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Updating of vague geographic objects in topographic databases of NMCAs – case Finland

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Abstract: The identification and delineation of geographic objects, a fundamental yet subjective aspect of topographic mapping, forms the basis for creating abstract models of our surrounding physical environment and has captivated researchers due to its complexity and conceptual challenges. Although topographic maps and databases of the National Mapping and Cadastral Agencies (NMCAs) often represent objects with sharp boundaries, this is usually the result of practical reasons and user needs for modelling the data, rather than our know knowledge of inherent vagueness of many geographic objects and the associated cognitive processes involved in their recognition. The main objective of this article is to increase our understanding of the role of vague geographic objects as part of the topographic data production of NMCAs and to develop a generic TDB Change Detection tool to help the analysis of changed features in topographic databases (TDBs). The experimental part of this work is focused on the TDB versions produced by the National Land Survey of Finland (NLS) in 2021–2024 and it provides answers to (a) what kind and how many changes are made to the vague features in the NLS TDB within the observation period, and (b) how are the changes distributed by feature class and region. The selected vague feature classes were outcrops of bedrock, cliffs, young and other bogs, lakes and ponds, and contours. Buildings were used as a reference when analysing the total number of changes over the whole of Finland. The results show that the number of changes made for analysed feature classes was much higher than expected. The largest number of changes occurred in bogs, outcrops and contours. In general, the largest amount of modified features appeared to be concentrated in southern Finland and in the northernmost parts of Finland. The spatial variation in changes is explained both by the spatial variation in topography and by the individual characteristics of different topographers operating in different parts of Finland. Based on the results, the work made it possible to make a number of recommendations to 1) improve the understanding of the nature and significance of topographic interpreted data within NMCAs, 2) clarify NMCAs own position on the quality requirements for the geometry and timeliness of vague topographic features, 3) develop precise guidelines and guidance for the data collection process, 4) to develop tools to monitor the topographic data collection work done, and 5) for NMCAs to regularly archive frozen versions of their TDBs to enable efficient monitoring of data production process afterwards.

Keywords: data acquisition, topographic mapping, change detection, topographic data production

1. Introduction

The nature of data in topographic maps and databases (definitions in Table 1), has captivated researchers for decades. An elementary part of topographic mapping the is the chosen model of abstraction, which is based on the identification of separable entities, i.e. geographic objects (e.g. Burrough 1996). While identifying and delineating the objects may seem obvious at first glance, on closer inspection very little, if any, of the identification process is obvious. In fact, as noted by Argialas and Miliaresis (2001), the hardest and quite subjective part of topographic conceptualization of reality is actually the identification of these geographic objects, their organization, their relations, and their combinations.

Understanding and characterising the vagueness of geographic objects opened a whole subfield of research within geographic information science in 1990s. In her typology for vague geographic objects, Couclelis (1996) identified three perspectives relevant for defining the "level of vagueness": 1) Empirical nature of the entity, 2) mode of observation (and representation), and 3) user purpose. In the typology, the definition of the empirical nature of the entity was based on the use of ten concept pairs: atomic-plenum, homogeneous-inhomogeneous, continuous-discontinuous, connected-distributed, solid-fluid, two-three-dimensional, actual-non-actual, permanent-variable, fixed-moving, and conventional-self-defining. The mode of observation determined directly what kind of boundaries the geographic object would have, and that was based on scale, resolution, perspective, time, error and theoretical basis of the observation. In user purpose it was identified that different end user applications have different expectations on the representation of geographic objects. While some applications require that geographic entities are well-bounded and modes of representation and observation yield well-bounded objects, there was identified many other applications where the crispness of geographic

Source	Definition
Beaman (1928)	"A topographic map is a representation on paper that is designed to **portray certain selected features** of a section of the earth's surface plotted on some form of projection and to a certain scale"
GA (2016)	"Topographic maps are detailed, accurate **graphic representations of features** that appear on the Earth's surface…It is important to note that a map is merely a two or three dimensional representation of the physical environment at a given time. Therefore, a map will never be entirely up to date. Changes to the landscape and cultural features regularly occur (such as roads, vegetation, and buildings), resulting in maps becoming dated, although the rate of obsolescence varies depending upon location.
OS (2022)	"A topographic map's principal purpose is **to portray and identify the features** of the Earth."
USGS (2024)	"The distinctive characteristic of a topographic map is the use of elevation contour lines to show the shape of the Earth's surface…USGS topographic maps also show **many other kinds of geographic features** including roads, railroads, rivers, streams, lakes, boundaries, place or feature names, mountains, and much more."

Table 1. Selected definitions of a topographic map. While all definitions identify the role of "features" in topographic mapping, it is noteworthy that none of the definitions consider the vagueness of features or the role of human interpretation in identifying the features.

entities is not relevant at all. Characteristic for a topographic maps and databases is that while the empirical nature of entities and mode of observation are known to be vague, the user purpose leads to representations with sharp boundaries.

A more recent categorization has been presented by Liu et al. (2019), where they propose a framework conceptualising, interpreting, and modelling of vague geographic objects. The basis of the formalisation lies on application of the fuzzy set theory (Zadeh, 1965). Authors identify five categories of vague regions: 1) Direct field-cutting objects, 2) Focal operation -based field cutting objects, 3) Element-clustering objects, 4) Object-referenced objects, and 5) Dynamic-boundary objects. Similarities in the categorisations are evident, and while Couclelis (1996) aimed to be exhaustive in the definition, Liu et al. (2019) provided a pragmatic implementation of categories with characteristic membership functions for each category. Both categorizations provide excellent framework to analyse the nature of vagueness of geographic features in topographic databases.

Another key research topic related to topographic mapping is the change detection. Automatic and semi-automatic change detection in the context of topographic mapping primarily focuses on identifying and quantifying landscape alterations over time, such as shifts in land use, build environment, or vegetation cover (e.g. Chugtai et al. 2021, Bouziani et al. 2010, Nielsen and Olsen 2010). Technological disruptions in remote sensing and Geographic Information Systems (GIS) have greatly improved the spatial and temporal accuracy and efficiency of detecting such changes in landscape. High-resolution imagery and LiDAR technologies now enable precise monitoring of both natural and anthropogenic changes (e.g. Kaartinen an Hyyppä 2006). While most previous research has focused on identifying changes in physical reality that should be updated in topographic databases, far fewer studies can be found that use topographic databases to assess changes in physical reality – and for a reason. Topographic databases, which are often updated periodically to reflect changes in the real world, provide valuable temporal records, but the challenge in using such data remains that changes in the database reflect either changes in the real world, or changes in the way physical reality is abstracted in the topographic database, or both. This leads to a research idea of this paper that has been largely unexplored: The use of topographic database time series for the analysis of topographic data updating processes.

Despite the undeniable challenges of making interpretations of geographic objects, topographic maps have maintained their unique position of authority amongst plethora of cartographic products. This status has been attributed, at least in part, to the apparent scientific precision with which the features of the map correspond to objects of the real world, but it is also a reflection of state authorship and production (Kent and Hopfstock 2018). However, it is noted that the main challenges for today's National Mapping and Cadastral Agencies (NMCAs) are the efficient management of resources, the productive use of new technologies, the development of diverse mapping products that meet the ever-increasing expectations of users in different application areas, and the management of competition from products developed by the private sector (Kent and Hopfstock 2018). The dichotomy in the present day NMCA's challenges is that despite the technological challenges leaning towards the future, the agencies must always make sure that the present-day production as efficient as possible. These are not mutually exclusive challenges, but both should be addressed continuously and simultaneously.

The main objective of this article is to increase the understanding of the role of vague geographic objects as part of the topographic data production of NMCAs. When the scientifically fascinating vagueness of geographic objects are handled in the context of topographic data production in NMCAs, the fascination turns quickly and very concretely into hours of work and ultimately into the amount of used resources. One might reasonably ask how

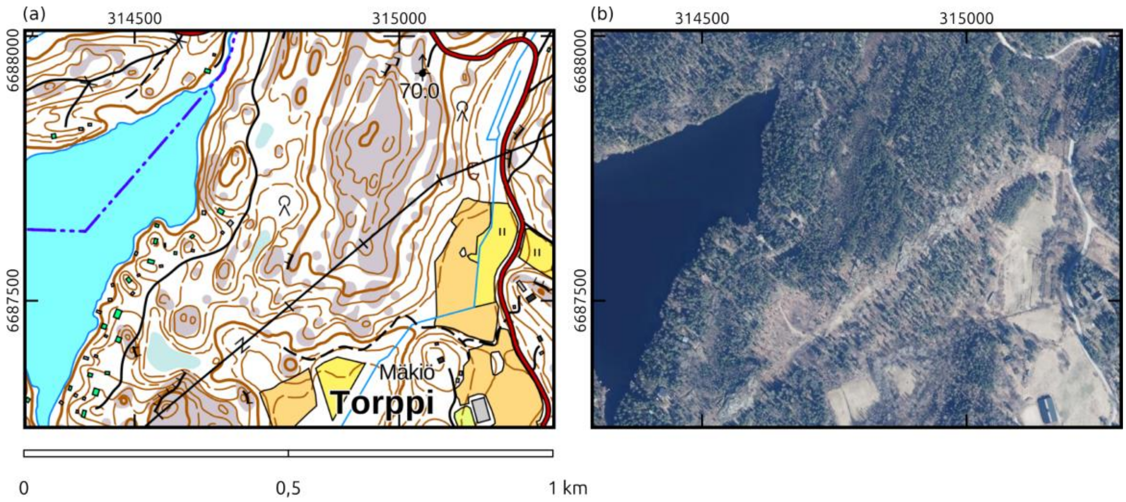

Figure 1. Example of the (a) topographic map and (b) the orthophoto by the NLS. Focus of this study are outcrops (grey polygons), cliffs (black lines with hairline tic marks), different types of bogs (cyan polygons without border lines), lakes and ponds (bright cyan polygons with blue border lines), and contours (brown lines). Buildings (green and grey rectangles) are used as a reference representing unambiguous objects in the TDB. Contains NLS Topographic data and Orthophoto 11/2024.

much time and money it is wise and sustainable to invest in frequently updating the details of such vague features, given that different topographers often interpret them differently, and even the same topographer may give different interpretations of the same feature on different days.

In order to meet this objective in a concrete way, the experimental part of this work is focused on the Topographic Database (TDB) produced by the National Land Survey of Finland (NLS). The main research questions of this work are:

a) What kind and how many changes are made to the vague features in the NLS TDB?

b) How are the changes distributed by feature class and region?

In order to answer the questions, this paper presents a generic open source QGIS Processing tool. The tool makes it easy to compare geometries in two different time points of a topographic database time series. Changes related to attributes are excluded in this study. The developed tool is used in a case study to identify changes in selected set of vague features in the Finnish Topographic Database. In addition, buildings representing unambiguous objects were included in the analysis for reference. As justified in the Introduction, it was assumed that the number of changes in selected feature classes would be small. Based on the results, suggestions for improvements are presented to enhance the efficiency of the production processes of the topographic data in NMCAs.

2. Materials and methods

The study focuses on changes of vague objects in the NLS TDB produced between 2021 and 2024 (Figure 1). The selected feature classes (and their geometry types) are as follows (Table 2):

a) outcrops of bedrock (polygon),
b) cliffs (line),
c) young bogs (polygon),
d) other bogs (polygon),
e) lakes and ponds (polygon), and
f) contours (line).

In addition to listed feature classes, changes in building feature class (polygon) were used as a reference for analysing the total number of changed objects. By using the typologies of Couclelis (1996) and Liu et al. (2019), outcrops, young bogs, and other bogs can be characterised as extensive regional entities (as opposed to

Feature class	2021	2024
Outcrops	*/MTK-kallio_21-06-03.gpkg	**/MTK-kallio_24-08-01.gpkg
Cliffs	*/MTK-muut_21-06-03.gpkg	**/MTK-muut_24-08-01.gpkg
Young bogs	*/MTK-suo_21-06-03.gpkg	**/MTK-suo_24-08-01.gpkg
Other bogs	*/MTK-suo_21-06-03.gpkg	**/MTK-suo_24-08-01.gpkg
Lakes/ponds	*/MTK-vakavesi_21-06-03.gpkg	**/MTK-vakavesi_24-08-01.gpkg
Contours	*/MTK-korkeussuhteet_21-06-03.gpkg	**/MTK-korkeussuhteet_24-08-01.gpkg
Buildings	*/MTK-rakennus_21-06-03.gpkg	**/MTK-rakennus_24-08-01.gpkg

* = https://www.nic.funet.fi/index/geodata/mml/maastotietokanta/2021/gpkg

** = https://www.nic.funet.fi/index/geodata/mml/maastotietokanta/2024/gpkg

Table 2. Datasets with URLs used in the study. 2021: http://urn.fi/urn:nbn:fi:att:da5e0f88-1ffd-4e24-841c-3fe2d22d1cce, 2024: http://urn.fi/urn:nbn:fi:att:939b5599-81bd-4def-a5bc-7589a00f51ee.


```
1: Initialize sources
    source_t1 ← set original vector dataset
    source_t2 ← set changed vector dataset
2: Extract processing parameters
    tolerance_internal ←
        set tolerance for detecting a change
    tolerance_external ←
        set tolerance for identifying duplicate changes
3: Calculate centroids for features
    centroids_t1 ← calculate centroids for source_t1
    centroids_t2 ← calculate centroids for source_t2
4: Buffer centroids
    buffers_t1 ← buffer centroids_t1 with tolerance_internal
    buffers_t2 ← buffer centroids_t2 with tolerance_internal
5: Identify changed centroids between t1–t2 and t2–t1
    changes_t1 t2 ←
        calculate difference between centroids_t1 and buffers_t2
    changes_t2 t1 ←
        calculate difference between centroids_t2 and buffers_t1
6: Remove duplicates of detected changes
    buffered_changes_t1 t2 ←
        buffer changes_t1 t2 with tolerance_external
    non-duplicate_changes_t2 t1 ←
        calculate difference between changes_t2 t1 and
        buffered_changes_t1 t2
7: Merge the final results
    all_changes_t1 t2 ←
        merge changes_t1 t2 and non-duplicate_changes_t2 t1
```

Table 3. Pseudo-code for the change detection algorithm.

atomic entities) with ill-defined boundaries. Cliffs can be seen as an example of the discontinuous-continuous case, where a place on a map that is certainly a cliff gradually changes into something that is definitely not a cliff. The shores of lakes and ponds are a special case because their water levels change seasonally and thus represent the dynamic boundary objects. Contours represent abstract cartographic elements that have no real-world counterpart. In this context, buildings are used to represent sharp objects, although it is well known that there are also many uncertainties associated with their digital representation. However, these are fundamentally different from the uncertainties associated with delineating, for example, outcrops or bogs.

2.1 QGIS Processing tool: TDB Change Detector

The developed TDB Change Detector tool is based on the identification of changes in the centroids of the geographic features represented as points, lines, or polygons (Table 3). The change in the centroid indicates one or more changes in the vertices of the feature, and conversely, the number of changed vertices cannot be deduced from the changed centroids. However, focusing on centroids simplifies the computational complexity of the task and provides information that is suitable for analysing the spatial frequency of changes.

Feature class	Internal tolerance (m)	External tolerance (m)
Outcrops	0.1	30
Cliffs	0.1	30
Young bogs	0.1	30
Other bogs	0.1	30
Lakes/ponds	0.1	50
Contours	0.5	30
Buildings	0.1	10

Table 4. Tolerance values for each feature class used in this study.

The change detection is controlled by two parameters: internal and external tolerance. The internal tolerance sets a limit of uncertainty for a change detection. This prevents over-sensitive interpretation of changes in situations where, for example, for cartographic reasons, the boundary of an object has been technically smoothed between two different points in time. The external tolerance is used for removing duplicate detections of change.

When data from two points in time are compared, the change between them is identified as applying to data from both moments. The external tolerance is defined as how close (in terms of spatial distance) a change in both moments is interpreted as representing the same change.

There are no universal optimal values for tolerances, but their values must be set interactively in a way that is appropriate for each data set being compared and the task to be fulfilled.

The tolerance values used in this work are summarised in Table 4. Using these parameters, the observed changes can be grouped into four different categories (Figure 2): 1) unchanged features, 2) added features, 3) removed features, and 4) geometrically modified features. This paper focuses on the analysis of the categories 2–4.

2.2 Cartographic representation of results

All detected changes in the NLS TDB between 2021–2024 are aggregated according to 12km*24km (288km^2) 1:25 000 scale map sheets of the TM35 map sheet division used together with the Finnish ETRS-TM35FIN coordinate system (NLS 2024). This is done to make regional comparison of detected changes easier and to make the results comparable with the NLS TDB

Feature class	Features 2021	Features 2024	Changes 2021-2024	% 2021-2024
Outcrops	1359169	1296647	247930	19%
Cliffs	206085	208771	40590	19%
Young bogs	647872	630730	111881	18%
Other bogs	1360398	1402869	334125	24%
Lakes/ ponds	160676	152908	32887	22%
Contours	6876906	6865642	247895	4%
Buildings	*5508185*	*5608923*	*811682*	*14%*

Table 5. Number of features in each observed feature class in 2021 and 2024, and number and percentage of changed objects between 2021–2024 (compared to 2024 datasets).

production areas. In total, there were 1409 map sheets with data included in this analysis.

3. Results

3.1 Characteristics of changed features

The changes that have been made to the vague features manifest themselves in many different ways. For example, it appears that small areas of outcrop have either been removed or merged into larger units. Also, entirely new outcrops have been added and the details of outcrop boundaries have been changed (Figure 2a). In the case of cliffs, in addition to new and deleted features, the ends of line segments have been either shortened or lengthened (Figure 2b). Young bogs and other bogs (Figures 2c-d) are characterized by large-scale changes in which the entire shape of the bogs has been reinterpreted. Lakes and ponds are characterized by changes in shoreline detail and the removal of entire ponds (Figure 2e). Contours are largely unchanged, but there are regions where the contour interpretation appears to have been completely reworked (Figure 2f).

3.2 Totals by all changes in each feature class

According to the results, the number of vague features in selected feature classes varied between 152 908 (Lakes and ponds in 2024) and 6 876 906 (Contours in 2021) (Table 5). The number of changed features in 2021–2024 varied between 32 887 (Lakes and ponds) and 334 125 (Other bogs). In this context, the indicator values of contour lines appear incommensurable because their division into individual objects and the changes occurring within them is particularly artificial. However, it is interesting to note that there were 247 895 contour objects that had changed. Buildings, used as a reference, had 811 682 changed features between 2021–2024.

Looking at all other vague feature classes, except

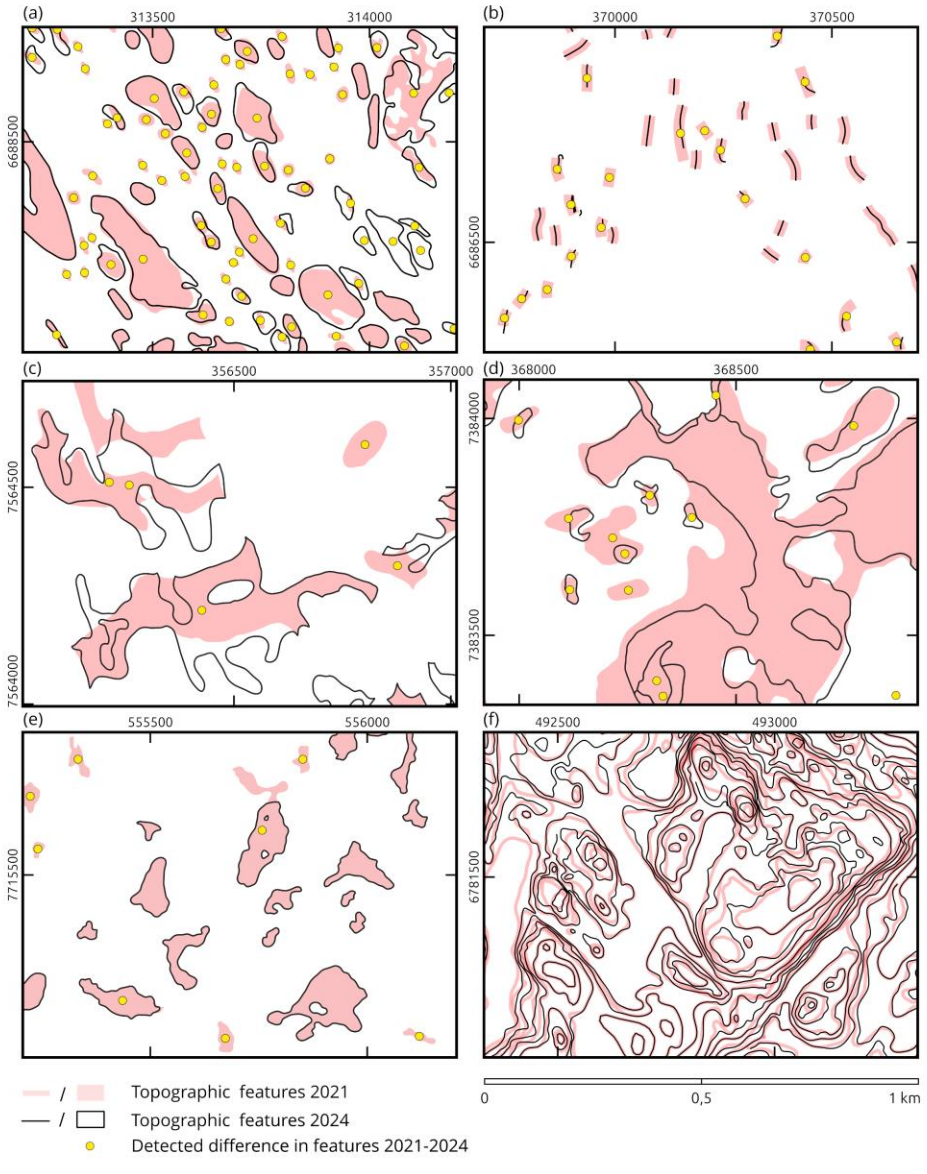

Figure 2. Examples of the application of the TDB Change Detection tool to the NLS Topographic Database features: (a) outcrops, (b) cliffs, (c) young bogs, (d) other bogs, (e) lakes and ponds, and (f) contours. The detected changes in the centroids of contours (f) are hidden to make the differences in individual contours more visible. Contains data from the NLS Topographic Database 2021 and 2024.

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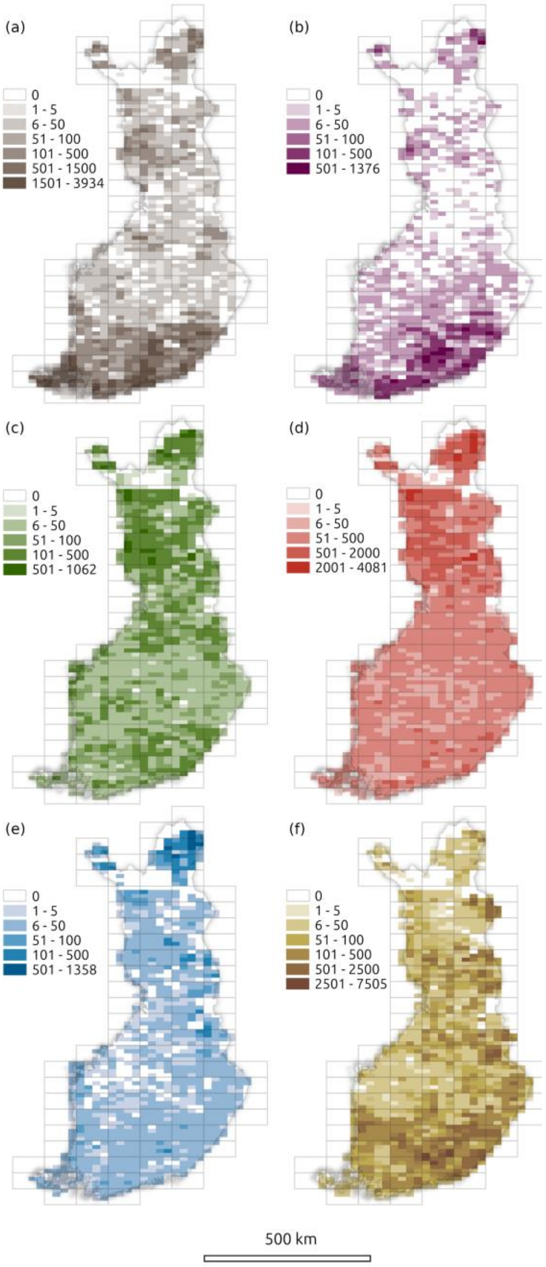

Figure 3. Number of detected changes in the NLS Topographic Database features 2021–2024 according to the Finnish TM35 map sheet division: (a) outcrops, (b) cliffs, (c) young bogs, (d) other bogs, (e) lakes and ponds, and (f) contours. Contains data from the NLS small scale maps 2024.

contours, it appears that on average 21% of the features in the 2024 datasets have been modified. This is 7 percentage units higher than the value for modified building features in 2021–2024. The total number of changed features in all observed vague feature classes is 1 015 308.

3.3 Regional results by each feature class

The number of changes in the features representing outcrops of bedrock varies between 0–3934 according to TM35 map sheet division (Figure 3a). In 17% of the map sheets there were no changes, whereas 34% had more than 50 changes. 37 (2.6%) map sheets had more than 1500 changed outcrops. The largest clusters of high change frequencies are in the Southern and North-Eastern Finland, where also the highest frequencies of the outcrops are found (Figure 4a).

When looking cliff features, the number of changes varied between 0–1376 (Figure 3b). As many as 33.5% (472) map sheets did not have any changes, whereas 1% (13) sheets had more than 500 changes. For nearly 55% (770) of map sheets there were 1-50 changes done for cliffs. Similar to outcrops, the largest clusters of high change frequencies are in the South-Eastern and North-Eastern Finland, where also the highest frequencies of the cliff features are found (Figure 4b).

For young and other bogs (Figure 3c-d), the highest number of changes per map sheet varies between 1062 (young bogs) and 4081 (other bogs). Less than 9% of the map sheets had no changes, while almost 44% (618) for young bogs and 69% (973) for other bogs of the map sheets had more than 50 changed features. Spatially, the highest frequencies of changes for both feature classes are clustered in the boggy area in North-Western Finland (Figures 3c-d and 4c-d).

The number of changes in the features representing lakes and ponds varies between 0–1358 (Figure 3e). In nearly 15% (207) of the map sheets there were no changes, whereas 8% (114) had more than 50 changes. The largest cluster of high change frequency is in the Lapland lake region in North-Eastern Finland (Figure 3e and 4e).

For contours, the number of changes varied between 0–7505 per map sheet (Figure 3f). In nearly 11% (153) of the map sheets there were no changes, whereas 46% (654) had more than 50 changes. All highest frequencies are clustered in South-Eastern Finland and more northern location in the immediate vicinity of the East border of Finland (Figures 3f and 4f).

4. Discussion

As summarised in the introduction to this paper, there is a large amount of uncertainty in the interpretation of topographic features. In the same way, there is also a large amount of uncertainty in the interpretation of changes in topographic features. While the detection of a change in the geometry of an object is unambiguous from the technical point of view, the actual nature of the change is still uncertain. Is the change a real change in the real-world object or merely a change in the interpretation of the object? When the number of changes that have occurred is considered, the interpretations become even more uncertain. When two objects in database from two different points in time merge into one object, has there happened one, two, or three changes? And what is the number of changes when two objects close to each other disappear and a new object appears near them? There is no real unambiguous answer to these questions, but we can still create criteria for the analysis process that will guide the output of the developed TDB Change Detector tool and allow us to interpret the changes in the topographic objects. What matters is not

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the exact number of changes detected, but the fact that vague geographic features are actively changing at all, and by analysing their spatial variation we can try to understand the processes that have led to the changes.

When we look at the geometries of the vague features in the selected target categories in the TDB, it seems that the changes made indicate more the difficulty of interpreting the features from the stereo model than changes in the landscape caused by human activity or ecological succession. In addition, the analysis period 2021–2024 is so short that it is not even possible to distinguish the natural changes in the environment in the selected target categories from aerial photographs. An exception to this would be changes associated with rapid hazardous events, such as a forest felled by a storm or a rapid drop in water level caused by a dam burst, but these are not the changes observed in this study on a large scale.

The hypothesis about the low number of changes in vague topographic features was not valid. The results show that the number of changes made was much higher than expected. The largest number of changes occurred in the target classes of bogs, outcrops and contours. In general, the largest number of changes seemed to be concentrated in southern Finland and in the northernmost parts of Finland. Large unaltered coherent areas were the most common for cliffs. The spatial variation in changes is explained both by the spatial variation in topography and by the individual characteristics of different topographers operating in different parts of Finland.

An overall view of the changes made to vague features allows speculation on the work time taken to make them. The total number of changes in the vague feature classes examined was 1015308 and if we assume that it takes the stereo operator one second to change one item, the total working time to implement all the changes observed in this analysis is 39 person-days (assuming a working day of 7.25 hours). If we assume that it takes 5 seconds to change one item, the total working time increases to 194 working days and to 389 working days if we assume 10 seconds. This example shows that even with small working time assumptions, the time taken to make the observed changes is significant. However, it is worth stressing that speculation on working times is not based on any real measurement of the work process and that the individual changes observed may have taken very short and very long periods of time.

Finally, it is worth noting that only six feature classes in the TDB were examined in this study. In total, there are currently more than 450 target categories in the TDB (NLS, 2025). It is a completely different subject of study to determine how many vague feature classes exist in the entire TDB and how many changes are identified in relation to them.

5. Conclusions

In this work, a tool was developed for the interpretation of changed objects in topographic databases and it was used to interpret the changes to the vague features in the NLS TDB from 2021 to 2024. The results showed that more changes than expected have been made to indeterminate objects in the data production process and based on the analysis of the results, it seems that the time spent on making them has possibly been significant. The work makes it possible to make a number of recommendations on data collection processes and tools:

- It would be important to improve the understanding of the nature and significance of

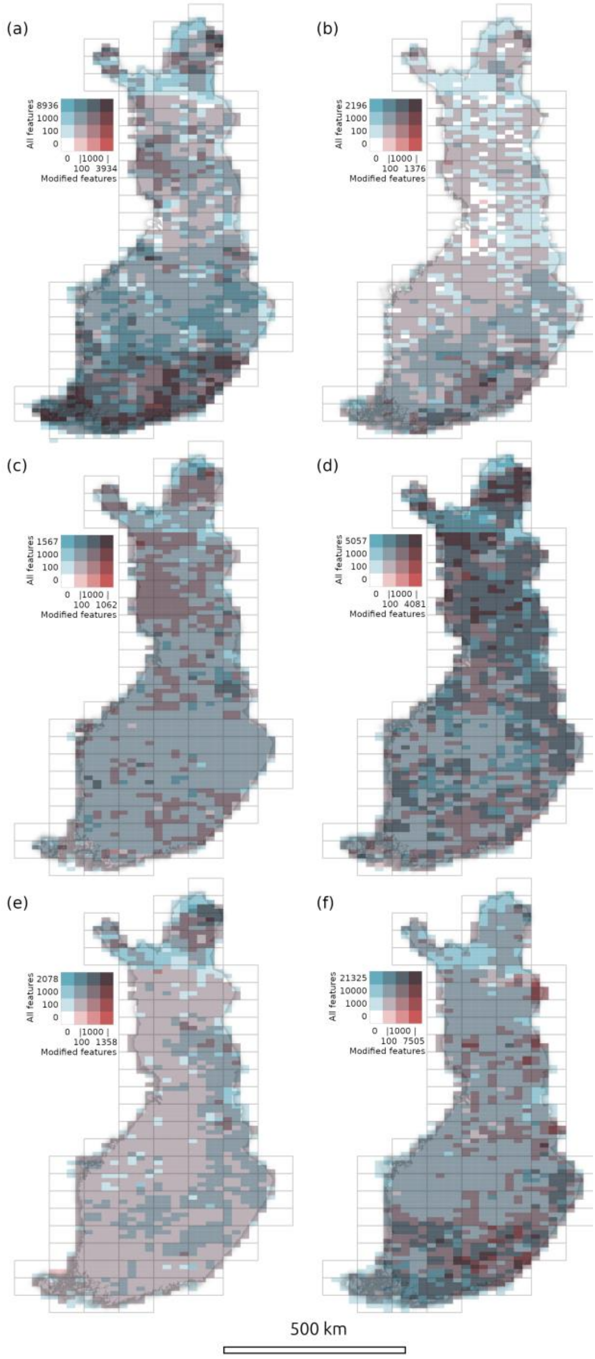

Figure 4. Number of features and number of detected changes in the NLS Topographic Database features 2021–2024 according to the Finnish TM35 map sheet division: (a) outcrops, (b) cliffs, (c) young bogs, (d) other bogs, (e) lakes and ponds, and (f) contours. Contains data from the NLS small scale maps 2024.

topographic interpreted data within NMCAs, both among stereo operators and management.

- It would be important for NMCAs to clarify their own position on the quality requirements for the geometry and timeliness of vague topographic features.
- Following this, it would be important to develop precise guidelines and guidance for the data collection process, so that time is focused primarily on identifying the targets that the NMCA wants.
- In addition to recommendations and guidelines, it would be essential for the management of the work to have tools to monitor the work done. With the right tools, transparency of the data collection process would increase and trust between the topographers and the work management would improve. An example of such a tool is the open TDB Change Detector QGIS Processing tool developed in this work.
- It would also be important for the NMCAs to regularly archive frozen versions of their TDBs. Traditional SDI solutions focus on storing and distributing the most current data, but historical data is also very important for monitoring environmental changes on the one hand, and data collection processes on the other.

In relation to the development of the NLS TDB production in Finland, the findings presented in this work have already influenced the production process and the future production system for terrain data will enable a whole new way of monitoring changes made to the topographic features in the TDB.

5.1 Acknowledgements

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5.2 Appendix

The TDB Change detection software (QGIS Processing tool) with instructions for use and sample data are available at Zenodo: 10.5281/zenodo.15166990

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