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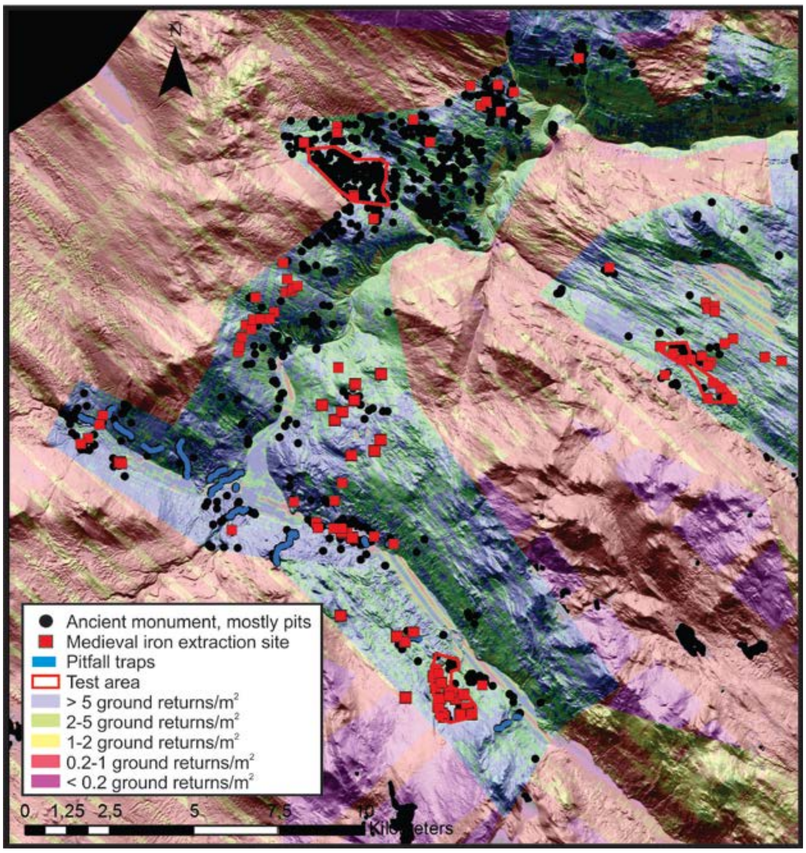
Note

Application of Remote Sensing in Cultural Heritage Management

Project report 2013



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UiO : Kulturhistorisk museum

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Abstract

This project was started in 2002 with the overall aim of developing a cost-effective method for surveying and monitoring cultural heritage sites on a regional and national scale. The project focuses on the development of automated pattern recognition methods for detecting and locating cultural heritage sites. The pattern recognition methods are included in a prototype software called *CultSearcher*. This software currently supports the following: (1) Search for crop marks and soil marks in optical satellite and aerial imagery; these marks could be levelled grave mounds. (2) Search for pits in airborne laser scanning (ALS) data; these pits could be pitfall traps or charcoal burning pits. (3) Search for heaps in ALS data; these heaps could be Iron Age or Bronze Age grave mounds.

This note describes the achievements of the project during 2013. The project is funded by the Norwegian Directorate for Cultural Heritage. In 2013, the semi-automatic method in CultSearcher for the detection of grave mounds was used in detailed mapping of grave mounds in Tønsberg municipality, Vestfold County. Oppland County Administration has continued to use the semi-automatic method in CultSearcher for detailed mapping of archaeological pits, and reports on such mapping in Nord-Fron and Sør-Fron municipalities.

Keywords	Airborne laser scanning, burial mounds, pitfall traps, hunting systems, charcoal burning pits, iron extraction sites, Iron Age, crop marks.
Target group	Archaeologists, remote sensing researchers
Availability	Open
Project number	220541
Research field	Archaeology, remote sensing
Number of pages	119

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1 Introduction

Several Norwegian municipalities are experiencing growing pressure on agricultural and forested land for development, being it new residential areas, new mountain cabins and hotels, new highways, or other purposes. The traditional mapping of cultural heritage, mainly based on chance discovery and with inaccurate positioning, has proven inadequate for land use planning. Therefore, the Norwegian Directorate for Cultural Heritage, in cooperation with some Norwegian counties and municipalities, are investing in the development of new methods, using new technology, for a more systematic mapping of cultural heritage.

A project was started in 2002 by the Norwegian Directorate for Cultural Heritage, aiming at developing cost-effective methods for surveying and monitoring cultural heritage on a regional and national scale. During the first years, the focus was on the automatic detection of crop marks and soil marks in cereal fields in satellite and aerial images (Aurdal et al., 2006; Trier et al., 2009). Several of these detections have been confirmed to be levelled grave mounds, dating to 1500-2500 years ago.

However, methods based on optical images are of limited value in forested areas, since the archaeology tends to be obscured by the tree canopies. However, by using airborne laser scanning (ALS) data, the forest vegetation can be removed from the data, which makes it possible to detect archaeology in a semi-automatic fashion, provided the archaeology manifests itself as details in the digital elevation model (DEM) of the ALS ground returns (Figure 1), and that these details may be described using some kind of pattern.

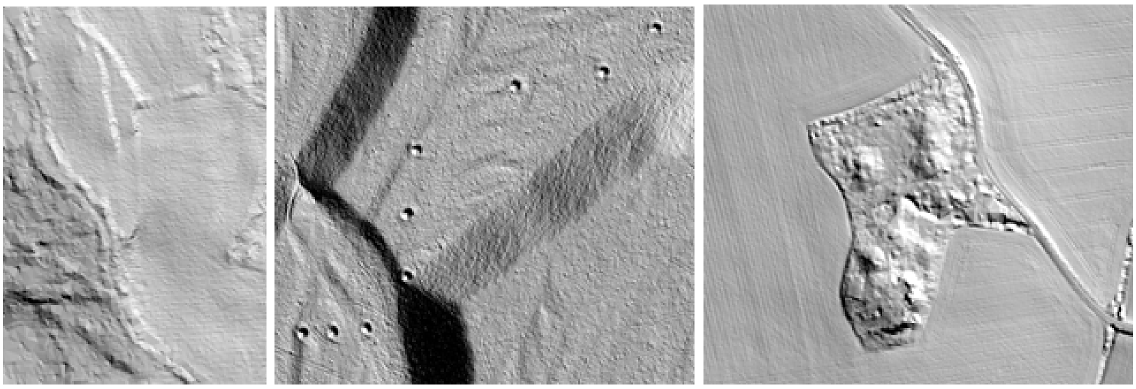


Figure 1. Airborne laser scanning (ALS) data from some Norwegian municipalities. Left: Kongsberg, with stone fences. Middle: Nord-Fron, with pitfall traps for moose hunting. Right: Larvik, with grave mounds.

In 2010, the project started the development of an automatic method for detecting pits in DEMs of ALS ground returns. The method was used to map hunting systems, iron extraction sites and charcoal burning pits (Trier and Pilø, 2012) in two ALS datasets: Olstappen (29 km^2, Nord-Fron municipality, Oppland County, 10 emitted pulses per m^2) and Øystre Slidre (400km^2, Øystre Slidre municipality, Oppland County, 5/m^2). In 2011, initial attempts were made at detecting heaps in ALS data. These heaps could be Iron Age or Bronze Age grave mounds. Preliminary experiments on ALS data from known grave mound sites in Larvik municipality, Vestfold County were promising.

The rest of the report is organized as follows. Section 2 describes the field work done in 2013 as part of the on-going mapping of cultural heritage from ALS data in Oppland County. Sections 3-5 describe field work done in 2013 in Tønsberg municipality, for the on-going mapping of grave mounds in Vestfold County. Section 6 contains a paper presented at the 4th EARSeL Workshop on Cultural and Natural Heritage, 6-7 June 2013, Matera, Italy.

Many of the illustrations are superimposed on base maps from the Norwegian Mapping Authority (Statens Kartverk).

2 Mapping of archaeological pits in Oppland County

By Lars Holger Pilø, Oppland County Administration

2.1 Introduction

The Cultural Heritage Department of Oppland County Council is currently conducting a large project, using high-density airborne laser scanning (ALS) to map ancient monuments. Approximately 3200 km^2 were mapped in 2013, mainly forested areas, bringing the total up to ca. 4700 km^2. Automatic pit detection by *CultSearcher* has been used to support visual inspection of the ALS data.

Oppland County Council undertook three separate ground-thruthings of objects in 2013, based on ALS data from 2012. The purpose was to investigate whether data collected during visual inspection of ALS data, supported by automatic detection, was of a sufficient quality to allow it to be entered into the national database of ancient monuments without a field control. The three areas chosen for fieldwork were situated in the Nord-Fron and Sør-Fron municipalities in the central part of Oppland County.

2.2 Data

The ALS data from 2012 is DTM10 5 point data, i.e. the number of first returns pr. m^2 is 5 points or better and the individual points have a precision of better than 10 cm. The ALS data for all the three areas belong to the same scanning-project. The laser-scanning instrument was a TopEye System, with a frequency of 200 000 Hz, mounted on a helicopter.

The density map of ground returns shows that nearly all the areas have more than 2 ground returns pr. m^2 (colour coding in Figure 2-Figure 4). Some parts have more than 5 ground returns.

2.3 Method

2.3.1 Visual inspection

A highly detailed model was constructed from the ALS ground points, with a grid size of 0.25 m. The software used was Quick Terrain Modeler. An additional generalized model was constructed, with a 2 m grid size. The generalized model was then subtracted from the highly detailed model as a change analysis with an interval of 0.5 m. In this way a local contrast was produced, showing very local differences in height as differences in color instead of as shadows, as in the case of hill-shade. In many ways this represents a local relief model (Hesse, 2010), and will be referred to further here as a LRM-model.

Visual inspection of the LRM-model took place using one screen with an exported 2D-geotiff of the LRM-model (azimuth 0, elevation 55) in in ESRI ArcGIS and one screen with a 3D-LRM-model in Quick Terrain Modeler. The visual inspection was supported by automatic pit detections marked in the ArcGIS-project. All automatic detections were visually checked on the screen. Some were found to be ancient monuments or anomalies, while others were discarded during the inspection process. CultSearcher produces a varying number of false detections depending on topography, data quality and modern activity. The main purpose of using automatic detections during the visual inspection is to achieve a consistent quality of archaeological data, cutting down on human error during inspection, i.e. missing objects.

Objects are marked in two different shape-files during visual inspection. Objects that are believed to be ancient monuments (based on experience) are geo-referenced with a point in the center of the objects in an “Ancient monument” shape-file. Other objects that could possibly be ancient monuments, but where interpretation of the DTM is more uncertain, are marked in an “Anomaly” shape-file. The main reason for splitting the objects into two groups is that the “Ancient monument” shape-file is made available to area-planners, while the “Anomaly” shape-file contains too many false objects to be of use to planners.

2.3.2 Fieldwork

In all three areas, a single archaeologist, using a handheld GPS with DPOS correction, undertook ground-truthing. The GPS contained a GIS-project, including the objects both from the “Ancient monument” and the “Anomaly” shape-file. To avoid visual clutter on the small GPS-screens the automatic detection data were not included.

Ground-truthing was undertaken by walking from “Ancient monument” point to point and checking each object. Anomalies were also checked, but to a varying degree in the different areas (see below). No systematic surface survey was undertaken, but the terrain was surveyed when walking between checked objects, yielding some impression as to the presence of visible objects, not found during the visual inspection of the ALS data.

Fieldwork at Venlisætra and Fagerlisætra was undertaken by Lars Pilø, while the ground truthing at Stølssletta was undertaken by Anna McLoughlin.

2.4 Results

2.4.1 Stølssletta, Nord-Fron municipality

The Stølssletta area is situated in a forested area adjacent to modern farm settlement in the Skåbu Valley at an altitude of 760-910 m.a.s.l. The checked area covered 2.5 km^2 (Figure 2). The hilly terrain is sloping towards the Northeast. The area contains single charcoal pits of a medieval date, and occasional pit fall traps, dating to the Iron Age and Medieval Period.

Anomalies were systematically checked during the ground-truthing at Stølssletta (Table 1). No additional objects were found during fieldwork.

Table 1. CultSearcher detections versus field verification at Stølssletta.

Objects	True	False	Total	% True
Ancient monuments	100	5	105	95,2
Anomalies	8	22	30	26,7
Total	108	27	135	

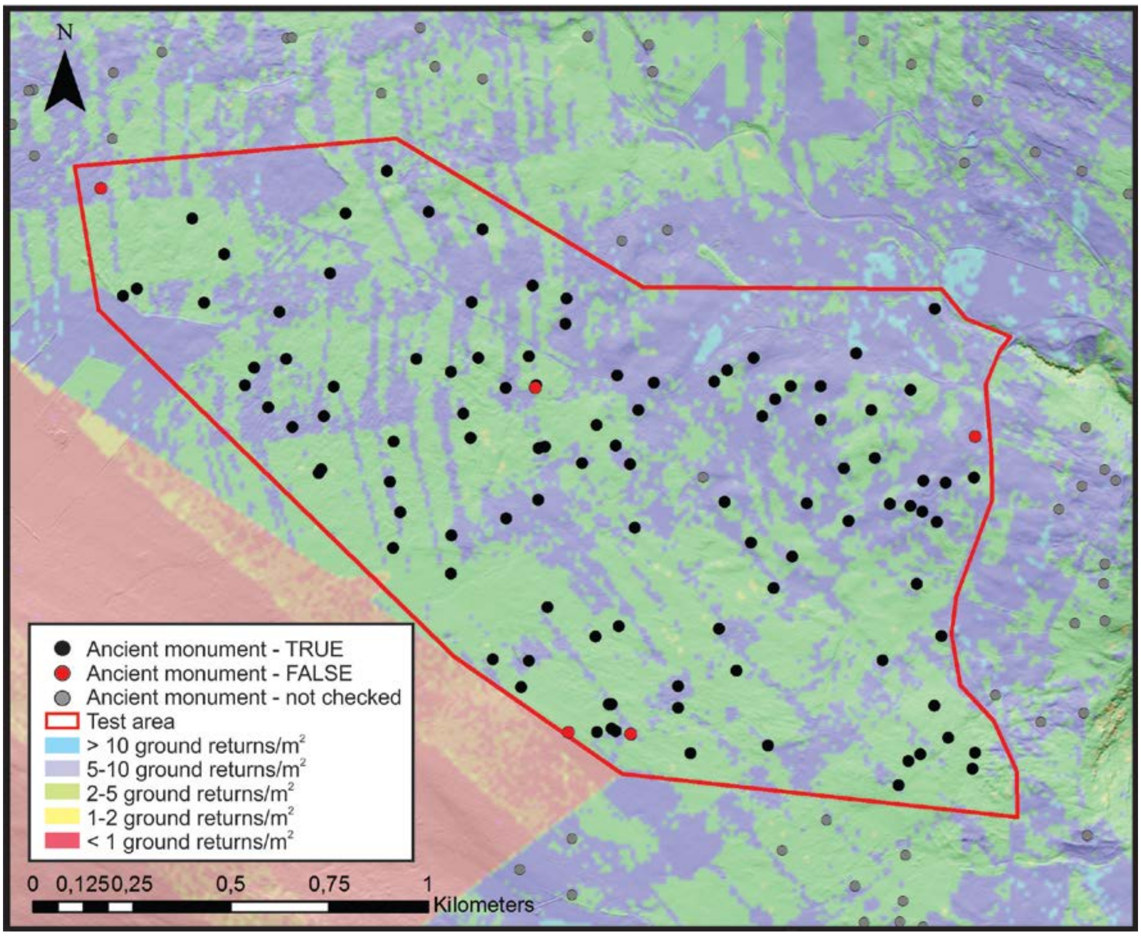


Figure 2. The test area at Stølssletta, Nord-Fron municipality.

2.4.2 Venlisætra

The Venlisætra area is a summer farm area at an altitude of 720-960. It covers 1.6 km^2 in a Northeast-facing slope. It contains Medieval iron extraction sites with clusters of charcoal pits, single charcoal pits from the Medieval Period, pitfall traps from the Iron Age and Medieval Period, and occasional above ground charcoal kilns mainly dating to between the 17th and 19th century.

Anomalies were checked in the first part of the survey, but as the first 11 yielded no true objects, the checking of these objects was discontinued, to allow for a larger number of checked objects in the “Ancient monuments” group (Table 2). No additional objects were found during ground truthing.

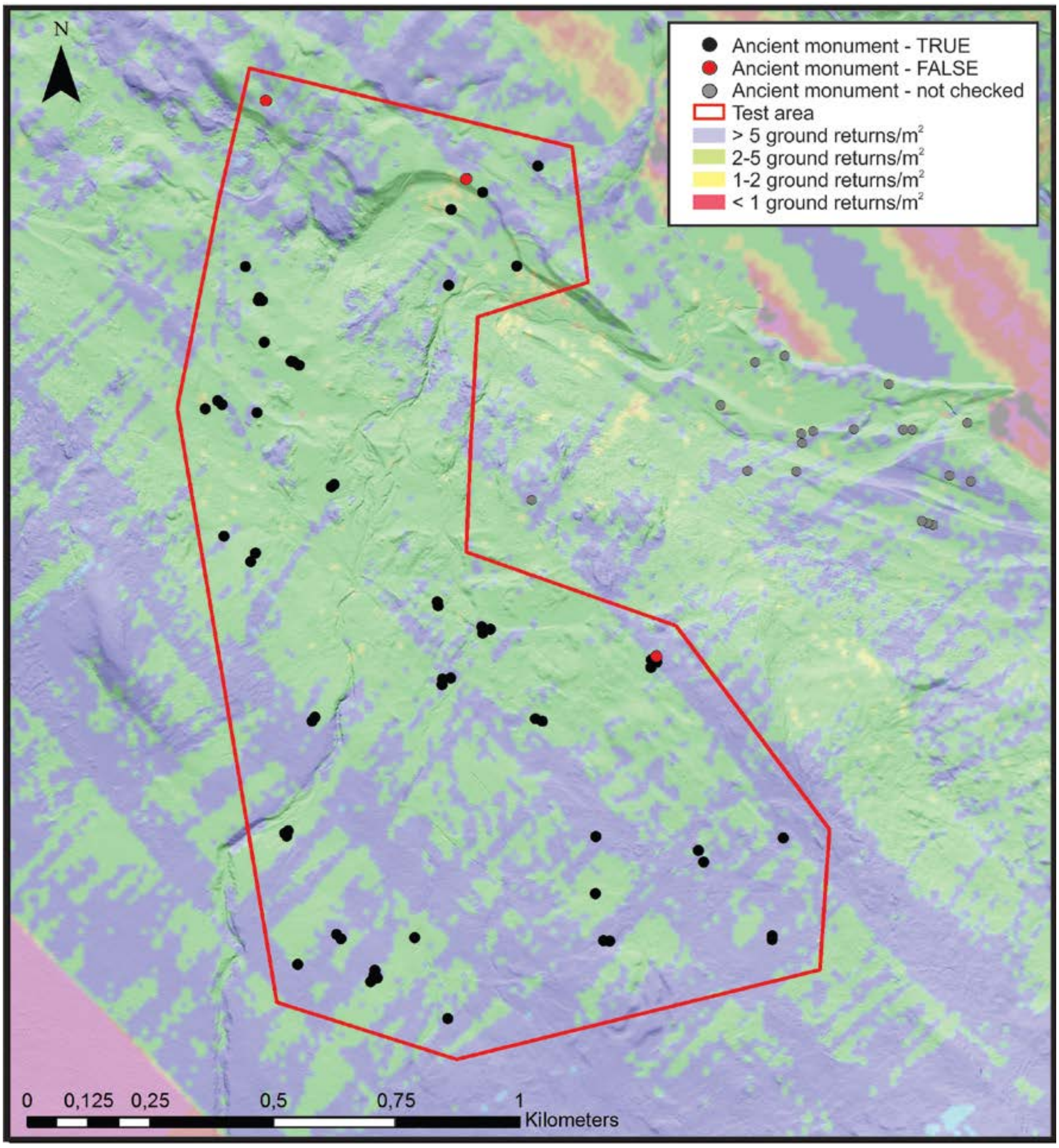


Figure 3. The test area at Venlisætra, Sør-Fron municipality.

Table 2. CultSearcher detections versus field verification at Venlisætra.

Objects	True	False	Total	% True
Ancient monuments	60	3	63	95.2
Anomalies	0	11	11	0
Total	39	0	39	

2.4.3 Fagerlisætra

The Fagerlisætra test area (Figure 4) is situated in a lightly forested area with summer farms. It covers 1.1 km^2 at an altitude of 870-930 m.a.s.l. The area contains medieval iron extraction sites with clusters of charcoal pits, single charcoal pits from the Medieval Period, and occasional above ground charcoal kilns mainly dating to between the 17th and 19th century.

Only two anomalies were checked in this area (Table 3). Both were small charcoal pits, adjoined to the same iron extraction site. Two additional objects were discovered during the ground-truthing. Both had been categorized as Class 2 objects (low probability) by CultSearcher during the automatic pit detection, but had been discarded during the visual inspection of the ALS data. As the automatic detections had not been included in the field GIS-project, it was only later discovered that they had in fact been targeted by the automatic detection.

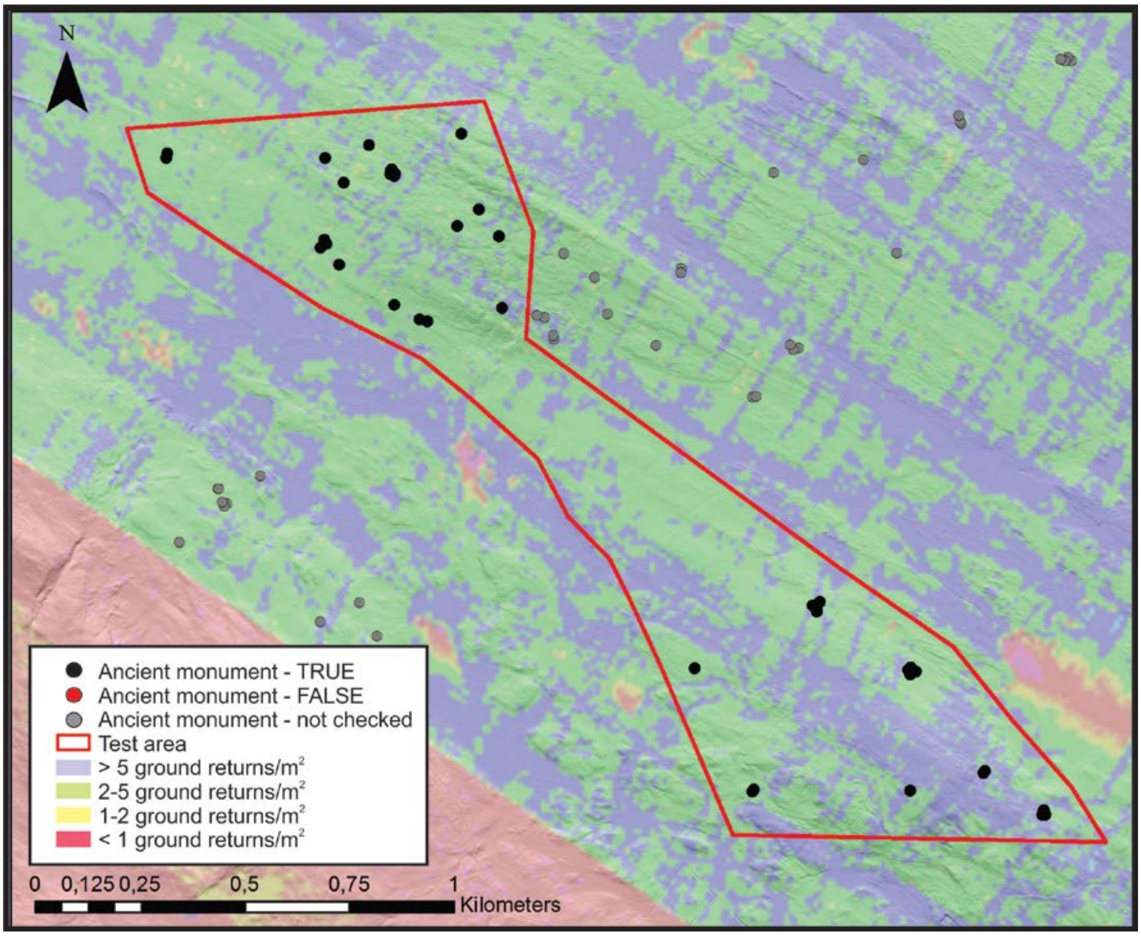


Figure 4. The test area at Fagerlisætra, Nord-Fron municipality.

Table 3. CultSearcher detections versus field verification at Fagerlisætra.

Objects	True	False	Total	% True
Ancient monuments	**37**	**0**	**37**	**100**
Anomalies	**2**	**0**	**2**	**100**
Total	**39**	**0**	**39**	

2.5 Discussion

The three checked areas are relatively similar. They are situated at an altitude of above 700 m.a.s.l. Two areas (Stølssletta and Venlisætra) are situated in a Northeast-facing slope while Fagerlisætra has a slightly undulating topography. All three areas showed a remarkable consistency in producing 95% or better of true objects in the “Ancient monuments” category.

On the basis of the evidence it seems reasonable to conclude that typical outfield monuments like charcoal pits and pitfall traps can be accurately mapped using visual inspection of detailed DTM, supported by automatic detection, provided that the number of ground returns is sufficiently high (> 2 ground returns pr. m^2, Trier & Pilø 2012). It should thus be possible to produce large-scale maps of these monument-types, provided that ALS data is available. This work is already on going in Oppland County.

This study does not give much information on the presence and number of visible ancient monuments not found during the visual inspection of the DTM. Based on the limited surveys conducted by walking in the terrain between the checked objects the number of additional objects in the test areas is believed to be low. However, information from previous ground-truthing in Gravfjellet in Øystre Slidre municipality provides more systematic information on this question. This area also contained medieval iron extraction sites with charcoal pits in clusters, single charcoal pits and some pitfall traps. A 70 km^2 ground-truthing in 2011, based on visual inspection of a one-light-source hillshade (and with less experience in interpretation of ALS data than now), led to the discovery of 1650 visible ancient monuments. In 2012 plans were initiated to develop ca. 10 km^2 of this area for cottages and infrastructure. This provided an opportunity to do systematic surface survey of this limited area (Tveiten 2013). An additional ca. 10 % of single charcoal pits were found during the systematic survey, which is a remarkable low number, considering the inspection was undertaken using hillshade, which is not really a suitable visualization technique for this kind of work. The impression of the distribution of single charcoal pits did not change after adding the extra objects. The additional pits were typically small, hidden in dense spruce forest or damaged.

The purpose of using ALS in the heritage management in Oppland is mainly as a tool to map outfield monuments. In this it succeeds brilliantly, providing in-expensive, good quality and above all systematic data, which is of great value for cultural heritage. It is, however, not a substitute for proper fieldwork on the ground, when an area is scheduled for development, as not all visible monuments are found in the ALS data, detail on some objects is lacking, and of course not all sites are visible above ground. In the forested areas of Oppland, however, most monuments are clearly visible above ground, making the interpretation of ALS data a very valuable tool for cultural heritage management. Under such conditions, ALS data provides excellent large-scale mapping opportunities (Figure 5).

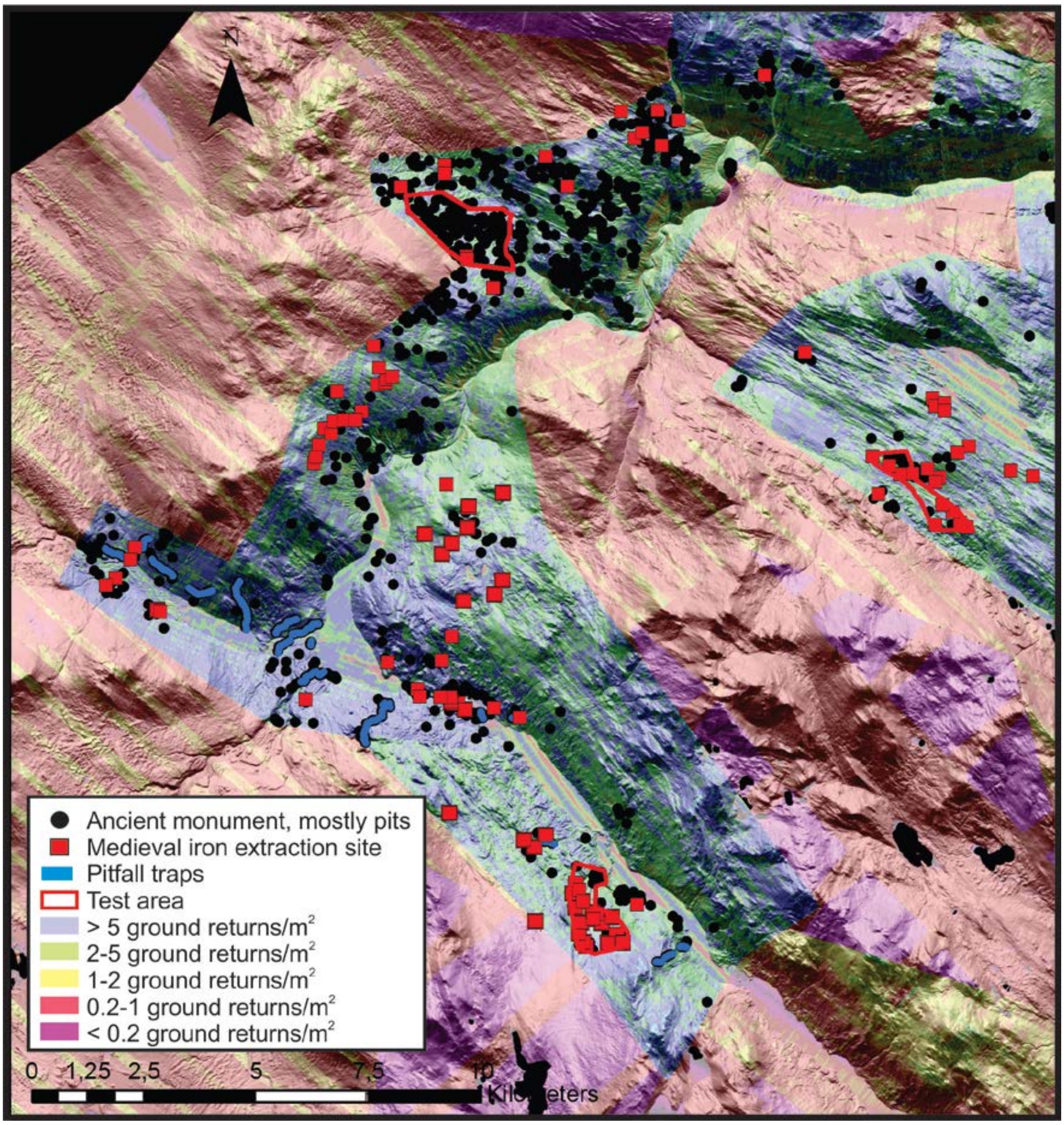


Figure 5. Overview of ancient monuments mapped from ALS data in Nord-Fron and Sør-Fron municipalities. The three field survey areas (test areas) are indicated with red polygons.

3 Mapping of grave mounds in Tønsberg municipality, Vestfold County

By Christer Tonning, Vestfold County Administration

3.1 Introduction

Building on our experiences from the field season of 2012, with the use of automatic heap detections in airborne laser scanning (ALS) data in Vestfold, we wanted to harvest more quantities of data concerning in field confirmed heap detections. This in order to secure a larger dataset for confirmed heaps, which can be used to train CultSeacher for detecting heaps with stronger confidence in other datasets with similar or better properties, and parts of the country.

Like in 2012 we tested the detection patterns on known sites, where we used the detections as a opportunity to update the previously measured (or otherwise documented) geometry properties of the heaps, and with the sites as origin checked out detections with high confidence (Category 5 and 4) surrounding the known sites.

We also wanted to test the confidence of the detection patterns in areas which showed many detections of high confidence (Categories 5 and 4), but no or few known archaeological sites mapped.

Unlike the season of 2012 we were able to join forces within the project to undertake the fieldwork in a joint effort. On all of the surveyed sites in Tønsberg, archaeologists from the Vestfold County council and/or NIKU and/or KHM participated in 2013.

Our area of focus for 2013, fell on Tønsberg municipality which was mapped with ALS in the spring of 2012.

3.2 Data

The ALS dataset was acquired on the 3rd of April 2012 by the mapping company Terratec ordered by the Norwegian Mapping Authority (Kartverket) as a financially joined regional project (Geovekst) in the counties of Telemark and Vestfold. The dataset was collected with a minimum point density of 2 points per square meter (a common standard for ALS data collection in Norway regarding Geovekst projects). Vestfold County Council argued in the winter of 2012 for a quality enhancement to 5 points per square meter, but the other participants in the project would not contribute financially to this enhancement due to lack of cost/benefit possibilities for the other participants. In connection to this issue, two studies (Bollandsås et al, 2012; Trier and Pilø, 2012) has argued that the benefit for archaeological remains being visible in ALS increases largely when the data quality is raised to 5 points per square meter, but further enhancements is not feasible considering cost/benefit involved.

Last time the municipality of Tønsberg was mapped by ALS was in 2008 also by the company Terratec, with the same contractor. The 2008 acquired dataset from Tønsberg is also acquired within the standard 2 points per square meter. The 2008 ALS data was acquired on the 20th of April, so a marginal later date with the possibilities of more vegetation visible in the dataset.

Combination of the two datasets for artificial enhancement of point density was not explored.

3.3 Method

ALS data was uploaded to an ftp server at Norwegian Computing centre on the 28th of june 2013. The first deliverance of automatic detections was received in October 2013 in shapefile format. But due to stricter filtering level of confidence to get the number of false detections down, alot of originally high leveled detections were missing. A new deliverance of detection files was available from the Norwegian Computer Centre shortly after.

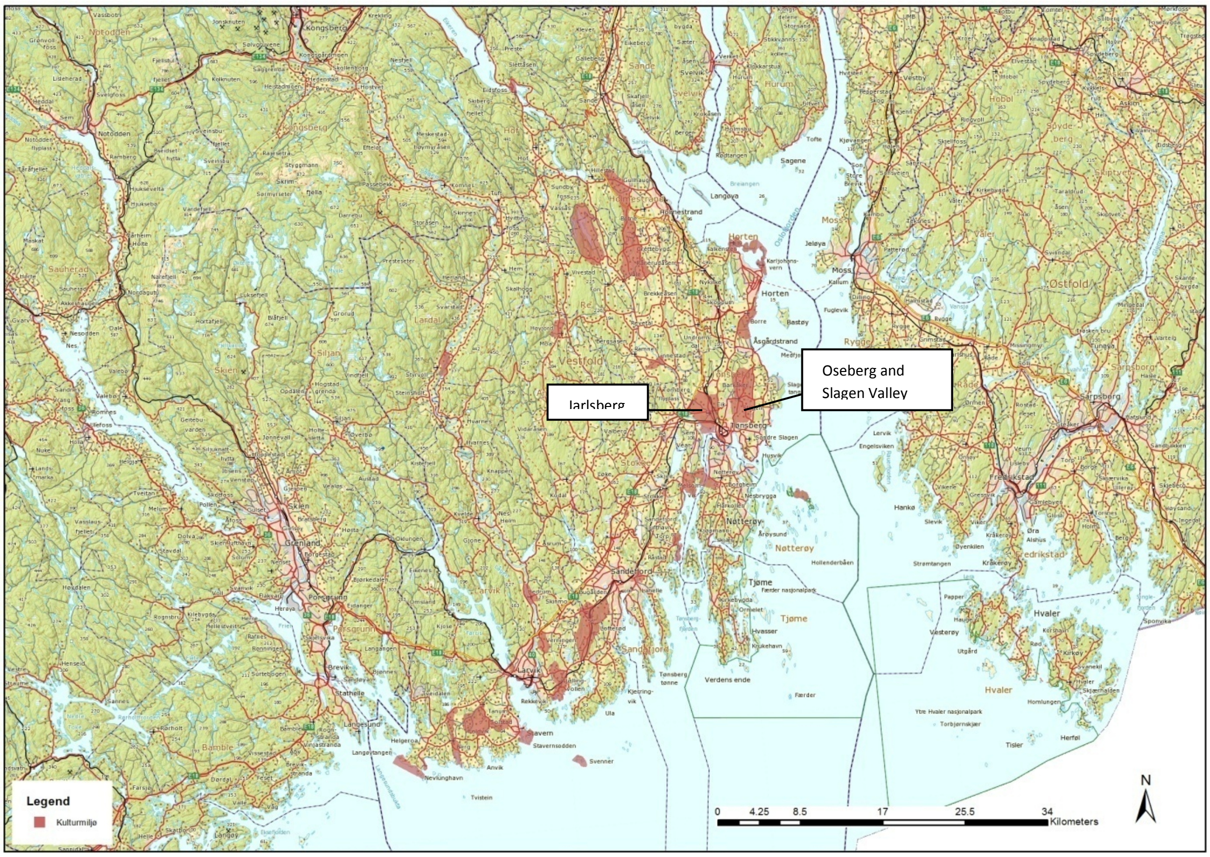


Figure 6. Of the 37 selected areas in Vestfold County, we focused on (1) the Jarlsberg area and (2) the Oseberg mound and the Slagen Valley.

3.3.1 Selection of field verification sites

Concerning the selection of verification sites this season, four factors were important in this regard.

1) The freshly acquired 2 point ALS of the complete area of Tønsberg municipality (2012). The dataset was as mentioned above acquired early april 2012, this could have some potential concerning the confidence of the detections, the produced DTM s and the derived visualization rasters showed slight improvement from 2008.

2) Since 2011 Vestfold County Council have proposed 37 areas throughout Vestfold County which is part of a larger plan dealing with sustainable development in the County the next 30 years (http://www.vfk.no/Tema-og-tjenester/Planlegging1/) . The 37 areas concerning Cultural heritage were selected as important national and regional sites and interconnected cultural

environments (http://www.vfk.no/Tema-og-tjenester/Kulturarv/Vestfoldhistorie-artikkel/Regionalt-viktige-kulturmiljo/). Vestfold County Council will in the years to come focus on these areas. We want to further map and closely monitor these areas in order to preserve them for the future Vestfold County generations. All of the sites surveyed in the project is situated within or on the fringe of the selected 37 areas. In Tønsberg three areas of the 37 is situated. Our field campaign this year were done within two of these areas ; Jarlsberg and Oseberg-Slagen Valley (fig.1).

3) To further close in on areas of high interest a cluster map was constructed for the detections of highest confidence, and this was again correlated with already known sites which was a method we also used in 2012 season. Our experience from 2012 was that in areas where no known Cultural Heritage sites are known and we have a lot of high confidence category 5 detections, this is due to geological or other nature created processes. We wanted to put this to test also in 2013, and one of the areas discussed in this paper will concentrate on this perspective.

4) Clusters of category 5 heap detections in densely populated areas with a lot of infrastructure were eliminated as interesting sites this time. These areas tend to artificially raise the quantity of category 5 detections which are of no archaeological interest.

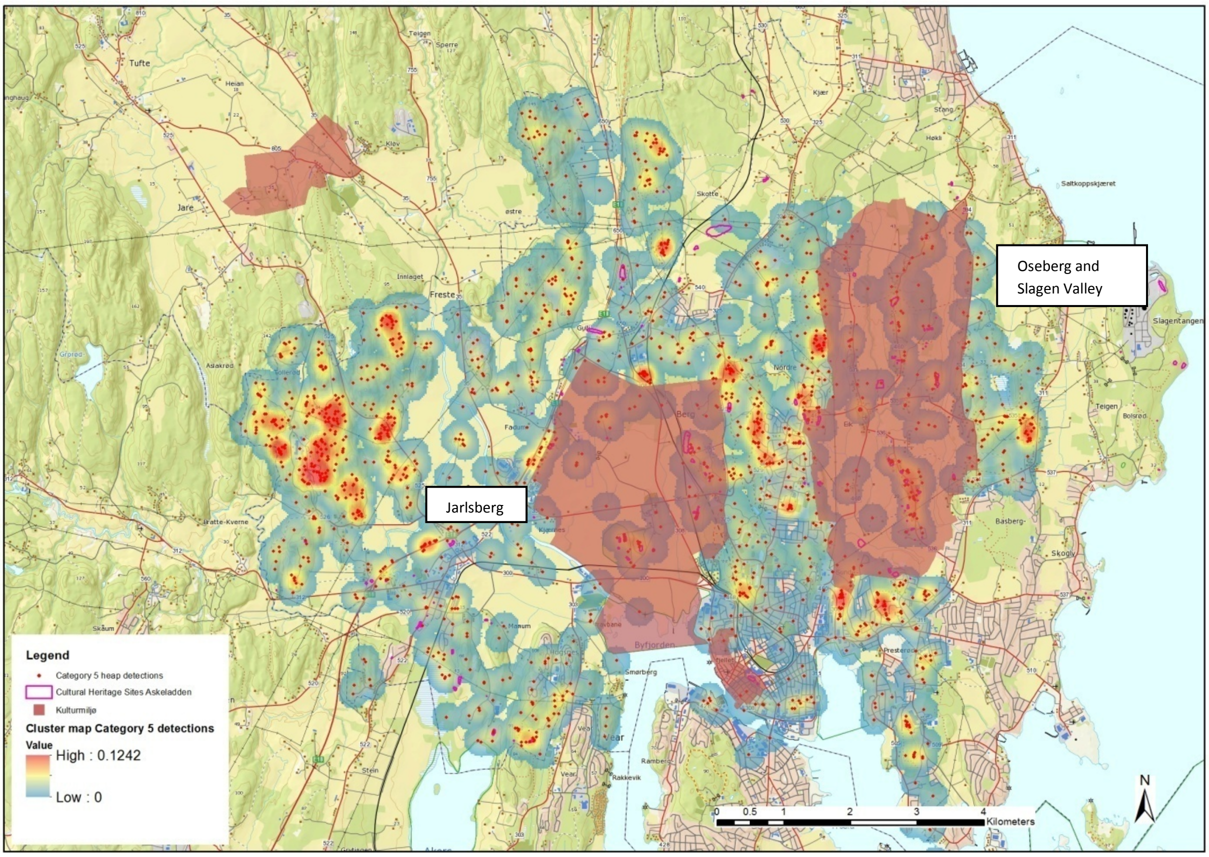


Figure 7. Showing the areas selected by Vestfold County Council in red, red dots is category 5 detections, purple polygons are known Cultural Heritage sites, and a cluster map showing from red (high) to blue (low) clustering of category 5 detections..

The following sites were picked out as field verification sites considering the four above mentioned criteria.

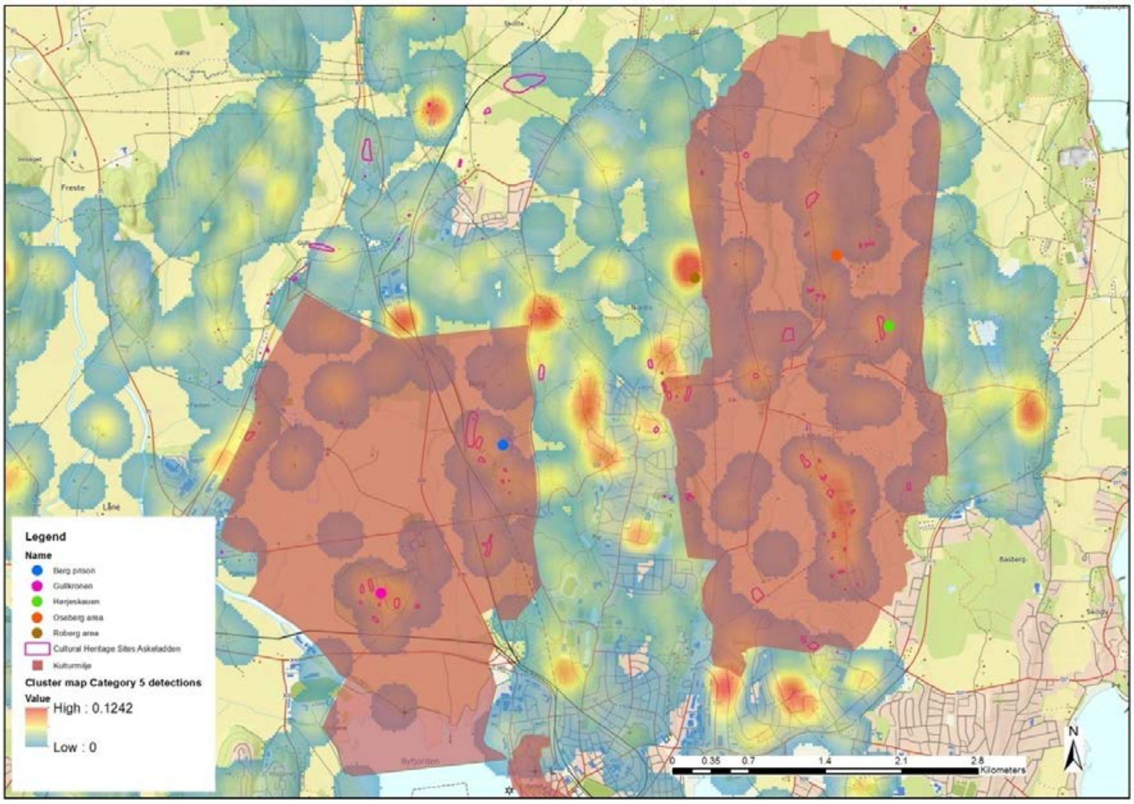
1) The site Hørjeskauen (ID 22244). Located in the area of Oseberg mound and Slagenvalley. Iron Age grave field, consisting of at least 20 heaps and two stone circles.

2) The area north and east of the Oseberg farm. Located in the area of Oseberg mound and Slagenvalley. containing several Iron Age sites with mounds and cairns. Especially ID 61689 was closer investigated.

3) The area of Roberg. Located in the area of Oseberg mound and Slagenvalley, and this areas western extension. Lots of category 5 detections but not a lot of known sites.

4) The area surrounding Berg prison close to Syrbekk. Located in the area of Jarlsberg. Containing many Iron Age grave sites. Both clustered in fields and singular heaps.

5) The area of Lille and Store Gullkronen, close to Jarlsberg manor. Located in the area of Jarlsberg. Containing grave fields and singular heaps.



3.3.2 General fieldwork procedure

This subsection describes how Vestfold County Administration is currently conducting its archaeological field work and how the automatic detections from CultSearcher fit into this procedure.

Vestfold County Administration is conducting regular archaeological survey in connection with zoning plans and in the early stages of construction work, whenever these could be in conflict with cultural heritage. The field work may involve test trenching with excavator, field walking in arable land, digging of test pits in forested areas, and/or general surface surveying. A rugged tablet computer connected to a precision GPS instrument is used to document the surveying and track coordinates. The archaeologist records the coordinates of all test trenches, test pits, cultural heritage sites, track logs, and more. The positional accuracy of the GPS instrument is a few centimetres. ESRI ArcPad 10 GIS software is used on the tablet computer.

Usually, prior to the field work, one creates a small GIS project which only includes the area relevant for the survey. Backdrop map layers may be downloaded from web map services published by the Norwegian Mapping Authority (In Norwegian: Statens Kartverk) or other providers. A geo-referenced raster hill-shade visualization of the ALS data is used as a backdrop layer. The automatic detections by CultSearcher are used as vector layers, one layer for each confidence layer, so that on may view, say only detections of medium high confidence or better. Also, the current status of the Askeladden Norwegian national cultural heritage database is used as a layer.

The original ALS data has 10 cm accuracy, and was converted to a DEM with 20 cm resolution as part of the automatic heap detection. The GPS instrument has a few centimetres accuracy, so when walking in the terrain with the DEM hill-shade visualization as a backdrop and the automatic detections of, say, medium high confidence or better, very little time was wasted on navigation; one could simply walk from one detection to the next and document the archaeological interpretation (mainly if the detection was false or not). In some cases, the diameter of the automatic detection did not match the actual size of the grave mound. Then, the archaeologist could walk along the circumference of the grave mound to digitize its extent rather quickly. Also, grave mounds missed by the automatic detection, whether spotted by visual inspection of the DEM hill-shade, or spotted in the field, could be digitized in the same fashion.

3.4 Results

The visualization of the ALS data was generated using the RVT software developed at ZRCSAZU in Slovenia (Zakšek et al., 2011; Kokalj et al., 2011)

3.4.1 Cultural heritage monument ID 22244 Hørjeskauen, Tønsberg Municipality

According to the national cultural heritage database Askeladden, there should be at least 20 heaps or cairns, and two stone circles within the borders of this site. The site itself is concentrated on a south-north bound stone ridge, which is not densely grown with mostly coniferous trees. The forest floor is grazed by cows; therefore little or no lower vegetation is present. But the conditions of the heaps are quite precarious due to the cows trampling on the heaps.

The soil is mostly a thin cover of earth containing lots of eroded rock. Most of the heaps on this site are more or less earth covered cairns.

The survey was conducted on the 13th and 14th of November 2013 by archaeologists Magne Samdal from Museum of Cultural History in Oslo (KHM), Lars Gustavsen from Norwegian

Institute for Cultural Heritage Research (NIKU) and Christer Tonning from Vestfold County Council.

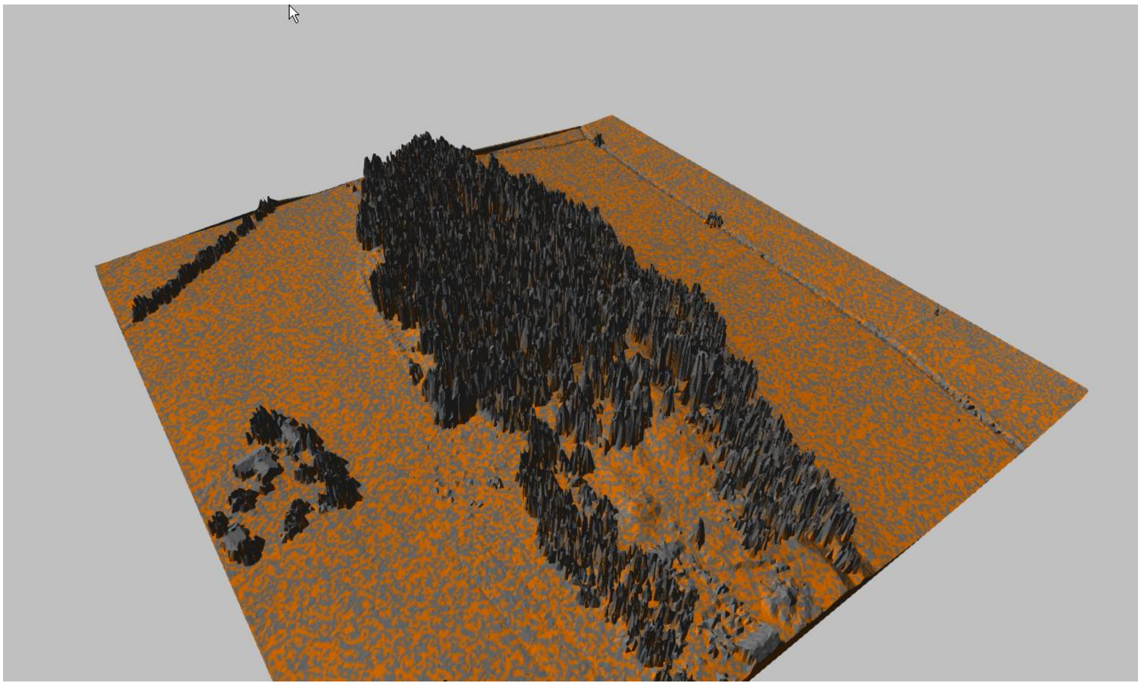


Figure 8. Showing a 3D visualization of the ALS data at Hørjeskauen. Orange: ground Grey : vegetation/infrastructure.

Table 4. The number of CultSearcher detections for each confidence level, at Hørjeskauen.

	Confidence of detection						not detected
Site	6	5	4	3	2	1	
ID 22244 Hørjeskauen	0	4	5	1	9	0	3

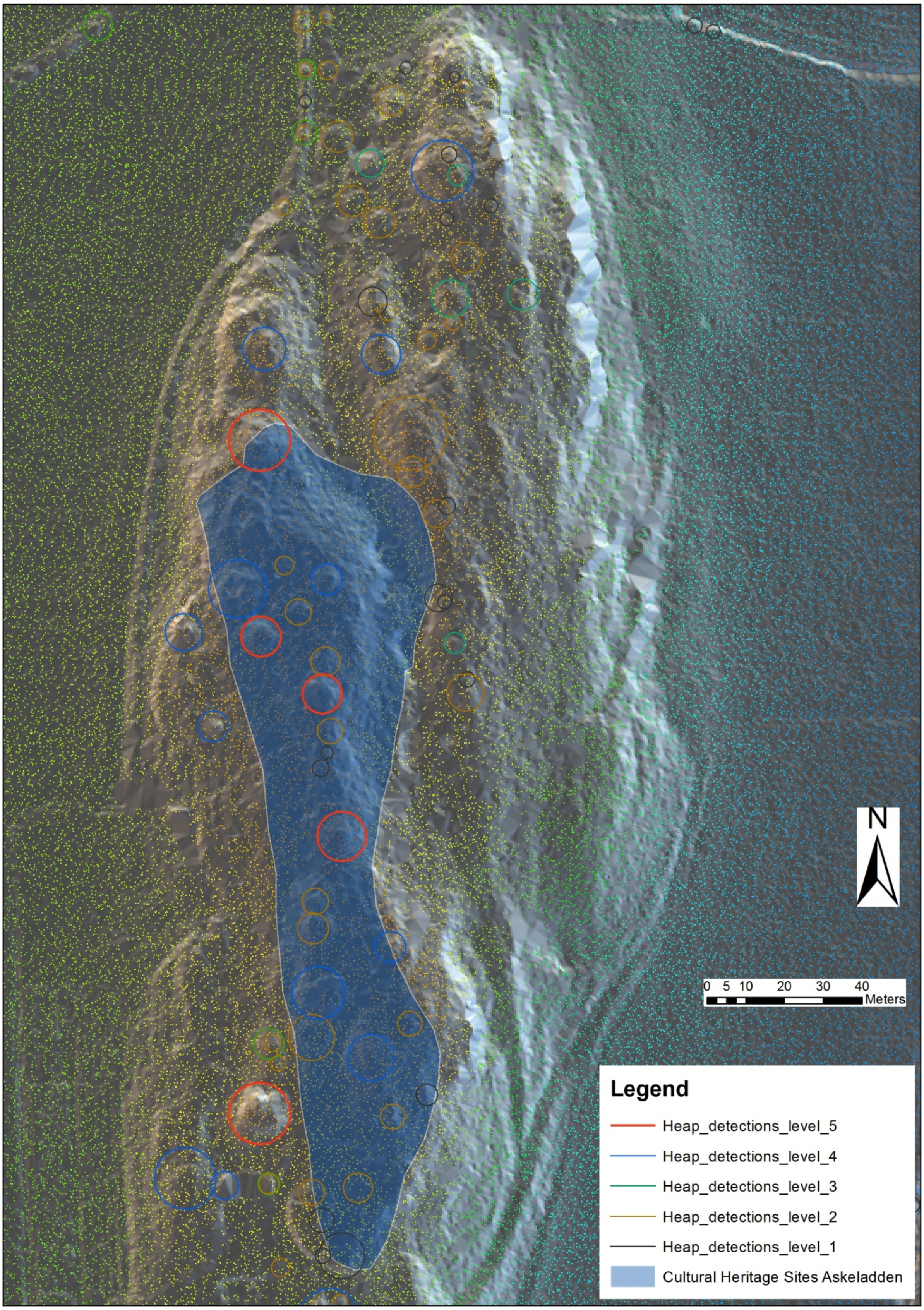


Figure 9. The grave field site with Askeladden ID ID 22244 Hørjeskauen .The colored dots indicates ALS ground point showing elevation (blue low, brown high). The underlying raster is a combination of slope (50 % transparent) and a multihillshade 16 directions derived from a DEM raster of the ALS data.

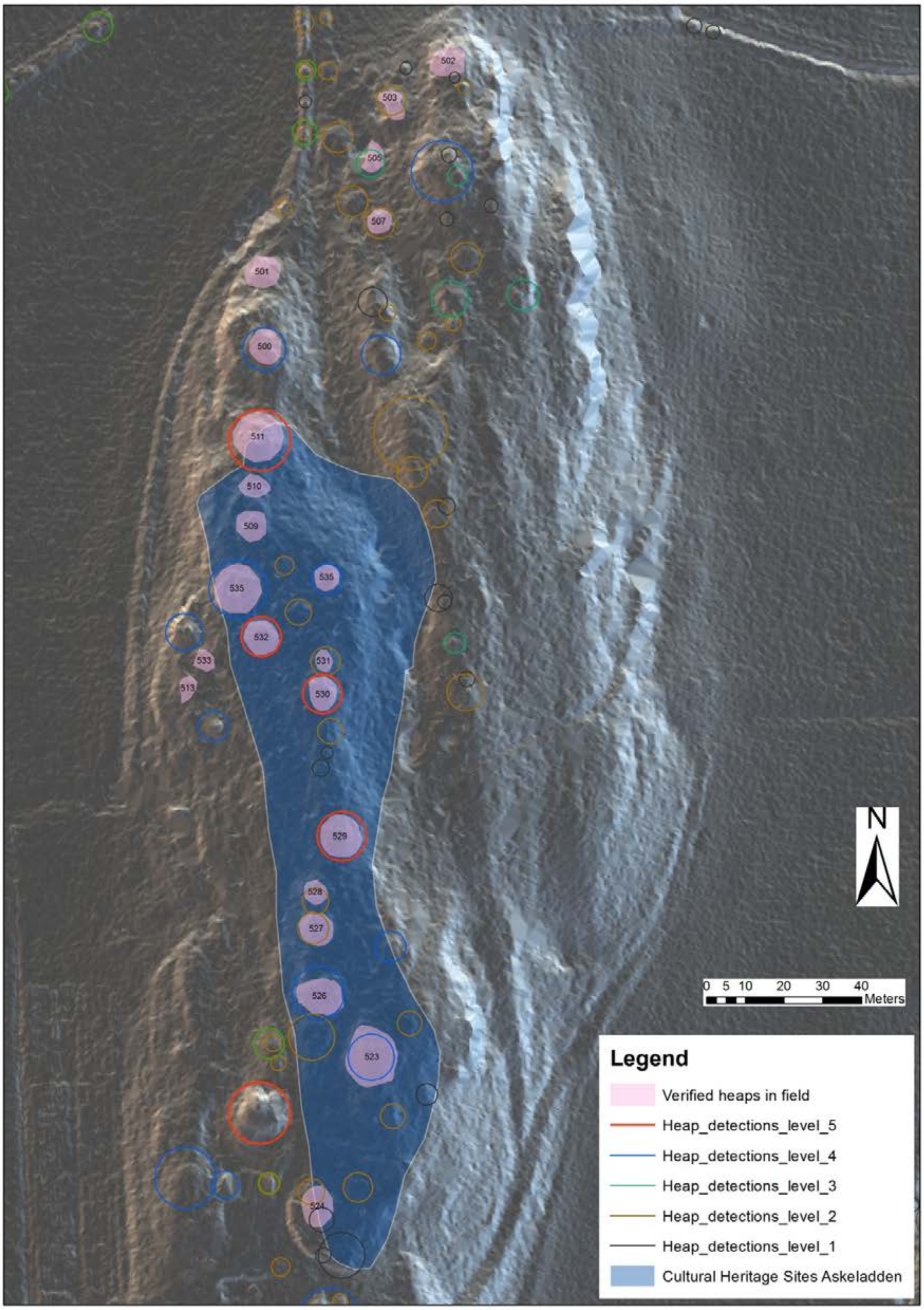


Figure 10. Showing the relationship between the detection data set and the ground controlled heaps.

A total of 19 heaps of 22 were detected by Cultsearcher at Hørjeskauen.. A detection rate of 86,4 %, and 45,5 % of the Cultsearcher detections is done within the three highest categories. The major reason that 54.5 % of the mounds is classified in the three lower categories of detection is a rather low point density of ground hits . Another is the poor condition of the mounds. Especially in the southern and western part, here the cows have trampled the mounds so badly that they are really not circular in shape, and quite low. Several of the mounds to the north was also damaged by unknown digging and moving of stones.

Figure 11. Shows archaeologist Lars Gustavsen from NIKU surveying a category 5 detection (mound 523). The mound is severely trampled down by cows, but still a detection with high confidence.

The ground controlled mounds 501 and 502 were not detected at all by Cultsearcher. Mound 524 is a long barrow and Cultsearcher has detected the southern part as a category 1 detection and the northern part as a category 2 detection. Mound 501 is situated on top of a very stony ridge, just north of mound 500. It has a plundering hole in the center and has a spruce tree in the north. Mound 502 is situated northernmost in the grave field. This mound has been badly trampled by cows to the north, and has a rather large pine tree to the south west. One false category 5 detection (this was a true heap, but a false grave mound), and seven false category 4 detections was also controlled. The geometrical improvement of the surveyed grave field at Hørjeskauen is considerable. 10 of the 22 mounds were not situated inside the original measurement and thus expanding the total size of the grave field with 110 meters further north. Probably two previously unknown mounds were detected, in the earlier descriptions of the grave field it was just estimated that it consisted of at least 20 mounds.

3.4.2 Cultural heritage monuments ID 32083, 51807, 51808, 62048 and 76828 Gullkronen, Tønsberg Municipality

The site Gullkronen in Tønsberg is a well-known archaeological site which is generally divided in the two forests of Lille Gullkronen and Store Gullkronen. Four of the sites (ID 32083, 51807, 62048 and 76828) is situated in the Store Gullkronen forest. It has been mapped several times by archaeologists and there has also been conducted excavations of the two long barrows in the site 51807 which is situated in the Lille Gullkronen forest. One of them was a boat grave and both mounds gave Viking Age dating (Grieg, 1932).

The two Gullkronen forests lies south of the Jarlsberg manor which has a long history as a residencial place for powerful families in Norway, all the way back to Viking age royalty. Today the forests lie in close connection to the current manor and is used as a public area for hiking. The forests consists of mainly beech. The low vegetation is quite intense in the forest. But the early timing for the ALS (8th of April 2012) is resulting in a quite good penetration for ground points.

The personnel doing the survey in Gullkronen was archaeologists Magne Samdal from Museum of Cultural History in Oslo (KHM) , Lars Gustavsen from Norwegian Institute for Cultural Heritage Research (NIKU) and Christer Tonning from Vestfold County Council. The ground proofing was conducted on the 14th of November 2013.

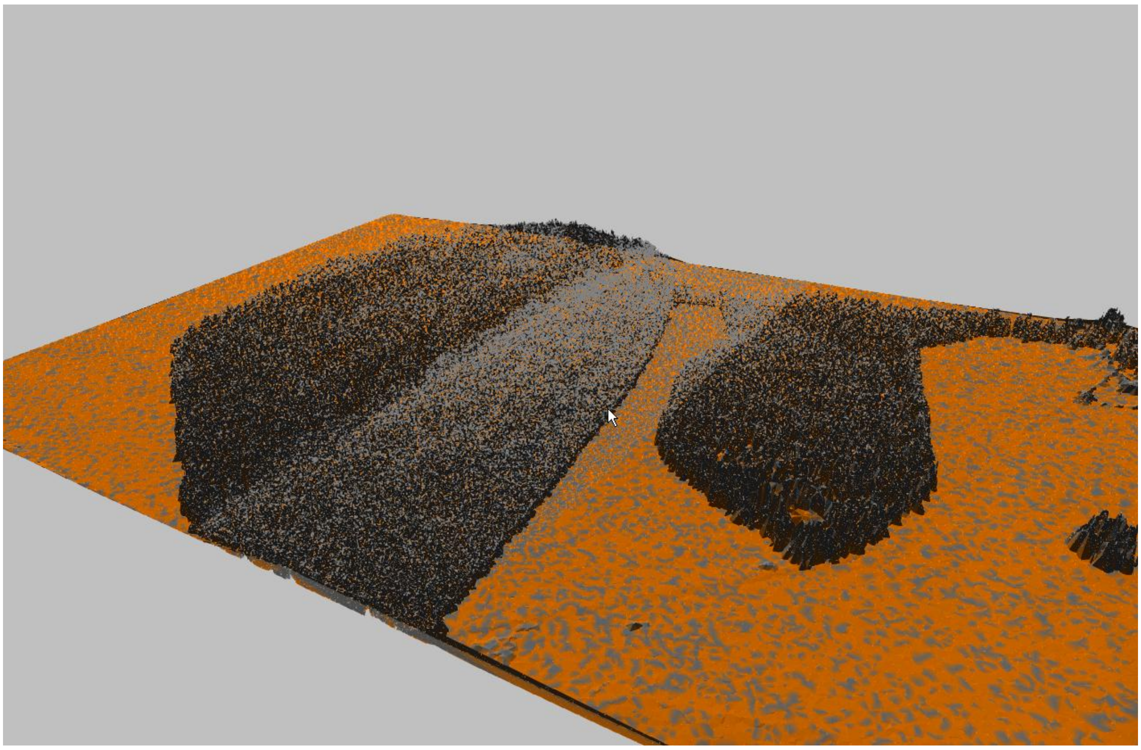


Figure 12. A 3D visualization of the ALS data including vegetation, on the site of the Gullkronen forests. Orange symbolizes ground hits, grey symbolizes vegetation.

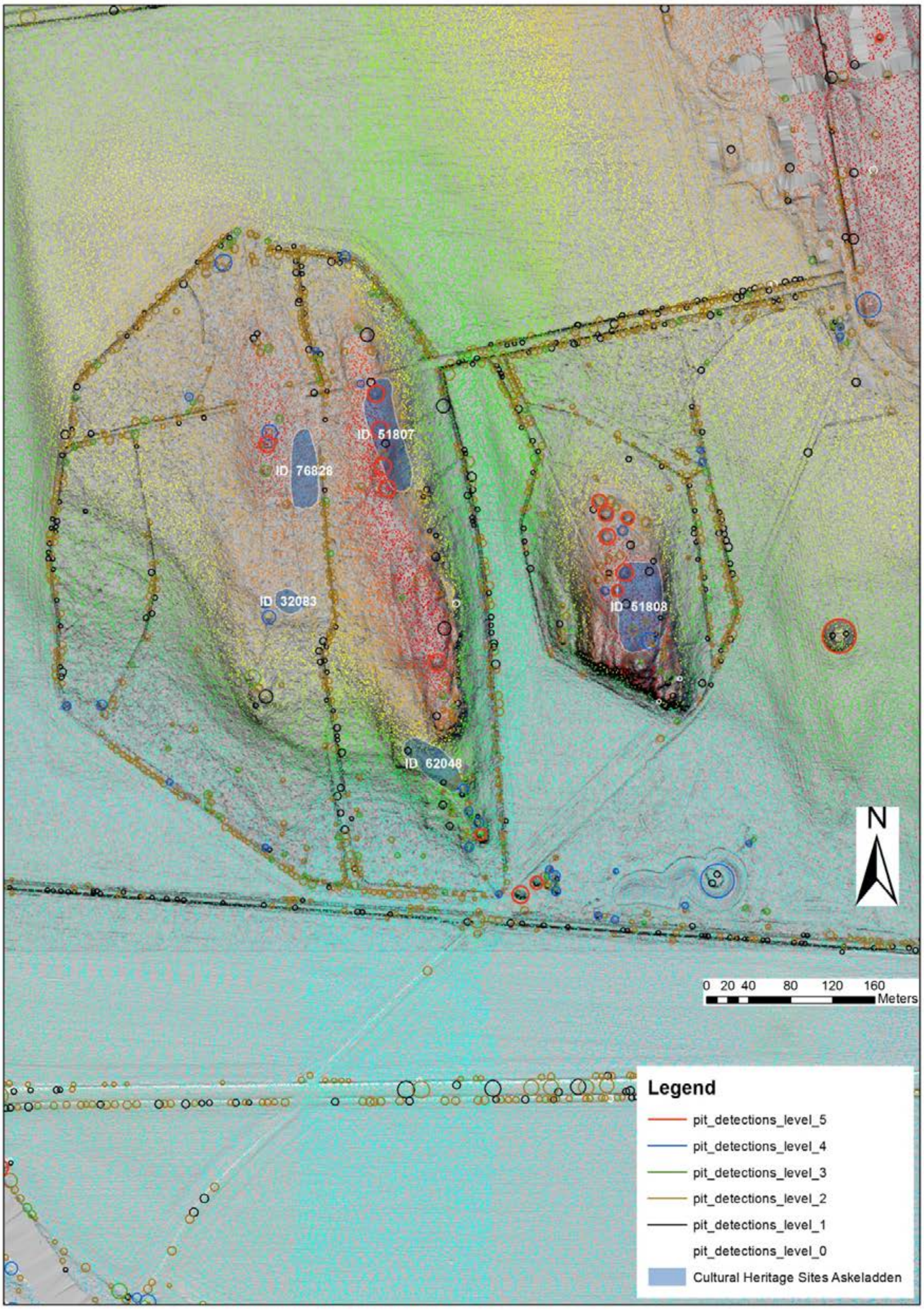


Figure 13. The registered sites at Lille and Store Gullkronen. Ground points showing as colored dots reflecting height (Blue=low, red =high).

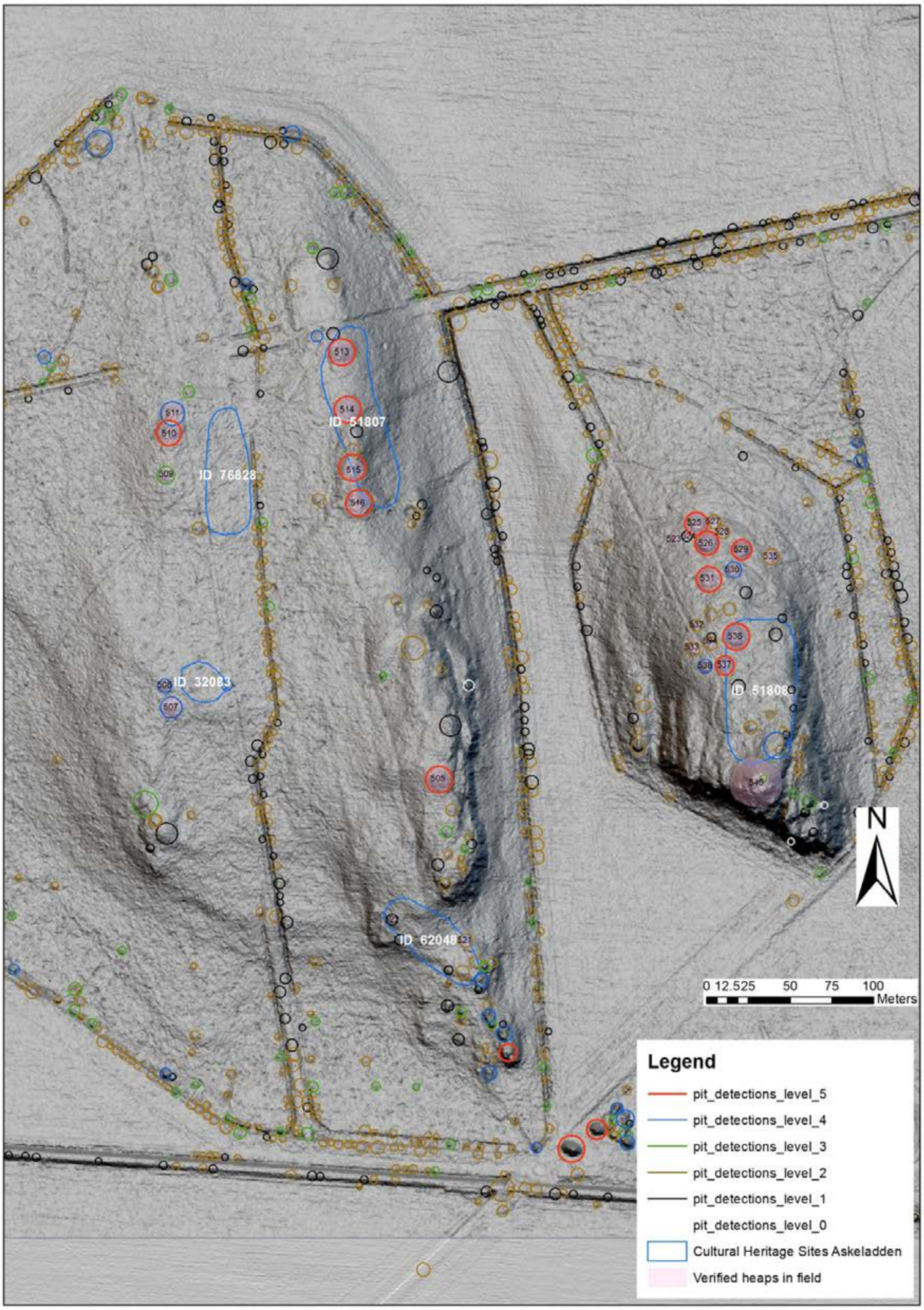


Figure 14. Showing the relationship between the registered Askeladden sites (blue outline), Cultsearcher detection patterns and ground controlled heaps.

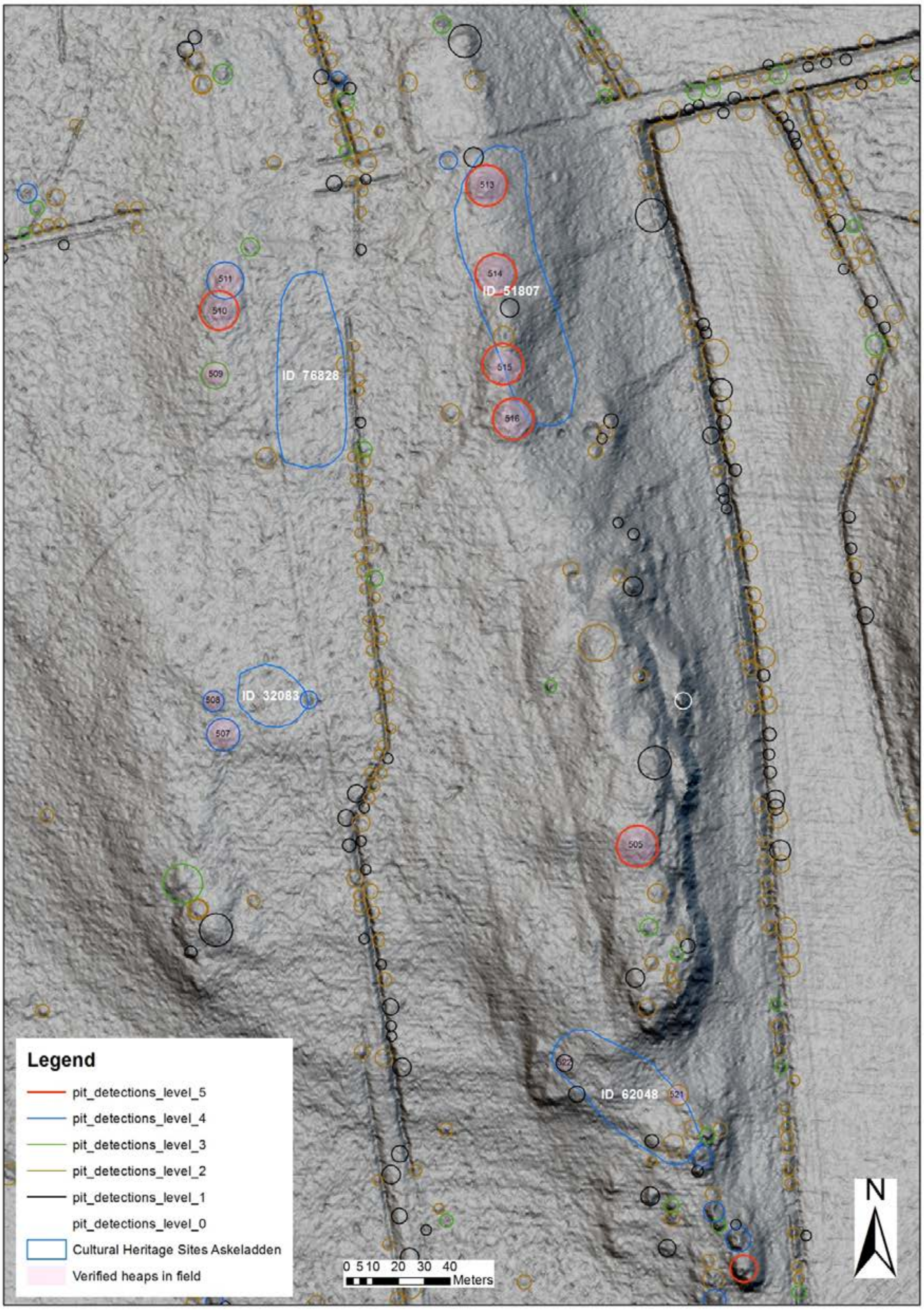


Figure 15. Detailed map of Store Gullkronen forest and the four registered Askeladden sites here.

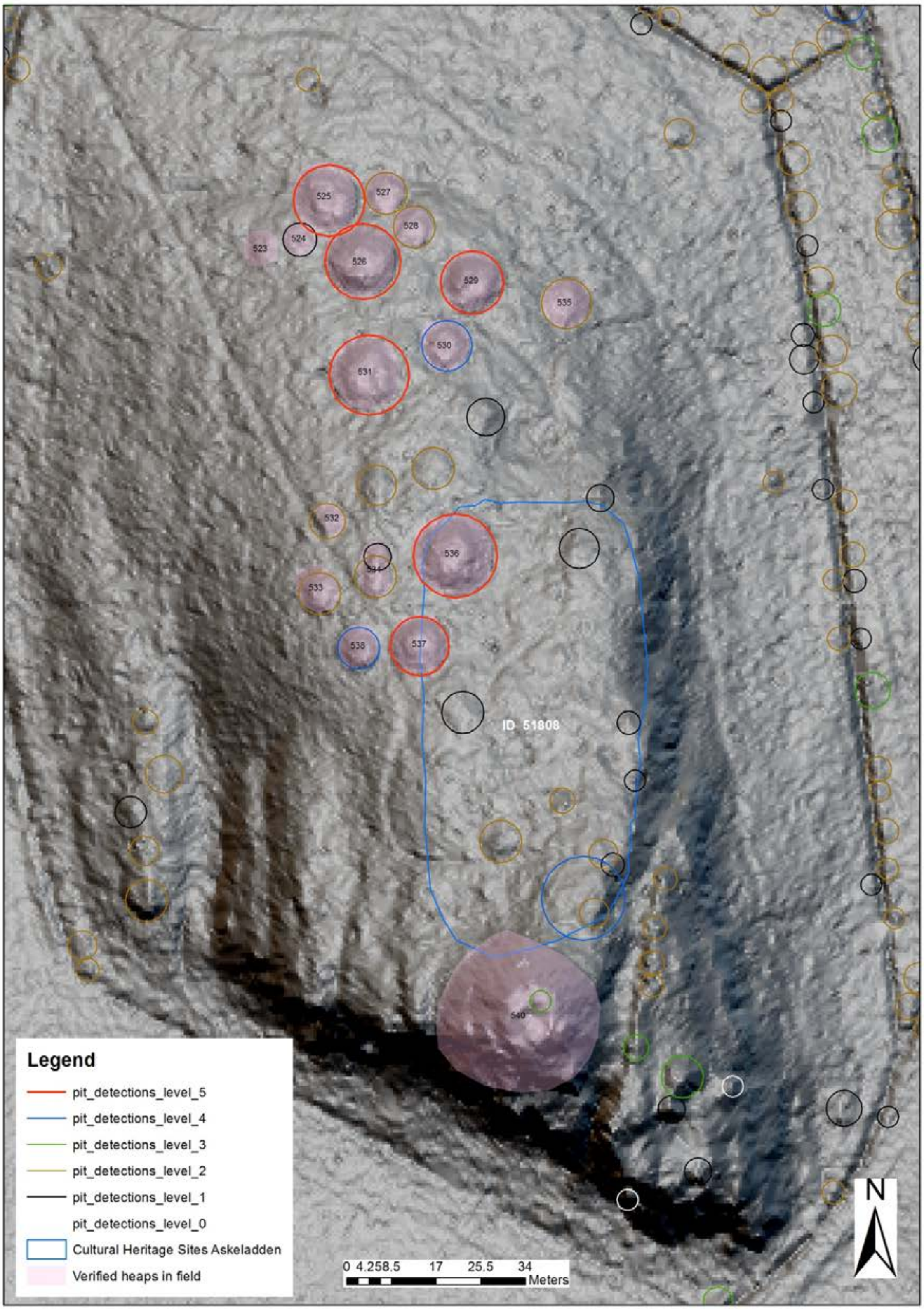


Figure 16. Detailed map of the one site ID51808 at Lille Gullkronen.

3.4.2.1 Site 32083

Table 5. CultSearcher detections at site ID 32083, Store Gullkronen.

	Confidence of detection						not detected
Site	6	5	4	3	2	1	
ID 32083 Store Gullkronen	0	0	2	0	0	0	0

At site ID 32083 both mounds were detected. The original survey of the two mounds was placed about 20 meters to the east of the correct placement. One category 4 detection was eliminated as a tree stump. Large beech trees were surrounding mound 507 in the south, and one beech tree growing on top of mound 508.

Figure 17. Mound 507, archaeologist Lars Gustavsen doing the survey.

3.4.2.2 Site 51807

At site ID 51807 all four mounds were detected in category 5 by Cultsearcher. In the original survey the placement of the two southernmost mounds 515 and 516 is wrong, not including these completely in the site geometry. The mounds are all well-defined grave mounds, about 1 to 1,5 meters in height and 10-13 meters in diameter. Little or no low vegetation on top, and just medium size beech trees surrounding the mounds.

Table 6. CultSearcher detections at site ID 51807.

	Confidence of detection						not detected
Site	6	5	4	3	2	1	
ID 51807 Store Gullkronen	0	4	0	0	0	0	0

Figure 18. Showing the mound 513 towards the south. A few medium sized beech trees growing on the edge of the mound.

3.4.2.3 Site 62048

Table 7. CultSearcher detections at site 62048.

	Confidence of detection						not detected
Site	6	5	4	3	2	1	
ID 62048 Store Gullkronen	0	1	0	0	1	1	0

The site ID 62048 was a strange experience. It was supposed to contain 1 grave mound, 1 grave cairn and one stone setting. In the Cultsearcher detection dataset it looked like we had strong category five and four detections in the south of the site and a really promising category five detection about 70 meters to the north of the site. All the category five and four detections south of the originally measured site was false heaps. These were all part of a larger rock formation. We then started to check out the category three to zero detections. This resulted in finding probably two of the described features in Askeladden. These were supposed to be 1: The stone setting and 2: A grave cairn. The feature described as a stone setting (521) is not a stone setting but a grave mound with a defined stone row outlining the mound. The mound is a category two detection consistent with the diameter noted on the first survey in 1993 (7.3 meters). Approximately the distance and bearing noted in 1993 (35 meters west by north-west) of 521 we find feature 522. This is noted as a grave cairn, but this is a grave much like feature 521; a grave mound with a very prominent stone row outlining. In the middle this mound has a plundering hole and a large stone close by the plundering hole. The third feature which is described in 1993, a grave mound was not found when surveying, and no detection was done in the nearby location mentioned in 1994 (4 meters south by south-west of 522).

About 70 meters north by north-east we had already confirmed a very clear category 5 detection as feature 505. This could be part of the site ID 62048 and is counted in as a detection under this site in the table above.

Figure 19. Mound 522 seen towards the north, a marked stone chain can be seen outlining the mound, this was especially clear towards the west.

Figure 20. The very prominent category 5 detection of mound 505. This is a mound not previously mentioned, and could be part of the site ID 62048.

Table 8. CultSearcher detections at site 76828.

	Confidence of detection						not detected
Site	6	5	4	3	2	1	
ID 76828 Store Gullkronen	0	1	1	1	0	0	0

According to Askeladden this site should consist of 3 mounds lying on a row from north to south. This was confirmed on the ground proofing of the site. The only error was that the site was placed 35 meters to the east of the actual mound, when being mapped in 1969. The mounds are quite low 30-40 cm in height, but well defined as grave mounds. These mounds have the feature number from 509-511 in the above map figure 11. Mound 509 was surrounded by beech trees, mound 510 had a plundering hole in the central part (could also be the result of a burrowing animal). Large beech trees surrounding both 510 and 511. Mound 511 had similar damage as 510 in the western part, and some rocks on top.

Figure 21. Showing archaeologist Lars Gustavsen survey mound 510, mound 511 is seen in the right corner (north) of the picture.

3.4.2.4 Site 51808

Table 9. CultSearcher detections at site 51808.

	Confidence of detection						not detected
Site	6	5	4	3	2	1	
ID 51808 Lille Gullkronen	0	6	2	0	6	1	2

According to Askeladden the site ID 51808 should contain circa 21 mounds, 2 long barrows and 19 round barrows. A total of 15 mounds was detected by Cultsearcher as shown in table above. Two mounds was not detected, but was found during the survey, a total of 17 mounds. Two of the mounds which Cultsearcher detected was long barrows (feature number 533 and 534), although they were detected (533 as a category two, and 534 as a category two and category 1) the mounds extends beyond the boarder of the detection in reality. Four mounds was not accorded for during the survey. This could be because all of these grave mounds were heavily grown with low vegetation and bush.

The large mound to the south was not detected either. This mound is called the badger mound, due to heavy digging from badgers during the centuries. The mound is lying on top of a cliff, and is about 30 meters in diameter. The reason for this not being detected by Cultsearcher could be the drop to the south which coincides with the southern extension of the mound. Mound 523 was not detected either by Cultsearcher, this mound is a quite low feature and heavily overgrown with bush.

Figure 22. Showing mound 540, the badger mound towards the south.

Figure 23. Archaeologists Lars Gustavsen and Magne Samdal survey the mound 538, a category 4 detection by Cultsearcher. A very clear mound, probably the oak trees to the south of this mound made it drop in confidence.

3.5 Discussion

The general impression of the Cultsearcher detections in the 2 point density dataset is impressive concerning the already registered cultural heritage sites. These sites are in general poorly surveyed from earlier investigations due to mainly inadequate precision of surveying equipment. The field season of 2013 showed us again that the Cultsearcher software has the potential to deliver good results for 2 point density data sets. But the time has come to look further into the potential which lies in datasets of higher point density. This year (and also for 2012) the testing of areas which show a high amount of category 5 detections but no known sites is a bit worrying, for the general usefulness of the software. The parameters for high category detections need to be adjusted for these areas in order to roll out the software for the entire Cultural Heritage Management in Norway.

The datasets which has been used in 2013 and partly in 2012 are datasets that are derived from projects (Geovekst) which are pleased with the current point density of 2 points. We need to test out Cultsearcher on optimized data (for archaeological purposes) and with a sufficient point density of 5 points per sq meter.

We need to focus on

1. optimal point of time to collect data, early spring before vegetation growth, maybe test out data collection in the fall when all vegetation has disappeared.

2. -data collection should be performed on a representative sets of cultural heritage sites with round barrows, in different part of the country (not optimized and groomed), with different kinds of terrain.

4 Cultural heritage monument at Berg, Tønsberg Municipality

By Magne Samdal and Steinar Kristensen, the Museum of Cultural History at the University of Oslo

4.1 Introduction

The cultural heritage site of Berg (Askeladden ID 76830) is a prominent and well known site in Vestfold (Figure 24). The main site contains several burial mounds situated around the property of Berg fengsel (prison) approximately 4 km north of the city of Tønsberg, in Tønsberg municipality. Parts of the site are represented by different ID numbers in the national cultural heritage database; Askeladden. The following ID-numbers are included in this investigation: 80590, 12378, 51811, 51812, 76833, 30859, 76830, 32086, 51810 and 52061 (Figure 25). The burial fields investigated are spread out over a large area, almost 700 m from the north to the south, in the western part of Berg, and at least 33 burial mounds have been recorded earlier, of which twelve were excavated in 1919 (Oldtiden X, page 45-47). The survey area is approx. 13 hectare.

The archaeological survey and control of the CultSearcher detections at Berg were conducted on two occasions; December 9th 2013 by Steinar Kristensen and Magne Samdal from The Museum of Cultural History, University of Oslo (KHM), and December 18th by Monika Kristiansen from The Norwegian Institute for Cultural Heritage Research (NIKU) and Steinar Kristensen (KHM). 15 cm snowfall the night before survey on December 9th (Figure 26) reduced the quality of the ground survey this day. The weather was fine on the 18th with no snow on the ground. The northern part of the survey area has open forest vegetation with big oak-trees and some low vegetation. The middle part contains mostly grass meadows and small areas with dense clusters of trees, while in the southern part the vegetation is dense, with small trees and low vegetation.

As described above the Berg heritage site was surveyed on two occasions under quite different conditions; with and without snow cover. This have in some degree influenced the observations. The large cemetery with large and clearly defined mounds with ring ditches is situated in the northern part of the survey area and because of the weather condition this area was surveyed the day with snow. The southern part with fewer mounds and with less clearly defined mounds/cairns were surveyed the day without snow on the ground.

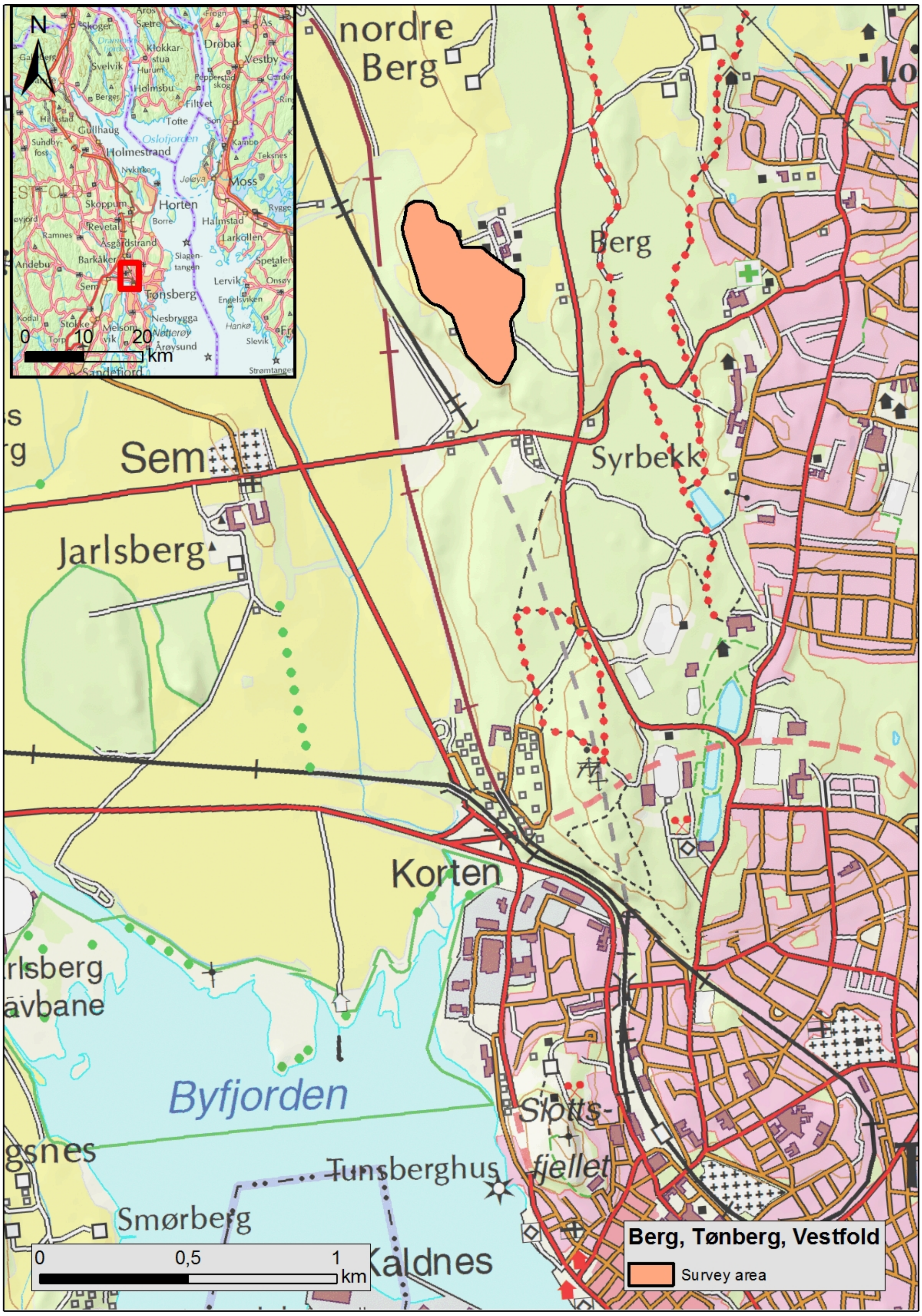


Figure 24. The survey area Berg, Tønsberg municipality, Vestfold County. The city of Tønsberg to the south-east.

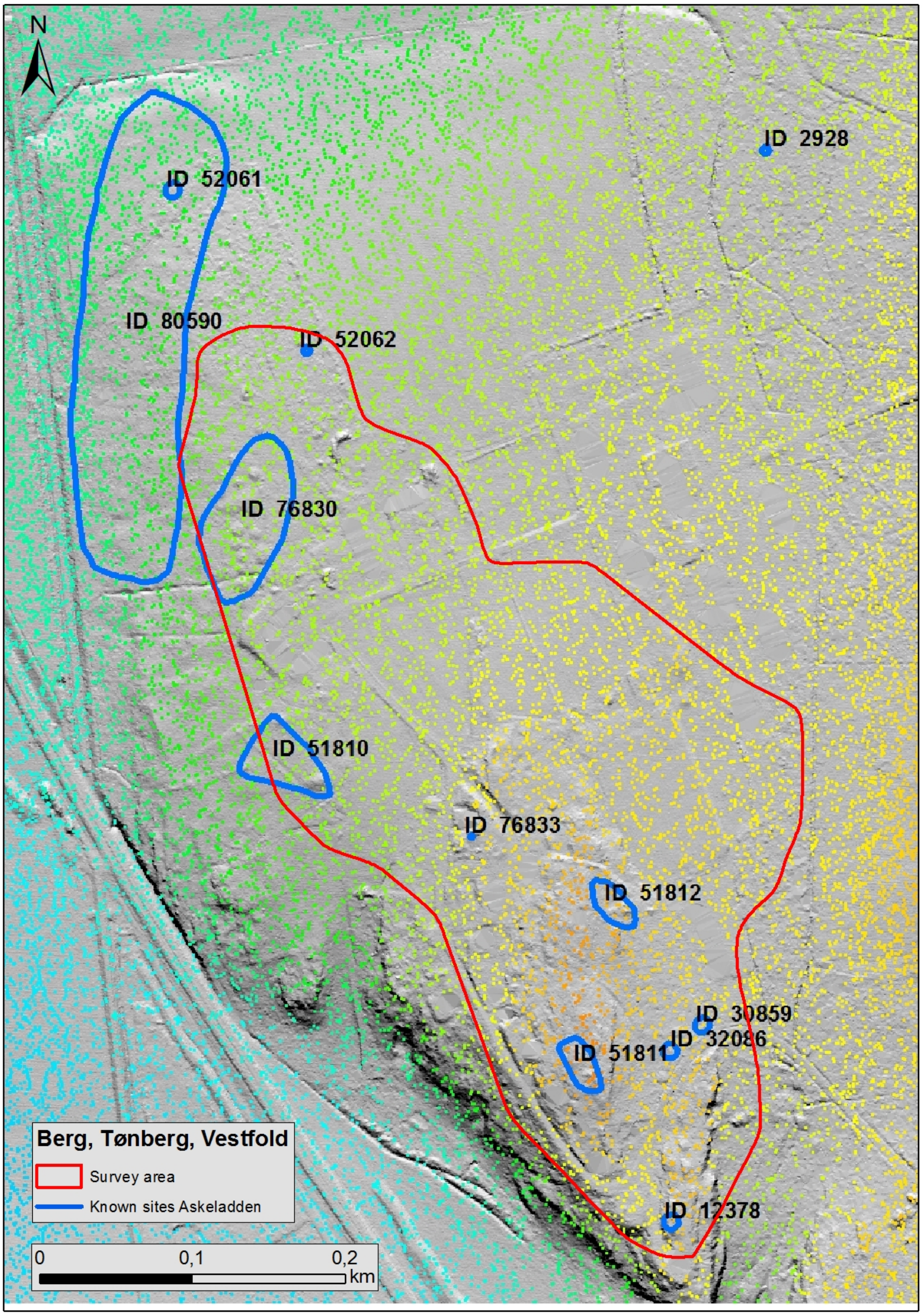


Figure 25. The survey area with ground hits points and the archaeological heritage sites recorded in the area.

Figure 26. Surveying by Magne Samdal on 9 December 2013.

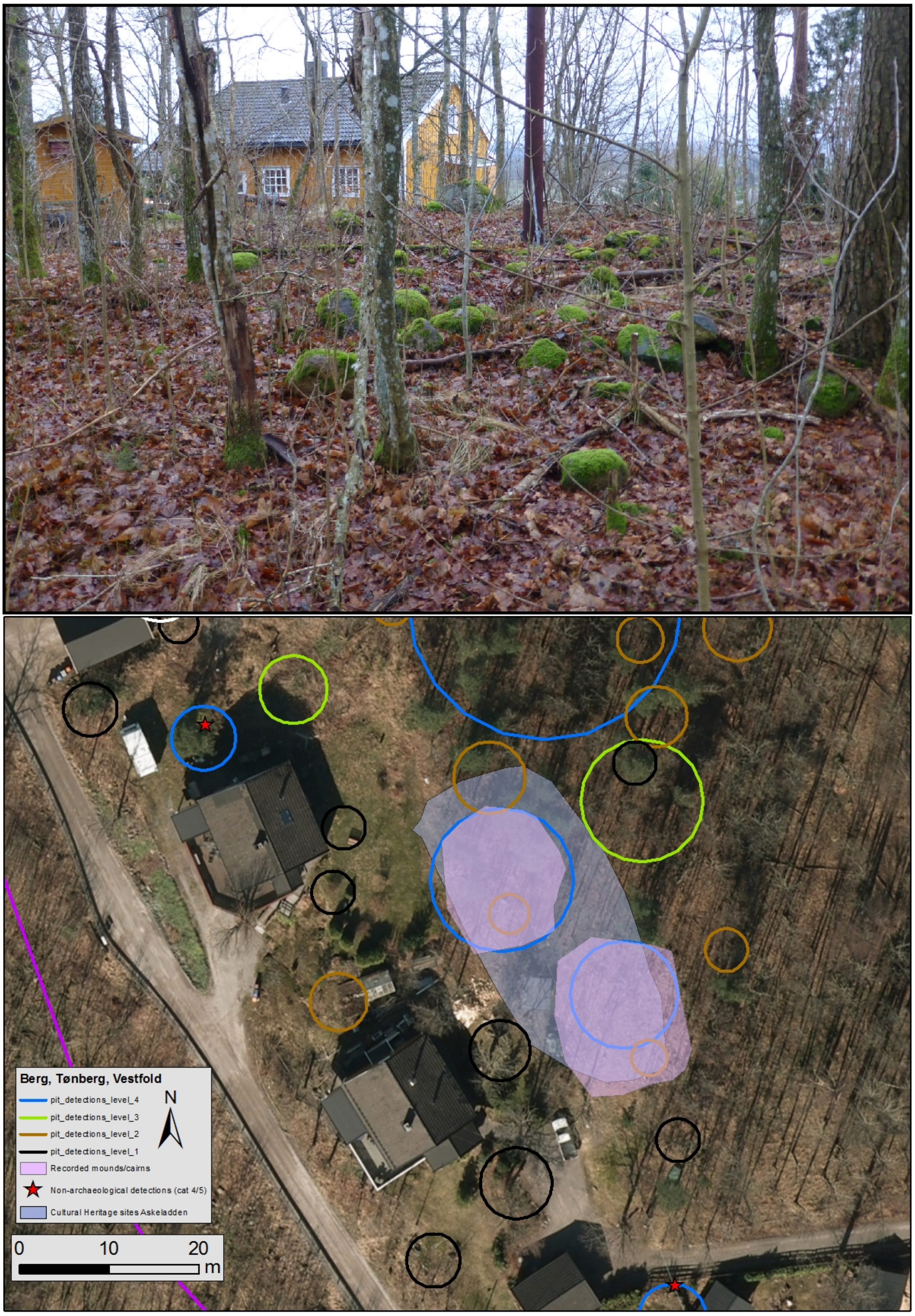


Figure 27. Detected burial cairns category 4 seen from NV. They lack clearly defined boundaries and have relatively low heights. Both cairns have already been registered in the Askeladden database (ID51811).

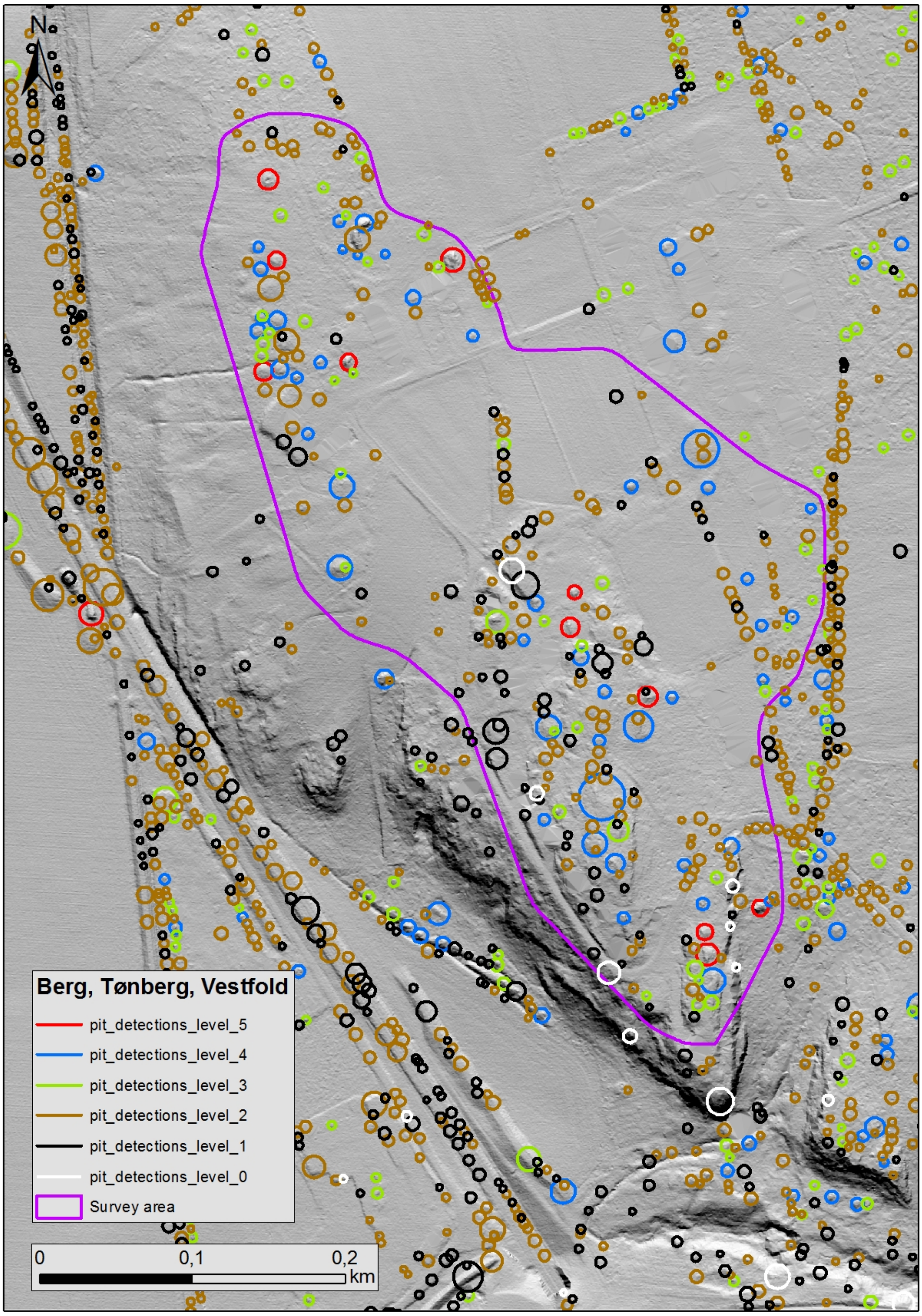


Figure 28. Survey area with CultSearcher detections.

CultSearcher provides a large amount of detections based on the ALS data. Within the defined survey area (Figure 28) there were a total of 310 detections in confidence value categories ranging from 0 till 5. The category with most detection was value 2 with 147 detections. Confidence value 0 had only 6 detections while the highest confidence value 5 had 11 detections (Table 10).

Table 10. Detections by CultSearcher and result of survey.

Confidence value	**5**	**4**	**3**	**2**	**1**	**0**	**Not detected**	**Sum**
Number of CultSearcher detections	11	44	37	147	65	6	0	310
Archaeological object recorded	4	14	7	11	0	0	(6)	42
Nature/modern	7	30	0	0	0	0	0	37
Not controlled	0	0	30	136	65	0	0	231
True archaeological hits of the detected %	**36,4**	**31,8**	**18,9**	**7,5**	**0**	**0**		**11,6**

4.2 Descriptions of the detections

Confidence value 5: Of the eleven detections with confidence value 5 four were recognized as archaeological detections, which gives a positive rate of 36%.Five of the detections (45%) were in the large cemetery in the north while the rest were spread out in the southern part of the survey area. Three of the four true archaeological detections were all clear defined burial mounds with clear ring ditches and with a height approx. 1-1, 5 m. The fourth observation was a less clear burial cairn. The detections corresponded relatively well with the mounds observed (10-12 m in diameter) while the cairn was quite smaller than the detection. To this should be noted that the cairn had less clear boundary than the mounds in the same category.

Confidence value 4: 44 detections within the survey area were categorized with value 4. Of these, 14 turned out to be archaeology: 11burial mounds and three cairns. Eight of the mounds were clearly defined while the cairns were all less clear in their shape. Of the 30 non-archaeological detections, there were mostly topographical elements like bed rock formations or three stumps that had been detected. Some negative detections were on buildings or other farming related activity as heaps of manure or fire wood.

Confidence value 3: None of the 37 detections in this category were surveyed intentionally as the time available for survey was limited. None the less there were seven archaeological objects observed as they were either neighbouring value 4 or 5 detections or that the area already was registered in the national Cultural Heritage database. Four of these were relatively clear defined burial mounds while two cairns detected were less visible and less defined. The remains of a nearly completely removed and damaged burial mound, which was mentioned in the Askeladden, was detected by CultSearcher with confidence value 3. This mound would clearly have been missed by most archaeologists if not recorded earlier.

Confidence value 2: As for confidence value category 3 none of the confidence value 2 detections were planned examined. Again they were observed due to either neighboring to category 4 or 5 or that the area was registered in the Askeladden. In total eleven burial mounds were observed at value 2 spots. Seven of these were clear defined and four less certain. Three had trees on them; either standing or fallen. Three mounds were also more oval than round in shape.

Confidence value 1 and 0: None of the 71 detections of value 1 and 0 were positively observed as in neighboring to value 4 or 5 or earlier recordings in the Askeladden.

Of the 310 CultSearcher detected heaps in the survey area, the number of positive archaeological observation (burial mounds/cairns) were 36 (11, 6 % of the detections). An additional six mounds were observed by the archaeologists but not detected by the program, which gives that approx. 14 % of the total number of archaeological monument observed was not detected by CultSearcher. This number might be too low as the purpose with the survey is controlling detections and not at total recording of the archaeological monuments in the area. The weather conditions can also have influenced on the result.

18 of the observed monuments were detected with the two highest confidence value category (42, 8%) while the same number of monuments was detected with low category values (cat 2/3).

Most of the detections with value 0-3 were situated in the southern part, e.g. that 60 of 65 detections in value 1 were detected here. In this area there is more bedrock visible than in the northern part where there are more grassing field (with or without threes). This can indicate the reason of the relatively high number of low confidence detections in the southern part.

As stated above the vegetation is lower in the southern part then in the northern part where there are more large oak trees. At the time of scanning (beginning of April) the vegetation is still low (not much leaves on threes or bushes). It does not seem to have given any significant differences in the results.

42 archaeological burial mounds or cairns were observed during the survey witch increase the number of burial monuments in the area with 27 %.

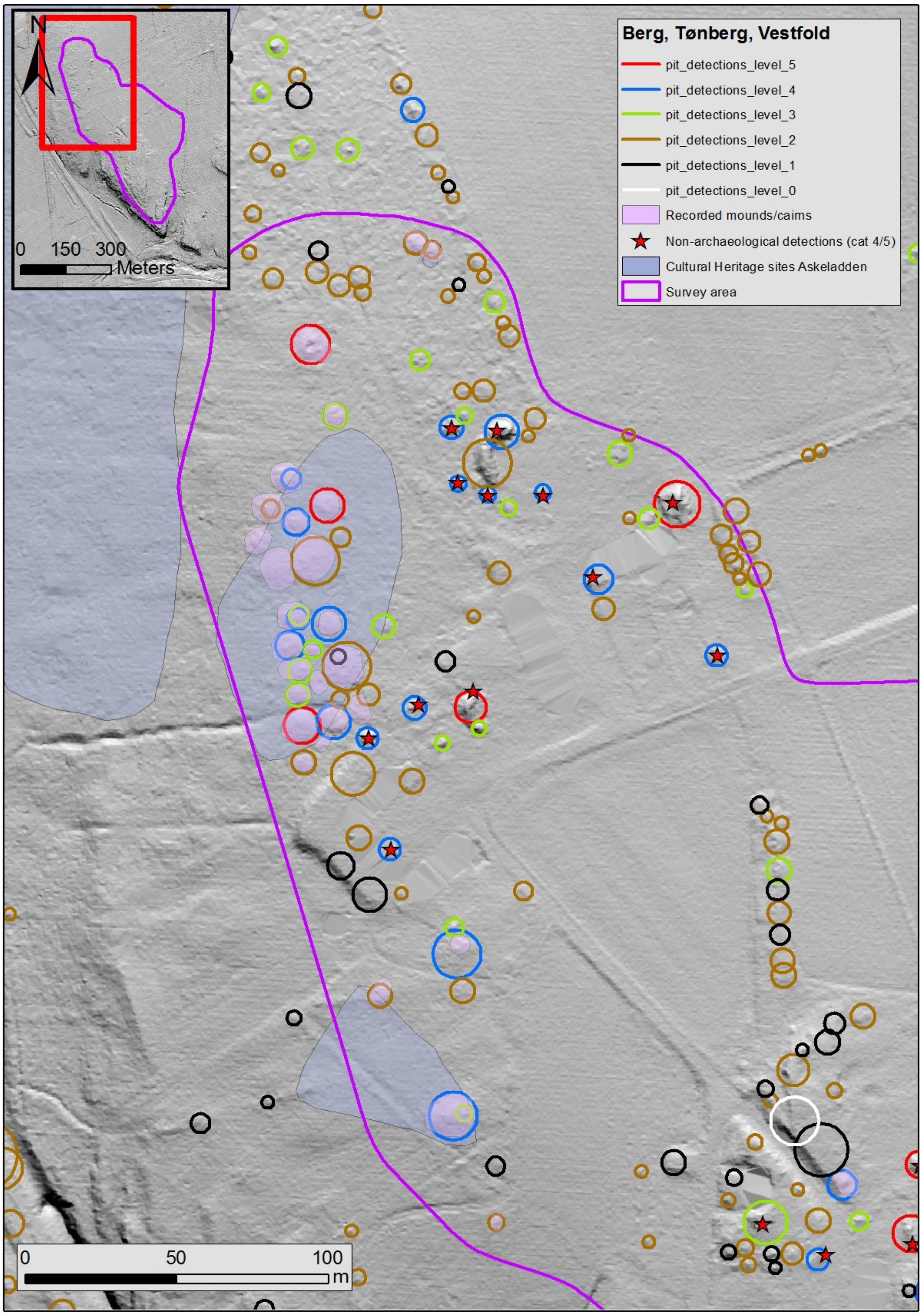


Figure 29. Northern part of survey area with detections and observations.

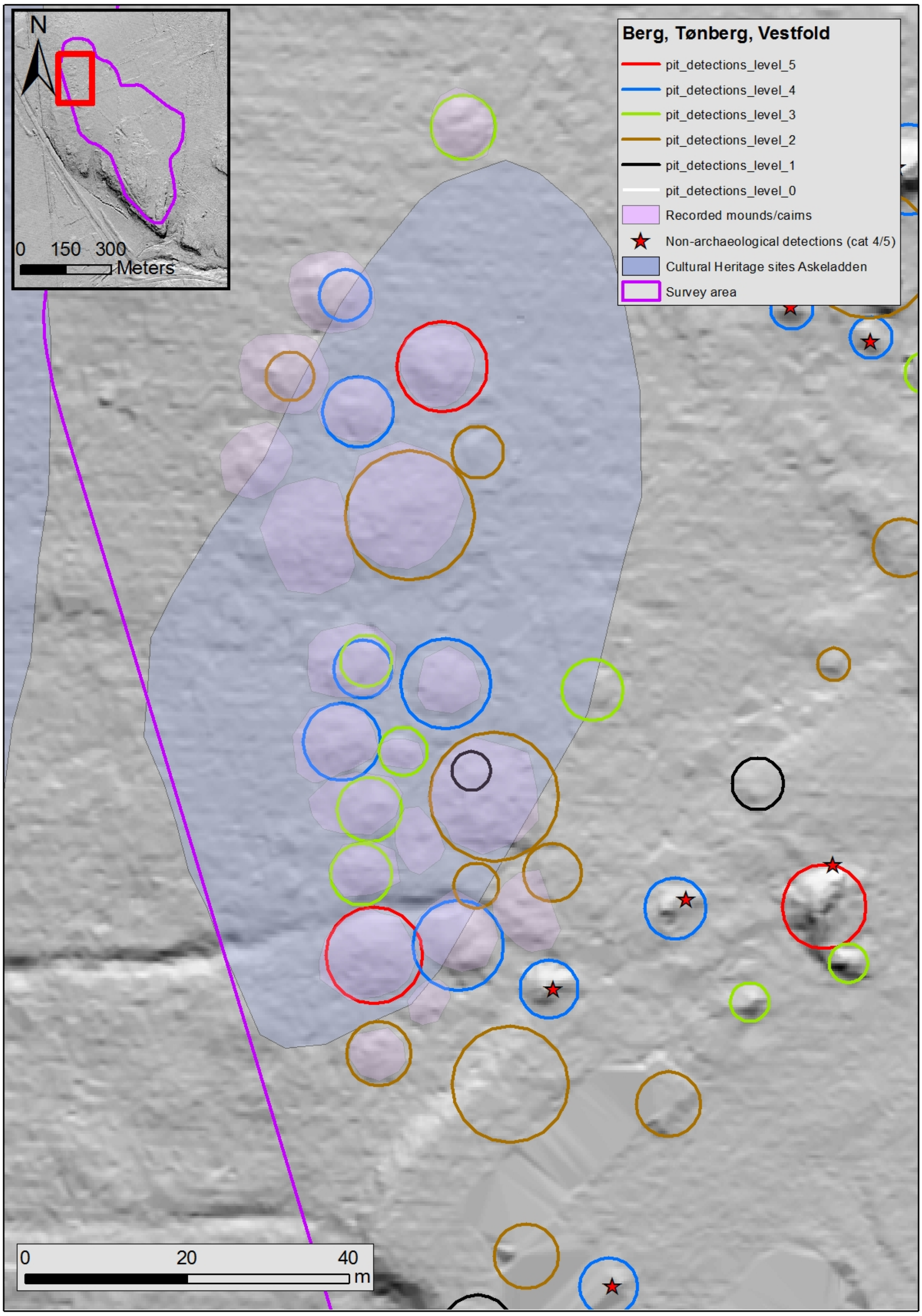


Figure 30. Detail from the northern part with the large cemetery ID 76830.

5 Mapping of cultural heritage in the Slagen Valley

By Monica Kristiansen,NIKU.

5.1 Results

The cultural heritage sites Oseberg Store, Rom Søndre and Roberg Søndre are located in the Slagen valley (Figure 31), approximately 5 km north of Tønsberg. This valley is widely known for its historic heritage and holds a high number of Iron Age grave fields. In 2013, representatives from the Norwegian Institute for Cultural Heritage Research (NIKU) and Vestfold County Council surveyed areas around Oseberg and Roberg to verify a subset of automatic heap detections done by *CultSearcher* on an airborne laser scanning (ALS) dataset of Tønsberg and Slagen. Based on the results of the heap detections, three areas were selected for an archaeological ground surveying: Rom Søndre, Store Oseberg and Roberg Søndre. In these areas there have been previously recorded several Iron Age grave fields, which makes these sites eligible for verifying heap detections. In the same areas *CultSearcher* also recorded several high confidence heap detections.

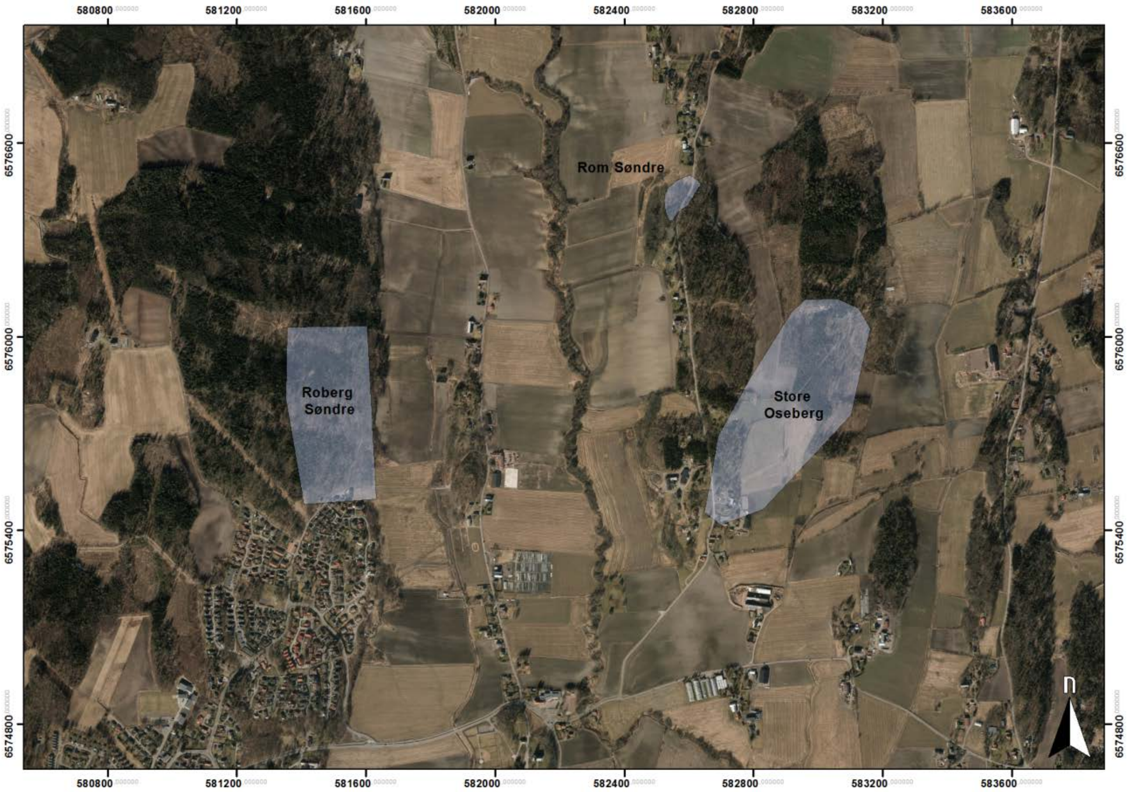


Figure 31: The sites Rom Søndre, Roberg Søndre and Store Oseberg.

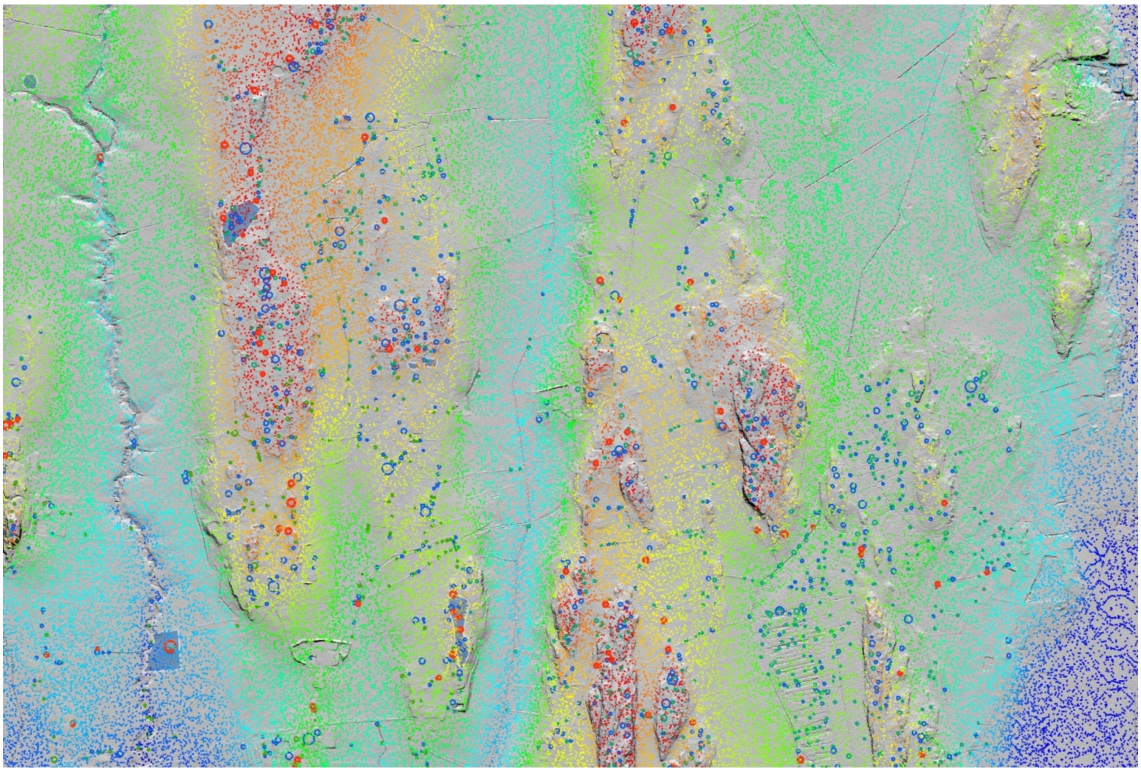


Figure 32: Visualisation of ALS ground points at Rom Søndre and Oseberg. The circles represent automatic heap detections. Red: high confidence (5), Blue medium high confidence (4), Green: medium confidence (3).

5.1.1 Cultural heritage monument ID 61689 Rom Søndre

The site “Rom Søndre” is located in the north eastern parts of Slagendalen, and is situated on a low, north-south oriented ridge. The site is surrounded by fields and farmland, but the ridge itself is grown with deciduous trees, coniferous trees and low shrubs. The surface of the ridge is somewhat coarse and the bedrock is partially visible. The terrain slopes steeply to the west and most grave mounds are located at the top of the ridge and in the lightly sloped areas in the east. In the north east a narrow road (Romsveien) cuts through parts of the site.

The site covers an area of 8900 m^2 and comprises, according to the national cultural heritage database (Askeladden), a stone circle, 21 round barrows and 4 long barrows. The barrows have not been mapped individually and the exact location of each grave was therefore unknown. The grave field lies mainly on the western side of the Romsveien road, but the site geometry indicates that some barrows may have been observed on the eastern side. The archaeological ground survey was conducted on 28 November 2013.

Table 11. CultSearcher detections at Rom Søndre.

Rom søndre	**Confidence of detection**						**not detected**
Confidence level	**6**	**5**	**4**	**3**	**2**	**1**	
Detections	0	2	8	6	24	10	-
Confirmed heaps	0	1	7	4	2	1	0
Positive detections	-	50 %	87,5 %	67 %	8 %	10 %	-

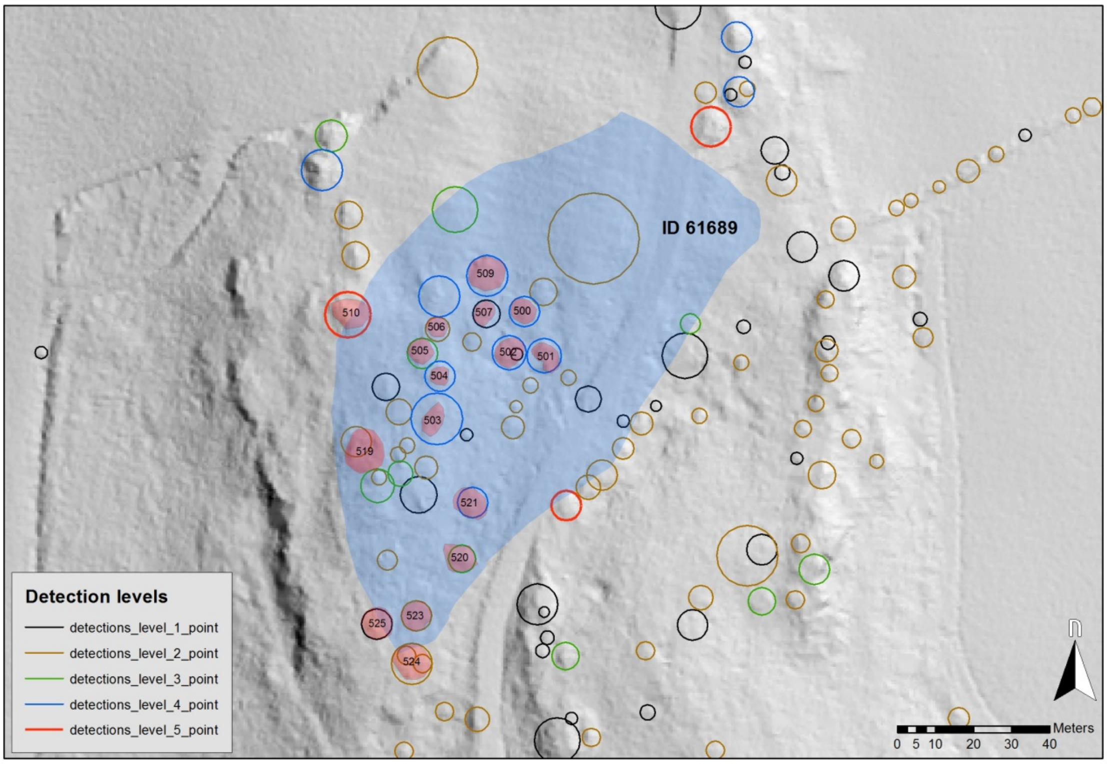


Figure 33: Grave field at Rom Søndre (ID 61689). The red polygons represent verified mounds and barrows. The outline of the site is presented as a blue shaded area.

Due to the dense vegetation the ALS ground point density in the forested areas is somewhat reduced. However, by applying *CultSearcher* a relatively high number of heap detections were recorded on the site. Most detections were of medium and low confidence and some were discarded as geological or natural features. During the ground survey a total of 15 round barrows were recorded, all detected by *CultSearcher* (Table 11, Figure 33). 7 mounds were detected on high or medium high confidence (4-5), 4 mounds were detected on a medium confidence level (3) and the final 3 on a low confidence level (1-2). Additionally, a long barrow (no 503) was detected by *CultSearcher* on a high confidence level (4), although with an incorrect detection diameter.

Despite the high detection rate at Rom Søndre, the detection diameter was in some cases incorrect (no 519). This was especially the case for the long barrow, probably due to its oval shape. Nevertheless, the high number of positive detections indicates that *CultSearcher* has worked successfully in this area.

The remaining 10 barrows listed in Askeladden were neither detected by the automatic system, nor by the archaeological ground survey. As indicated by the site geometry some barrows were located on the eastern side of the road, but all heap detections in this area were discarded as geological features. Mounds may have been damaged or removed during road work, or simply the result of incorrect mapping.

East of the site the terrain rises steeply towards a taller ridge. In this area CultSearcher had detected some high confidence heap detections that were inspected during the ground survey. All detections were verified as geological formations.

5.1.2 Cultural heritage monuments Store Oseberg (ID 61846, 22242, 12384, 42112).

The cultural heritage monument “Store Oseberg” represents several small grave fields located north and north west of the Oseberg farm. Some mounds are situated in the residential areas along Romnesveien, and others are located in a small forested area merely 300-800 m north of the Oseberg farm. According to the national cultural heritage database (Askeladden) the sites were listed in 1969, and comprise grave mounds and barrows as well as stone monuments and stone rings. The archaeological ground survey was conducted on 28 November 2013.

The sites are mainly situated in the outskirts of Osebergskogen, a densely grown mixed forest area dominated by coniferous trees. The area is widely known for its historical heritage and is also a popular environment for outdoor excursions. The forest is surrounded by fields and most of the mounds and barrows are located in the liminal zone between forested and farming areas.

Figure 34: 3D visualization of the ALS dataset from Oseberg, including vegetation.

The fields are surrounded by stone walls, which have affected the detection rate in two ways: firstly the stone walls have generated a high number of low confidence heap detections (confidence 1-2). Secondly, some walls seem to have been built from stones collected from the grave mounds. Therefore, many mounds are misshaped, reduced in size, or even included as part of the stone walls and hence more difficult to track with automatic detection systems.

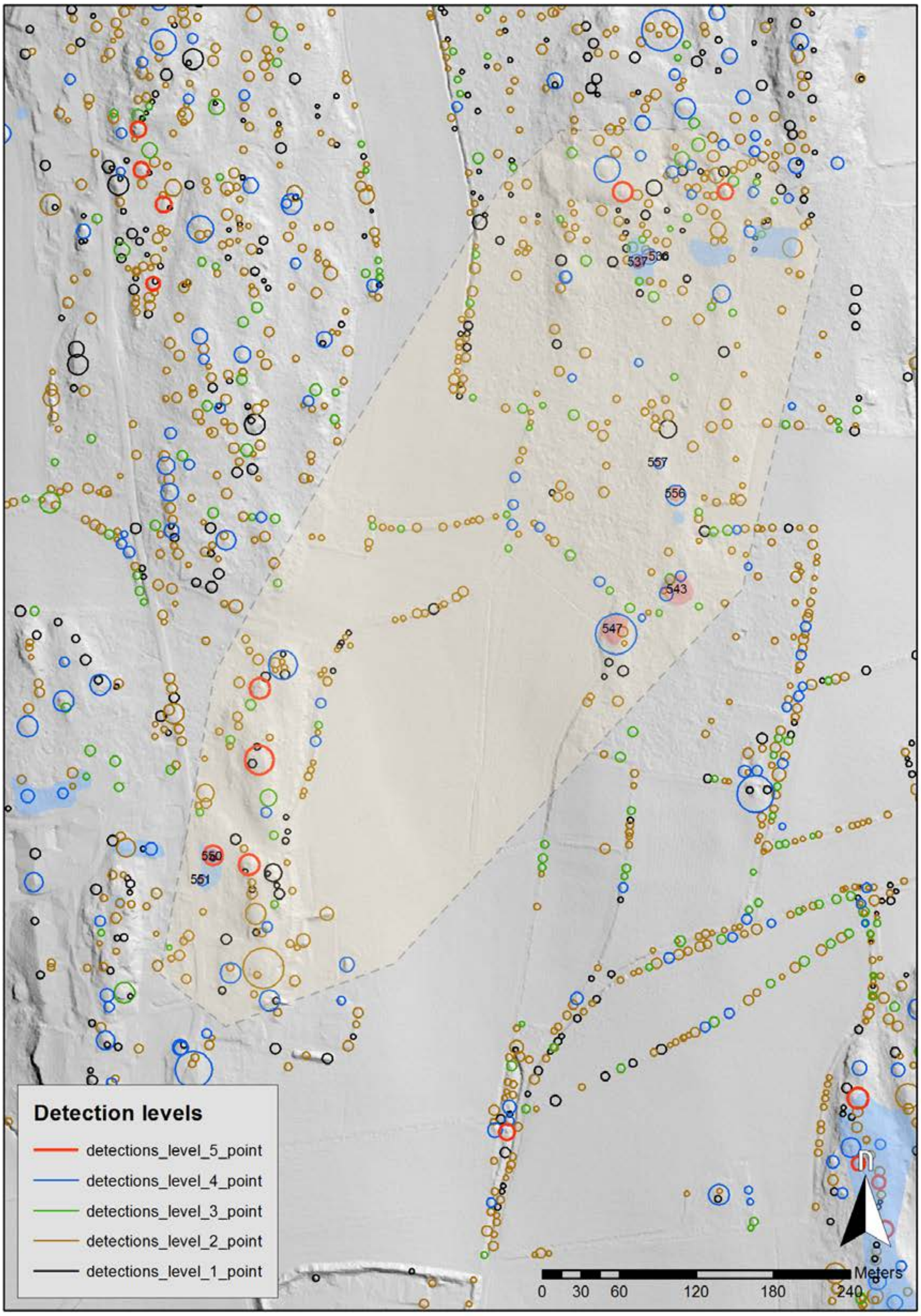


Figure 35: Sites at Store Oseberg. The red polygons are verified mounds and barrows. The blue shaded areas represent the outline of the listed sites. The yellow shade illustrates the surveyed area at Oseberg.

At "Oseberg Store", 6 out of 7 previously listed barrows and mounds were confirmed by *CultSearcher* (Figure 35; no 536, 537, 547, 550, 551, 556), . The detections were of high and medium high confidence (4-5). Additionally, one unrecorded barrow (no 557) was detected with medium high confidence (4). The undetected barrow (no 543 in Figure 36) was severely damaged and could only be recognized as a low stone circle on the ALS data. Due to its vague shape it should perhaps not be considered a real "non-detection" (Figure 37; * in Table 12).

As the site "Store Oseberg" has not been recorded as one confined area, but is spread throughout a large area with varying topography and vegetation, calculating the number of false detections is difficult. However, it may be useful to make a general evaluation of the detection rate in this area. Within the distance of 200 meters from the grave fields there are five high confidence detections. One of them is confirmed as a grave mound, which results in a detection rate of 20 %. Within the same range there are about 80-100 detections of medium high confidence (4), whereof 6 are verified as grave mounds or barrows. The positive detection rate at this confidence is only 6-7.5 %. The number of low confidence detections is very high due to the many stone walls in this area, and have not been counted.

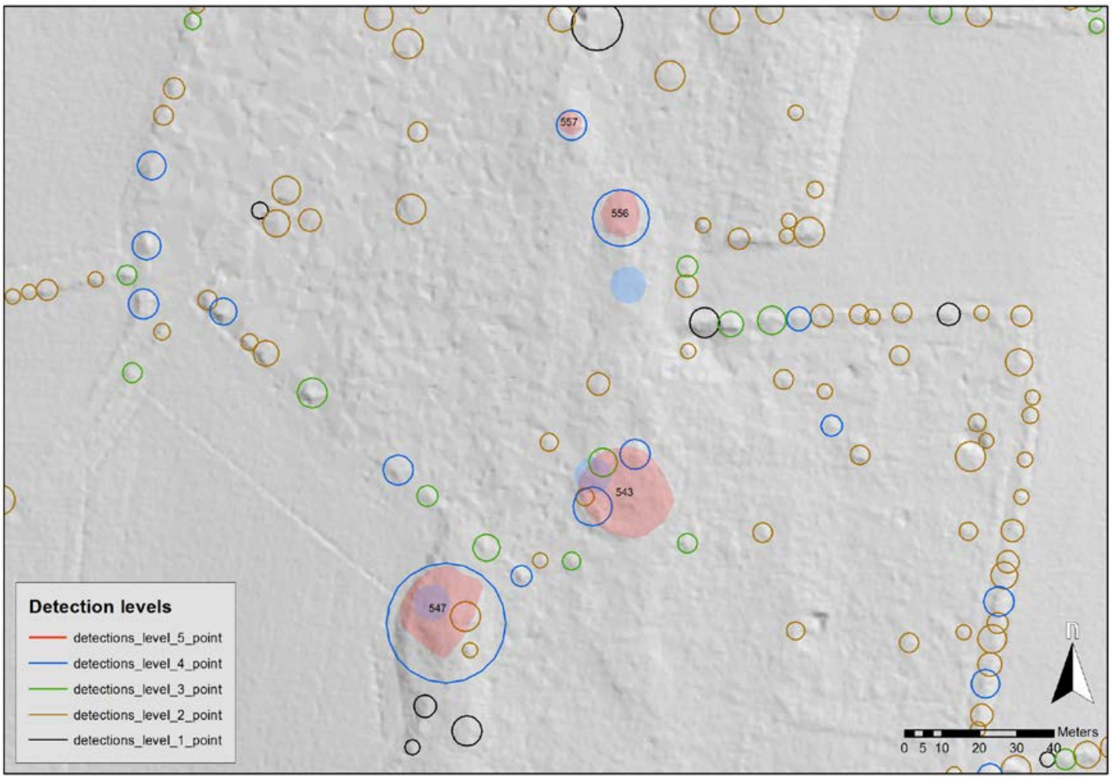


Figure 36: Detail from Store Oseberg (ID 12384, 32094, 42112). Red polygons: verified barrows. Blue shade: old site geometry. The medium and low confidence detections are mostly stone walls.

Figure 37: Undetected grave barrow (no 543). The barrow was severely damaged and merged with a stone wall. Photo: Christer Tonning.

Table 12. CultSearcher detections at Oseberg Store.

Oseberg Store	**Confidence of detection**						**not detected**
Confidence level	**6**	**5**	**4**	**3**	**2**	**1**	
Detections	0	5	80-100	-	-	-	-
Confirmed heaps	0	1	6	-	-	-	(1)*
Positive detections	-	20 %	6-7,5 %	-	-	-	-

5.1.3 Roberg Søndre (including ID 51832-1 Roberg Søndre)

Roberg Søndre is situated in the western part of the focus area, approximately 800-1000 meters west of “Rom Søndre”. Only one grave mound has been previously recorded in this area, but after running *CultSearcher* there were a high number of high confidence heap detections in its close vicinity (Figure 41). Many of the detections were located just a few hundred meters north of the known grave mound, hence making the area eligible for an archaeological ground survey. The survey was conducted on 12 December 2013.

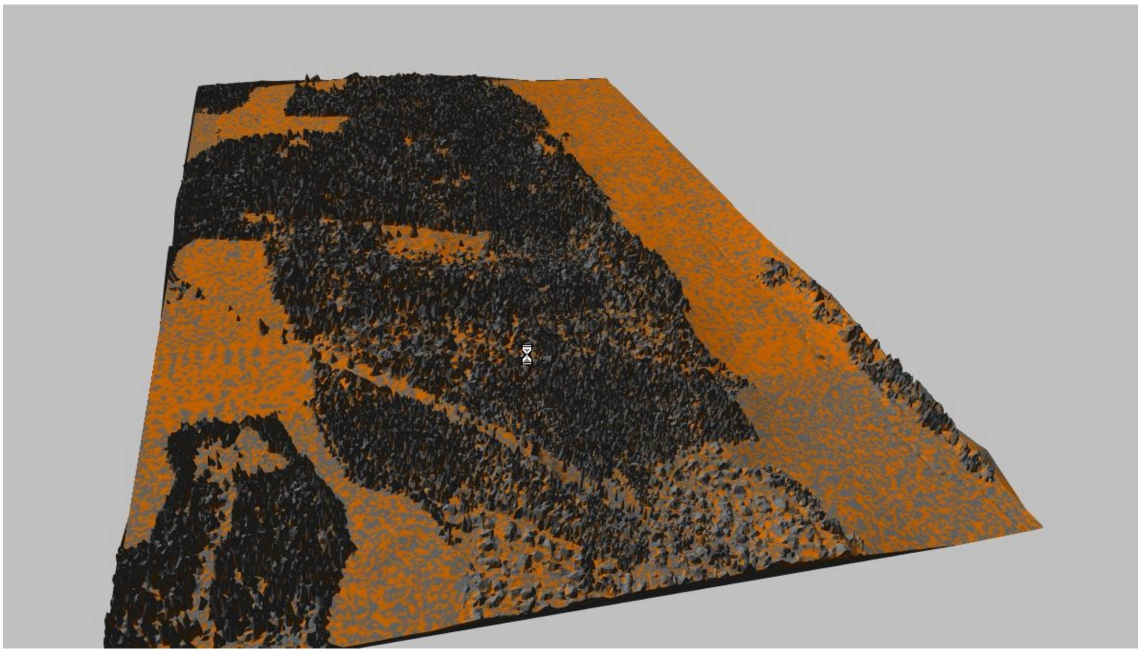


Figure 38: 3D visualization of the ALS data from Roberg Søndre, including vegetation.

The heap detections were located in a small forest surrounded by fields and residential areas. Vegetation is in some areas quite dense as parts of the forest are dominated by coniferous trees. Other areas, however, are open or grown with deciduous trees. The topography is characterized by steep hills and coarse ridges. Also, in some parts of the area there were recorded some modern stone- and sand heaps that were detected by *CultSearcher*. These formations had a close resemblance to grave mounds and barrows, and must thus be characterized as “correct false detections”.

The previously recorded grave mound at Roberg Søndre (no 571/ID 51832-1) was only partially detected by *CultSearcher*, although with low confidence (1-2). This mound was damaged and judging by its current shape it may have been used as a shooting hide. Additionally, an unlisted mound (no 571) was detected with medium high confidence (4). All other detections in this area, 19 of high confidence (5) and 98 of medium high confidence (4), were geological or natural formations, causing a very low positive detection rate in this area.

Table 13. CultSearcher detections at Roberg Søndre.

Roberg søndre	**Confidence of detection**						**not detected**
Confidence level	**6**	**5**	**4**	**3**	**2**	**1**	
Detections	0	19	98	88	283	103	-
Confirmed heaps	0	0	1	0	0	0	1
Positive detections	-	0%	>1 %	0%	0%	0 %	-

Figure 39: Geological formation detected by CultSearcher with high confidence (5). Photo: Christer Tonning.

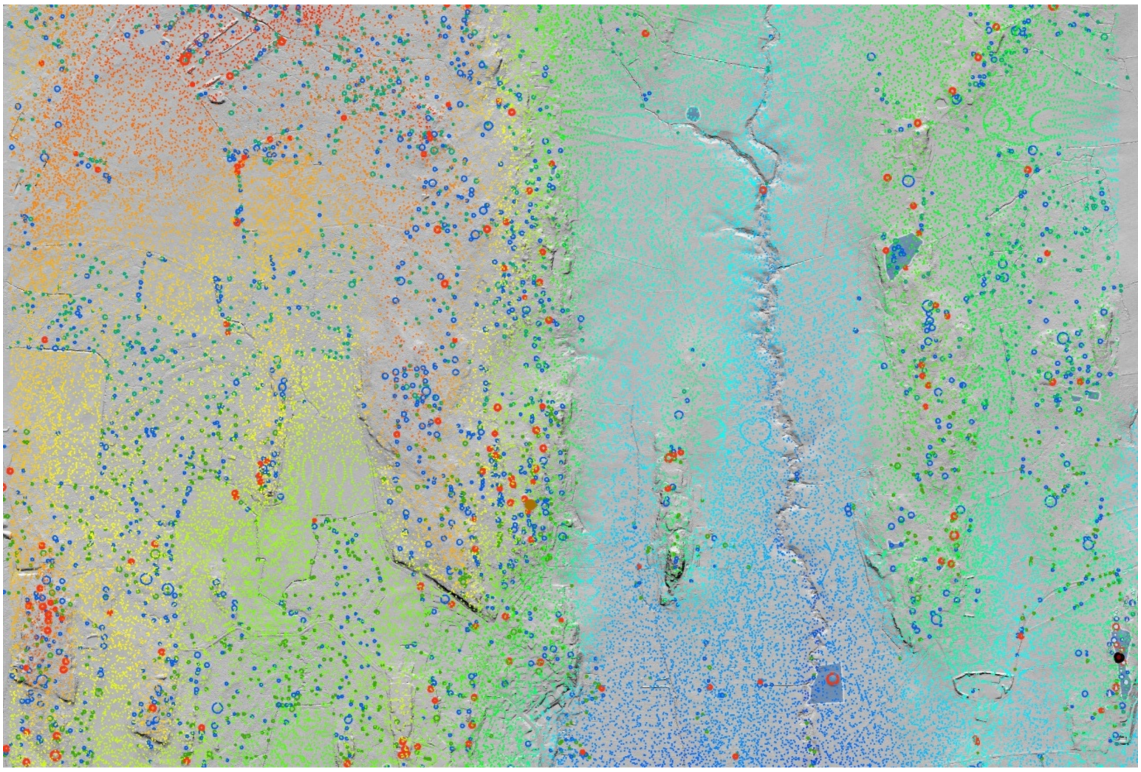


Figure 40: ALS ground points at Roberg. Circles represent automatic heap detections. Red: high confidence (5), Blue: medium high confidence (4), green: medium high confidence (3).

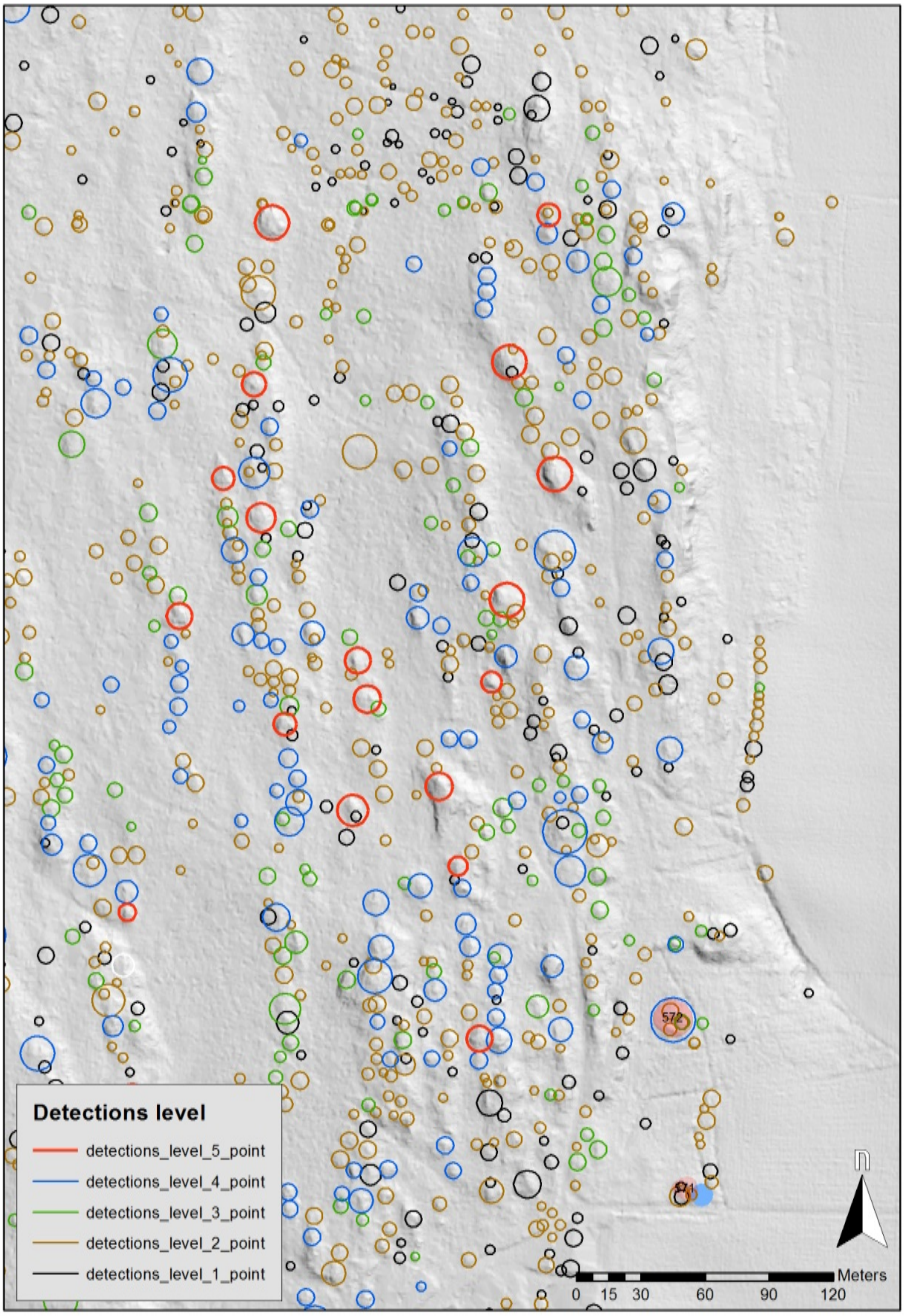


Figure 41: Heap detections at Roberg Søndre. The red shaded polygons (right bottom corner) represent confirmed mounds; the blue shaded polygon is the old site geometry (ID 51832). All high confidence heap detections in this area were false detections.

5.2 Discussion

At the sites Roberg Søndre, Oseberg and Rom Søndre, *CultSearcher* detected 21 out of 23 grave mounds and barrows, which give a detection rate of 91 %. The survey shows that the *CultSearcher* works well even with ALS scans of low ground point density. However, coarse ground surfaces like small ridges, rocks and bare bedrock produces a high number of negative detections – both of high and low confidence. Thus the pattern recognition may need to be utterly adjusted in order to lower the number of negative detections.

6 Grave mounds discovered by automatic heap detection method – and how that may change procedures in cultural heritage management

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Paper presented at the 4^{th} *EARSeL Workshop on Cultural and Natural Heritage*, 6-7 June 2013, Matera, Italy.

6.1 Abstract

A previously unknown grave field containing 19 grave mounds has recently been discovered by automatic pattern recognition software developed by the Norwegian Computing Center. Covered by spruce forest, the grave field is impossible to discover from aerial photography.

The *CultSearcher* software scans systematically for heaps in airborne laser scanning (ALS) data. The ALS data contains three-dimensional points, each labelled as vegetation, ground, building, or other. By only keeping the ground points, a very detailed digital elevation model (DEM) is obtained, in which the forest vegetation has been removed. This makes it possible to see the grave mounds even in dense forest. The automatic method slides a model heap over all positions in the DEM, and assigns scores to anything resembling a heap. By using heaps with gradually increasing diameters from 1.4 to 10 meters, the method is able to detect all heaps in this range. The integer scores range from 0 to 6.

CultSearcher has already significantly increased the number of archaeological heritage sites in the national database for protected cultural heritage. Furthermore, it has corrected the geographical position of several known archaeological heritage sites, relocating some up to 50 m. An accurate cultural heritage database is vital in detailed land use planning, to avoid the destruction of cultural heritage during construction work. The use of tools like *CultSearcher* needs to move beyond pilot projects, to be part of the standard cultural heritage mapping procedures in all Norwegian counties.

6.2 Introduction

Several Norwegian municipalities are experiencing growing pressure on forested land for development, being it new residential areas, industry, tourism, or new highways. The traditional mapping of cultural heritage, mainly based on chance discovery and inaccurate positioning, has proven inadequate for land use planning. Therefore, the Norwegian Directorate for Cultural Heritage, in cooperation with some counties and municipalities, are investing in the development of new methods, using new technology, for a more systematic mapping of cultural heritage.

One of the most frequent types of archaeological structure in Norway is grave mounds (Figure 42). We have earlier developed a method for the automatic detection of circular soil marks and crop marks in cereal fields in satellite and aerial images (Trier et al., 2009). Several of these detections have been confirmed to be levelled grave mounds, dating to 1500-2500 years ago.

Figure 42. Examples of grave mounds, Larvik municipality, Vestfold County, Norway. Top: a grave mound in Bøkeskogen, with a thin layer of snow. Bottom: a grave mound in Brunlafeltet, with a looting pit in the middle.

Methods based on optical images are of limited value in forested areas, since the archaeology tends to be obscured by the tree canopies. By using airborne laser scanning (ALS) data, also called airborne lidar data, and by only keeping the ground returns and not the returns from trees and buildings, the forest vegetation can be removed from the data, and a very detailed digital elevation model (DEM) of the ground surface can be constructed (Devereux et *al*., 2005). This makes it possible to detect archaeology in a semi-automatic fashion, provided the archaeology manifests itself as features in the digital elevation model of the ALS ground returns, and that these features may be described using some appropriate kind of pattern. In the majority of Norway's 19 counties, there are intact grave mounds in forested areas. This means that a semi- automatic method for the detection of grave mounds in ALS data would be an important tool in a more systematic mapping of archaeology in Norway.

We have recently developed a method for the semi-automatic detection of hunting systems and iron extraction sites from ALS data (Trier and Pilø, 2012). These archaeological features manifest themselves as pits in a digital elevation model (DEM) derived from the ALS ground returns. The method detects pits automatically in this DEM, followed by manual inspection by an archaeologist. This method is now in use as part of the standard procedure for archaeological mapping in Oppland County, Norway.

The purpose of this study is to develop a similar method for the automatic detection of heaps in ALS data, to assist archaeologists in a more accurate and complete mapping of grave mounds. Preliminary results have been presented at conferences in 2012 (Trier and Zortea, 2012; Trier et *al*., 2012).

6.3 Data

Larvik municipality in Vestfold County is known to contain a large number of grave mounds in forested areas. Vestfold County Administration has used airborne laser scanning (ALS) data extensively for the last three years (2010-2012). In 2010, Vestfold County Administration was involved in a mapping project concerning ALS data collection in Larvik municipality in the south of Vestfold. Originally, as defined by the municipality, this project did not intend to collect high resolution ALS data, but aimed at creating a new digital elevation model (DEM) for the purpose of deriving elevation contour lines, so an ALS pulse density of $1/m^2$ was considered adequate. In most cases, the original three-dimensional point measurements are never used by the municipalities, they are, in general, happy to have the derived contour lines, which are much more accurate in forested areas than traditional contour lines generated from stereo aerial photography.

However, when Vestfold County Administration got involved in the ALS data collection through the Norwegian 'Geovekst' geographical data collaboration programme in 2010, the motivation was to collect high-resolution ALS data for the purpose of mapping cultural heritage by visual inspection of a hill-shade relief model of the DEM. Through participation in another cultural heritage project, Vestfold County Administration was able to pay for upgrading the pulse density to $22/m^2$ for a 228 km2 area of interest in the south of Larvik municipality. This ALS dataset was acquired 3-7 June 2010 by Blom Sweden with a TopEye laser scanner on a helicopter at 450 m altitude. The raw data contains full waveform information, but was subsequently processed and converted to LAS 1.2 format, with up to 4 discrete returns for each emitted pulse, by Blom Sweden. ALS data for the remaining 390 km^2 of Larvik municipality was collected at $1/m^2$ pulse density on 24 May 2010 by Blom Geomatics with an Optech ALTM Gemini laser scanner on an airplane at 1275 m altitude.

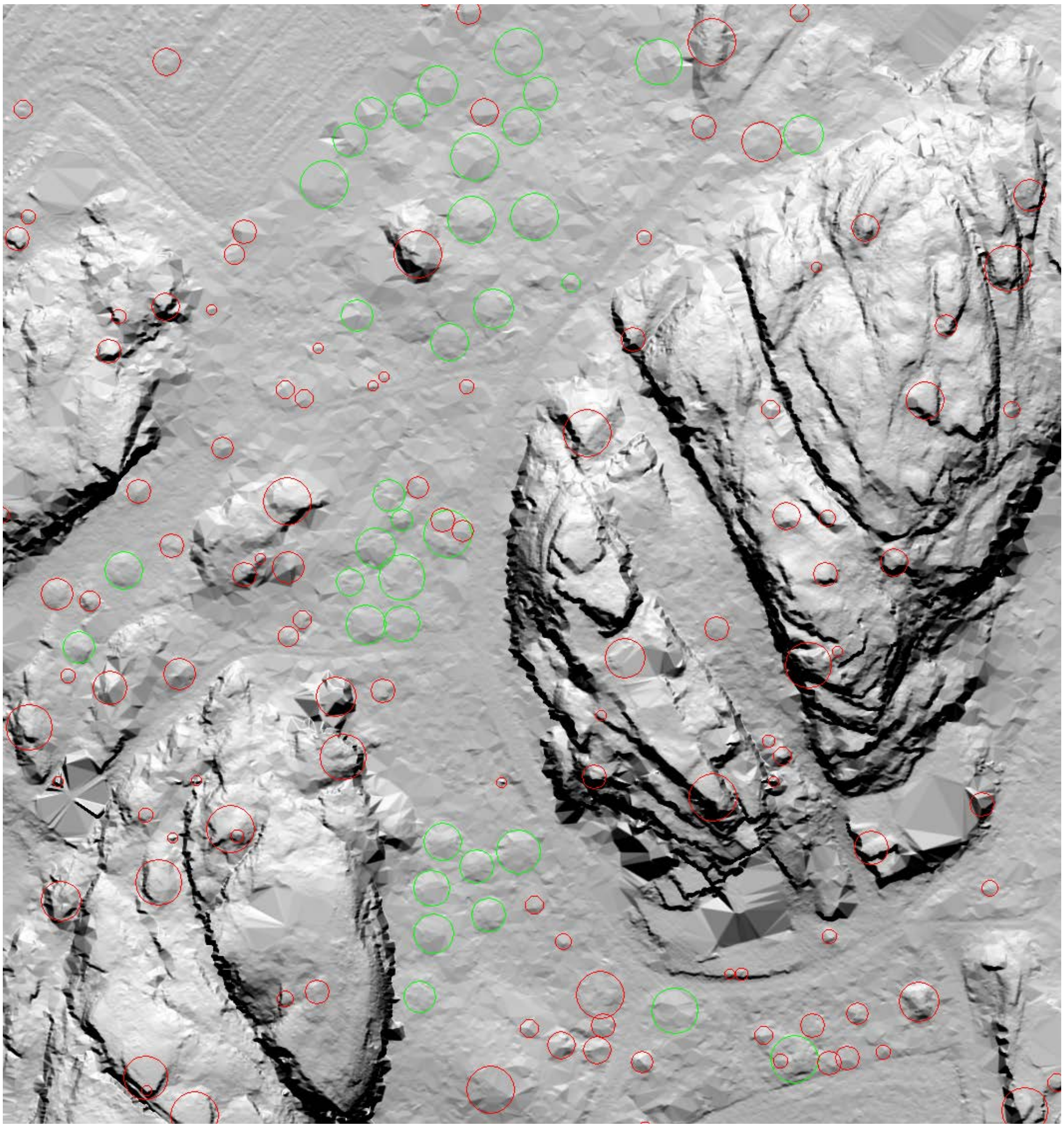

Figure 43. A 210 m × 225 m part of the Kaupang, Larvik training data set for heap detection. True (green) and false (red) grave mounds have been labelled manually.

Originally, data acquisition in late April 2010 was planned. However, the flight was delayed by over a month due to other engagements and faulty equipment. By early June, the leaves on deciduous trees, as well as low herbaceous vegetation, were almost fully developed, thus reducing the number of emitted laser pulses which actually hit the ground. Further, many laser pulse returns labelled as 'ground' may actually be returns from low vegetation. As a result, there are many areas in the dataset with a scarce amount of points labelled as ‘ground’ returns, and the height accuracy of the ‘ground’ points may be reduced.

From the 22/m^2 data set, 12 small portions containing known grave mounds were extracted for the development of the automatic heap detection method. Four of these are used as a training set: Kaupang (Figure 42), Store Sandnes, Tanum, and Ødelund. The remaining eight comprise a test set: Berg, Bommestad, Bøkeskogen (Figure 44), Hvatumskjeet, Kjerneberget, Lunde (near Valby), Valby, and Valbysteinene.

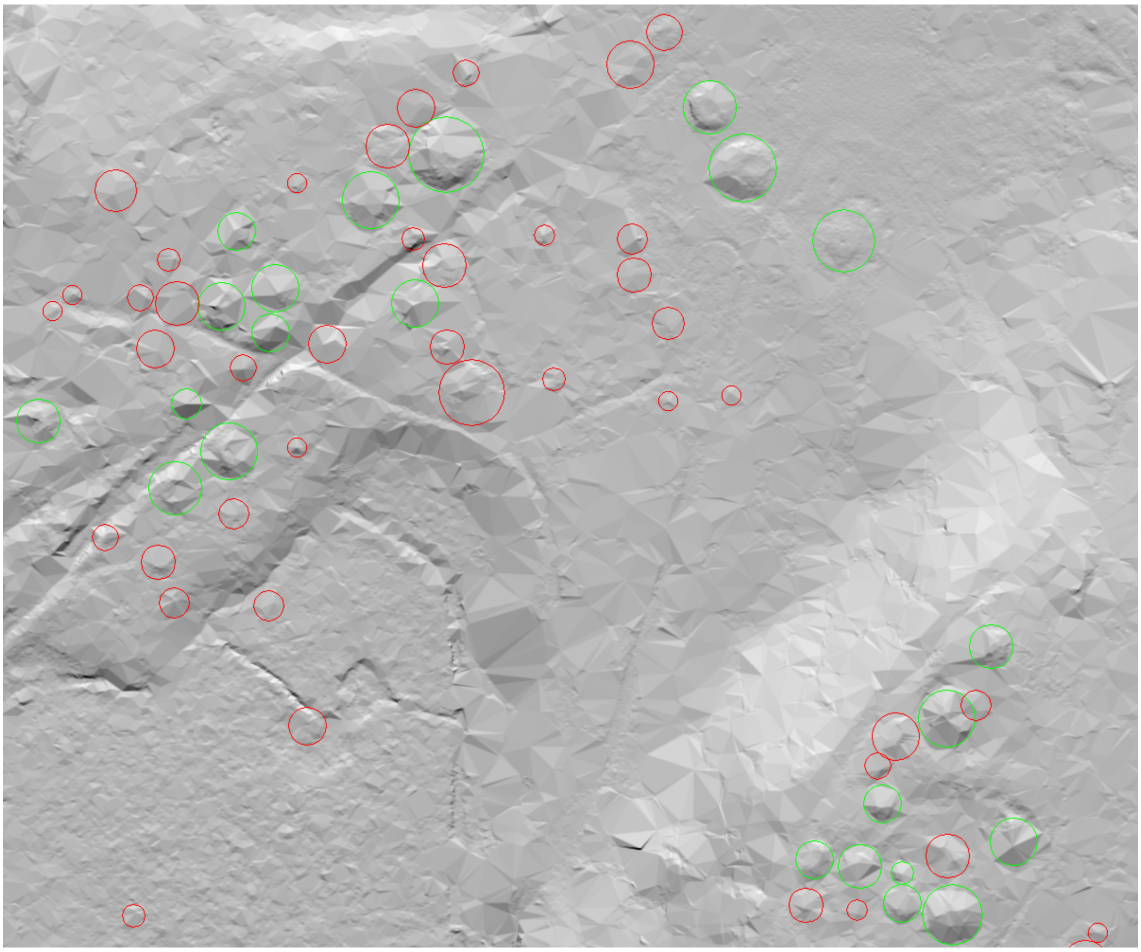

Figure 44. A 245 m × 200 m part of the Bøkeskogen, Larvik test data set for heap detection. True (green) and false (red) grave mounds have been labelled manually.

6.4 Methods

Building on our previous work (Trier et al., 2009; Trier and Pilø, 2012), we propose a processing chain for the automatic detection of heaps in ALS data:

1. Obtain ALS data from a commercial provider, in the form of LAS files (LAS specification, 2010). The point density should be at least 5 emitted pulses per m2, and the discrete returns must be labelled as ground, building, vegetation, etc.

2. Convert the ALS ground returns to digital elevation models (height images) with 0.2 m resolution.

3. Convolve the height images with dome-shaped heap templates (Figure 45) of varying sizes. Threshold each convolution result to obtain candidate heap detections.

4. Merge detections that are overlapping, keeping the strongest detections.

5. For each candidate heap detection, compute various measures of the deviation from an ideal dome.

6. Using thresholds on some of the measures, remove the most obvious non-heaps.

7. Assign confidence levels, either using a statistical classifier, a decision tree classifier, or a combination.

8. The list of detected heaps is verified by an archaeologist, first by visual inspection of the ALS data, then by field work.

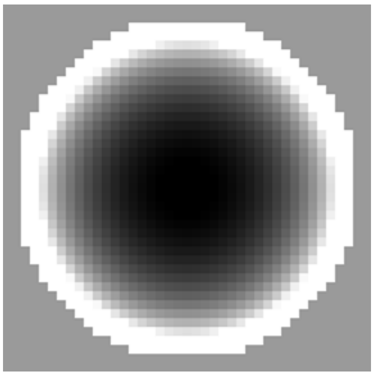

Figure 45. Heap template, shaped as a half-dome circumscribed by a flat ring. Black pixels are +1, white pixels are –1, and grey pixels in between. The medium grey pixels outside the white ring edge are exactly zero, thus not contributing to the convolution value. This particular heap template has 3.4 m radius.

6.4.1 Computation of attributes

Computation of attributes

In step 5 above, the following 15 attributes are computed:

1. Correlation value, obtained from the convolution step.

2. Normalized correlation value, that is, the correlation value divided by the radius.

3. Average heap height, measured as the height difference between the highest point inside the heap and the average height on the ring edge outside the heap.

4. Minimum heap height, measured as the height difference between the highest point inside the pit and the highest point on the ring edge.

5. Normalized average heap height, that is, average heap height divided by the radius.

6. Normalized minimum heap height.

7. Standard deviation of height values on the ring edge.

8. Root mean square (RMS) deviation from a perfect hemisphere, i.e., a perfect U-shaped heap.

9. RMS deviation from a perfect V-shaped heap.

10. For each heap, a threshold is defined as the value that separates the pixels inside the heap into two groups, the 25% of the pixels that are brighter than the threshold, and the 75% that are darker. Use this threshold to extract a bright blob segment from a square image centred on the heap, with sides equal to six times the radius. This is called the 25%-segment. If this results in a compact, central segment inside the heap, connected to a larger segment outside the pit, with only a few connecting pixels on a ring just outside the heap, then the central segment is separated from the outside segment. From the extracted segment, the following measures are computed:

    a. Offset: distance from heap centre to the segment's centre.

    b. Major axis length; for a definition, see, e.g., (Prokop and Reeves, 1992).

    c. Elongation, defined as major axis divided by radius.

11. Similarly to above, extract the 50%-segment and compute offset, major axis and elongation from that segment as well.

6.4.2 Initial screening

Thresholds are set on some of the attributes to remove detections that are very unlikely to be archaeology, while at the same time keeping all true archaeological features. By sorting a training set of labelled detections on one attribute at a time, one can manually identify attributes that can be thresholded so that all detections labelled as 'true' or 'possible' archaeology be kept, keeping several 'unlikely' and 'false' detections as well, but at the same time removing many 'unlikely' and 'false' detections. These thresholds should not be set too tight, to allow for slightly more variation in the attribute values for the 'true' and 'possible' archaeological features than was observed in the training data.

6.4.3 Statistical classification versus decision tree

For step 7 in the detection method above, a manually designed decision tree could be used to assign confidence values 1-6, with 1 meaning 'very low' and 6 meaning 'very high' (Trier and Pilø, 2012). However, this requires that a number of fixed thresholds be set manually, based on training examples. An alternative is to use a statistical classifier, and use thresholds on the estimated probability that a heap is a grave mound. We have previously compared the two approaches for automatic pit detection in the context of semi-automatic detection of pitfall traps and charcoal burning pits (Trier and Zortea, 2012). The statistical approach was better than the manually constructed decision tree when the confidence was medium high or better.

For medium or lower confidence, the manually constructed decision tree seemed to be better. Thus, it appears that a combined approach could be a good alternative. We will compare two approaches: (1) using statistical classifier, and (2) first using statistical classifier, then for confidence levels medium or lower, using a decision tree to reassign the confidence levels.

6.4.4 Automatic heap detection method: common steps

The first five steps in the heap detection method are common for both the manually designed decision tree and the statistical classifier approach. These five steps were applied on the Larvik data set. A number of parameters had to be selected in this process. A DEM grid size of 0.2 m was used to preserve the accuracy of the ALS height measurements, thus converting the ground hits to 25 interpolated height values per m^2. In the convolution step, heap templates corresponding to heap radii from 1.4 to 10.0 m were used, corresponding to the wide range of expected grave mound sizes. Each template has 0.2 m larger radius than the next smaller. As this is a first attempt, to avoid overlooking true grave mounds, the initial screening uses very relaxed thresholds on a subset of the attributes as follows:

1. Normalized correlation > 1.0
2. Average heap height > 0.2 m
3. Minimum heap height > 0.0 m
4. RMS u-shape < 0.2
5. RMS v-shape < 0.2
6. 25% segment elongation < 5

The result of the initial screening was a training set with 785 heap detections, of which 96 were labelled ‘true’ and the remaining ‘false’; and a test set of 905 heap detections, of which 96 were labelled ‘true’ and the remaining labelled ‘false’. The labelling was done by a non-archaeologist.

6.4.5 Automatic heap detection using statistical classifier

When using a statistical classifier, a number of parameters need to be estimated from the training data. The actual number of parameters varies between the different statistical classifiers. With a limited training set size, there is a trade-off. If we use a model with many parameters, less accurate estimates of these parameters may result than when using a model with fewer parameters. The following six different classifiers were evaluated (Hastie et *al*., 2009):

1. Decision tree (CART algorithm)
2. Nearest neighbour
3. Naïve Bayes (assuming independent attributes)
4. Mahalanobis distance

5. Linear discriminant analysis

6. Quadratic discriminant analysis

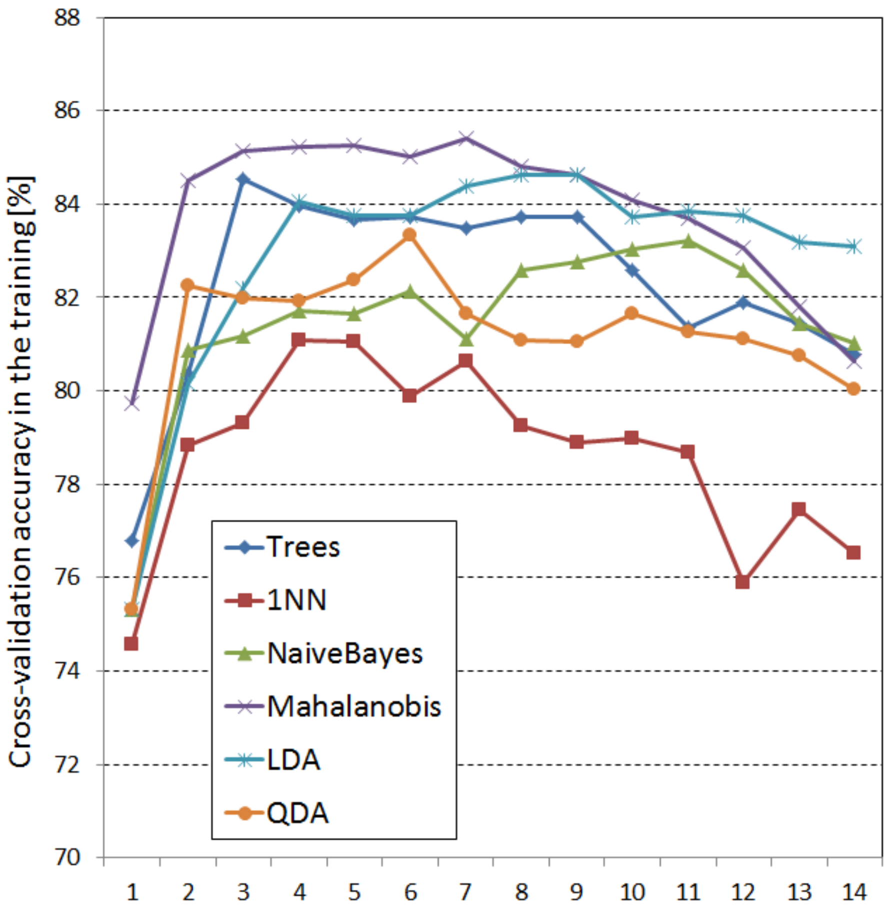

Figure 46. Performance of the six different classifiers on the Larvik training set, as a function of the number of attributes.

For each classifier, the best subset of the 15 attributes is determined using the sequential forward attribute selection algorithm (Pudil et *al*., 1994). The subset of attributes that maximizes the 10-fold cross-validation of average accuracy in the training set is retained. The best classifier turned out to be the Mahalanobis distance classifier (Figure 46), with the following seven attributes, in order of importance:

1. RMS U-shape

2. Correlation

3. Elongation of 25% segment

4. Offset of 25% segment

5. Standard deviation on edge

6. Major axis of 50% segment

7. Offset of 50% segment

We will now use the estimated posterior probability, that is, the probability that the detected heap is a grave mound, to assign a confidence level to each detection. With six confidence levels, we need to determine five thresholds. These can be found by defining and solving an optimization problem. As initial threshold values, we use the values corresponding to the 10th percentile, 25th, 50th, 75th and 90th percentile. Then, we can count the number of pits and non-pits in each confidence level, multiply with penalty weights (Table 2) and accumulate to obtain a score for the particular choice of thresholds. The counts for the grave mound and non-grave mound classes are normalized according to the respective number of samples. By adjusting the threshold values iteratively using a sequential loop strategy, they can be optimized to minimize the final score. By doing this on the training set, the thresholds in Table 3 are obtained, which assign 'medium high' or better confidence to most of the true grave mounds, and 'medium' confidence or lower to most non-archaeological heaps (Table 4).

Table 14. Penalty weights used for optimizing confidence level thresholds.

Score value	1	2	3	4	5	6
Confidence	very low	low	medium	medium high	high	very high
grave mounds	1024	256	64	16	4	1
not grave mounds	1	4	16	64	256	1024

Table 15. Optimized thresholds for confidence assignment for heap detection.

1	2	3	4	5
0.05072984	0.05121662	0.47666119	0.67167690	0.76737689

Table 16. The result of using the Mahalanobis distance classifier for confidence estimation on the Larvik training set.

Score value	1	2	3	4	5	6	
Confidence	very low	low	medium	medium high	high	very high	sum
grave mounds			16	47	21	12	96
not grave mounds	55	1	554	72	7		689
sum	55	1	570	119	28	12	785

6.4.6 Using a decision tree to reassign low confidence values

Since the statistical classifier does not assign meaningful confidence values when the confidence values are very low, low or medium, neither for pits, as observed in another study (Trier and Zortea, 2012), nor for heaps (Table 4), a decision tree classifier may be used to reassign confidence levels medium or lower. For this purpose, a number of thresholds were used (Table 5).

Table 17. Thresholds for reassigning confidence levels.

optimised on training set	confidence	
measurements	**low**	**medium**
RMS diff from U-shape	≤0.08	≤0.06
radius	≥1.4	≥1.8
correlation	≥1.2	≥2.0
25% segment elongation	≤4	≤1.6
standard deviation on ring edge	≤0.7	≤0.4
25% segment offset	≤25	≤15
normalized average height	≤0.3	≤0.25
normalized average height	≥0.05	≥0.06
normalized correlation	≤8	≤8
normalized correlation	≥1	≥1.5
average height	≥0.1	≥0.2

If a heap detected by the Mahalanobis distance classifier has medium or lower confidence, then it is first set to very low. If all the threshold tests for low in Table 5 are met, then the detection gets low confidence. Next, if all the thresholds for medium in Table 5 are met, then the confidence changes again from low to medium.

6.5 Evaluation of automatic heap detection on an independent test set

The proposed method has been implemented as ENVI/IDL code in a prototype software system called *CultSearcher*.

By running the Mahalanobis distance classifier on the Larvik test set, a slightly higher number of true grave mounds obtained high or very high confidence (Table 6) compared with the training set (Table 4). At the same time, about twice as many false detections obtained medium high, high or very high confidence. None of the true detections and almost none of the false detections got 'low' or 'very low' confidence. So, in an operational setting, to successfully verify the 14 true grave mounds with 'medium' confidence, 647 false detections have to be checked as well. By accumulating the detection counts (Table 7), the trade-off between detecting as many grave mounds as possible while at the same time limiting the number of false detections is more evident. E.g., 82 out of 96 grave mounds were detected with medium high confidence or better (Table 7); this is 85% of the true grave mounds that were successfully segmented in the template matching step. At the same time, 158 of the detections with medium high or better confidence were false.

In order to obtain more true detections, e.g., by considering all detections with medium or better confidence, 805 false detections are obtained as well. By using the decision tree to reassign confidence levels for detections with medium or lower confidence, the same numbers of true and false detections with medium high confidence as before are obtained (Table 8). However, it is now possible to detect eight additional grave mounds, with medium confidence, with the additional cost of obtaining 155 false detections, labelled with medium confidence. This means that 94% of the true grave mounds are detected with medium confidence or better, with 313 false detections in addition (Table 9).

When running the automatic method on the Kaupang part of the training data, and overlaying with grave monuments from the official '*Askeladden*' Norwegian cultural heritage database, it becomes evident that a number of true grave mounds are not detected by the method (Figure 47). The percentages in Table 6-Table 9 are estimated without taking these missing detections into account.

Table 18. Result of running the Mahalanobis distance classifier for confidence estimation on the Larvik test set.

Score value	1	2	3	4	5	6	
Confidence	very low	low	medium	medium high	high	very high	sum
grave mounds			14	39	25	18	96
not grave mounds	4		647	144	13	1	809
sum	4	0	661	183	38	19	905

Table 19. Accumulated heap detection counts for the Mahalanobis distance classifier on the Larvik test set.

Score value	≥1	≥2	≥3	≥4	≥5	≥6	
Confidence	very low or better	low or better	medium or better	medium high or better	high or better	very high or better	sum
grave mound	**96**	**96**	**96**	**82**	**43**	**18**	**96**
not grave mound	809	805	805	158	14	1	809
sum	905	901	901	240	57	19	905
grave mounds detected	100%	100%	100%	85%	45%	19%	
grave mounds missed	0%	0%	0%	15%	55%	81%	

Table 20. Result of running the combined classifier for confidence estimation on the Larvik test set.

Score value	1	2	3	4	5	6	
Confidence	very low	low	medium	medium high	high	very high	sum
grave mounds	1	5	8	39	25	18	96
not grave mounds	145	351	155	144	13	1	809
sum	146	356	163	183	38	19	905

Table 21. Accumulated heap detection counts for the combined classifier on the Larvik test set.

Score value	≥1	≥2	≥3	≥4	≥5	≥6	
Confidence	very low or better	low or better	medium or better	medium high or better	high or better	very high or better	sum
grave mound	**96**	**95**	**90**	**82**	**43**	**18**	**96**
not grave mound	809	664	313	158	14	1	809
sum	905	759	403	240	57	19	905
grave mounds detected	100%	99%	94%	85%	45%	19%	
grave mounds missed	0%	1%	6%	15%	55%	81%	

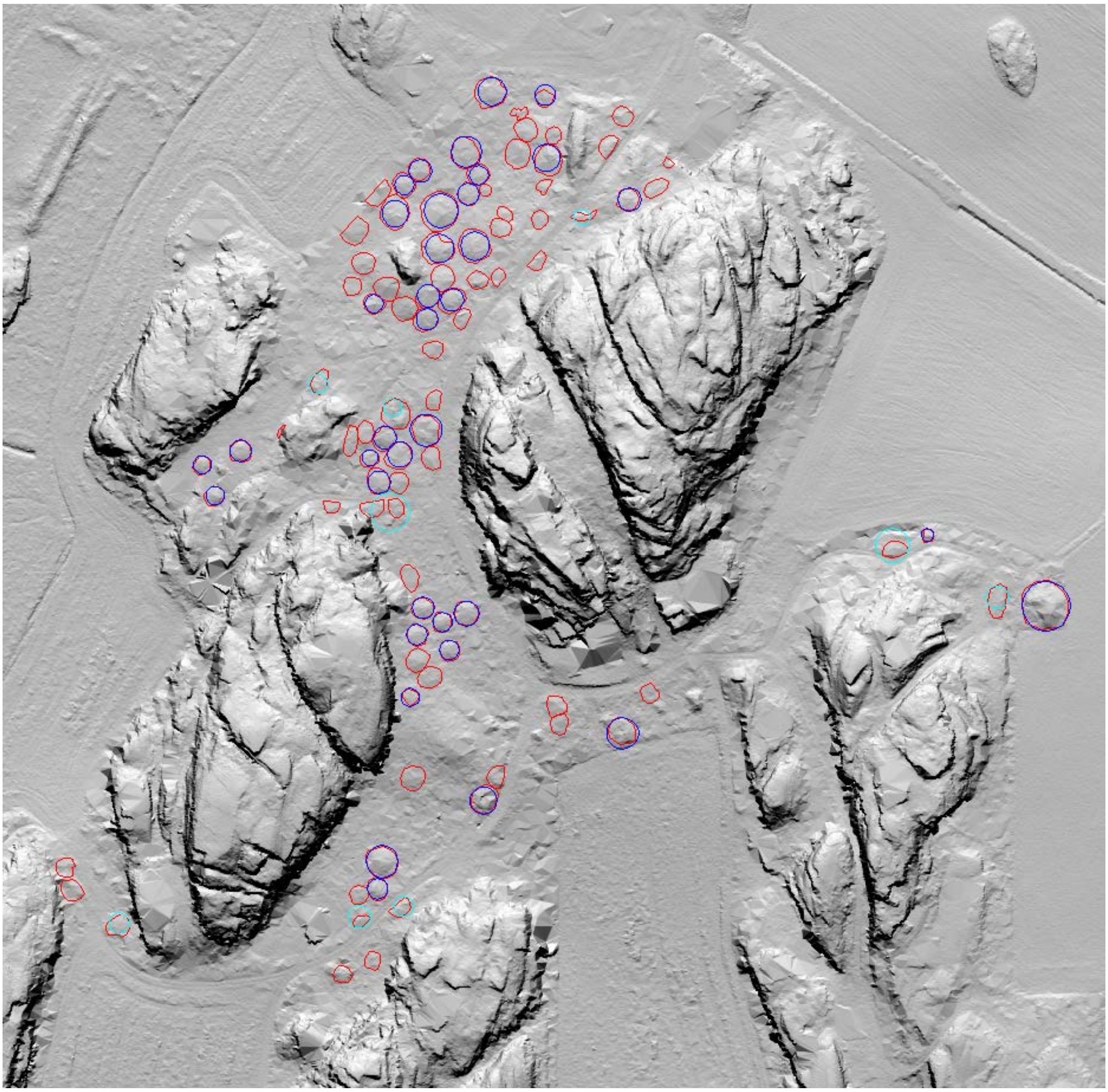

Figure 47. Grave mounds at Kaupang, Larvik municipality. Red: previously mapped grave mounds. Dark blue: automatic detections, with correct geometry. Cyan: automatic detections, with incorrect geometry. Automatic heap detections that are not grave mounds are not shown.

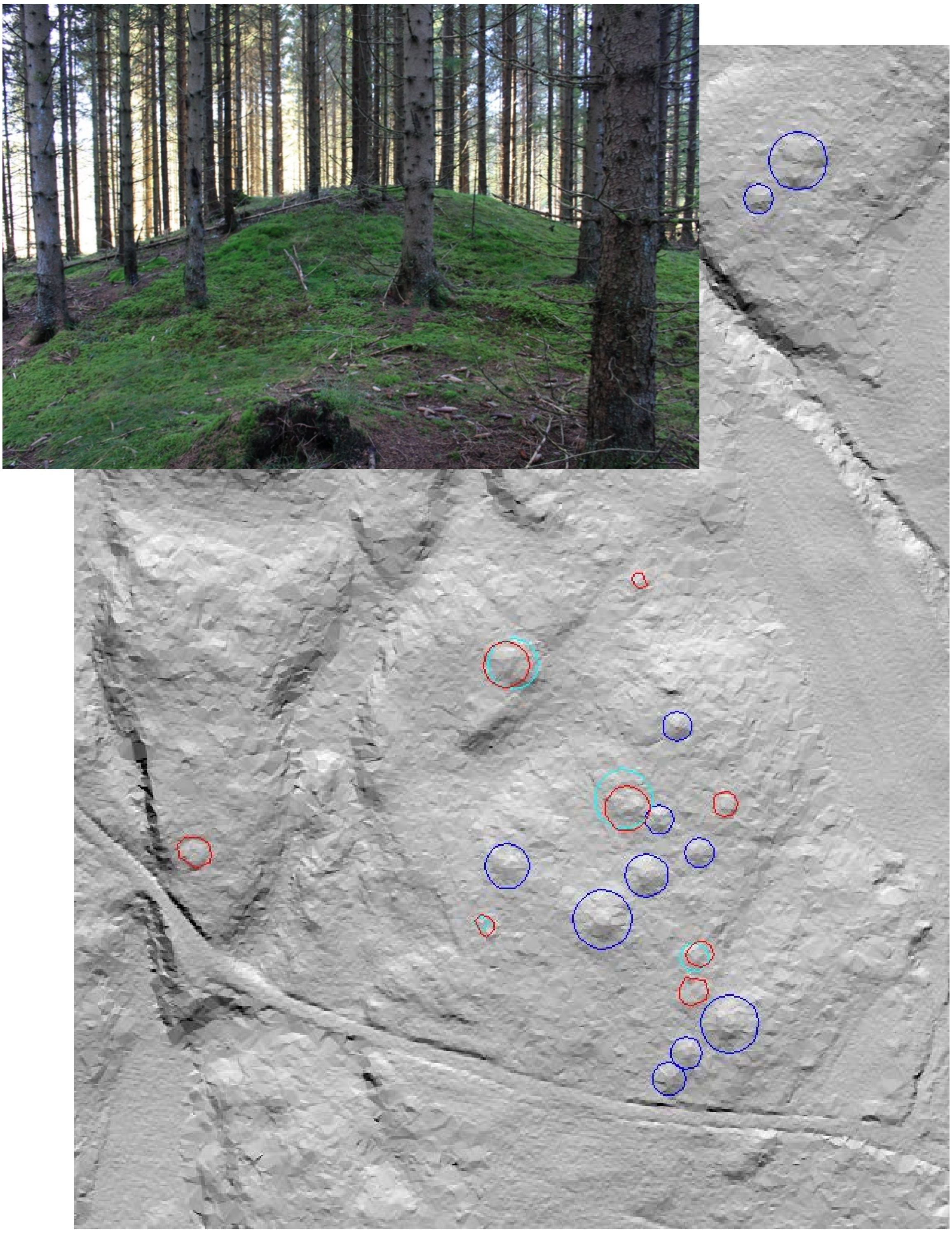

Figure 48. Grave mounds at Omsland søndre, Larvik municipality, Vestfold County, Norway. Dark blue: 11 mounds detected by automatic method, with correct geometry. Cyan: four mounds detected by automatic method, but with incorrect geometry. Red: correct geometry of grave mounds, of which four were detected with incorrect geometry, and four were not detected. Colour image inset: one of the grave mounds.

6.6 Results

For the previously known grave fields, the *'Askeladden'* Norwegian national cultural heritage database contains polygons describing the extent of the grave field. The polygons from Askeladden and the automatic detections from *CultSearcher* were overlaid on a relief model of the ALS data. The typical pattern was that the polygon from Askeladden, describing the extent of the grave field, was inaccurate, with many candidate grave mounds appearing outside the polygon. This visual assessment was then used for planning of field work for accurate mapping of the individual grave mounds.

Field work was done at six previously known grave fields in 2012. Also, field work was done at a few selected locations with a large number of high confidence automatic detections. One of these, located at Omsland søndre, turned out to be a grave field that was previously not known (Figure 48). This is the largest discovery of grave mounds in Norway for many years, and made headlines in the national newspaper Aftenposten (Guhnfeldt, 2012), two regional newspapers, and a radio interview.

In addition, previous field work at Kaupang and Bøkeskogen was included. Individual grave mounds at Kaupang had been mapped by total station in 2005 by Steinar Kristensen, the Museum of Cultural History at the University of Oslo. Individual grave mounds in Bøkeskogen were mapped in 2001 by Lars Forseth.

The field work mapping of individual grave mounds was compared with the automatic detections (Table 10). Overall, 36% of the true grave mounds were detected with correct geometry by *CultSearcher*, 26% of the true grave mounds were detected with incorrect geometry, and 38% were missed. For the individual grave fields, these percentages vary substantially, which is an expected statistical effect in small sample sizes.

As mentioned above, the grave field extent polygons in the Askeladden database are in general inaccurate. For example, at Ødelund (Figure 49), 15 individual grave mounds were mapped. Of these, two were totally outside the grave field extent polygon from the Askeladden data base, and six were partially outside.

Table 22. The number of verified grave mounds that the automatic method did detect and did not detect.

Grave field or farm name	ALS ground point density, file average	detected, correct geometry		detected, incorrect geometry		not detected		sum
Kaupang	5.0	16	18%	29	32%	46	51%	91
Brunlafeltet	5.6	45	68%	7	11%	14	21%	69
Bøkeskogen	3.3	18	26%	18	26%	33	48%	69
Lunde søndre (near Hedrum)	0.65	6	18%	8	24%	20	59%	34
Løvall	4.4	1	14%	4	57%	2	29%	7
Ødelund	6.1	11	73%	2	13%	2	13%	15
Omsland nordre	0.89	5	33%	6	40%	4	27%	15
Omsland søndre	0.89	11	58%	4	21%	4	21%	19
Store Sandnes / Hem østre	5.3	7	41%	10	59%	0	0%	17
sum		120	36%	88	26%	125	38%	333

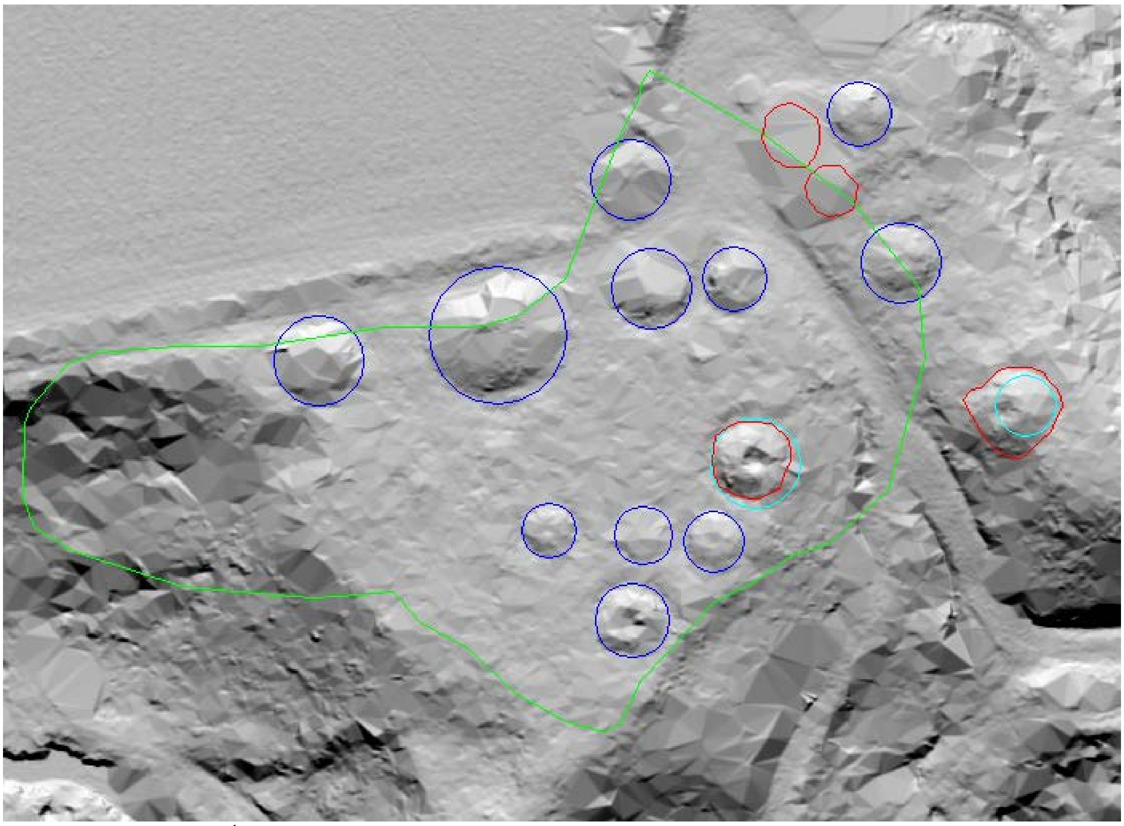

Figure 49. Grave mounds at Ødelund, Larvik municipality. Green: outline of grave field according to the 'Askeladden' national cultural heritage database. Dark blue: automatic detections, with correct geometry. Cyan: automatic detections, with incorrect geometry. Red: correct geometry of grave mounds.

6.7 Discussion and conclusions

The grave mound detection results on the grave fields that have been verified by field survey, indicate that the proposed automatic heap detection method is able to detect 62% of the true grave mounds, despite less than optimal ALS data quality. This varied between 41% and 100% for the individual grave fields. At the same time, the heap detection results on the Larvik test set indicate that the combined confidence assignment method is capable of assigning medium confidence or better to 94% of the grave mounds that it is able to detect, while at the same time, 3-4 times as many false detections as true detections are assigned medium confidence or better. From previous experience (Trier and Pilø, 2012), this is an acceptable trade-off. However, 38% of the true grave mounds have not been detected at all (Table 10). This could either be due to missed detections in the template matching step, or due to removal of true detections in the subsequent thresholding step, which aims at removing obvious non-heaps. We need to investigate the reason these were missed, in order to improve the method.

Further, we need to quantify how the method performs in areas with few grave mounds. We suspect that the number of false detections remains relatively stable for geographical areas of similar size, which means that the number of false detections could be overwhelming. If this is indeed the case, we need to consider ways of improving the method.

However, improving the method is of limited value if the problems are due to the quality of the ALS data. Previous experience with pit detection in ALS data clearly demonstrates the negative effect of reduced ground point density (Trier and Pilø, 2012). Low ground point density may be due to wrong acquisition time, dense or low vegetation, too few emitted pulses per square meter, or a combination of these. Since there is a large proportion of deciduous tree in the forests in Larvik municipality, the archaeologists recommended that the acquisition of ALS data be done in late April 2010, which would have been an ideal time, with no snow on the ground and no leaves on the trees. For some reason, the ALS acquisition was postponed until the beginning of June 2010, with full-size leaves on the trees. We recommend that future ALS data sets be acquired in the early spring with no leaves on the deciduous trees, to allow more true grave mounds to be detected by the method.

Another possibility for obtaining better ALS data is to re-process the raw, full waveform ALS data to produce new LAS files, optimized for obtaining a better elevation model of the ground. This was demonstrated in April 2013 on the Kaupang grave field, and visual comparison of hill-shaded reliefs indicated improved appearance of the grave mounds (Doneus, 2013). However, at the time of writing, we do not have access to the reprocessed data.

Another potential problem related to the ALS ground point density is that some grave mounds are small, either measured as height difference relative to the surrounding landscape, or measured as radius from centre to edge. Clearly, if the grave mound does not manifest itself in the data, then it cannot be detected. There could also be a problem if the heap template does not resemble the true shape of grave mounds. One possible way of studying this is to estimate from the data the shape of an average grave mound, and how it varies; then to generate simulated grave mound templates.

Further, we could consider extracting more attributes from the detected heap candidates, in the hope that some of these may improve the ability to discriminate between grave mounds and non-archaeological heaps. Additional attributes could include, e.g.:

1. Average ALS ground point density within the area covered by the heap template
2. Average ALS intensity
3. Average height gradient
4. Average gradient squared
5. Average gradient entropy.

The motivation for the various gradient measurements is that some heap detections are natural terrain features, which, by inspection of the ALS data, contain steeper slopes than found on grave mounds. Two of the suggested gradient measures are weighted averages, which place more emphasis on the high gradient values than a non-weighted average. The intensity might give some hints as to the hardness of the ground surface, as well as whether part of the emitted pulse did not reach the ground. The point density could indicate how well the shape of a possible heap is preserved.

Many grave mounds are surrounded by a circular ditch. Also, many grave mounds have a pit, indicating that it has been plundered. *CultSearcher* should look for these shapes in addition to heaps, and when occurring in combination, the confidence of the heap detection should increase.

CultSearcher has been used extensively in Oppland County, Norway, since 2010 for the mapping of archaeological pits, like pitfall traps in hunting systems, and charcoal burning pits in iron extraction sites. Thus, *CultSearcher* has already significantly increased the number of archaeological heritage sites in 'Askeladden', the Norwegian national database for protected cultural heritage. Furthermore, it has corrected the geographical position of several known archaeological heritage sites, relocating some up to 50 m. An accurate cultural heritage database is vital in detailed land use planning, to avoid the destruction of cultural heritage during construction work. The use of tools like *CultSearcher* needs to move beyond pilot projects, to be part of the standard cultural heritage mapping procedures in all Norwegian counties.

Ideally, automatic detections by *CultSearcher* need to be verified by archaeologists, first by visual inspection of the ALS data with the detection results overlaid, then by field work. However, the current results on automatic heap detection and previous results on automatic pit detection (Trier and Pilø, 2012) indicate that *CultSearcher* may also be able to estimate cultural heritage density maps, which could be used as an 'early warning' in land use planning.

As a conclusion, the present study demonstrates that automatic heap detection is a useful tool for the semi-automatic detection of grave mounds in Norway from airborne laser scanning data, especially when the number of ground points per square meter is not too low. We have identified a number of possible improvements of the method, some of which could be important in an operational setting with non-optimal data. However, the highest potential for better detection performance is in better ALS data quality.

6.8 Acknowledgements

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7 19 Grave mounds in Vestfold, Norway discovered by automatic heap detection method

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Keywords: Pattern recognition, statistical classification, digital elevation model, airborne laser scanning, lidar.

7.1 Abstract

A previously unknown grave field containing 19 grave mounds has recently been discovered by automatic pattern recognition software proposed in this paper. Covered by spruce forest, the grave field is impossible to discover from aerial photography.

The *CultSearcher* software has a module which scans systematically for heaps in airborne laser scanning (ALS) data. The ALS data contains three-dimensional points, each labelled as vegetation, ground, building, or other. By only keeping the ground points, a very detailed digital elevation model (DEM) is obtained, in which the forest vegetation has been removed. This makes it possible to see the grave mounds even in dense forest. The automatic method slides a model heap over all positions in the DEM, and assigns confidence scores to anything resembling a heap. The integer scores range from 1 to 6. By using heap templates with gradually increasing radii from 1.0 to 16 meters, the method is able to detect all heaps in this range, provided they are present in the DEM.

CultSearcher has already significantly increased the number of archaeological heritage sites in the national database for protected cultural heritage. Furthermore, it has corrected the geographical position of several known archaeological heritage sites, relocating some up to 50 m. An accurate cultural heritage database is vital in detailed land use planning, to avoid the destruction of cultural heritage during construction work. The use of tools like *CultSearcher* needs to move beyond pilot projects, to be part of the standard cultural heritage mapping procedures in all Norwegian counties.

7.2 Introduction

Several Norwegian municipalities are experiencing growing pressure on forested land for development, being it new residential areas, industry, tourism, or new highways. The traditional mapping of cultural heritage, mainly based on chance discovery and inaccurate positioning, has proven inadequate for land use planning. Therefore, the Norwegian Directorate for Cultural Heritage, in cooperation with some counties and municipalities, are investing in the development of new methods, using new technology, for a more systematic mapping of cultural heritage.

One of the most frequent types of archaeological structure in Norway is grave mounds (Figure 1). We have earlier developed a method for the automatic detection of circular soil marks and crop marks in cereal fields in satellite and aerial images (Trier et al., 2009). Several of these detections have been confirmed to be levelled grave mounds, dating to 1500-2500 years ago.

Methods based on optical images are of limited value in forested areas, since the archaeology tends to be obscured by the tree canopies. By using airborne laser scanning (ALS) data, also called airborne lidar data, and by only keeping the ground returns and not the returns from trees and buildings, the forest vegetation can be removed from the data, and a very detailed digital elevation model (DEM) of the ground surface can be constructed (Devereux et al., 2005). This makes it possible to detect archaeology in a semi-automatic fashion, provided the archaeology manifests itself as features in the digital elevation model of the ALS ground returns, and that these features may be described using some appropriate kind of pattern. In the majority of Norway's 19 counties, there are intact grave mounds in forested areas. This means that a semi- automatic method for the detection of grave mounds in ALS data would be an important tool in a more systematic mapping of archaeology in Norway.

Recently, ALS data has been used for the purpose of detecting cultural heritage sites. Bewley et al. (2005) used a digital elevation model (DEM) derived from ALS height measurements to map previously unknown details of the Stonehenge World Heritage Site. The height accuracy of the ALS measurements was able to reveal details that previously had been overlooked. Devereux et al. (2005, 2008) explored the possibilities of varying the sun elevation and illumination direction when hillshading the ALS DEM, and noted that some structures may be missed by human interpretation if only one illumination direction is used. They further demonstrated that by using only the ALS pulses that were reflected by the ground, and not the pulses reflected by trees, in effect removing the forest vegetation from the DEM, a very detailed elevation model of the ground was obtained. For the particular study site, more detail was apparent in the DEM than could be seen in the existing archaeological map. Hesse (2010) subtracted a smoothed version of the ground surface DEM from the original to obtain a local height model, thus enhancing local detail and suppressing the large-scale terrain. The local height model could be viewed directly as a grey-scale image. It was often an advantage to view both the local height model and a hill-shade model of the original ground surface DEM to get the landscape context when doing visual interpretation. Kokalj et al. (2011) computed the sky-view factor to emphasize local detail. Hesse (2010) noticed that some archaeological structures, such as burial mounds, can be confused with natural phenomena such as small natural hills, wood piles, and patches of low vegetation. Doneus et al. (2008) and Coluzzi et al. (2010) used full waveform lidar to better discriminate between low vegetation and structures of archaeological interest. Automatic detection in ALS data may be done either directly on the point cloud or on a derived DEM with a suitably chosen pixel size. Sampath and Shan (2010) extracted planar surfaces directly from the point cloud to detect building roofs. Wang and Tseng (2004) used an octree subdivision of the point cloud to identify planar patches, then merging patches belonging to the same plane. To extract buildings, Rottensteiner and Briese (2002) filtered the ALS points into terrain and off-terrain points in an iterative process, resulting in a digital terrain model (DTM),which is a smoothed model of the terrain points, and a digital surface model (DSM), which is a non-smoothed model of all the ALS points. The DTM was subtracted from the DSM, resulting in a local height model. This DEM was then used for building extraction. Kwak et al. (2007) used the TerraScan software to classify ALS points into ground, low vegetation, medium vegetation and high vegetation. The high vegetation returns were used to generate a DSM, while the ground returns gave a DTM. By subtracting the DTM fromthe DSM, a digital canopy model (DCM) was obtained, and individual trees were extracted from this DEM.

We have recently developed a method for the semi-automatic detection of hunting systems and iron extraction sites from ALS data (Trier and Pilø, 2012). These archaeological features manifest themselves as pits in a digital elevation model (DEM) derived from the ALS ground returns. The method detects pits automatically in this DEM, followed by manual inspection by an archaeologist. This method is now in use as part of the standard procedure for archaeological mapping in Oppland County, Norway.

The purpose of this study is to develop a similar method for the automatic detection of heaps in ALS data, to assist archaeologists in a more accurate and complete mapping of grave mounds. Preliminary results have been presented at conferences (Trier and Zortea, 2012; Trier et al., 2012; Trier et al., 2013).

7.3 Data

Larvik municipality in Vestfold County is known to contain a large number of grave mounds in forested areas. Vestfold County Administration has used airborne laser scanning (ALS) data extensively for the last three years (2010-2012). In 2010, Vestfold County Administration was involved in a mapping project concerning ALS data collection in Larvik municipality in the south of Vestfold. Originally, as defined by the municipality, this project did not intend to collect high resolution ALS data, but aimed at creating a new digital elevation model (DEM) for the purpose of deriving elevation contour lines, so an ALS pulse density of 1/m^2 was considered adequate. In most cases, the original three-dimensional point measurements are never used by the municipalities, they are, in general, happy to have the derived contour lines, which are much more accurate in forested areas than traditional contour lines generated from stereo aerial photography.

However, when Vestfold County Administration got involved in the ALS data collection through the Norwegian 'Geovekst' geographical data collaboration programme in 2010, the motivation was to collect high-resolution ALS data for the purpose of mapping cultural heritage by visual inspection of a hill-shade relief model of the DEM. Through participation in another cultural heritage project, Vestfold County Administration was able to pay for upgrading the pulse density to 22/m^2 for a 228 km^2 area of interest in the south of Larvik municipality. This ALS dataset was acquired 3-7 June 2010 by Blom Sweden with a TopEye laser scanner on a helicopter at 450 m altitude. The raw data contains full waveform information, but was subsequently processed and converted to LAS 1.2 format, with up to 4 discrete returns for each emitted pulse, by Blom Sweden. ALS data for the remaining 390 km^2 of Larvik municipality was collected at 1/m^2 pulse density on 24 May 2010 by Blom Geomatics with an Optech ALTM Gemini laser scanner on an airplane at 1275 m altitude.

Originally, data acquisition in late April 2010 was planned. However, the flight was delayed by over a month due to other engagements and faulty equipment. By early June, the leaves on deciduous trees, as well as low herbaceous vegetation, were almost fully developed, thus reducing the number of emitted laser pulses which actually hit the ground. Further, many laser pulse returns labelled as 'ground' may actually be returns from low vegetation. As a result, there are many areas in the dataset with a scarce amount of points labelled as 'ground' returns, and the height accuracy of the 'ground' points may be reduced.

Figure 50. Examples of grave mounds, Larvik municipality, Vestfold County, Norway. Top: a grave mound in Bøkeskogen, with a thin layer of snow. Bottom: a grave mound in Brunlafeltet, with a looting pit in the middle.

From both datasets, portions containing known grave mounds were extracted for the development of the automatic heap detection methods. The training set consists of 14 small portions from the 22/m^2 data (Table 11). The test set consists of four portions from the 22/m^2 data and three portions from the 1/m^2 data (Table 12). These two parts of the test set are called the high-resolution test set and the low-resolution test set.

Table 23. Training data.

Name	pulse density	Extent in UTM zone 32N								# known mounds
		west	east	south	north	size (m^2)			area	
Berg	$22/m^2$	552 800	552 930	6 539 150	6 539 250	130	×	100	13 000	4
Bommestad-1	$22/m^2$	561 420	561 500	6 550 030	6 550 110	80	×	80	6 400	1
Bommestad-2	$22/m^2$	561 600	561 790	6 549 820	6 549 960	190	×	140	26 600	9
Bøkeskogen	$22/m^2$	558 600	558 950	6 546 800	6 547 140	350	×	340	119 000	72
Hvatumskjeet	$22/m^2$	554 850	554 960	6 542 230	6 542 570	110	×	340	37 400	12
Kjerneberget-1	$22/m^2$	561 600	561 730	6 548 850	6 549 000	130	×	150	19 500	2
Kjerneberget-2	$22/m^2$	562 120	562 250	6 548 760	6 548 870	130	×	110	14 300	19
Tanum	$22/m^2$	556 470	556 700	6 543 960	6 544 150	230	×	190	43 700	12
Valby-1	$22/m^2$	563 000	563 300	6 545 670	6 545 970	300	×	300	90 000	4
Valby-2	$22/m^2$	562 560	562 770	6 545 930	6 546 170	210	×	240	50 400	5
Valby-3	$22/m^2$	563 100	563 250	6 546 430	6 546 600	150	×	170	25 500	3
Valby-4	$22/m^2$	563 450	563 580	6 546 290	6 546 510	130	×	220	28 600	5
Valby-5	$22/m^2$	563 640	563 720	6 546 440	6 546 520	80	×	80	6 400	1
Valby-6	$22/m^2$	563 740	563 830	6 546 220	6 546 340	90	×	120	10 800	4
Sum									491 600	153

Table 24. Test data.

Name	pulse density	Extent in UTM zone 32N					# known mounds
		west	east	south	north	size	
Brunlafeltet	$22/m^2$	557 600	559 200	6 541 200	6 541 800	1600 x 600 m^2	71
Løvall	$22/m^2$	551 200	552 000	6 536 400	6 537 600	800 x 1200 m^2	7
Store Sandnes	$22/m^2$	568 000	568 800	6 547 200	6 548 400	800 x 1200 m^2	24
Ødelund	$22/m^2$	552 800	553 600	6 540 600	6 541 800	800 x 1200 m^2	17
Sum							119
Lunde	$1/m^2$	560 000	561 600	6 552 600	6 553 800	1600 x 1200 m^2	35
Omsland (Nordre)	$1/m^2$	549 600	551 200	6 666 666	6 666 666	1600 x 600 m^2	18
Skogen	$1/m^2$	560 800	561 600	6 555 000	6 555 600	800 x 1200 m^2	26
Sum							79
Total							198

7.4 Methods

Building on our previous work (Trier *et al.*, 2009; Trier and Pilø, 2012), we propose a processing chain for the automatic detection of heaps in ALS data:

1. Obtain ALS data from a commercial provider, in the form of LAS files (LAS Specification, 2011). The point density should be at least 5 emitted pulses per m^2, and the discrete returns must be labelled as ground, building, vegetation, etc.

2. Convert the ALS ground returns to digital elevation models (height images) of multiple spatial resolutions: 0.2 m, 0.3 m, 0.4 m, 0.6 m, 0.8 m, 1.2 m, 1.6 m, 2.4 m, and 3.2 m. Also, generate slope images of the same resolutions.

3. Convolve the height images with dome-shaped heap templates (Figure 51) of varying sizes. Threshold each convolution result to obtain candidate heap detections.

4. For each candidate heap detection, compute various measures of the deviation from an ideal dome.

5. Using thresholds on some of the measures, remove the most obvious non-heaps.

6. Assign confidence levels, by using a statistical classifier.

7. The list of detected heaps is verified by an archaeologist, first by visual inspection of the ALS data, then by field work.

This method is a modification of the method we proposed for the detection of pit structures in LAS data. One difference is that we are using multiple resolutions. There are two reasons for this. First, the range of heap sizes is large, from 1 m to 16 m in radius, which means that details in a 0.2 m pixel size DEM that could be relevant for small heaps might not be relevant for large heaps. Second, convolutions with large templates (in number of pixels) is very slow.

7.4.1 Obtain LAS files

The ALS data described in section 2 were obtained.

7.4.2 Preprocessing of LAS files

The ALS data is available as binary data files in the LAS file format (LAS specification, 2011), containing up to four returns per emitted laser pulse. Each return contains x-, y-, and z-coordinates in UTM zone 32, and a class label denoting ground, vegetation, or building point. We are only interested in the ground points, and prefer to do the detection on a regular grid (image) rather than arbitrary points. The following steps are used to convert the LAS files to DEM files and slope files of different resolutions. The best resolution with a 0.2 m grid in the x-y plane, with floating point height values in metres. This gives 25 grid cells per square metres, and appears to preserve almost all of the detail of lidar point clouds with up to 25 emitted pulses per square metre.

2.1. Create a triangulation of all the ground returns.
2.2. Convert the triangulation to a digital elevation model (DEM) with 0.2 m ground resolution in the x- and y-coordinates, and floating point-valued height values in metres. Also, create a slope image of the same resolution.

2.3. Repeat step 2.2 for the following resolutions: 0.3 m, 0.4 m, 0.6 m, 0.8 m, 1.2 m, 1.6 m, 2.4 m, 3.2 m.

7.4.3 Convolution

For each resolution, up to 1.6 m pixel size, construct heap templates (Figure 51) with radii ranging from 5 times the pixel size to 20 times the pixel size, but not larger than 24 m. So, for 0.2 m pixel size, the radii ranges from 1.0 m to 4.0 m, and for 0.3 m pixel size, the radii ranges from 1.5 m to 6.0 m. This results in a considerable overlap in radii ranges for the different pixel sizes, allowing the method to automatically detect the most appropriate resolution for each candidate heap.

3.1. For each pixel size, do steps 3.2. to 3.4.:

3.2. Construct heap templates with radii ranging from 5 times to 20 times the pixel size.

3.3. Convolve the height image with each heap template. Threshold the convolution results to obtain candidate heap detections. The threshold is a fixed constant multiplied with the heap radius in meters.

3.4. For each detection, compute the normalized correlation, that is, the convolution value divided by the radius in meters.

3.5. Merge overlapping detections, in each case keeping the one with the higher normalized correlation.

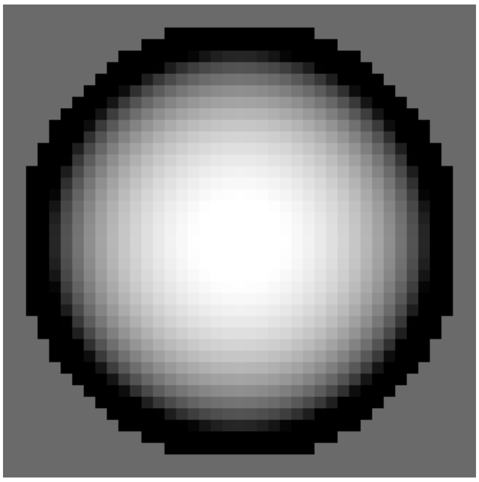

Figure 51. Heap template, shaped as a half-dome circumscribed by a flat ring. White pixels are +1, black pixels are –1, and grey pixels in between. The medium grey pixels outside the black ring edge are exactly zero, thus not contributing to the convolution value. This particular heap template has 3.4 m radius and 0.2 m pixel size.

7.4.4 Computation of attributes

In step 5 of the processing chain, a number of attributes are computed. The following values are already available from the convolution step:

- Radius, in meters

- Correlation, i.e., convolution value.
- Normalized correlation, that is, correlation divided by radius
- Pixel size of DEM that gave the strongest normalized correlation, this is called the best pixel size.

Of these, the radius in meters is used as an attribute in statistical classification. Next, the following attribute is computed on the 0.2 m pixel size:

- Intensity, that is, the average ALS intensity of the ground returns within the heap.

Then, the below 20 attributes are computed for three resolutions: 0.2 m pixel size, the best pixel size from the convolution, and two times the best pixel size. The reason for using three different resolutions is that at the best resolution, i.e., the smallest pixel size, the DEM might contain detail that turns out to be irrelevant in deciding if the heap is a grave mound or not.

- Correlation
- Normalized correlation
- Average heap height, measured as the height difference between the highest point inside the heap and the average height on the ring edge outside the heap.
- Minimum heap height, measured as the height difference between the highest point inside the heap and the lowest point on the ring edge.
- Standard deviation of height values on the ring edge.
- Root mean square deviation from a perfect hemisphere, i.e., a perfect upside-down-U-shaped heap.
- Root mean square deviation from a perfect upside-down-V-shaped heap.
- For each heap, a threshold is defined as the value that separates the pixels inside the heap into two groups, the 25% of the pixels that are darker than the threshold, and the 75% that are brighter. Use this threshold to extract a dark segment from a square image centred on the heap, with sides equal to six times the radius. This is called the 25%-segment. If this results in a compact, central segment inside the heap, connected to a larger segment outside the heap, with only a few connecting pixels on a ring just

outside the heap, then the central segment is separated from the outside segment. From the extracted segment, the following measures are computed:

  - Offset: distance from heap centre to the segment's centre.
  - Major axis length; for a definition, see, e.g., Prokop and Reeves (1992).
  - Elongation, defined as major axis divided by radius.

- Similarly to above, extract the 50%-segment and compute offset, major axis and elongation from that segment as well
- Gradient, that is, the average of the slope image within the heap
- Maximum gradient within the heap
- Standard deviation of the gradient within the heap
- Squared gradient, that is, the average of the squared slope image within the heap
- Gradient entropy within the heap

This gives a total of 62 attributes available for use in statistical classification in step 6: the radius in meters, the intensity, and the 20 attributes that are computed on three resolutions.

7.4.5 Initial screening

Thresholds are set on some of the attributes to remove detections that are very unlikely to be archaeology, while at the same time keeping all true archaeological features. By sorting a training set of labelled detections on one attribute at a time, one can manually identify attributes that can be thresholded so that all detections labelled as 'true' or 'possible' archaeology be kept, keeping several 'unlikely' and 'false' detections as well, but at the same time removing many 'unlikely' and 'false' detections. These thresholds should not be set too tight, to allow for slightly more variation in the attribute values for the 'true' and 'possible' archaeological features than was observed in the training data. The following thresholds were used on the features computed on the 0.2 m pixel size elevation image, requiring that all these conditions be met for a heap detection to be kept:

1. Normalized correlation > 0.5
2. Average heap height > 0.2 m
3. Minimum heap height > 0.001 m
4. RMS u-shape < 0.1

5. RMS v-shape < 0.1

6. 25% segment elongation < 4.0

7. Standard deviation on ring edge < 1.5

8. 25% segment offset < 6.0 m

9. Normalized average height > 0.005

10. Normalized average height < 0.3

11. Normalized correlation < 8.0

7.4.6 Assigning confidence values by using a statistical classifier

We use a statistical classifier (e.g., see Duda and Hart, 1973; Hastie et al., 2009) to compute the probability that each heap detection is a grave mound (versus not being a grave mound). The probability values are then thresholded into confidence levels. The thresholds are estimated from the training data as follows. First we have set goals for each confidence level, in the form of desired detection rates (Table 13). Detection rate means the percentage of the true grave mounds that were detected. Then, we run the classifier on the training data, which is a collection of heap detections, where each has been labelled as either 'grave mound' or 'not grave mound', but this labelling is not revealed to the classifier. Running the classifier results in, for each heap detection, a probability that the heap is a grave mound. We then sort the heap detections by the grave mound probability, and select the probability thresholds for each confidence level so that the required percentage of true heaps get this confidence level or better, and at the same time, we get as few false detections as possible. For example, it could happen that the threshold for medium high confidence were 0.45, meaning that all heap detections with grave mound probability higher than 0.45 would get medium high or better confidence. Obviously, this would include many heap detections that are not grave mounds as well. In fact, the number of non-heaps that are included at different confidence levels may be used to compare different classifiers.

Table 25. Desired detection rates, and example probability thresholds, for the different confidence levels.

score	1	2	3	4	5	6
confidence level	very low	low	medium	medium high	high	very high
Detection rate	100 %	99 %	90 %	75 %	50 %	10 %
example probability thresholds	0.00	0.15	0.30	0.45	0.60	0.75

7.4.6.1 Classifiers used in this study

In a preliminary study (Trier and Zortea, 2012), six different classifiers were evaluated:

1. Decision trees (CART algorithm)
2. Nearest neighbor
3. Naïve Bayes
4. Mahalanobis distance
5. Linear discriminant analysis
6. Quadratic discriminant analysis

In that study, the Mahalanobis distance classifier performed best, followed by linear discriminant analysis. Here, we compare Mahalanobis distance classifier with linear discriminant analysis and quadratic discriminant analysis.

For all three classifiers, with a given number *d* of attributes to measure, each heap detection gets a *d*-dimensional measurement vector or attribute vector *x*. From the training data, we extract the sample mean vectors of the two classes: c_1='grave mound' and c_2='not grave mound'. These mean vectors are denoted m_1 and m_2. We then extract the sample covariance matrixes of the two classes: S_1 and S_2. For the linear discriminant analysis, we replace the class-specific covariance matrixes with one common, pooled sample covariance matrix:

$$S = (n_1 S_1 + n_2 S_2)/(n_1 + n_2)$$

where n_1 and n_2 are the number of training samples for the two classes, c_1 and c_2, respectively. In a traditional classification problem, we would assign each measurement vector *x* to the class which gives the highest probability. Instead, we want to use the probability that the observation is a grave mound to assign confidence values 1-6.

In quadratic discriminant analysis, the multivariate Gaussian distribution is used. The probability of observing a specific observation vector *x*, belonging to class *i*, is defined as:

$$p_i(x) = \frac{1}{(2\pi)^{d/2}|S_i|^{1/2}} e^{-\frac{1}{2}(x-m_i)^T S_i^{-1}(x-m_i)}$$

Assuming equal priors, we can compute the probability that the vector *x* belongs to class *c* as:

$$p(c|x) = \frac{p_c(x)}{\sum_i p_i(x)}$$

With two classes, this simplifies to:

$$p(c_1|x) = \frac{p_1(x)}{p_1(x) + p_2(x)}$$

$$p(c_2|x) = 1 - p(c_1|x)$$

In linear discriminant analysis, we replace the class-specific covariance matrix S_i with the pooled covariance matrix S in the equation for the multivariate Gaussian distribution.

In the Mahalanobis distance classifier, we compute the squared Mahalanobis distances between an observation x and the class means m_i as:

$$r_i^2(x) = (x - m_i)^T S_i^{-1} (x - m_i)$$

We then compute the probability that the vector x belongs to class c as

$$p(c|x) = \frac{r_c^2(x)}{\sum_i r_i^2(x)}$$

Again, with only two classes, this can be simplified:

$$p(c_1|x) = \frac{r_1^2(x)}{r_1^2(x) + r_2^2(x)}$$

And as before:

$$p(c_2|x) = 1 - p(c_1|x)$$

For the above classifiers, a number of parameters need to be estimated from the training data. With d-dimensional measurement vectors, each mean vector has d parameters, and each covariance matrix has $d(d+1)/2$ parameters. So for the Mahalanobis distance classifier and quadratic discriminant analysis, the number of parameters is: $2d + d(d+1) = 3d + d^2$. For linear discriminant analysis, the number of parameters is: $2d + \frac{d(d+1)}{2} = 2.5d + 0.5d^2$. With a limited training set size, there is a trade-off. If we use a model with many parameters, less accurate estimates of these parameters may result than when using a model with fewer parameters.

Assuming equal priors, as we have done above, is clearly unrealistic. It is not so that half of the heaps detected by the initial template matching step will be grave mounds. However, ideally, we don't want to miss any grave mounds, but we may tolerate quite large numbers of non-heaps, given that they are assigned meaningful confidence levels.

7.4.6.2 Feature selection and comparison of classifiers

For each classifier, the best subset of the 62 attributes is determined using the sequential forward attribute selection algorithm (Pudil *et al.*, 1992). The subset of attributes that maximizes the 10-fold cross-validation of detection accuracy in the training set is retained. Specifically, the optimized detection accuracy was the area under the so-called receiver operating characteristics (ROC) curve (Hastie et al., 2009). The ROC curve is computed using the rates of true positive and false positive detections.

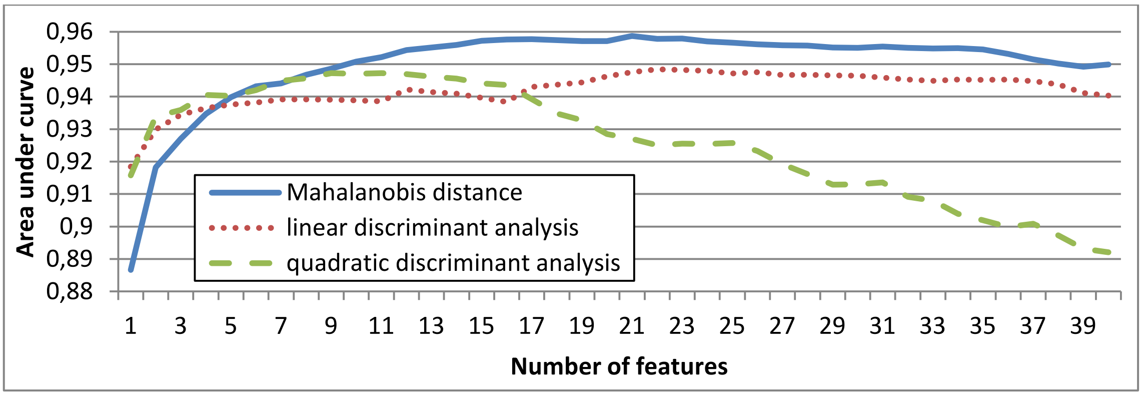

Figure 52. Result of feature selection on the training data set.

The best classifier on the training set was the Mahalanobis distance classifier with 21 features (Figure 52). For the linear discriminant analysis classifier, 22 attributes gave the best performance, whereas 9 attributes gave the best performance for the quadratic discriminant analysis classifier on the training data (Figure 52). For the training data, the Mahalanobis distance classifier had higher true detection rates than the other classifiers for most false detection rates (Figure 53). The two other classifiers performed equally well, with only small differences in true detection rates for all false detection rates (Figure 53). The actual area under the curve (AUC) values for the ROC curves of each classifier (Table 16) confirms this: The Mahalanobis distance classifier with the 21 best features obtained AUC=0.96, slightly better than the linear discriminant analysis and quadratic discriminant analysis classifiers, which both obtained 0.95.

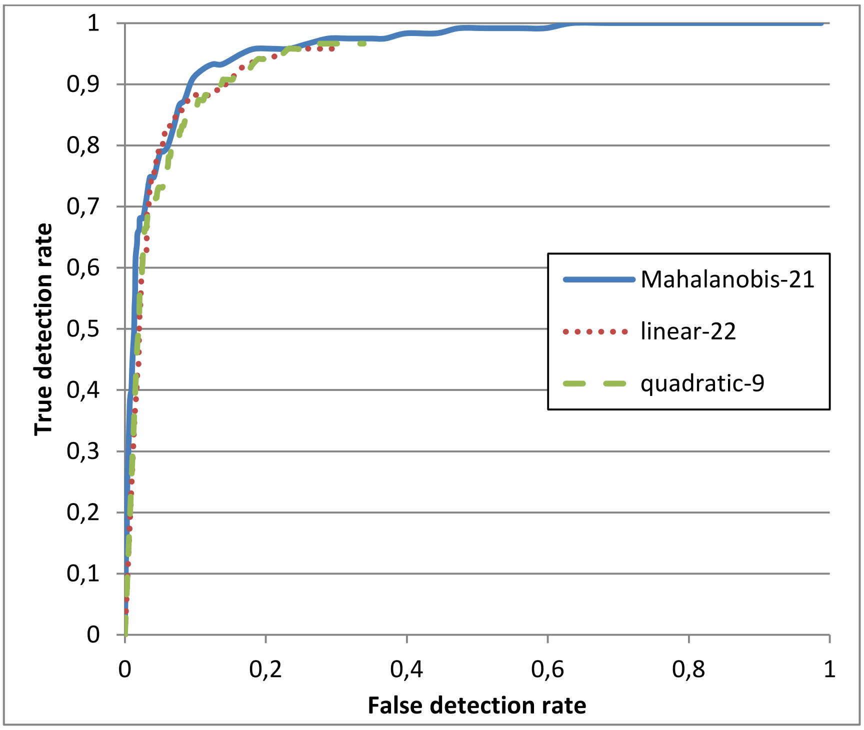

Figure 53. ROC curves for the three classifiers, with optimum number of features, on the training data with 10-fold cross-validation.

Table 26. Results of automatic feature selection for Mahalanobis distance classifier

rank	attribute		area under curve
	no.	name	
1	8	RMS U-shape, full resolution	0,8866
2	24	minimum height, medium res	0,9182
3	6	normalized average height, full res	0,9270
4	29	RMS U-shape, medium resolution	0,9347
5	9	RMS V-shape, full resolution	0,9398
6	46	normalized min height, low res	0,9432
7	40	gradient squared, medium res	0,9440
8	19	st. dev gradient, full resolution	0,9468
9	17	gradient, full resolution	0,9486
10	5	norm min height, full res	0,9508
11	23	norm correlation, medium res	0,9521
12	20	gradient squared, full resolution	0,9543
13	50	RMS V-shape, low res	0,9551
14	42	correlation, low resolution	0,9559
15	14	major axis, 23%-segment, full res	0,9572
16	48	standard deviation edge, low res	0,9576
17	54	offset 25%-segment, low res	0,9577
18	49	RMS U-shape, low resolution	0,9574
19	16	intensity	0,9571
20	41	gradient entropy, medium res	0,9571
21	37	gradient, half resolution	0,9587

Table 27. Result of automatic feature selection, quadratic discriminant analysis classifier.

	attribute		area under curve
rank	no.	name	
1	8	RMS U-shape, full resolution	0,9158
2	6	normalized average height, full res	0,9339
3	18	max gradient, full resolution	0,9359
4	9	RMS V-shape, full resolution	0,9405
5	28	std dev edge, medium res	0,9402
6	3	minimum height, full resolution	0,9420
7	23	norm correlation, medium res	0,9448
8	31	offset 50%-segment, medium res	0,9456
9	44	minimum height, low res	0,9473

Table 28. Area under curve comparison of classifiers on the training data with 10-fold cross-validation.

classifier	Mahalanobis						linear	quadratic
# features	21	12	10	5	3	1	22	9
AUC	0,9587	0,9543	0,9508	0,9398	0,9270	0,8866	0,9484	0,9473

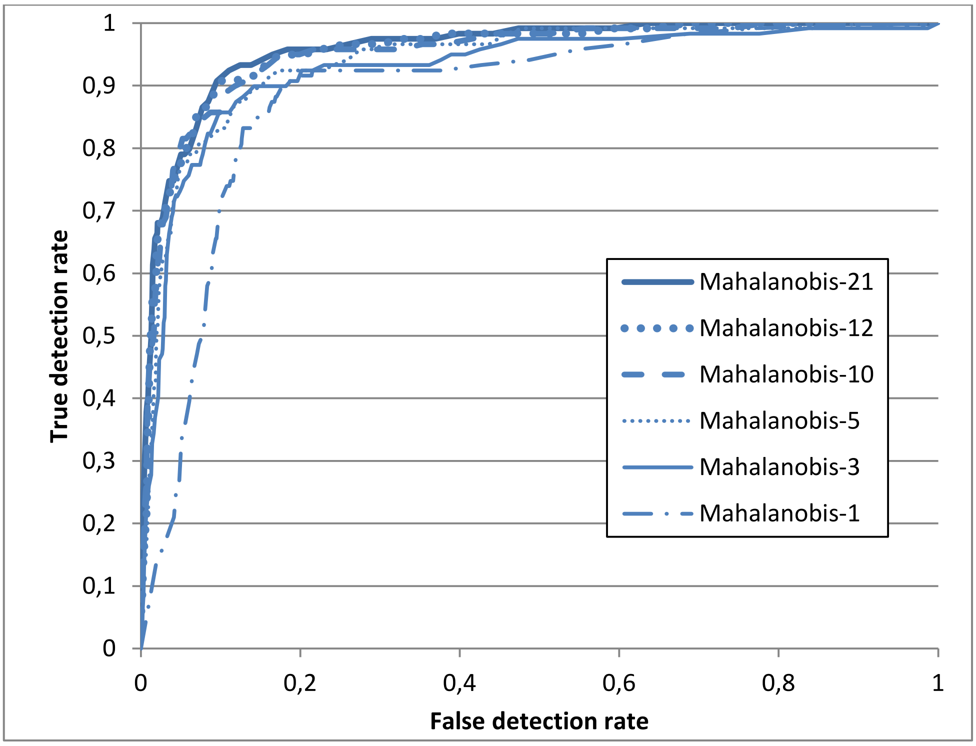

Figure 54. ROC curves for Mahalanobis distance classifiers, with different number of features, on the training data with 10-fold cross-validation.

Table 29. Detection rates on training set with Mahalanobis distance classifier and the 21 best features.

score value	1	2	3	4	5	6		
confidence	very low	low	medium	medium high	high	very high	missing	total
grave mounds	1	11	18	30	47	12	34	153
accumulated	119	118	107	89	59	12		
classifier's true detection rate	100,00 %	99,16 %	89,92 %	74,79 %	49,58 %	10,08 %		
user's detection rate	77,78 %	77,12 %	69,93 %	58,17 %	38,56 %	7,84 %		
not grave mounds	1089	317	37	14	8	2		1467
accumulated	1467	378	61	24	10	2		
false detection rate	100,00 %	25,77 %	4,16 %	1,64 %	0,68 %	0,14 %		

The first feature selected for all three classifiers was ‘RMS U-shape, full resolution’ (Table 23, Table 24). Four of the nine best features for quadratic discriminant analysis were also among the 11 best features for the Mahalanobis distance classifier. More importantly, the curves in Figure 52 are very flat on both sides of their respective maxima. This means that very little information is added for each new included feature, and indicates that a lower number of features could be selected without reducing detection performance significantly. By gradually decreasing the number of features in the Mahalanobis distance classifier from 21 to one, the AUC values drop from 0.96 to 0.89 (Figure 55, Table 16).

The training data has only 119 grave mounds that were detected by the template matching step (Table 26). A general rule-of-thumb suggests that the number of features should not exceed about one tenth of the number of samples in the smallest class, so a maximum of 12 features may be used in our case. By using too many features, one may risk that the classifier is over-optimized for the training data, and may perform worse on the test data than when fewer features are being used.

The training step has also produced probability thresholds for the different classifiers for each of the desired confidence levels. These are used to assign a confidence level (1-6) to each heap detection, based on the posterior probability that the heap detection is actually a grave mound. By doing this on the training data, using the best classifier, that is, the Mahalanobis distance classifier with the 21 best features, we see that, for example, 89 true grave mounds receive confidence 4, 5 or 6, while at the same time, only 24 non-grave mounds receive confidence 4, 5 or 6 (Table 26). This is overly optimistic as a prediction of the performance on other data sets, for example, the test set, since the training data consists of small areas centred on known grave mound clusters.

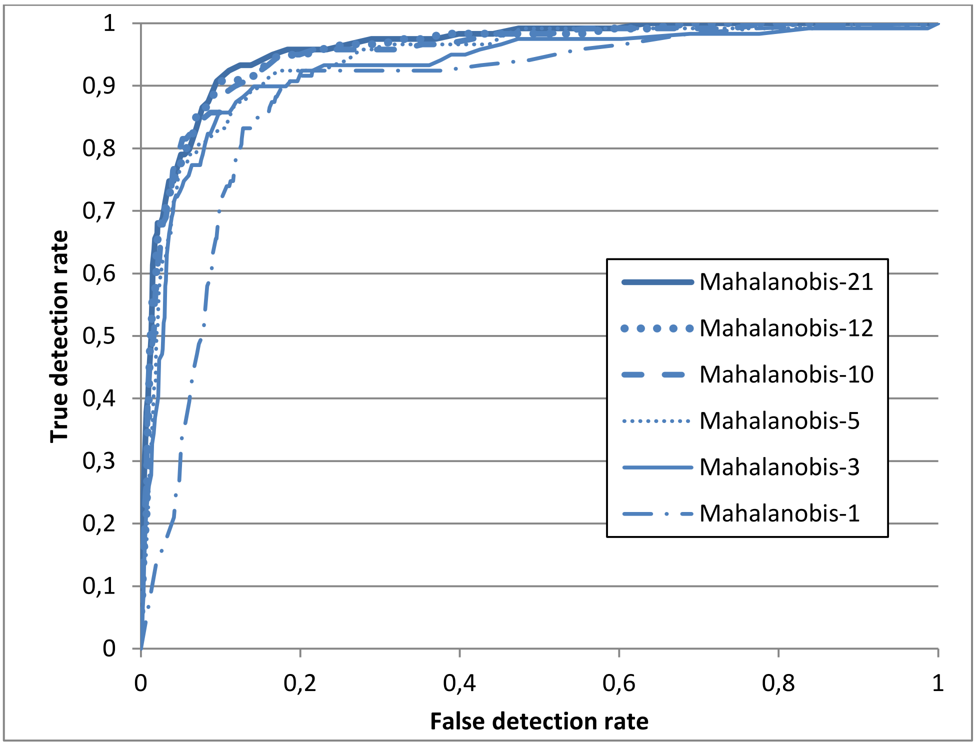

Figure 55. ROC curves for Mahalanobis distance classifiers, with different number of features, on the training data with 10-fold cross-validation.

7.4.7 Verification by archaeologist

The detection results are converted to ESRI shape files, with one file for each confidence level. The current procedure is as follows:

7.1. View the detections with confidence levels 4-6 or 5-6, overlaid on a hill-shade model of the ALS ground points, with polygons of known grave fields and single grave mounds as an additional overlay.
7.2. When zooming in on an area, heap detections with confidence levels 4, 3, 2 and/or 1 may be switched on and off as a tool to identify possible grave mounds.
7.3. Inspect areas with known grave fields to look for additional grave mounds outside the currently mapped grave field boundary.
7.4. If individual grave mounds have been mapped previously, then inspect the accuracy of the current mapping
7.5. Look for similar patterns of heap detections outside the known grave fields to spot possible locations for grave fields
7.6. Field survey. Grave mounds that were detected with correct geometry are copied from the automatic detection result. Grave mounds that were missed or detected with wrong geometry are mapped in the field using RTK-GPS.
7.7. Update the 'Askeladden' national cultural heritage database in Norway.

7.5 Results

This section contains three parts. First, a surprising discovery of 19 grave mounds is described. Second, we compare the three classifiers, with varying number of features, on the test set. Third, we compare the automatic detections with field work, to get a practical evaluation of the new method.

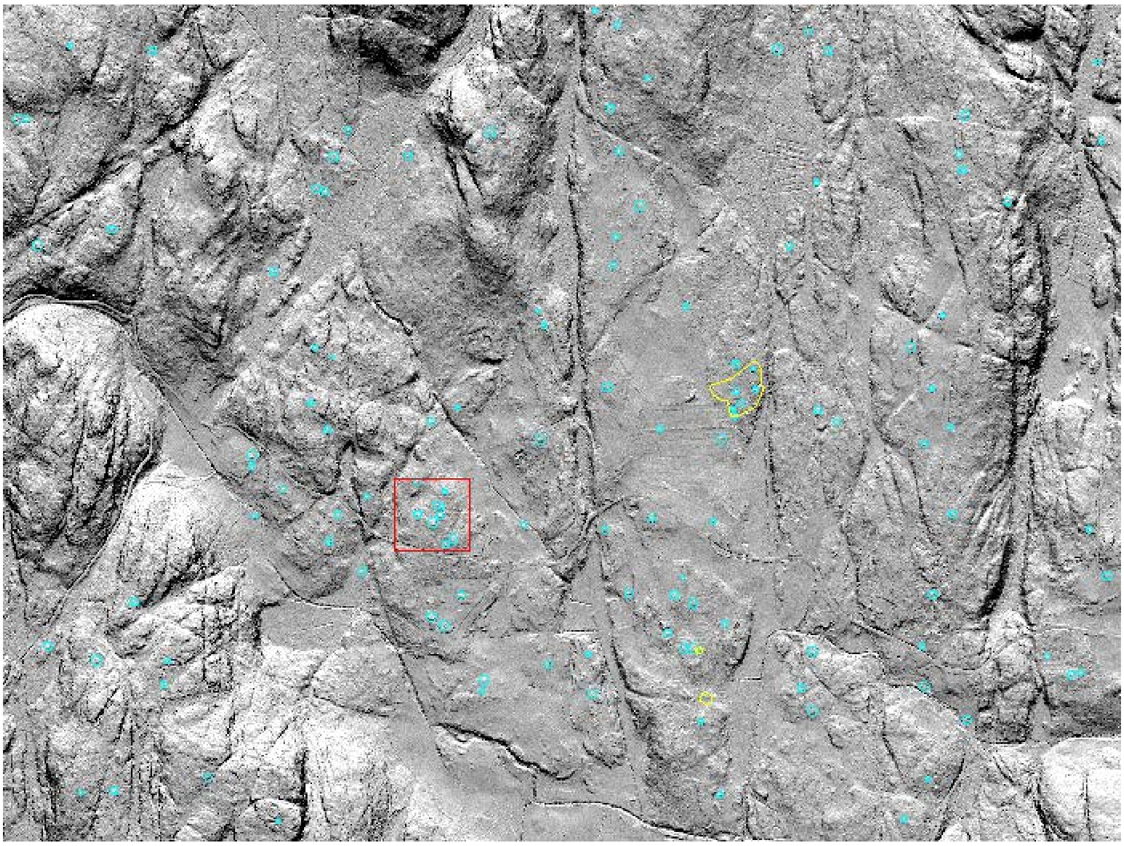

Figure 56. Area surrounding known grave field at Omsland Nordre (yellow outline containing five cyan circles). A cluster of high confidence detections (inside red square) led to the discovery of the grave field at Omsland Søndre.

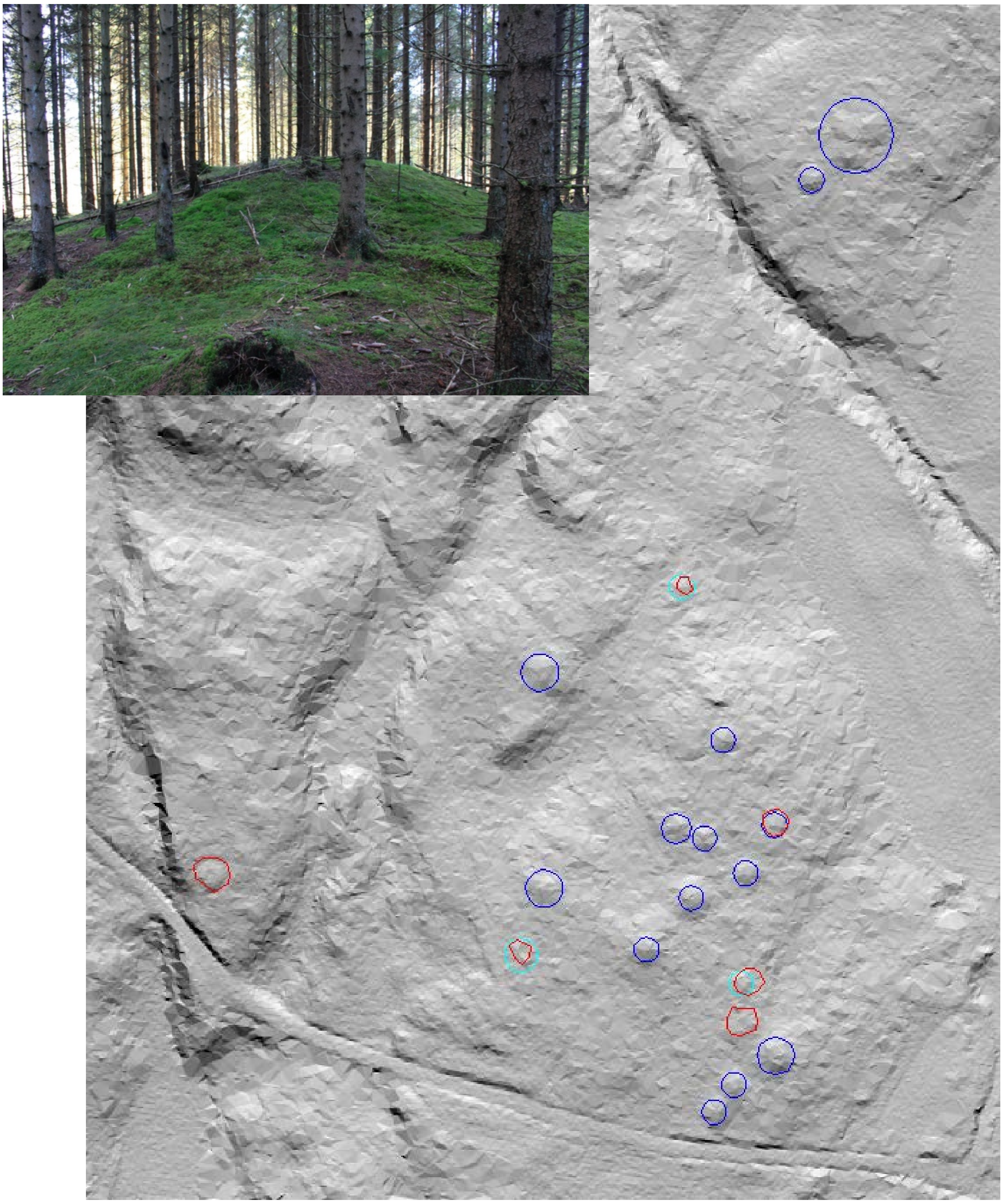

Figure 57. Grave mounds at Omsland Søndre, Larvik municipality, Vestfold County, Norway. Dark blue: 11 mounds detected by automatic method, with correct geometry. Cyan: four mounds detected by automatic method, but with incorrect geometry. Red: correct geometry of grave mounds, of which four were detected with incorrect geometry, and four were not detected. Colour image inset: one of the grave mounds.

7.5.1 Discovery of 19 grave mounds at Omsland Søndre

In the process of planning field work for the summer of 2012, automatic detections, from a preliminary version of the method, were inspected visually. The detection patterns at known grave mounds were studied. By only displaying detections with confidence values 5-6 (high or very high), the existing grave fields appear as clusters. When looking at these detections in an area surrounding the known grave field at Omsland Nordre, a larger cluster of confidence 5 detections appeared further west (Figure 56), near the farm Omsland Søndre. Field work was done at this location, and a few other similar clusters. The cluster at Omsland Søndre turned out to be a grave field that was previously not known (Figure 57). This is the largest discovery of grave mounds in Norway for many years, and made headlines in the national newspaper Aftenposten (Guhnfeldt, 2012) and two regional newspapers, and a radio interview. These 19 newly discovered grave mounds (Figure 57) have been added to the 198 previously known grave mounds in the test set (Table 12), so that the test set now contains 217 known grave mounds (Table 28).

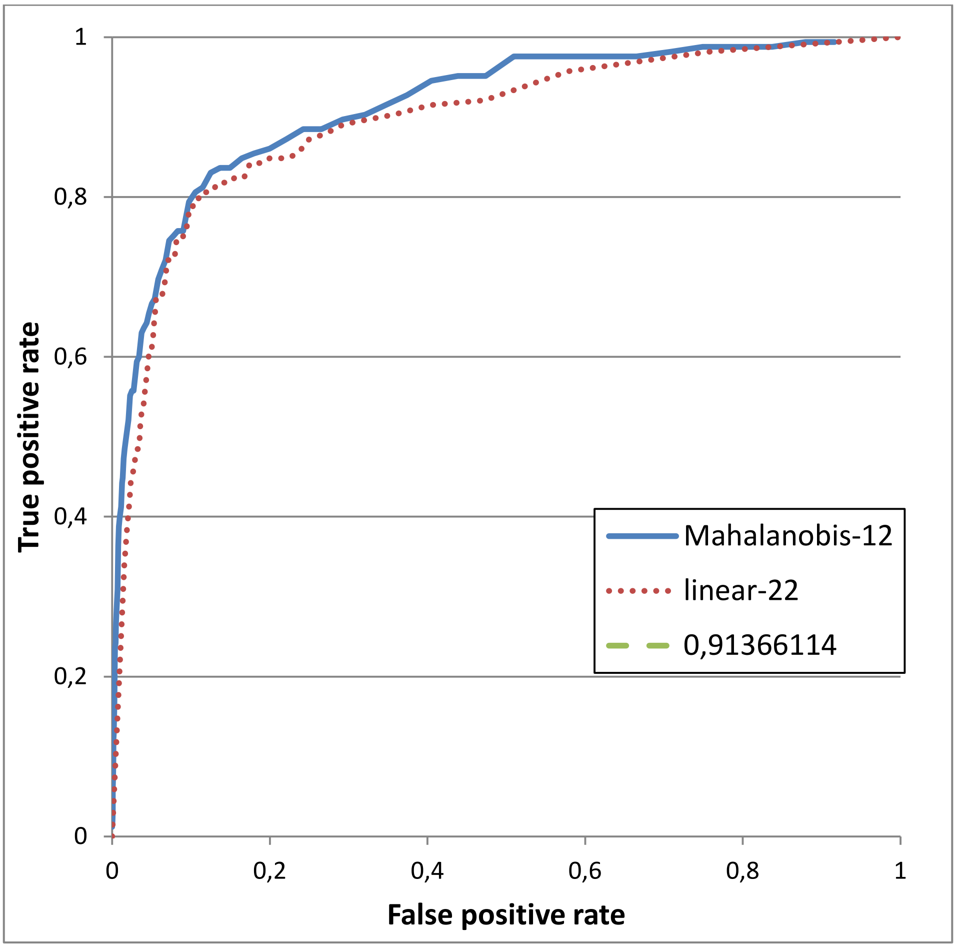

Figure 58. Comparison of classifiers on the entire test set. Blue solid line=Mahalanobis distance classifier, 21 best features. Red dotted line=linear discriminant analysis classifier, 22 best features. Green dashed line=quadratic discriminant analysis classifier, 9 best features.

7.5.2 Comparison of classifiers on the test set

We have compared different varieties of the three classifiers on the entire test set. With the 'optimum' number of features selected on the training data, the Mahalanobis distance classifier is somewhat better than both the linear discriminant analysis and the quadratic discriminant analysis classifiers (Figure 58). However, by reducing the number of features, both the Mahalanobis distance classifier (Figure 59) and the quadratic discriminant analysis classifier get a higher area under the curve (AUC) value (Table 27). Then, the best classifier is the Mahalanobis distance classifier with the 12 best features. However, the ROC curves of the Mahalanobis distance classifiers with the 21 and 12 best features cross each other (Figure 59), which means that for some confidence levels, The Mahalanobis distance classifier with the 21 best features is better than the one with the 12 best features.

Based on the above, we will use the Mahalanobis distance classifier with the 12 best features when searching for heaps in new datasets. When used on the test set, this classifier assigns confidence 4, 5 or 6 to 108 true grave mounds, while at the same time, 594 non-grave mounds are assigned confidence levels 4, 5 or 6 (Table 28). However, 52 of 217 heaps are not detected at all, which gives a user's detection rate of 76.0% when detections in all confidence levels are included (Table 28).

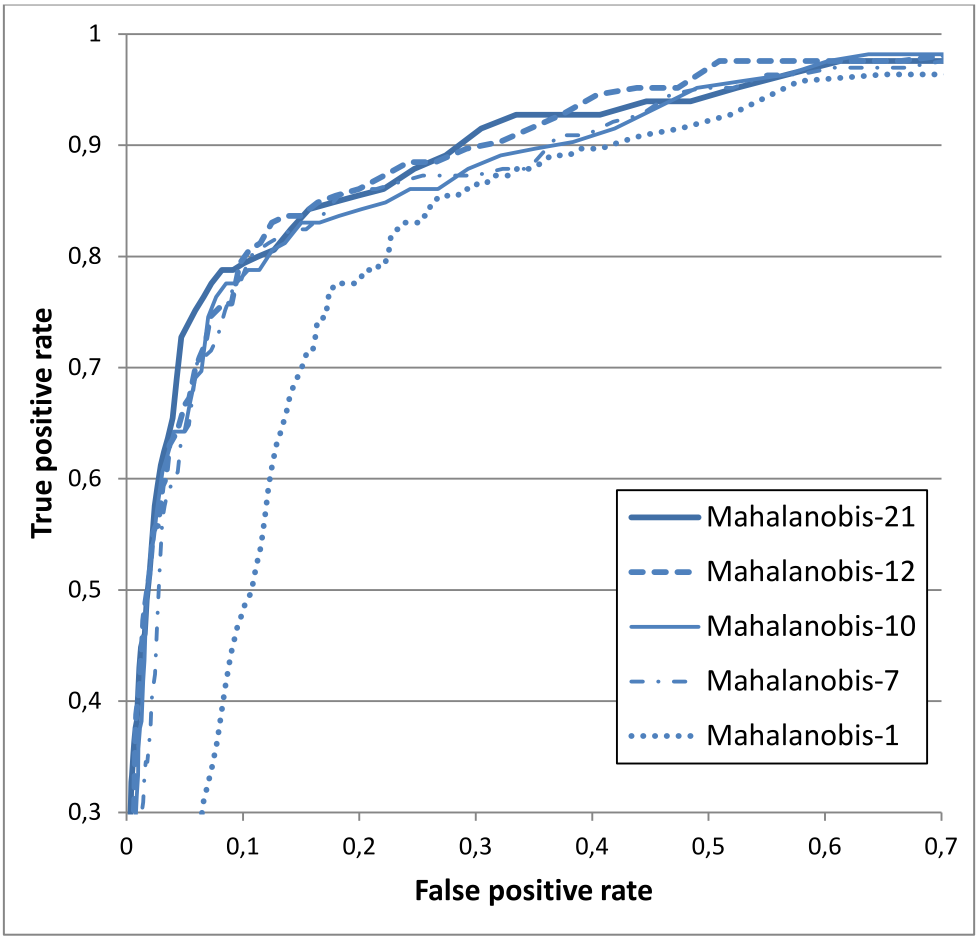

Figure 59. ROC curve comparison of Mahalanobis distance classifiers with different number of features, on the entire test set.

Table 30. Area under curve (AUC) comparison of classifiers on the test set.

classifier	Mahalanobis					linear			quadratic		
# features	21	12	10	7	1	22	7	1	9	7	1
AUC	0,9134	**0,9137**	0,9037	0,8996	0,8370	0,8943	0,8832	0,8628	0,8970	0,9040	0,8601
AUC hires	0,9140	0,9082	0,8961	0,8921	0,8334	0,8749	0,8726	0,8554	0,8946	0,9050	0,8534
AUC lowres	0,9180	0,9259	0,9158	0,9087	0,8446	0,9237	0,8980	0,8775	0,9058	0,9087	0,8733

Table 31. Detection rates on the entire test set, with Mahalanobis distance classifier and the 12 best features.

score value	1	2	3	4	5	6		
confidence	very low	low	medium	medium high	high	very high	missing	total
grave mounds	8	27	22	35	63	10	52	217
accumulated	165	157	130	108	73	10		
classifier's true detection rate	100,0 %	95,2 %	78,8 %	65,5 %	44,2 %	6,1 %		
user's detection rate	76,0 %	72,4 %	59,9 %	49,8 %	33,6 %	4,6 %		
not grave mounds	8979	6891	870	594	203	14		17551
accumulated	17551	8572	1681	811	217	14		
false detection rate	100,0 %	48,8 %	9,6 %	4,6 %	1,2 %	0,1 %		

Table 32. Detection rates on the high resolution test set, with Mahalanobis distance classifier and the 12 best features.

score value	1	2	3	4	5	6		
confidence	very low	low	medium	medium high	high	very high	missing	total
grave mounds	6	17	16	23	30	5	22	119
accumulated	97	91	74	58	35	5		
classifier's true detection rate	100,0 %	93,8 %	76,3 %	59,8 %	36,1 %	5,2 %		
user's detection rate	81,5 %	76,5 %	62,2 %	48,7 %	29,4 %	4,2 %		
not grave mounds	4551	3414	418	260	79	3		8725
accumulated	8725	4174	760	342	82	3		
false detection rate	100,0 %	47,8 %	8,7 %	3,9 %	0,9 %	0,0 %		

Table 33. Detection rates on the low resolution test set, with Mahalanobis distance classifier and the 12 best features.

score value	1	2	3	4	5	6		
confidence	very low	low	medium	medium high	high	very high	missing	total
grave mounds	2	10	6	12	33	5	30	98
accumulated	68	66	56	50	38	5		
classifier's true detection rate	100,0 %	97,1 %	82,4 %	73,5 %	55,9 %	7,4 %		
user's detection rate	69,4 %	67,3 %	57,1 %	51,0 %	38,8 %	5,1 %		
not grave mounds	4428	3477	452	334	124	11		8826
accumulated	8826	4398	921	469	135	11		
false detection rate	100,0 %	49,8 %	10,4 %	5,3 %	1,5 %	0,1 %		

Table 34. The number of verified grave mounds that the automatic method did detect and did not detect.

Grave field or farm name	ALS pulse density	ALS ground point density	detected, correct geometry		detected, incorrect geometry		sum detected		not detected		sum
Ødelund	22/m²	6,1/m²	14	82 %	2	12 %	16	94 %	1	6 %	17
Brunlafeltet	22/m²	5,6/m²	46	65 %	7	10 %	53	75 %	18	25 %	71
Store Sandnes / Hem østre	22/m²	5,3/m²	22	92 %	1	4 %	23	96 %	1	4 %	24
Kaupang	22/m²	5,0/m²	45	49 %	18	20 %	63	68 %	29	32 %	92
Løvall	22/m²	4,4/m²	3	43 %	2	29 %	5	71 %	2	29 %	7
Bøkeskogen	22/m²	3,3/m²	25	35 %	20	28 %	45	63 %	27	38 %	72
Sum high resolution			155	55 %	50	18 %	205	72 %	78	28 %	283
Omsland nordre	1/m²	0,89/m²	9	50 %	1	6 %	10	56 %	8	44 %	18
Omsland søndre	1/m²	0,89/m²	14	74 %	3	16 %	17	89 %	2	11 %	19
Lunde søndre (near Hedrum)	1/m²	0,65/m²	10	29 %	7	20 %	17	49 %	18	51 %	35
Sum low resolution			33	46 %	11	15 %	44	61 %	28	39 %	72
sum			188	53 %	61	17 %	249	70 %	106	30 %	355

We also investigated if there were any systematic differences in detection performance on the high resolution part of the test set versus the low resolution part of the test set. We found that the AUC values were slightly higher for the low resolution test set than for the high resolution test set (Table 27). This result may seem counter-intuitive, but it might reflect that the heaps that were detected have, on average a slightly more well-defined shape than the ones that were detected in the high resolution test set. On the other hand, the user's detection rates were lower for the low-resolution test set (Table 30) than for the high-resolution test set (Table 29).

7.5.3 Detailed comparison of automatic detections with field survey

For the previously known grave fields, the 'Askeladden' Norwegian national cultural heritage database contains polygons describing the extent of each grave field. The polygons from Askeladden and the automatic detections from CultSearcher were overlaid on a relief model of the ALS data. The typical pattern was that the polygon from Askeladden, describing the extent of the grave field, was inaccurate, with many candidate grave mounds appearing outside the polygon. This visual assessment was then used for planning of field work for accurate mapping of the individual grave mounds.

Field work was done at six previously known grave fields in 2012. Also, field work was done at a few selected locations with a large number of high confidence automatic detections. As mentioned above, one of these, located at Omsland Søndre, turned out to be a grave field that was previously not known (Figure 57). In addition, previous field work at Kaupang and Bøkeskogen was included. Individual grave mounds at Kaupang had been mapped by total station in 2005 by Steinar Kristensen, the Museum of Cultural History at the University of Oslo. Individual grave mounds in Bøkeskogen were mapped in 2001 by Lars Forseth. These nine grave fields include six of the seven grave fields in the test set (all except Skogen, Table 12), one grave field from the training data (Bøkeskogen), one grave field not occurring in neither the training data nor the test data (Kaupang), and the newly discovered field (Omsland Søndre).

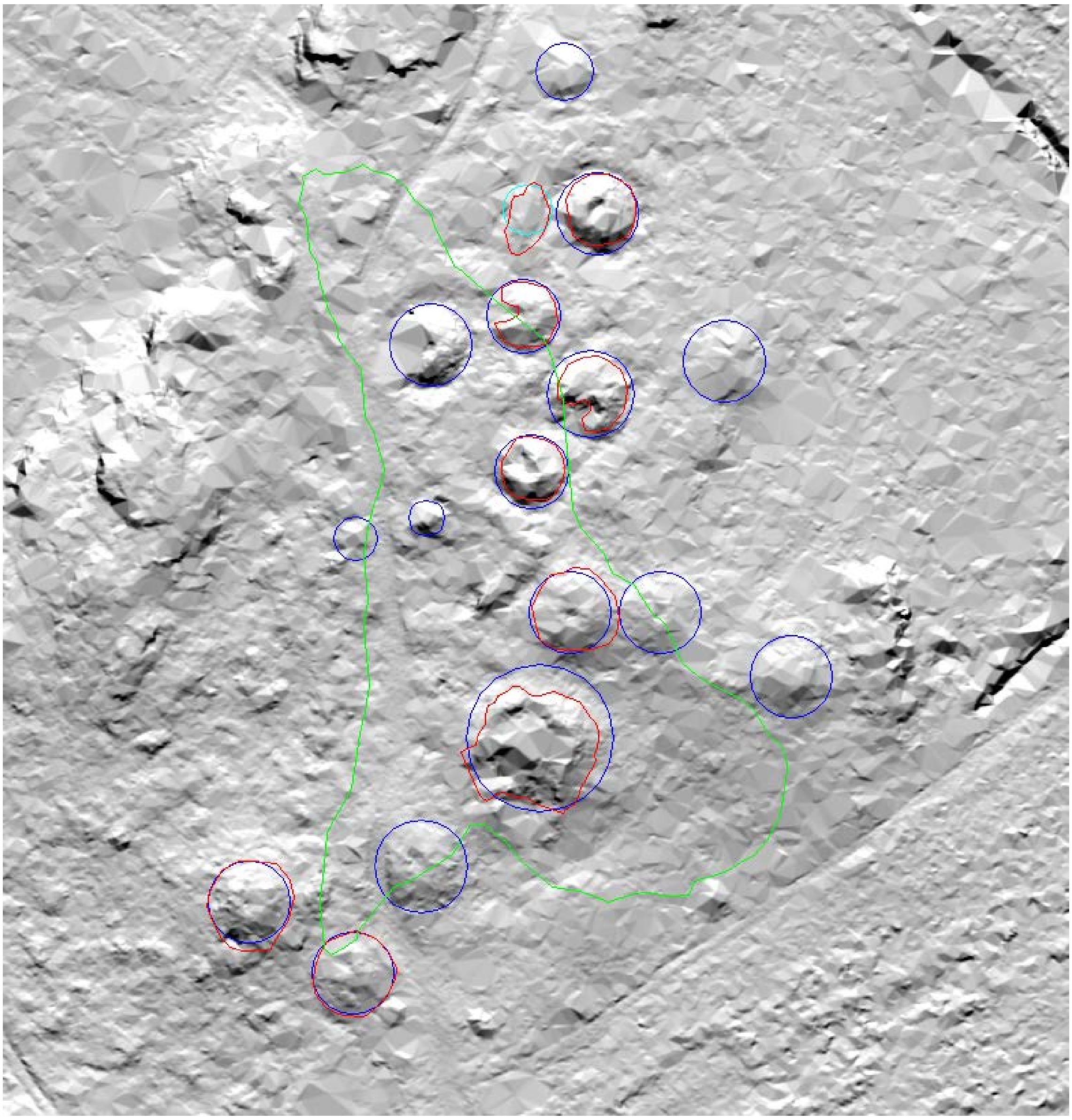

Figure 60. Grave mounds in the major grave field at Store Sandnes / Hem østre, Larvik municipality. Green: outline of grave field according to the 'Askeladden' national cultural heritage database. Dark blue: automatic detections, with correct geometry. Cyan: automatic detections, with incorrect geometry. Red: correct geometry of grave mounds.

The field work mapping of individual grave mounds was compared with the automatic detections (Table 31). Overall, 53% of the true grave mounds were detected with correct geometry by CultSearcher, 17% of the true grave mounds were detected with incorrect geometry, and 30% were missed. For the individual grave fields, these percentages vary substantially, which is an expected statistical effect in small sample sizes. The best detection rate was obtained at Store Sandnes / Hem Østre, where 23 of 24 grave mounds were detected, albeit one with incorrect geometry (Figure 60). The second best rate of detections with correct geometry was 82%, at Ødelund (Figure 61). The lowest detection rate, 49%, occurred at Lunde (Figure 62), in the low resolution data set. The lowest detection rates in the high resolution data set were 63%, at Bøkeskogen (Figure 63) and 68%, at Kaupang (Figure 64).

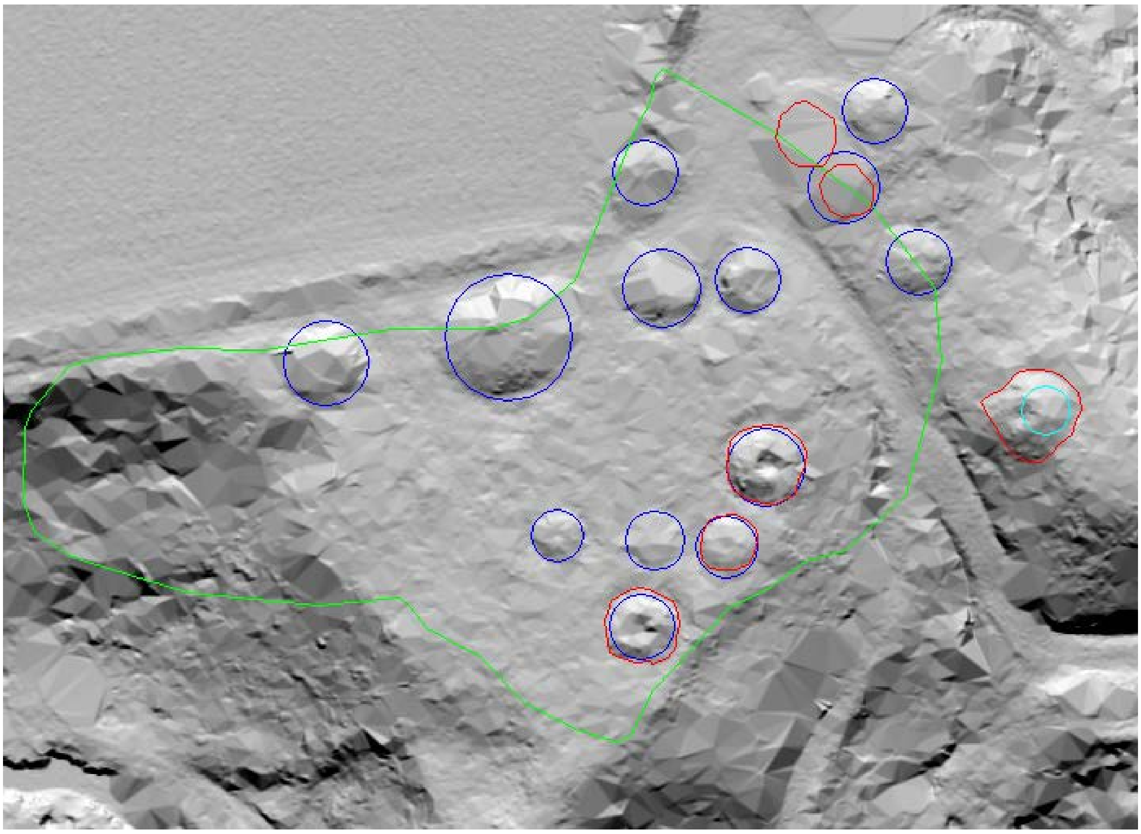

Figure 61. Grave mounds in the major grave field at Ødelund, Larvik municipality. Legend: same as in Figure 60.

As mentioned above, the grave field extent polygons in the Askeladden database are in general inaccurate. For example, at Ødelund (Figure 61), 15 individual grave mounds were mapped as part of the major grave field. Of these, two were totally outside the grave field extent polygon from the Askeladden data base, and six were partially outside. This is even worse at Store Sandnes / Hem østre, where 12 out of 17 grave mounds within the major grave field were either partially or fully outside the Askeladden polygon (Figure 60). Note that both at Ødelund and Store Sandnes / Hem Østre, there are some additional grave mounds outside of the main grave fields, which explains why there are more grave mounds in Table 31 for these two areas than in Figure 60 and Figure 61.

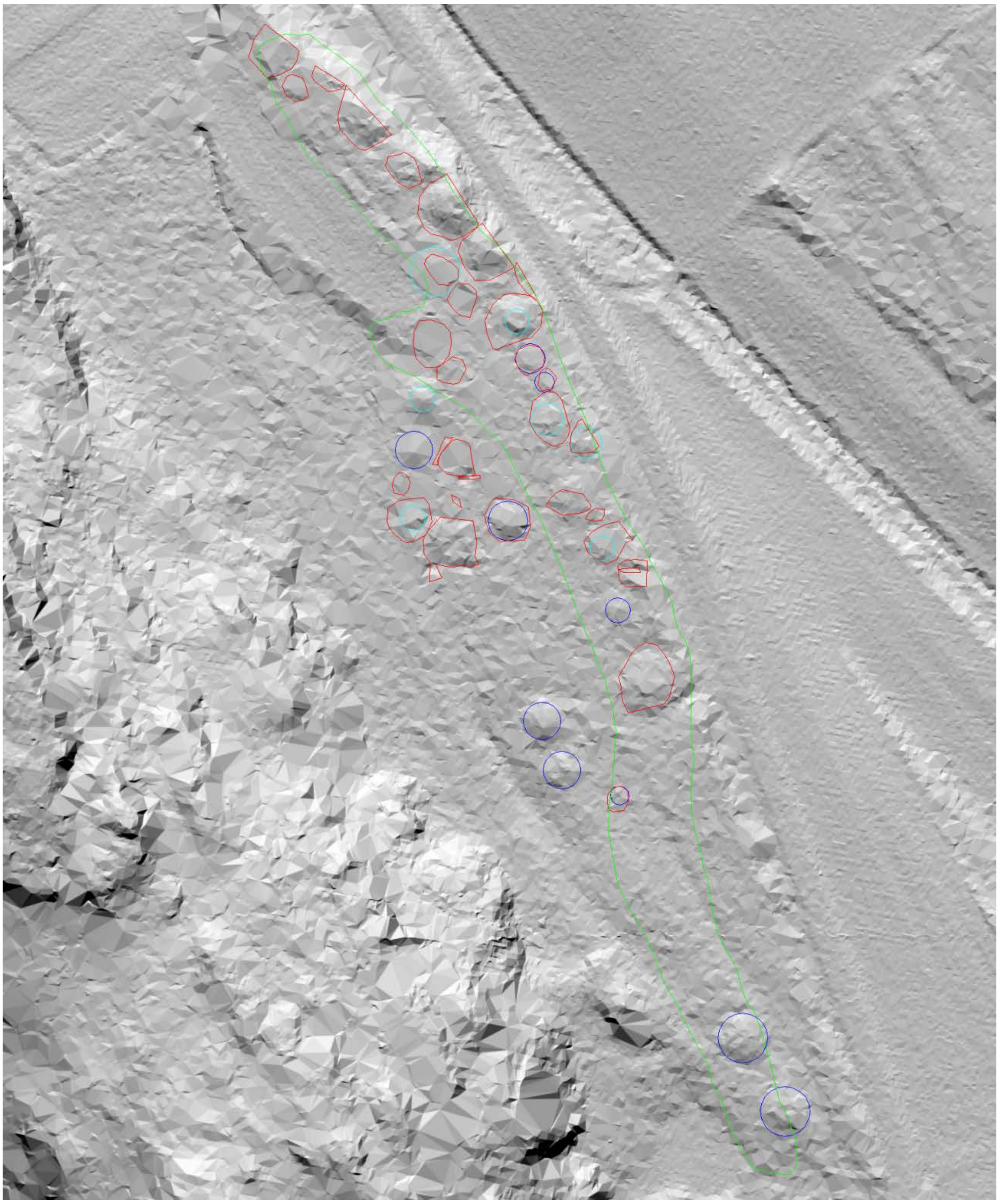

Figure 62. Grave mounds at Lunde, Larvik municipality. Legends: same as in Figure 60.

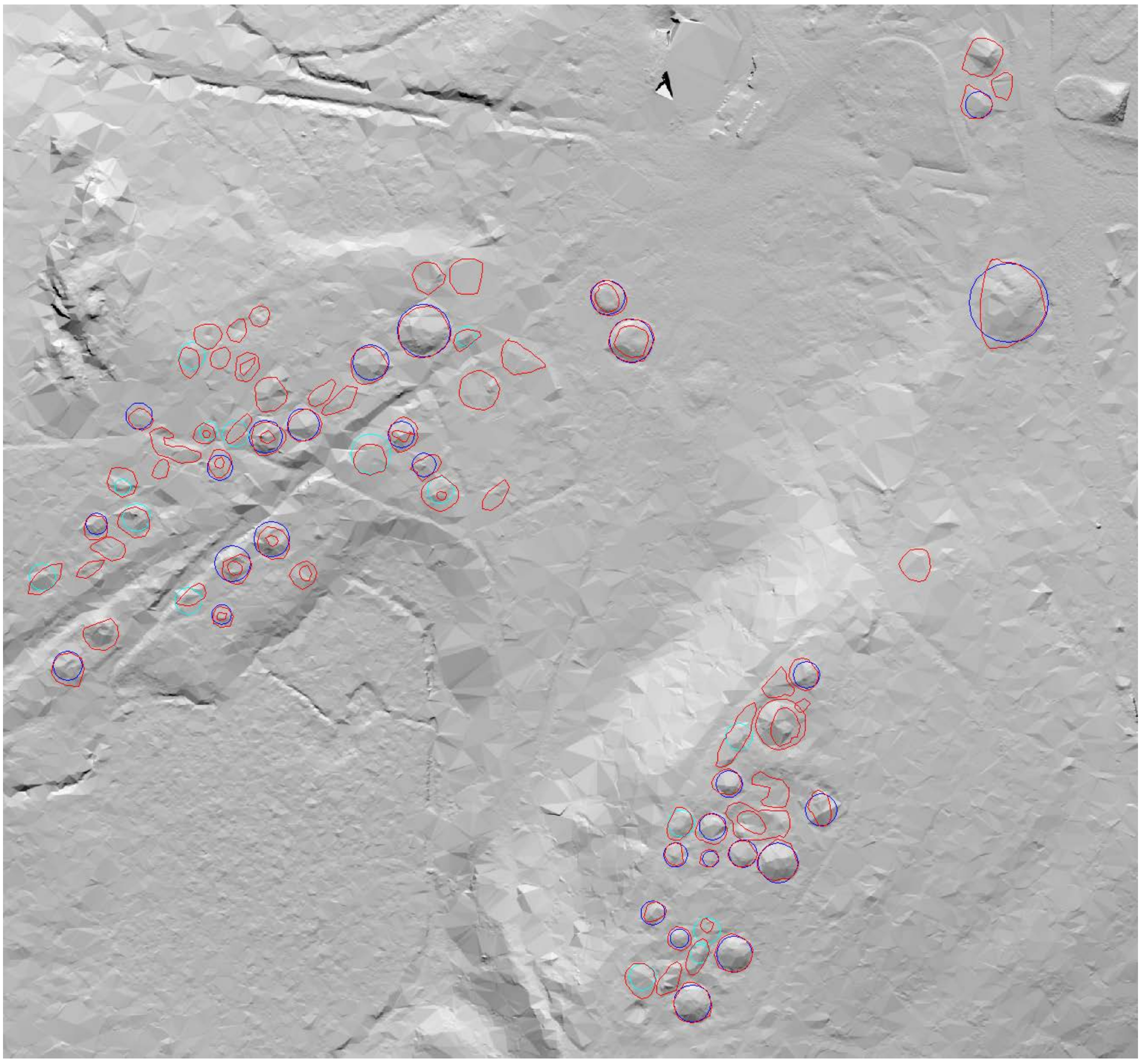

Figure 63. Grave mounds at Bøkeskogen, Larvik. Red: grave mounds, surveyed in 2001. Dark blue: automatic detections with correct geometry. Cyan: automatic detections with incorrect geometry.

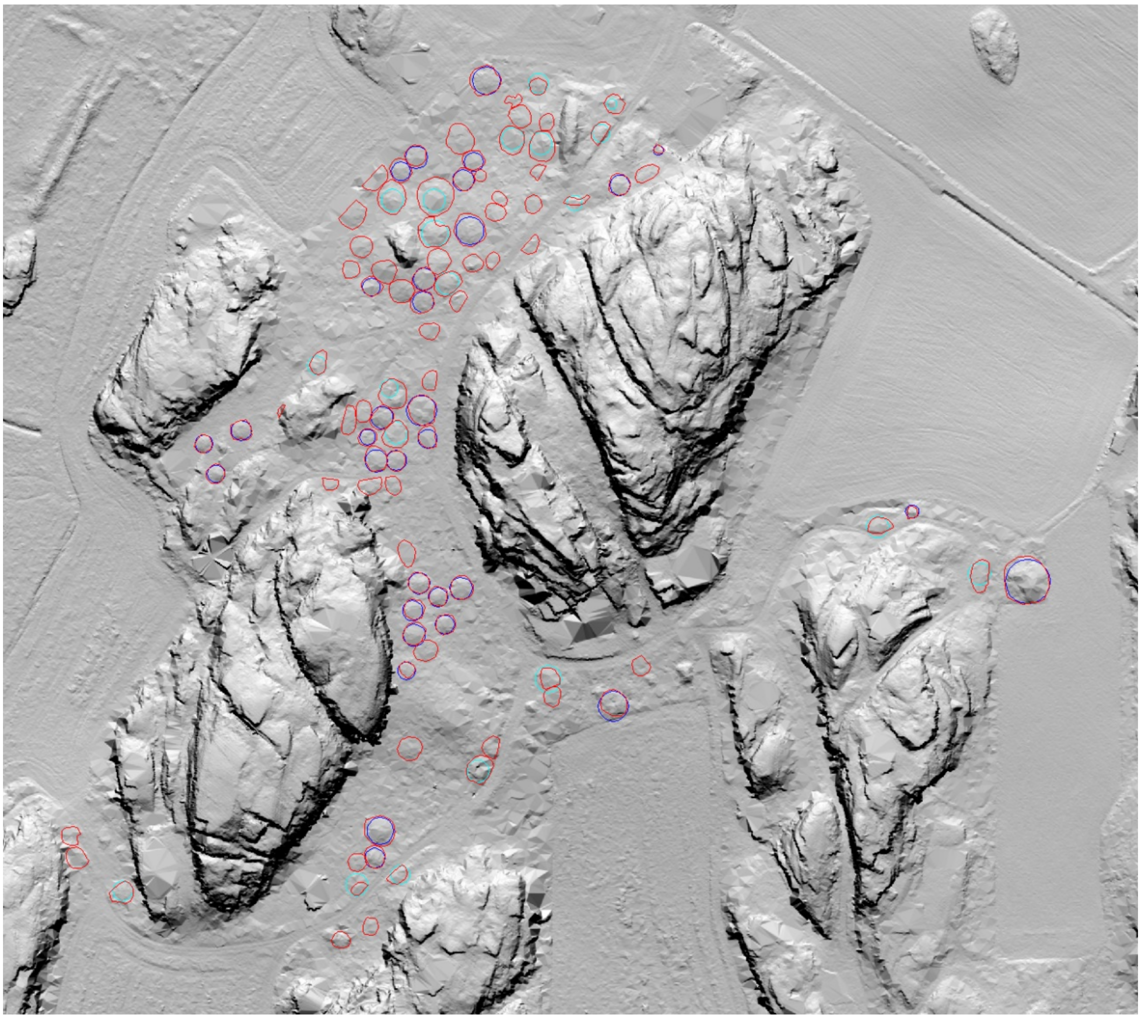

Figure 64. Grave mounds at Kaupang. Red: grave mounds, surveyed in 2005. Dark blue: automatic detections, with correct geometry. Cyan: automatic detections, with incorrect geometry.

7.6 Discussion and conclusions

The grave mound detection results on the grave fields that have been verified by field survey, indicate that the proposed automatic heap detection method is able to detect 70% of the true grave mounds, despite less than optimal ALS data quality. This varied between 49% and 96% for the individual grave fields (Table 31). At the same time, the heap detection results on the test set indicate that the confidence assignment method, based on Mahalanobis distance classifier and the 12 best attributes, is capable of assigning medium high confidence or better to 50% of the true grave mounds, while at the same time, 8 times as many false detections as true detections are assigned medium high confidence or better (Table 28). This may be acceptable when looking for grave fields: if, say, eight out of 16 grave mounds are detected, then they will probably catch the attention of an archaeologist. However, single grave mounds risk being ignored.

30% of the true grave mounds have not been detected at all (Table 31). The main reason seems to be very few ALS ground returns on these grave mounds, leading to either distorted shapes or no heap-shaped structures in the DEM. For a small number of grave mounds, the shape deviates too much from a round shape to be detected by the method. When comparing the results of this study with our previous results of automatic pit detection in Oppland County (Trier and Pilø, 2012), we obtain lower detection rates and a higher number of false detections in this study, even for the part of the dataset where the ALS pulse density was higher. There may be several reasons for this. First, the pit structure is a more unique terrain feature and more likely to be archaeology than the heap structure, as there are many heap-like natural terrain features. Second, the acquisition time of the ALS data was not ideal for the parts of the landscape in Larvik which contain deciduous tree vegetation. Third, the tree vegetation is, in general, more dense in Larvik than in the parts of Oppland that we studied, mainly due to elevation above sea level. Forth, many of the grave mounds are quite flat. All in all, a large proportion of the grave mounds do not stand out very clearly in the ALS data.

The selection of training data and test data could affect the selection of the “optimum” set of features. Initially, we attempted to use equally large portions of the data for the training set as for the test set, but this led to a very much larger number of heaps versus non-heaps in the training data, which in turn gave numerical problems in estimating the classifier statistics. The current training data has 119 heaps and 1468 non-heaps after the initial screening (step 5). The test set has 165 grave mounds and 17551 non-heaps. We also tried to reduce the training set further, by removing non-heaps with low confidence from a previous version of the method. This also resulted in poorer performance on the test set. The reason could be that there is much larger variability in shape among non-heaps than heaps, so that a much larger number of heaps than non-heaps need to be present in the training data.

Further, we need to quantify how the method performs in areas with few grave mounds. We suspect that the number of false detections remains relatively stable for geographical areas of similar size, which means that the number of false detections could be overwhelming. If this is indeed the case, we need to consider ways of improving the method.

However, improving the method is of limited value if the problems are due to the quality of the ALS data. Previous experience with pit detection in ALS data clearly demonstrates the negative effect of reduced ground point density (Trier and Pilø, 2012). Low ground point density may be due to wrong acquisition time, dense or low vegetation, too few emitted pulses per square meter, or a combination of these. Since there is a large proportion of deciduous tree in the forests in Larvik municipality, the archaeologists recommended that the acquisition of ALS data be done in late April 2010, which would have been an ideal time, with no snow on the ground and no leaves on the trees. For some reason, the ALS acquisition was postponed until the beginning of June 2010, with full-size leaves on the trees. We recommend that future ALS data sets be acquired in the early spring with no leaves on the deciduous trees, to allow more true grave mounds to be detected by the method.

Another possibility for obtaining better ALS data is to re-process the raw, full waveform ALS data to produce new LAS files, optimized for obtaining a better elevation model of the ground.

Another potential problem related to the ALS ground point density is that some grave mounds are small, either measured as height difference relative to the surrounding landscape, or measured as radius from centre to edge. Clearly, if the grave mound does not manifest itself in the data, then it cannot be detected. There could also be a problem if the heap template does not resemble the true shape of grave mounds. One possible way of studying this is to estimate from the data the shape of an average grave mound, and how it varies; then to generate simulated grave mound templates.

Further, we could consider extracting more attributes from the detected heap candidates, in the hope that some of these may improve the ability to discriminate between grave mounds and non-archaeological heaps.

Many grave mounds are surrounded by a circular ditch. Also, many grave mounds have a pit, indicating that it has been plundered. *CultSearcher* should look for these shapes in addition to heaps, and when occurring in combination, the confidence of the heap detection should increase.

CultSearcher has been used extensively in Oppland County, Norway, since 2010 for the mapping of archaeological pits, like pitfall traps in hunting systems, and charcoal burning pits in iron extraction sites. Thus, *CultSearcher* has already significantly increased the number of archaeological heritage sites in 'Askeladden', the Norwegian national database for protected cultural heritage. Furthermore, it has corrected the geographical position of several known archaeological heritage sites, relocating some up to 50 m. An accurate cultural heritage database is vital in detailed land use planning, to avoid the destruction of cultural heritage during construction work. The use of tools like *CultSearcher* needs to move beyond pilot projects, to be part of the standard cultural heritage mapping procedures in all Norwegian counties. At the moment, the heap detection method is being used for the mapping of grave mounds in Sandefjord and Tønsberg municipalities in Vestfold County, Norway.

Ideally, automatic detections by *CultSearcher* need to be verified by archaeologists, first by visual inspection of the ALS data with the detection results overlaid, then by field work. However, the current results on automatic heap detection and previous results on automatic pit detection (Trier and Pilø, 2012) indicate that *CultSearcher* may also be able to estimate cultural heritage density maps, which could be used as an 'early warning' in land use planning.

As a conclusion, the present study demonstrates that automatic heap detection is a useful tool for the semi-automatic detection of grave mounds in Norway from airborne laser scanning data, especially when the number of ground points per square meter is not too low. We have identified a number of possible improvements of the method, some of which could be important in an operational setting with non-optimal data. However, the highest potential for better detection performance is in better ALS data quality.

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8 Discussion

In 2013, automatic detection methods in CultSearcher were used for the mapping of cultural heritage from airborne laser scanning (ALS) data, in combination with visual inspection of the ALS data and field surveys. This included:

1. Mapping of archaeological pits in Oppland County, including pitfall traps in hunting systems and charcoal burning pits in iron extraction sites.

2. Mapping of grave mounds in Vestfold County.

3. Early experiments on the mapping of charcoal burning sites (kullmile) in Oppland.

The current version of CultSearcher works very well for the mapping of archaeological pits from ALS data. For the mapping of grave mounds from ALS data, CultSearcher works reasonably well as an aid in detailed mapping of grave mounds inside already known sites. However, for the discovery of new sites, the false detection rate is too high for the current version of CultSearcher to be an efficient tool. Clearly, there are many more heap-shaped than pit-shaped natural terrain formations in Norway, meaning that semi-automatic heap detection is a more challenging problem than semi-automatic pit detection.

The automatic detection methods involve the following steps:

1. Identify candidate cultural heritage locations

2. Compute measurements for each location, describing the size and shape of each patch of ground surface that could be a cultural heritage location

3. Assign a confidence level (1-6) to each location

Until now, we have used template matching in step 1. In 2014, we will investigate alternative methods, including local relief models (Hesse, 2010) and openness (Yokoyama et al., 2002; Doneus, 2013). We will also investigate new measurements in step 2, some of which could be based on the result of using local relief models or openness in step 1. Then, step 3 needs to be adjusted to account for the improvements in steps 1 and 2.

Another potential for improved performance is to re-process full waveform data in order to better separate overlapping returns from low vegetation and the ground, and also to capture very weak ground returns that are now possibly being discarded. This could potentially give a more detailed digital elevation model of the ground surface. The 22 pulses/m^2 dataset of parts of Larvik municipality was recorded in full waveform, but processed into discrete return data before delivery to us.

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