial data preparation

Data preparation started with the rectification of historical maps. All the maps were rectified using properly distributed ground control points in characteristic locations (e.g. crossroads, churches, bridges). Polish topographic maps from the 1970s were used as a reference. The first order polynomial transformation was used to georeference the data. The maximal root mean square error was 32 m for the second military map and 12 m for the interwar Polish military map. The Polish topographic map was already available in the georeferenced form. All the maps were transformed finally to the Universal transverse Maeracor (UTM) coordinate system (34 N zone).

## Vectorisation

For independent vectorisation forest mask acquisition was based on manual, on-screen vectorisation (the second Austrian military survey maps, the Polish military map) and automatic feature extraction supported by manual error correction (the Polish topographic map). Manual vectorisation was conducted in detailed zoom to scale (1: 2000 – 1: 4000). Automatic forest extraction was based on colour segmentation and morphological image processing and achieved an accuracy reaching 95% (Ostafin *et al.*, in review).

Dependent vectorisation was retrospective (backdating) starting with the 1970s forest mask and going back in time (Fig. 2). The forest mask for the 1930s was a backdated 1970s forest mask using the interwar Polish military map, then the 1860s forest mask was a backdated 1930s forest mask using the second Austrian military survey maps. The backdating process employed several formal rules with a general aim to avoid sliver polygons representing false changes on later change maps (Sae-Jung *et al.* 2008):

- if the difference in forest boundary position between consecutive maps was less than the line width defined in the map symbology as forest boundary, the forest boundary was considered to be stable (Fig. 1, Fig. 3);
- if the position of the forest boundary on consecutive maps was stable in relation to other map features, e.g. aligned to the same road in both cases, but not aligned

due to georeferencing inaccuracies, the forest boundary was considered to be stable;
– if forest polygons were presented both by line symbols (lines, dots) and colour fill, forest edges were defined according to the position of the line symbols (Fig. 1)
– iformation about forest cover from the 1970s map was assumed to be certain.

## Change detection

Forest cover change analysis was conducted separately for two vectorisation approaches for the 1860s–1930s and 1930s–1970s. The differences among the approaches were then compared for the whole study area and for 408 regular grid cells (500×500 m) covering the whole study area.

To verify whether the vectorisation type influenced the forest cover change maps for the whole analysed period, we compared temporal forest cover trajectories for both vectorisation types. Specifically, we computed an overlay of the forest masks for the 1860s, 1930s and 1970s and assigned one of six change trajectories (0-0-1, 0-1-1, 1-1-0, 1-0-0, 1-0-1, 0-1-0, where 0 means non-forest and 1 is forest) to each polygon resulting from the overlay. For instance, the polygon with the trajectory 1-0-0 was forested in the 1860s and not forested in the 1930s and 1970s. The dependent vectorisation, by definition, suppresses the overall number of polygons resulting from the map overlay as compared to independent vectorisation. We hypothesised that this reduction should affect in particular the smaller polygons or those that represent less likely change trajectories, that is 1-0-1 or 0-1-0. To test this assumption, we compared the overall number and the number of the smallest polygons (less than 1 mm$^2$, that is 625 m$^2$ in reality) for each change trajectory and both vectorisation approaches.

Additionally, to verify whether the differences between vectorisations depended locally on a specific variable, we calculated Pearson correlation coefficients (*r*) between the local differences within 500 x 500 m grid cells and the following variables computed for each grid cell: forest edge tortuosity index $\gamma$ (1), proportion of forest change based on dependent vectorisation, proportion of forest change based on independent vectorisation, mean slope and mean elevation. The analysis was prepared separately for two periods (1860s–1930s, 1930s–1970s). The tortuosity index $\gamma$ was calculated as:

$$\gamma = \frac{s}{l} \tag{1}$$

where *s* is the forest edge length within the grid cell and *l* is the mean forest edge length for all grid cells in the study area. Values of $\gamma$ higher than 1 show a more complicated (more tortuous) forest edge and less than 1 indicate a less tortuous forest edge for the grid cell than on average for the study area (Kot, Leśniak 2006). The complete workflow is presented in Fig. 4.

# Results

## Overall differences

Both vectorisation approaches indicated a gradual increase in forest cover over time. The analysis showed that the overall differences between vectorisation approaches for the whole study area are not higher than 1% for both time periods, and less than 3% with relation to the change category area (with one exception – 17%, see Tab. 1). The highest differences in relation to total area were recorded for the period 1862–1936 for forest gain (0.92%). For the period 1936–1979, the highest difference was recorded for forest loss (0.5%) and afforestation (0.41%). In all other cases, the differences were lower than 0.2% (Tab.1). The highest difference in relation to the change category area was recorded for the 1936–1979 deforestation (17.37%).

## Local differences

The local differences between two vectorisation types were much higher than values for the entire study area (Fig. 5, Fig. 6). For the period 1862–1936, the highest rates of difference were found in the eastern part of the study area (maximal

Table 1. Forest cover change differences between 1862 and 1970 for the whole study area (without stable non-forest)

| Time period | Forest change history | Dependent vectorisation | | Independent vectorisation | | Differences | | |
|---|---|---|---|---|---|---|---|---|
| | | area [ha] | [%] | area [ha] | [%] | [ha] | [% of total] | percent of independent category area [%] |
| 1936–1979 | stable forest | 3680.72 | 65.06 | 3682.82 | 65.02 | 2.10 | 0.04 | 0.06 |
| | deforestation | 135.71 | 2.40 | 164.24 | 2.90 | 28.53 | 0.5 | 17.37 |
| | afforestation | 1840.77 | 32.54 | 1817.35 | 32.08 | 23.42 | 0.41 | 1.29 |
| 1862–1936 | stable forest | 2453.76 | 60.67 | 2446.89 | 60.04 | 6.87 | 0.17 | 0.28 |
| | deforestation | 228.31 | 5.64 | 228.50 | 5.61 | 0.19 | 0.005 | 0.08 |
| | afforestation | 1362.68 | 33.69 | 1400.17 | 34.36 | 37.49 | 0.92 | 2.68 |

difference – 38%). In the period 1936–1979 the local differences were more visible and recorded the highest values in the southern part of the study area (maximal difference – 42%).

The comparison between the number of polygons representing different trajectories between the two vectorisation approaches showed that both the total number of polygons and the number of polygons smaller than 1 mm$^2$ was lower for the dependent vectorisation (Fig. 7).

For the first period differences between the two vectorisation types were only correlated to percent of change and mean slope. However, the values of correlation coefficients were not high. For the second period, the correlation coefficients were

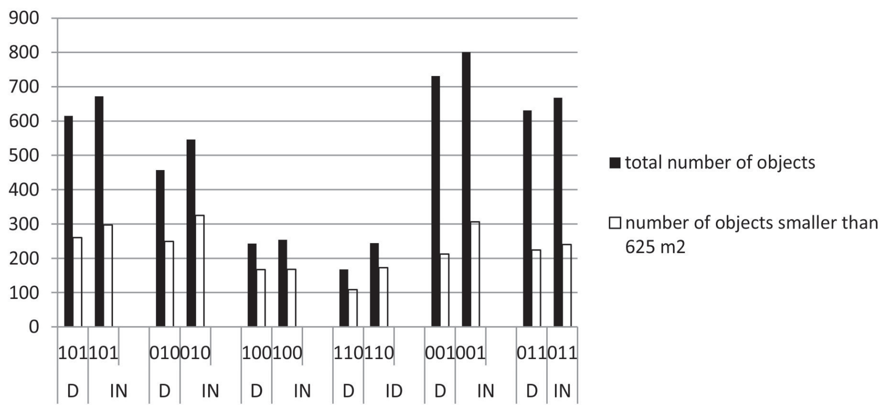


Fig. 7. Number of polygons for all change trajectory types (D – dependent vectorisation, IN – independent vectorisation)

Table 2. Correlation coefficients of differences between vectorisation approaches and other variables

| Difference | Tortuosity index | | | % of change | | Mean | | % of change | |
|---|---|---|---|---|---|---|---|---|---|
| | 1862 | 1936 | 1979 | 1862– – 1936 D | 1936– –1979 D | eleva- tion | slope | 1862– –1936 IN | 1936– –1979 IN |
| 1862/1936 | – | – | n/a | 0.37 | n/a | – | 0.22 | 0.36 | n/a |
| 1936/1979 | n/a | – | 0.12 | n/a | 0.15 | –0.17 | – | n/a | 0.21 |

*Explanations*: (n/a – not applicable; D – dependent vectorisation; IN – independent vectorisation; only statistically significant ($p < 0.05$) correlation coefficients were shown.

lower than for the first period, with the highest values also for percent of change (Tab. 2). In this case, weak correlations were recorded for the tortuosity index in 1979 and mean elevation.

## Discussion

The comparison between dependent and independent vectorisation was tested in the mountainous region characterised by substantial change in forest cover over time. The results showed that for the whole study area the vectorisation approach influenced the forest change map to a very limited degree (max difference – 0.92% for the 1936–1979 forest gain). Such a value of difference is, for instance, lower than the difference between forest cover reconstructions based on polygon and point vectorisation for the whole territory of the Polish Carpathians, representing a typical population-sample relation (Kaim *et al.* 2016). Therefore, the dependent vectorisation gives comparable results to the independent vectorisation offering an interesting and efficient alternative. However, although the time efficiency when using the dependent approach is higher for larger polygons with relatively simple shapes, it is not so in terms of more diverse landscape patterns when the decision about the relative positions of land cover boundaries on various maps has to be taken with more care. This might be quite often the situation in mountainous regions. In our case, the relatively low difference between the two vectorisation approaches indicates also high quality standards of the manual independent vectorisation and a relatively low level of human-induced errors. The local differences were much higher (up to 38% for 1862–1936 and 42% for 1935–1970; Fig. 5, Fig. 6); nevertheless, the correlation analysis showed that local differences were positively correlated mostly with the amount of local change and were occurring in areas with higher change rates. In general, small discrepancies between dependent and independent approaches, especially when randomly distributed, make it difficult to determine one particular variable as being responsible.

Change detection over long periods very often creates a high number of sliver polygons, resulting from several inaccuracies, for instance, differences in georeferencing errors among the maps, differences in cartographic representations of objects on the maps or simply human errors (Wolski 2012). Our comparison of temporal polygon trajectories showed that sliver polygons cannot be fully eliminated using dependent vectorisation. There are many reasons for this, for instance: (a) differences in the map symbols we digitise (e.g. marking forests with line symbols and colour fills vs line symbols or colour fill only); (b) stable relation of forest boundary to other map features (e.g. river or road), but differences in the shape of these features at the same time. Although we had a set of rules defined to overcome similar issues (listed in subsection 2.4), ultimately the interpreter has to decide subjectively how to solve a specific issue. Our analysis shows that the number of sliver polygons can be reduced. This is visible both in terms of the total number of such spatial objects and for the smallest polygons, which have a higher risk of recording a false change (Fig. 7). It is important to highlight that the number of polygons of the dependent approach was substantially lower than for the independent one, with trajectories exposed to the highest risk of being errors (1-0-1 and 0-1-0). Elimination of sliver polygons is one of the most important aspects of technical issues of change detection (Delafontaine *et al.* 2009) as this is the basic indicator of the map change accuracy assessment (Linke *et al.* 2008). Dependent vectorisation may therefore increase data reliability as compared to the situation if vector layers were created independently (Linke *et al.* 2008). This is especially important when we compare maps published in different periods, based on different cartographic rules, and in addition for different purposes (Wolski 2012). For instance Troll (2013) argues that the second Austrian military survey maps, as a result of cadastral mapping generalisation, present the land use in accordance with land property boundaries, neglecting real land cover patterns. Dependent vectorisation hence provides a chance to limit the amount of errors when such data are overlaid with other topographic maps showing rather land use and land cover boundaries and not ownership. Dependent vectorisation is also a better choice if a minimal mapping unit for change layers has to be defined (Feranec *et al.* 2007). Nevertheless, when using the dependent approach, there is a risk of eliminating map objects created in accordance with the overall aim of the map and reflecting real features. For instance, the parcel boundaries mentioned above might be important when ownership is included as one of the variables in the analysis and in such cases the dependent vectorisation approach may limit the variable's true role or impact.

## Conclusions

Our comparison of dependent and independent vectorisation conducted in the study area characterised by diverse environmental conditions and substantial change in forest cover over more than one hundred years showed that the difference between these two types of vectorisation has a low overall impact on the resulting forest change maps, although local differences might be relatively high. Taking into account the time efficiency, possibilities to correct map errors and limit the role of sliver polygons during the vectorisation process, it seems that in many cases dependent vectorisation might be a better solution than the independent one. This is important especially for low quality historical maps for which other methods enabling data acquisition are not efficient enough.

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