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KIIRA MÕISJA

Thematic accuracy and completeness of topographic maps

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Thematic accuracy and completeness of topographic maps

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Department of Geography, Faculty of Science and Technology, University of Tartu, Estonia

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LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following publications referred to in the text by Roman numerals:

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II. **Mõisja, K.**, Oja, T., Uuemaa, E., Hastings, J. T. (2017) Completeness and classification correctness of features on topographic maps: An analysis of the Estonian Basic Map. *Transactions in GIS*, 21:954–968
III. **Mõisja, K.**, Uuemaa, E., Oja, T. (2018) The implications of field worker characteristics and landscape heterogeneity for classification correctness and the completeness of topographical mapping. *ISPRS International Journal of Geo-Information,* 7, 205

Author's contribution

I The author is partially responsible for the study design and data collection; fully responsible for the creation of error database and data processing; primarily responsible for creation of figures; partially responsible for interpretation of the results; primarily responsible for writing the manuscript.
II The author is partially responsible for the study design and data collection, fully responsible for the creation of error database, data processing and creation of figures; primarily responsible for interpretation of the results and writing the article.
III The author is partially responsible for the study design and data collection; fully responsible for the creation of error database and data processing; primarily responsible for creation of figures; partially responsible for interpretation of the results; primarily responsible for writing the manuscript.

1. INTRODUCTION

1.1. Topographic data

Topographic data, presented in the topographic map, provide detailed and accurate information about anthropogenic and natural features on the ground such as buildings, roads, railways, power transmission lines, contours, elevations, rivers, lakes and geographical names. As highly accurate topographic mapping is costly (Monmonier, 1996), the maps are compiled mainly by national mapping agencies (NMA), like the Estonian Land Board, Lantmäteriet (the Swedish mapping, cadastral and land registration authority), IGN (National Institute of Geographic and Forest Information in France) or Ordnance Survey in Great Britain. The most common scale of collected topographic data is 1:10 000 (Eurogeographics Expert Group on Quality, 2005).

Jakobsson (2006) pointed out that topographic data can be considered as a resource, commodity, asset, and infrastructure. In our days, topographic information is captured in vector data sets which provide a reference framework for other spatial datasets (Jakobsson and Giversen 2007) and is the basis for spatial data infrastructure (Rhind, 1992). Topographic data can be generalised in order to produce maps in smaller scales. Also, the use of topographical data saves a lot of resources for many users. Among the main users of the topographic data are governmental agencies, municipalities, first responders, and utility and transportation service providers (Jakobsson, 2003). The use of topographic data has so far been inhibited by data availability. By today several national mapping agencies, like the Dutch Cadastre, Land Registry and Mapping Agency (Bakker *et al.*, 2013), the National Land Survey of Finland (2018), the Norwegian Mapping Authority (Kartverket, 2017), and the Estonian Land Board (Estonian Land Board, 2018) have made their topographic datasets available to the public to be used freely. The value of topographic information is heavily dependent on its usage (Jakobsson, 2006). The wide user-community for topographic data and the increasing adoption of GIS, requires interoperability across geographic scales and sets high expectations for data quality and also for ongoing data quality management.

The real world is in constant change. One of the characteristics of the geographic information is that it loses value over time (Jakobsson, 2006). Therefore, in order to have valuable and high-quality topographical data, the update of geographical data is essential. There are two options for updating, which differ from each other by scope and updating frequency. Firstly, data are updated by feature classes for the whole database and each feature class has their own update frequency (Estonian Land Board, 2006; Eurogeographics Expert Group on Quality, 2005). The maintenance is mainly performed through data exchange between topographical databases and other registers. Secondly, data are updated by new mapping where all feature classes are updated simultaneously on the same mapping area. The update frequency is usually longer than the first one and it is more costly. Therefore, new technologies, like LiDAR

(Nakajima, 2016) or spaceborne synthetic aperture radar (Tamm *et al.*, 2016) for updating are investigated. In our days, the potential of volunteers for the update of governmental geospatial data has been widely explored (Johnson, 2017; Touya *et al.*, 2017). Beside legal restrictions (Saunders *et al.*, 2012) a question about VGI quality is discussed (Dorn *et al.*, 2015; Fonte *et al.*, 2017; Senaratne *et al.*, 2017). Nowadays when many volunteers are mapping the world and the use of VGI is increasing, the quality of VGI data has become an important subject of discussions (Antoniou and Skopeliti, 2015; Senaratne *et al.*, 2017).

1.2. Uncertainty and quality of spatial data

Spatial data quality has been the subject of discussions for almost 40 years (Devillers, R. and Jeansoulin, 2006; Goodchild and Gopal, 1989; Guptill *et al.*, 1995; Shi *et al.*, 2002, 2016; Veregin, 1999). Researchers have conducted several academic studies on error or uncertainty modelling (Collins and Smith, 1994; Fisher, 1999; Hunter and Beard, 1992) and on how to communicate data quality information (Devillers, R. and Beard, 2006; Goodchild and Clark, 2002; MacEachren, 1992). Hunter *et al.* (2009) and Devillers *et al.* (Devillers, R. *et al.*, 2010) outlined several achievements but also failures on the field of spatial data quality during last decades. One of the achievements that has significantly influenced the production of contemporary spatial data is an agreement in international standards for spatial data quality (Kresse *et al.*, 2011): ISO 19113 (International Organization for Standardization, 2002) that determines the elements of quality, ISO 19114 (International Organization for Standardization, 2003) that describes the quality assessment procedure, and ISO/TS 19138 (International Organization for Standardization, 2006) that defines the quality measures. In 2013 a new data quality standard ISO 19157 (International Organization for Standardization, 2013) was published that updated and combined all these three standards (Jakobsson *et al.*, 2013; Leibovici *et al.*, 2013). The new standard clarifies the scope of data quality, defines the elements and the measures of quality, describes quality assessment procedures, provides guidelines for reporting the results of the quality evaluation, and introduces the concept of metaquality. The use of ISO19100 quality standards has been investigated by Eurogeographics (Eurogeographics Quality Knowledge Exchange Network, 2013, 2018). The results showed that the organisations that have members in the Quality Knowledge Exchange Network (Q-KEN) of Eurogeographics and those involved in INSPIRE are the users of the ISO 19100 quality standards or other spatial quality standards.

In ISO 19157 the quality is described by 21 quality elements belonging into six categories: completeness, thematic accuracy, logical consistency, temporal quality, positional accuracy, and usability. World-wide quality management study of 79 national mapping agencies demonstrated that 43 % of the respondents use subjective (without clear rules) evaluation or do not use any methods to evaluate positional accuracy, 48 % use subjective evaluation or do not evaluate thematic accuracy, and 56 % of the respondents use subjective evaluation or do not evaluate completeness (Östman, 1997). In European national mapping agencies, positional accuracy was used by 71%, completeness by 63 % and thematic accuracy by 46% of respondents (Jakobsson and Vauglin, 2001).

In the current study, commission, omission and classification correctness of topographical Estonian Basic Map (EBM) were explored (Publication II and III; in colour on Figure 1). Omission represents a case in which a landscape feature that must be mapped is missing, whereas commission represents a case in which a feature exists on the map, but not in the landscape. Classification correctness means conformance of map features to entities in the landscape.

However, according to the standard, the list of quality elements is expandable. Based on the value-analysis theory, Talhofer *et al.* (2012) suggested new quality elements as database content, database technical quality, database timeliness, area importance, and user friendliness. The latter is intended to consider data quality from the user's perspective. Fonte *et al.* (2017) proposed additional quality indicators for volunteered geographic information (VGI).

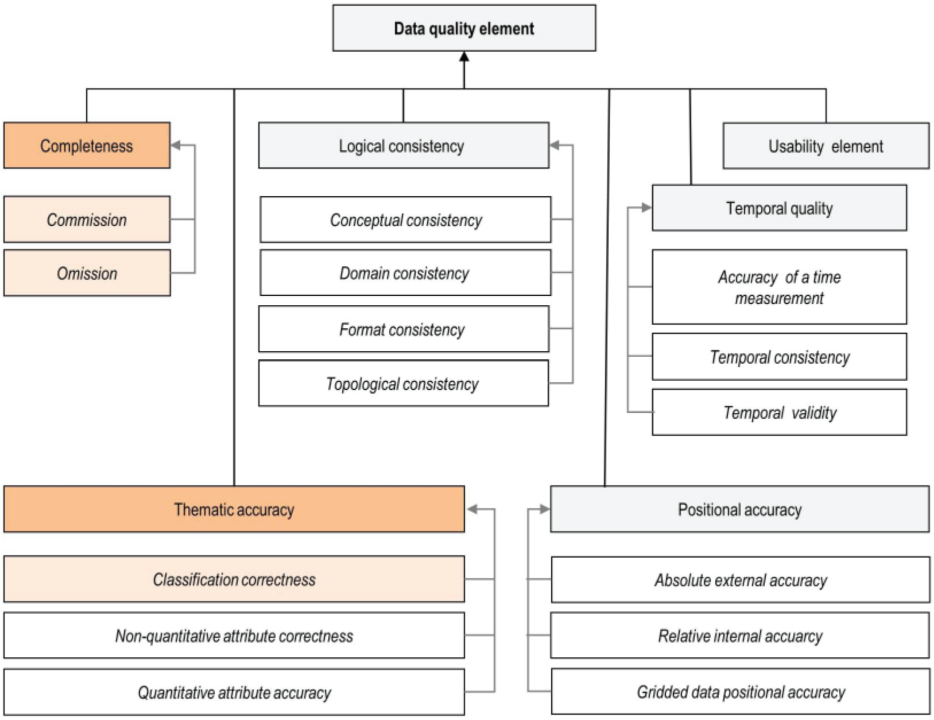


Figure 1. Overview of the ISO 19157:2013 data quality elements (according to International Organization for Standardization, 2013). The focus of the present study is highlighted (Publication III).

Data quality is a concept related to uncertainty (Fisher *et al.*, 2006; Shi *et al.*, 2002; Zhang and Goodchild, 2002), which is endemic in all geospatial data (Goodchild, 2009) and should not be forgotten while producing or using spatial data (Fisher, 1999). For a data producer, it is important to determine the sources of uncertainty, find the methods to measure them and minimize them by using quality management (Jakobsson *et al.*, 2016). The source of uncertainty is depending on whether the feature class to be described is well or poorly defined (Fisher *et al.*, 2006; Longley, P. A. *et al.*, 2005). If the feature class is well-defined, clearly separable from other geographical objects, the uncertainty is caused by errors (Fisher *et al.*, 2006). There are several reasons why errors emerge which is reflected by the huge amount of error classifications (Devillers, R. and Jeansoulin, 2006; Fisher, 1999). The errors may also be distinguished from each other based on whether they are: 1) objective and caused by the measurement accuracy of the instruments; 2) subjective and caused by the human error; 3) temporal and caused by the actual changes happening over time.

For the poorly-defined feature class, the spatial extent of the geographical object is not clearly recognizable or the feature class identifiers are confusing, so the same phenomenon can be assigned to different classes. Usually they mean natural phenomena like a shoreline, forest, mountain, but also some anthropogenic phenomena like ruins and relict foundation. The uncertainty of the poorly-defined feature class is caused by vagueness or ambiguity (Fisher *et al.*, 2006). In case the definitions are given to such phenomena, they are ill-defined and do not allow to specify the phenomenon. This is the case of vagueness. Ambiguity arises when one object could be placed into two or more different classes because of disagreements about the definition or because of using different classification procedures. Users may have a problem when the definition used does not meet the definition expected by a user. Comber *et al.* (2005) have analysed and graphically presented different definitions of a forest applicable in the world. Moreover, there are at least two definitions of a forest used in Estonia. On topographic maps, a forest has to have a tree height over 4 metres (Estonian Land Board, 2002). Whereas, in the Forest Register, a minimum tree height is 1.3 m (Forest Act, 2006). These definitions resulted in substantially different areas of forest to be mapped. Therefore, specifications must be determined prior mapping and made clear to map- and data-producers.

Hunter *et al.* (2009) and Devillers *et al.* (2010) indicate that nowadays one of the problems is that data quality is analysed and presented at a generic global level rather than at a more detailed levels of granularity. Based on the work of several authors, Devillers and Beard (Devillers, R. and Beard, 2006) introduced the hierarchical model of levels of detail which consists of four levels – global dataset, feature class, feature instance and geometric primitive. Sadiq et al (2006) brought out spatial variation in data quality due to different data capturing techniques, compilation, analysis, and representation. In the current study the list of granularity levels was extended by the characteristics of field workers who inevitably interpret the nature subjectively to some extent (Cherrill, 2016; Cherrill and McClean, 1999; Stevens *et al.*, 2004).

Studies on VGI quality (Girres and Touya, 2010; Haklay, 2010; Dorn *et al.,* 2015) have revealed that the spatial data quality differs by landscapes. To explore the relation between landscapes and spatial data quality landscape indicators are used (van Oort *et al.,* 2004). In order to describe and analyse the heterogeneity of landscape, hundreds of landscape indicators have been proposed by various researchers within the past 30 years (Uuemaa *et al.*, 2013; Dramstad, 2009). Landscape indicators are calculated by using either vector or raster data sources (Publication I). The raster format is more widely used because of the availability of satellite imagery and the ease of conducting complex spatial computations. Nevertheless, the resolution of raster image is often too coarse to depict the small-scale landscape features like ditches, narrow roads or trees (Jaeger, 2007). Less attention has been on the use of more detailed topographical vector data where small-scale landscape features are mapped as point elements or lines. For large areas, size of vector data is smaller than size of raster data. Therefore, vector format is more suitable for analysing big territories in detail. For calculating landscape indicators, the integration of these features and land use/cover (LULC) polygons is needed. For that purpose, buffering of the linear and point features is most commonly used. Linear features are buffered for the average width of the corresponding feature, with a minimum buffer width of 2 m (Herzog *et al.*, 2001; Lausch and Herzog, 2002), or for constant width (Wade *et al.*, 2003) and in some studies the buffer width has not been mentioned (Moser *et al.*, 2002). None of the referred studies provides any reasoning why certain buffer widths were used. Moreover, there are not many papers addressing the impact of integrating point and line features into the polygon layer on the values of landscape indicators (Höbinger *et al.,* 2012; McGarigal *et al.*, 2009; Hou and Walz, 2013).

1.3. The aim of the thesis

The aim of this thesis is to investigate the thematic accuracy and completeness of topographic maps using empirical field inspection in topographic mapping.

To achieve this aim, the following tasks were set:

1. to create a seamless spatial error database from the data collected by Estonian Land Board's field inspectors in order to analyse the errors;
2. to find the most comprehensive method for integrating points and lines into LULC polygons in order to analyse landscape heterogeneity;
3. to analyse spatial data quality for the EBM at two levels: in general, where all errors are analysed together; and in detail, where the same errors are analysed according to the field worker in order to determine the most error-prone feature classes and the reasons of those errors;
4. to determine whether and how misclassification, commission and omission errors differed among field workers and whether any differences were influenced by landscape heterogeneity and characteristics of field workers.

2. DATA

For the current research, the topographical data of the Estonian Basic Map was used. EBM in scale 1:10 000 is a national topographic vector database. The aim of the database is to serve as the basis for national thematic maps and registers containing spatial information (Riigi Maa-amet, 1991). EBM includes information about infrastructure (e.g., roads, electric power lines), settlements, hydrography, and land use (Estonian Land Board, 2016).

In the current study we used EBM data (produced in years 2003–2006) and EBM quality control results (produced in year 2003–2006).

2.1. Development of the EBM

The project for the production of EBM was completed in 1991, shortly after regaining the independence (Riigi Maa-amet, 1991). The project was mainly compiled by Lembit Tamme, Heiki Potter (Estonian Land Board), and Jüri Jagomägi (University of Tartu). The EBM project identified a map projection and coordinate system, format and tiling of the map sheets, mapping technology, time schedule, and budget. As a result, a national Lambert-Est projection based on GRS80 was chosen. Map sheets in paper format 50x50 cm are covering 25 km^2 in the real world. The cost of one map sheet was set at 31 484 Estonian kroons (approximately 2020 €) (Riigi Maa-amet, 1991). Eventually the actual cost exceeded the estimated budget many times.

According to the project, the whole Estonia was divided into 17 mapping objects and was planned to be mapped by year 2005. However, the actual area of the mapping objects and the mapping time were different from the planned one right from the start of the works (Figure 2). The pace of mapping was very slow in the first years, so the work of the Vastseliina mapping object planned for 1992 was not started until 1995. In reality, the EBM was completed for the most part of Estonia in 2003. However, the map of the North-Eastern and South-Eastern border regions was completed only in 2007.

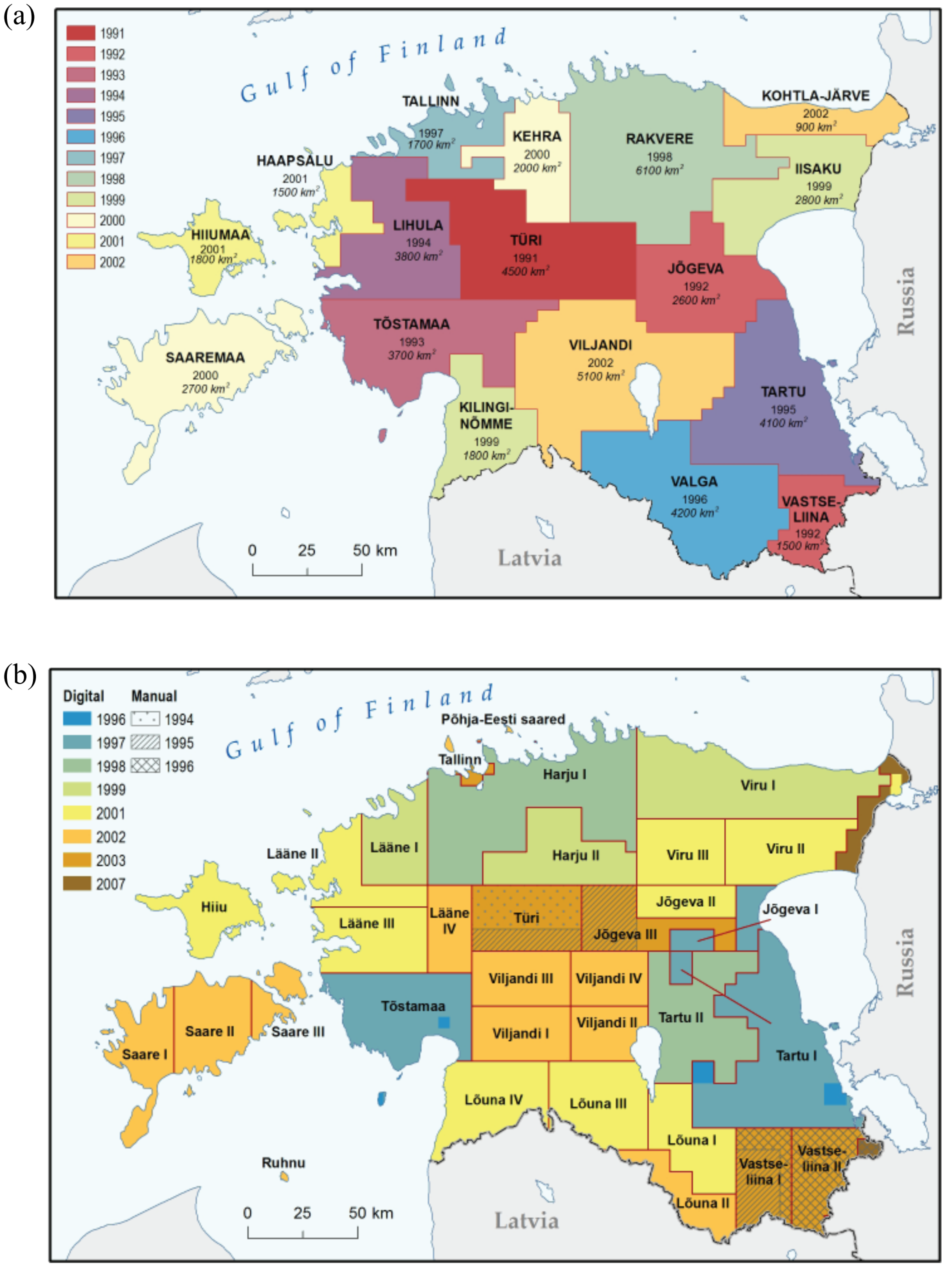


Figure 2. The objects of the Estonian Basic Map: (a) planned mapping objects and (b) real mapping objects, manually completed objects shown by a pattern and digitally completed objects by colours.

To cover the country's territory with a seamless and high-quality large-scale topographic map, clear mapping specifications are required. Basic mapping work was started without official guidelines. The documentation required for mapping was developed in parallel with the mapping work. In 1994 the Land Board ordered the preparation of the guidelines for the EBM and in 1995 by chapters from various institutions – from the state owned mapping company Estonian Map Centre, from first private mapping company Regio, and from the Estonian Language Institute which is the national Research and Development institution. However, a uniform manual was not combined from these chapters. The chapters were written based on the main requirements for the national basic map developed in 1994 (Riigi Maa-amet, 1994), which, among other things, stated the transfer of the technology of the basic mapping to the full digital technology. In 1994, “Setting up a digital database for the basic map and data exchange” (Aunap *et al.*, 1994), was published, which stated the use and data exchange of digital spatial data, pricing policy and terms of sale. A separate chapter discusses the development of spatial data infrastructure. Unfortunately, this document did not find a direct implementation. The terms of reference, which was later developed into the specifications being actually used, was “Mapping Guide 1:10 000” (Eesti Kaardikeskus, 1994). This was a classic map specification, listing the phenomena to be mapped, their given definitions and map symbols. The authors of the specification state that they have taken the lead in topographic maps of Finland, Sweden, Denmark, the Netherlands, the USA, and Canada. The symbology of the EBM is new and developed specifically for that map. Additionally, the general part describes the precision requirements for objects that are included in the photo plan. In 1995, the Estonian Language Institute completed the principles for developing the database of place names of the basic map (Aunap *et al.*, 1995). The document addressed the collection, storage, and mapping of place names. The creation of a separate register of place names was provided.

In 1999 and 2000 major changes took place in the mapping guidelines. In 1999 for the first time the guide provided a data model for the digital basic map and in 2000, mapping quality requirements, which were compliant with the standard 19113 developed by ISO, but formally not yet approved (International Organization for Standardization, 2002). The guide also outlined the quality elements to be assessed: location accuracy, semantic accuracy, completeness, attribute accuracy, and topology, the compatibility of the edges of adjacent map sheets. Each element had their defined quality values, which they had to meet. In 2002, “Requirements for editing the printed map of the Estonian Basic Map 1:20 000” were formulated. The project of EBM was completed in 2007. The timeline of the development of EBM is shown on Figure 3.

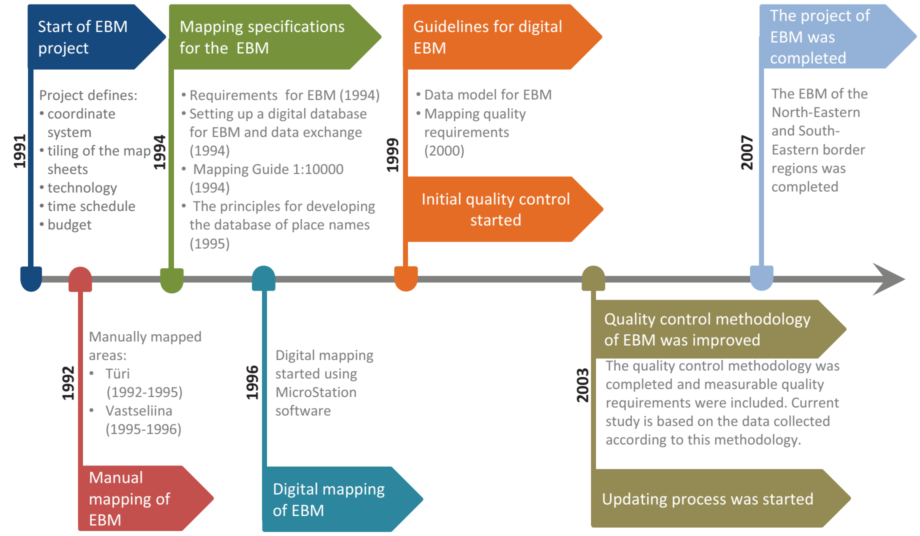


Figure 3. Timeline of the development of the Estonian Basic Map (EBM).

2.2. Production of EBM

Due to the poor quality of the Soviet maps (Mardiste, 2009), the EBM was created from scratch by means of stereo-photogrammetry (Li *et al.*, 2012) supported by extensive field work (Publication III). The basic production scheme for EBM consists of five steps: aerial photographing, photogrammetry works, field work, map drawing and map printing. From 1992 to1996 the mapping was carried out manually, and since 1996 digitally (Figure 4).

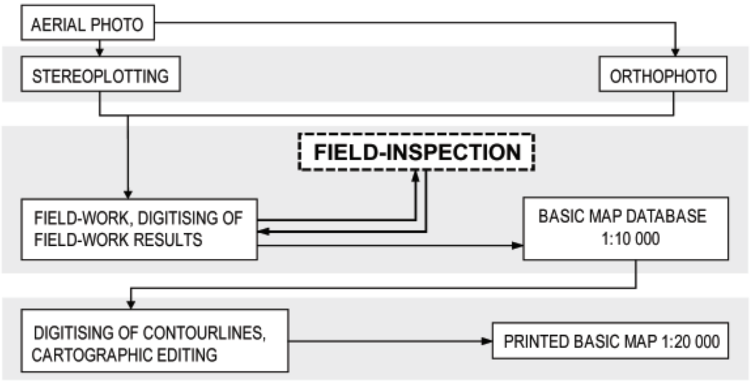


Figure 4. Production scheme for the Estonian Basic Map (adapted from Estonian Land Board). The focus of this dissertation is on the centre text box, dash-outlined (Publication II).

In the beginning there was a dilemma what is more efficient – whether 1) to make a stereophotogrammetric measurement based on aerial photos, and then check the measured information with the field work; or 2) to carry out field work first, and then transfer the data collected in the field work to a stereophotogrammetric digital map. The first digital maps were made in 1996 on single sheets (Figure 2), where both technologies were tested, and it was found that the first method leads to a higher quality result.

The quality of the EBM was significantly influenced by the time of taking aerial photos and the age of the photos at the time of mapping. In Estonia, the perfect time for taking aerial photos for topographic mapping is early spring when the snow has already melted and trees have no leaves yet, as the photos provide the possibility to see narrow line features inside the forest as well as the farm buildings hidden under the trees in the yard. The Estonian Land Board did not have technical resources for aerial photography until 2006, so flights were outsourced from Finnish, Swedish and Danish companies who were only able to take pictures in late spring or early summer when the tree crowns were sprung. The legibility of such photos in forest areas is poor and increases the volume of the field work mapping. Aerial photos were funded until 2006 by external aid funds, which meant that more photos were taken than mapping was performed, and by the time of mapping, some of the aerial photos were already outdated. On average, mapping was carried out using 2–3 year old photos but sometimes photos were up to 5 years old (Maa-amet, 2013).

The EBM data used in this study has been produced according to the production scheme shown in Figure 4. The stereophotogrammetric map was printed on a transparent film that was placed in alignment with the orthophotos for the field work. The task of the field worker was to check the mapping of the entire area, add missing objects to the stereoplots and remove the excess objects, and add objects that cannot be distinguished from the stereos. For example, it was necessary to determine the widths of forest roads, types of buildings, and to distinguish the types of land parcels that seem similar on aerial photos (for example, grasslands and fields), etc. The stereoplot enhanced with field works was scanned and its corrections and supplements were digitised. As a result, there were 129 different feature classes defined and symbolised on the DGN format EBM vector database, which consists of points, lines, polygons and texts.

Until 1999, the EBM was produced by the Estonian Map Centre for the Estonian Land Board. Since 1999 the producers of EBM have been chosen through public procurement procedures (Mõisja, 2003). Separate procurements were carried out for each stage of the production process, as shown in Figure 4 with grey squares. In addition to the above-mentioned Estonian Map Centre, also private companies such as EOMap and Regio performed fieldwork mapping of the EBM.

2.3. Field work

From 1996 to 2006 121 different field workers in total were involved in the field work mapping of the EBM, 13 of which have mapped half of Estonia (Kaldma, 2005). One to four or six field workers could map one map sheet (5×5 km), so the smallest area that one mapper executed on the map sheet was either 1/4 or 1/6 (6.25 or 4.17 km^2 respectively). Depending on the heterogeneity of the landscape, it took 4–15 working days for one field worker to map their area.

This thesis examined the field workers whose minimum mapped area is 1/4 of the map sheet (6.25 km^2) and who participated in mapping works from 2003 to 2006. There were 21 such field workers altogether (Table 1), 67% of them were male and 33% female. Ten of the field workers had carried out 67% of all field work (Publication II). The mapping experience of field workers ranged from 2 to 11 years. One third of the field workers had 5 or fewer years of experience, and two thirds had more than 5 years of experience (Publication III).

Table 1. Field workers' gender, years of experience in field mapping, and the number of inspected sites in different landscapes and in total (adapted from Publication III).

Field worker ID	Gender	Years of experience	Number of inspected sites in			
			built-up-diverse landscape	open-simple landscape	closed-complex landscape	total
1	M	6	0	1	2	3
2	F	6	2	4	2	8
3	M	5	0	1	0	1
4	M	2	0	5	1	6
5	M	4	0	2	2	4
6	M	7	6	2	3	11
7	M	7	0	4	1	5
8	F	11	0	4	2	6
9	M	7	0	4	6	10
10	M	7	4	2	3	9
11	M	5	0	1	2	3
12	M	5	0	0	2	2
13	M	6	0	4	4	8
14	M	7	1	0	2	3
15	F	7	1	0	0	1
16	F	8	1	1	1	3
17	M	3	0	0	1	1
18	F	8	2	2	2	6
19	M	5	0	0	1	1
20	F	8	0	0	1	1
21	M	7	0	0	1	1

2.4. Quality control of EBM data

Until 1999, the Estonian Land Board did not systematically monitor the quality of the EBM, as mapping was solely carried out by the Estonian Map Centre. The main competence of topographical mapping was also concentrated in this organisation. In 1999, when mapping companies were selected through public procurement, the Estonian Land Board also developed a preliminary quality control methodology. The methodology was developed by the author of this thesis who was EBM project manager at that time. This was supplemented over several years and the final version, which is also the basis for this study, was completed with measurable quality requirements in 2003. Mainly direct internal evaluation methods were used (International Organization for Standardization, 2013). The quality evaluation procedure was divided into two parts: 1) field inspection where thematic accuracy and completeness were evaluated and 2) indoor inspection where logical consistency by full automatic inspection and edge matching by visual inspection were evaluated (Figure 5).

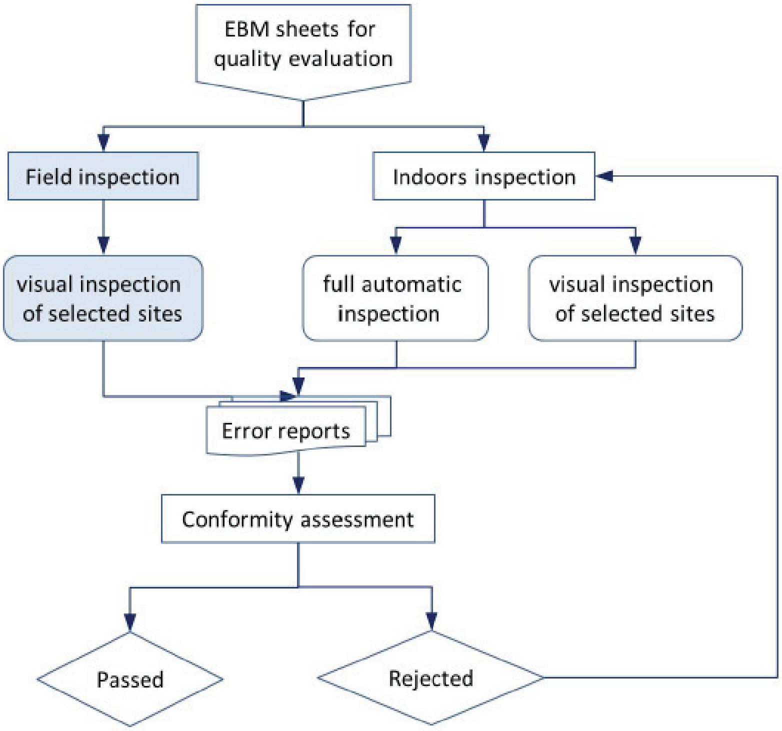


Figure 5. Quality evaluation process of digital EBM sheets. The scope of the current study is shown by coloured boxes.

Field inspectors evaluated thematic accuracy, omission, and commission which are quality elements defined in ISO 19157 (International Organization for Standardization, 2013). Additionally, the field inspectors observed (by eye, without the direct measurement) the "wrong size" and "wrong place" as indicators of positional inaccuracy. The wrong place was recorded in cases the mapped object was clearly in a wrong place or in a wrong position, for example, a house was turned in comparison to another house. The wrong size was evaluated as nonconformity in cases, where buildings or small line objects had incorrect size on the map, for example, a culvert was of incorrect length or the shape of a house was different from the actual one. All errors were recorded as Boolean values (Publication II).

Field inspection was carried out in the samples. Inspected map sheets were selected so that the work of as many different field workers as possible would be inspected. During the field inspection, the correspondence of mapping to the map specification was checked. Field inspector walked through and recorded all nonconformities occurred along the linear route in the selected map sheet (Publication II). The inspected site was considered a buffer of 50 m (forests, bushes, and yards) or 100 m (all the rest land cover types) to both sides of the route (Figure 6). Routes were 11 to 15 km long. In order to show the location and extension, all the errors found and inspection route as well were shown on the map by filed inspector. Quality evaluation results were documented in a detailed quality report. Based on the evaluation results, the conformity assessment of quality was performed. In case the field inspection showed the mapping work to be below the quality threshold, the field worker had to correct the nonconformities in all mapped areas, not only in the sample areas.

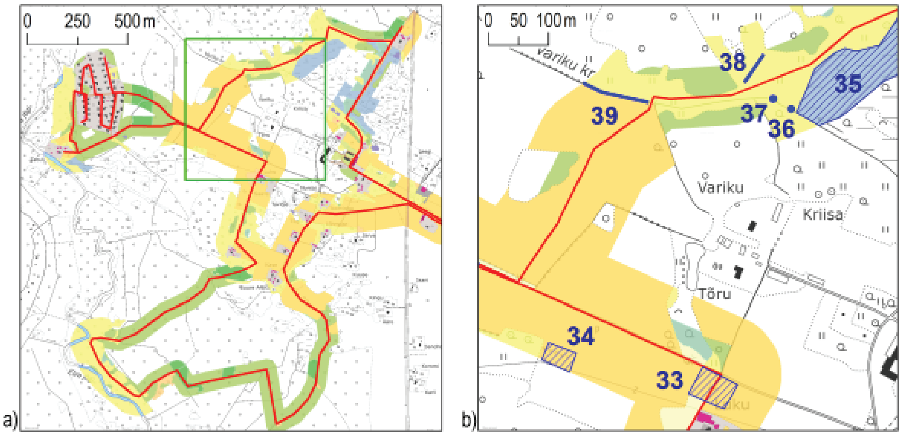


Figure 6. Sample section of a field inspection, at two scales. On the left, an overview of the field inspection route is marked with a red line and the inspected area with colour fills: yellow and light blue polygons are the landscapes with an open view; green and grey polygons are the landscapes with a closed view. On the right, in detail, mapped and reported discrepancies are numbered in dark blue: 36, 37 refer to point features; 38, 39 to line features; 33, 34, 35 to polygon features (Publication II).

Similarly to field work, the field inspection is subjective and therefore uncertain as well. Firstly, there where cases where the landscape had changed in a period between the submitted field work and field inspection, the most typical example is forest logging. Therefore, the minimisation of the time difference between the mapping and field inspection is important as was also demonstrated in Finland by Jakobsson and Marttinen (2003). In Estonia the time difference between the field work and field inspection was approximately two months. Nonconformities occurred because the time difference were mapped by field inspectors, but not considered as mapping errors. Secondly, field workers were given the opportunity to rebut a quality report, where appropriate. In the event of doubt, the decision was made in favour of the field worker (Publication II).

In the first year the field inspection was purchased. Since 2001, the quality control of the field works and the digital mapping was performed by the staff of the Estonian Land Board. From 2003 to 2006, the field inspection was carried out by six employees of the Estonian Land Board Cartography Bureau. In order to harmonise feature classification, a joint 2-day seminar for all field workers and field inspectors was held in each spring before the mapping season (Publication III).

Altogether, 1 455 km of field inspection was performed along 93 routes. The total area of sites was 159 km^2. The indicators characterizing the data of the current study are summarized in Table 2.

Table 2. Summary of the characteristics of the field inspection

Characteristic	Value
Quality control period	2003–2006
Number of field inspectors	6
Number of inspected field workers	21
Field workers' gender	6 female, 15 male
Field workers' years of experience	2–11 years
Number of inspected sites	93
Total length of inspection routes	1 455 km
Length of inspection routes	11–15 km
Total area of inspected sites	159 km^2
Minimum area mapped by one field worker	¼ of map sheet

3. METHODS

Current work can be divided into two large parts: 1) the pre-processing of data and 2) the error analysis. In the pre-processing part the landscape indicators were calculated, and the landscapes were classified by using the k-means clustering during the preparation of the data. Then, a database of errors was created based on field inspection quality reports. Analyses were made with regard to 1) the structure of errors; 2) the specific feature classes involved; 3) error differences among field workers by gender, years of experience and mapped landscape type.

3.1. Pre-processing of data

3.1.1. Calculation of landscape indicators and landscape clustering

Although seamless, very detailed, and accurate, large-scale topographical data in vector has full coverage of many countries, these data are not widely used in landscape research. In topographical vector data, land use/land cover (LULC) is presented as polygons, small size landscape elements like trees, heap of stones, ditches, and roads are presented as points and lines. Landscape indicators can be calculated only for polygons. However, points and lines represent important landscape elements and could be incorporated into the calculation of landscape indicators. Although the use and misuse of landscape indicators has been widely studied over the last 30 years, there has been almost no attention on incorporating small-scale landscape elements presented as points and lines into landscape analysis by using vector data. In order to find most comprehensive method for integrating points and lines of EBM into LULC polygons of EBM for landscape studies, the influence of different integrating methods on the values of landscape indicators were analysed (Publication I).

There are not many tools that use vector data as an input for calculating landscape metrics: 1) V-Late (Tiede, 2016) and 2) Patch Analyst. For this research, Patch Analyst 5.1 (Rempel *et al.*, 2012) was chosen, as with large numbers of polygons, the core metrics calculations work better (Zaragozí *et al.*, 2012). In order to automate calculation, ArcGIS Model Builder was used (ESRI, 2016). All 14 indicators available on Patch Analyst were calculated (Table 3).

For the integration of point and line features into the LULC polygons, the buffers for points and lines with different widths from 20 cm up to 3.5 m as well as the average width of the phenomenon in reality were generated. Obtained buffers for the point elements and lines were integrated into polygon layers using two different methods: a) buffers overlap the polygons; b) buffers were cut out from the polygons. Altogether combining these different geometry types (points, lines, polygons), buffer widths (0.2 m, 0.5 m, 1.5 m, 2.5 m, 3.5 m, average width of the phenomenon in reality), integration methods (cut out and overlapping) (Figure 7), and the polygon layer as a comparison layer, gave 37 datasets (Figure 8) for 35 study areas representing all different landscape types in Estonia (Publication I). Finally, landscape level landscape indicators were calculated for all datasets. For comparing the values of landscape indicators calculated from different datasets, Mann-Whitney *U* test were used. The level of significance of a p=0.05 was accepted in all cases.

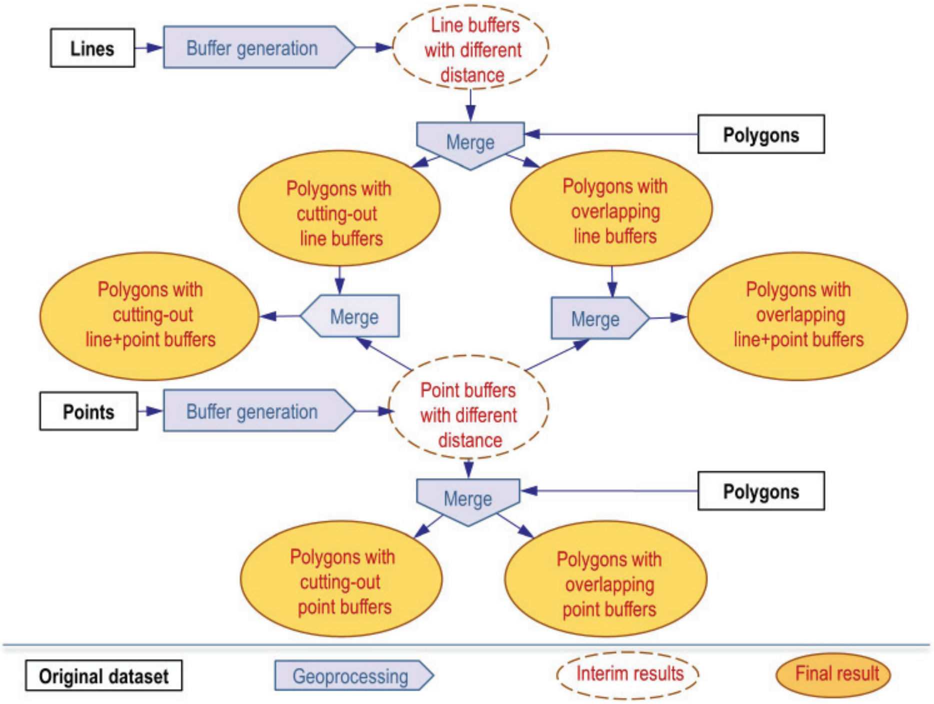


Figure 7. Conceptual workflow of integrating point elements and lines into the polygon layer (Publication I).

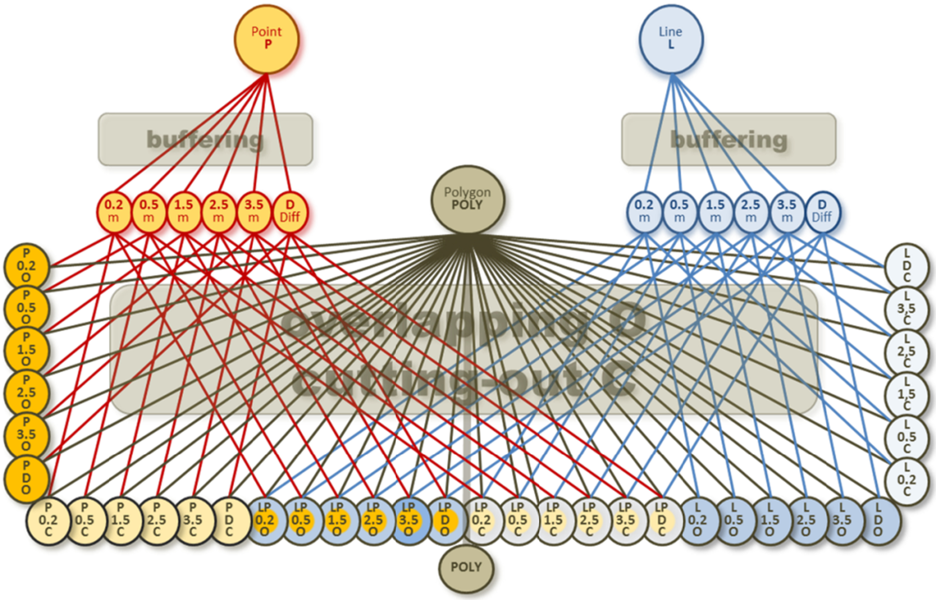


Figure 8. Conceptual scheme of the 3 input layers (P – point, L – line and POLY – polygon layers), 12 intermediate layers (buffers with 0.2, 0.5, 1.5, 2.5, 3.5 meters and D – different width) and 36 output layers (buffers integrated by O – overlapping or C – cutting-out from the polygon layer) (Publication I, supplementary materials).

The study revealed that integrating small-scale landscape elements into land use/cover layers by using buffers gives more realistic results if the buffer size is in compliance with the size of the phenomena in reality. Also, integration method does not affect the values of landscape indicators. Therefore, for points and lines of every field inspection site buffers with an average width in compliance with the size of the phenomena in reality were generated for the following study. The obtained buffers were integrated into the polygon layers by overlapping (Publication I).

For the error analysis, in addition to the indicators available in Patch Analyst, the patch density, patch richness density, the proportion of open areas (e.g., field, grassland), closed areas (e.g., forest, bush, orchard), and built-up areas (e.g., yards with buildings) were calculated (Table 3, marked grey).

Table 3. Landscape indicators used in the study. Indicators calculated in addition for the second part of the study are marked grey. For a more detailed description, see Rempel *et al.* (2012) (adapted from Publication III).

Landscape indicator type	**Landscape indicator**
Diversity metrics	*SDI*: Shannon's diversity index *SEI*: Shannon's evenness index
Shape metrics	*AWMSI*: area-weighted mean shape index *MSI*: mean shape index *MPAR*: mean perimeter–area ratio *MPFD*: mean patch fractal dimension *AWMPFD*: area-weighted mean patch fractal dimension
Edge metrics	*TE*: total edge *ED*: edge density *MPE*: mean patch edge
Patch density and size metrics	*MPS*: mean patch size *NumP*: number of patches *MedPS*: median patch size *PSCoV*: patch size coefficient of variance *PSSD*: patch size standard deviation
	PD: patch density *PRD*: patch richness density
Land use composition	*OV*: proportion of land use creating open viewsheds in the landscape of the site *CV*: proportion of land use creating closed viewsheds in the landscape of the site *BU*: proportion of built-up areas in the landscape of the site

Landscape indicators have different units and scales and many of them are very strongly correlated. For analyses, all landscape indicators by standardisation to obtain normal distribution with $\mu = 0$ and $\sigma = 1$ were rescaled. Factor analysis by the varimax rotation for the elimination of correlated landscape indicators was used. As a result, four factors were determined: diversity, patch size distribution, closure, patch complexity. First two factors together explained 62, 9% of the total variation in the landscape indicators, and the first four factors explained 82.3% of the variation (Publication III).

In order to see if there were differences in error rates within landscape types, similar landscapes among the field inspection sites were found by using *k*-means clustering (Bishop, 1995) which is based on the factor scores for the landscape indicators and additionally on the value of the proportion of built-up areas in the landscape of the site. Cluster analyses revealed three clusters: built-up-diverse, open-simple and complex-closed (Publication III) (Figure 9).

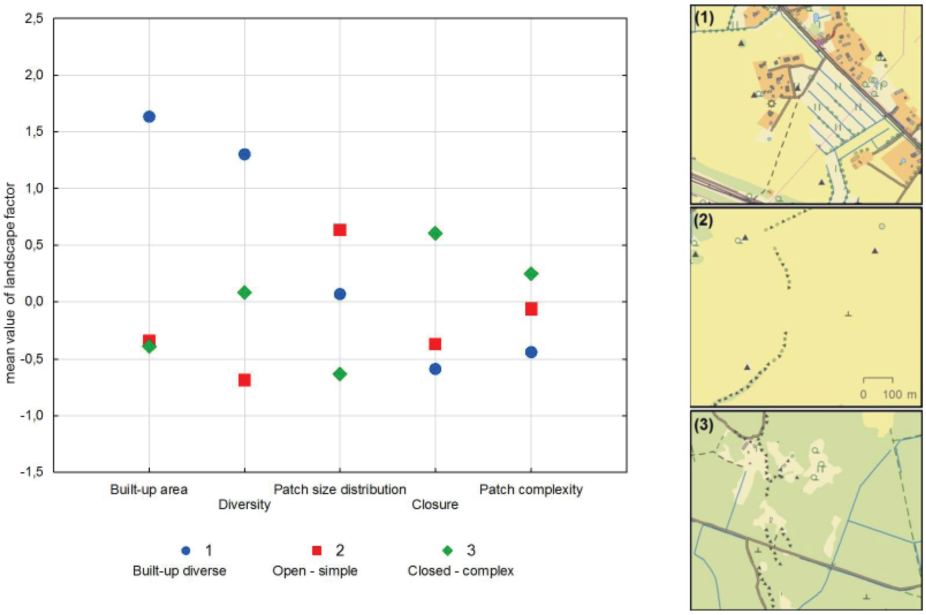


Figure 9. The plot of the mean values of landscape factors and built-up area for the three landscape clusters (types) and example maps for those landscape clusters: (1) an example of a built-up–diverse landscape, (2) an example of an open–simple landscape, and (3) an example of a closed–complex landscape (Publication III).

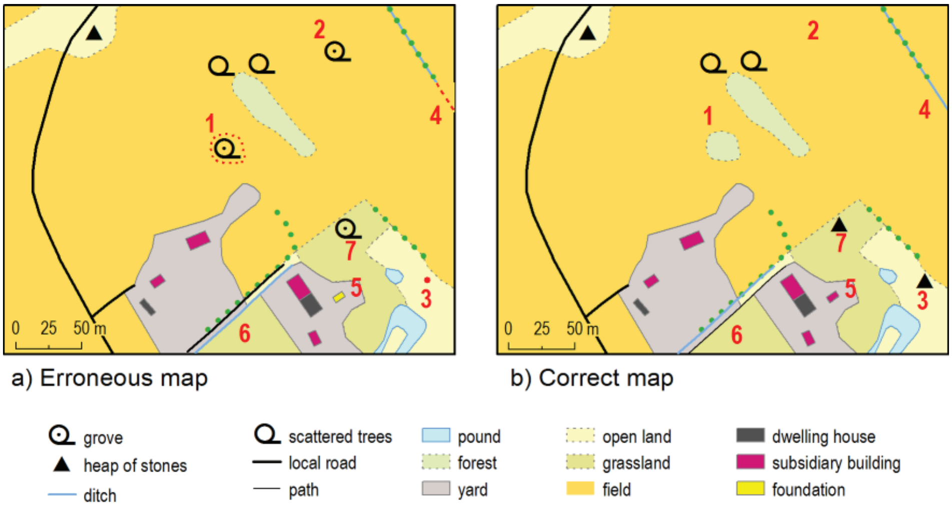
3.1.2. Creation of an error database

A spatial database of mapping errors (hereafter error database) was created from the errors recorded in quality reports and accepted by field workers from years 2003-2006. For all errors, the type was determined according to the ISO 19157 (International Organization for Standardization, 2013) quality elements. The error database consists of 5100 errors found in 93 inspected sites.

While creating the error database, it appeared that different field inspectors have recorded error types differently. Classifying the type of error by its completeness or thematic correctness is subjective, as also mentioned by ISO 9157 (International Organization for Standardization, 2013). For example, if a ditch is mapped as a path it can be treated as a classification error (misclassified linear feature) or a completeness error (ditch omitted, path committed). Error recording becomes even more complicated in case the correct mapping requires a change of a geometry type – like a grove (point-feature) turns into a forest (areal-feature). Such error can be recorded in three ways: 1) misclassification (forest instead of grove); 2) commission (grove) and omission (forest); 3) commission (grove) and misclassification (forest instead of field).

To be systematic and consistent in methodology, all errors in the error database were transferred into a common classification system applying the following rules (Figure 10) (Publication II).

- Point features could have all error types (Figure 10, errors 2, 3, and 7).
- Line features could have all error types. Where line lengths were either shorter or longer than they should have been, the error was noted as either omission or commission, respectively, not as a wrong size (Figure 10, error 4). In addition, where nearby parallel line features had swapped places with each other (Figure 10, error 6), a classification error was noted, not a wrong placement.
- Polygon features that participated in a full tessellation (no holes or overlap) could only be misclassified. However, small polygon features (Figure 10, error 5) that were recognized as point features during the field inspection could have all error types, as could short linear features (culverts, bridges).
- Finally, when the geometry type changed from the point to the polygon or from the line to the polygon (Figure 10, error 1), the point or line was recorded as an error of commission and polygon as a misclassification, not an omission.


a) Erroneous map

b) Correct map

Figure 10. Examples of discrepancies in an erroneous map (left) and the corrected map after the field inspection (right). The erroneous “grove” (numbered 1) can be considered in three ways: a simple misclassification (forest instead of grove); a paired commission (grove) and omission (forest); or a commission (grove) and misclassification (forest instead of field) (Publication II).

3.2. Error analyses

3.2.1. Quality measure calculations

To analyse errors, quality measures were calculated. ISO19157 (International Organization for Standardization, 2013) provides a list of data quality measures in order to provide quality results in a comparable way. In the current research, error count, error sum and error rate were calculated for all quality elements. *Error count* indicates the total number of errors and shows the frequency of errors. *Error sum* characterises the magnitude of the errors and is calculated separately for each geometry type: the total length of incorrect line items, the total area of incorrect polygon items, and the total number of incorrect point items. *Error rate* is expressed as the total number, the length or area of erroneous items in a geometrical type (e.g., lines) divided by the total number, length or area of items in that geometrical type and multiplied by 100.

In order to aggregate quality results a weighted average for the error rate was calculated for each three geometrical types for every quality element and summarised these values across all types to obtain a single combined error rate (Equations 1–3) The weights equalled the proportion of the total number point, line and polygon features in the total number of features (based on the total number from the assessments by the expert quality controllers).

$$M_{\mathrm{WA}} = 0.22\, M_{\mathrm{poly}} + 0.48\, M_{\mathrm{line}} + 0.30\, M_{\mathrm{point}} \quad (1)$$

$$C_{\mathrm{WA}} = (0.48\, C_{\mathrm{line}} + 0.30\, C_{\mathrm{point}}) / (0.48 + 0.30) \quad (2)$$

$$O_{\mathrm{WA}} = (0.48\, O_{\mathrm{line}} + 0.30\, O_{\mathrm{point}}) / (0.48 + 0.30) \quad (3)$$

where M, C, and O are the rates of misclassification, commission, and omission errors, respectively; WA indicates the weighted average, and “poly”, “line”, and “point” subscripts represent the corresponding geometrical types (Publication III).

3.2.2. Statistical analyses

In statistical analyses the structure of errors was analysed firstly *in general*, by considering the whole set of errors and secondly *in detail*, by each field worker to determine the similarities and differences between the analyses results (Publication II). The structure of errors was analysed with regard to the type of error, the geometry of the error, the most erroneous feature classes and the most misclassified feature classes. Next, the most misclassified feature classes were determined (Table 4) by using scatterplots which are not common in the quality analysis. The feature classes that appeared in the upper left quarter on the scattered plots were considered critically. These graphs were drawn separately for each geometry type (Publication II).

Across field workers, the distribution of errors is described by the coefficient of variation. An error matrix (Congalton and Green, 1993; Foody, G. M., 2002) (in the literature also called the confusion, contingency, validation or feature misclassification matrix) was used to study the misclassifications in the whole database. The matrix was generated separately for each geometry type by using the quality measure of error sum.

Table 4. Data quality measures used in different analysis**.**

Analysis	Measure	Definition
Type of errors (misclassification, omission, commission)	error count	number of incorrect items
Geometry of errors (point, line, polygon)	error count	
Feature classes of errors	error sum	total number of incorrect point items, length of incorrect line items, or area of incorrect polygons
Most misclassified feature class	error sum	
Differences in errors among filed worker by gender and years of experience	error rate	total number, length or area of erroneous items in a geometrical type (e.g., lines) divided by the total number, length or area of items in that geometrical type and multiplied by 100
Differences in errors among filed worker by landscape types	error rate	

To detect the differences in errors among the field workers by gender, years of experience and landscape types (Figure 9) we used box-plots and the Mann-Whitney *U* test. All analyses were performed in the Statistica 12 software (StataCorp LP, 2011) (Publication III).

4. RESULTS

The structure of errors and errors by the feature class were investigated at two levels: firstly, *in general*, where all data of the error database was included in the analysis and secondly, *in detail* by each field worker to determine the similarities and differences between the analysis results. In order to explore reasons for the occurrence of errors, gender, years of experience and landscape type among field workers were examined.

4.1. The structure of errors

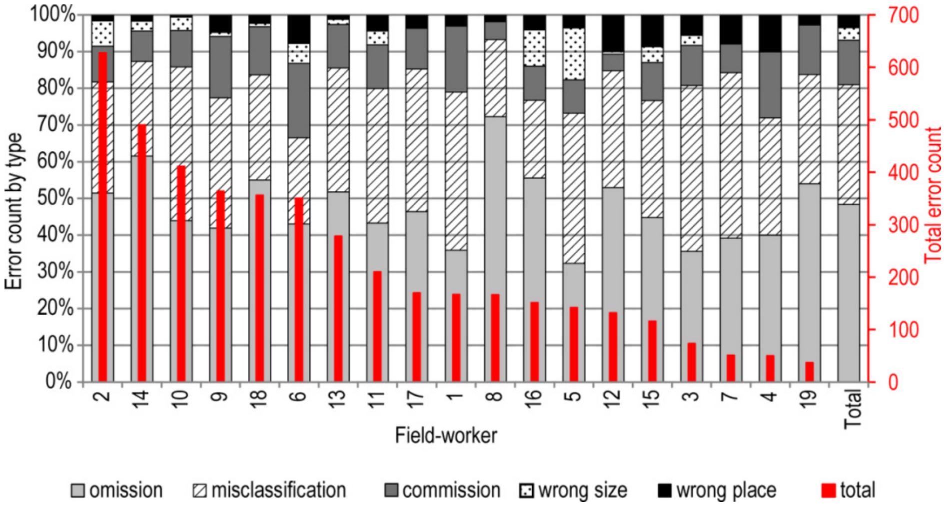
Error types are distinguished according to the following *quality elements*: omission, commission, misclassification, wrong size and displacement. In general, nearly half (48%) of the errors were omission and nearly one third (33%) were misclassification (Figure 11a, column Total). Predominant error among field workers was also omission. However, a slight variation among field workers occurred in a type of errors.

The analysis of the error by the *geometry type* revealed in general that errors of line features and errors of point features had a similar share - 46% lines, 40% points (Figure 11b, column Total). Although the main geometry type of errors was a line, field workers 8 and 19 made more errors in point features. The share of errors of polygon features was 14%. The share of features by the geometry type on the field inspection sites was more nearly uniform: 47% lines, 30% points, and 23% polygons.

By the field workers, much larger variability in a share of the geometry type appeared. In conclusion, when considering the geometry type and error type together, three equal groups of field workers can be distinguished (Publication II): (1) six field workers with omissions comprising over 50% of all errors both in line and point features; (2) another six field workers with omissions exceeding 50% only for point features; and (3) the final six having omission exceeding 50% only for lines. By contrast, only one field worker consistently misclassified features of all geometries.

The Kruskal-Wallis *H* test showed a statistically significant difference between the error rates in different *landscapes*. Error rates and variation of error rates of misclassification, commission, and omission were the lowest in the built-up–diverse landscapes (Figure 12) and the highest on the in closed–complex landscapes, which also had the highest variation. While the misclassification error varied the most across landscapes, with the highest values in closed–complex landscapes and the lowest values in built-up–diverse area, the commission had the lowest error rate across all landscapes. The statistically significant difference for commission error rates occurred only between the built-up–diverse and open–simple landscapes.

(a)



(b)

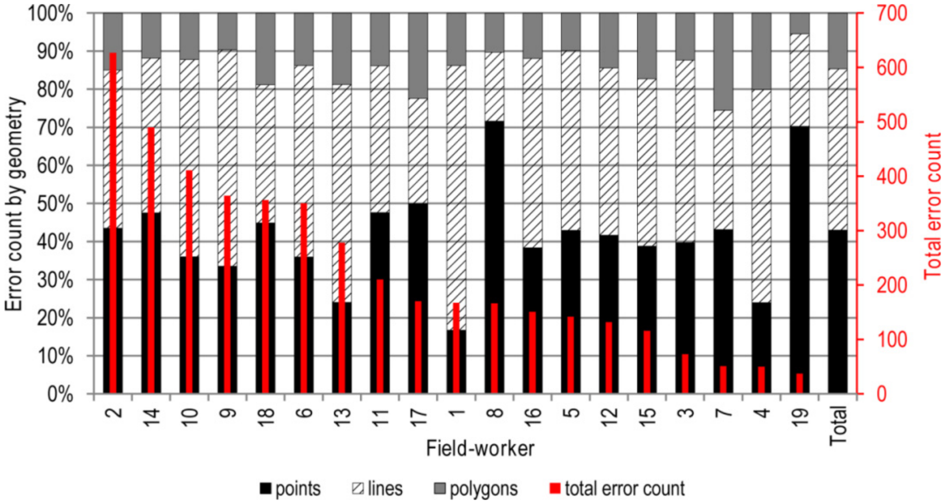


Figure 11. The variability of errors (a) by type and (b) by geometry among field workers. The ordinate (the X-axis) ranks field workers by their decreasing share of errors overall (red stripe), measured by the Y-axis on the right. The Y-axis on the left shows the distribution of errors by the type or by the geometry for each field worker (Publication II).

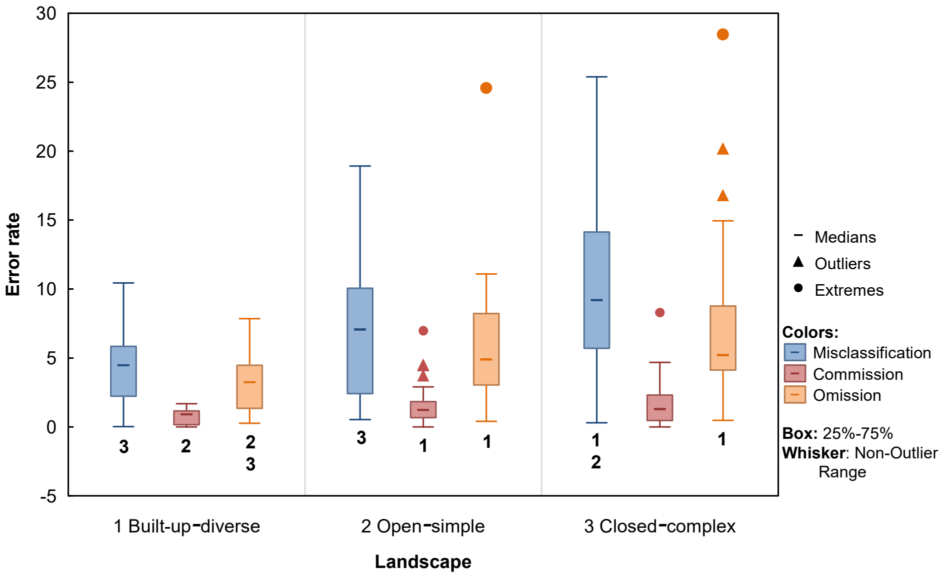


Figure 12. Box plots for the rates of misclassification, commission, and omission errors in the different landscapes defined in Table 4. For a given error type, based on the Kruskal-Wallis multiple comparison of mean ranks for all groups: 1 – statistically significant difference from built-up–diverse, 2 – statistically significant difference from open–simple, 3 – statistically significant difference from closed–complex (Publication III).

4.2. Errors by the feature classes

There were no errors recorded for 20 feature classes out of 104. These were features that were clearly recognizable in stereo images (lake, railway, radio-tower, high voltage power-line *etc.*), or that were corroborated by other reliable databases (1. and 2. class roads *etc.*), or that appeared infrequently in nature (ruins of windmill, light tower *etc.*) that field workers cannot be mistaken in their nature (Publication II).

In general, five point, three line, and two polygon feature classes are highlighted in the critical quadrant of the scatter plots (Figure13). Heap of stones and culverts were mainly missing from the maps, while the highest share of commissions occurred for scattered trees. The analysis of the error matrix of the point features indicated that two feature class pairs, deciduous grove vs. deciduous tree and dwelling house vs. subsidiary building, were the most mixed up. If the two building type were equally confused, then deciduous groves might be mapped as deciduous trees but not contrariwise. The most misclassified line features were two groups of feature classes, of which the path caused 40% of all misclassifications and the ditch caused 32% (Figure 14). Paths and forest cutlines were classified in a higher road class in 25% of the cases. Also, in 20%

of cases, the width class of ditches was overestimated. Among polygon features, 43% of all misclassifications involved the three most common classes: arable field, grassland, and open space. Most commonly an arable field was mapped as grassland and forest as a young forest, the latter was also used for forest cutlines (Publication II).

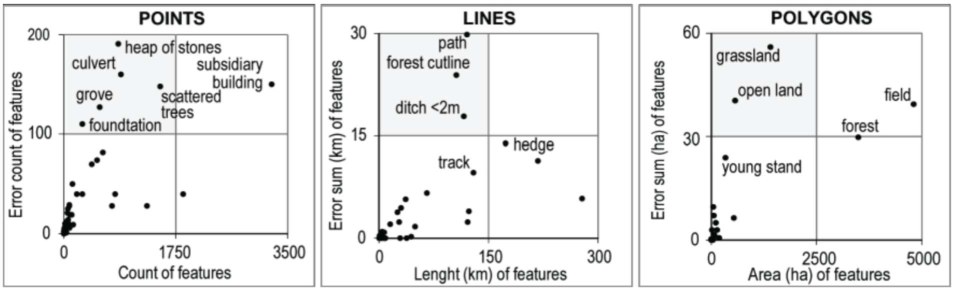


Figure 13. Quartile-quartile plots of errors in the three feature geometries against their summary measures, with individual feature classes labelled. The feature classes having relatively few errors appear close to the horizontal axis. The feature classes placed clearly above the diagonal (upper left quadrant) may be considered more problematic: the frequency of this particular feature class in the landscape is relatively low, but the number of errors is high compared to other feature classes (Publication II).

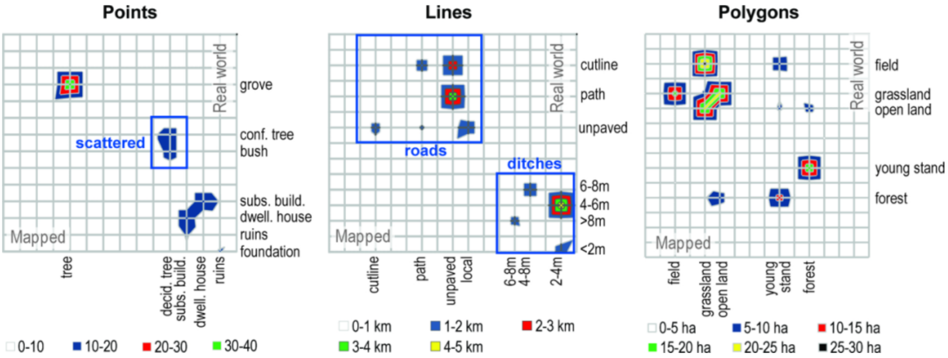


Figure 14. Selections from confusion matrices for the most misclassified feature classes, by geometry. The horizontal axis shows features presented on the map, the vertical-axis features occurring in the real world (Publication II).

Among filed workers the variability of most misclassified feature classes occurred (Table **5**). The path and heap of stones occurred in the critical quadrant of scatter plots for at least half of the field workers. By contrast, a narrow ditch <2 m wide, which was clearly problematic in general, only caused errors for four field workers. Moreover, a forest appeared problematic only for two field workers. Forest vs. grassland and forest vs. open space misclassifications were made by field workers number 19 and 14, respectively. Thus, despite that the total area of misclassifications was small, which is why it did not appear in the general analysis, the classification of forest-grassland-open space was a problem for field workers.

Table 5. Standard deviation, mean and coefficient of variation of error sums for selected feature classes among field workers. Number in parentheses indicates the number of field workers who had these features represented in the critical quadrants of scatter plots (adapted from Publication II).

Feature class	StDev	Mean	CV
POINTS			
heap of stones (9)	7.5	9	0.83
foundation (8)	3.6	6	0.66
scattered trees (7)	6.9	8	0.83
grove (7)	5.1	7	0.73
culvert (7)	10.5	12	0.90
LINES			
path (14)	958	1334	0.72
forest cutline (7)	1112	1432	0.78
ditch <2m (4)	1542	1295	1.19
POLYGONS			
open space (8)	26745	26043	1.03
grassland (6)	51582	29796	1.73
forest (6)	12730.2	14669	0.87

There was a statistically significant difference of misclassification, omission, and commission error rates in different landscape types by the Kruskal-Wallis *H* test.

4.3. Error differences among field workers by gender, years of experience and the mapped landscape type

The field workers' gender, years of experience and mapped landscape type were explored to elucidate their influence on the errors. In order to analyse differences across field workers, an error rate was used. The analyses reviled that female field workers had slightly lower error rates than men (Publication III). This difference was not statistically significant according to the Mann-Whitney *U* test (Figure 15a).

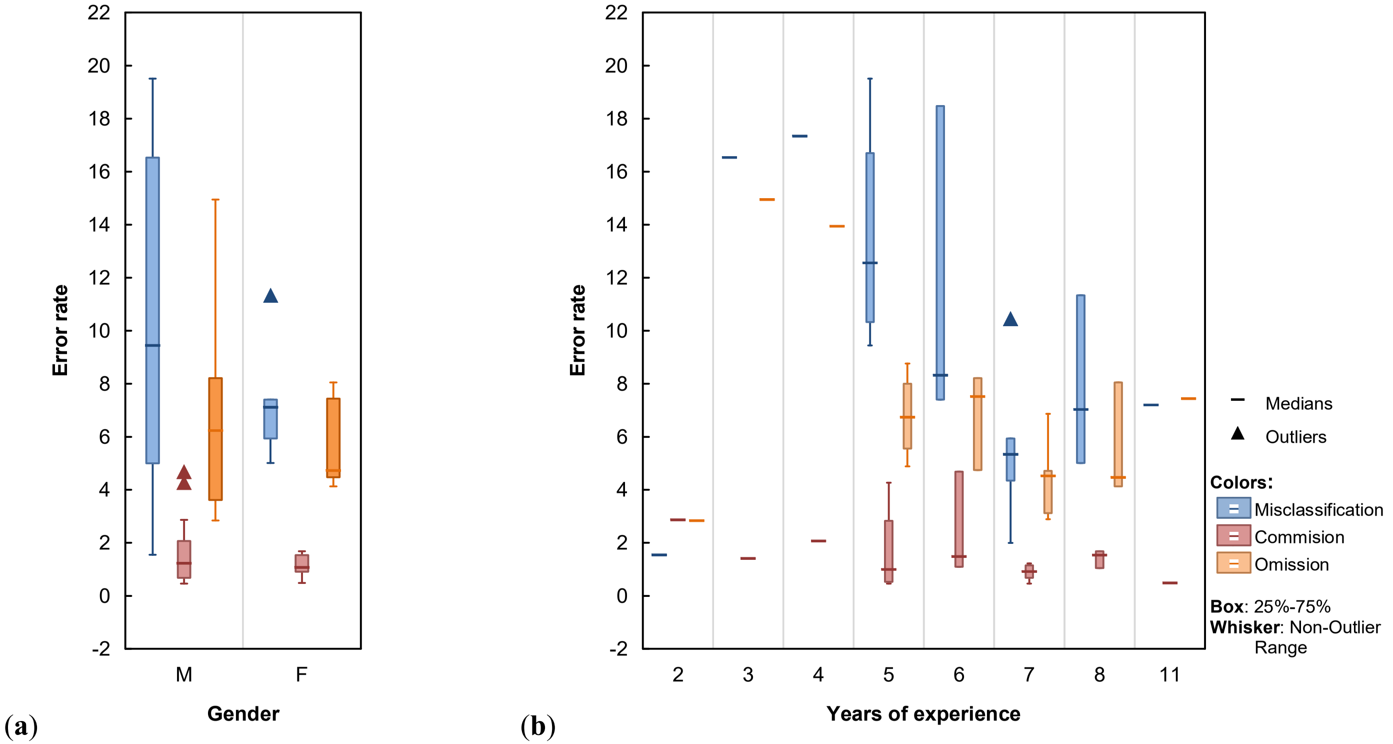


Figure15. Box plots of the error rates by field workers based on (a) gender (M – male; F – female) and (b) years of experience. For each field worker, we calculated the median value across the sites they examined (Publication III).

Figure 15b indicates an overall decreasing trend in error rates with increasing years of experience. There was only one field worker with two years of experience, and he had one of the lowest error rates. Workers with three to four years of experience had significantly higher error rates, but the error rate decreased thereafter. However, according to the Spearman rank-order correlation, there was a statistically not significant negative relationship (σ = –0.38; p=0.09) between the years of experience and the misclassification, omission, and, commission error rates (Publication III).

As shown in Table 1, the number of sites mapped by a given field worker was unevenly distributed. Six field workers had inspected only 1 site, but 9 field workers had inspected at least 5 sites. Seven field workers had inspected sites in the built-up–diverse landscapes, 14 field workers had inspected sites in the open-simple landscapes, and 19 field workers in the closed-complex landscapes. The error rates were relatively low for all field workers in the built-up–diverse landscapes. However, there were nine field workers out of 13 who made the least mistakes in open-simple landscapes.

There were five field workers (2, 6, 10, 16 and 18) who worked in all three landscape types (Figure 16). This provides us with a possibility to evaluate the effect of the landscape type on mapping quality independently from the field workers' characteristics. All field workers had higher error rates in the closed-complex than in the built-up–diverse landscapes. Four out of five had the lowest error rates in the built-up–diverse landscapes, and three out of five showed the highest error rates in the closed-complex landscapes (Publication III).

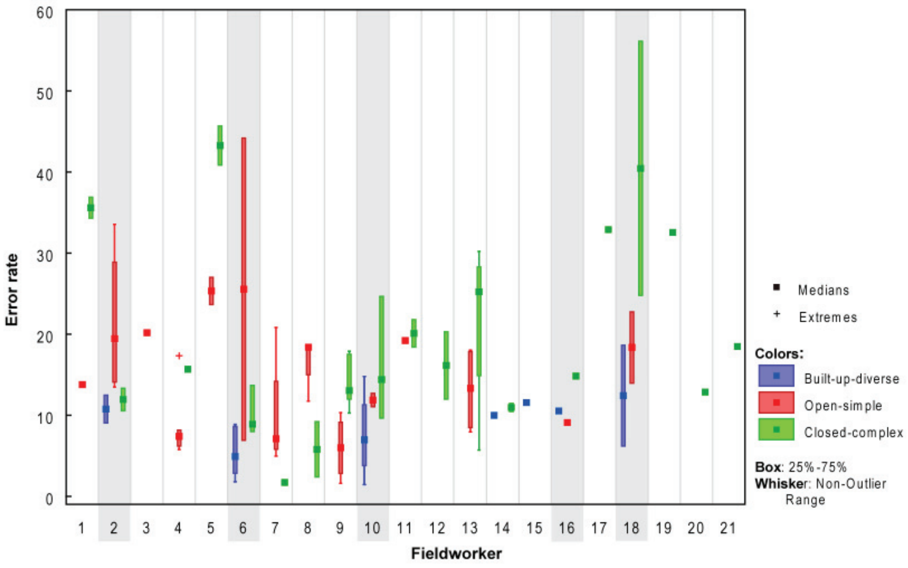


Figure 15. Box plots of the summed values of MCO error rates (all three categories combined) by field workers in the three landscape types defined in Figure 9. Field workers who mapped all three landscape types are shaded grey (Publication III).

5. DISCUSSION

Error analyses are one of the constituents of data quality management (Jakobsson, 2003). The results of error analyses on one hand are important information as metadata for data users and on the other hand serve as the basis for the improvement of data production (Dassonville *et al.*, 2002; Harding, 2006; Jakobsson and Marttinenen, 2003).

5.1. Measures of quality elements

ISO 19157 (International Organization for Standardization, 2013) provides numerous measures for each quality element. In the current study, only error count, error sum, and error rate were considered (Table 4). For different analyses various quality measures are suitable. Therefore, unlike the error sum, the error count does not depend on the type of geometry and this allows to analyse all errors together. Error rate is normalised and useful for a comparative analysis.

Moreover, the counts and sums characterise the overall impact of errors differently. Error count and error sum may have dissimilar interpretations for data providers and data users. For example, the errors in the map consist of three (error count) missing paths with a total length (error sum) of 250 m and one (error count) superfluous ditch with a length (error sum) of 500 m. For a data provider the omission of three paths are more critical as the number of errors is bigger, whereas for a data user the commission of a longer ditch may have a higher impact, even in case there is just one mistake. Different quality measures indicate different feature classes as most erroneous. For example, the total area of forest on the test area is 1 km^2 and the total area of grasslands 0.5 km^2. From each of those areas 0.1 km^2 are misclassified. In this case, error rate for forest is 10% and for grassland 20% but error sum would be equal (0.1). Therefore, the most erroneous feature class can be different according to different quality measures.

Hence, in order to explore the most erroneous feature classes the visual inspection of graphs (Figure 12, Figure 13; Publication II), makes the analysis more comprehensive.

5.2. The structure of errors

The results of two first simple analyses by error type and feature geometry in Publication II demonstrated considerable difference between the outcomes of general and detailed level analysis by field workers, which confirms the theory of Devillers and Beard (2006). Based only on general analysis, one could conclude that point and line features are equally problematic, and nonconformities are caused mainly by omission and misclassification. Detailed analysis by field workers showed that one field worker mainly omitted point features, while the other field worker misclassified lines. However, the analysis by error type and feature geometry did not sufficiently explain the variability of errors across the sites. Very likely the number of errors in mapping does not depend so much on the geometry but rather on the specific feature class or field worker.

In terms of spatial variation across different landscape types, rates of misclassification, omission, and commission errors in built-up–diverse, open–simple, and closed–complex landscapes differed significantly (Publication III). The lowest rates of errors occurred in the built-up–diverse landscapes. Very good landmarks, such as buildings, are distinctive features in landscape and easily recognizable. Although buildings increase the landscape diversity and therefore the potential for making mistakes is higher, they also likely increase the attention of the field worker, leading to fewer mistakes. In addition, built-up–diverse landscapes are well-structured due to the street network. The accessibility and visibility are good which eases mapping.

The highest rates in error of misclassification, omission, and commission were mainly in the forested closed–complex landscape types. This can be easily explained by low visibility, complicated penetrability of the landscape, and by the outdated aerial photos which were captured in summer instead of early spring. The latter fact has a direct influence on stereoplotting, which was one of the data sources for the field workers.

It is more complicated to find an explanation for the high values of the error rates in open-simple landscapes where error rates could be expected to be the lowest. One possible explanation is that erroneous features of open-simple landscapes are mostly placed on their patch edges. However, this would need further research.

5.3. Errors by the feature classes

At both, general and field workers level, analyses highlighted several common critical feature classes, which can be divided into three groups: (1) features that were frequently omitted, e.g. a heap of stones, relict foundation, culvert, path, forest cutline; (2) features that tended to be committed in excess, e.g. scattered trees; and (3) features that were mostly misclassified, e.g. deciduous grove and open space (Publication II).

The omission of features may result due to several reasons. Regarding the heap of stones and footpath, the reason is clearly an insufficient definition of the feature classes involved. Estonia has many heaps of stones of different sizes and shapes collected from fields and piled in or along fields, and also numerous paths of different widths and qualities, which are not always obvious in the forested areas. In these cases, the high number of errors relates to the field workers' inability to decide which class to should be used based on the existing definitions, or whether to map the feature at all. For culverts, relict foundations, and forest cutlines the problem may also be the visibility on the field and/or cognition on aerial photos as well. Foundations are often overgrown by vegetation limiting their detection in landscape. The same is with cutlines which may be also obscured by new growth. Similarly to our results, Pätynen *et al.* (1997) and Jakobsson (2002) found in Finland that the biggest concern in completeness is related to buildings, streams with current width under 2 m, and light-traffic routes.

In terms of misclassification, the problematic features were buildings and agricultural lands. There were many abandoned fields in Estonia in the end of 1990s (Peterson and Aunap, 1998). Field workers could not decide in which feature class they belonged. The most misclassified features were those “neighbouring” each other (like agricultural field–grassland – open space); and those rapidly changing in time (forest–forest cutline–young forest). Similar issues are well known in habitat mapping (Cherrill and McClean, 1999; Stevens *et al.*, 2004). The abundant commission of scattered trees in this study is closely related to the misclassification of forest too.

Forest feature class was not problematic in the general level due to the small value of erroneous area, although the high coefficient of variation (0.87) for this class indicates uniform distribution of errors among the field workers. Forest was frequently mixed-up with grassland and open space. It appears that usually the problem starts from the forest being primarily mapped with a wrong shape. Thus, erroneous areas were mainly located along the forest edge where the neighbouring grassland with scattered trees or open space with scattered trees made the border of the forest vague.

In contrast to the forest class, some feature classes that appeared frequently misclassified in the general level, had high number of nonconformities produced by only few field workers. In this study, the feature classes ditch < 2 m and grassland were problematic because of the errors made by just two field workers, who produced more than half of such errors.

Feature classes that are more problematic in general level or have more or uneven distribution of the errors across field workers should be revised and improved in the data capture specification (Harding, 2006). If uneven distributions of error rates occur, additional training for some field workers recommended.

5.4. Differences in errors among field workers by gender, years of experience and mapped landscape type

It is often assumed that the data collected following the same procedures have similar quality (Frank *et al.*, 2004). It may be true assumption for data acquired in remote sensing. However, the current study demonstrates that this assumption does not hold in field mapping. Different field workers may have remarkable differences in their quality level. The causes may be insufficient mapping tutorials or training but might also include in the field workers’ personal characteristics such as gender, years of experience or the ability to interpret landscape.

There are several studies investigating the differences in spatial ability and orientation between *men and women*. Most of the studies found that men have better spatial orientation abilities (Coluccia *et al.*, 2007; Coluccia and Louse, 2004; Lawton, 1994). Although results of the current study showed lower error rates for women, the difference with man was not a statistically significant (Publication III). The reason may lie in professionality. The participants in previous studies were mostly volunteers with no previous training or professional mapping experience, whereas all the field workers of EBM were trained and had 2-11 years of experience in mapping. In addition, several studies pointed out that people are navigating better in a safe environment (Lawton, 1994; Lawton and Kallai, 2002; Schmitz, 1997). The field workers of EBM could choose their preferred landscapes; this means that if a worker did not feel confident or safe in the forested areas, then he or she was assigned to map open and built-up areas. It can be seen that women mapped only 23% of the forested closed-complex landscapes, whereas the share of the open-simple landscape was 45% (Table 1). This indicated the preference of open landscapes by women and this may also partially explain why there was no significant difference in mapping quality between genders.

There was a general decreasing trend in the values of error rates with increasing years of experience of field workers (Publication III). However, the trend was not statistically significant. Moreover, the field worker with the fewest years of experience had one of the lowest error rates, which was an unexpected result and it could be hypothesized that the relationship between the years of experience and mapping quality may not be linear, rather U-shaped. Nevertheless, as there were only few field workers with short experience, this hypothesis cannot be confirmed. Similar results, where the years of experience were not significantly correlated with classification correctness, were described by Hearn *et al.* (2011) in habitat mapping.

Within each landscape type, the large variation in error rates occurred, which indicates that the individual characteristics of field workers have some effect on the mapping quality. The study showed that in the built-up–diverse landscapes, the variation of error rates and overall error rates were lower than in the closed-complex and open-simple landscapes. This suggests that built-up areas were easier to map than natural areas. Girres and Touya (2010), Haklay (2010), and Dorn *et al.* (2015) reached the same conclusion. They found that in VGI the mapping quality is higher in urbanized areas. This leads us to a conclusion that landscape might affect the mapping quality of both – amateurs and professionals.

6. CONCLUSIONS

This thesis is based on an empirical database of mapping errors that comprised 5100 records. Errors were detected for the Estonian Basic Map and found during the routine field inspection based on the determined methods. The results showed the importance of error analyses on the level of a field worker and by landscapes as well, which is rather a new approach, by our knowledge, in quality assurance.

The results of the research led to the following main conclusions.

- Error analyses by MCO, by geometry type, and by feature classes showed differences at the general and field workers' level which implies to the need to explore the individual characteristics of the field workers.
- Field workers' years of experience had a decreasing trend of mapping quality with the increasing years of experience. The trend was not statistically significant because the field worker with the fewest years of experience had the lowest error rate, whereas the field workers with average experience showed the poorest results in quality, and the field workers with the most extensive experience showed an improved mapping quality.
- Field worker's gender did not have an influence on the mapping quality. There was no statistically significant difference in the results of error analyses between men and women.
- The quality of mapping varied among the landscape types. Built-up–diverse landscapes showed higher correctness than open-simple and closed-complex landscapes. Partially because the number of field workers was limited and because these effects are interrelated, it was impossible to clearly differentiate the effect of the individual characteristics of the field workers on the mapping quality from the effect of the landscape.
- To improve the mapping quality, we suggest that the field workers could choose their preferred landscape. Moreover, monitoring field work to detect errors, so the workers can be trained to avoid such errors in the future, would also improve mapping accuracy.
- The most critical features were the heap of stones, relict foundation, scattered trees, path, forest cutline and grove. To improve the data quality in mapping these features, it is necessary to revise their definitions or methods of determination in a mapping specification or to consider whether mapping these features is absolutely necessary.

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SUMMARY IN ESTONIAN

Topograafiliste kaartide temaatiline õigsus ja täielikkus

Suuremõõtkavalised topograafilised kaardid on tänapäeva ruumiandmete taristute lahutamatuks osaks. Tänu sellele on kaardil kujutatud andmete kasutajaskond laialdane alates nii riigi- kui omavalitsusest ja lõpetades hariduse või ettevõtlusvaldkonnaga. Suur kasutajaskond eeldab andmetelt kõrget kvaliteeti. Ruumiandmete kvaliteediga on nii teadlased kui ruumiandmete tootjad tegelenud üle 40 aasta. Ühe suurima saavutusena nimetavad mitmed autorid (Devillers, R. *et al.*, 2010; Hunter *et al.*, 2009) ISO 19100 ruumiandmete kvaliteedi standardite loomist. Rahvuslike kaardistusagentuuride katusorganisatsiooni Eurogeographics'i 2018. a uurimus näitab, et INSPIREga ühinenud liikmete seas on ruumiandmete kvaliteedi standardite kasutus suurenenud. Samas tuuakse välja ka kvaliteedi valdkonna mõned kitsaskohad. Üheks suuremaks puuduseks on see, et kvaliteeti käsitletakse kogu ruumiandmekogu ulatuses monotoonsena. Kvaliteedinäitajate väärtused arvutatakse välja ning esitatakse kogu andmekogule tervikuna. Tegelikult peaks kvaliteeti analüüsima ning väärtuseid esitama suurema detailsusega kas väiksemate territoriaalsete üksuste kohta, nähtuskihtide kohta või mõne muu omaduse, näiteks kaardistuse teinud välitöötaja järgi moodustatud alamhulga, kohta. Detailsem kvaliteedi analüüs ning saadud näitajate esitamine on vajalik nii andmetootjatele kvaliteedi paremaks tagamiseks kui ka kasutajatele.

Doktoritöös on kasutatud Eesti põhikaardi 1:10 000 välitööde kontrolli andmeid aastatest 2003–2006. Töö eesmärgiks on uurida välitöötajate mõju topograafilise kaardistuse kvaliteedile. Põhiliselt on analüüsitud klassifitseerimise õigsust ning täielikkust, mida kirjeldati liigsete ja puuduvate objektide näitajatega. Välikaardistusel tehtud vigu ja nende struktuuri analüüsiti kahel tasandil: 1) üldisel tasandil, kus analüüsis osalesid kõik andmebaasis olnud vead korraga; 2) detailsel tasandil, kus vigu analüüsiti välitöötajate lõikes. Selgitati välja vigade struktuur ning kvaliteedilt kriitilisemad nähtused.

Topograafiliste andmete kvaliteet võib erineda ka ruumiliselt. Selle põhjuseks võib olla maastiku keerukus, välitöötaja isikuomadused ning võimekus maastikku tõlgendada. Käesolevas doktoritöös uuriti kas ja mil määral mõjutavad kaardistuse kvaliteeti välitöötaja sugu ja töökogemus ning maastiku keerukus. Vektorandmetest maastiku keerukuse indeksite arvutamiseks töötati välja metoodika, mille abil väiksed punkt ning joonobjektid lõimiti pindobjektidega ühtseks pinnakatte kihiks.

Doktoritöö näitas, et üldisel ja detailsel tasandil tehtud kaardistusvigade analüüsid andsid teatud juhtudel erinevaid tulemusi ning teatud juhtudel sarnaseid tulemusi. Vead, mis ilmnesid mõlemal tasandil, olid süsteemsed, teisel juhul aga põhjustatud peamiselt üksikutest välitöötajatest. Nähtused, mis olid kriitilisemad mõlema tasandi analüüsides, olid kivihunnik, vundament, harvik, rada, siht ja salu. Välitöötaja sugu kaardistuse kvaliteeti ei mõjutanud. Samas väikse töökogemusega välitöötajate kaardistuskvaliteet oli kõrgem, kui keskmise töökogemusega välitöötajatel ning kvaliteet tõusis jällegi väga kogenud töötajatel. Analüüsi tulemused näitasid, et hoonestatud-mitmekesises maastikutüübis oli välitöötajate lõikes kaardistuse kvaliteet kõrgem, kui avatud-lihtsas või suletud-keerukas maastikutüübis. Sarnastele tulemustele on jõudnud ka mitmed vabatahtlike kaardistuste (VGI) kvaliteeti uurinud autorid.

Kaardistuse kvaliteedi tõstmiseks tuleks süsteemsete vigade vältimiseks täiendada kaardistusjuhendeid – täpsustada nähtuse definitsiooni või tunnuseid või kaaluda, kas antud nähtuse kaardistamine on üldse vajalik. Individuaalsete, üksikute välitöötajate põhjustatud vigade vältimiseks on soovitav viia läbi koolitusi. Samuti võiks välitöötaja valida endale sobiva maastikutüübi kaardistamise, sest uuringud on näidanud, et sobiv maastik tõstab turvalisust ning enesekindlust ja seeläbi ka kvaliteeti.

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PUBLICATIONS

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Education:

1999–…	doctoral studies in geoinformatics, University of Tartu
1992–1994	MSc in geoinformaics and cartography, University of Tartu
1985–1990	diploma studies in geography, *cum laude*, University of Tartu
1974–1985	Valga I Secondary School

Additional education

2017	e-course "Programmeerimisest maalähedaselt", University of Tartu
2011	e-course "E-kursuse loomine õpikeskkonnas Moodle", University of Tartu
2011	course "Õppimine ja õpetamine kõrgkoolis", University of Tartu
2010	course "Õppejõust saab mentor", University of Tartu
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Academic degrees:

Master of Science, 1994, "Kaardi kirjastamise andmestik ja selle ohjamine (Data of map publishing and data management)", (sup) Teet Jagomägi.

Professional employment:

2018–…	specialist in geoinformatics, University of Tartu, department of geography
2006–2018	lecturer in cartography, University of Tartu, department of geography
2002–2018	lecturer in cartography, University of Life Science
1998–2006	head of the bureau of Cartography, Estonian Land Board
1996–1997	consultant, specialist of Interpgraph software, KARTTA-KESKUS, Finland
1992–1998	map editor, AS Regio
1990–1992	senior engineer, University of Tartu, laboratory of geoinformatics

Projects:

1998–2006	Estonian Basic Map
2010–2011	Mentor lecturer

Courses presented:
Cartography (3EAP)
Map use (3EAP)
MicroStation (2EAP)
ArcGIS Software (3EAP)
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Standards and Data Quality in Geoinformatics (3EAP)
Generalisation of Spatial Data (2EAP)
Field Training in Land Survey (3EAP)

Supervised dissertations:
2015 Krõõt Kaldma, Master's Diploma, "Estonian basic map's fieldworkers' database in 1996–2007", University of Tartu, department of geography
2015* Merike Puura, Bachelor's Diploma, "Linguistic and spatial analysis of the Place Names Database and the Place Names Register by the example of Värska parish", University of Tartu, TÜ Institute of Estonian and General linguistics, department of Estonian
2015* Olga Rõbkina, Bachelor's Diploma, "Accessing relative accuracy of The Estonian Base map on the basis of three different periods of mapping", University of Tartu, department of geography
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Publications:

2018

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2017

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Jaagus, Jaak; Sepp, Mait; Tamm, Toomas; Järvet, Arvo; Mõisja, Kiira (2017). Trends and regime shifts in climatic conditions and river runoff in Estonia during 1951–2015. Earth System Dynamics, 8, 963−976.esd-2017-24.

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Honours and awards:

2015	The best lecturer in 2015 (by students of geography)
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Mander, Ülo; Kull, Ain; Uuemaa, Evelyn; Mõisja, Kiira; Külvik, Mart; Kikas, Tambet; Raet, Janar; Tournebize, Julien; Sepp, Kalev (2018). Green and brown infrastructures support a landscape-level implementation of ecological engineering. Ecological Engineering, 120, 23−35.10.1016/j.ecoleng. 2018.05.019.

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Quality, Coimbra 12–14 October 2011. (Toim.) Cidalia C. Fonte, Luisa M.S. Goncalves, Gil Goncalves. Coimbra, Portugal, 2011, 171–176

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2015	Parim õppejõud aastal 2015. Geograafide valik
2009	Tartu Ülikool 2009. a. parim õppejõud realia et naturalia valdkonnas
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2. **Urmas Peterson.** Studies on Reflectance Factor Dynamics of Forest Communities in Estonia. Tartu, 1993.
3. **Ülo Suursaar.** Soome lahe avaosa ja Eesti rannikumere vee kvaliteedi analüüs. Tartu, 1993.
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9. **Kalev Sepp.** The methodology and applications of agricultural landscape monitoring in Estonia. Tartu, 1999.
10. **Rein Ahas.** Spatial and temporal variability of phenological phases in Estonia. Tartu, 1999.
11. **Эрки Таммиксаар.** Географические аспекты творчества Карла Бэра в 1830–1840 гг. Тарту, 2000.
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19. **Arvo Järvet.** Influence of hydrological factors and human impact on the ecological state of shallow Lake Võrtsjärv in Estonia. Tartu, 2004.
20. **Katrin Pajuste.** Deposition and transformation of air pollutants in coniferous forests. Tartu, 2004.

21. **Helen Sooväli.** *Saaremaa waltz*. Landscape imagery of Saaremaa Island in the 20th century. Tartu, 2004.
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23. **Anto Aasa.** Changes in phenological time series in Estonia and Central and Eastern Europe 1951–1998. Relationships with air temperature and atmospheric circulation. Tartu, 2005.
24. **Anneli Palo.** Relationships between landscape factors and vegetation site types: case study from Saare county, Estonia. Tartu, 2005.
25. **Mait Sepp.** Influence of atmospheric circulation on environmental variables in Estonia. Tartu, 2005.
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27. **Aarne Luud.** Evaluation of moose habitats and forest reclamation in Estonian oil shale mining areas. Tartu, 2006.
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31. **Üllas Ehrlich.** Ecological economics as a tool for resource based nature conservation management in Estonia. Tartu, 2007.
32. **Evelyn Uuemaa.** Indicatory value of landscape metrics for river water quality and landscape pattern. Tartu, 2007.
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