Norsk Regnesentral
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Note

Application of Remote Sensing in Cultural Heritage Management

Project report 2012

Note no. SAMBA/09/13

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RIKSANTIKVAREN

UiO : Kulturhistorisk museum

NIKU

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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 2012. The project is funded by the Norwegian Directorate for Cultural Heritage. In 2012, the method for automatic pit detection was used on several ALS datasets from Oppland County, as part of their on-going mapping of cultural heritage in areas with planned land development. A method for automatic heap detection was developed, and used in the mapping of grave mounds in Larvik municipality, Vestfold County. As a result of this, a previously unknown Iron Age grave field was discovered. The project is continuing to acquiring Worldview-2 satellite images of selected areas to monitor these for crop marks in cereal fields. In 2012, an image of Ørland, Sør-Trøndelag County, was acquired, but no clear crop marks were detected.

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	108

Table of Content

List of figures

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.

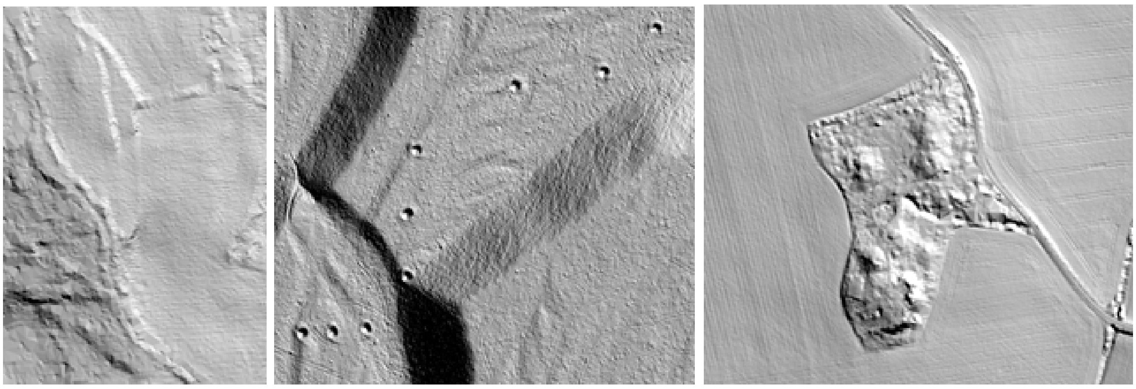

Figure 1. Airborne laser scanning (ALS) data from some Norwegian municipalities. Left: Kongsberg, with stone fences. Middle: Nord-Fron, with pitfall traps for deer hunting. Right: Larvik, with grave mounds.

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. Therefore, the project decided to make a major effort to further develop automatic heap detection in 2012.

The rest of the report is organized as follows. Section 2 reports on the mapping of archaeological pits in several municipalities in Oppland County from airborne laser scanning (ALS) data. Sections 3-4 report on the mapping of grave mounds from ALS data in Larvik municipality, Vestfold County. Section 5 describes the mapping of cultural heritage in Ørland municipality, Sør-Trøndelag County, from both ALS data and optical satellite imagery. Sections 6-7 contain two papers that were presented at international conferences in 2013. Together they present the developments and improvements of the automatic methods in CultSearcher for detecting pits and heaps in ALS data. This is followed by a discussion in Section 8, which also describes planned work for 2013.

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 750 km^2 were mapped in 2012, mainly forested areas. Automatic pit detection by *CultSearcher* has been used to support visual inspection of the ALS data.

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.

2.3 Method

The field data collected in 2012 derives from two different types of fieldwork – prognosis and systematic archaeological survey.

Two areas (Gålå and Skottåsen) were selected for establishing a prognosis for ancient monuments, as there was little or no data available. Pits found during visual inspection of the DTM were checked in the field. These were in general also detected by CultSearcher. In addition a number of pit detections, which could not be visually confirmed on the DTM were checked in the field.

One area (Gravfjellet) had seen similar prognosis work in 2011. Here regular and systematic archaeological survey took place in 2012, upgrading the field data from checked anomalies to a general ancient monuments map.

2.4 Results

The results from Gålå and Skottåsen prognosis surveys were just as good as the 2011 Gravfjellet prognosis survey. Most objects were large pits, which were easily seen and detected before the survey, and confirmed in the field. In both areas, but especially so in Skottåsen, there were large numbers of false detections caused by the uneven terrain.

The 2012 systematic survey in Gravfjellet led to the discovery of a limited number of small pits which had been missed by the 2011 visual inspection and automatic detection of the LIDAR data.

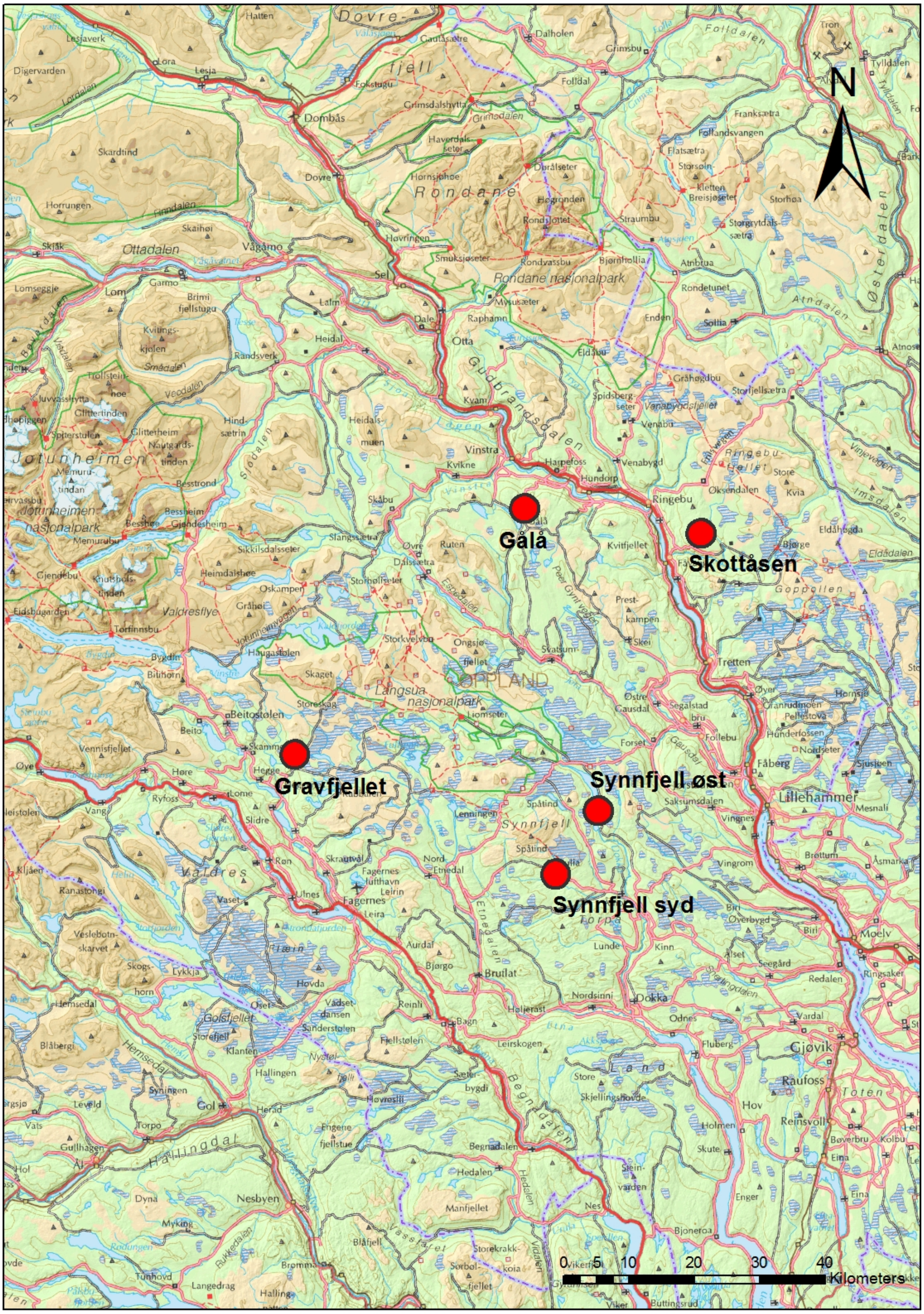

Figure 2. Five areas in Oppland County which have had major field campaigns to validate ALS-based detections of cultural heritage.

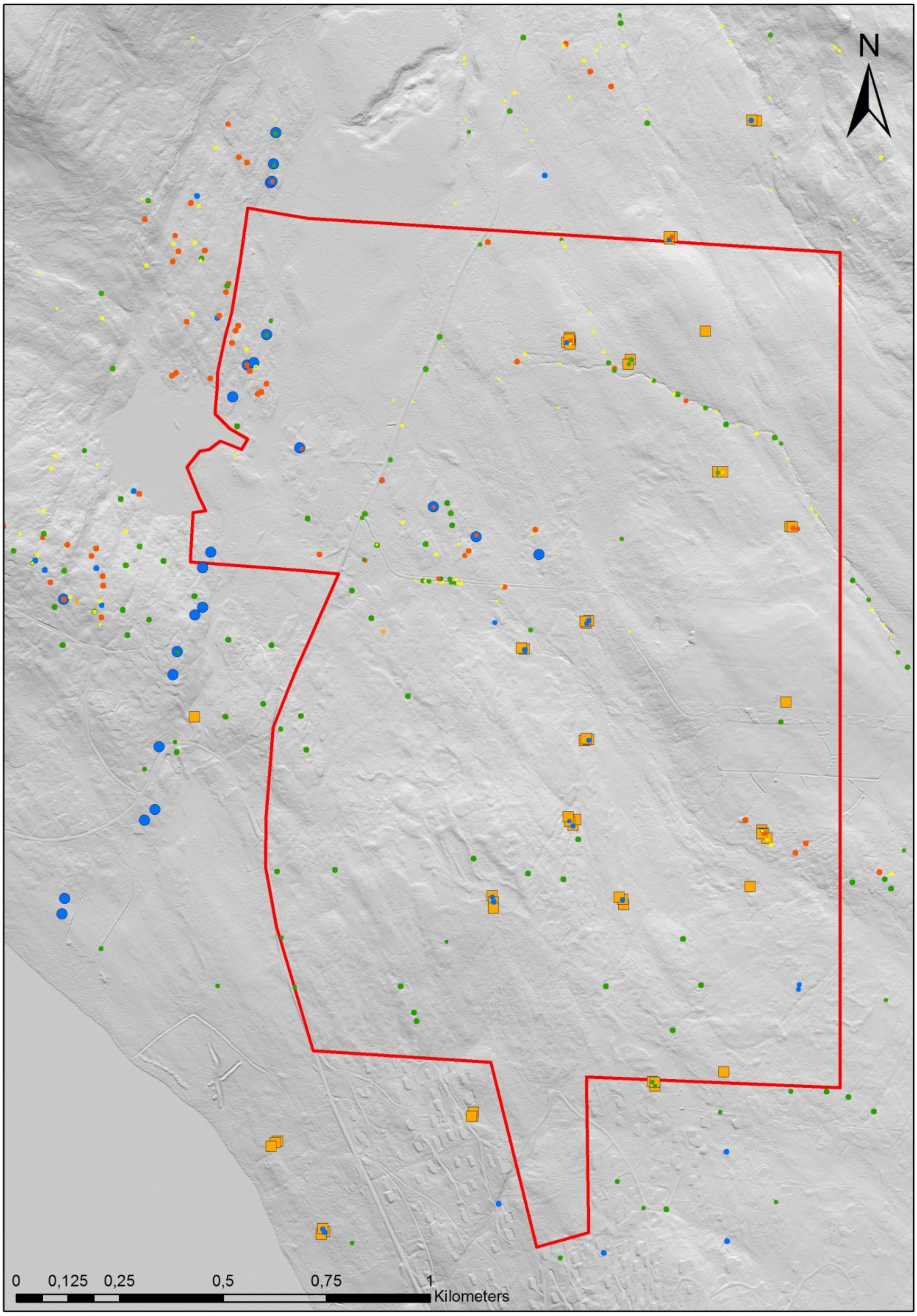

Figure 3. Gålå. Red polygon: Sør-Fron municipality's planned area for development. Blue large dots: pitfall traps for moose hunting, confirmed by field survey. Orange squares: charcoal burning pits, confirmed by field survey. Clusters of orange squares denote iron extraction sites. Small dots are automatic pit detections, with the following colours: blue = high confidence, orange = medium high, green = medium, and yellow = low confidence. Many false detections occur along roads and ditches, and in parts of the terrain with many natural pit-like structures.

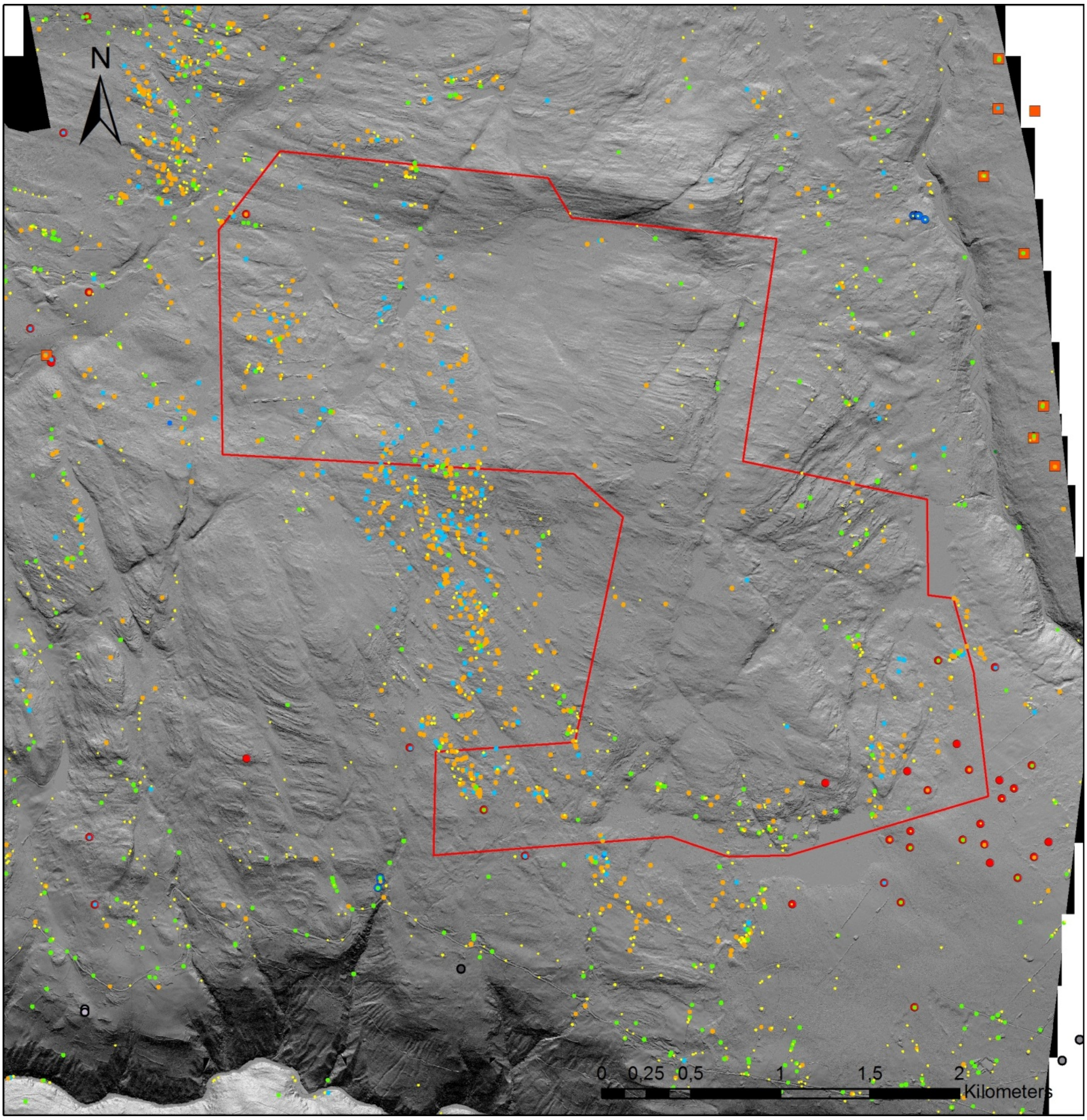

Figure 4. Skottåsen. Red polygon: Ringebu municipality's planned area for development. Blue large dots: pit fall traps for moose and reindeer hunting, confirmed by field survey. Orange large squares: iron extraction sites (containing multiple charcoal burning pits) confirmed by field survey. Red large dots: single charcoal burning pits, confirmed by field survey. Small dots are automatic pit detections, with the following colours: cyan = high confidence, orange = medium high confidence, green = medium confidence, and yellow = low confidence. Natural terrain features led to an excess amount of pit detections that are not cultural heritage.

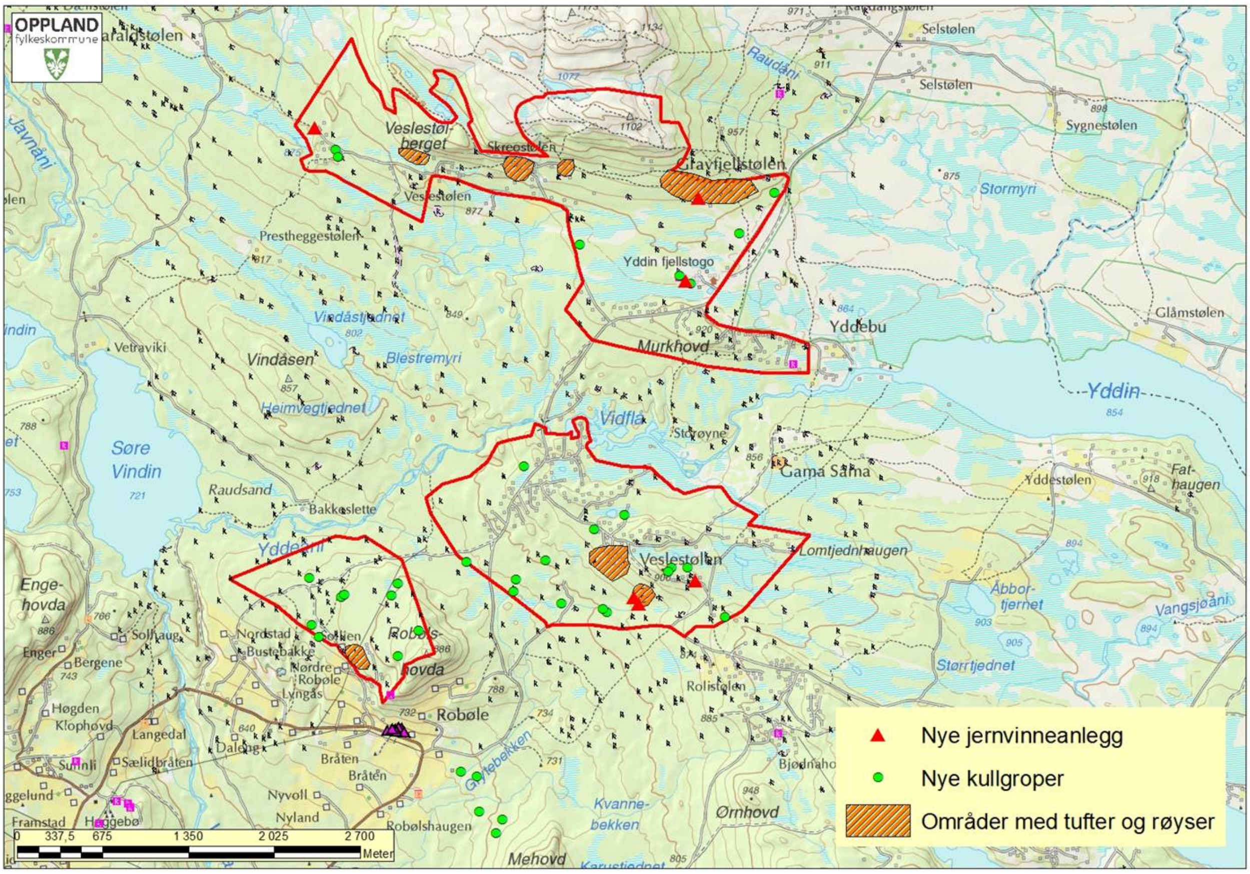

Figure 5. Gravfjellet, Øystre Slidre municipality. Red triangles: iron extraction sites not previously known. Green dots: charcoal burning pits not previously known.

2.5 Discussion

The automatic pit detection by CultSearcher works well when the terrain surface is even or slightly undulating. When the terrain gets “bumpy” the number of false detections increases sharply, and the value of the detections decreases. In addition modern structures like buildings, roads and ditches lead to false detections. As an experienced user of detection data these false detections are easily dismissed, but more inexperienced users may find this confusing.

It would be valuable if future CultSearcher pit detections also would include information about the presence/absence of a low bank around the pits. It would also make CultSearcher detections visually easier to use if detections connected to modern structures were filtered out. The same goes for areas with a high number of false detections due to terrain.

3 Mapping of grave mounds in Larvik municipality, Vestfold County

By Christer Tonning, Vestfold County Administration

3.1 Introduction

In 2010 and 2011, this project successfully used automatic pit detection in airborne laser scanning (ALS) data in Oppland County. In the autumn of 2011, the project decided to attempt at using automatic heap detection in ALS data for the mapping of grave mounds. The template matching step of the pit detection method uses an ideal, upside-down dome-shaped template to find initial pit candidates. By using an upright half-dome, heaps could be detected instead of pits. However, there are differences. Whereas the archaeological pits are quite unique structures in Norwegian terrain, grave mounds may resemble natural terrain features in many cases. Grave mounds are usually larger than the archaeological pits, and the dome shape is more flat than for these pits. The grave mounds vary a lot in diameter and height, and the shape may also deviate substantially from a perfect dome or circular structure.

On the other hand, many grave mounds may have details that could potentially be used to separate them from natural terrain features:

1. A central pit, usually an indication that the grave mound has been plundered

2. A circumscribing circular ditch

3.2 Data

Vestfold County Administration has used 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 $10\text{-}12/m^2$ for a $243km^2$ area of interest in the south of Larvik municipality. ALS data for the remaining $365km^2$ of Larvik municipality was collected at $1/m^2$ pulse density.

ALS data was acquired in early June 2010. Unfortunately, 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, was 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 labeled as 'ground' returns, and the height accuracy of the 'ground' points may be reduced.

3.3 Method

3.3.1 Selection of field verification sites

ALS data was uploaded as LAS files to an ftp server at the Norwegian Computing Center (NR) in the late autumn of 2011. NR then developed the automatic heap detection method in CultSearcher, as described in Sections 6-7. The result of running the automatic heap detection on the Larvik ALS data was delivered as shape files on 11 April 2012. Vestfold County Administration had selected four areas for field verification. These areas are known to contain medium to large collections of grave mounds. The result of the field work could then be used to improve CultSearcher with the goal of reducing the number of 'false' detections and the number of missing detections. In this context, 'false' means detection of terrain features that are not grave mounds, and missing means grave mounds that were not detected by the automatic method.

On 16 April 2012, the project went on field excursions to the following four locations:

1. Hem Østre
2. Brunlafeltet
3. Ødelund
4. Bøkeskogen (means beech forest)

Of these four areas, we discovered that the Bøkeskogen area had a very low ground point density, distorting the shape of many grave mounds in the DEM. As the beech forest is deciduous, ALS data collection in early June was clearly a disadvantage. As a consequence, Bøkeskogen was excluded from the list of areas for field verification, and replaced by Omsland, giving the following list of known grave fields for field verification (Figure 6):

1. Hem Østre
2. Brunlafeltet
3. Ødelund
4. Omsland

The Norwegian Computing Center delivered shape files with automatic detection results for each of these areas, and geo-referenced hill-shade raster files for use as backdrop for the shape files. Each of the detections was labelled with a confidence value 0-6 (Table 1). It is important to bear in mind that the automatic method assigns a confidence value based on the shape in the DEM only, so, in principle, even a very high confidence detection could be a natural terrain feature, such as a rock, a heap of twigs, etc., and is thus 'false' since it is not a grave mound.

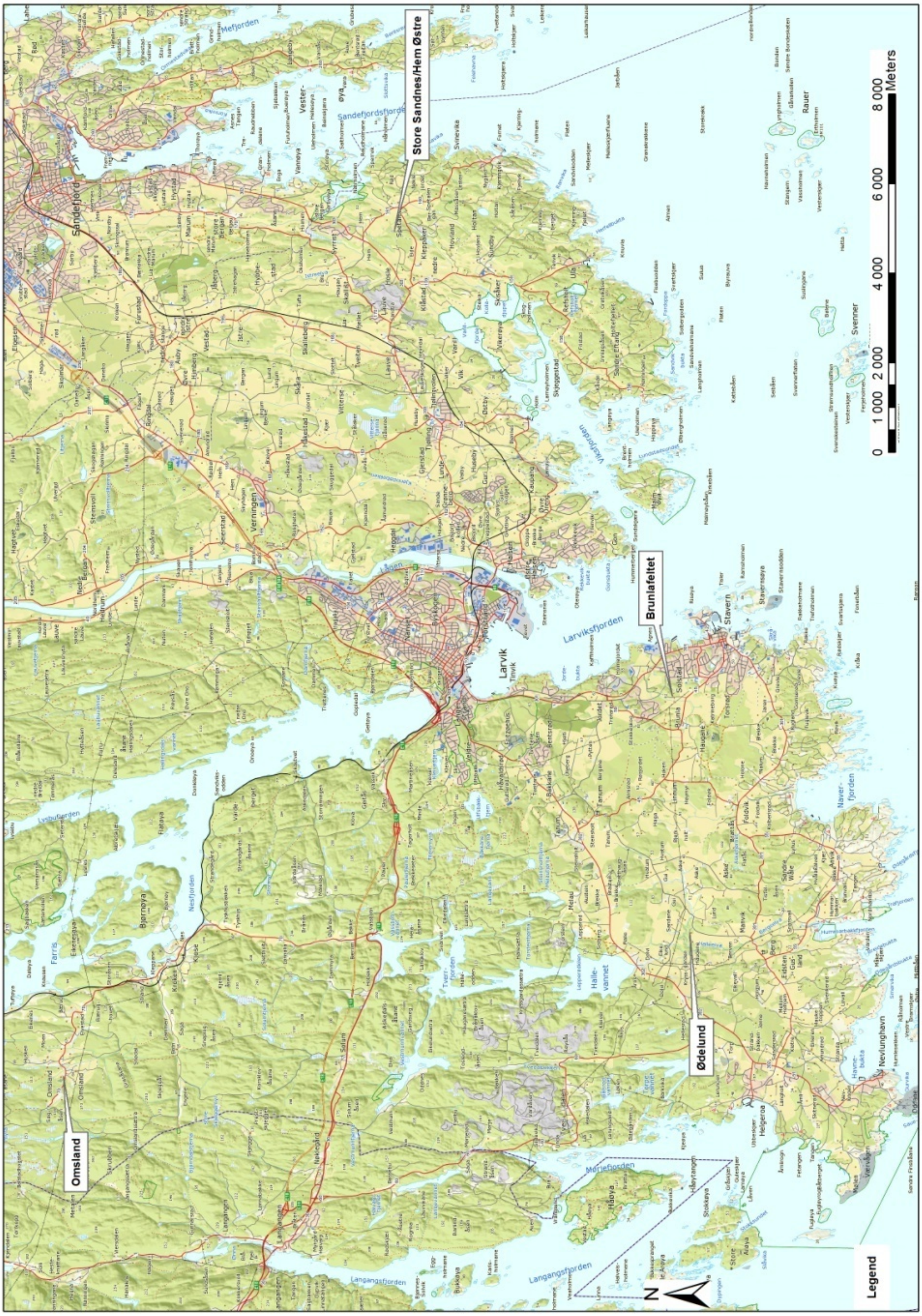

Figure 6. The location of the four grave field sites selected for field survey

Table 1. Confidence values, their meaning and the colour codes used in figures in this section. As no detections received confidence value 6 (very high), there is no colour code for this confidence value.

confidence value	6	5	4	3	2	1	0
description	very high	high	medium high	medium	low	very low	zero
colour		red	blue	green	brown	black	white

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 centimeters. 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.

3.3.3 Field verification of selected sites

According to the previous subsection, archaeological field work may have to be done at a specific time to fit the schedule of zoning plans or construction work. However, since the sites selected for field verification contained major known grave fields and were not in conflict with any zoning plans or planned construction work, we had the leisure to decide the time of the field work. In order to better understand the nature of missing detections and false detections, we decided to conduct the archaeological field work in early June, which was approximately the same time as when the LIDAR acquisition was done in 2010.

3.4 Results

3.4.1 Cultural heritage monument ID 38735 Hem Østre, Larvik Municipality

According to the national cultural heritage database Askeladden, this monument or grave field consists of 12 round barrows; 10 of them are located east of a north-south oriented tractor path, and two of them are located on the western side. In June 2010, when the LIDAR data acquisition was done, this site was covered with dense forest (Figure 7), mostly spruce and some pine.

Today the forest has been cut down and the graves are quite easy to see. When the forest is removed from the ALS data and the actual laser ground returns are displayed on the DEM hill-shade (Figure 8), it becomes evident that the number of laser pulses that actually hit the ground is quite small, indicating that the quality of the DEM is far from ideal. Nevertheless, despite this, CultSearcher managed to detect all of the grave mounds (Table 1).

When ground proofing this site by archaeological survey, it also became evident that CultSearcher had flagged 3 additional grave mounds which were never detected at the original survey in the 1970s. In addition to this important observation, the geometry of this site as it was recorded by the original survey was also poor (Figure 9). This is a fairly common problem with archaeological sites in Norway.

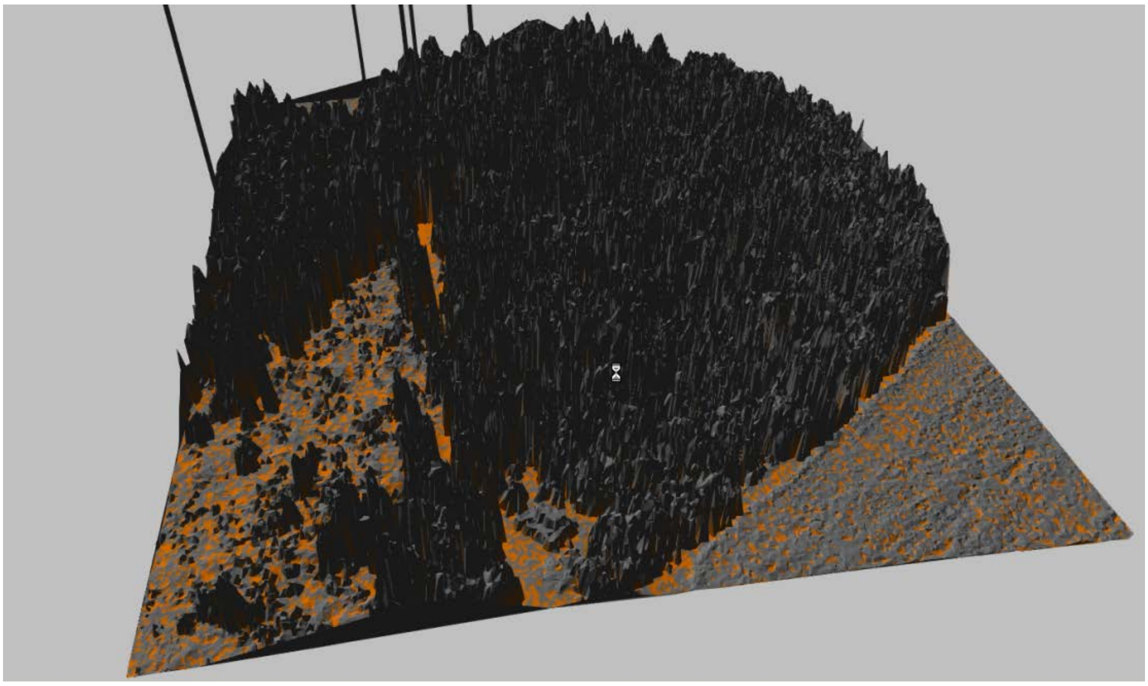

Figure 7. A 3D visualization of the ALS data, including vegetation, of the site at Hem Østre, as of June 2010. Orange: ground, grey: vegetation.

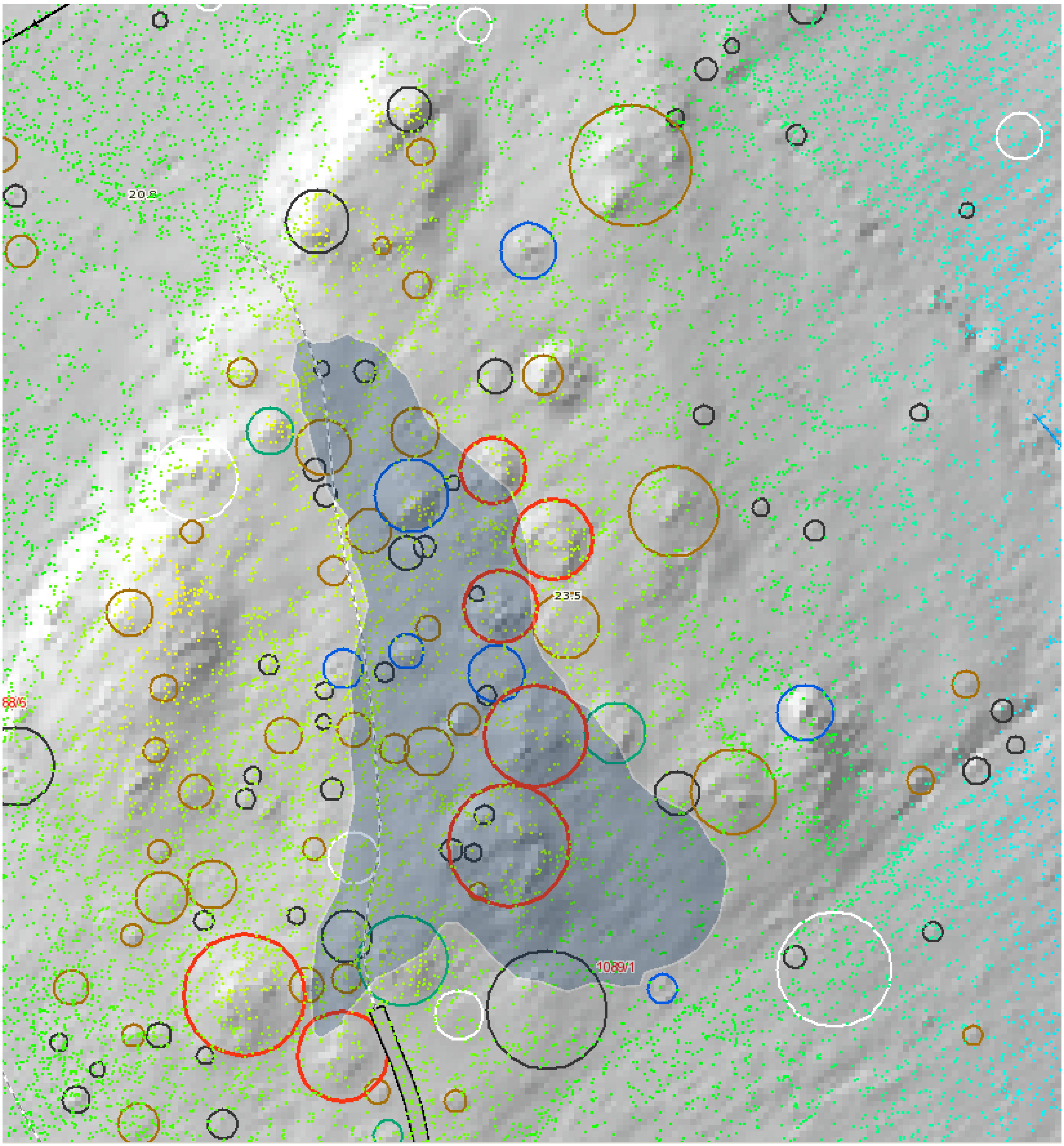

Figure 8. The grave field site with Askeladden ID 38735 at Hem Østre. Blue shade: outline of grave field, according to Askeladden. Coloured dots: ALS ground points, the colour indicates the elevation. Circles: automatic heap detections, with red=high confidence, blue=medium high, green=medium confidence, brown=low. black=very low, and white=zero confidence. Grey scale shades: hill shade visualization of the DEM.

Table 2. The number of automatic detections in each confidence level for the Hem Østre site.

	Confidence of detection						not
Site	6	5	4	3	2	1	detected
ID 38735 Hem Østre	0	7	4	2	3	1	0

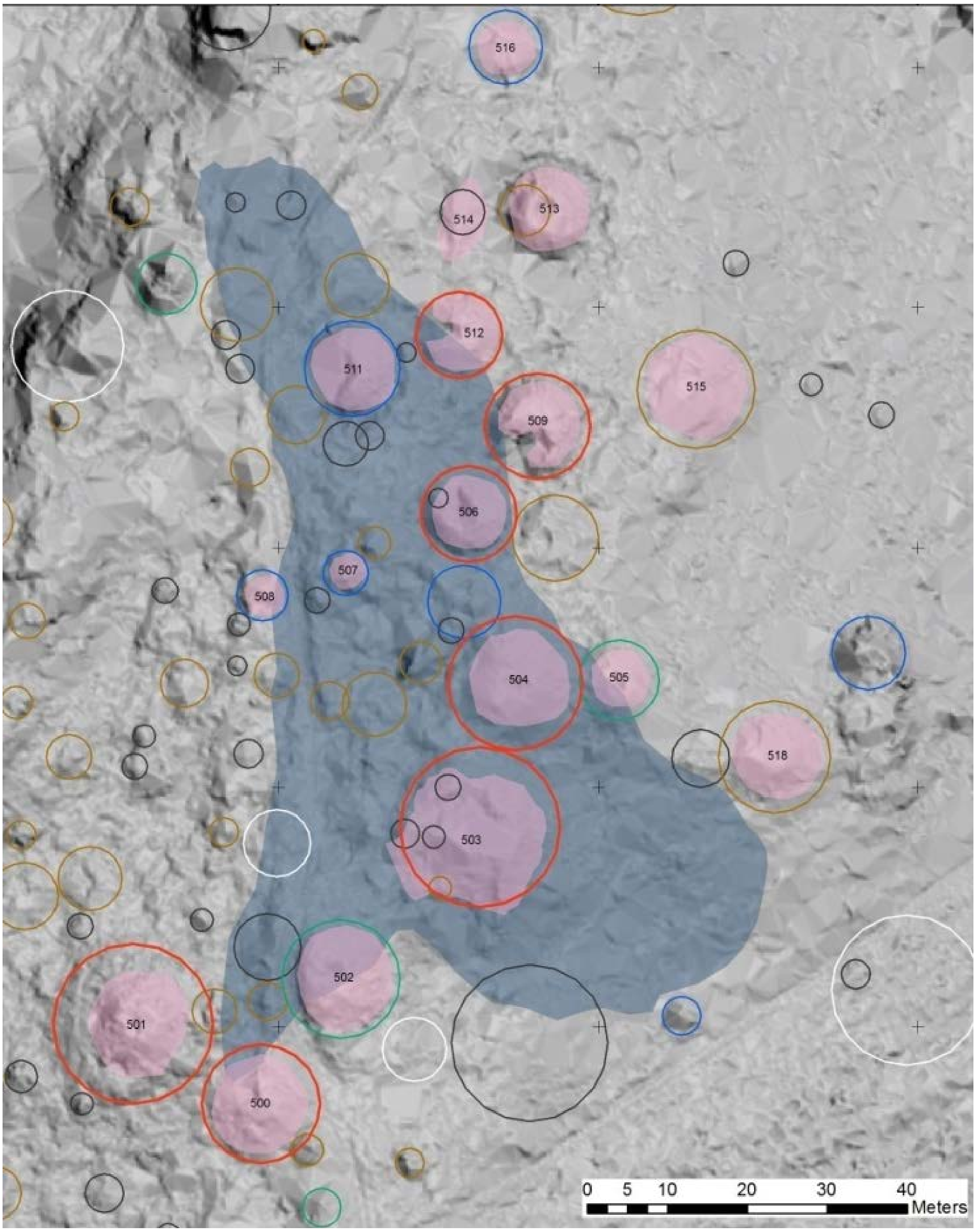

Figure 9. The grave field at Hem Østre. Blue polygon: Askeladden site ID 38735 as it was documented in the original survey in the 1970s. Circles: CultSearcher automatic heap detections, with red=high confidence, blue=medium high, green=medium, brown=low, black=very low, and white=zero confidence. Pink polygons: field survey of grave mounds in June 2012.

Although all grave mounds were detected by CultSearcher, some were detected with a too small or too large diameter. Mounds nos. 513 and 514 (Figure 9) were only partly discovered by Cultsearher. Mound 514 is a long barrow, and since the automatic detection method focuses on detecting circular objects, one may not expect a long barrow to be detected. Parts of the mound was detected, but with very low confidence. Mound 513 is one of the most prominent mounds on this site, and it is also very evident in the hill shade image and the slope image. Only the mound's western part, between natural ground and a plundering hole, has been detected with low confidence. The reason for this is probably the large plundering hole in the centre of mound, making the mound deviating too much from the dome shape expected by CultSearcher. In conclusion, all of the grave mounds on this site were detected by CultSearcher, but four of them with low or very low confidence, and some with wrong diameter. It might be that all the mounds had been detected with correct sizes, if the ALS acquisition had been performed after the clear cut of the forest.

3.4.2 Cultural heritage monument ID 3671 Brunlafeltet, Larvik Municipality

The cultural heritage site of Brunlafeltet (Askeladden ID 3671) is a prominent and well known site in Vestfold. The site has been maintained as a combined public park and outdoor museum by the Vestfold County Administration. The maintenance is evaluated every year to ensure that the grave monuments are well preserved. Issues that are evaluated include how to deal with low vegetation. The northern part of the site has a medium-dense, quite tall forest, forming a roof of leaves and branches in the summertime. The southern part is a more open grass field, with few barriers towards the sky. As expected, this leads to fewer ALS ground points in the northern part of the grave field compared to the southern part of the grave field (Figure 11). The entire site is facilitated for the public, with benches and walking paths. The archaeological surveying and checking of the CultSearcher detections were conducted on 7 June 2012.

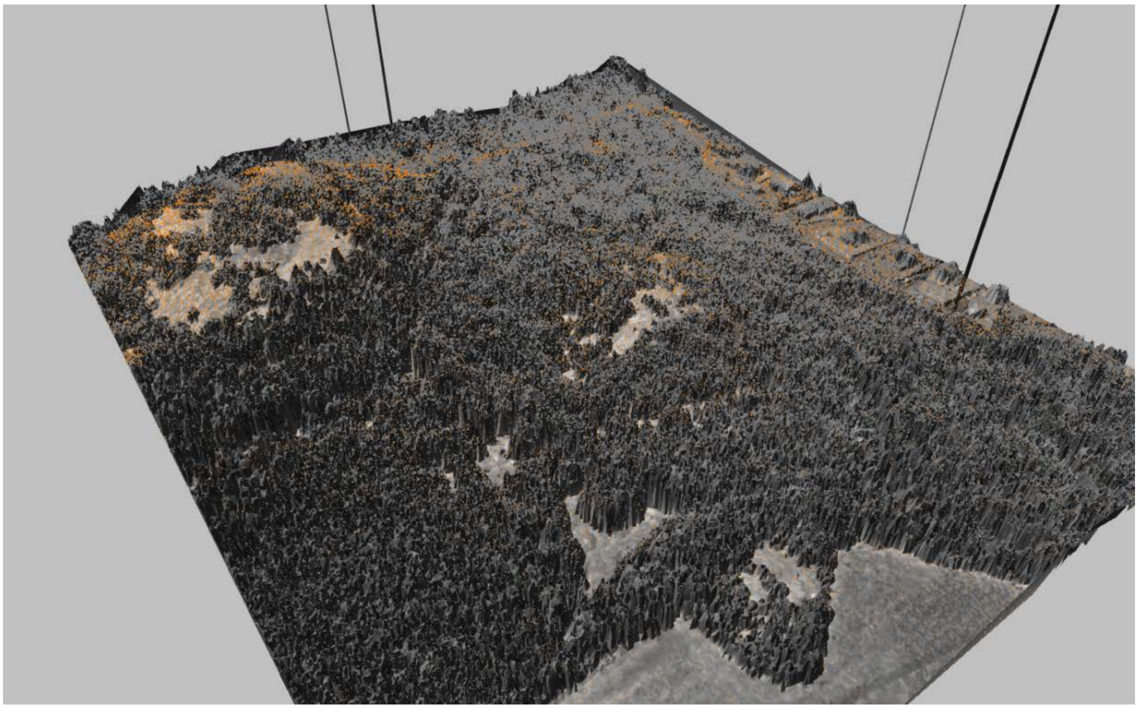

Figure 10. The digital surface model (DSM), including vegetation, of the Brunlafeltet grave field and surrounding landscape. The grave field site resides in the central part of this image.

Brunlafeltet is consisting of "at least 60 grave mounds" according to the national cultural heritage database Askeladden. CultSearcher had somewhat more trouble with detecting the grave mounds on this site. The central part of the site is quite complex: small mounds reside closely together, and some of these are probably not mounds, but residues from destroyed or partly destroyed mounds. The grave field site spreads out over a large area (almost 400 m from north to south). A total of 70 grave mounds were confirmed by the ground survey, an increase of 10 mounds from the original registration.

The north-eastern part is densely grown with trees and low vegetation, almost impossible to penetrate with laser. The situation concerning vegetation is better in the middle and southern part. This is also quite evident in the hill shade image (Figure 15). Nevertheless, CultSearcher has managed to detect several grave mounds with high and medium high confidence in these areas (Table 3). All the confirmed grave mounds except one (mound no. 1013) were detected, but when including medium or lower confidence detections, the number of false detections increase dramatically, making the medium or lower confidence detections impractical to use in the field survey.

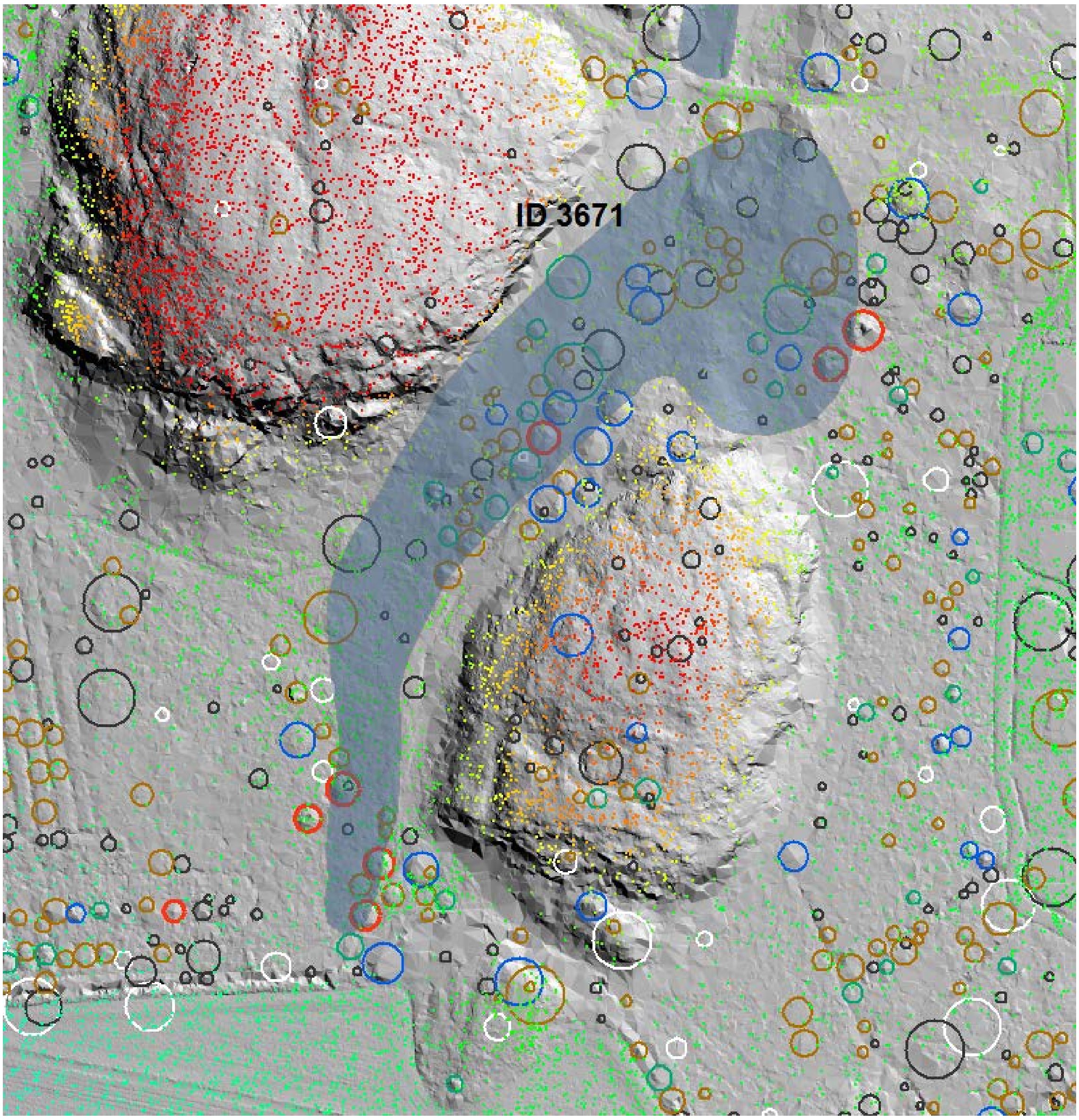

Figure 11. The grave field Brunlafeltet, with Askeladden site ID 3671. Blue shade: outline of grave field, according to Askeladden. Coloured dots: ALS ground points. Circles: automatic heap detections by CultSearcher, with red=high confidence, blue=medium high, green=medium, brown=low, black=very low, and white=zero confidence.

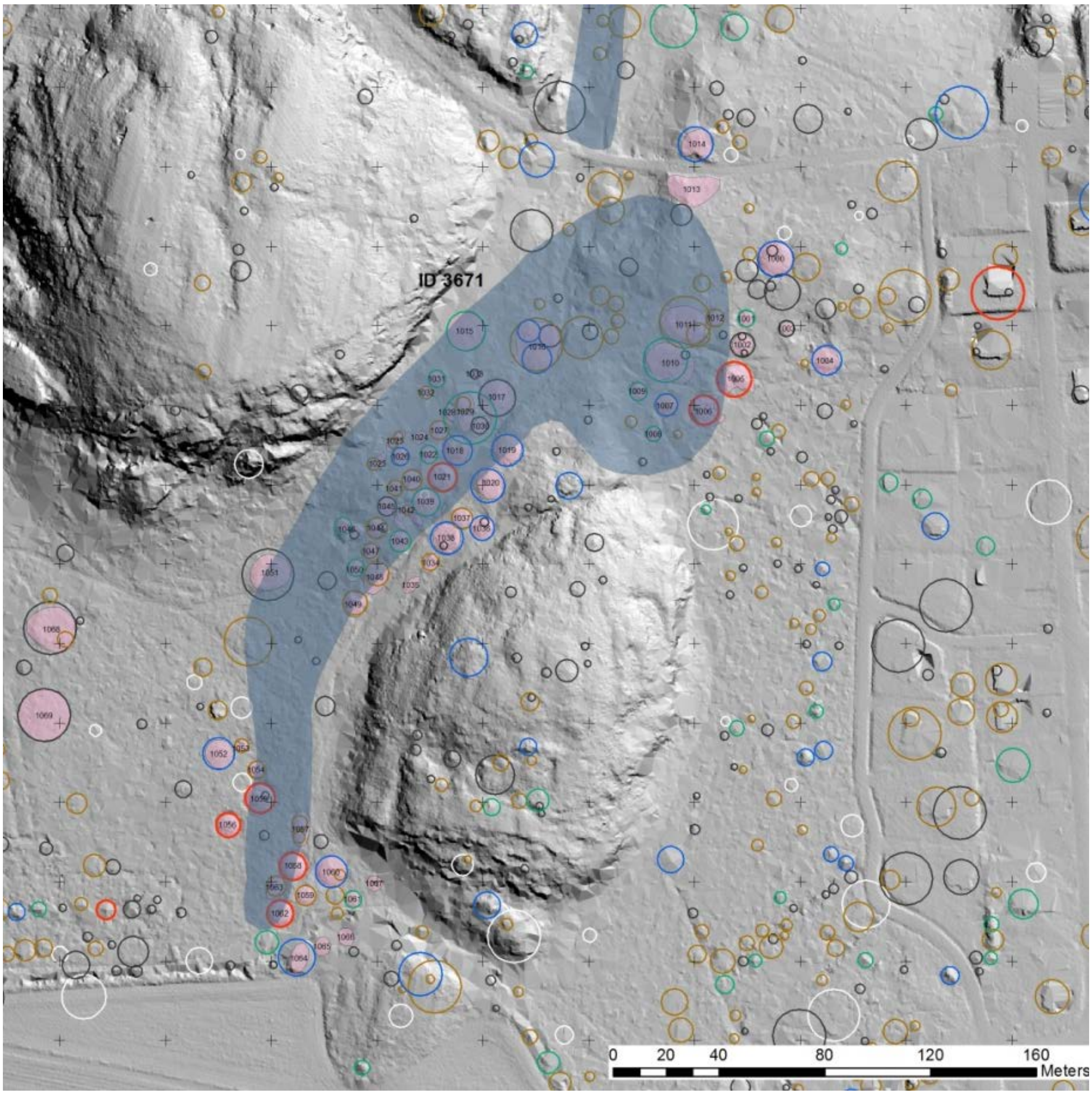

Figure 12. Brunlafeltet. Blue shade: outline of grave field according to Askeladden. Pink shaded polygons: confirmed grave mounds from the field survey in June 2012. Circles: automatic detections by CultSearcher, same colours as in Figure 11.

Some of the detections are of fractions of mounds (e.g., mounds 1028, 1029, and 1030; Figure 13), either due to lack of a sufficient number of ALS ground points, or due to the mounds having a non-circular shape. The surveyed objects nos. 1068 and 1069 (Figure 14) are not grave mounds, but remnants of charcoal production.

Table 3.The number of grave mounds detected by CultSearcher at different confidence levels, and the number of grave mounds missed by CultSearcher at Brunlafeltet.

	Confidence of detection						not
Site	6	5	4	3	2	1	detected
ID 3671 Brunlafeltet	0	7	19	30	18	6	1

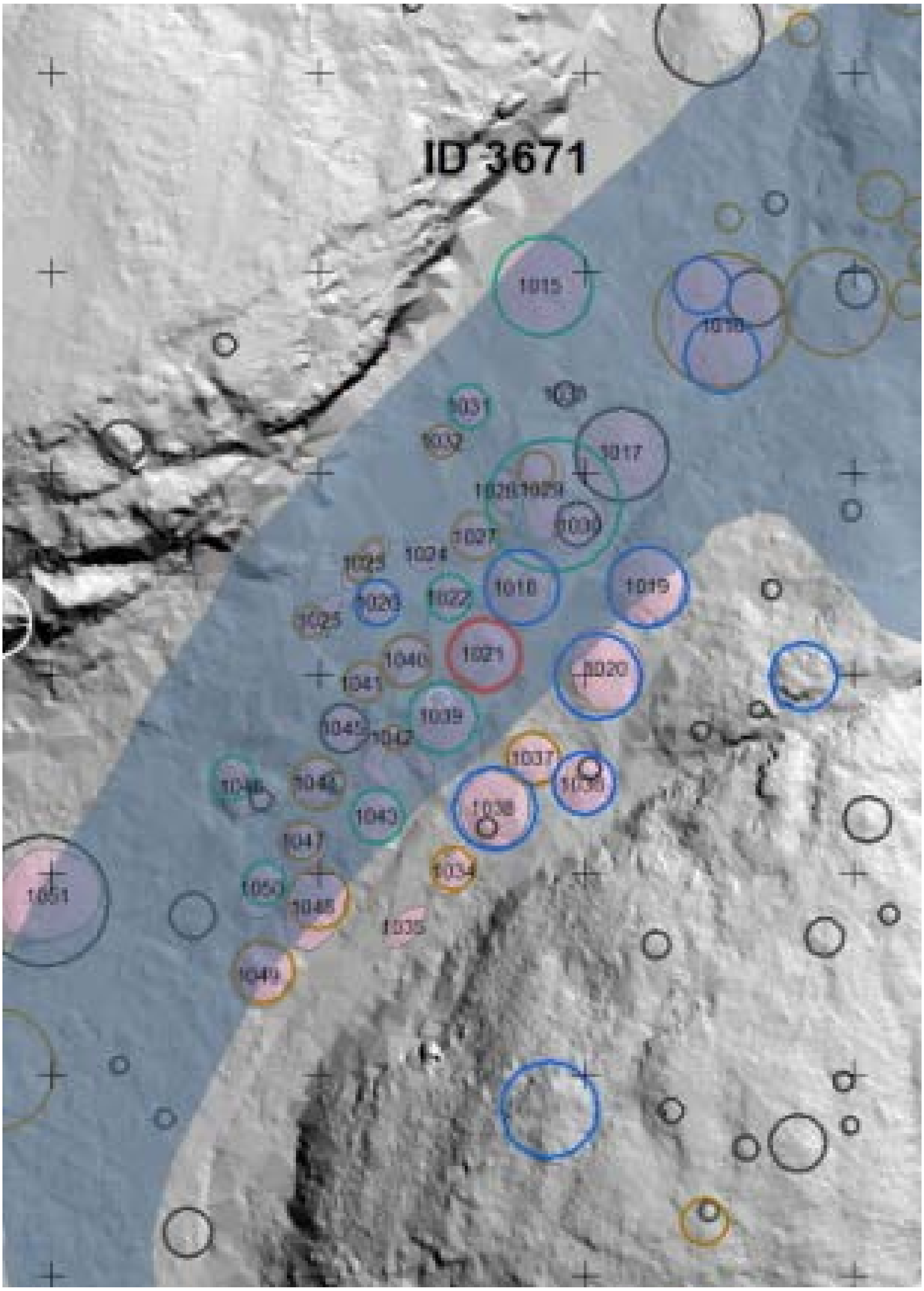

Figure 13. Detail of the central part of Brunlafeltet.

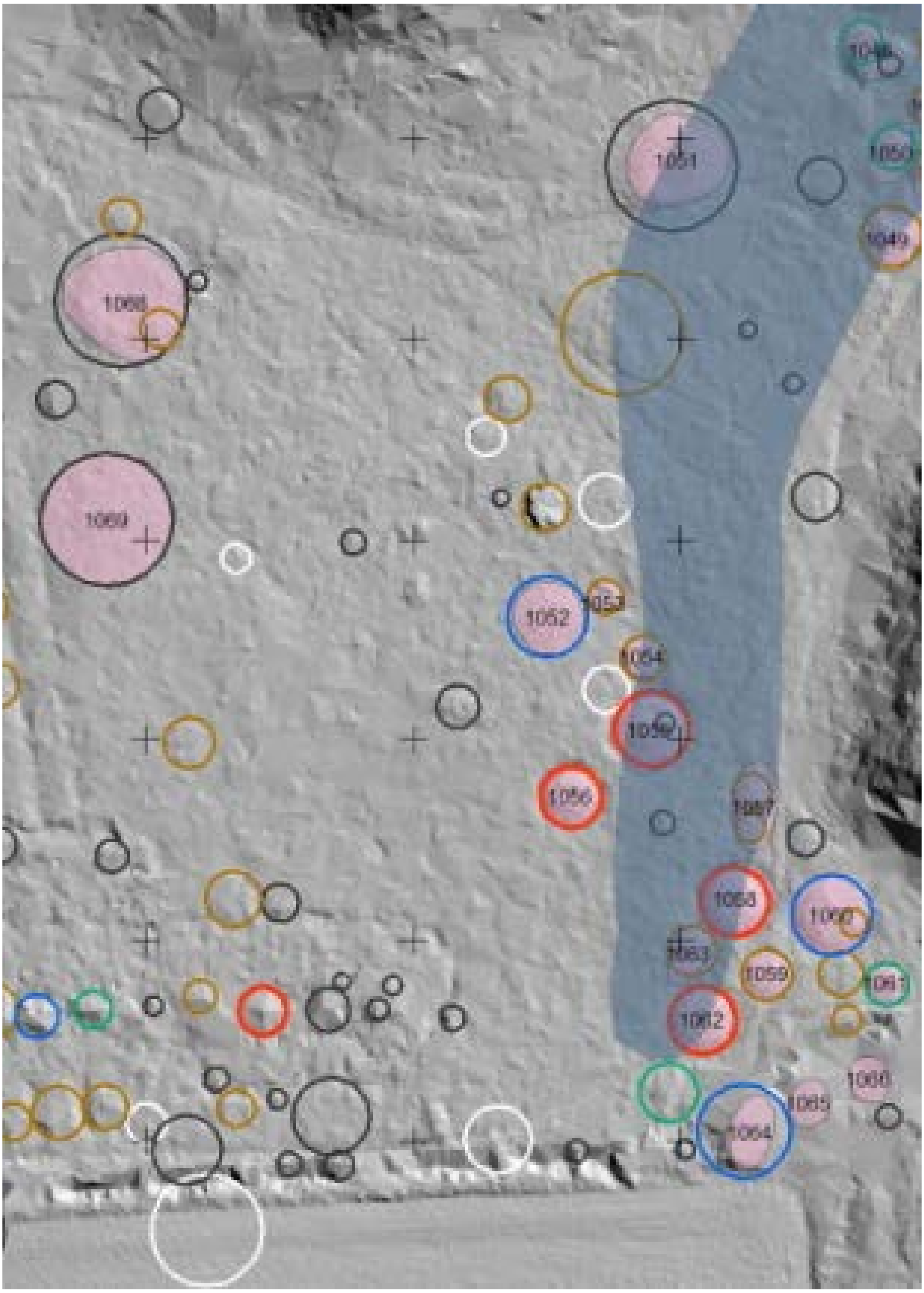

Figure 14. Detail of the southern part of Brunlafeltet, and two remnants of charcoal production (1068 and 1069) west of Brunlafeltet.

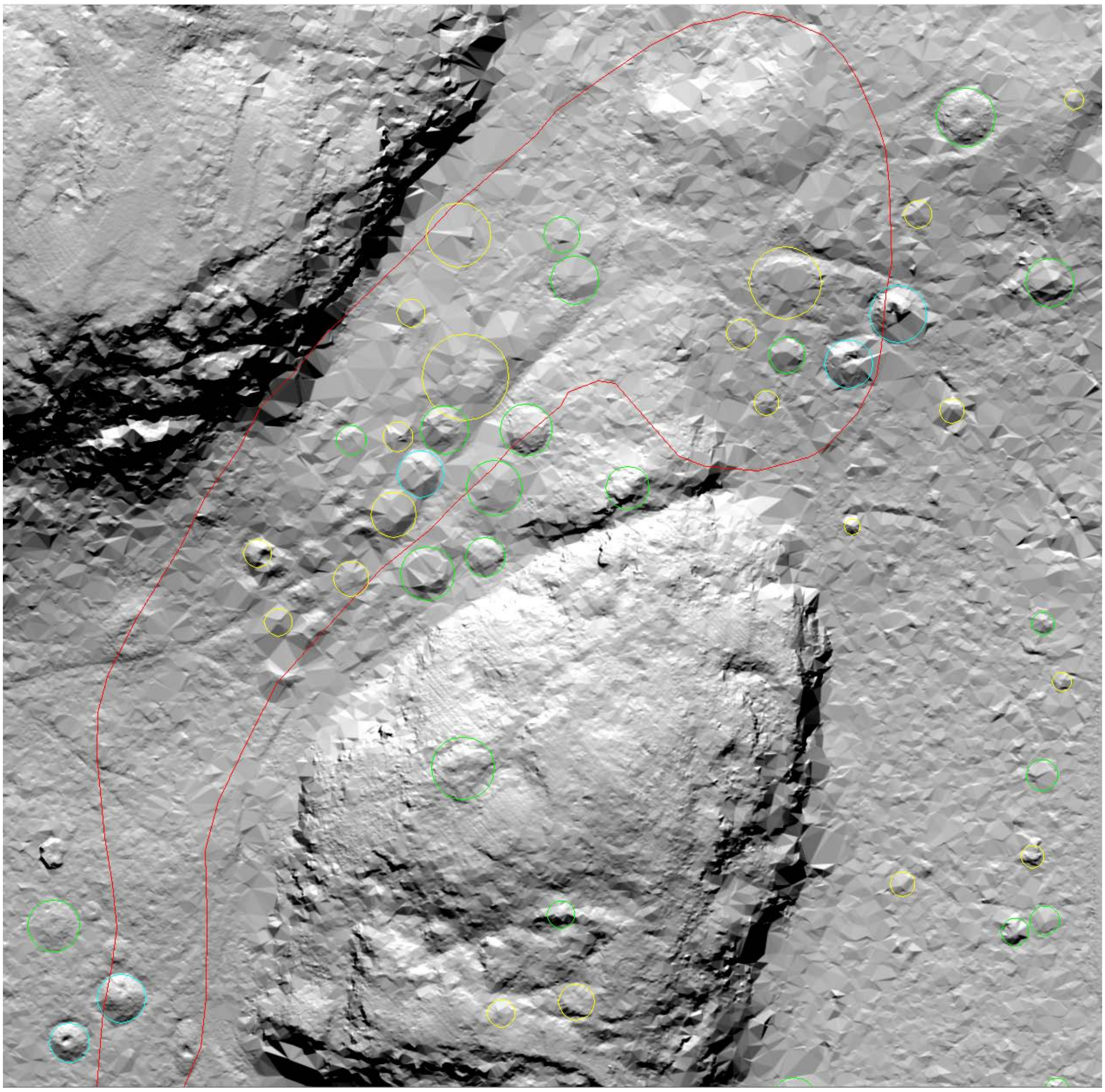

Figure 15. Detail of hill-shaded DEM of the northern and central parts of Brunlafeltet. Circles: automatic heap detections by CultSearcher, with cyan=high confidence, green=medium high, and yellow=medium confidence. Red: outline of grave field according to Askeladden, prior to the field survey of June 2012. The level of detail in the DEM varies a lot locally due to the presence of deciduous trees. Low ALS ground point density is evident by the presence of quite large triangles in the DEM.

3.4.3 Cultural heritage monument ID 71016 Ødelund, Larvik Municipality

The site Ødelund, with Askeladden ID 71016, is an average size grave field in Vestfold County, similar in size to the site of Hem Østre discussed above. It is situated a bit closer to arable land than Hem Østre, and has some farm buildings close in its vicinity. The terrain at Ødelund is quite steep. South of the grave field the terrain falls steeply down a ravine and towards a small river. The tree vegetation at Ødelund has a large proportion of deciduous trees, including Birch, Oak and Beech (Figure 16). Also, there is a lot of herbaceous low vegetation in June (Figure 16). Combined, this resulted in a low density of ALS ground points at the time of acquisition in June 2010.

Figure 16. Top: vegetation as of 16 April 2012, at one grave mound in the Ødelund grave field. Bottom: vegetation as of 13 June, at the same grave mound.

A total of 12 mounds were registered on the original survey in 1979. To the northeast of the site there is a large farm building. There is a tractor path which cuts through the grave field, intersecting the edge of the largest grave mound (no. 826). There is a possibility that mounds that were registered in 1979 have been destroyed due to agricultural operation in the area. There are also clusters of garbage in the area.

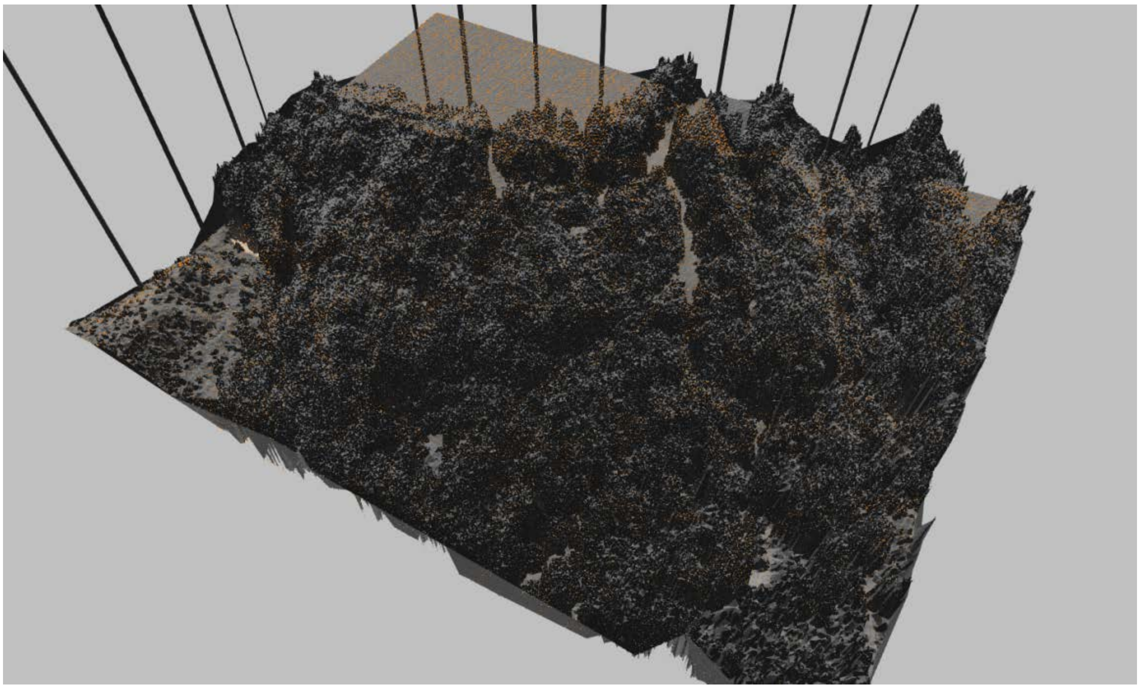

Figure 17. DSM including vegetation of the grave field at Ødelund and surrounding landscape, as of June 2010.

Figure 18. The grave field at Ødelund, with Askeladden site ID 71016. Blue shade: outline of grave field, according to Askeladden. Coloured dots: ALS ground points, with the colour indicating terrain elevation. Circles: automatic heap detections by CultSearcher, with red=high confidence, blue=medium high, green=medium, brown=low, black=very low, and white=zero confidence.

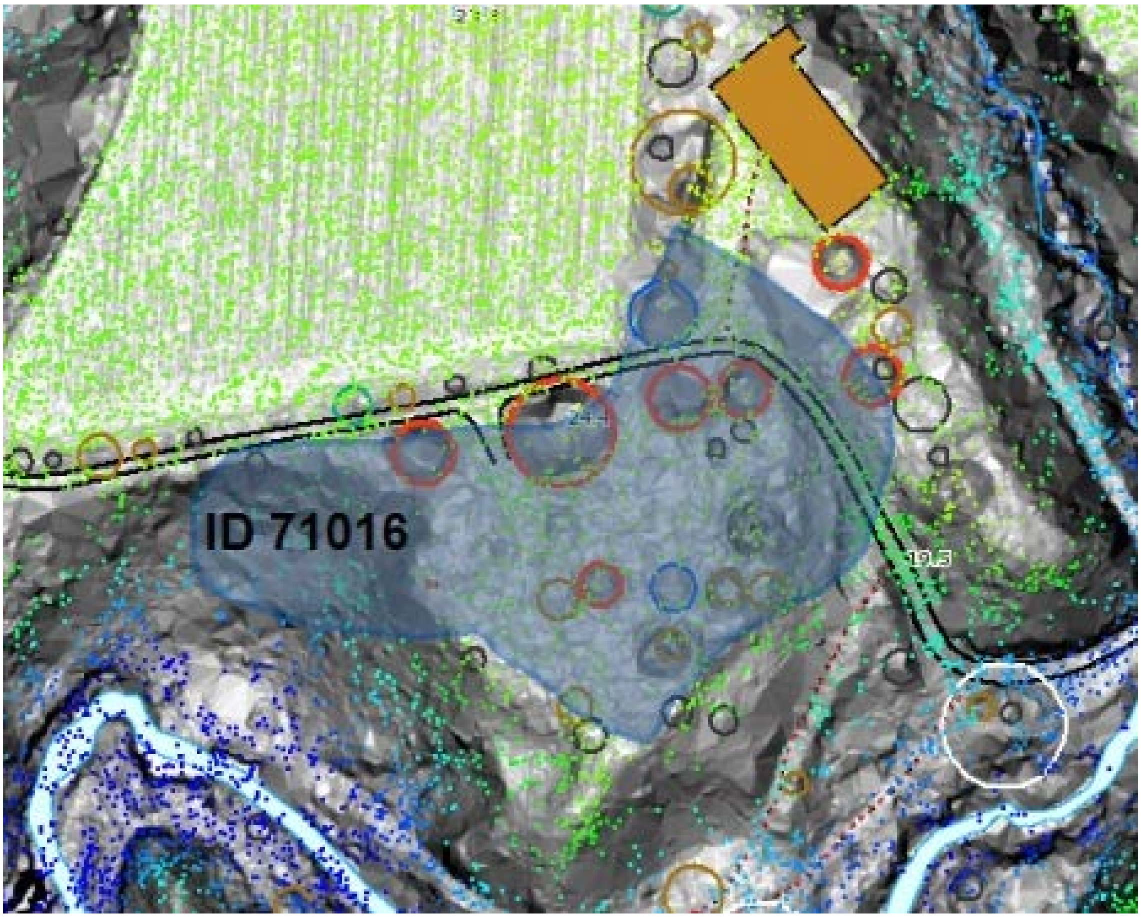

Figure 19. Detail of ALS ground point density at Ødelund.

Table 4.The number of grave mounds detected by CultSearcher at various confidence levels, and the number of grave mounds that CultSearcher did not detect.

	Confidence of detection						not
Site	6	5	4	3	2	1	detected
ID 36071 Ødelund	0	7	2	0	2	0	4

The ALS ground point density at the Ødelund site is low due to the dense deciduous tree vegetation and seasonal herbaceous vegetation in early June (Figure 18-Figure 19). Nevertheless, seven of the confirmed grave mounds are detected with high confidence, and a total of 11 confirmed grave mounds were detected by the automatic method (Table 4, Figure 20). Four grave mounds (nos. 800, 805, 807 and 814; Figure 20) are not detected by CultSearcher. It could also be questioned if mound no. 818 was detected by CultSearcher, since only a fraction of the mound was detected, and this part of the mound is actually a small heap between a looting trench and natural ground. For mound no. 815, the diameter is slightly underestimated. The four grave mounds that were not detected by the automatic method were found to be well-defined by the field survey. For mounds nos. 805 and 807, the ALS ground point density is very low, and as a result, the DEM is very coarse. For mounds nos. 800 and 814, the ALS ground point density is about the same as for the grave mounds that were detected by the automatic method. For mound 814, the south-eastern part has very low point density, which is due to a tall birch tree (Figure 22). The mound also has a big looting hole in the centre. For mound 800, the shape also deviates substantially from a perfect dome.

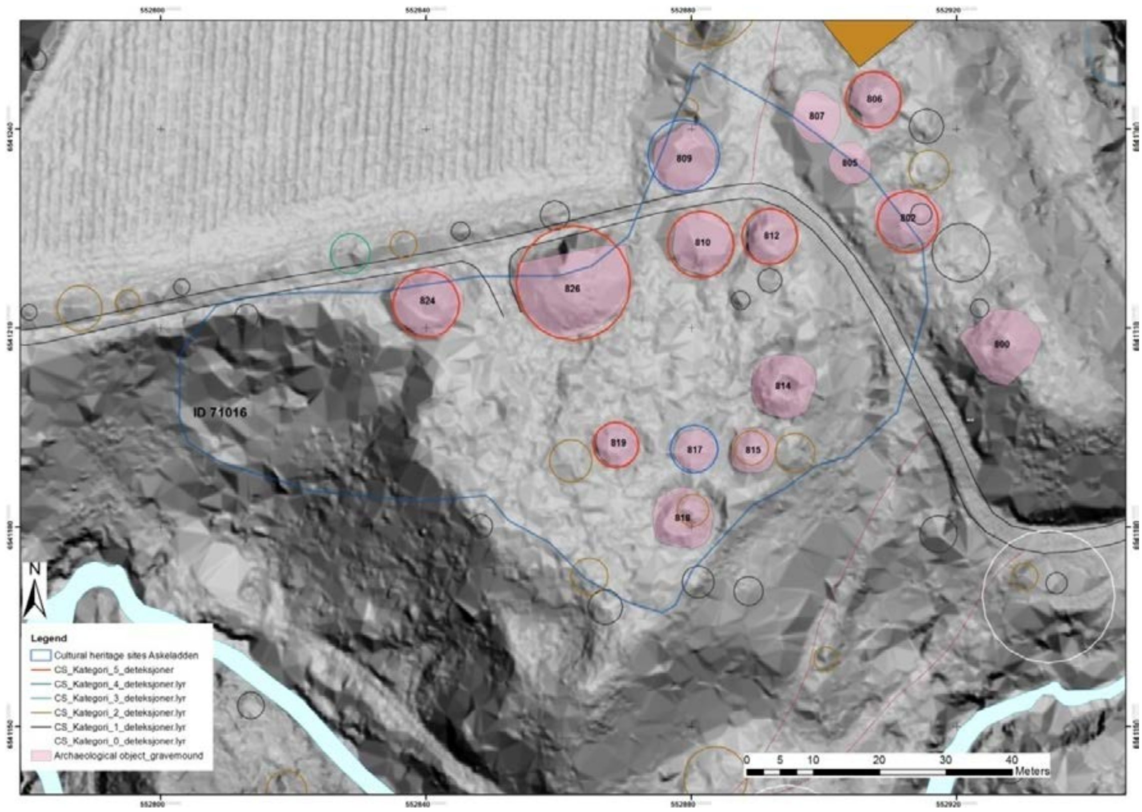

Figure 20. The Ødelund grave field. Blue line: outline of grave field from 1979 survey. Pink shaded polygons: confirmed grave mounds from June 2012 survey. Black parallel lines: outline of tractor path. Coloured circles: automatic heap detections, with red=high confidence, blue=medium high, brown=low, black=very low and white=zero confidence.

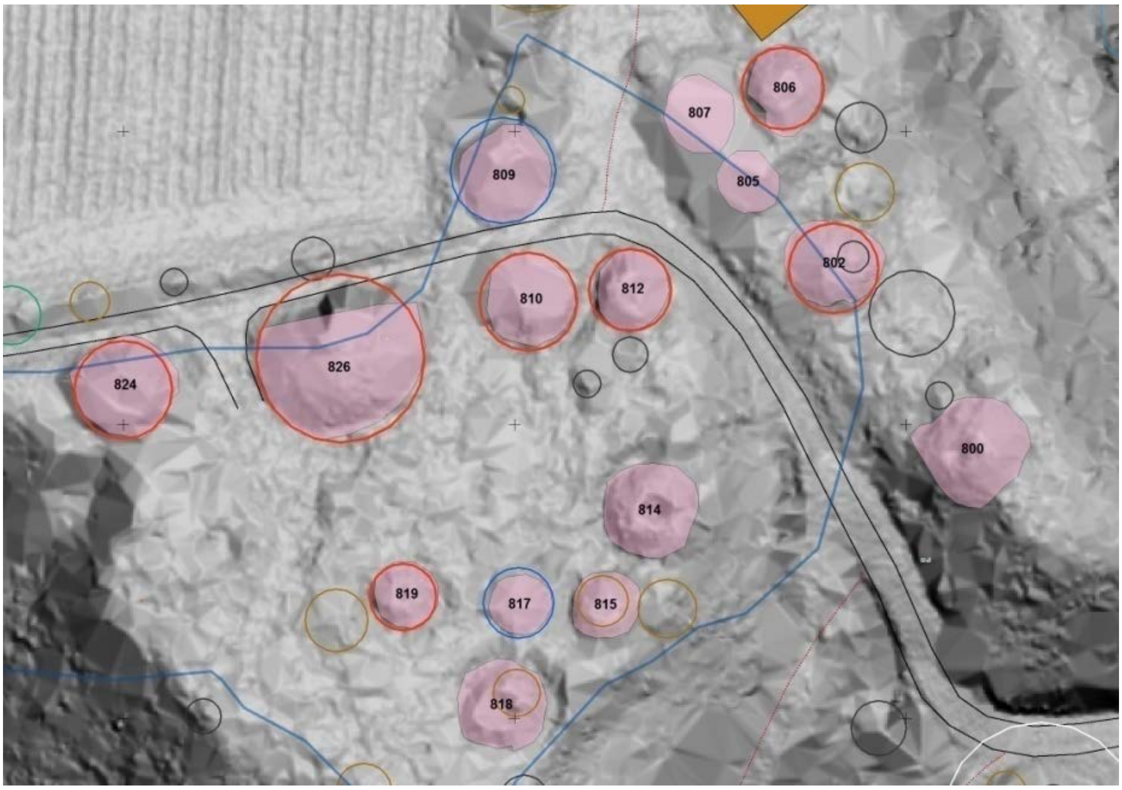

Figure 21. Detail of the Ødelund grave field

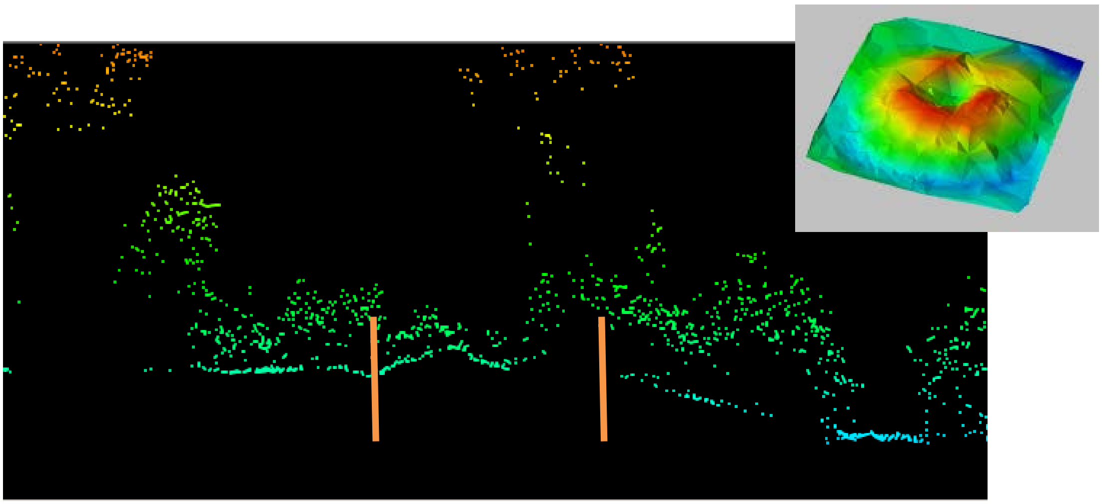

Figure 22. Profile of ALS points for mound 814. The orange lines indicate the northwest and southeast edges of the mound. Inset at top right: terrain model of the mound.

3.4.4 Cultural heritage monument ID22925 Omsland Nordre, Larvik Municipality

The Omsland nordre grave field site is located outside of the area with high point density ALS data. It was selected to assess the impact of low point density (1 emitted pulse per m^2 on average) on the detection performance of the automatic heap detection method. The vegetation on this site is dominated by spruce and fir (Figure 23), with low vegetation only appearing on the edges of the forest. With an ALS pulse density of $1/m^2$, it is difficult to do a visual assessment of the DEM as to which heaps may be grave mounds and which may not (Figure 24).

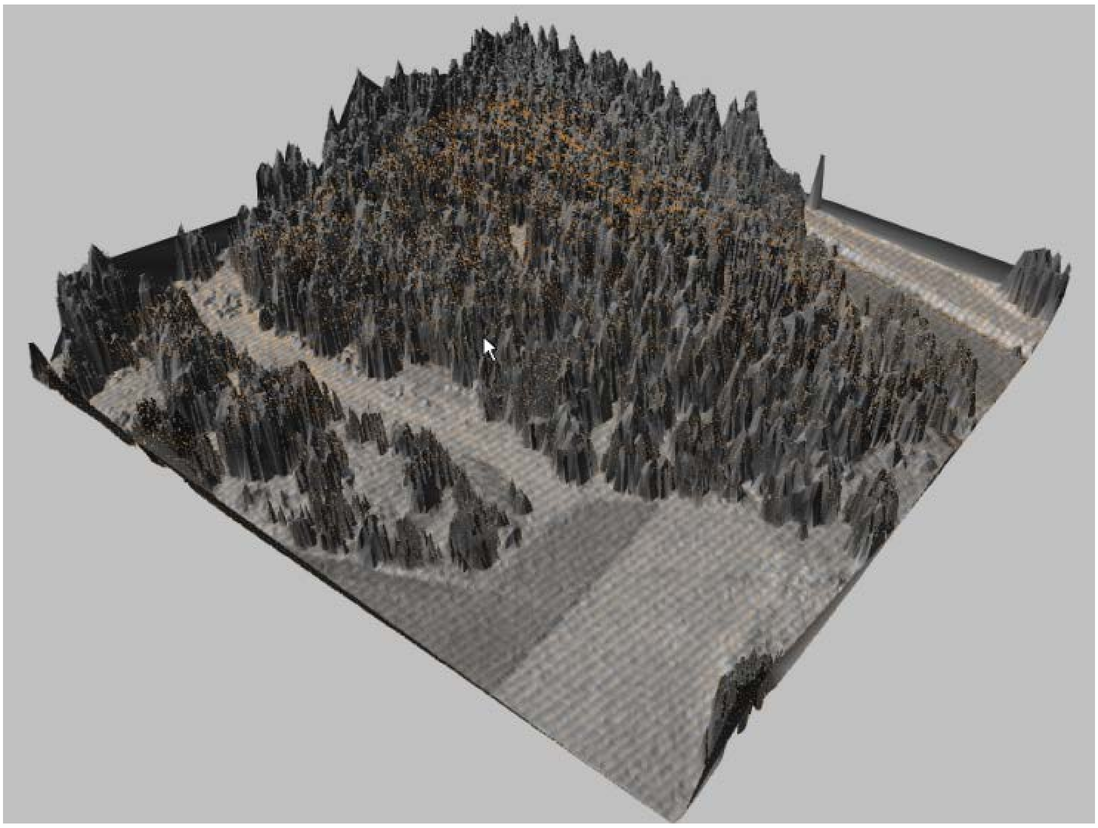

Figure 23. DSM including vegetation of the grave field at Omsland Nordre and surrounding landscape.

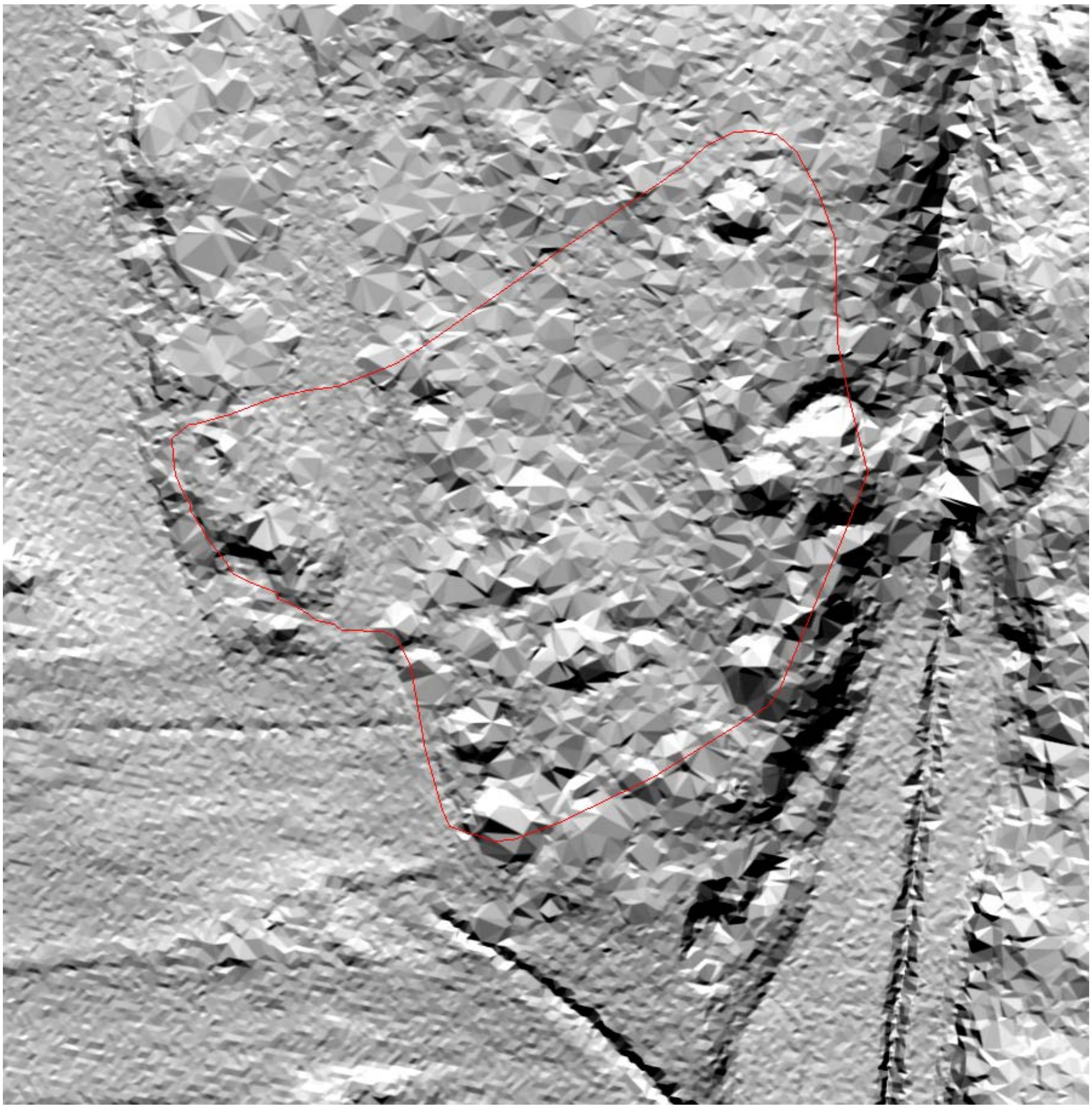

Figure 24. DEM of ALS ground points, grave field at Omsland Nordre. Red line: outline of grave field according to Askeladden, prior to June 2012 survey.

In 1978 when the site was first surveyed, it was reported to be at least 20 mounds here, three of them were long barrows and the rest round barrows. The site is surrounded by cereal fields.

The coniferous trees, especially the spruce trees, block the ALS pulses quite effectively from hitting the ground, leaving holes in the plot of ALS ground points (Figure 25). This effect is independent of the time of the year of the ALS data acquisition. Combined with a low ALS point density, this makes it difficult to interpret the terrain based only on visual inspection of the DTM. However, the result of automatic heap detection is somewhat surprising: Six heap detections with high confidence and five with medium high confidence appear inside the 1978 grave field boundary. With these strong indications of possible positive grave mound detections by CultSearcher, despite the low ALS point density, we decided to include the site for field survey, which was conducted on 11 June 2012.

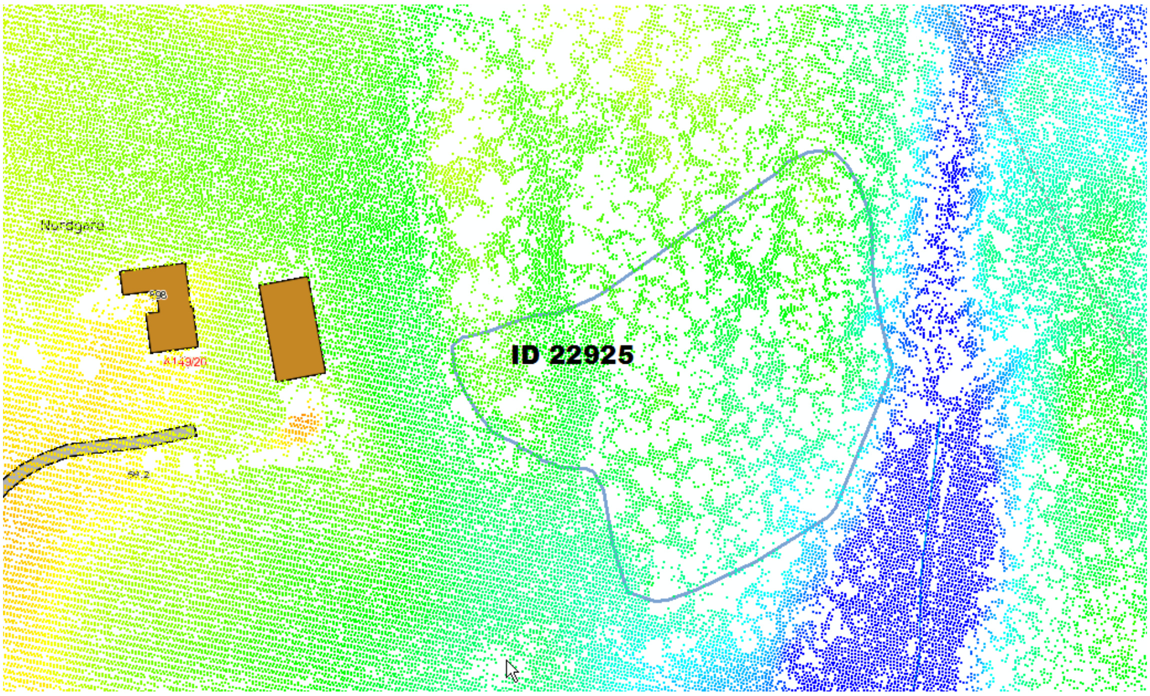

Figure 25. ALS point density at the Omsland Nordre grave field. Coloured dots: ALS ground points, the colour indicates terrain elevation. Blue outline: The outline of the grave field according to the 1978 survey.

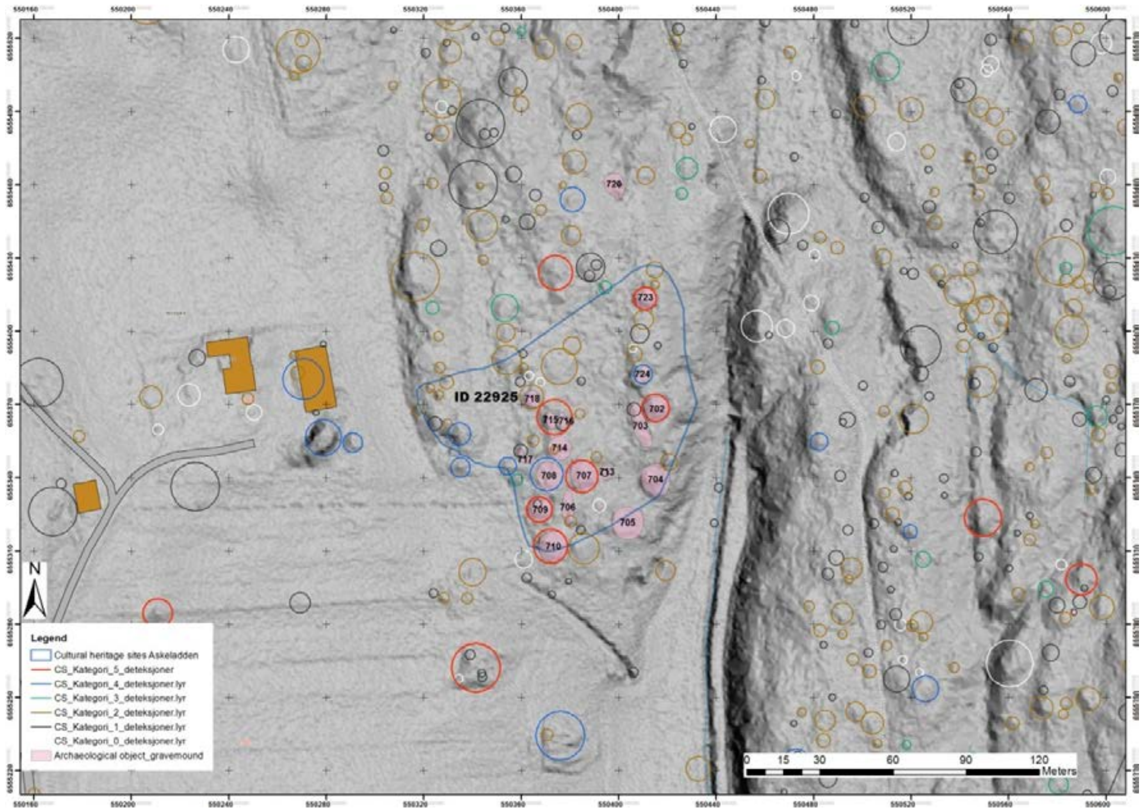

Figure 26. The Omsland Nordre grave field. Blue outline: extent of grave field according to 1978 survey. Pink shaded polygons: grave mounds confirmed by June 2012 survey. Coloured circles: automatic heap detections by CultSearcher.

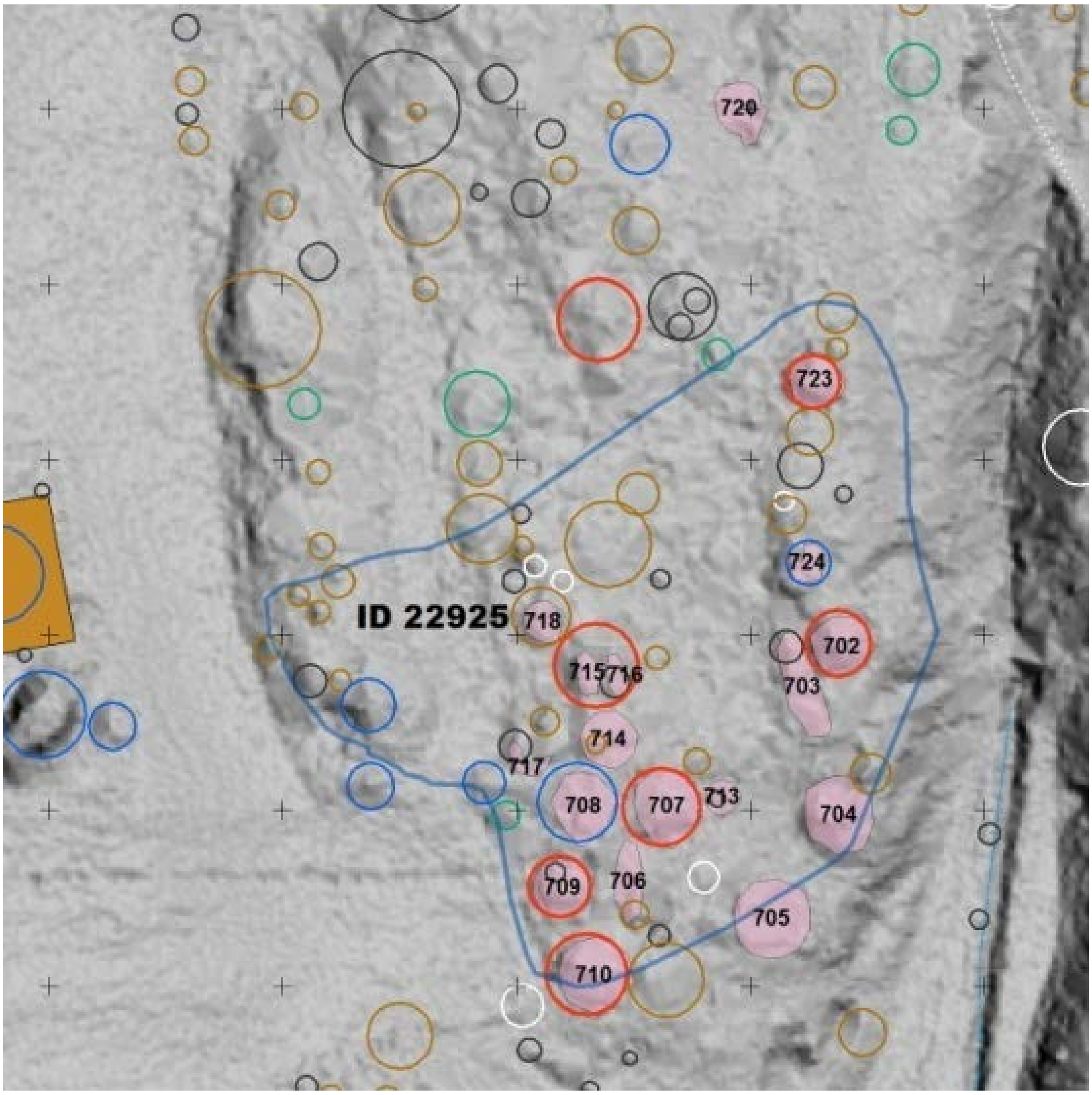

Figure 27. Detail of the Omsland Nordre grave field.

Table 5. The number of true grave mounds detected by CultSearcher at different confidence levels, and the number of grave mounds missed by CultSearcher.

	Confidence of detection						not
Site	6	5	4	3	2	1	detected
ID 22925 Omsland Nordre	0	5	2	0	1	1	8

Inside the boundary of the site, five of the six high confidence detections were confirmed as round barrows by the ground surveying. The sixth high confidence detection consisted of two long barrows (nos. 715 and 716 in Figure 27). Two of the four medium high confidence detections are confirmed to be grave mound (nos. 708 and 724 in Figure 27), and one of the 23 low confidence detections was confirmed. A total of nine grave mounds were detected by CultSearcher in the dataset (Table 5).

17 grave mounds were detected during ground surveying (Table 5). Also, one clamp from charcoal production (720) north of the site was discovered. Four of the grave mounds from the

ground survey were long barrows (nos. 703, 706, 715 and 716). One round barrow (no. 717) was badly disturbed, only remnants of the southern part of the mound were still visible. A part of this mound was detected as a heap with very low confidence. Four of the round barrows (nos. 704, 705, 713 and 714) were not detected by CultSearcher. A small heap detection with very low confidence picked up a part of mound no. 713.

The grave mounds that CultSearcher did not detect, that is, grave mounds nos. 704, 705, 713 and 714, were heavily overgrown with large to medium sized spruce trees. Several of the grave mounds in the western part of the site are damaged by unknown activity, and over the whole site there were tipped-over tree trunks. Of the original reported "at least" 20 mounds, 17 were found during the ground survey.

Figure 28. Grave mound no. 704, covered by dense spruce vegetation and not detected by the automatic heap detection method.

3.4.5 Cultural heritage monuments ID160282, 162123 and 162124 Omsland Søndre, Larvik Municipality

The three sites at Omsland Søndre were not previously known before the field survey was done here on 11-12 June 2012. While surveying the grave field at Omsland Nordre (site ID 22925) a concentration of high confidence heap detections was noticed in the map project's westernmost part, approximately 600 meters to the west. Out of curiosity, these automatic heap detections were visited, and the heaps turned out to be a previously undiscovered grave field.

The vegetation and terrain type was similar to that of Omsland Nordre (ID 22925). The grave field is located on a north-south bound ridge, heavily vegetated with spruce and fir (Figure 29, Figure 30), but slightly less dense than on the Omsland Nordre site (ID 22925). As with Omsland Nordre, the DEM of ALS ground points at Omsland Søndre is so coarse that it is difficult to make a visual assessment of the DEM to decide which heaps may be grave mounds (Figure 31).

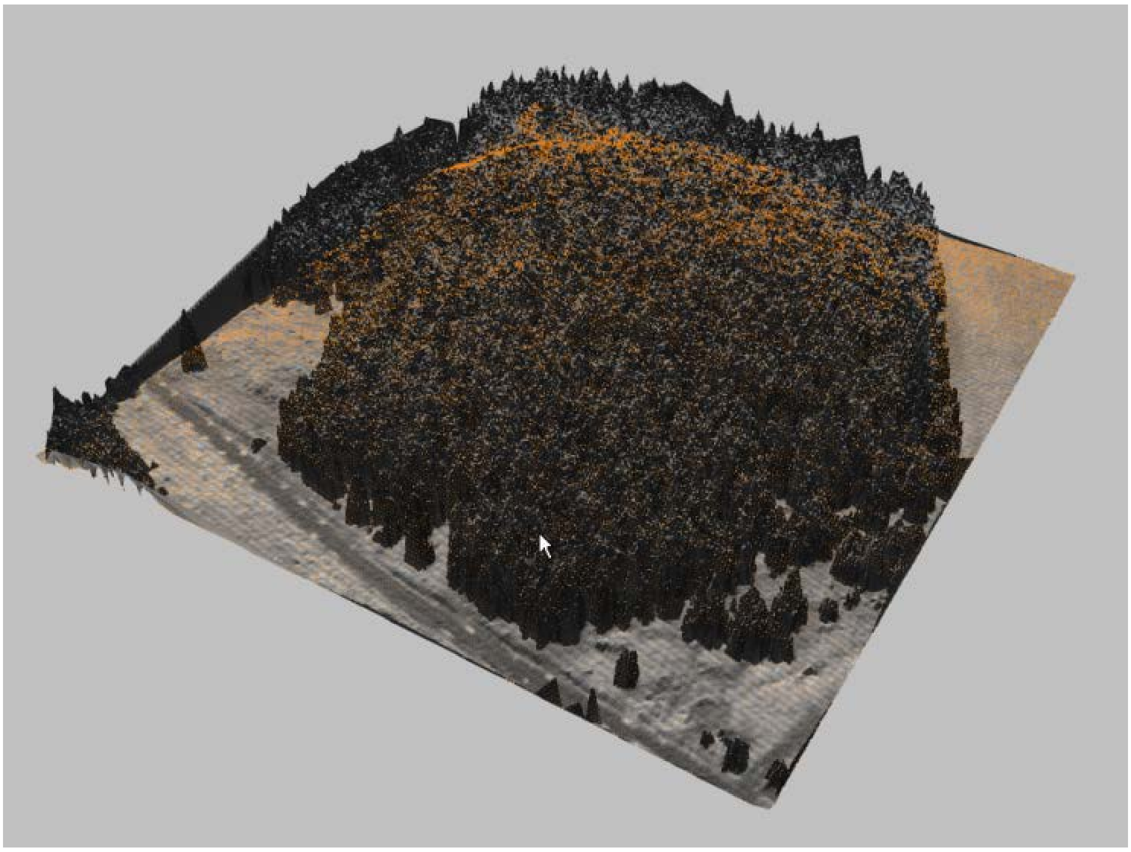

Figure 29. DSM, including vegetation, of the grave field at Omsland Søndre and surrounding landscape.

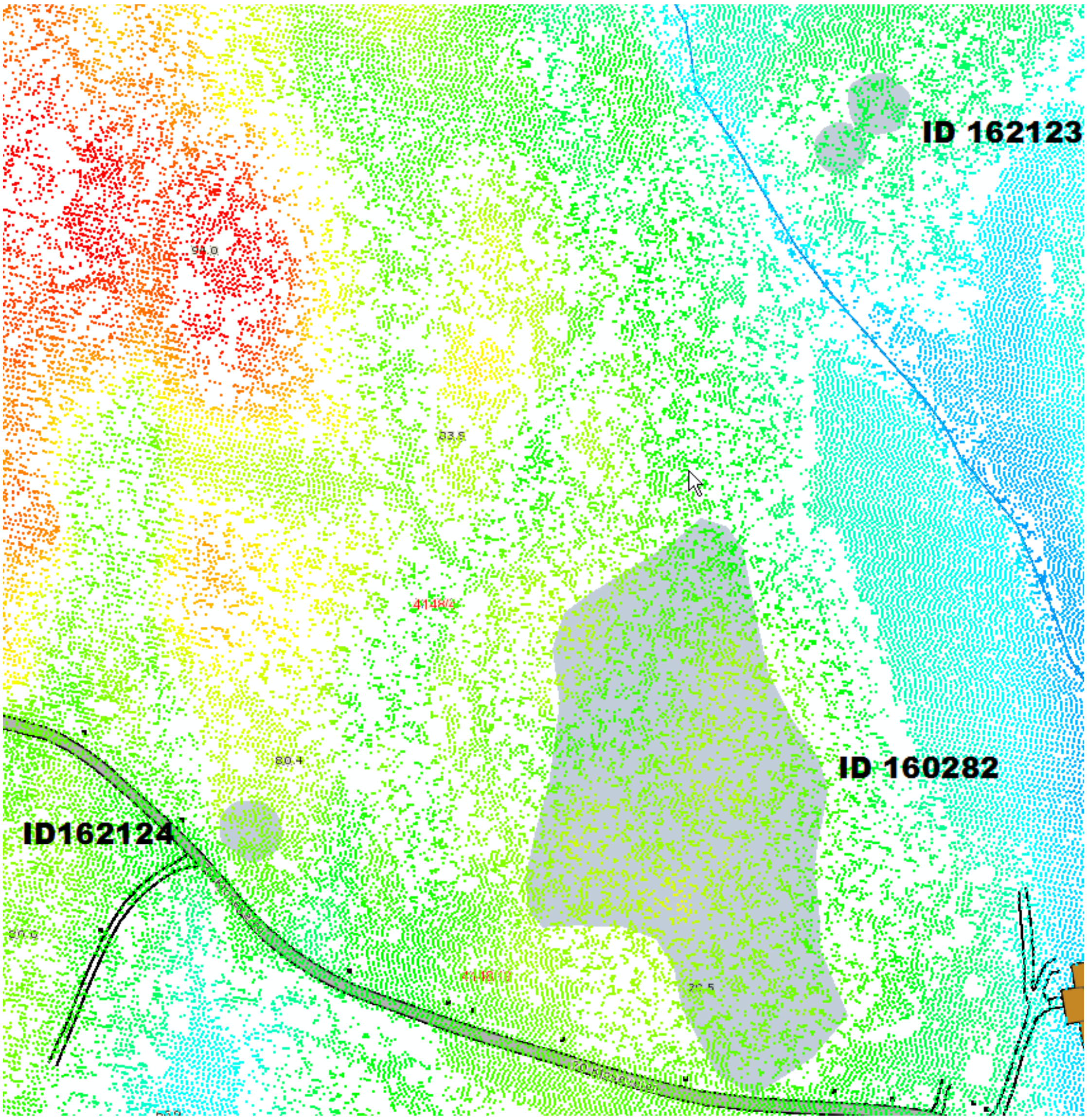

Figure 30. ALS ground points at the Omsland Søndre sites. Coloured dots: ALS ground points, with the colour indicating terrain elevation. Grey shade: the three new sites.

Figure 31. DEM of ALS ground points, grave field at Omsland Søndre.

Table 6. Grave mounds detected by CultSearcher at the previously unknown grave field at Omsland Søndre.

	Confidence of detection						not
Site	6	5	4	3	2	1	detected
ID 160282 Omsland Søndre	0	9	3	0	1	1	2
ID 162123 Omsland Søndre	0	1	1	0	0	0	0
ID 162424 Omsland Søndre	0	0	0	0	0	0	1

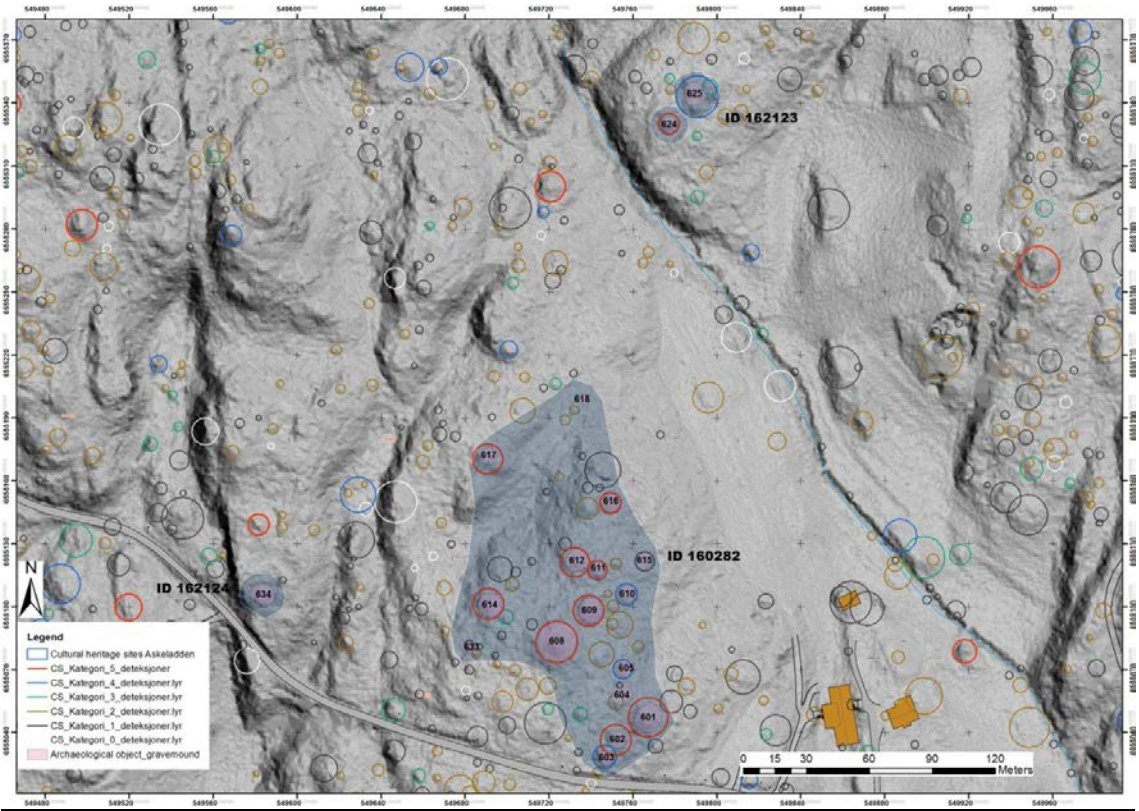

Figure 32. The three new sites at Omsland Søndre. Blue shade: area covered by the three grave monument sites. Pink shaded polygons: grave mounds confirmed by field survey. Coloured circles: automatic heap detections from CultSearcher.

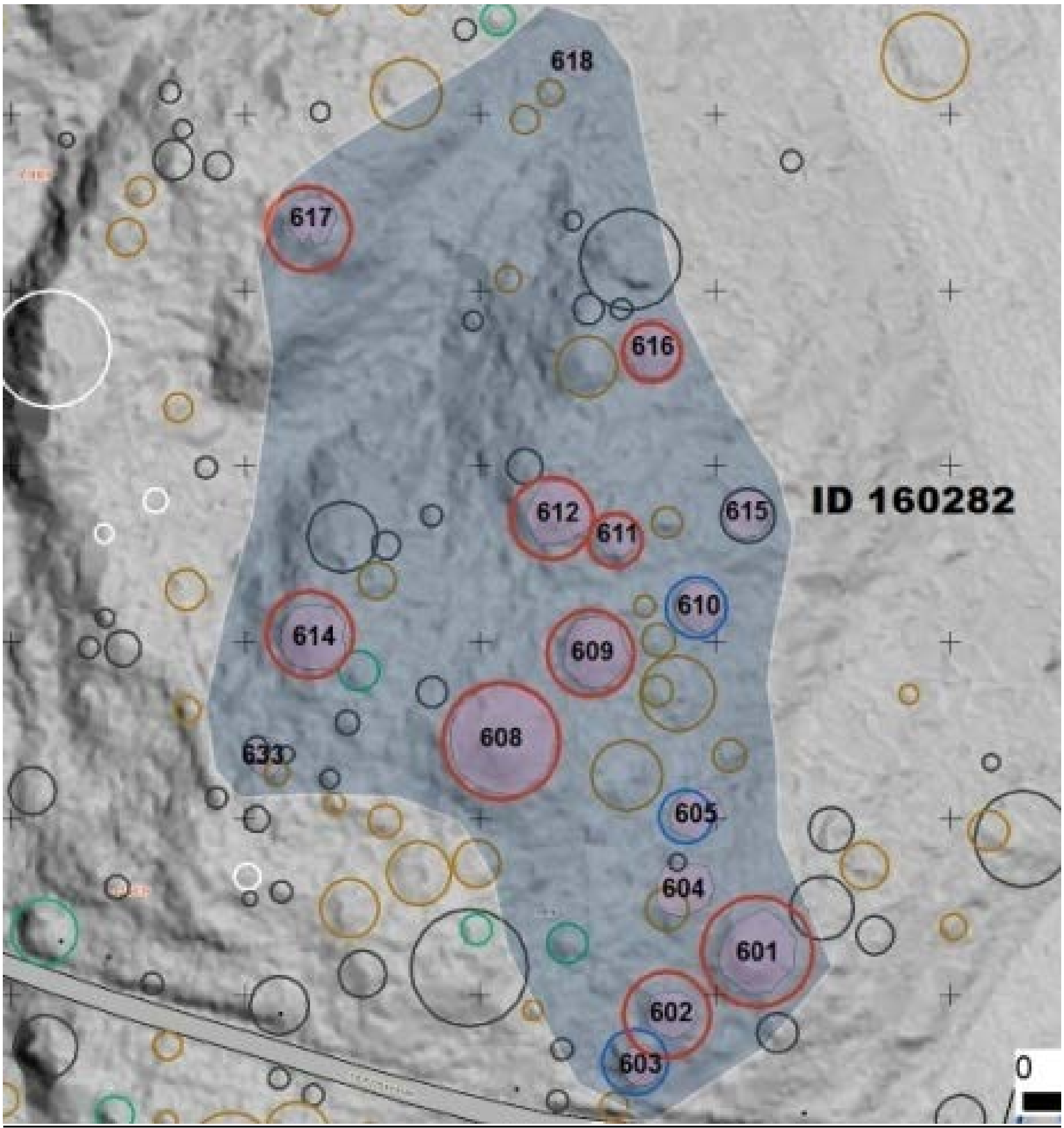

Figure 33. Detail of the largest site at Omsland Søndre.

For the largest site at Omsland Søndre (ID 160282) all but two grave mounds were detected by CultSearcher. The missing are mounds nos. 633 and 604 (Figure 33). Mound no. 604 is quite vague on the surface but nevertheless a grave mound, and also heavily overgrown with spruce trees. It is somewhat unclear why mound no. 633 was not detected. This mound is not covered by coniferous forest, but a large boulder is lying on the southern part of the mound.

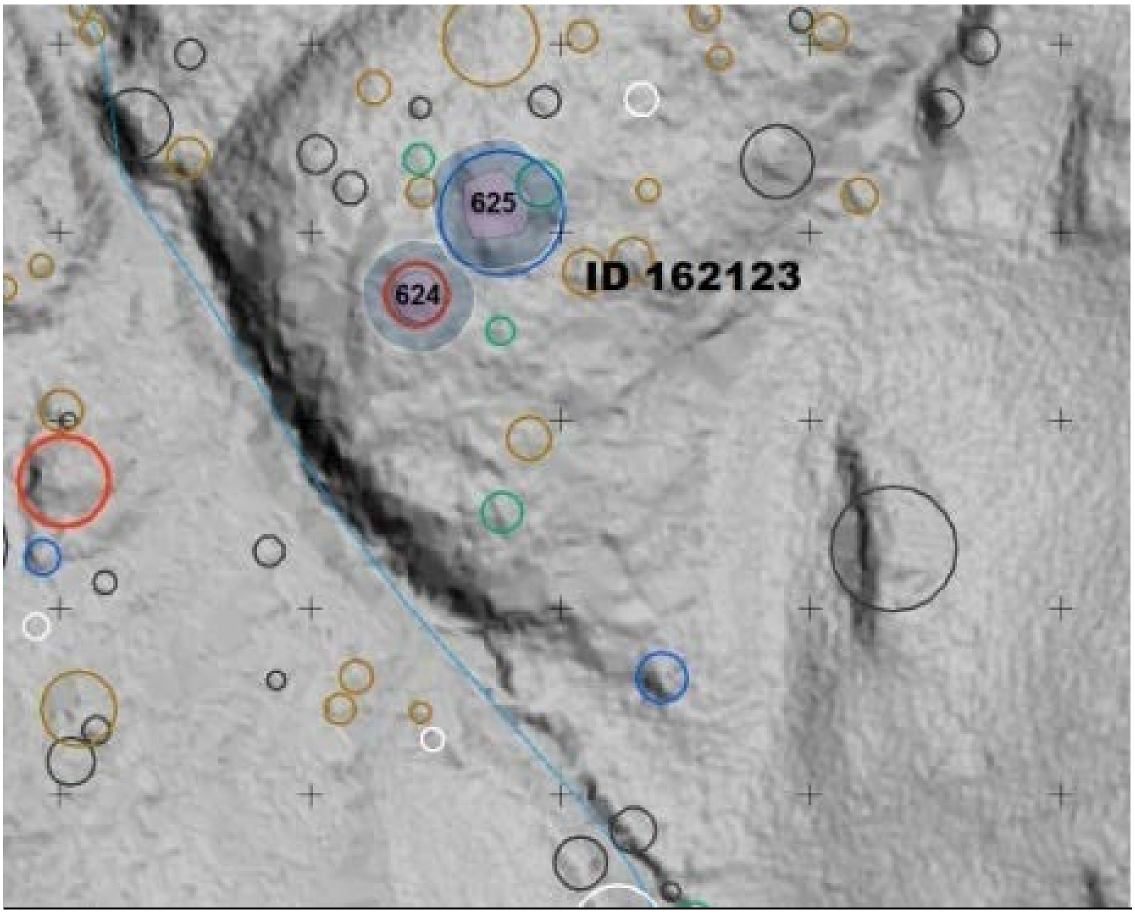

Figure 34. Detail of the small site north of the large site at Omsland søndre.

For the larger of the two small sites (ID 162123), which is north of the large site, both grave mounds were detected by CultSearcher (Figure 34). However, for one of the mounds, the size was overestimated.

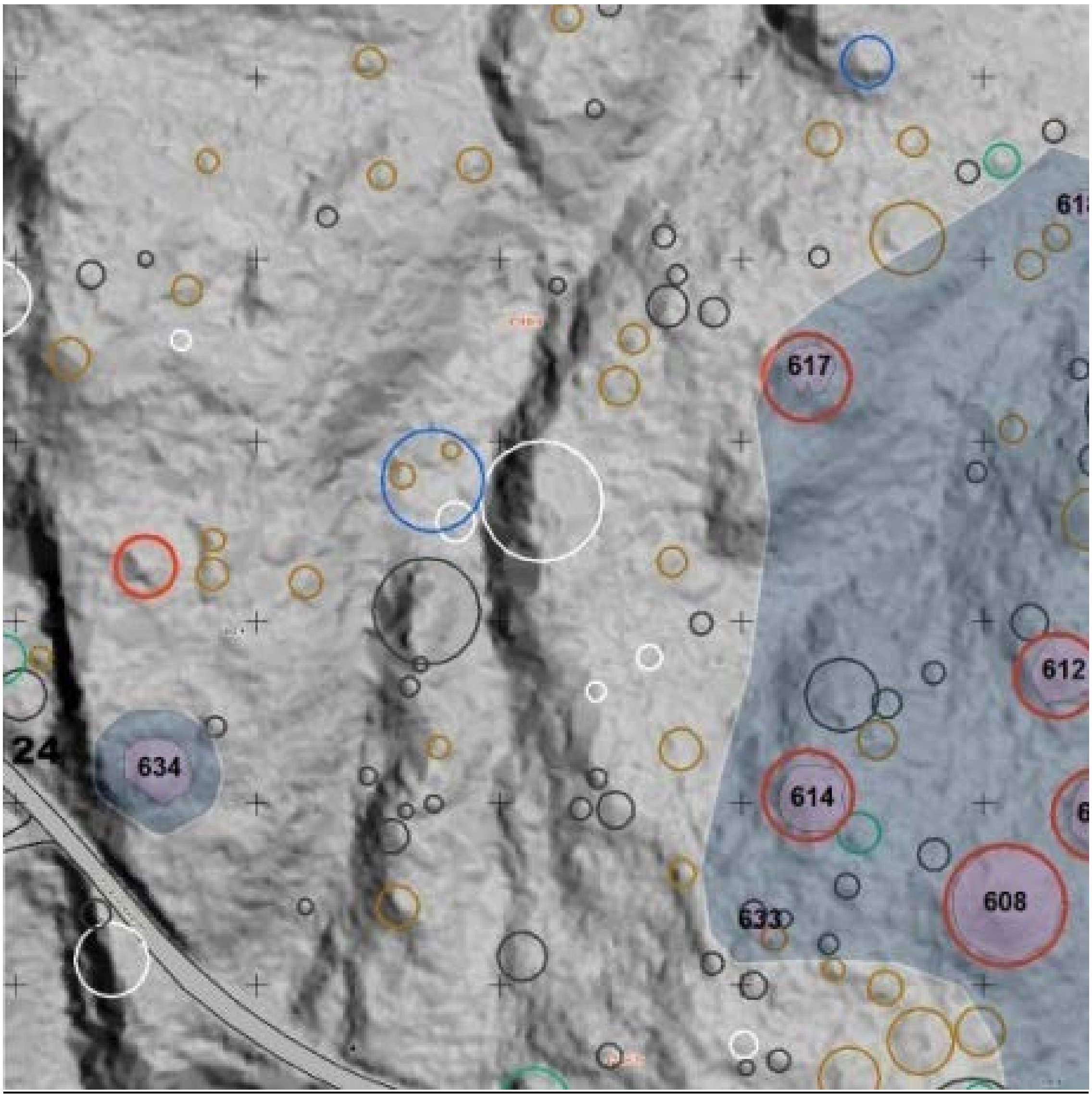

Figure 35. Detail of the smallest site and parts of the large site at Omsland Søndre.

For the smallest site at Omsland Søndre (ID 162124), which is located west of the large site, the single grave mound (no. 634) was not detected by CultSearcher (Figure 35). A possible reason could be that the quality of the DEM of ALS ground points is reduced due to 0.5-1 m grass and low vegetation on top, and a large birch at the southern end of the mound.

3.5 Discussion

The use of CultSearcher’s automatic heap detection to locate grave mounds in forested areas has a great potential. As demonstrated with the four sites at Omsland, Larvik County, there is also a big potential for the use of CultSearcher in low resolution data. In the high resolution dataset, most grave mounds are clearly discernible in the hills hade/slope raster. However, this is not the case in the low resolution data.

Still, there are many false detections to cope with when using CultSearcher. However, when used in connection with physical ground surveying, time is saved when measuring previously registered (but wrongly geographically located) grave mounds. Also, CultSearcher clearly has the potential to help archaeologists discover new grave mound sites.

It is desirable that the automatic heap detection method in CultSearcher be improved to deliver more reliable detection results. In order to achieve this, it is important that more field survey be conducted to verify detection results.

The need for further refinement of Cultsearcher is demonstrated by the large number of automatic heap detections within the two ALS datasets in Larvik municipality (Figure 36). Obviously, one could suppress the display of low confidence detections, but there are still many medium to very high confidence detections that turn out to be something else than grave mounds. In addition, a few grave mounds are not detected. In order to improve the pattern recognition methods in CultSearcher’s automatic heap detection method, more training examples of true grave mounds are needed. These may be obtained by field survey.

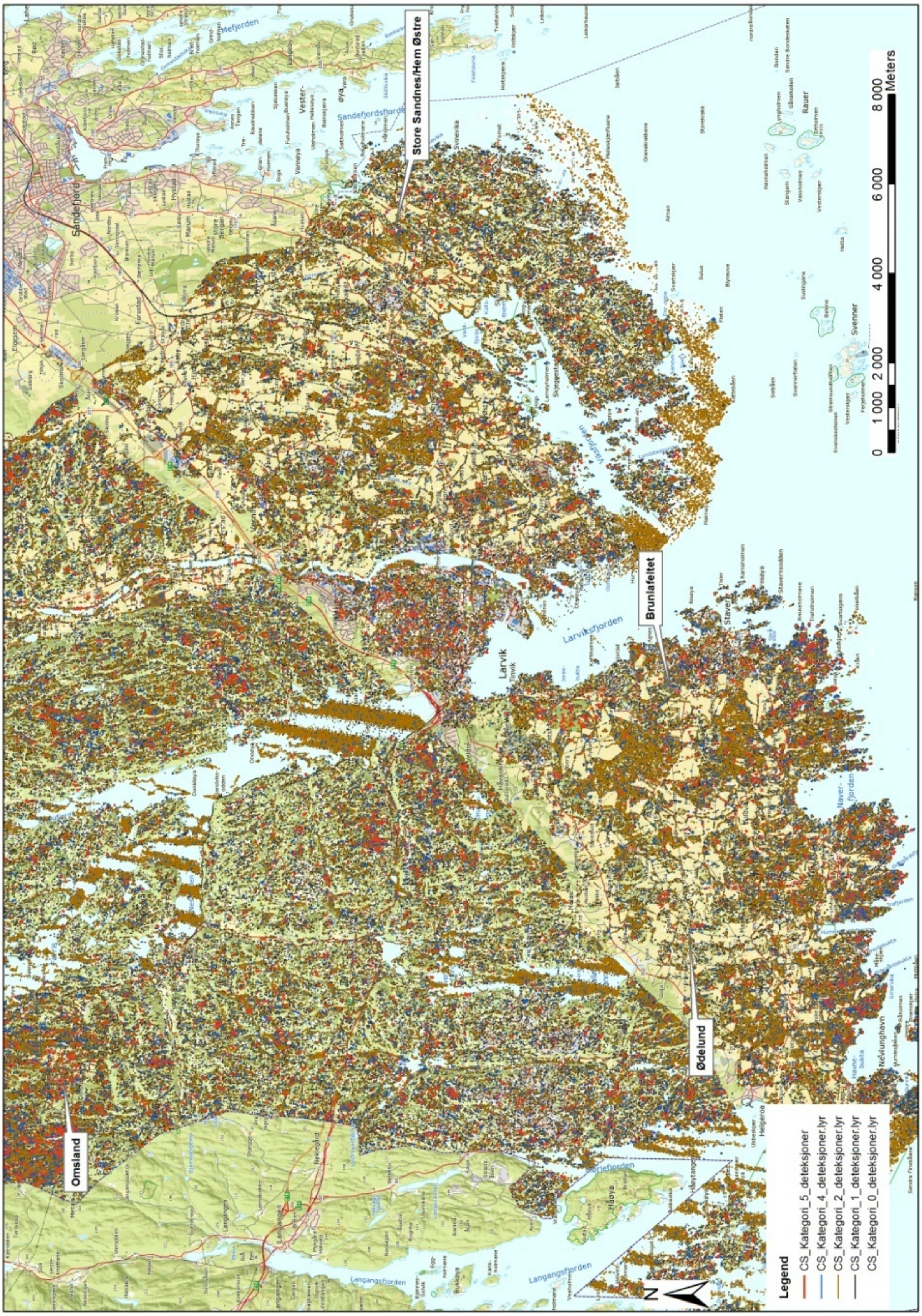

Figure 36. Automatic heap detections in Larvik municipality from the high resolution area (south), and the low resolution area (north).

4 Field work at two selected sites in Larvik municipality

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

4.1 Introduction

The Museum of Cultural Heritage has participated in this year's survey effort by verifying a small subset of automatic heap detections done by Cultsearcher on an airborne laser scanning (ALS) dataset in Larvik municipality, Vestfold. Two areas were selected: Lundre søndre and Bergan nedre, both approximately 8 km north of the town of Larvik (Figure 37). The two areas have different topography. The area at Lunde søndre that was surveyed consists of two flat areas on the river bench of the river Lågen, separated by a steep hill. The area is for the most part covered by cultivated spruce forest. The part closest to Lågen contains a previously known grave field. The surveyed area at Bergan nedre is in a hilly area with open vegetation and bare bedrock.

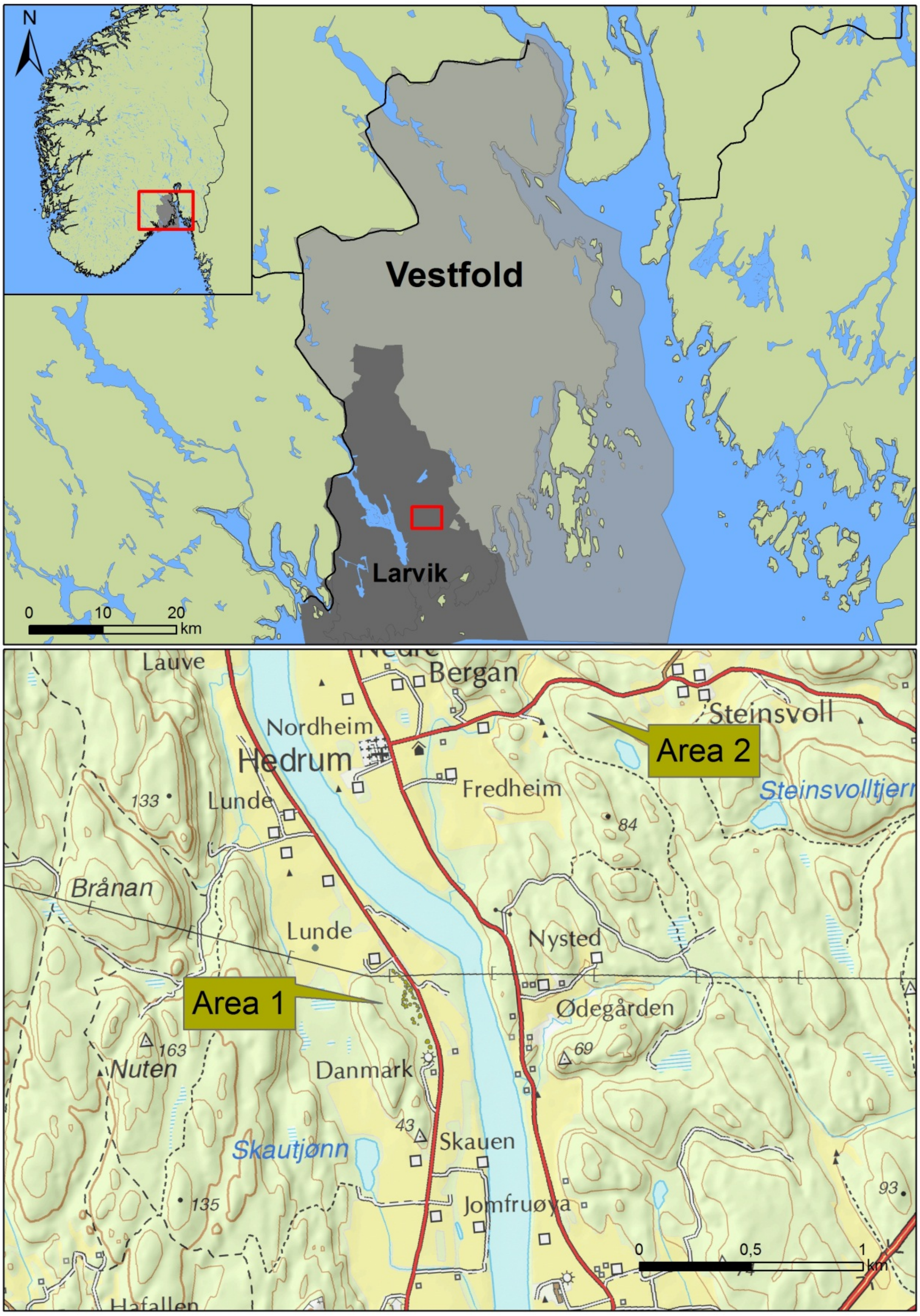

Figure 37. The two areas, area 1 at Lunde søndre (=southern) and area 2 at Nedre Bergan, are located close to Hedrum Church, about 8 km north of Larvik town.

4.2 Data

The area was scanned 24 May 2010 with a laser pulse density of $1/m^2$ on average (Figure 38). The height accuracy is on average 5.6 cm. The scanning was done by Blom Geomatics and the dataset was delivered as LAS-files of (x, y, z) point measurements, each labelled as either ground, vegetation, or building.

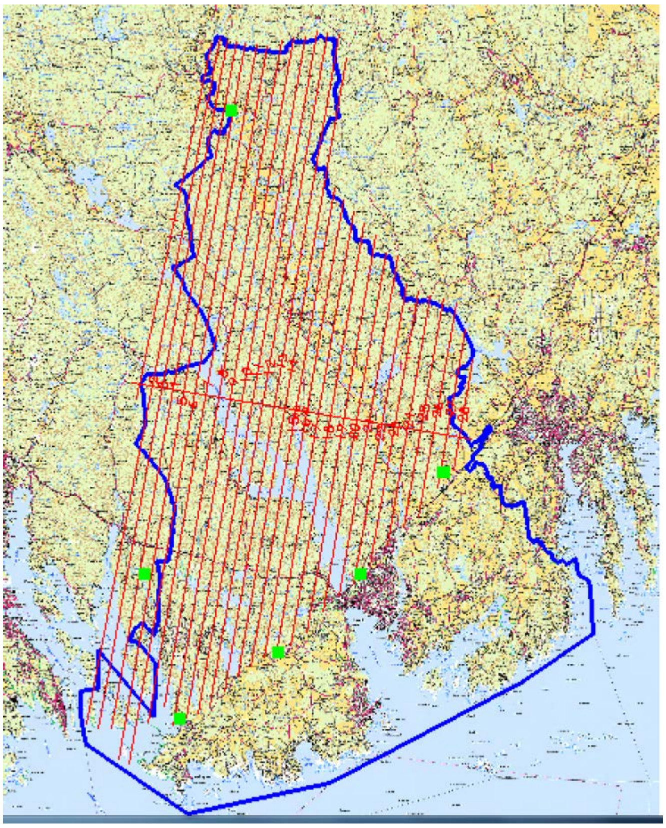

Figure 38. Red hatching: the area scanned with 1 emitted pulse per m^2. Blue polygon: Larvik municipality border (except some minor islands). The area within the blue polygon but outside the red hatching was scanned at higher point density

4.3 Method

The LAS-dataset was used to produce digital elevation models (DEM) for automatic heap detection, and raster hill shades for visual interpretation (Figure 39). The Norwegian Computing Center ran *CultSearcher* on the DEM to produce heap detections, labelled with confidence levels 0 (zero confidence), 1 (very low), 2 (low), 3 (medium), 4 (medium high), 5 (high), and 6 (very high). The heap detections were delivered as ESRI shape files.

In cooperation with Christer Tonning, Vestfold fylkeskommune (VFK), two areas were chosen for survey and verification of automatic heap detections. No detections had confidence 6 (very high). Detections with confidence levels 4 (medium high) to 5 (high) were prioritized for verification, but some detections with medium confidence (3) were also verified. These automatic detections were controlled by Christer Tonning (VFK), Espen Uleberg (KHM) and Steinar Kristensen (KHM). Hill-shade raster, orthophoto and the automatic detections were used as overlays during the fieldwork. Grave mounds and clamps for charcoal production were measured with a GPS (Trimble R6) with C-POS accuracy. Due to dense forest, the accuracy was not that good and it was difficult to get good measurements. Most of the measured points have an accuracy between 50-100 cm. Points with deviation larger than 100 cm were remeasured. Negative detections were measured with just one point for control. The positive detections were described in short text, but unfortunately, due to a technical error, only the descriptions from the first few verified detections have been kept.

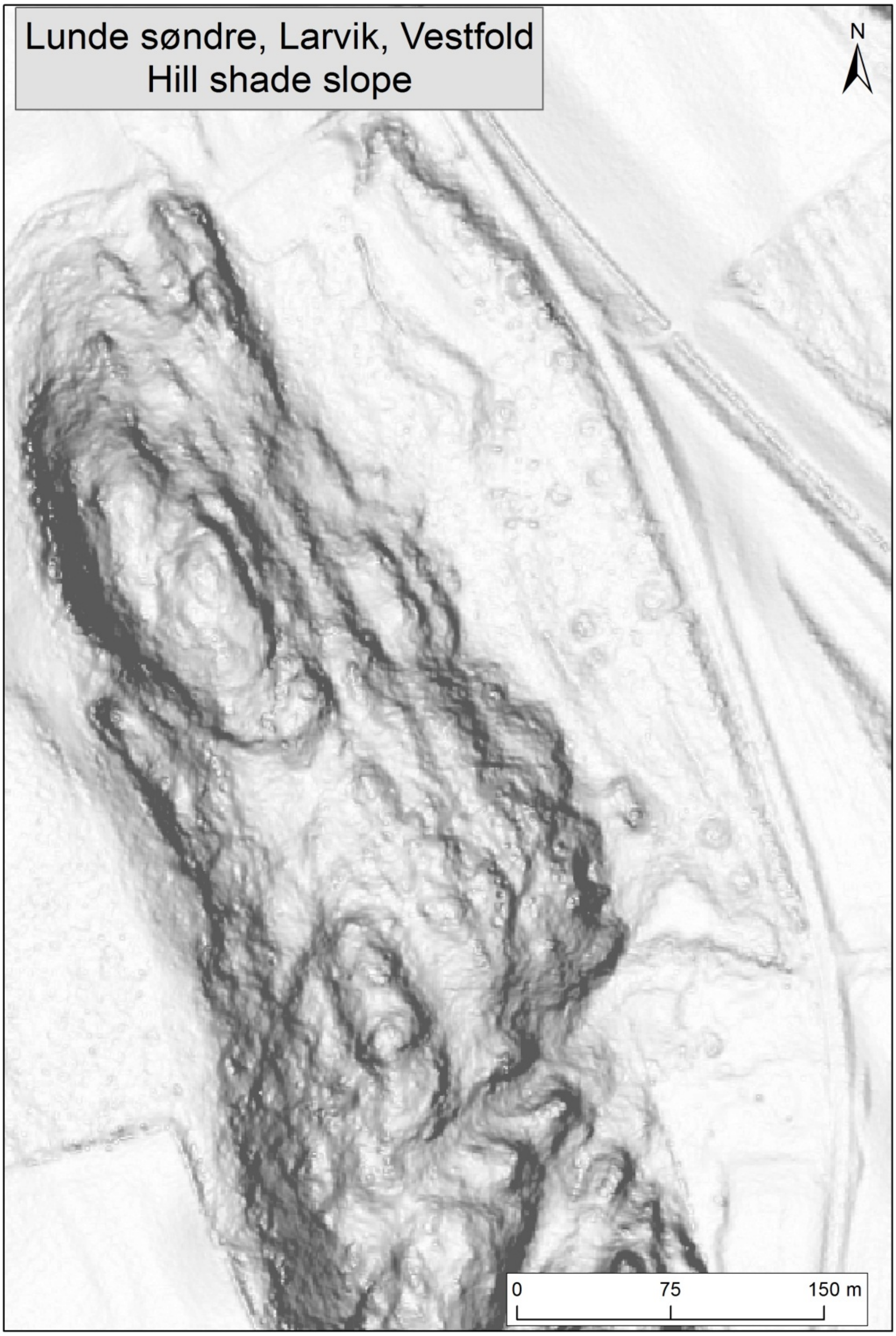

Figure 39. Hill shade slope visualization of the lidar data at Lunde søndre (Askeladden ID 135038), Larvik municipality, Vestfold County.

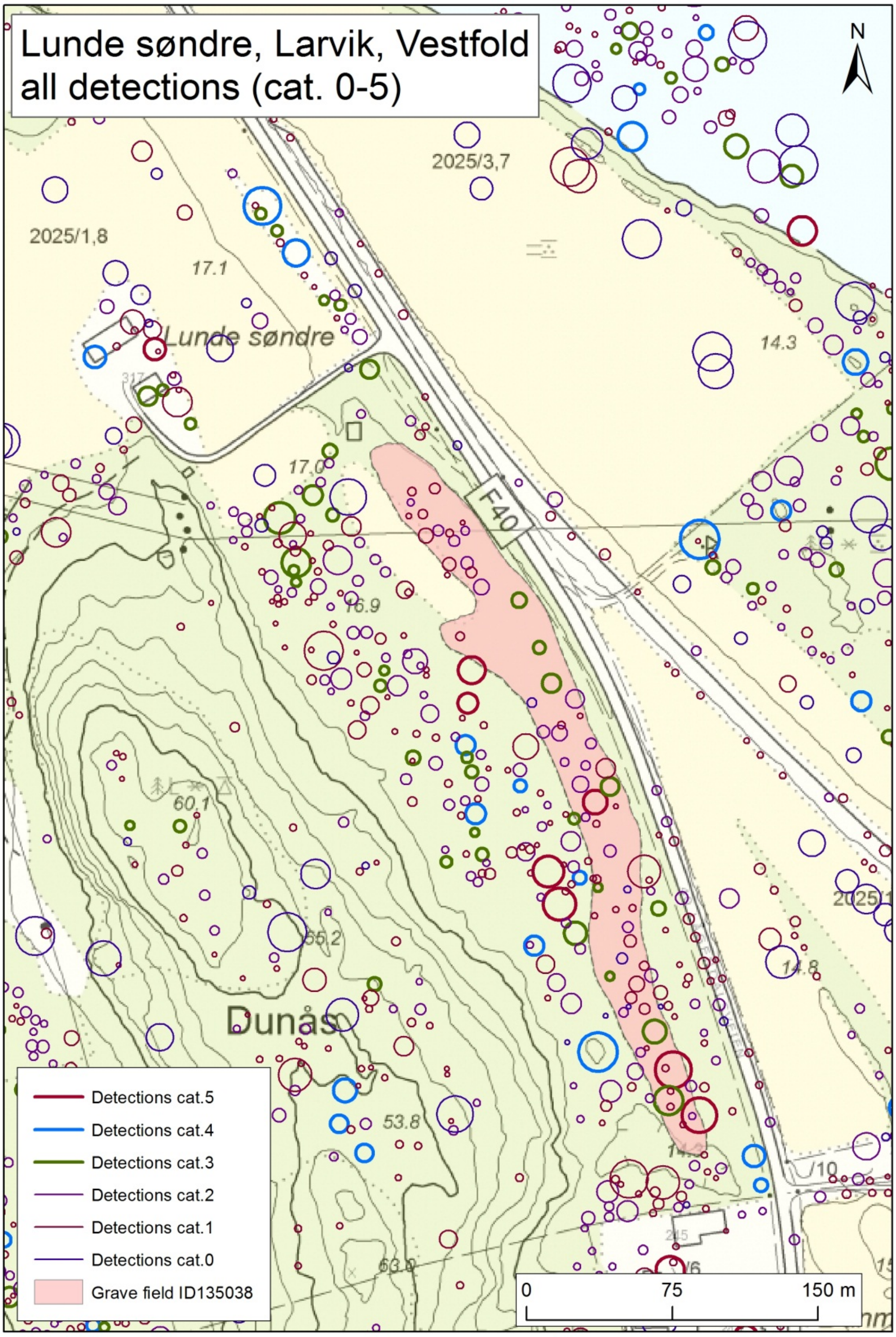

Figure 40. The Lunde søndre area with all heap detections (confidence levels 0-5).

4.4 Results, area 1

The farm Lunde Søndre is situated on the western banks of the river Lågen. In west, a north-south orientated hill, Dunås (approx. 60 m high), divides the survey area in two parts; a plain with a known grave field (5,5 hectares) and an cultivated forest with extreme dense vegetation and many automatic detections (about 12 hectares).

4.4.1 Grave field

Approx. 150 m south of the farm lays a known grave field (Askeladden ID 135038) with a large number of grave mounds. The grave field is approx. 400 m long and 35 m wide, and the mounds themselves have never been measured. The area has some low vegetation (dense in the north) and the trees are quite large spruce and some different types of hardwood. The field is situated between the county road in east and the hill Dunås in the west. The terrain is rather flat and has dry sandy soil in the east, but wet boggy areas in the west at the bottom of the hill.

Within the boundary of the grave field according to Askeladden, there were three detections in cat. 5, none in cat 4 and nine in cat 3. However, as there were many automatic detections to the west of the grave field polygon in Askeladden, the survey area was extended to include the flat area east of the foothill of Dunås. The many heap detections on the hill Dunås were not included in the survey area, as these were presumed to be natural terrain features. Within the survey area, CultSearcher made 15 heap detections which were verified to be grave mounds (Table 7).

Table 7. CultSearcher detections inside the survey area.

Confidence level		Automatic detections	verified grave mounds	% positive detections
5	high	7	7	100
4	medium high	8	1	12,5
3	medium high	19	3	16
0-2	low or lower	about 250	4	1,6

Level 5, high confidence detections: the three detections within the known grave field were all verified as large grave mounds, of size between 8 and 18 meters. Outside the known grave field (but within the survey area) CultSearcher had additional four high confidence detections; all verified as grave mounds. Two were 16 meters in diameter, one was 14-meters (detections and measurement coincides), and the last was detected as 10 m in diameter but was in fact 13 m.

Level 4 , medium high confidence detections: no medium high confidence detections were made within the known grave field, but in the surrounding area to it there were eight detections. Only one of them was a grave mound, with 14 meter in diameter. The others were bedrock and detections for reason unknown.

Level 3, medium confidence detections: within the known grave field there were nine medium confidence detections, of which three were actual grave mounds, approx. 10 m in diameter. Outside the grave field there were 10 additional medium confidence detections, all being nature.

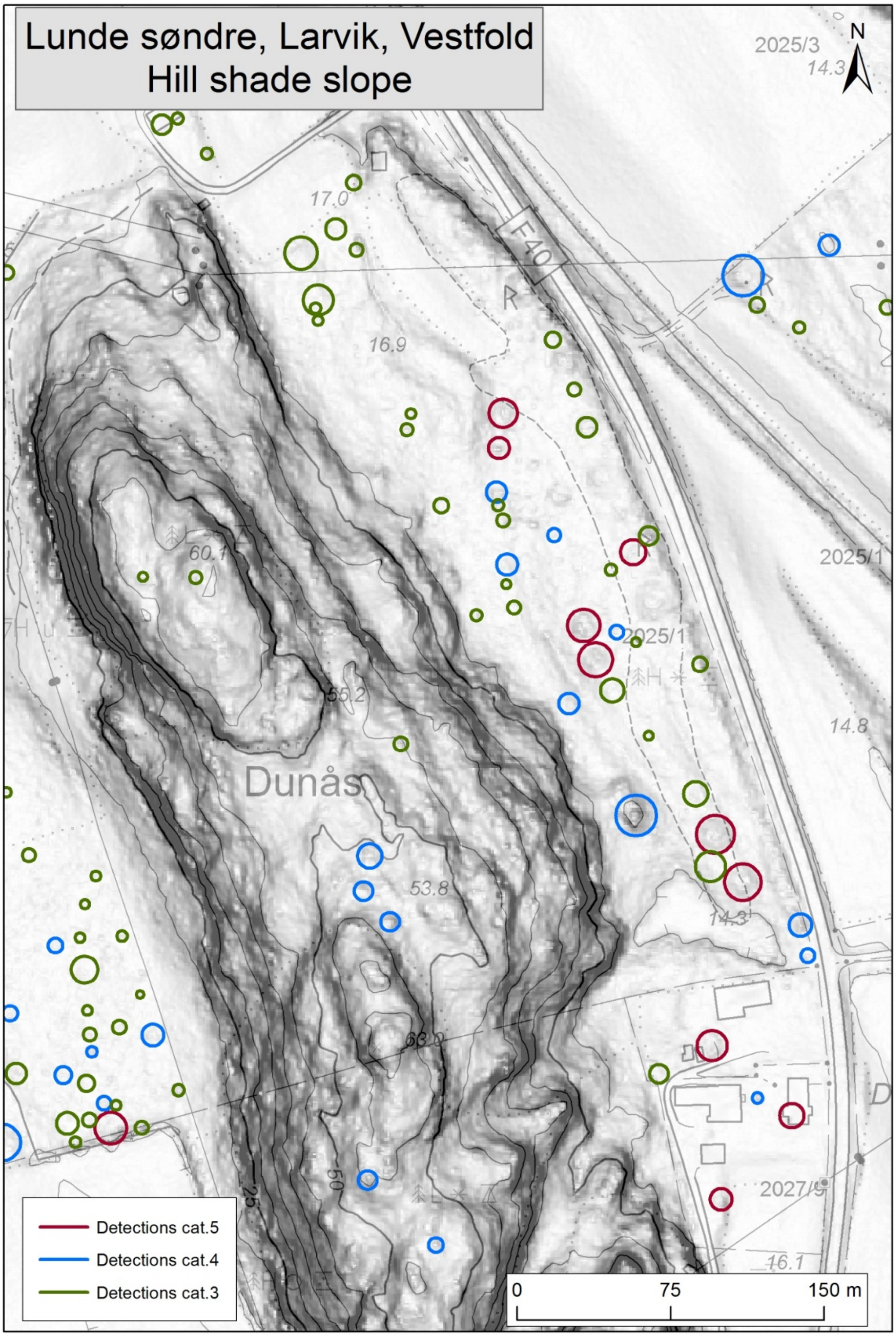

Figure 41. Automatic heap detections of confidence levels from 3 (medium) to 5 (high).

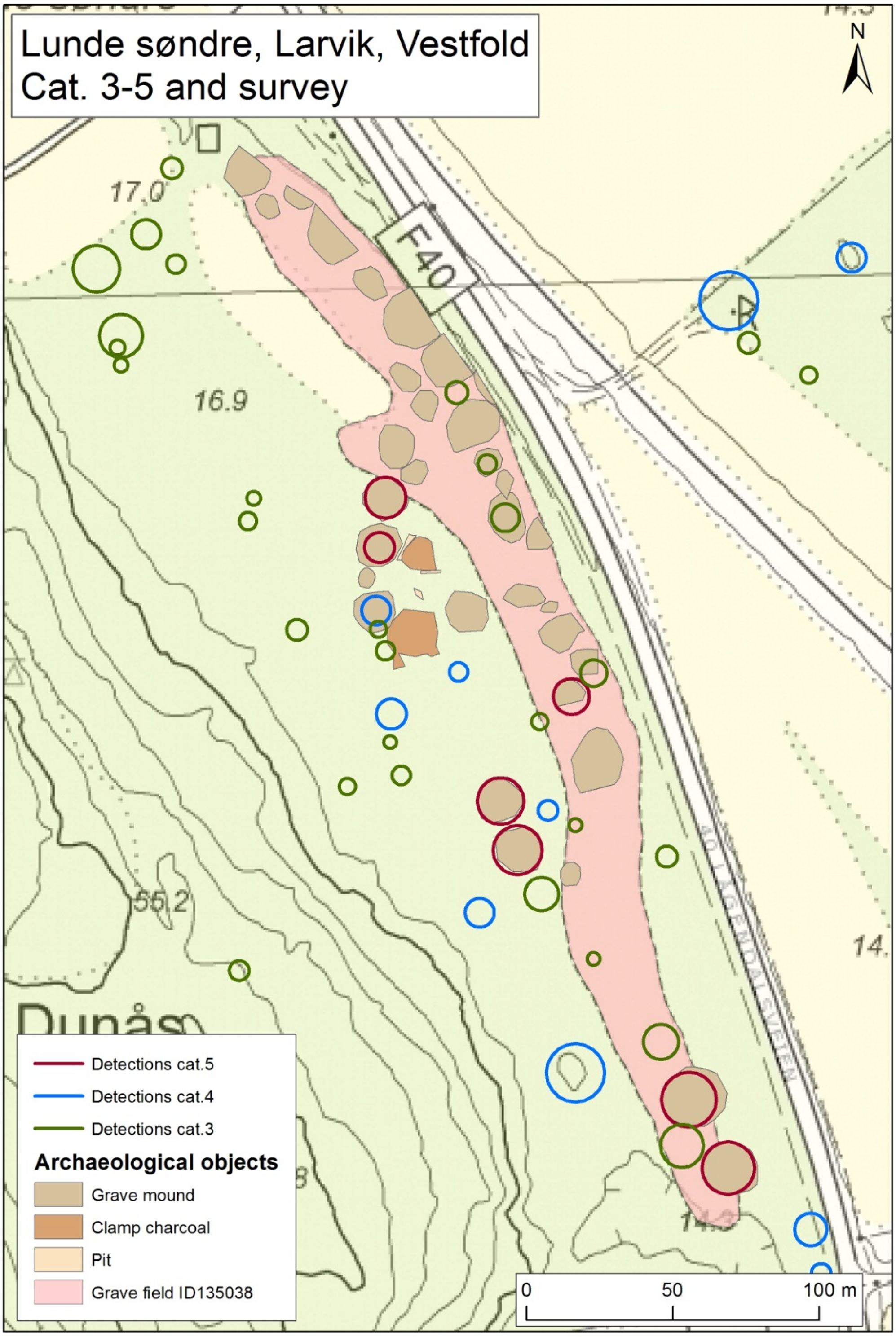

Figure 42. Result of field survey at Lunde søndre.

In the lowest detection categories (0-2) there are some detection that can be seen as coinciding with measured grave mounds. Four detections (three in level 2, one in level 1) were verified as grave mounds. The level 2 detections were just partly coinciding, while the level 1 detection coincides perfectly with the verified grave mound.

None of the two clamps were detected by CultSearcher.

The automatically detected grave mounds were all relatively large with a clear profile and height between 0.5 – 2 meters. Within the surveyed area, a total of 34 automatic detections of medium confidence or better (levels 3-5) were made. Of these, 11 (32%) were confirmed as being grave mounds.

On the other hand, the survey resulted in a total of 33 grave mounds, two charcoal clamps and one path/holloway. Of the 33 actual grave mounds, a total of 15 (45%) were coinciding with automatic detections made by CultSearcher. This means that 18 grave mounds (55 %) were not detected by CultSearcher. Of these, five are quite large, with a diameter of approximately 20 meters. Three of these are nearly cut in half, possibly as a result of constructing the road east of the grave field.

A detailed inspection of the DEM of ALS ground points (Figure 43) may explain some of the missing automatic detections. For example, the four northernmost missing detections are in an area with few ALS ground points due to dense tree vegetation, and it is also difficult to see the grave mounds visually in the DEM. The mounds that were, apparently, partially removed by road construction work, have shapes that deviate substantially from an ideal dome. One large missing detection, a little south of the centre of the grave field, is quite flat, it is 20 m wide and 1.5 m high.

In the north-west of the area (Figure 42) there are some medium confidence detections that are not grave mounds. It is a boggy area with several tussocks, which could explain the detections.

A curiosity: south of the grave field there is today a garage/workshop. The owner bought the property in the fall of 2010. CultSearcher made a medium high confidence automatic detection on the patio in front of the building. Today, there is no heap there, just a flat gravel surface. The owner explained the detection with the fact that there had been an approximately 15 m high pile of stone debris on the patio as the building had been used as a stone factory (headstone etc.). The pile had been removed by the owner in 2011 about a year after the ALS-scanning had been performed.

Figure 43. DEM of ALS ground points for the grave field at Lunde Søndre.

4.4.2 The Woodland

200-300 m west-southwest of the farm is an area (450 x 250 m) with extremely dense cultivated spruce forest in a rather wet area (Figure 44). In this area, there are three high confidence detections, 33 medium high and 109 medium confidence detections (Figure 45). The forest was nearly impossible to penetrate and no positive cultural observations were made during the survey. The three high confidence detections turned out to be fallen trees with the roots standing up. Grass turf and small openings in the forest might be the reason for the quite high number of medium high and medium confidence detections.

Figure 44. Detection results superimposed on an aerial orthophoto of the very dense forest southwest of the farm Lunde søndre.

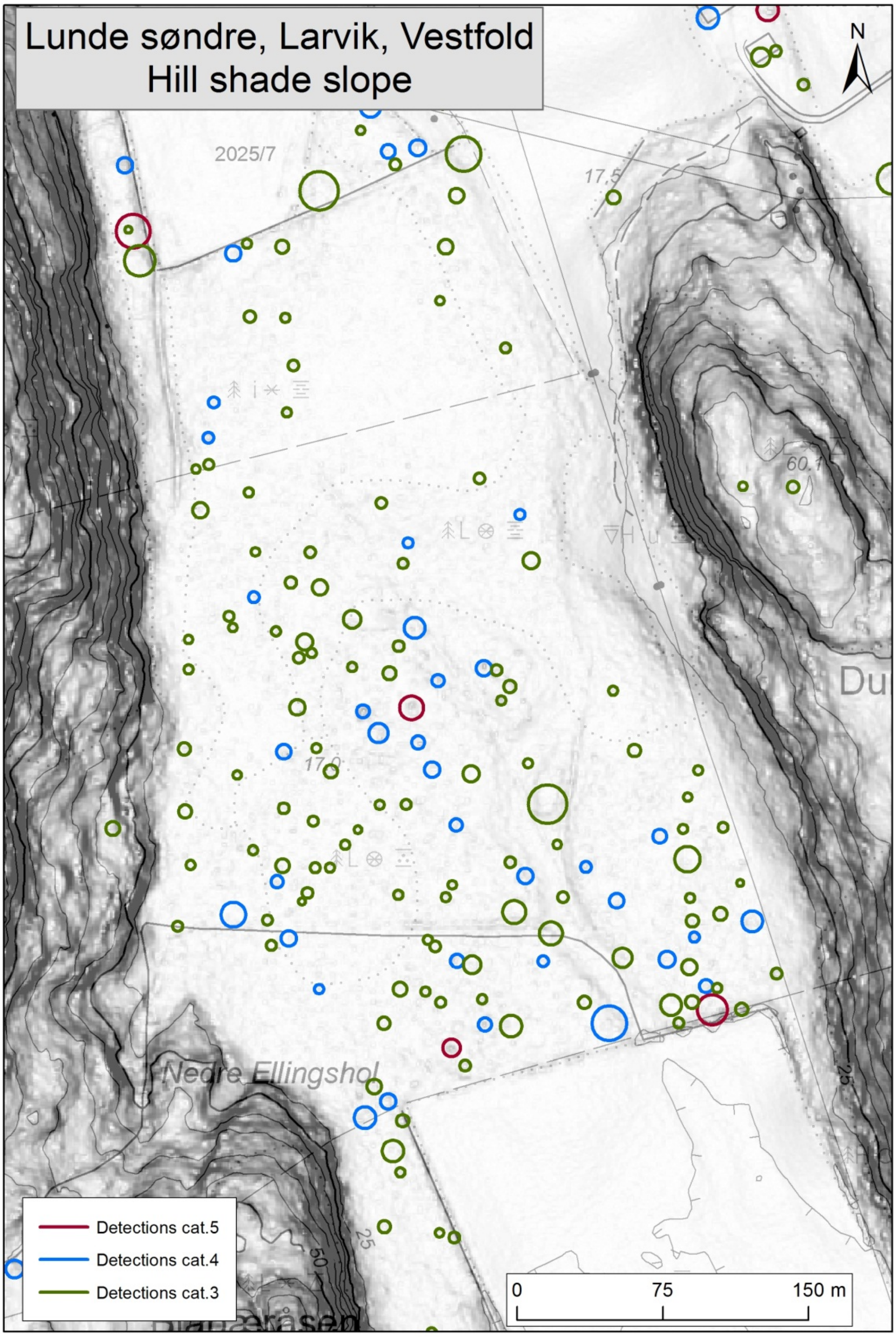

Figure 45. Automatic detections of medium to high confidence in the flat, dense forest southwest of the farm Lunde søndre

4.5 Results, area 2

The second survey area, at Bergan nedre (approx. 8 hectare), is situated on the east side of the river Lågen, approximately 850 m west-northwest of Hedrum church. The topography is a hilly landscape with steep bedrock with spruce forest, bare bedrock, and some low vegetation. A total of four high confidence, 13 medium high confidence and 15 medium confidence detections were examined (Figure 46). All of these detections turned out to be nature, such as bare bedrock (in Norwegian: bergrabber) and large boulders.

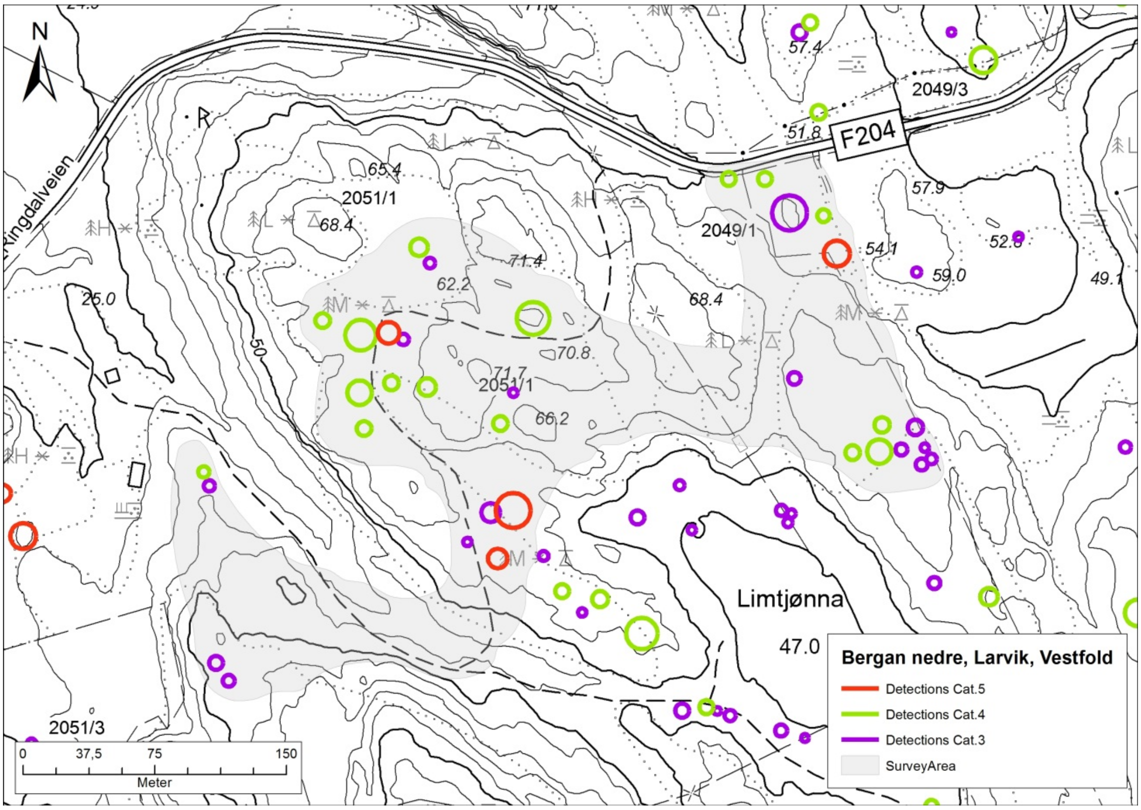

Figure 46. Survey area at Bergan nedre (grey shade) and automatic heap detections by CultSearcher (coloured circles).

4.6 Discussion

The field work verifying automatic detections made by CultSearcher gave many positive results. Fifteen grave mounds were detected in at relatively dense forest of spruce. However, the maximum heap diameter had been set to 16 m in the automatic method (to save computation time), which was probably too small to detect the largest mounds, with about 20 m in diameter. The large amount of detections in the both the extremely dense forest in the west of area 1 and in the hilly bedrock in area 2 shows that there are still challenges to reduce the number of false detections. In the flat forest of area 1 it was difficult to understand the reason for the false detections. In area 2, the detections made by CultSearcher were very distinct circular ice- and wave shaped bedrock and boulders, and thus, natural heaps in the terrain. It would probably be a mistake to force CultSearcher to not detect these.

5 Analysis of remote sensing data of Ørland municipality

By Knut Harald Stomsvik, Sør-Trøndelag County Administration.

5.1 Optical satellite image

Ørland municipality is located northwest of Trondheim, in Sør-Trøndelag County (Figure 47). A Worldview-2 image of a large part of Ørland municipality was acquired on 26 August 2012 (Figure 48). CultSearcher was used to detect circular patterns, in order to locate possible circular crop marks in cereal fields caused by levelled grave mounds.

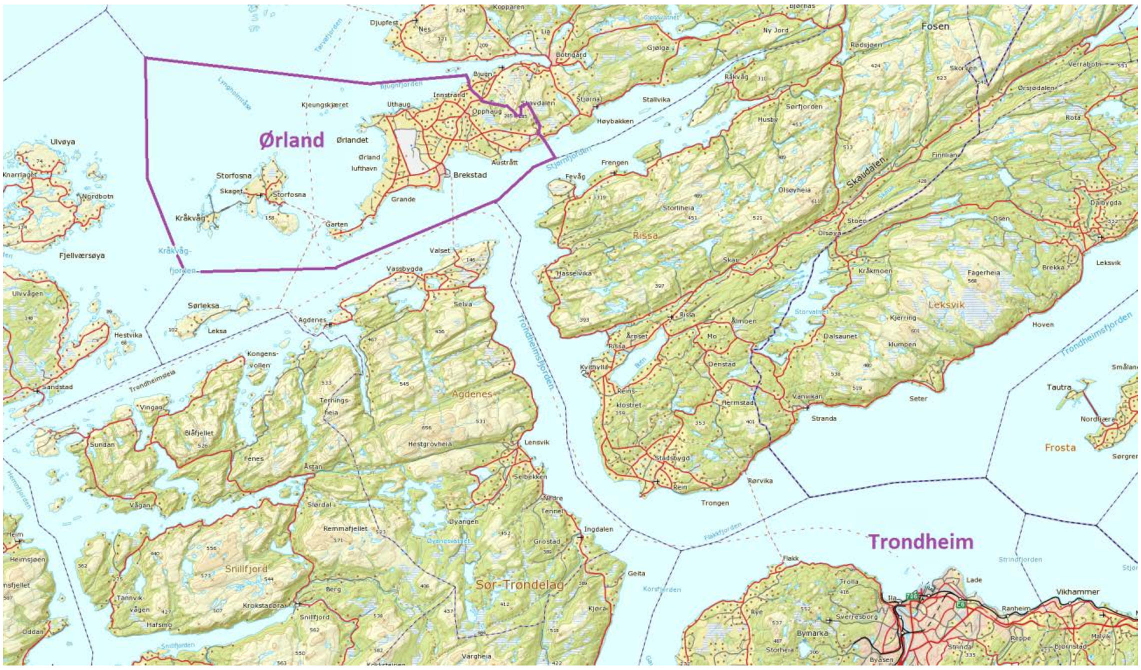

Figure 47. The location of Ørland municipality in Sør-Trøndelag County, Norway.

CultSearcher made 92 detections of circular patterns, of which the majority do not seem to represent levelled grave mounds. All detections have been visually assessed by looking at the satellite image and available aerial orthophotography. However, the ring detections nos. 8, 18, 69, and 88 (Figure 49-Figure 53) are located within an area which is under planning for development and at the same time is assumed to potentially contain cultural heritage hidden under the agricultural soil. Therefore, these detections will be inspected by field work in 2013. Detection no. 69 is interesting, as it is partially overlapping a structure which is visible in an orthophoto of 1969 (Figure 54). The resolution of the orthophoto is too low to determine what the structure might be. Possible interpretations include building remains from an abandoned farm, or traces of a grave monument. In the neighbourhood there are additional structures which possibly resembles stone cairns or grave mounds, and there is also a stone fence nearby. The detection is thus located in a complex cultural environment, which is worth further investigation.

Figure 48. Worldview-2 image of Ørland, 26 August 2012.

Ring detection no. 43 appears as a bright circle with 8 m diameter (Figure 55). This size is in agreement with grave monuments in the area. The detection is considered as a fairly good indication of a levelled grave mound, and should be verified by digging. However, the observation in the Worldview-2 image cannot be confirmed by any of the available orthophotos, neither from 1969, 2004, 2008 nor 2012 show any ring corresponding to the one in the satellite image.

Visual inspection of the satellite image, both in the 0.5 m resolution grey scale (panchromatic) image and the 0.5 m pan-sharpened natural colour image, did not lead to any additional indications of cultural heritage.

The most common 'false' detections of circular structures are individual tree crowns and their shadows, buildings, and building shadows.

Figure 49. Ring detections inside an area planned for land development.

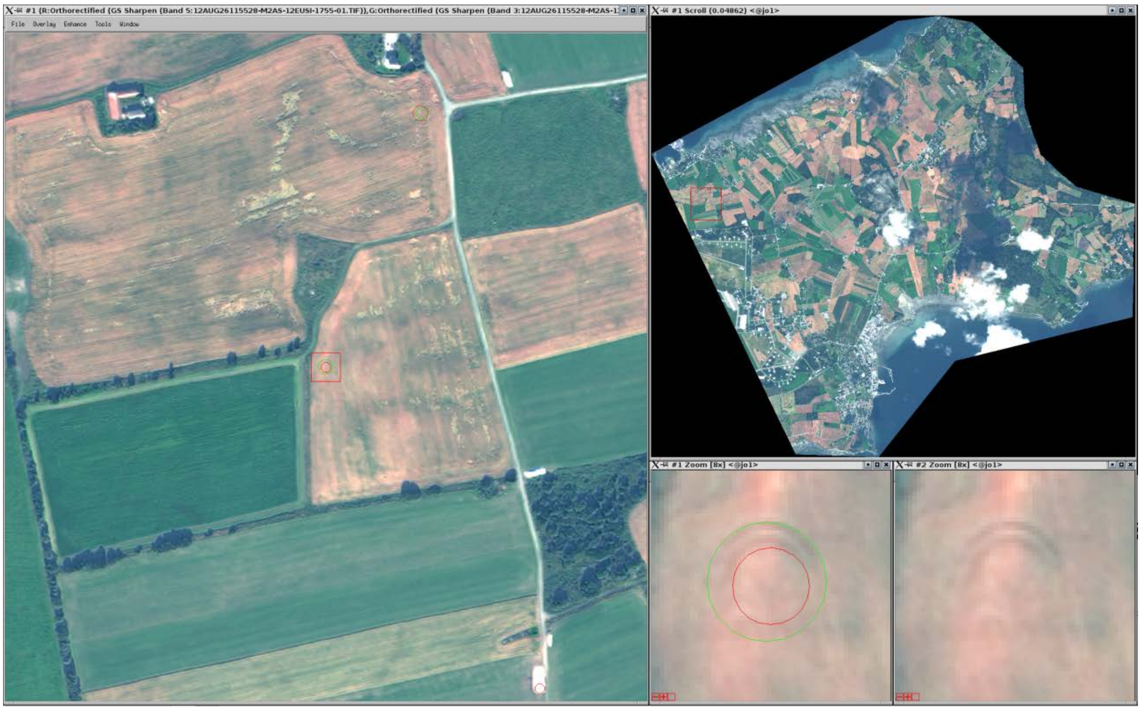

Figure 50. Ring detection no. 8.

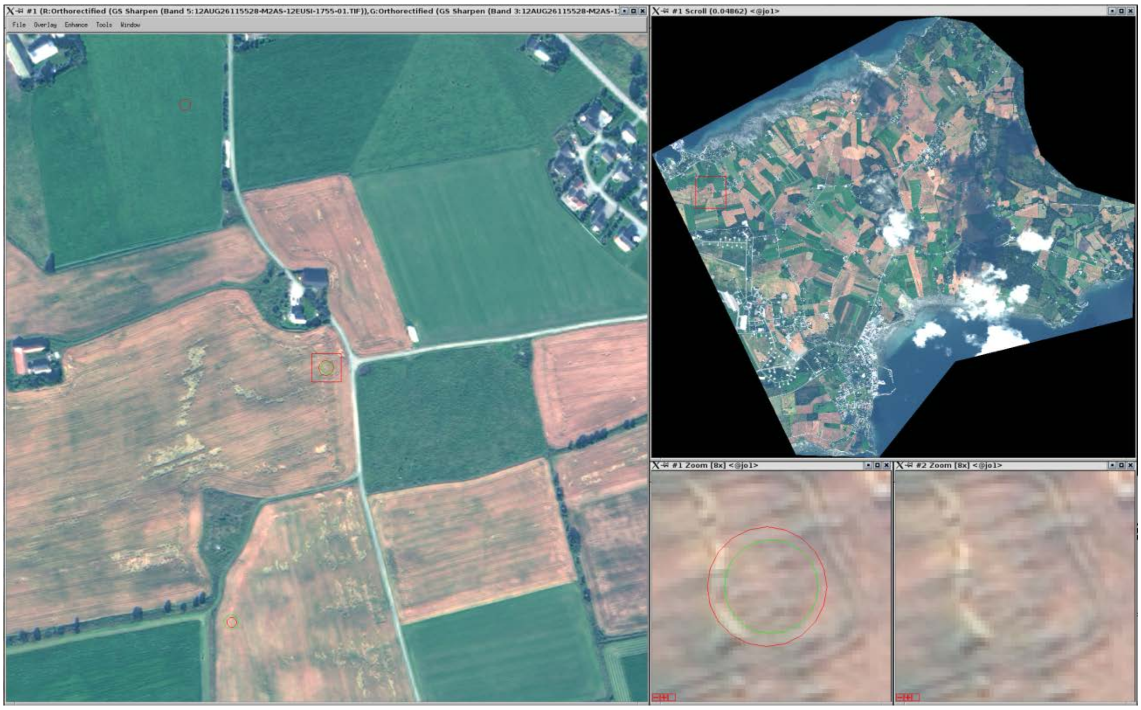

Figure 51. Ring detection no. 18.

Figure 52. Ring detection no. 69.

Figure 53. Ring detection no. 88.

Figure 54. Location of ring detection no. 69 superimposed on 1969 orthophoto. Other visible structures include: stone cairn west-southwest of the ring detection, unknown structure north of the detection, and building (not present in 2012) west-northwest of the detection, and a stone fence further north.

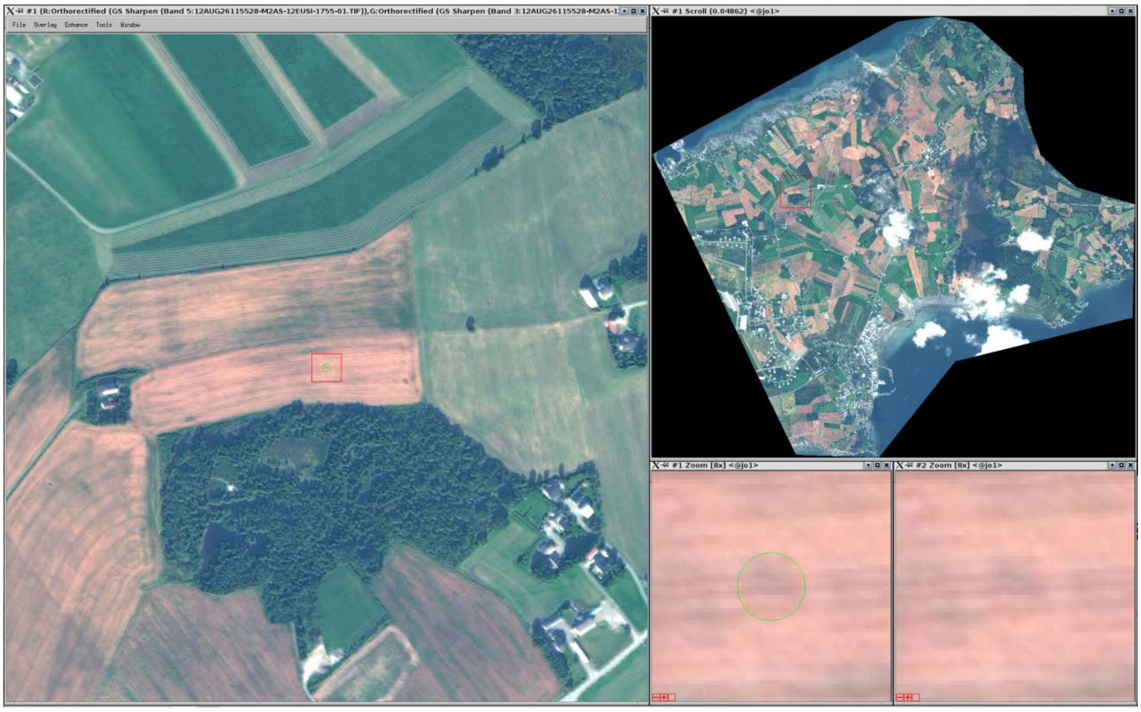

Figure 55. Ring detection no. 43.

5.2 Airborne laser scanning data

Airborne laser scanning (ALS) data of Ørland was acquired in 2010. CultSearcher was used to detect pit structures in a digital elevation model with the vegetation removed. As Ørland mainly consists of flat agricultural fields, it is not an ideal area for searching for pit shaped cultural heritage, like pitfall traps used for deer hunting, or charcoal burning pits. In addition, the point density is not sufficiently high to preserve the shape of pits at the level of detail needed for visual assessment. However, within the area planned for development, mentioned above, four pit detections were made (nos. 386, 387, 389, and 391, at high confidence). These will be further investigated during the 2013 field work.

An unintended asset of the pit search is that looting pits in grave mounds may be detected. Examples include detections nos. 4262 (medium confidence, Figure 56) and 4789 (medium high confidence, Figure 57), each of which marks an actual pit in a large grave mound or cairn. The ALS data has not yet been subject to heap detection. The above observation, regarding the looting pits, indicates that combined pit search and heap search may be worth considering. Pit detections within heap detections could then indicate grave mounds with looting pits, since many grave mounds actually have looting pits or other depressions.

The automatic pit search in ALS data leads to an abundance of 'false' detections (Figure 58), especially along ditches, road edges, building edges and corners, and floor lay in cereal fields.

Figure 56. Pit detection no. 4262 (red circle), inside a large cairn grave (blue shade) from the Bronze Age or Iron Age.

Figure 57. Pit detection no. 4789 (red circle) inside a large Iron Age grave mound (blue shading).

Figure 58. False pit detections, especially along ditches. Different colours denote different confidence levels.

6 Semi-automatic detection of cultural heritage in lidar data

By Øivind Due Trier and Maciel Zortea, Norsk Regnesentral.

Paper appearing in *Proceedings of the 4th International Conference on Geographic Object-Based Image Analysis (GEOBIA)*, Rio de Janeiro, Brazil, 7-9 May 2012, pp. 123-128.

6.1 Abstract

This paper presents new methods for the semi-automatic detection of some kinds of cultural heritage in forested areas in Norway, and reports on a work in progress. Some areas have a large number of old pitfall traps that were used for deer hunting 2000-500 years ago. Other areas have a large number of iron production sites that were in use 1400-700 years ago. These two kinds of cultural heritage manifest themselves as pits in the terrain. We have developed methods for the automatic detection of such pits in lidar data with at least 5 emitted pulses per m^2. We are now extending the automatic detection methods to locate grave mounds, stone fences, and old roads in the lidar data.

Experience from on-going archaeological field work clearly demonstrates the benefits of combining automatic detection methods with visual inspection of the lidar data to achieve a map of possible cultural heritage remains, before the actual field survey. The field work can be performed much more efficiently. Since the archaeological feature candidates have already been geo-referenced and measured in the lidar data, the field work is reduced to accepting or rejecting the candidates. Thus, a much larger number of archaeological features can be mapped per day.

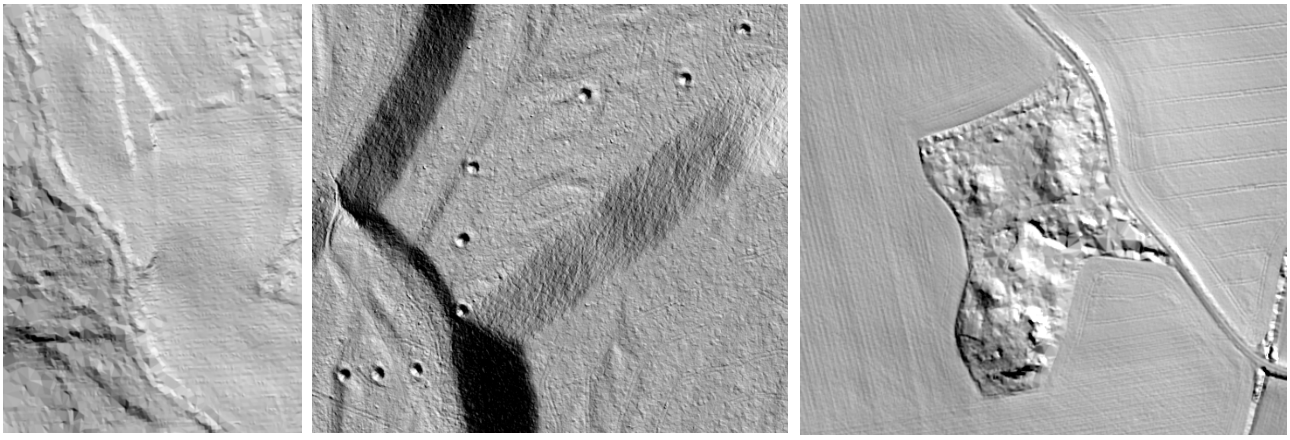

Figure 59. Lidar data from some Norwegian municipalities. Left: Kongsberg, with stone fences. Middle: Nord-Fron, with pitfall traps for moose hunting, which appear as pits. Right: Larvik, with grave mounds, which are seen as heaps in the terrain.

6.2 Introduction

Several Norwegian municipalities are experiencing growing pressure on forested land for development, being it new residential areas, new mountain cabins and hotels, 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.

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. By using airborne laser scanning 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 lidar ground returns (Figure 59), and that these features may be described using some appropriate kind of pattern.

6.3 Data and methods

6.3.1 Airborne lidar height measurements

For an area surrounding the lake Olstappen in Nord-Fron municipality, Oppland County, data was acquired by helicopter, with a minimum of 10 emitted laser pulses per m^2. The data set covered a total area of 29.3 km^2, with 7.3 ground hits per m^2 on average. This terrain is dominated by open pine forest, allowing a large proportion of hits from the ground. This area is known to contain several systems of pitfall traps that were used in moose hunting 500-2000 years ago, and some iron extraction sites with charcoal burning pits dating to 700-1400 years ago. The data set is split geographically in two halves, one western training set, and one eastern test set.

Larvik municipality in Vestfold County is known to contain a large number of grave mounds in forested areas. From a lidar data set that covers about 150 km^2 of the southern part of Larvik municipality, 12 small portions containing known grave mounds were extracted. Four of these are used as a training set: Kaupang (Figure 60), Store Sandnes, Tanum, and Ødelund. The remaining eight comprise a test set: Berg, Bommestad, Bøkeskogen (Figure 61), Hvatumskjeet, Kjerneberget, Lunde, Valby, and Valbysteinene.

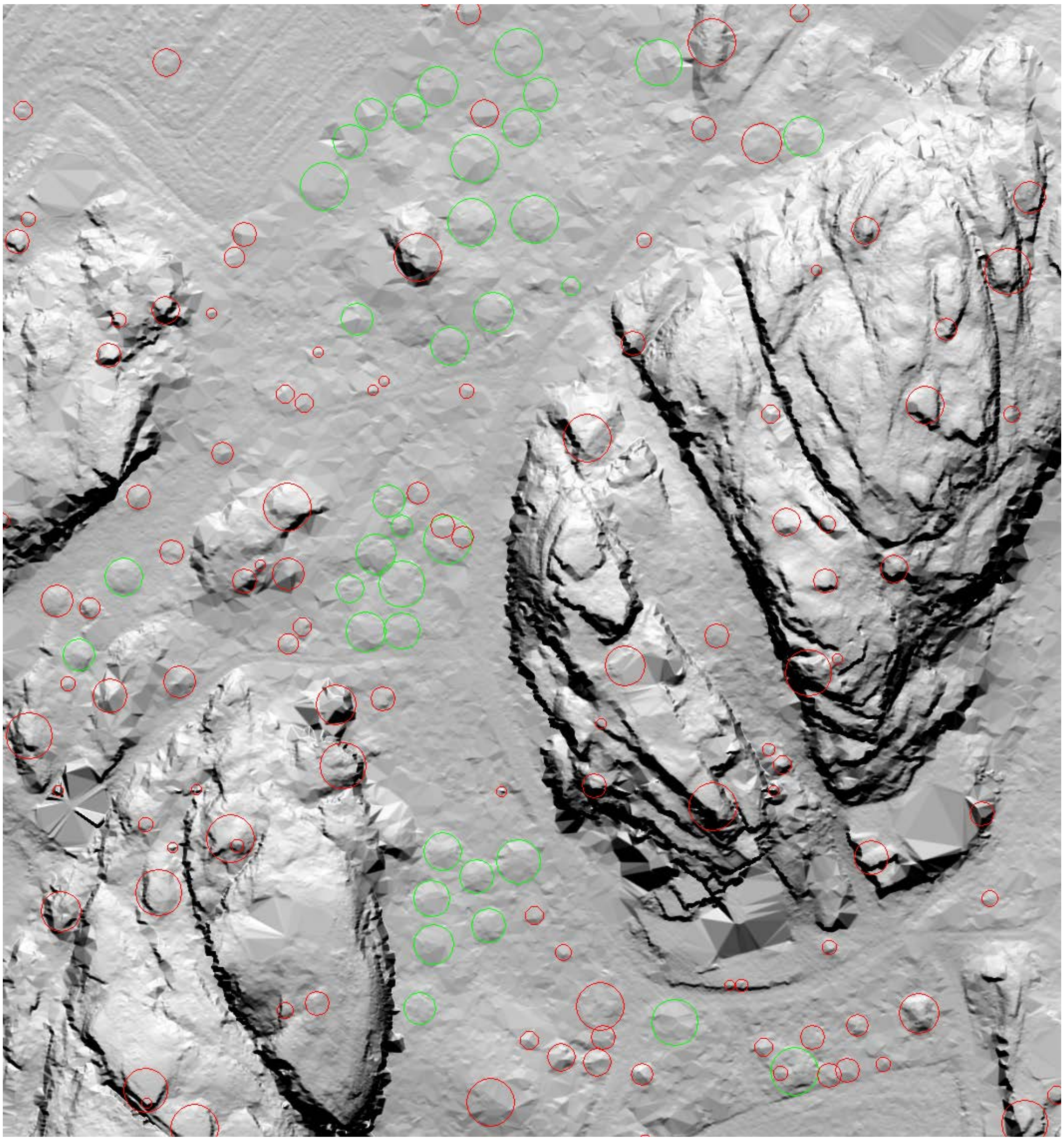

Figure 60. A 210 m × 225 m part of the Kaupang, Larvik training data set for heap detection. True (green) and false (red) grave mounds have been labelled manually.

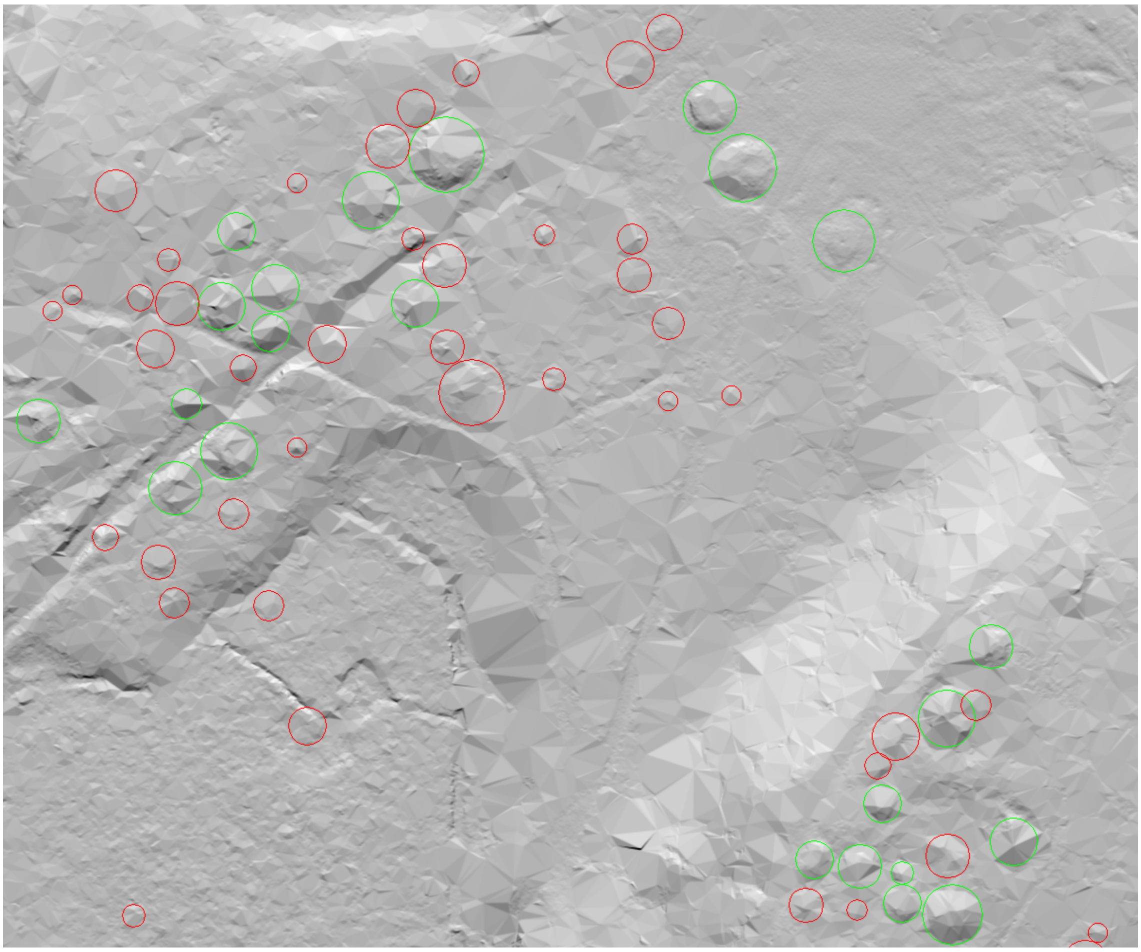

Figure 61. A 245 m × 200 m part of the Bøkeskogen, Larvik test data set for heap detection. True (green) and false (red) grave mounds have been labelled manually.

6.3.2 Automatic detection of circular features

For the detection of circular features, the following general method is applied (Trier and Pilø, 2012):

1. Convert the input LAS files (LAS Specification, 2010), containing individual (x, y, z) point measurements to a regular grid of interpolated height measurements, i.e., a digital elevation model (DEM). Only the (x, y, z) points labelled as 'ground' are used to construct the DEM.

2. Convolve the image with templates of varying sizes. Threshold each convolution result to obtain detections.

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

4. For each detection, compute various attributes that measure the deviation from an ideal model, using different measures than the convolution in step 2.

5. Remove detections that have attributes in step 4 outside prescribed intervals.

6. Assign confidence values to the remaining detections.

The above method is applied for each class of archaeological feature. The same templates (Figure 62) may be used to detect pitfall traps, charcoal burning pits, and grave mounds. However, for grave mounds, the range of template sizes is different than for pitfall traps and charcoal pits. Further, a pit template will give negative convolution values for heaps (e.g., grave mounds).

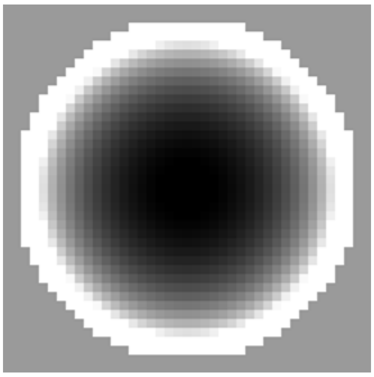

Figure 62. Pit template, shaped as a half-dome circumscribed by a flat ring. White pixels are +1, black pixels are -1, and grey pixels in between. The medium grey pixels outside the white ring edge are exactly zero, thus not contributing to the convolution value. This particular pit template has 3.4 m radius.

6.3.3 Computation of attributes

In step 3 above, the following attributes are computed:

1. Correlation value, obtained from the convolution step.
2. Radius, also obtained from the convolution step.
3. Normalized correlation value, that is, the correlation value divided by the radius.
4. Average pit depth, measured as the height difference between the lowest point inside the pit and the average height on the ring edge outside the pit.
5. Minimum pit depth, measured as the height difference between the lowest point inside the pit and the lowest point on the ring edge.
6. Standard deviation of height values on the ring edge.
7. Root mean square (RMS) deviation from a perfect hemisphere, i.e., a perfect U-shaped pit.
8. RMS deviation from a perfect V-shaped pit.
9. For each pit, a threshold is defined as the value that separates the pixels inside the pit 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 blob segment from a square image centred on the pit, with sides equal to six times the radius. This is called the 25%-segment. If this results in a compact, central segment inside the pit, connected to a larger segment outside the pit, with only a few connecting pixels on a ring just outside the pit, then the central segment is separated from the outside segment. From the extracted segment, the following measures are computed:
    a. Offset: distance from pit 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.

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

6.3.4 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' archaeological feature 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.

6.3.5 Statistical classification versus decision tree

For step 6 in the circular feature detection method above, a manually designed decision tree was originally 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. If a large number of training examples are available, an alternative is to use a statistical classifier. We will compare the two approaches below for automatic pit detection in the context of semi-automatic detection of pitfall traps and charcoal burning pits.

6.3.6 Automatic pit detection method: common steps

The first five steps in the general circular feature detection method are common for both the manually designed decision tree and the statistical classifier approach. These five steps were applied on the Olstappen 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 lidar height measurements, thus converting the, on average, 7.3 ground hits per m^2 to 25 interpolated height values per m^2. In the convolution step, pit templates corresponding to pit radii from 1.2 to 3.4 m were used, corresponding to the expected pit sizes; each template having 0.2 m larger radius than the next smaller. The initial screening exercise resulted in the following subset of attributes to be used for thresholding as follows:

1. Normalized correlation > 2.0
2. Average pit depth > 0.5 m
3. Minimum pit depth > 0.1 m
4. RMS u-shape < 0.2
5. RMS v-shape < 0.2
6. 25% segment elongation < 4

When applied on the entire Olstappen data set, the initial screening resulted in 2018 detections, which were then labelled manually, resulting in 258 verified archaeological pits. All these were first verified visually by archaeologists. 67 of these were also verified by archaeological field survey. In addition to these 258 confirmed pits, four detected pits were found to be modern by field survey, and 10 archaeological pits were detected visually in the lidar data by archaeologists. Of these 10 pits that were missed by the automatic method, six have been confirmed by field survey. Field survey to verify the remaining 191 + 4 pits is pending additional funding.

The data set was split in two; a training set containing 129 confirmed archaeological pits and 1000 false detections, and a test set containing 128 confirmed pits and 866 false detections. This split was done by listing pit detections ordered alphabetically on tile names, resulting, roughly, in a western training set and an eastern test set.

6.3.7 Automatic pit detection using manually designed decision tree

Table 8. Thresholds for assigning confidence values for pitfall trap detection.

	confidence					
feature	very low	low	medium	med. high	high	very high*
normalized correlation	≥2	≥2.5	≥2.5	≥3	≥3.5	
minimum depth	≥0.1	≥0.1	≥0.23	≥0.4	≥0.5	≥1.0
average depth	≥0.5	≥0.5	≥0.5	≥0.55	≥0.75	
RMS u-shape	≤0.2	≤0.1	≤0.07	≤0.05	≤0.04	≤0.02
RMS v-shape	≤0.2	≤0.085	≤0.07	≤0.05	≤0.03	≤0.015
25% segment offset	≤40	≤6	≤6	≤6	≤5	
25% segment elongation	≤4	≤2	≤1.5	≤1.3	≤1.2	
assigned tag	1	2	3	4	5	6

Table 9. The effect of running the confidence assignment on the Olstappen training set for pitfall trap detection.

score value	1	2	3	4	5	6		
confidence	very low	low	medium	medium high	high	very high	not detected	sum
pit confirmed in field			2	2	5	16	1	26
modern/other visually								0
pit visually in image		7	27	32	17	21	4	108
not pit visually	329	517	136	15	3			1000
sum	329	524	165	49	25	37	5	1134

By using the thresholds in Table 8 in a decision tree, confidence values were assigned to all the detections in the training set (Table 9). For confidence values from ‘very low’ to ‘high’, all the tests have to be fulfilled, and each detection is assigned the best possible confidence according to the rules. For a detection with ‘high’ confidence, it is upgraded to ‘very high’ if at least one of the tests for ‘very high’ are fulfilled. Obviously, by adjusting the thresholds in Table 8, different number of ‘true’ and ‘false’ detections will get the various confidence values (Table 9), and the goal is to achieve a meaningful balance of ‘true’ and ‘false’ detections within each confidence level.

6.3.8 Automatic pit detection using statistical classifier

In this variety of the pit detection method, the decision tree classifier in the confidence assignment step is replaced by a statistical classifier. 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

For each classifier, the best subset of the 13 attributes computed in Section 6.3.3 is determined using the sequential forward attribute selection algorithm (Pudil *et al.*, 1994). The subset of attributes that maximize 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 5), with the following seven attributes, in order of importance:

1. Minimum depth
2. RMS V-shape
3. Standard deviation on edge
4. Offset of 25% segment
5. Normalized correlation
6. Average depth
7. Elongation of 25% segment

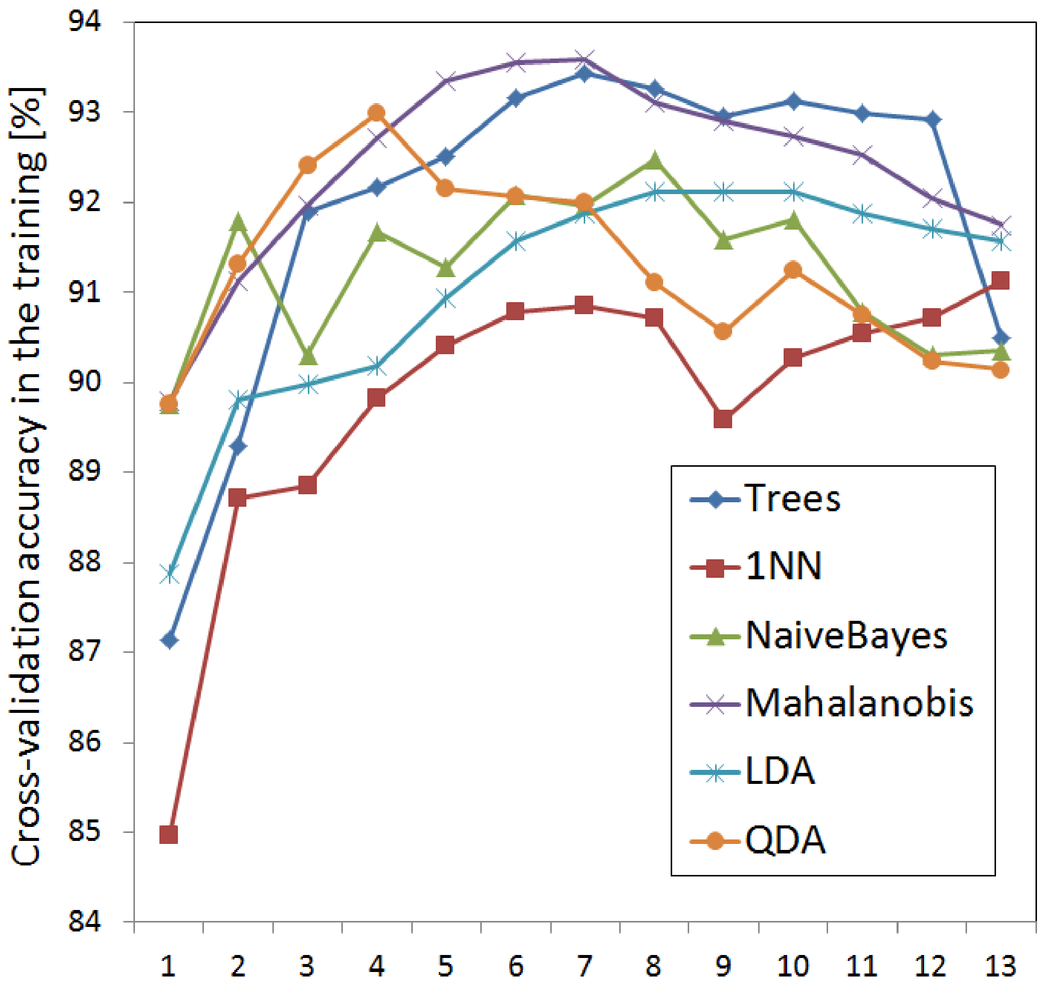

Figure 63. Performance of the six different classifiers on the Olstappen training set, as a function of the number of attributes.

We will now use the estimated posterior probability, that is, the probability that the detected pit is archaeology, to assign a confidence level to each detection. With six confidence levels, we need to determine five thresholds. 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 10) and accumulate to obtain a total penalty for the particular choice of thresholds. By adjusting the threshold values, they can be optimized to minimize the total penalty. By doing this on the training set, the thresholds in Table 11 are obtained, which assign 'medium high' or better confidence to most of the true archaeological pits, and 'medium' confidence or lower to most false pits (Table 12).

Table 10. 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
pit	1024	256	64	16	4	1
non-pit	1	4	16	64	256	1024

Table 11. Optimized threshold values for pit detection.

1	2	3	4	5
0.07374048	0.12168859	0.32615019	0.58907545	0.80731382

Table 12. The result of using the Mahalanobis distance classifier on the Olstappen training set.

score value	1	2	3	4	5	6		
confidence	very low	low	medium	medium high	high	very high	not detected	sum
pit confirmed in field				2	1	22	1	26
pit visually in image		3	7	20	29	45	4	108
not pit visually	27	380	528	62	7			1004
sum	27	383	535	84	37	67	5	1138

2.8 Automatic heap detection using statistical classifier

The method for pit detection can be modified to detect heaps that could be grave mounds. As for pit detection, 0.2 m grid size was used for the DEM. By reversing the sign of the pit templates, heap templates are obtained. Heap templates with radii in the range 1.0-10 m are used, again with each radius being 0.2 m larger than the next smaller. The same attributes as for pits are used, with the obvious exception that average and minimum heap heights are computed instead of the respective pit depths. In addition, two more attributes were computed, by dividing the heap height measurements by the heap radius:

1. Normalized average heap height
2. Normalized minimum heap height

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.

Again, we evaluate six different classifiers and different attribute combinations. The Mahalanobis distance classifier performs best on the Larvik training set, with the following seven features, 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 25% segment

As for pit detection in Section 6.3.7, thresholds on the posterior probability are used to assign a confidence level to each heap detection. The thresholds were optimized on the Larvik training set, using the same penalty weights as before (Table 10). The resulting thresholds (Table 13) assigns ‘medium’ confidence to the majority of the false detections, and ‘medium high’ or better confidence to heaps that we think are grave mounds (Table 14).

Table 13. Thresholds for confidence assignment for heap detection.

1	2	3	4	5
0.05072984	0.05121662	0.47666119	0.67167690	0.76737689

Table 14. 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 Results

6.4.1 Automatic pit detection using manually designed decision tree

Table 15. The result of running the decision tree confidence assignment on the Olstappen test set for pit detection.

score value	1	2	3	4	5	6		
confidence	very low	low	medium	medium high	high	very high	not detected	sum
pit confirmed in field		2	13	10	7	8	5	45
pit visually in image	1	11	28	24	19	5		88
sum true pits	1	13	41	34	26	13	5	133
modern/other in field	1	1	1	1				4
not pit visually	384	375	90	11	2			862
sum	386	389	132	46	28	13	5	999

Table 16. Accumulated pit detection counts for different confidence levels on the Olstappen 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	not detected	sum
pit confirmed in field	40	40	38	25	15	8	5	45
pit visually in image	88	87	76	48	24	5		88
sum true pits	**128**	**127**	**114**	**73**	**39**	**13**	**5**	**133**
modern/other in field	4	3	2	1				4
not pit visually	862	478	103	13	2			862
sum	994	608	219	87	41	13	5	999
pits detected	96.24%	95.49%	85.71%	54.89%	29.32%	9.77%		
pits missed	3.76%	4.51%	14.29%	45.11%	70.68%	90.23%		

By running the confidence assignment decision tree with the thresholds in Table 8 on the Olstappen test set, slightly worse results were obtained (Table 15) compared with the training set (Table 9). Fewer true detections obtained very high confidence, and more true detections obtained low or medium confidence. Still, the confidence levels reflect the number of true versus false detections in a meaningful way. All detections with ‘very high’ confidence are confirmed by archaeologists, either by field survey or by visual inspection of the lidar data. By accumulating the detection counts (Table 16), the trade-off between detecting as many pits as possible while at the same time limiting the number of false detections is more evident. E.g., 114 of 133 pits of archaeological interest were detected with medium confidence or better (Table 16); this is 85.7% of the pits of archaeological interest. At the same time, 103 of the detections with medium or better confidence were false. Alternatively, one may want to accept a higher number of false detections to obtain more true detections. 127 of 133 ‘true’ pits were detected with low or better confidence, which is 95.5%. This is achieved by accepting 478 ‘false’ pits. Of the remaining 6 pits of archaeological interest that were not detected, 5 were lost due to missing ground returns in the lidar data due to vegetation. Many of the false detections could easily be removed by using digital map overlays, or were otherwise obvious misclassifications due to the context of the terrain.

6.4.2 Automatic pit detection using statistical classifier

By running the Mahalanobis distance classifier as described in Section 2.6 on the Olstappen test set, more archaeological pits were assigned ‘high’ and ‘very high’ confidence (Table 17-Table 18) than when using the manually designed decision tree (Table 15-Table 16). On the other hand, very few false pits were assigned ‘very low’ confidence by the Mahalanobis distance classifier. It seems like most of the true and false pits that the decision tree classifier labelled with ‘very low’ or ‘low’ confidence, were labelled with ‘low’ or ‘medium’ confidence by the Mahalanobis distance classifier.

Table 17. The result of confidence level assignment using the Mahalanobis distance classifier on the Olstappen test set.

score value	1	2	3	4	5	6		
confidence	very low	low	medium	medium high	high	very high	not detected	sum
pit confirmed in field	1	1	4	13	6	15	5	45
pit visually in image		5	9	13	27	34		88
not pit visually	22	406	391	41	6			866
sum	23	412	404	67	39	49	5	999

Table 18. Accumulated pit detection counts for the Mahalanobis distance classifier

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	not detected	sum
pit confirmed in field	40	39	38	34	21	15	5	45
pit visually in image	88	88	83	74	61	34		88
sum true pits	**128**	**127**	**121**	**108**	**82**	**49**	**5**	**133**
not pit visually	866	844	438	47	6			866
sum	994	971	559	155	88	49	5	999
pits detected	96,24 %	95,49 %	90,98 %	81,20 %	61,65 %	36,84 %		
pits missed	3,76 %	4,51 %	9,02 %	18,80 %	38,35 %	63,16 %		

For pit detection the best statistical classifier is better than the manually constructed decision tree for high confidence detections. On the Olstappen test set, the Mahalanobis distance classifier assigns ‘high’ confidence or better to 82 confirmed pits, which is 62% of the confirmed pits, with only six additional false detections. The manually designed decision tree assigns ‘medium high’ confidence or better to 73 confirmed pits (55%), with 14 false detections. However, for the ‘low’ confidence detections, the manually designed decision tree seems to work better. The Mahalanobis distance classifier assigns ‘very low’ confidence to only 22 false pits, while the manually constructed decision tree assigns ‘very low’ confidence to 385 false pits. Both methods assign ‘very low’ confidence to only one confirmed pit.

6.4.3 Automatic heap detection using statistical classifier

By running the Mahalanobis distance classifier on the Larvik test set (Table 19), almost none of the false detections get ‘low’ or ‘very low’ confidence. So, in an operational setting, to successfully verify the 14 grave mounds with ‘medium’ confidence, 647 false detections have to be checked as well. However, for the 'medium high' or better confidence levels, the number of false detections is reasonable (Table 20).

Table 19. 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 mound			14	39	25	18	96
not grave mound	4		647	144	13	1	809
sum	4	0	661	183	38	19	905

Table 20. 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	sum
grave mound			14	39	25	18	96
not grave mound	4		647	144	13	1	809
grave mound	**96**	**96**	**96**	**82**	**43**	**18**	**96**
not grave mound	809	805	805	158	14	1	866
sum	994	608	219	87	41	13	999
heaps detected	100,00 %	100,00 %	100,00 %	85,42 %	44,79 %	18,75 %	
heaps missed	0,00 %	0,00 %	0,00 %	14,58 %	55,21 %	81,25 %	

6.5 Discussion and conclusions

The pit detection results on the Olstappen test set indicate that the manually designed decision tree method is capable of detecting 95% of the pits of archaeological interest that were visible in the terrain, while at the same time producing four times as many false detections as true detections. Experience from field work indicates that this is an acceptable trade-off. Further, the automatic method was able to detect several small pits that were overlooked by visual inspection of the lidar data. The combined use of automatic detection and visual inspection prior to field survey is now being used by archaeologists in Oppland County, Norway, for the mapping of ancient hunting systems and iron production sites.

We have seen that the best statistical classifier for pit detection in the Olstappen data set, i.e., the Mahalanobis distance classifier, seems to work better than the manually constructed decision tree for the detection of pits with high confidence. However, the decision tree seems to be better for low confidence pit detections. Perhaps better performance could be obtained for the Mahalanobis distance classifier by reducing the penalty weights for confirmed pits with low confidence values. Alternatively, one could use a separate method to re-estimate confidence values for pit detections with very low to medium confidence, or to detections with posterior pit probability < 0.5.

It should also be noted that the heap detections have not been verified by archaeologists yet, as this part of our work is in an early stage. We plan a field work campaign in Larvik municipality this summer, after which we plan to redo the evaluation of automatic heap detection methods.

The lidar data could also be used to extract other features of archaeological interest than circular features, like pits and heaps. For linear features, like stone fences and old roads, we propose to use the following general method:

1. Apply multi-resolution edge- and/or ridge-detectors.

2. Use digital map overlays to remove detections due to modern features such as roads.

3. For each resolution, threshold the detection result and connect neighbouring detections having approximately the same orientation.

4. Close small gaps.

5. Compute measures such as length, height above terrain, etc.

6. Classify the linear features either by using fixed thresholds or by using a statistical classifier.

In conclusion, semi-automatic detection of cultural heritage in lidar data is a valuable tool in combination with visual inspection of the lidar data, prior to field survey. Provided that the point density of the lidar data is high enough, the experience from the automatic pit detection method suggests that field survey can be accomplished ten times faster compared to the traditional approach without lidar data. Obviously, this is mainly due to the use of lidar data in itself, but automatic detection contributes both by reducing the time required for visual interpretation and by detecting pits that are missed during visual inspection.

7 Semi-automatic detection of burial mounds in forested areas

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Paper presented at the EARSeL 32nd Annual Symposium, Mykonos, Greece, 21-24 May 2012.

7.1 Abstract

This paper describes a new method for the automatic detection of heap structures in airborne laser scanning data, and reports on a work in progress. The heaps could be ancient grave mounds, dating to 1500-2000 years ago. Such grave mounds are automatically protected in Norway. 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.

Grave mounds are one of the most frequent types of archaeological structure in Norway. 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. Several of these detections have been confirmed to be levelled grave mounds.

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 lidar data, the forest vegetation can be removed from the data, making it possible to detect archaeology in a semi-automatic fashion, provided the archaeology manifests itself as structures in the digital elevation model of the lidar ground returns, and that these structures may be described using some 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 lidar data would be an important tool in a more systematic mapping of archaeology in Norway.

The automatic method has been applied on lidar data from Larvik municipality in Vestfold County, Norway. Preliminary results are promising, and indicate that this may be a very useful tool for archaeologist in Norway for a more systematic mapping of cultural heritage.

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 64). 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 64. 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 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 and Amable, 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 lidar 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 lidar 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 airborne lidar data (Trier and Pilø, 2012). These archaeological features manifest themselves as pits in a digital elevation model (DEM) derived from the lidar 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. This method can be modified to detect heaps instead of pits.

7.3 Data

Larvik municipality in Vestfold County is known to contain a large number of grave mounds in forested areas. A lidar data set covering about 150 km^2 of the southern part of Larvik municipality was acquired on 3-7 June 2010, with 22 emitted pulses per m^2 on average. From this data set, 12 small portions containing known grave mounds were extracted. Four of these are used as a training set: Kaupang (Figure 60), Store Sandnes, Tanum, and Ødelund. The remaining eight comprise a test set: Berg, Bommestad, Bøkeskogen (Figure 61), Hvatumskjeet, Kjerneberget, Lunde, Valby, and Valbysteinene.

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 lidar data:

1. Obtain lidar 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 m^2, and the discrete returns must be labelled as ground, building, vegetation, etc.

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

3. Convolve the height images with dome-shaped heap templates (Figure 65) 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 lidar data, then by field work.

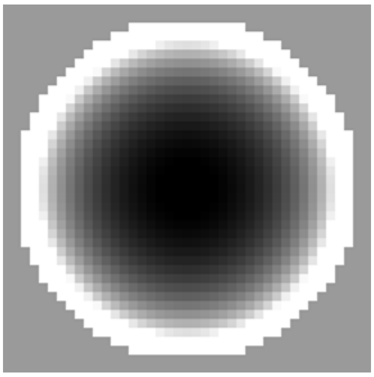

Figure 65. Heap template, shaped as a half-dome circumscribed by a flat ring. Black pixels are +1, white pixels are –1, and grey pixels in between. The medium grey pixels outside the white ring edge are exactly zero, thus not contributing to the convolution value. This particular heap template has 3.4 m radius.

7.4.1 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.

7.4.2 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.

7.4.3 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.

7.4.4 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 lidar 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 1.0 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

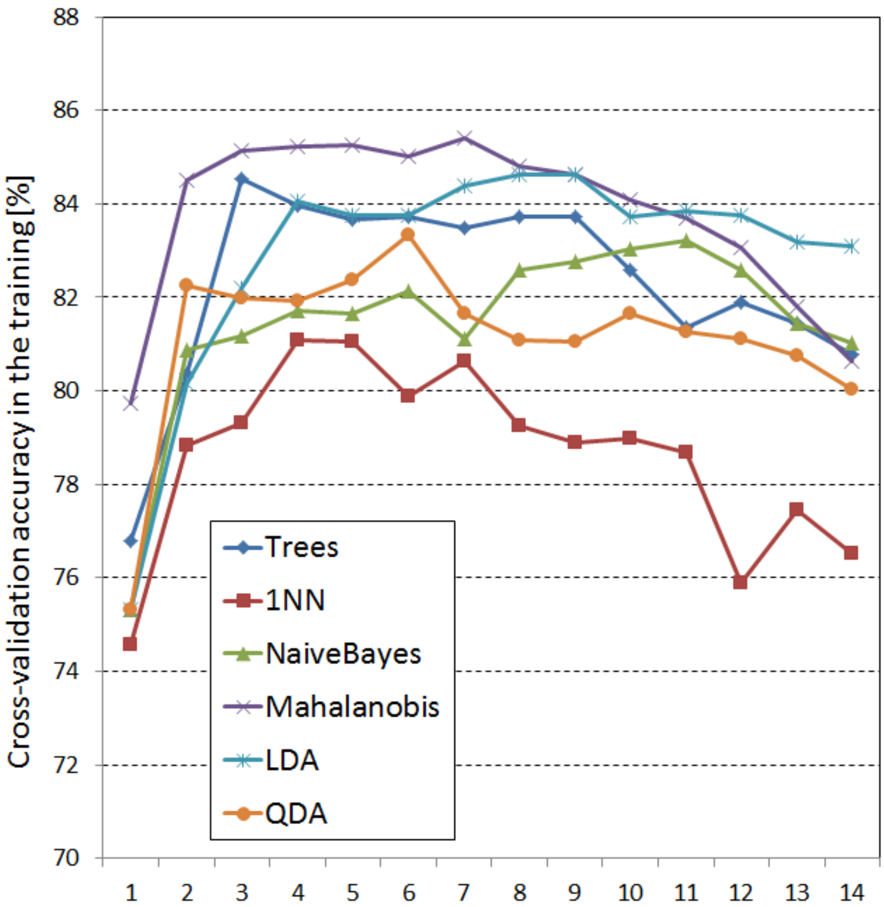

Figure 66. Performance of the six different classifiers on the Larvik training set, as a function of the number of attributes.

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.

7.4.5 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

For each classifier, the best subset of the 15 attributes computed in Section 2.2.1 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 66), 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 25% 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 21) 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 22 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 23).

Table 21. 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
pit	1024	256	64	16	4	1
non-pit	1	4	16	64	256	1024

Table 22. Optimized thresholds for confidence assignment for heap detection.

1	2	3	4	5
0.05072984	0.05121662	0.47666119	0.67167690	0.76737689

Table 23. 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

7.4.6 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 [8], nor for heaps (Table 23), a decision tree classifier may be used to reassign confidence levels medium or lower. For this purpose, a number of thresholds were used (Table 24).

Table 24. 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 avgerage height	≤0.3	≤0.25
normalized avgerage 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 24 are met, then the detection gets low confidence. Next, if all the thresholds for medium in Table 24 are met, then the confidence changes again from low to medium.

7.5 Results

7.5.1 Automatic heap detection using statistical classifier

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 25) compared with the training set (Table 23). 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 26), 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 26), 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.

Table 25. 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 mound			14	39	25	18	96
not grave mound	4		647	144	13	1	809
sum	4	0	661	183	38	19	905

Table 26. 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	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 27. Result of running the combined classifier for confidence estimation on the Larvik test set.

confidence	very low	low	medium	medium high	high	very high	sum
grave mound	1	5	8	39	25	18	96
not grave mound	145	351	155	144	13	1	809
sum	146	356	163	183	38	19	905

Table 28. Accumulated heap detection counts for the combined classifier on the Larvik test set.

confidence	very low or better	low or better	medium or better	medium high or better	high or better	very high	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 %	

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 27). 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 28).

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 67). The percentages in Table 25-Table 28 are estimated without taking these missing detections into account.

7.6 Discussion and conclusions

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 applied on, 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, a substantial number of grave mounds have not been detected at all (Figure 67). 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 lidar data. Previous experience with pit detection in lidar data clearly demonstrates the negative effect of reduced ground point density. 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 trees in the forests in Larvik municipality, the archaeologists recommended that the acquisition of lidar 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 lidar acquisition was postponed until the beginning of June 2010, with full-size leaves on the trees. We recommend that future lidar 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.

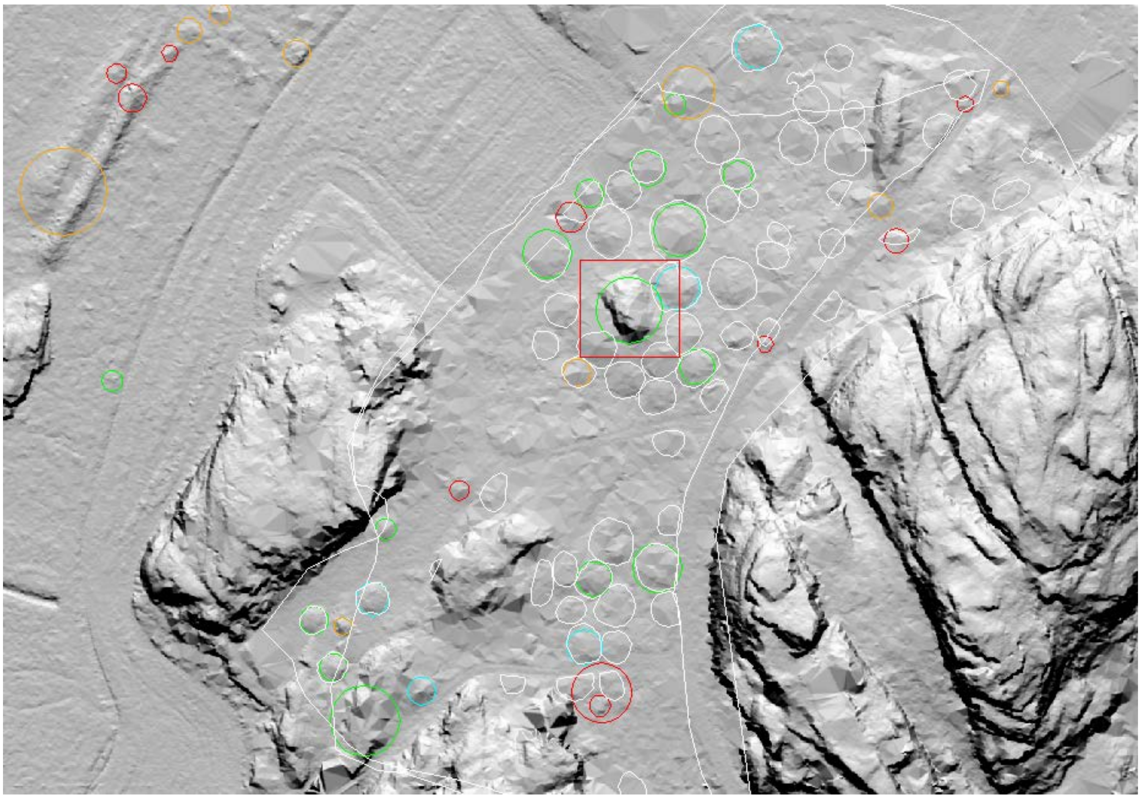

Figure 67. Detection results on a part of the Kaupang training data. The white polygons are previously mapped grave monuments, containing individually mapped grave mounds and grave field boundaries. Coloured circles are automatic heap detections, using the combined method for confidence assignment: blue=very high, cyan=high, green=medium high, yellow=medium, orange=low, red=very low. The red square indicates a natural terrain feature which has been detected as a grave mound with medium high confidence (green ring).

Another potential problem related to the lidar 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.

Finally, 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 lidar ground point density within the area covered by the heap template

2. Average lidar 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 lidar 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.

As a conclusion, the present study demonstrates that automatic heap detection could be a useful tool for the semi-automatic detection of grave mounds in Norway from airborne laser scanning data, provided the number of ground points per square meter is not too low. The method needs improvement to be used in an operational setting with non-optimal data.

8 Discussion

In 2012, automatic heap detection in airborne laser scanning (ALS) data was included in CultSearcher. This has been used on ALS data from Larvik municipality in Vestfold County, and led to the sensational discovery (Guhnfeldt, 2012) of a grave field which was not present in the "Askeladden" Norwegian national cultural heritage database. For known 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.

Section 2 contained a detailed assessment of CultSearcher's automatic heap detection results for some known grave fields in Larvik municipality. Since then, the method has been improved, (Trier et al., 2012, included in this report as Section 7). As an example, two of the missing mounds from the April 2012 automatic detection results for the Ødelund grave field (mounds nos. 800 and 814, Figure 68) are now being detected by the latest version of the method (Figure 69). Further, mounds nos. 815 and 818 are now detected with correct size and high confidence instead of low confidence.

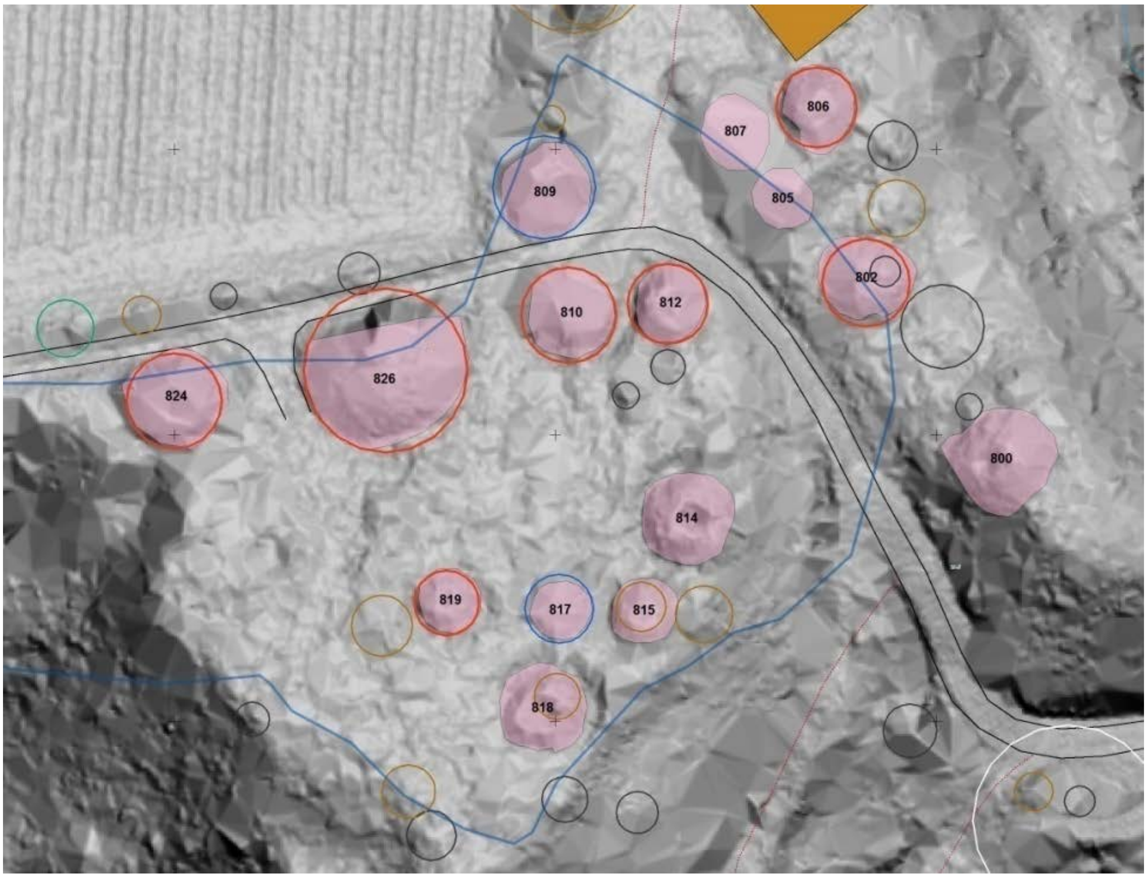

Figure 68. The Ødelund grave field. Pink shaded polygons: confirmed grave mounds from June 2012 field survey. Coloured circles: automatic heap detections, with red=high confidence, blue=medium high, brown=low, black=very low, and white=zero confidence.

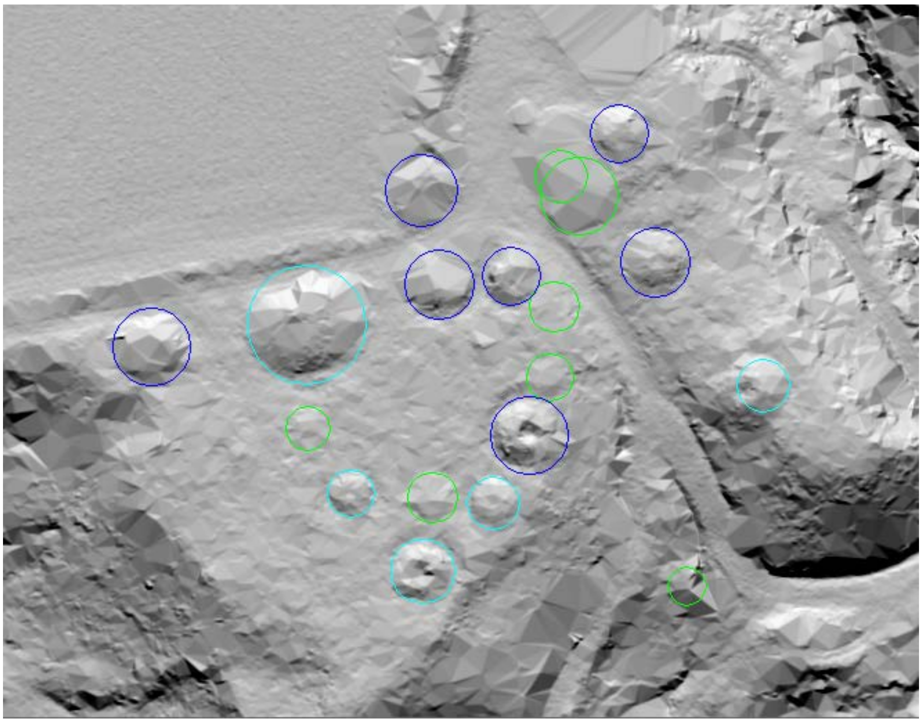

Figure 69. Automatic heap detections at Ødelund. Blue=very high confidence, cyan=high, and green=medium high confidence.

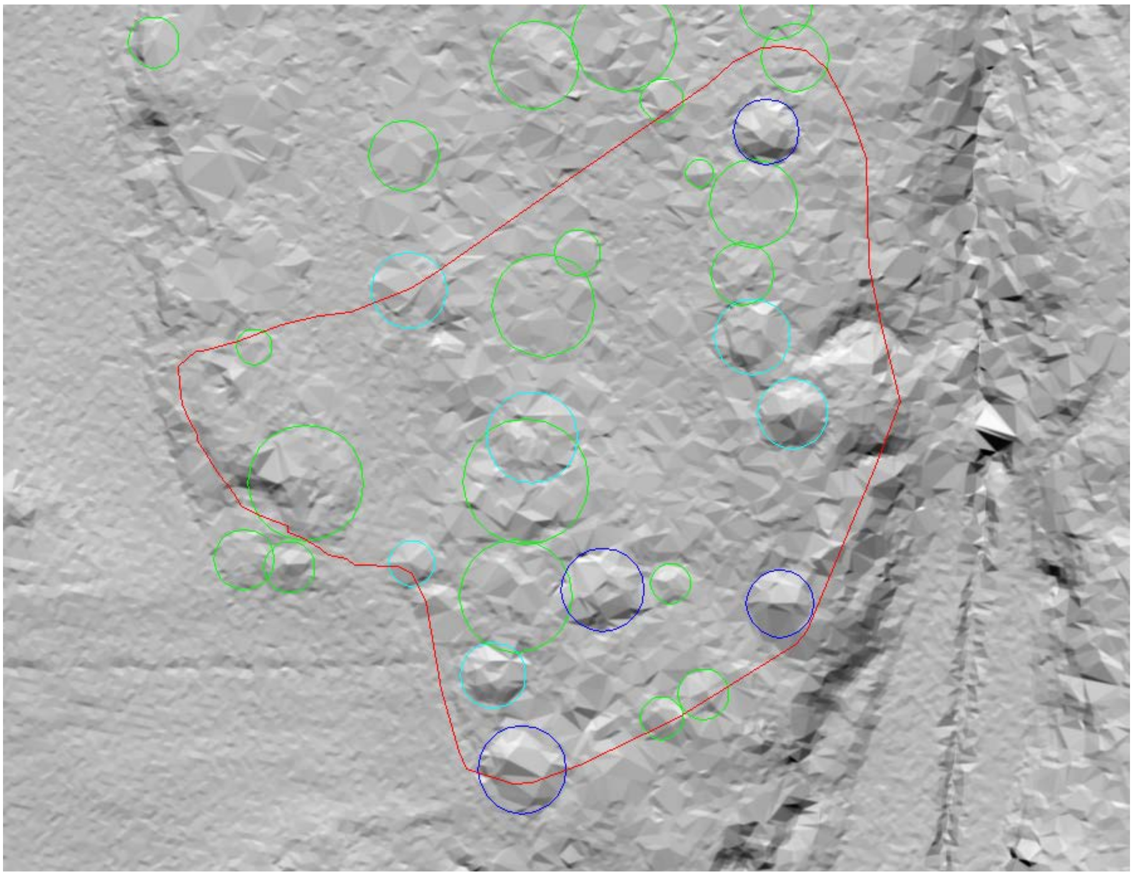

Figure 70. Automatic heap detections at Omsland Nordre: blue=very high confidence, cyan=high, and green=medium high confidence. Red outline=outline of grave field according to Askeladden, prior to survey of June 2012.

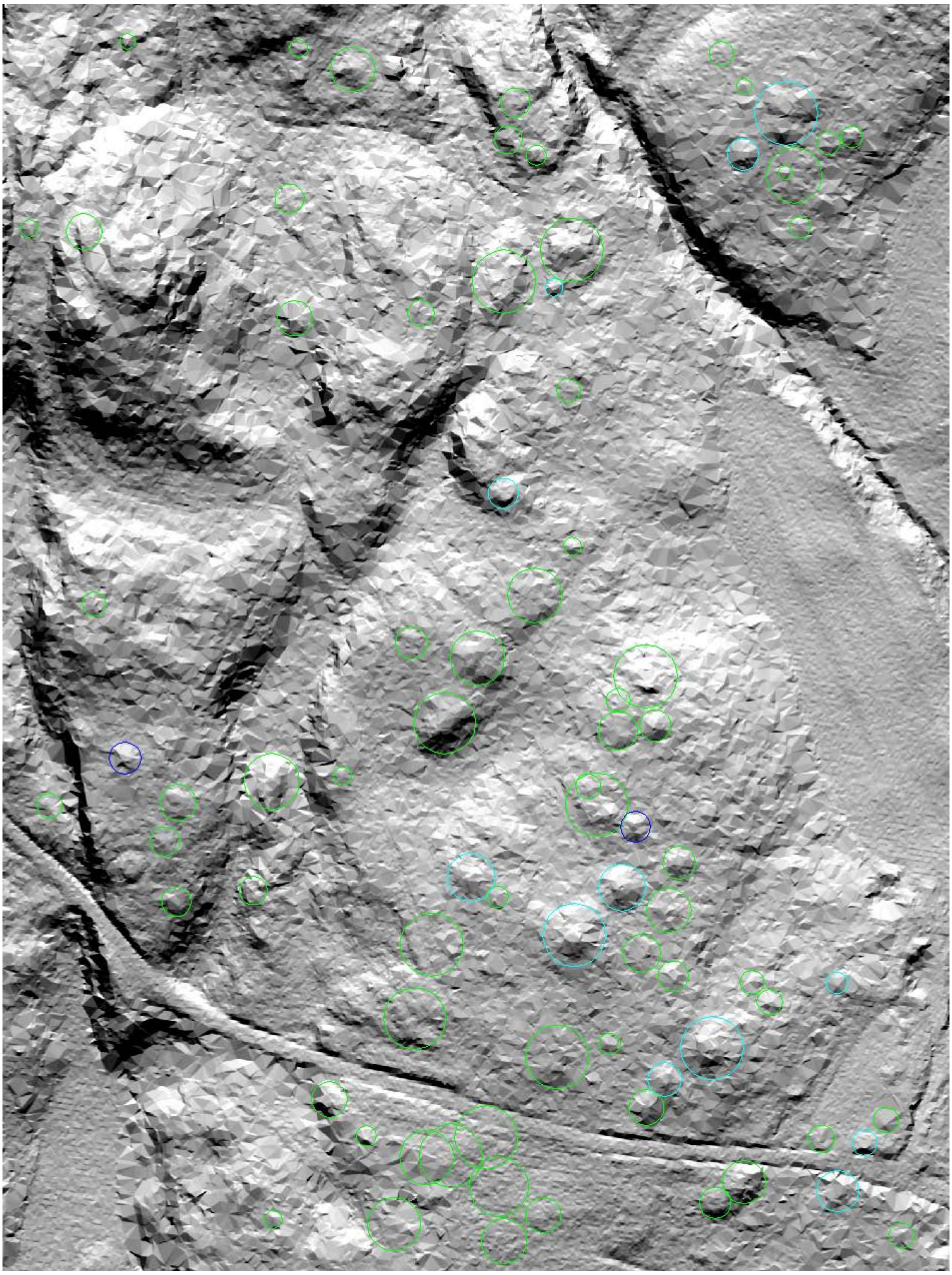

Figure 71. Automatic heap detections at Omsland Søndre: blue=very high confidence, cyan=high, and green=medium high confidence.

The sensational discovery at Omsland Søndre may lead one to believe that $1/m^2$ ALS pulse density is sufficient for semi-automatic detection of grave mounds in forested terrain. However, although the automatic heap detection method in CultSearcher did indeed detect 16 out of 19 previously unknown grave mounds at Omsland Søndre, the DEM is so coarse that it is difficult to do a visual assessment of the DEM as to which heaps are grave mounds and which are not, and to spot grave mounds that the automatic method missed (Figure 71). The same is true for the known grave field ad Ødelund Nordre (Figure 70). The coarseness of the DEM is a combined effect of low ALS pulse density (1/m^2) and dense forest vegetation. Whenever the forest tree vegetation is not too dense, allowing some ALS pulses to hit the ground and be reflected back to the ALS sensor, an increase in ALS pulse density may result in a more detailed DEM of the ground beneath the tree vegetation. However, if a tree is so dense that no ALS pulses reach the ground beneath it, then the patch of the DEM under that tree will be coarse no matter what the ALS pulse density is. On the other hand, when there is little tree vegetation, as is the case for the grave field at Skauen søndre, about 1 km south of the grave field ad Lunde søndre, the ALS ground point DEM can be reasonably good even at 1/m2 ALS pulse density (Figure 72). However, even in this grave field, there are patches of much coarser DEM locally (e.g., see enlargements in Figure 72), due to scattered trees.

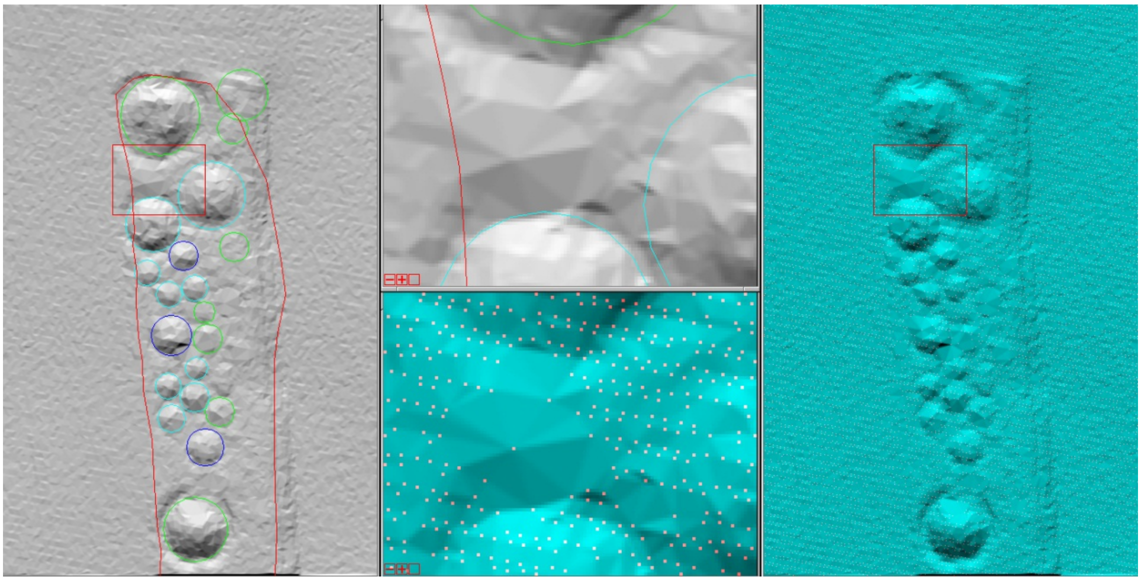

Figure 72. Grave field at Skauen søndre. Left: DEM with automatic heap detections from CultSearcher, with blue=very high confidence, cyan=high confidence, and green=medium high confidence. Red=outline of grave field according to Askeladden. Right: DEM hillshade in cyan, and ALS ground points in pink. Middle: enlargement of the little red square in the left and right images.

The automatic pit detection method in CultSearcher, which had been used successfully on some ALS datasets in Oppland County in 2011, was used on more ALS datasets in Oppland in 2012. The automatic pit detection works well when the terrain surface is even or slightly undulating. When the terrain gets “bumpy” the number of false detections increases sharply, and the value of the detections decreases. In addition modern structures like buildings, roads and ditches lead to false detections. As an experienced user of detection data these false detections are easily dismissed, but more inexperienced users may find this confusing.

It would be valuable if future Cultsearcher pit detections also would include information about the presence/absence of a low bank around the pits. It would also make Cultsearcher detections visually easier to use if detections connected to modern structures were filtered out. The same goes for areas with a high number of false detections due to terrain.

Automatic pit detection has also been run on ALS data from Ørland municipality, Sør-Trøndelag County, but automatic heap detection also needs to be done.

8.1 Planned work for 2013

The plans for 2013 include:

1. Run CultSearcher on more ALS datasets
2. Further development of the CultSearcher software
3. Field work to verify automatic detections by CultSearcher
4. Internet pilot portal for running CultSearcher
5. Satellite acquisition if favourable weather conditions
6. Publication

8.1.1 Run automatic detection on more ALS datasets

We will run CultSearcher on more ALS datasets. Oppland will get more ALS datasets of large areas in 2013. There are existing ALS datasets in Vestfold that we plan to run automatic heap detection on: Bommestad (2009), Lardal (2009), Sande-Svelvik (2010), and Andebu (2009).

In Sør-Trøndelag, there are two available ALS datasets: Ørland (2010) and Røros (2012). For Ørland, automatic pit detection has already been done, but heap detection should also be done. The Røros data set contains both pitfall traps (Figure 73) and flat coal burning sites (Figure 74).

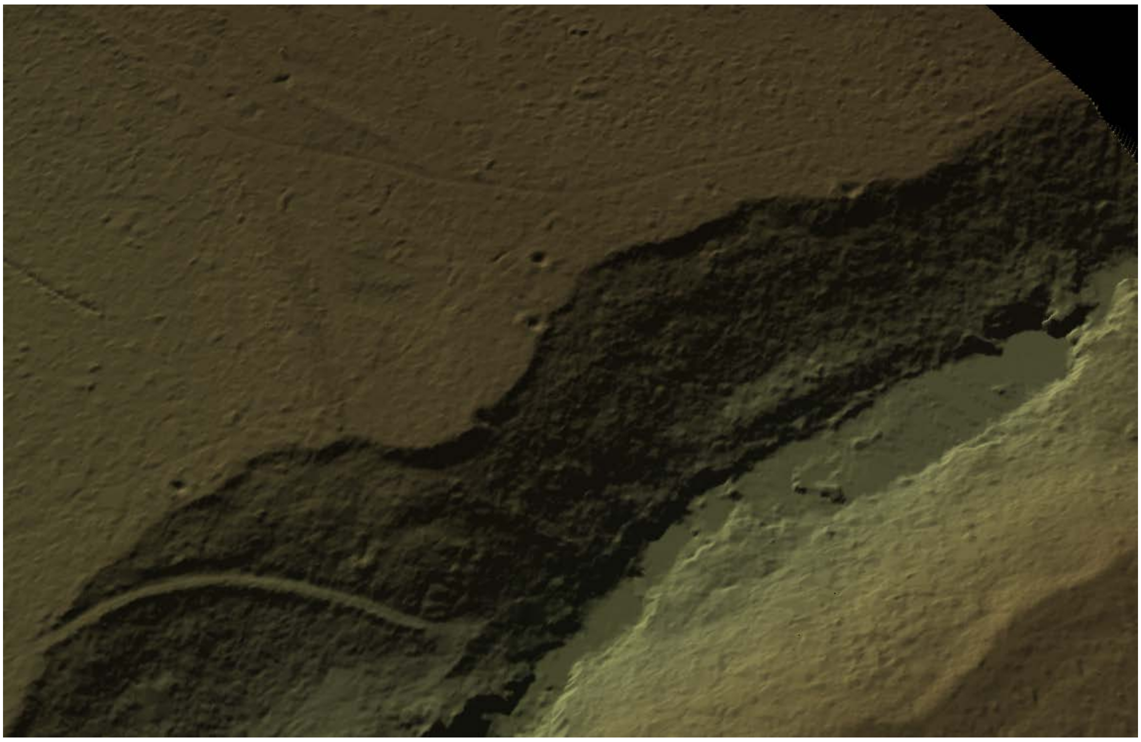

Figure 73. Pitfall traps in the Røros ALS data set.

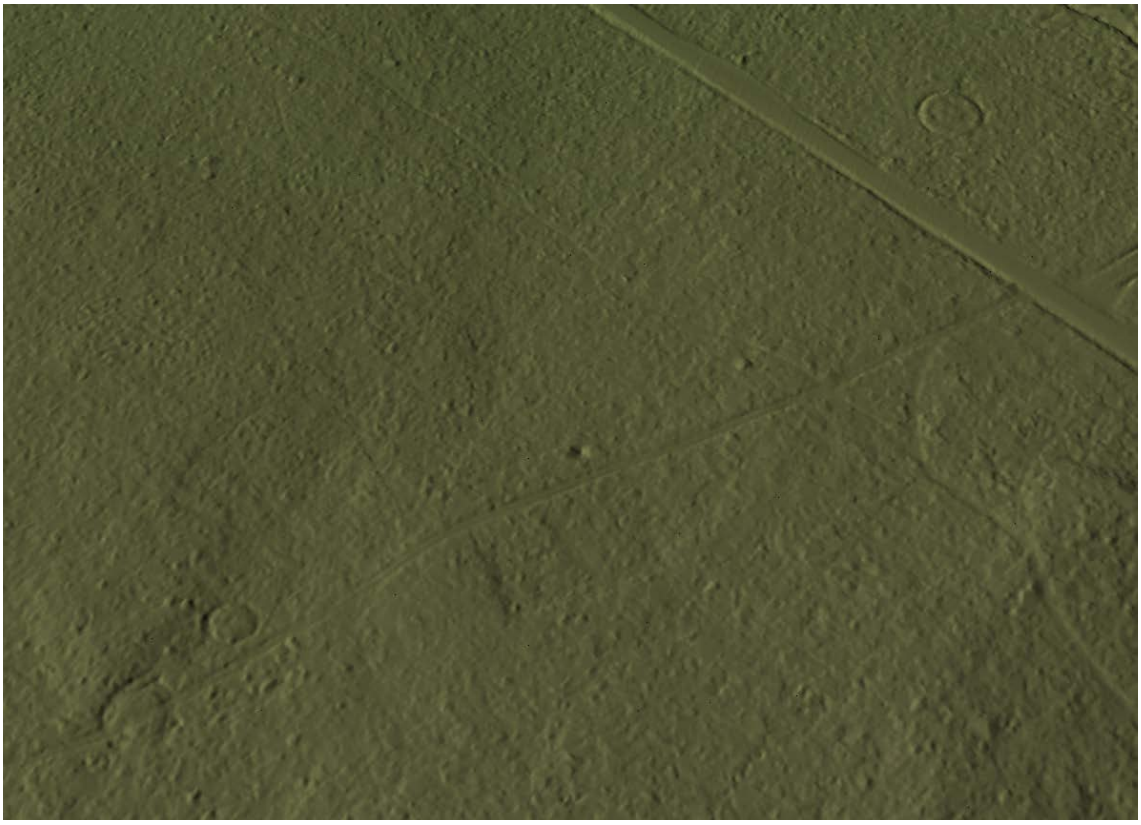

Figure 74. Three flat coal burning sites, seen by the surrounding circular ditches, in the Røros ALS data set.

8.1.2 Further development of CultSearcher

A number of possible improvements of CultSearcher have been identified:

1. At the moment, CultSearcher creates one DEM for each LAS file, and runs automatic detection on these individual DEMs. We have seen a few cases, where, say, a pitfall trap is on the border of two neighbouring DEM files. The step that converts LAS files to DEM files should include, say, a 10 m wide strip from each neighbouring LAS file. This will make it possible to detect circular objects (heaps, pits, etc.) that intersect the LAS file boundaries.

2. At the moment, pit and heap detection has been done on one resolution only, 0.2 m. This has put a limit on the size of pit and heap templates that can be used. The reason is that one of the processing steps is a convolution of the DEM image with a pit or heap template, and the execution time is proportional to the number of pixels in the template, which is proportional to the square of the diameter of the template. So, in order to keep execution times within reasonable limits, templates with larger pit or heap diameters than a specific maximum diameter have not been used. This could be the reason why some large grave mounds at Lunde søndre were not detected.

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

For the Røros dataset, a large number of flat coal burning sites exist. These are flat circular areas surrounded by a circular ditch. In order to find these automatically, a new detection method must be developed. It will have many common processing steps to the existing ones for automatic heap and pit detection in ALS data, but will also have some novel steps.

8.1.3 Field work to verify automatic detections by CultSearcher

In order to improve the detection methods in CultSearcher, it is vital that true archaeological objects be verified by field survey, especially the ones that were missed by CultSearcher, but also the ones that were found. The preferred format is a Microsoft Excel file with LAS file name, UTM coordinates in meters, diameter in meters, CultSearcher confidence level, archaeological interpretation, whether this was done by field survey or visual inspection of the DEM, and any other recorded information. In addition, a shape file with surveyed, confirmed archaeological objects is desired (one shape file for each type of object).

8.1.4 Internet pilot portal for running CultSearcher

The project has already developed a pilot portal for running CultSearcher. However, there are some technical issues, preventing it from running on anything but very small datasets. We should look into the possibility of splitting the process up in smaller IDL jobs, so that if one of them doesn't finish within reasonable time, processing may continue, ignoring the missing parts, which, however, need to be flagged in a processing report.

8.1.5 Satellite acquisition if favourable weather conditions

We will continue to monitor selected areas in Vestfold and Sør-Trøndelag for favourable conditions for crop marks in cereal fields, and if so, order Worldview-2 images.

8.1.6 Publication

An abstract entitled "grave mounds discovered by automatic heap detection method" by Øivind Due Trier, Maciel Zortea, Christer Tonning and Anke Loska has been accepted for oral presentation at the 4th EARSeL Workshop on Cultural and Natural Heritage, 6-7 June 2013, Matera, Italy (Trier *et al.*, 2013).

Based on feedback on the presentation and further improvements of the heap detection method, we plan to submit a journal paper on automatic heap detection in ALS data.

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