Norsk Regnesentral
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Note

Application of satellite data in management of cultural heritage

Project Report 2008

Note no: SAMBA/08/09

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Norsk Regnesentral

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Cover page photo

Aerial photo taken by archaeologist Dagfinn Skre in August 2001 of site Lauve (Gbnr. 2023/1, 15), Larvik Municipality. These well-defined ring ditches were also visually confirmed in an Ikonos image.

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Abstract

This report describes the achievements of the project during 2008. The CultSearcher software has been tested on many agricultural areas in Vestfold County. This has given a broader overview of potential obstacles and important experience for further development of the ring detection algorithms. Some improvements have been implemented in the user interface as well as the detection algorithm, the latter in order to increase the number of detections of real crop and soil marks as well as reducing the number of detections of non-interesting marks. Also, an approach for making a frequency map of potential cultural heritage in agricultural fields ('probability maps') has been developed and tested out for a region in Vestfold County. Since there is interest in the methodological approach of CultSearcher in other county administrations as well, a dialogue has been established with Sør-Trøndelag and Oppland County Administrations. The 2008 project was led by the Norwegian Computing Center (Norsk Regnesentral, NR), who carried out the project under a contract with the Norwegian Directorate for Cultural Heritage (Riksantikvaren, RA), who funded the project. The user side was represented by the Vestfold County Administration (Vestfold fylkeskommune) and the Norwegian Institute for Cultural Heritage Research (Norsk Institutt for Kulturminneforskning, NIKU).

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Target group	Archaeological management, archaeologists
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Research field	Earth observation
Number of pages	54

Executive summary

The main focus of the 2008 project was to cover most of the Vestfold County with satellite images and carry out large-scale application and evaluation of the CultSearcher system analysing these data. This has given important experience with the system and a broader overview of obstacles, which is crucial for further improvement of the ring detection algorithm. Some improvements have been implemented in the user interface as well as the detection algorithm, the latter in order to increase the number of detections of real crop and soil marks as well as reducing the number of detections of non-interesting marks. Also, an approach for making a frequency map of potential cultural heritage in agricultural fields ('probability maps') has been developed and tested out for a region in Vestfold County. Since there is interest in the methodological approach of CultSearcher in other county administrations as well, a dialogue has been established with Sør-Trøndelag and Oppland County administrations.

The idea of a probability or frequency map is to give an overview indicating where archaeological sites, in this case ring structures, are frequent. A frequency map could then be a tool where to proceed with further investigation. The procedure used was to run CultSearcher on the Ikonos image, flagging detected ring centres, and finally using Krieging to produce a continuous frequency map over the area. The frequency map approach was this year only an illustration of the method of making such a map.

In order to make comprehensive satellite coverage of the Vestfold County, four new archived Ikonos images were ordered and applied together with four other Ikonos images bought previously. Selected parts of these images were investigated intensively by Vestfold County Administration (VFK) and Norwegian Institute for Cultural Heritage Research (NIKU) in order to test CultSearcher on a larger number of known ring structures as well as regions where undiscovered ring structures might be present. These experiments also gave NR valuable input for improvements of the detection algorithm as well as the user interface.

Although the archaeologists concluded that the current version of CultSearcher is a marked improvement over previous versions – both in user-friendliness and in its capability for detecting archaeological features – they felt that a substantial amount of work remains to create a working tool for archaeologists. The main concern is that the software in its default setting detects far too many features for the archaeologist to validate, or, if the settings are tightened, far too few.

Furthermore, finding a suitable parameter set manually has also proven difficult. These concerns are well illustrated by the testing performed in the area where known crop marks were present. With certain settings all the crop marks could be detected, but the amount of false detections around these was far too high for an efficient use of the program. Similarly, if the settings were tightened, only a few of these highly visible features would be detected.

Improvements of the CultSearcher software might include improvements of the template matching step, the use of a statistical method to find the threshold for the correlation image computing features that measure the deviation from the ideal ring, improved decision tree classifier, and extraction of features from the original image instead of/in addition to the local contrast-enhanced image or another transformed version of the image. It has also become apparent that the Ikonos satellite imagery is not sufficiently suited to this type of work, and that satellite imagery with higher resolution might yield better detection results.

Contents

1 Introduction

The increasingly intensive use and modification of the landscape resulting from modern demands for efficient infrastructure and land use (agriculture, road construction, urban development, energy sources, leisure/tourism facilities, etc.) exerts growing pressure on cultural heritage in the landscape. In order to match the political intentions of updated and sustainable cultural heritage management, it is necessary to develop a cost-effective method for locating and monitoring cultural heritage sites. In recognition of this, a 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 early stage of the project focused on the development of automated methods, such as pattern recognition, for detecting and locating potential cultural heritage sites. The working assumption is that cultural heritage sites with no visual apparent manifestations above ground may be detectable in satellite images due to alterations in the spectral signature of the bare soil or of uniform vegetation growing there (crops). During the last project years the aim was to develop a software prototype, CultSearcher, to provide computerized assistance in the analysis of satellite images. In particular, the software marks possible sites that could be further inspection by an archaeologist.

The methods currently used in CultSearcher to search for potential cultural heritage sites are performed in three main steps: *Segmentation, feature extraction* and *classification*. In the first step potentially interesting locations are detected as image segments, in the second step characteristics of these segments are computed, before the last step undertakes a classification of the various segments by comparing them to inherent class descriptors. Before these main steps are performed, the images have to be imported, and regions/areas of interest must be identified (agricultural fields). After the main steps, the results need to be checked. In addition, the system contains functionality for interactive training of the algorithm to recognize and discriminate between the various region types (classes) of interest and non-interest.

The 2008 project was led by the Norwegian Computing Center (Norsk Regnesentral, NR), who carried out the project under a contract with the Norwegian Directorate for Cultural Heritage (Riksantikvaren, RA), who funded the project. The user side was represented by the Vestfold County Administration (Vestfold fylkeskommune, VFK) and the Norwegian Institute for Cultural Heritage Research (Norsk Institutt for Kulturminneforskning, NIKU). The aim of their involvement was twofold: Firstly, to test how capable the software would is detecting actual archaeological features in satellite imagery; and secondly, it was aimed at testing the suitability and functionality of the software for use in a cultural heritage management environment.

The main focus of the 2008 project was to cover most of the Vestfold County with satellite images and carry out large-scale application and evaluation of the CultSearcher system analysing these data. This has given important experience with the system and a broader overview of obstacles, which is crucial for further improvement of the ring detection algorithm. Some improvements have been implemented in the user interface as well as the detection algorithm, the latter in order to increase the number of detections of real crop and soil marks as well as reducing the number of detections of non-interesting marks. Also, an approach for making a frequency map of potential cultural heritage in agricultural fields ('probability maps') has been developed and tested out for a region in Vestfold County. Since there is interest in the methodological approach of CultSearcher in other county administrations as well, a dialogue has been established with Sør-Trøndelag and Oppland County administrations.

The user representatives concludes that CultSearcher is clearly still a prototype software, but with significant potential. It can offer archaeologists a better view of what to expect when prospecting and excavating agrarian landscapes. From visual inspections of satellite imagery it became evident that archaeological features can in fact be seen from space in the form of ring-shaped crop marks. The user interface in CultSearcher and the process from creating masks and importing satellite images to extracting the final interpretation of detections is still somewhat complicated. However, the current main obstacle is that the user of the system has to go through too many false detections. The main focus of further development of ring detection should, therefore, be to reduce the number of false detections significantly and at the same time assure that most actual sites of interest are detected.

2 New satellite data

At the start of 2008, four images made from Ikonos scenes had been acquired. These were selected to cover areas along the E18 highway through Vestfold. The scenes are numbered from south towards north in Table 1. In addition, a Quickbird image covering a part of Lågendalen was available. In **Figure 1** the areas covered by the images are shown. The Ikonos images along E18 are shown in cyan, while the Quickbird image is shown in magenta.

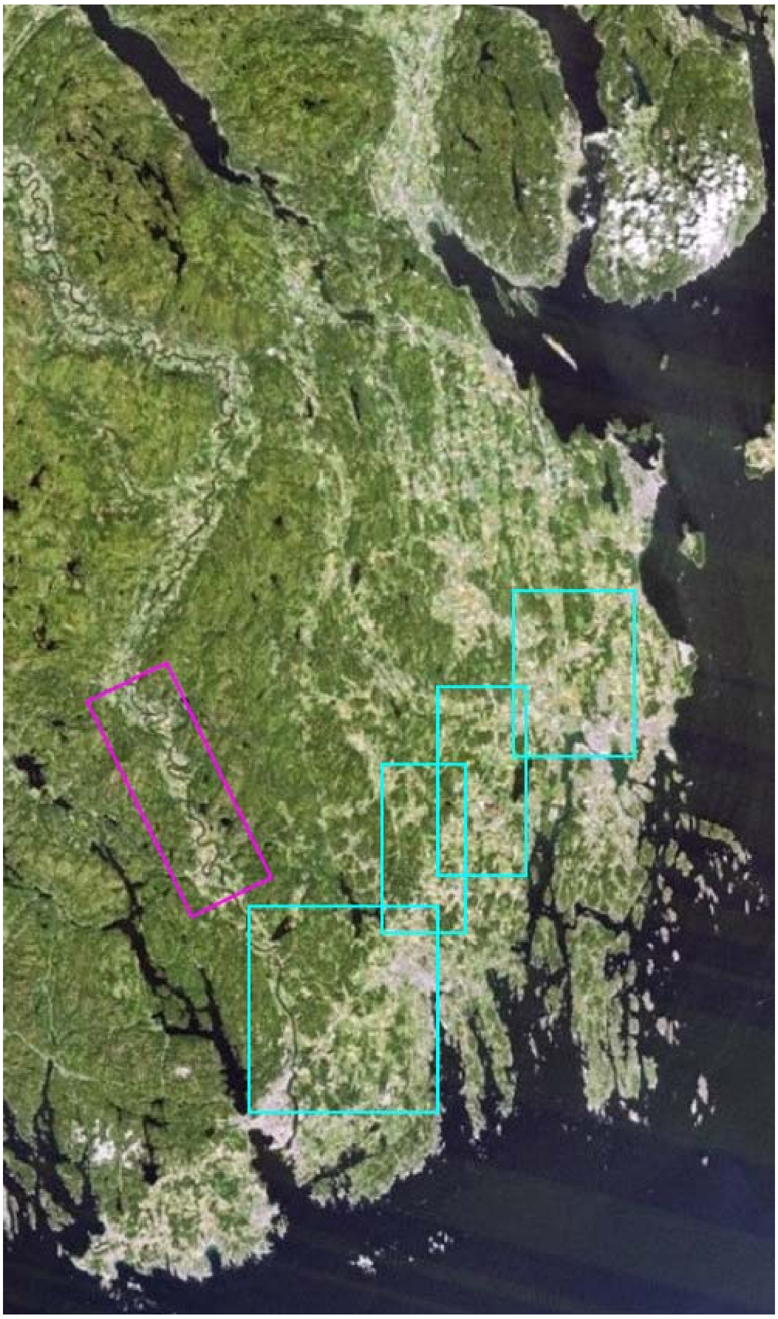


Figure 1. Satellite scenes delivered before 2008. Cyan: Ikonos images covering E18, magenta: Quickbird image covering part of Lågendalen

Table 1. Ikonos and Quickbird images from Vestfold County delivered before 2008.

Region	Satellite	Date	Time (UTC)	Off nadir angle (degrees)	Area (km²)
E18 1	Ikonos	30.06.2006	11:12	26.6	155
E18 2	Ikonos	30.06.2006	11.12	26.6	54
E18 3	Ikonos	13.08.2001	10:51	14.7	68
E18 4	Ikonos	13.08.2001	10:51	14.7	74
Lågendalen	Quickbird	27.04.2005	10:45	20.4	88

Table 2. Ikonos images from Vestfold County delivered in 2008.

Region	Satellite	Date	Time (UTC)	Off nadir angle (degrees)	Area (km²)
Lågendalen	Ikonos	24.08.2002	10:56	7,7	206
Vestfold east	Ikonos	13.08.2001	10:51	14,7	209
Tønsberg	Ikonos	10.07.2006	10:39	26,7	153
Tjølling	Ikonos	30.06.2006	11:12	26,6	63

In 2008 four new Ikonos images were acquired. The characteristics of these images are listed in Table 2. The areas covered by these images are shown in Figure 2.

The following parts of Vestfold were not covered:

- The Sande area in the north, approximately 63 km². An Ikonos scene from 30 June 2006 covers this region.
- The central areas of Vestfold, from Eikeren in the north to the northern parts of Larvik and Sandefjord in the south. This region is also covered by Ikonos scenes from 30 June 2006. The size of the total area is around 300 km², but there is a high proportion of forest in this region, so it should be possible to reduce the size when ordering images.
- The southern part of Tjøme. The area is covered by Ikonos scenes from 10 July 2006 and 13 July 2006. The area is not particularly large, but the minimum size of ordered archive images is 49 km².
- Brunlanes, the south-western part of Larvik. This area is not covered by existing Ikonos or Quickbird images. To order new images, the minimum size is 64 km² for Quickbird and 100 km² for Ikonos.

The price of archive images is $ 23.40 per km² for Ikonos and $ 20 for Quickbird. For new images the price is $ 29.25 for Ikonos and $ 25 for Quickbird.

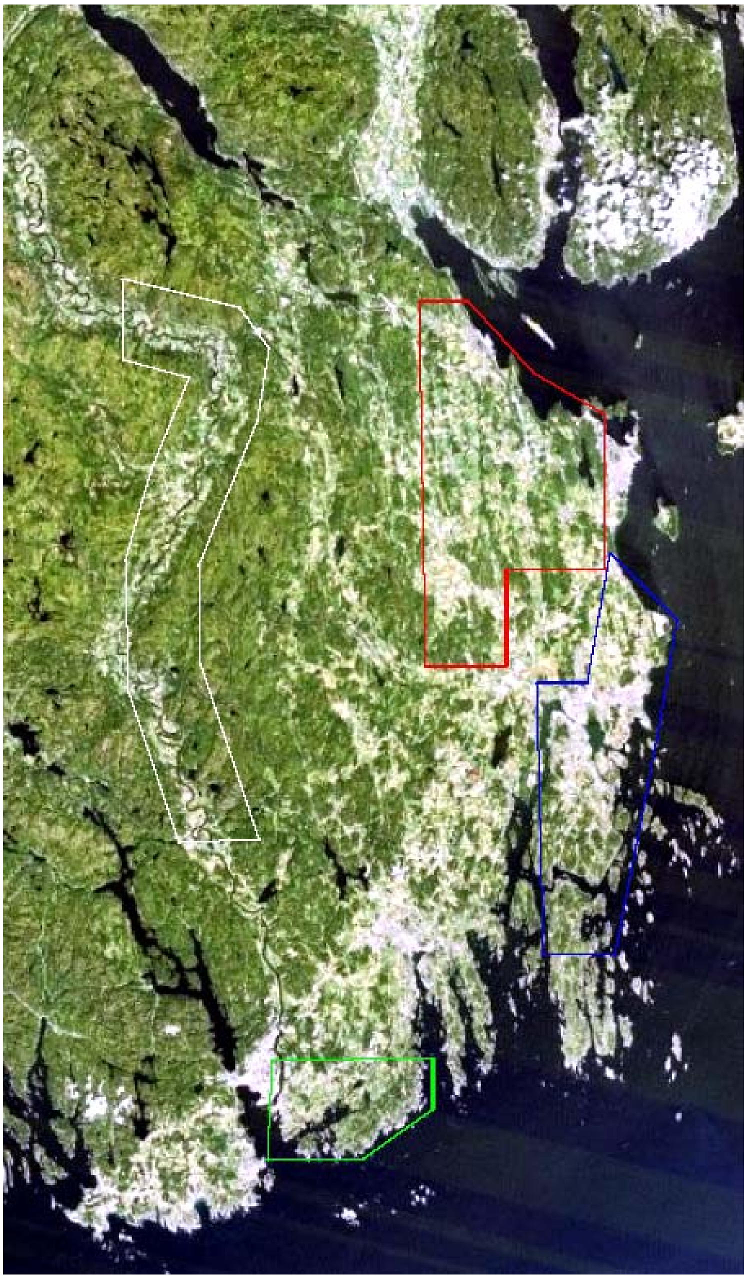


Figure 2. Ikonos images from Vestfold delivered in 2008. White: Lågendalen; red: Vestfold east; blue: Tønsberg; green: Tjølling

3 Testing and evaluating CultSearcher, VFK

3.1 Choosing the experimental data for testing

For 2008, the Vestfold County Administration has focused on the CultSearcher functionality, testing out the program and weeding out bugs and weak spots while doing a practical search for ring shaped structures on well-known cultural heritage sites in Vestfold County. We received the first working version of CultSearcher with the embedded ring structure algorithm on the 1st of July 2008.

In the late 1970s and early 1980s the Norwegian archaeologist Per Haavaldsen conducted systematic flights in Vestfold County. He photographed and recorded 18 sites from the air, in which ring ditches connected with Iron Age burial mounds were found. In addition to these sites documented by Haavaldsen (two examples appear in Figure 3 and Figure 4), data exists for 10 new sites discovered in later years. A total of 28 sites have been subject to investigation by Vestfold County Administration in 2008, using the CultSearcher tool. Note that the four- and five-digit IDs in Figure 3 to Figure 5 are unique identifiers in the Norwegian national archaeological database *Askeladden*.

Before starting the work with CultSearcher's embedded ring algorithm in 2008, these sites were considered to be of vital importance when tuning the program for optimal detection patterns of real ring ditches, and decimating the number of false detections.

Figure 3. Oblique aerial image (ID13037) in Larvik municipality taken from airplane reconnaissance in 1977. Within the ring ditch a boat shaped structure is clearly visible. (Photo: P. Haavaldsen, Museum of Cultural Heritage, University of Oslo)

Figure 4. Oblique aerial image (ID 9990) in Sandefjord municipality. (Photo: P. Haavaldsen, Museum of Cultural Heritage, University of Oslo)

In 2007-2008 the project acquired Ikonos satellite images from Eurimage, primarily taken during the harvest season in Vestfold County (July-August), in order to secure the best possible conditions for crop-mark detections. Despite these considerations, the hotspots of historically documented ring ditches/graves were quite difficult to spot in the satellite images. This has a composite causality:

- Due to changes in crops in some fields, where cereals (wheat, barley, etc) previously were cultivated, now carrot or potato crops are cultivated. These are not suited for crop-mark detection.
- The satellite images show great variations in background contrast. This is probably due to ground variations and the time of day for the satellite image acquisition. For example, the field including the site ID 9990 (Figure 4) is clearly visible in the aerial photo, but in the Ikonos image the field turns out white, and is impossible to interpret.
- Seasonality is of vital importance when documenting these sites in the Vestfold County (and Norway in general). Cold spring/summer weather may cause delay, and a smaller crop when harvesting. The optimal conditions when documenting crop marks is during a warm and long-lasting period close to harvest time. When satellite imagery is taken during a 'normal' season, the crop marks can be quite difficult to detect with the human eye.
- Major soil works like ground levelling, water pipes, irrigation etc may disturb the visibility of the sites.
- The Ikonos satellite images are now considered by the project as less suited for detection of over-ploughed cultural heritage sites. The resolution in Ikonos images with a ground pixel size of 1 meter is too coarse in many cases.

3.2 The research area

The Ikonos images that the Vestfold County Administration has worked on consist of 8 scenes (Table 3).

Table 3. Ikonos images covering parts of Vestfold County.

Name	Date of capture
Vestfold east	August 13, 2001
Tønsberg	July 10, 2006
Tjølling	June 30, 2006
Lågendalen	August 24, 2002
E18 Tønsberg	August 13, 2003
E18 Torp	June 30, 2006
E18 Stokke	August 13, 2003
E18 Larvik-Sandefjord	June 30, 2006

The research area was limited by the archive footage (available at, e.g., DigitalGlobe, http://www.digitalglobe.com). The southernmost part of Vestfold County was not present in the archive.

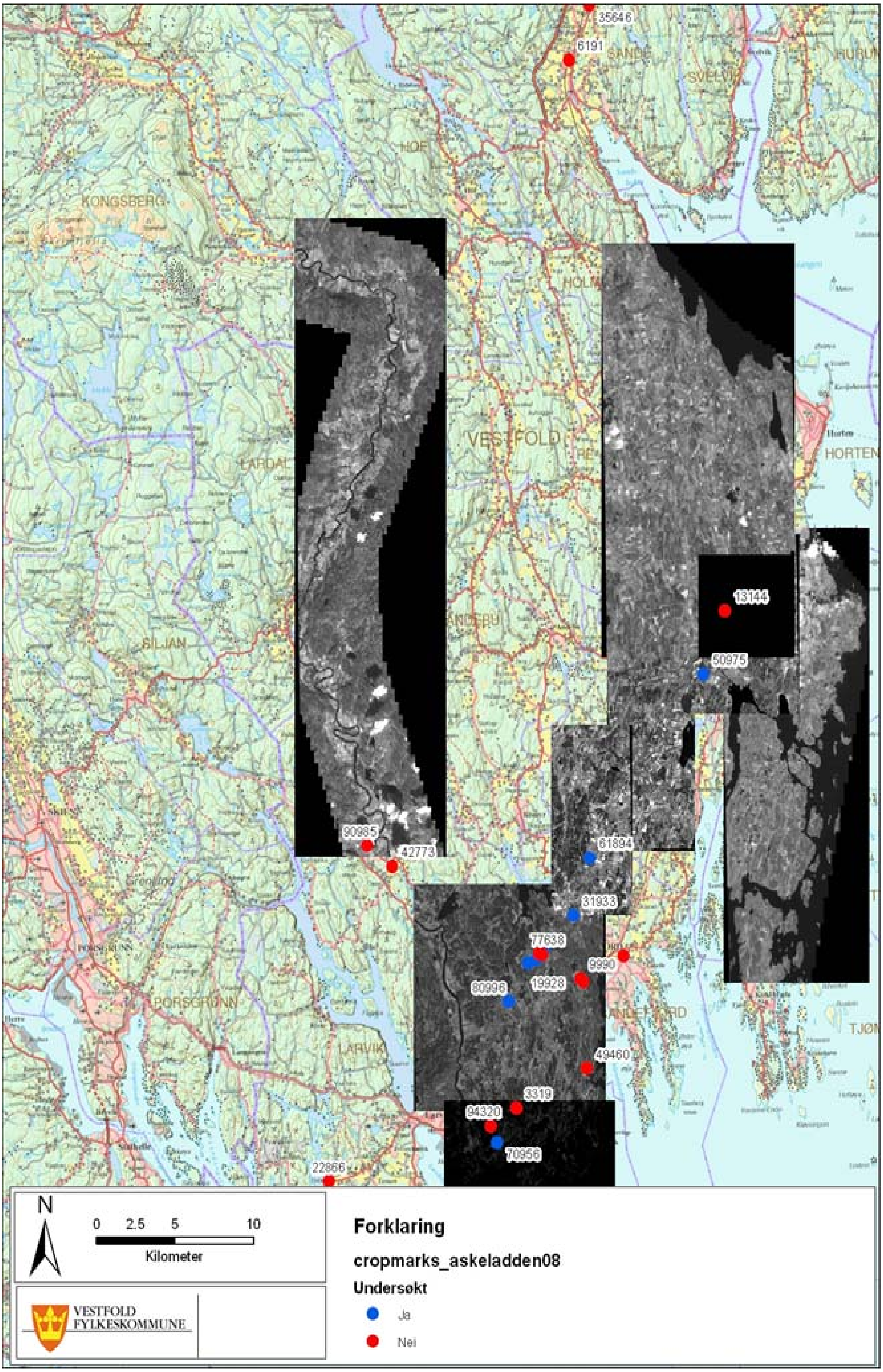


Figure 5. The Ikonos scenes which have been used in the investigation. The red and blue dots marks the hotspots with historically documented crop marks from airplane and field observations.

Figure 6. The alternatives for the single parameter in the simple parameter settings dialogue.

Figure 7. The available parameters in the advanced parameter settings dialogue.

3.3 Procedure for working with CultSearcher

A preliminary investigation was conducted before the work with the historically known sites was undertaken. As mentioned above, we had difficulties observing these sites in the Ikonos imagery, and the tuning of CultSearcher was therefore focused on cultural heritage sites in which undisputable ring ditches were recognized in the Ikonos imagery. Before a search with CultSearcher starts, certain parameters must be set. The system developers have given users two alternatives for setting the search parameters. These are: "User specified Class Definitions" (Figure 6) and "Advanced parameter settings" (Figure 7). We started out trying the first alternative. However, we quickly discovered that CultSearcher returned far too many false detections of ring ditches, or too few. When using the "Advanced parameter settings" options, a more refined parameter tuning was possible.

This tuning process eased the phase of interpreting the detections greatly. For example at the location Lauve in the Larvik municipality (visible in the E18 Larvik-Sandefjord image at N 6554900 E 559997, Euref89, UTM32N), a search with the condition "strict" in "User Specified Class Definitions" returns 1 detection, which is false. Setting the condition down to "relaxed" returns 8 detections, all false. Finally, setting the condition "very relaxed" returns 12 detections all false. In contrast, as we shall se below, by using the advanced parameter settings and tuning the parameters, eight true detections were made (Table 4).

Trying to use Cultsearcher on a large data set proved difficult. The original plan was to use a large vector data set when applying masks for arable land. This data set is readily available to Vestfold County Administration through the *Norway Digital* (Norge Digitalt) organization. The Ikonos images are geographically rectified but not with sufficient accuracy to use them together with the vector dataset for arable land. When we first tried this procedure, CultSearcher returned a vast amount of detections. CultSearcher detected roads, woodland, woodland shadow close to arable land, houses etc. It proved impossible to work efficiently with these datasets because of the great number of detections and the comprehensive process of validating these results. A different approach was to create smaller masks which consisted of arable land close to the historically known sites mentioned above. By using the "Advanced parameter settings" alternative in combination with smaller masks, we were able to tune in to visually confirmed detections, and at the same time not getting too many false detections. When creating these limited masks, we used the GIS application ArcMap (version 9.2 or 9.3) to create an Esri shape file. This was done simply because we needed additional map data which were viewed alongside the Ikonos images. (Creation of masks can also be done inside the Envi program.) The Esri shape file was then imported to Envi and converted to a mask file. Using the ROI (region of interest) file, CultSearcher cuts Ikonos panchromatic images to smaller views and automatically

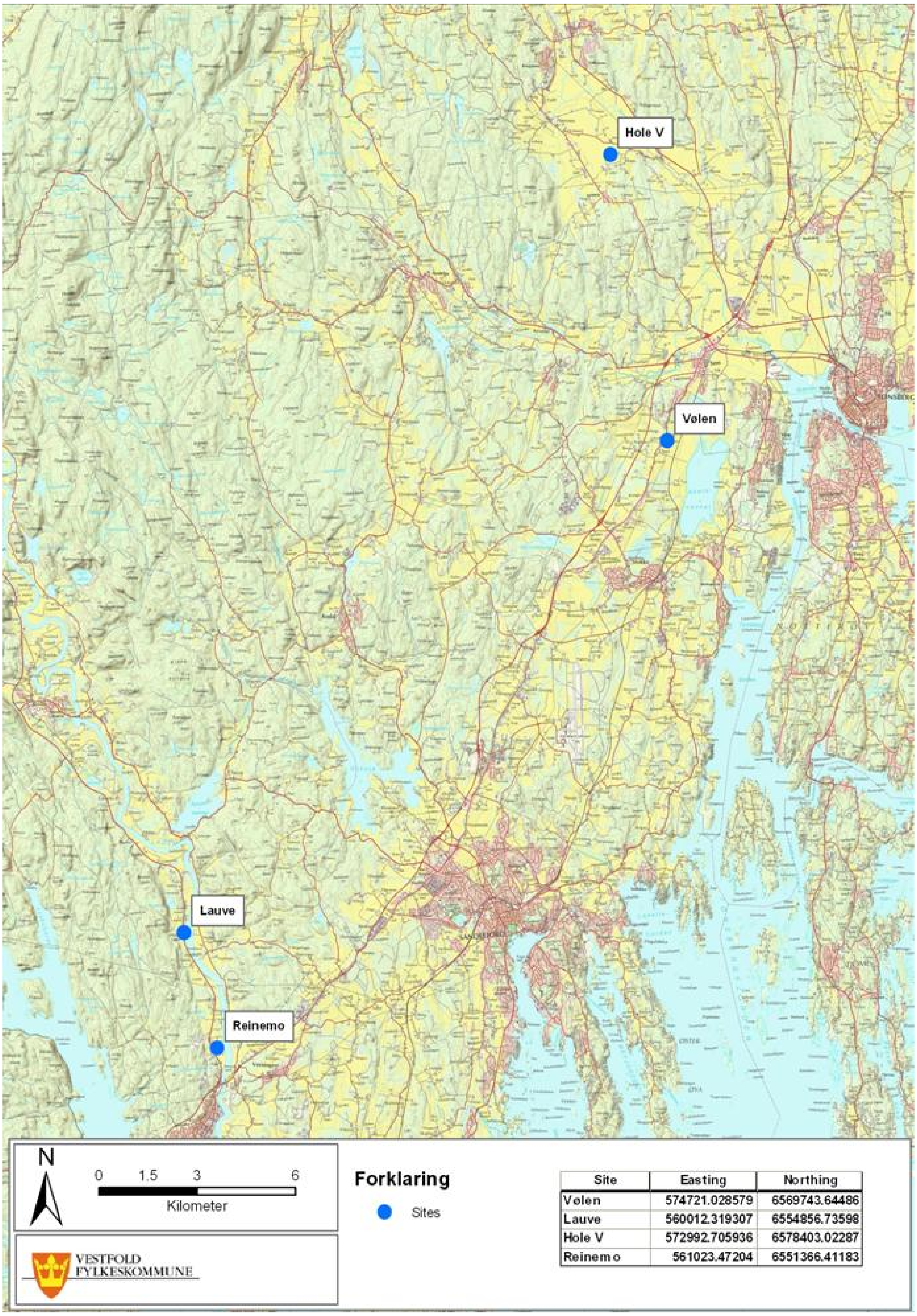


Figure 8. The location of the four sites in Vestfold County.

creates a contrast-enhanced image, which CultSearcher then uses alongside the original clip for optimal detection. When detection is finished the validation session can begin. The final product from the validation step is a ROI file containing the detected circular patterns that the user has verified.

3.4 The test sites

The tuning of CultSearcher was performed on four sites, in which we had a good visual confirmation of over-ploughed ring ditches in the Ikonos imagery. For three of these sites, we had good visual confirmation of ring ditches in other data (e.g., orthophoto and oblique aerial photographs). On the fourth site we only had visual confirmation of ring ditches in the Ikonos image. The four sites are Lauve, Vølen, Reinemo and Hole Vestre (Figure 8).

3.4.1 Site Lauve

Site Lauve (Gbnr. 2023/1, 15), Larvik Municipality (Ikonos image E18 Larvik Sandefjord) was first detected when documenting crop mark sites in 2001 (Figure 9). These well-defined ring ditches were also visually confirmed in the Ikonos image “E18 Larvik-Sandefjord”. When tuning CultSearcher for the best possible detection performance, we adjusted the parameters in “Advanced Parameter Settings” (Figure 7).

Figure 9. Aerial photo taken by archaeologist Dagfinn Skre in August 2001, of the site at Lauve, viewed towards east.

Site	MinRad x 0.1m	MaxRad x 0.1m	RadStep x 0.1m	MinSim	Ring template	No of detections	Confirmed detections
Lauve	45	250	5	20	1	212	Cancelled
Lauve	45	250	5	30	1	12	1
Lauve	45	200	5	33	1	8	1
Lauve	45	250	5	25	1	66	Min 1, not verified all.
Lauve	**100**	**450**	**5**	**20**	**2**	**58**	**8**
Lauve	100	450	5	20	3	30	2
Lauve	100	450	5	20	4	76	0

Table 4. The advanced parameter settings for the site Lauve. The best set of parameters is marked in blue

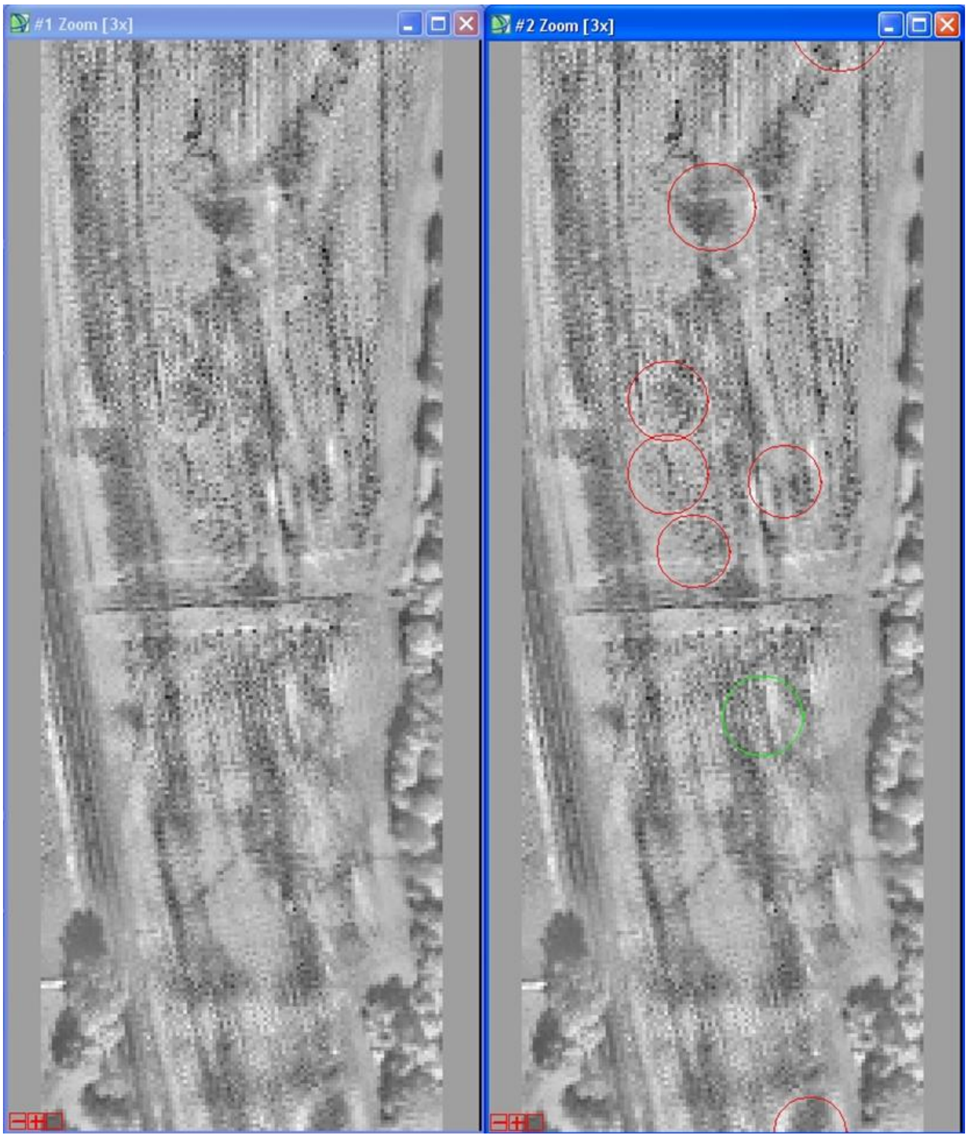


Figure 10. Left: A portion of an Ikonos satellite image over a site in a cereal field in Lauve, Larvik Municipality. Here, archaeologist Dagfinn Skre photographed a grave field in 2001 (Figure 9). Right: Running CultSearcher on the Ikonos image resulted in 7 definite detections of ring ditches connected to Iron Age grave mounds. The images are oriented with north upwards.

The experiences with using CultSearcher on the Lauve site are, in general, good. By adjusting the parameters, CultSearcher reaches a high detection rate on Lauve (Table 4). The best set of parameters here is marked in blue. The field is cultivated with a crop that produces crop marks, the background contrast is acceptable, and no major earthworks that could disturb the result have been performed.

3.4.2 Site Vølen

The Vølen site (Gbnr. 85/4), Stokke Municipality, Ikonos E18 Stokke, was detected during archaeological survey during the summer of 2007, where Vestfold County archaeologists found two connected ring ditches (Figure 11). The new site is a continuation of an already registered and intact grave mound. When we received the Ikonos images for Stokke Municipality in the autumn of 2007, we also discovered the grave field in the satellite image (Figure 12). Here we have unambiguous evidence that our interpretations of ring ditches in satellite images truly are ring ditches. The Vølen site is therefore well suited as a test site.

Figure 11. Two ring ditches, which were discovered during archaeological fieldwork at Vølen. The already registered grave mound, with ID 21803-1, is visible in the background.

Figure 12. Part of the Ikonos image 'E-18 Stokke', which covers the Vølen test site. Ring ditches are clearly visible inside the red circle

Table 5 lists the different parameter settings and the detection results for the Vølen test site. Experiences using CultSearcher on the Vølen site is in general very good, despite that the fields surrounding the site and the field on the site are partially dried out and/or the crop has fallen down (wind fall). Several parameter settings (Table 5) result in the detection of both ring ditches found by Vestfold County Administration in 2007. The preferred parameter setting is marked in blue. This results in an acceptable amount of detections to validate, and the detection of the two known ring ditches.

Site	MinRad x 0.1m	MaxRad x 0.1m	RadStep x 0.1m	MinSim x 0.1m	Ring template	No of detections	Confirmed detections
Vølen	45	350	4	24	2	0	-
Vølen	45	350	4	24	1	1	0
Vølen	45	350	4	24	3	5	1
Vølen	45	450	4	24	4	33	0
Vølen	45	450	4	24	1	1	0
Vølen	45	450	5	20	2	142	2
Vølen	45	450	5	24	1	142	2
Vølen	45	450	5	26	1	95	2
Vølen	45	450	5	28	1	65	2
Vølen	45	450	5	30	1	41	2
Vølen	**45**	**450**	**5**	**32**	**1**	**29**	**2**
Vølen	45	450	5	34	1	21	1

Table 5 CultSearcher parameter settings for the site Vølen

Figure 13. The two confirmed ring ditches at Vølen. Left: a portion of the original panchromatic image, right: the contrast enhanced version.

3.4.3 Site Reinemo

Site Reinemo (Gbnr 2029/1), Larvik Municipality, Ikonos image E18 Larvik Sandefjord, was discovered during air photography of an excavation site nearby (Bommestad) in 2006 by archaeologist Tom Heibreen. The site on the Heibreen photo is divided in two parts (Figure 14), a western part with one large confirmed ring ditch, and an eastern part close to the river Lågen consisting of 3 smaller ring ditches. In the Ikonos image (Figure 15), only the eastern part of the site is visible.

Figure 14. Aerial photo from 2006 of the site at Reinemo. Photo by Tom Heibreen, the Museum of Cultural Heritage, the University of Oslo

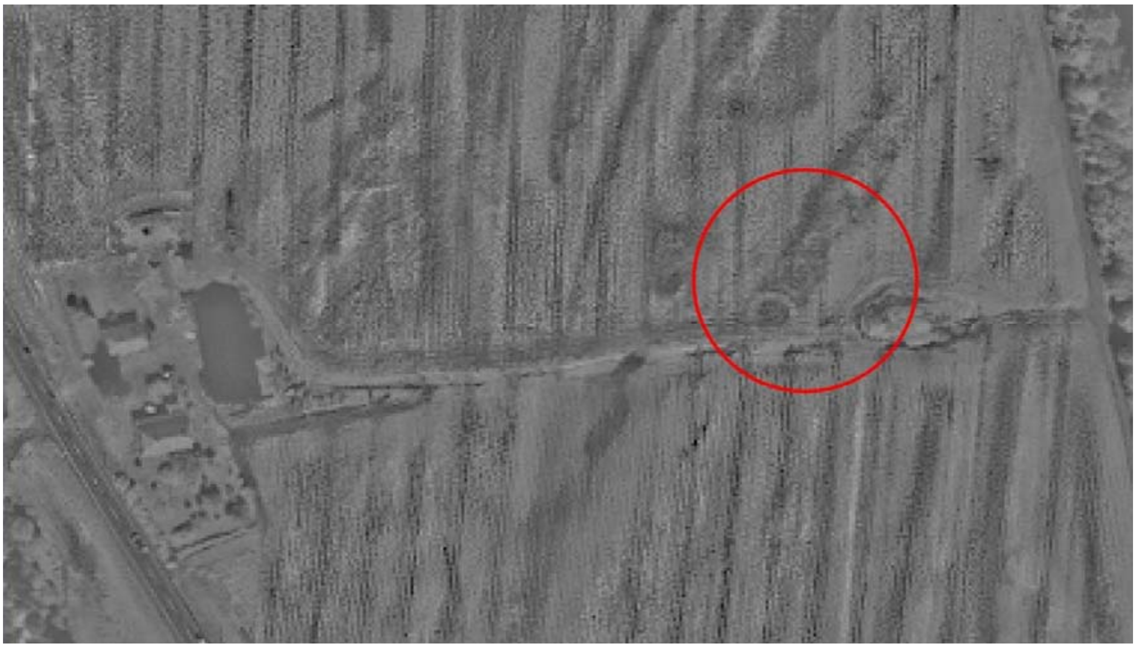


Figure 15. Part of the Ikonos image "E18 Sandefjord-Larvik", showing the Reinemo site. Inside the red ring, three ring ditches are clearly visible. The largest has a radius of 7.5 m.

Site	MinRad	MaxRad	RadStep	MinSim	Ring template	No of detections	Confirmed detections
Reinemo	85	450	5	25	1	11	0
Reinemo	45	450	5	25	1	421	Cancelled
Reinemo	45	450	5	25	2	1000+	1
Reinemo	45	450	5	25	2	500+	1
Reinemo	45	450	5	35	2	574	1
Reinemo	45	450	5	40	2	236	1
Reinemo	45	450	5	35	3	35	0
Reinemo	45	450	5	35	4	222	1
Reinemo	45	450	5	35	5	85	0
Reinemo	45	450	5	45	4	87	1
Reinemo	45	450	5	60	4	2	0
Reinemo	**45**	**450**	**5**	**50**	**4**	**33**	**1**
Reinemo	**45**	**450**	**5**	**34**	**1**	**32**	**1**

Table 6. The CultSearcher search parameters for the site at Reinemo

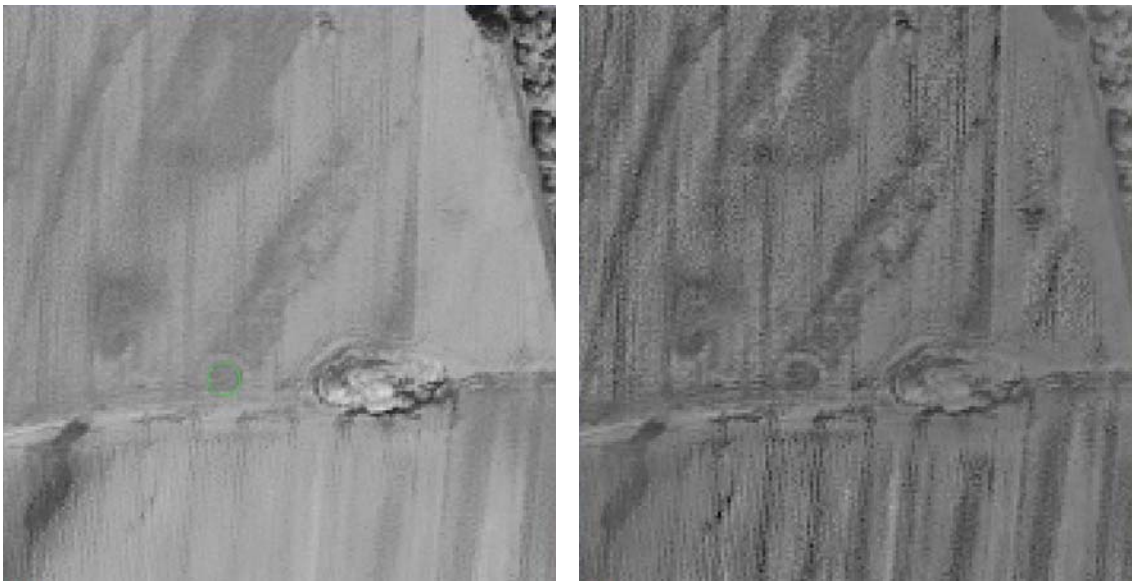


Figure 16. Left: CultSearcher is able to detect the largest ring ditch at Reinemo. Right: the contrast enhanced version of the panchromatic image to the left.

Table 6 lists the different parameter settings and the detection results for the Reinemo test site. The result of using CultSearcher on the Reinemo site is mixed. CultSearcher detects one definite ring ditch (Figure 16), but considering the conditions in the field and the clarity of the ring ditches that were not detected, it is strange that CultSearcher did not find these ring ditches. The preferred parameter values for the Reinemo test site differs from those used for the other sites. This is especially true for the *minimum ring similarity* parameter.

3.4.4 Site Hole Vestre

Site Hole Vestre (Gbnr 255/2), Re Municipality, Ikonos image Vestfold Øst, has been known for a long time and was first registered on the 9th of August 1974 (ID 42100). It was investigated once more in 1992, but by then the original six grave mounds had been over-ploughed and destroyed. The following passage (in Norwegian) is the description of the grave field in the nationwide cultural heritage database "Askeladden":

> *"Inne på kulturbeite og i S-kanten av dyrka mark ligger et gravfelt bestående av 6 rundhauger. Alle haugene er bygd av steinblanda muldjord. 4 av haugene er markert med vag fotgrøft. Alle er tydelige i terrenget. Formen varierer fra jevnt avrunda til brattsida. Skader: Den N-ligste har overpløyd sidekant med utgravd midtparti og sjakt i N-lig retning, l 5m, br 1,5m, dybde 0,7m. Den V-ligste og største haug har dyp sjakt fra sentrum og utover i N-sida, l 5m, br 2m, dybde 0,9m, som trolig er gravd i nyere tid. Steinpakning sees i skjæringa. De øvrige har få skader. Den S-ligste har bare dårlig markering mot S. Her går den nesten i ett med bakkehellinga. Alle har en tykk gressmatte, noe løvkjerr vokser her og der. D 7-23m, h 0,5-1,5m.*
> *Se skisse. Den gamle kirkevegen i bygda gikk forbi feltet. Opplyst v/ Øyvind Øren, 3110 Ramnes. Ved kontroll 1992 av Jan Lindh var haugene overpløyd."* [1]

The Hole Vestre site is visible in the field with well marked ring ditches in the Ikonos image (Figure 17), and is the most unambiguous over-ploughed grave field seen in this project.

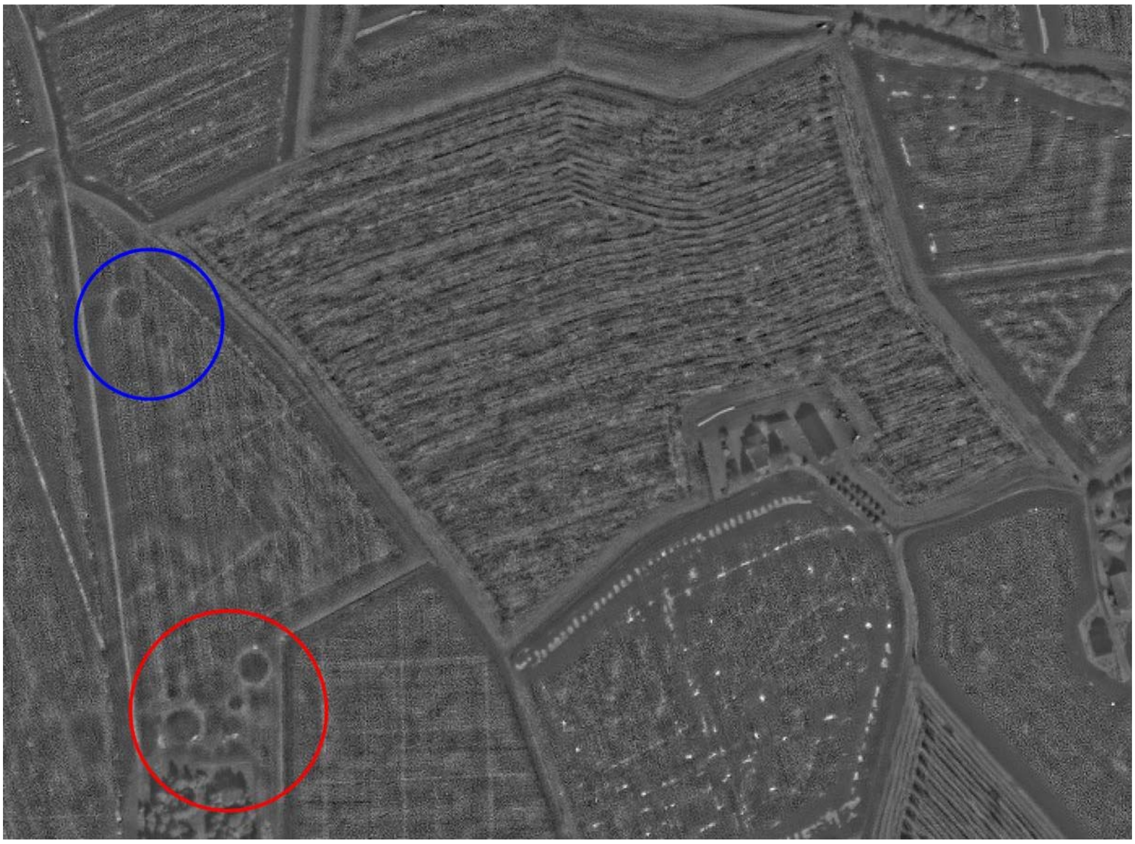


Figure 17. Grave mound sites at Hole Vestre, shown in the contrast-enhanced version of a part of an Ikonos image. The red ring indicates the location of ID 42100. Six grave mounds were situated here in 1974. The blue ring indicates the location of an, until now, unknown site consisting of at least 3 grave mounds.

[1] http://askeladden.ra.no/vis/lokalitet.jsp?minneType=lokalitet&minneId=497333#

Site	MinRad x 0.1m	MaxRad x 0.1m	RadStep x 0.1m	MinSim	Ring template	No of detections	Confirmed detections
Hole V	85	450	5	20	2	1000+	Cancelled
Hole V	85	450	5	35	2	5	2
Hole V	45	450	5	30	2	836	Cancelled
Hole V	45	450	5	40	2	318	Cancelled
Hole V	100	450	5	40	2	2	2
Hole V	**85**	**450**	**5**	**35**	**2**	**18**	**3**
Hole V	85	450	5	35	1	1	1
Hole V	85	450	5	30	1	5	2
Hole V	**85**	**450**	**5**	**25**	**1**	**30**	**3**

Table 7. The CultSearchers search parameters for the site at Hole Vestre.

Askeladden ID	Site Name	Reason for cancellation
13144	Gulli, Tønsberg	Not visible in Ikonos image
90985	Kvelde kirke, Larvik	Site under cloudcover
39818	Virik Østre, Sandefjord	Not visible in Ikonos image
3319	Tjølling prestegård, Larvik	Not visible in Ikonos image
70957	Torp, Larvik	Site not covered by Ikonos image
22866	Halle Østre, Larvik	Site not covered by Ikonos image
94320	Valby, Larvik	Not visible in Ikonos image
42773	Gjone Mellom, Larvik	Site not covered by Ikonos image
35646	Rølles, Sande	Site not covered by Ikonos image
19925	Elgesem, Sandefjord	Not visible in Ikonos image
49460	Bergan, Store, Sandefjord	Not visible in Ikonos image
6191	Ås Østre, Sande	Site not covered by Ikonos image
77638	Elgesem, Sandefjord	Not visible in Ikonos image
21645	Kråkelitraet, Sandefjord	Site not covered by Ikonos image
9990	Virik vestre	Not visible in Ikonos image
13037	Foldvik Nordre	Site not covered by Ikonos image
80996	Ringdal	Site destroyed by road

Table 8. Known ring ditch sites which were unsuitable for detection by CultSearcher.

Table 7 lists the different parameter settings and the detection result for the Hole Vestre test site. Experiences using CultSearcher at Hole Vestre are quite good, although sometimes mixed. CultSearcher detects the largest ring ditches, but in order to detect the smaller ones, the minimum radius must be set below 4.5 m. The drawback when the minimum radius is this low is that the total number of detections is huge, and exceeds what is practical to validate for a human operator.

3.5 Applying the tested parameters on other sites

Of the 28 known ring ditch sites, four have been the subject of thorough testing with CultSearcher. For the remaining 24 sites, 17 were either not covered by Ikonos images that we had acquired, or could not be seen in the Ikonos images for various reasons (Table 8).

The seven remaining sites had potential (correct crop, correct contrast) when looking at the Ikonos images, but there were no crystal-clear ring ditches as on the sites in Section 3.4 above. Nevertheless, CultSearcher was tested on these seven sites, building on experience from the four sites in Section 3.4. In addition to the Ikonos images, we also used available orthophoto series from Norway Digital (Norge Digitalt, www.norgedigitalt.no). This was done if the ring ditches were visible in the orthophoto, in which case a better insight into the geographical extent of the sites could be obtained.

3.5.1 Site Kaupang

The Kaupang site, (Gbnr. 1029 and Bjønnes Gbnr.1031/5), Larvik Munincipality, Ikonos Tjolling (ID 70956), is a world-known archaeological site. The viking town of Kaupang lies south of the registered over-ploughed ring ditches. The ring ditch site is part of the remains of a large viking age grave field connected to the viking town of Kaupang. This grave field is described in Askeladden (in Norwegian):

"Gravfelt på nordre Kaupang, beskrevet og opptegnet av Nicolaysen i 1867. Skråtatte flyfoto av nordre deler av flyfoto er grunnlag for utstrekning. Kristensen skriver i 2005: Registrering vår 2005: Gravfeltene på Kaupang nordre ligger i dag under dyrket mark, bygninger og veier med unntak av et ubestemt antall flatmarksgraver på og ved Bikjholberget. Ingen hauger er i dag synlige over bakken, men spor etter overpløyde graver kan observeres på flyfoto som finnes i Riksantikvarens arkiv. Bildene viser at det trolig har ligget flere gravhauger nord for det området som Nicolaysens kart fra 1867 viser som feltets utstrekning. Vegetasjonsmerke viser mulige fotgrøfter minst 180 m nord for den østligste delen av Nicolaysens gravfelt. Følgende vegetasjonsmerke kan ses på flyfoto: På jordet rett nord for drivhusene på Kaupang nordre, 1029/4, observeres 3 sirkler som kan være fotgrøfter, hvorav den ene må være av om lag samme størrelse som de største på Nicolaysens kart. På jordet NV for drivhuset og på vestsiden av traktorveien til Guri, om lag 50 m mot NV, kan minst 5 sirkler, som trolig er fotgrøfter, ses på flyfoto. Nicolaysens hauger nr. 90, 91, 92 og 93 kan trolig kobles til disse observasjonene (Nicolaysen 1867:77). Haug som er gjenkjent på flyfoto som nr. 91 kan synes å ha en båtformet nedgravning i midten. Den er orientert Ø-V. Litt syd for denne strukturen synes ytterligere en nedgravning. På jordet nord for Guribekken, 200 m N for drivhuset på gnr. 1029/4, kan ytterligere 2 sirkler/fotgrøfter observeres. De ligger på flaten mot jernbanen, mellom åkerholmen og traktorveien. I knekken på jordet, mellom flaten og bakken sydover mot Guribekken, kan et annet vegetasjonsmerke observeres. Det er båtformet og er orientert Ø-V. Dette kan være rester etter en båtgrav. Det observeres ingen sirkel/fotgrøft i tilknytning til denne strukturen. Ved sjaktingen 250 NV for NV-hjørnet på drivhuset på gnr. 1029/4, ble det oppdaget en struktur som trolig er rester etter en fotgrøft (se maskinsjakting, struktur A414). Det kan være en sammenheng mellom denne fotgrøften og gravfeltet i SØ (ID19107, ID70956). Gravfeltet på Kaupang nordre har derfor trolig vært betydelig større enn tidligere antatt, og sannsynligvis også større enn det Nicolaysens kart fra 1867 viste. Hans notat i Norske Fornlevninger om at det i 1859 lå hundrevis av hauger nord for gården (Nicolaysen 1862:199) synes dermed sannsynlig. Registreringene så langt har, sammen med analyse av synlige vegetasjonsmerke på flyfoto, gitt en indikasjon på feltets utstrekning. Gravfeltet kan trolig ha strukket seg minst 200 m lenger nord enn det som går fram av Nicolaysens kart."[2]

For the Kaupang site, a mask based on vector data describing arable land was created. This was done to save time creating masks and because this is a very important national cultural heritage site (Figure 18).

[2] http://askeladden.ra.no/vis/lokalitet.jsp?minneId=592715&minneType=lokalitet

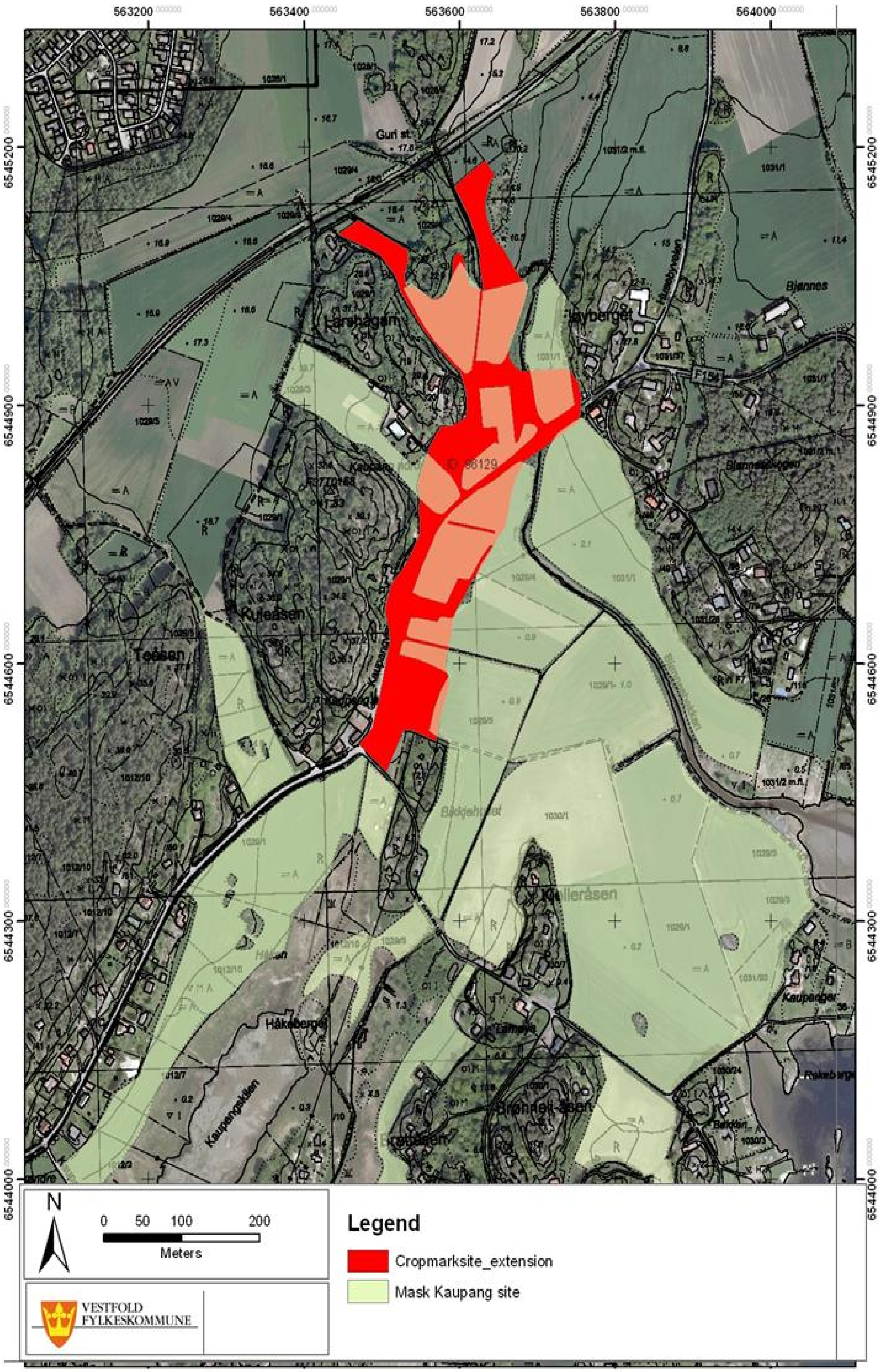


Figure 18. Map of the site at Kaupang, with search mask in pale green.

Site	MinRad x 0.1m	MaxRad x 0.1m	RadStep x 0.1m	MinSim	Ring template	No of detections	Confirmed detections
Kaupang	80	200	5	33	1	4	0
Kaupang	80	200	5	33	2	29	1*
Kaupang	45	200	5	33	2	1243	Cancelled
Kaupang	45	200	5	35	2	Too many	Cancelled
Kaupang	45	200	5	40	2	Too many	Cancelled
Kaupang	45	200	5	60	2	3	0
Kaupang	**45**	**200**	**5**	**50**	**2**	**58**	**2****
Kaupang	**45**	**200**	**5**	**33**	**1**	**118**	**4***
Kaupang	**45**	**200**	**5**	**35**	**1**	**61**	**1***

Table 9. CultSearcher parameters and detection results at the Kaupang site. * Uncertain, ** Uncertain, but lies well within the over-ploughed grave field. The preferred parameter values are marked in blue.

Experiences using CultSearcher at Kaupang site was mixed/poor. An attempt was made to use the search parameters which were relatively good at sites in Section 3.4, but ring template no. 2, which worked well at the Lauve site, returned far too many detections at the Kaupang site.

3.5.2 Site Bjørnumrød

For the site Bjørnumrød (Gbnr. 18/1), Sandefjord Munincipality, Ikonos image E18 Larvik-Sandefjord (ID 61894), several crop marks were observed in the Ikonos image prior to running CultSearcher. However, according to documented air photos only two ring ditches are documented in Askeladden.

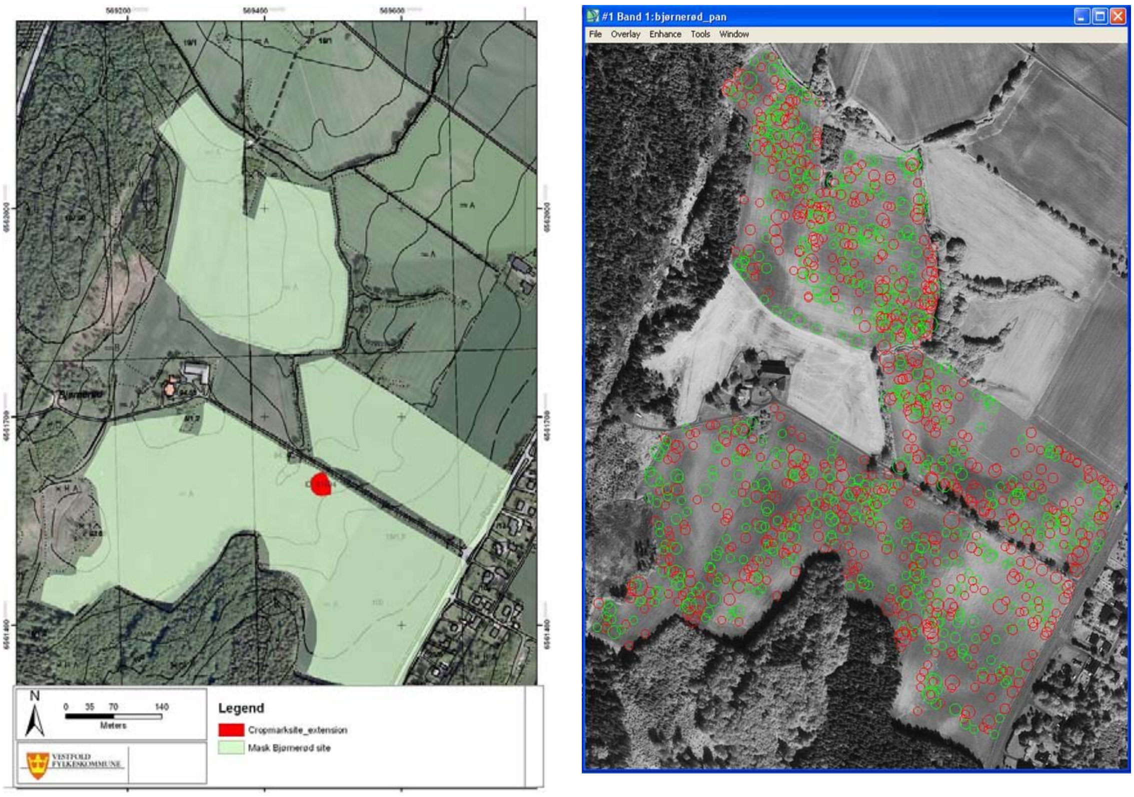


Figure 19. Left: the registered site, and the masks used by CultSearcher. Right: CultSearcher detection result for three fields at the site at Bjørnumrød. The parameters were: ring filter no. 1, minimum similarity = 20 and radius range 4.5 m to 40 m. 1199 detections were made.

Site	MinRad x 0.1m	MaxRad x 0.1m	RadStep x 0.1m	MinSim	Ring template	No of detections	Confirmed detections
Bjørnumrød	45	450	5	20	1	1199	Cancelled
Bjørnumrød	45	450	5	33	2	907	Cancelled
Bjørnumrød	45	450	5	33	1	34	2*
Bjørnumrød	45	450	5	34	1	22	2*

Table 10 CultSearcher search parameters for site Bjørnumrød. * Uncertain, not detections inside known site.

If the same parameters values that were used at Lauve were used at Bjørnumrød, 1199 detections were made, which would then have to be manually verified. The mask at Bjørnumrød exceeds the Lauve mask in size, but nevertheless the search here at Bjørnumrød with the same parameters is quite useless. When trying out the parameters values that were used at Reinemo and Vølen (RF 1, MS 34 and min/max Rad 45-400, the result was 22 detections. Two of these detections were categorized as uncertain. All detections lie well outside the known cultural heritage site

The experience with CultSearcher at Bjørnumrød is mixed/poor, no detections inside the registered site were obtained when using parameters values that do not result in too many detections.

3.5.3 Site Bø

According to descriptions in Askeladden, site Bø (Gbnr.159/16), Sandefjord Municipality, Ikonos image E18 Larvik-Sandefjord (ID 68914), is registered with 6-7 ring ditches. In the description of the site, it is also mentioned that major ground works have been performed here when a major water pipe was dug down. This is also evident in the Ikonos image. No clear ring ditches are evident inside the registered site on the Ikonos image prior to investigation. But unclear crop marks are observed.

Figure 20 The CultSearcher detection results at the site at Bø. Left: Parameters set to: ring template no. 1, minimum similarity = 20, radius range = 4.5 m – 45 m, which gave 267 detections to verify. Right: Parameters set to: ring template no. 1, minimum similarity = 34, radius range = 4.5 m – 45 m, which gave 6 detections.

Site	MinRad x 0.1m	MaxRad x 0.1m	RadStep x 0.1m	MinSim	Ring template	No of detections	Confirmed detections
Bø	45	450	5	34	1	6	0
Bø	45	450	5	34	2	120	Cancelled
Bø	45	450	5	20	1	267	Cancelled
Bø	45	450	5	20	2	583	Cancelled

Figure 21 The CultSearcher parameters used at the site at Bø

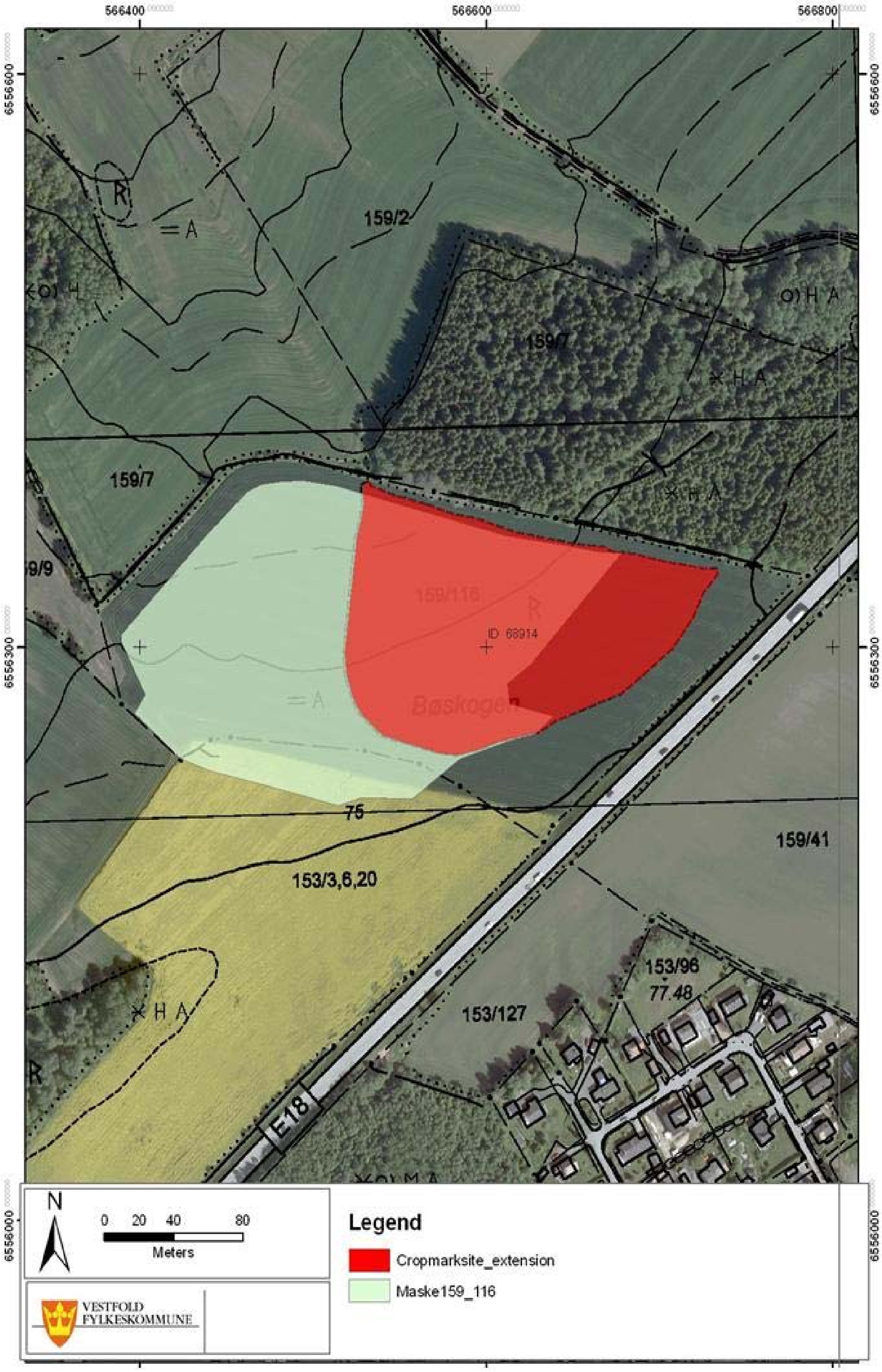


Figure 22 Map of the crop mark site at Bø, with the search mask used in CultSearcher superimposed.

Experience with using CultSearcher at the Bø site is poor. The site is clearly disturbed by modern earthworks. By applying the parameter settings used earlier the overall impression is that the number of false detections is too high, this is probably due to the earthworks disturbances.

3.5.4 Site Elgesem

According to descriptions in Askeladden, site Elgesem (Gbnr. 153/17), Sandefjord Municipality, Ikonos image E18-Larvik Sandefjord (ID 77633), contains at least 32 ring ditches. No ring ditches inside the registered area were observed in the Ikonos image prior to the experiments using CultSearcher.

Site	MinRad x 0.1m	MaxRad x 0.1m	RadStep x 0.1m	MinSim	Ring template	No of detections	Confirmed detections
Elgesem	45	450	5	34	1	13	0
Elgesem	45	450	5	34	2	180	Cancelled
Elgesem	45	450	5	20	1	513	Cancelled

Table 11 The CultSearcher parameters and search results for the site at Elgesem

The experiences using CultSearcher at the site at Elgesem was poor.

Figure 23 The crop mark site registered in Askeladden and the mask used in CultSearcher.

3.5.5 Site Hundstok

According to descriptions in Askeladden, there is one ring ditch at the site Hundstok (Gbnr 12/1), Sandefjord Municipality Ikonos image E18 Larvik-Sandefjord (ID 31933). In addition to the ring ditch, a World War II anti-tank defence structure has been found here. Prior to using CultSearcher, no ring ditches were found inside the registered site by visual inspection of the Ikonos image.

Experiences using CultSearcher at site Hundstok was poor. The vast amount of detections is probably due to plough furrows in the two fields inside the mask.

Figure 24. Map of the registered crop mark site and mask area for CultSearcher investigation.

Site	MinRad x 0.1m	MaxRad x 0.1m	RadStep x 0.1m	MinSim	Ring template	No of detections	Confirmed detections
Hundstok	45	450	5	34	1	17	0
Hundstok	45	450	5	34	2	248	Cancelled
Hundstok	45	450	5	20	1	961	Cancelled

Table 12. The Cultsearcher parameters values used at the site at Hundstok.

3.5.6 Site Auli

According to descriptions in Askeladden site Auli, (Gbnr. 51/9) Tønsberg Municipality, Ikonos image E18 Tønsberg, (ID 50975), should contain a large number of ring ditches. These were visible during air photography in 1993-94. On this site two over-ploughed graves are visible both in the Ikonos image and in the Orthophoto available from Norway Digital.

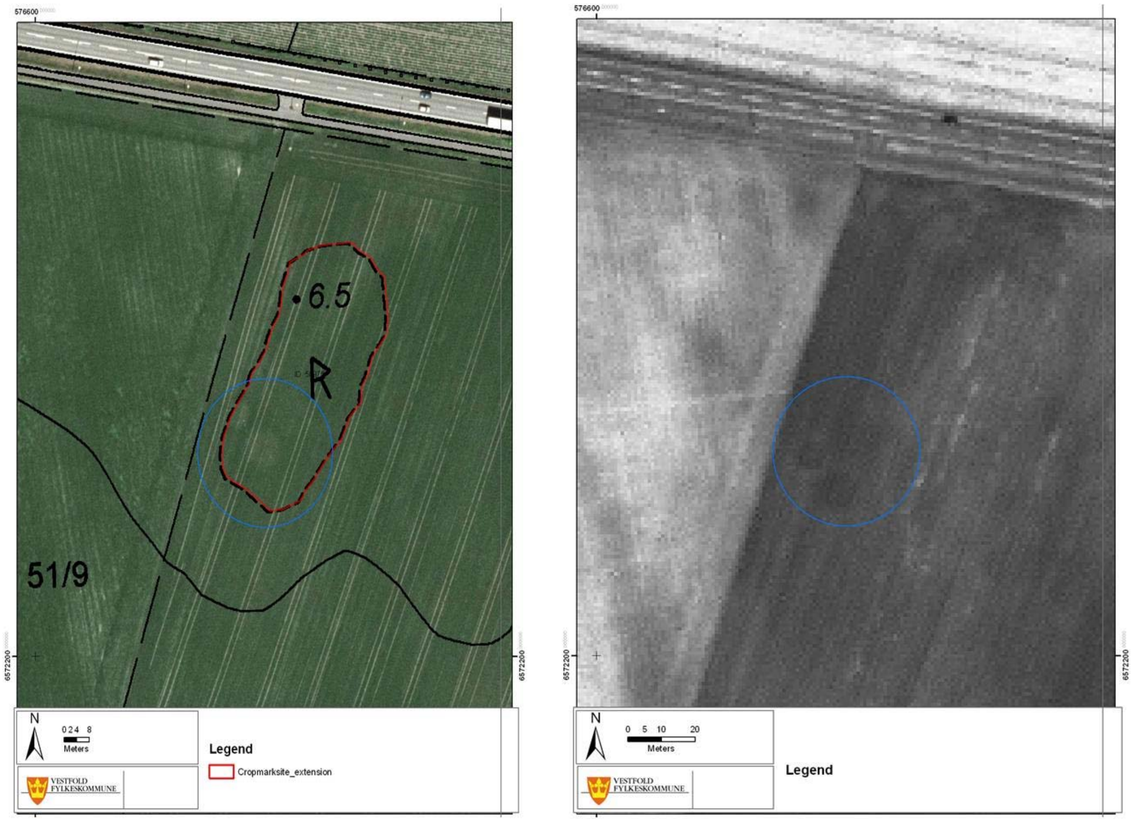


Figure 25. Two over-ploughed graves at the site at Auli. Left: Orthophoto from 1993-94. Right: Ikonos image.

Site	MinRad x 0.1m	MaxRad x 0.1m	RadStep x 0.1m	MinSim	Ring template	No of detections	Confirmed detections
Auli	45	450	5	34	1	34	1
Auli	45	450	5	34	2	705	Cancelled
Auli	45	450	5	33	1	35	1*
Auli	45	450	5	33	2	813	1*

Table 13. CultSearcher parameter values and search results at the site at Auli. * Two new ring ditches detected by the operator, but not by CultSearcher: no. 1 at Northing 6572282, Easting 577002, Euref 89, UTM zone 32N; and no. 2 at N 6572259, E 576663).

The experiences of using CultSearcher at Auli were good. The crop on this field is probably not at its most optimal, but still the ring ditches are clearly visible.

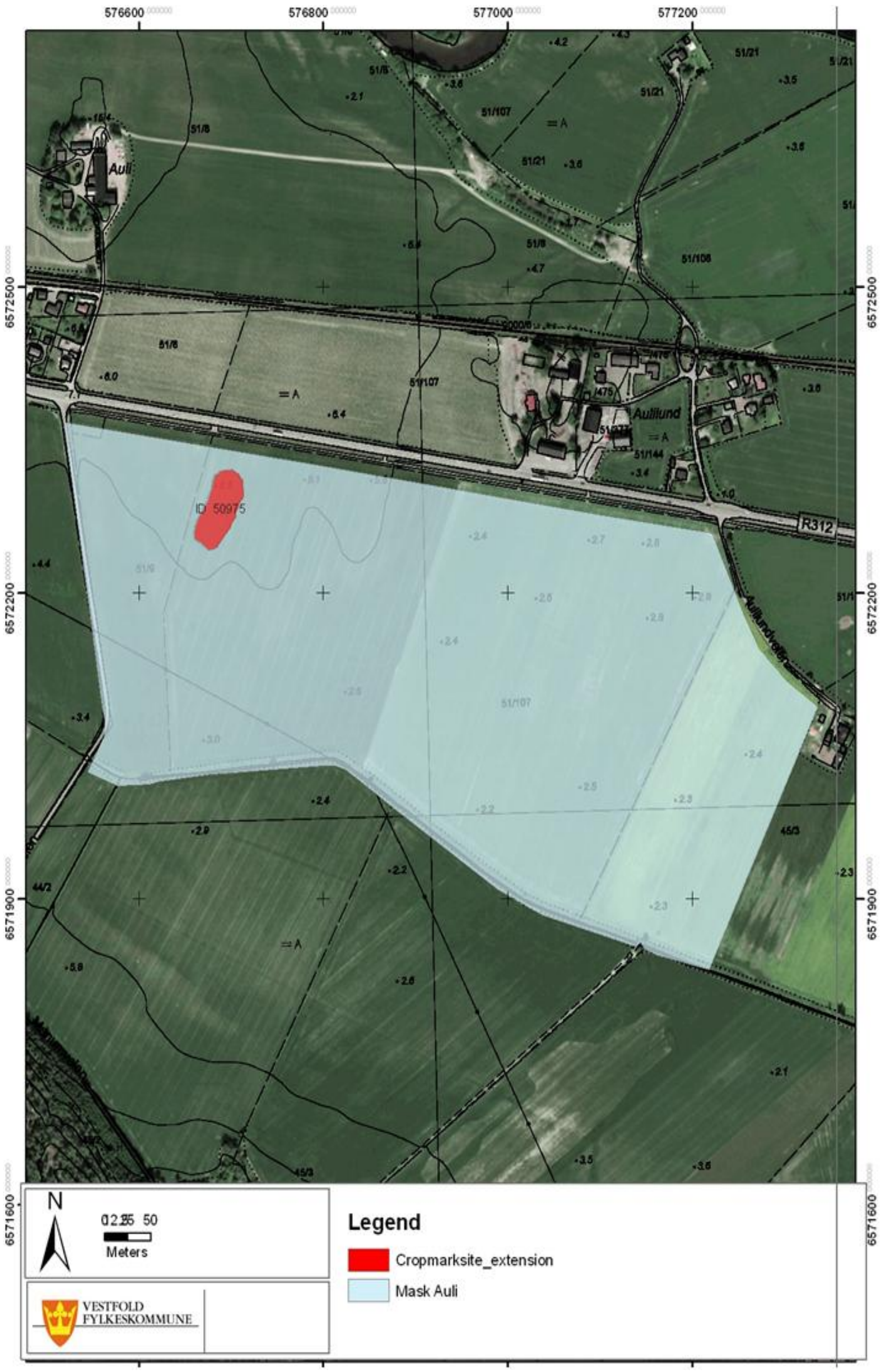


Figure 26. A map of the crop mark site at Auli, with the mask used in CultSearcher superimposed.

3.5.7 Site Haga

According to the Askeladden description, site Haga (Gbnr. 154/1) Sandefjord Municipality, Ikonos image E18 Larvik-Sandefjord, contains at least two ring ditches and one rectangular structure. No ring ditches were detected by visual inspection of the Ikonos image prior to using CultSearcher.

Figure 27. A map of the site at Haga, with the agricultural mask, for use in CultSearcher, superimposed.

MinRad x 0.1m	MaxRad x 0.1m	RadStep x 0.1m	MinSim	Ring template	No of detections	Confirmed detections
45	450	5	33	1	17	(1 *)
45	450	5	30	1	32	(1*)
45	450	5	30	2	370	(1*) Cancelled
45	450	5	33	2	176	(1*) Cancelled

Table 14 The CultSearcher parameter values and detection results at the site at Haga.

The experiences of using CultSearcher at Haga were mixed/poor. The false ring detections are probably due to extensive plough furrows, which may have disturbed the detection method in CultSearcher.

4 Testing and evaluating CultSearcher, NIKU

This chapter focuses on a series of tests of the CultSearcher software carried out in November 2008. The area on which the software was tested is located in Vestfold County in south-east Norway and includes parts of the municipalities of Horten and Re. This area is rich in both cultivated areas and previously recorded scheduled monuments.

4.1 Procedure

Prior to testing the CultSearcher software, a visual inspection of the satellite imagery was undertaken. This was done in order to identify suitable areas, and to investigate whether crop marks could be identified visually. An area centred on UTM32-coordinates E:572400 N:6578950 proved interesting, as it includes large areas of open, cultivated soils as well as easily identifiable crop marks. An area of particular interest was centred on the coordinates E:572860 N:6578450, where a series of crop marks from a previously recorded but over-ploughed grave field could be seen.

In order to find further areas of interest, two Esri shape files covering the above municipalities were downloaded from the Askeladden database of cultural heritage sites (http://askeladden.ra.no). This database is maintained by the Norwegian Directorate for Cultural Heritage (Riksantikvaren). The downloaded data was filtered to only include recorded grave mounds and grave fields.

As CultSearcher can only detect features located in cultivated areas, a mask had to be produced for these types of soil. Therefore, Esri shape files with this type of data had to be downloaded and fitted to the satellite data. Alternatively, this could have been done manually, by drawing polygons in a GIS. The manual approach ensures a high degree of spatial correlation but can be time consuming if a larger area is to be covered. The drawback of using already compiled soil data is that the spatial correspondence between the satellite data and the soil maps tends to be inaccurate. In this case, however, the satellite images appeared to be well-referenced, and thus it was possible to use the soil maps directly in the testing.

A problem with the current technology available to archaeologists for testing CultSearcher is that it is impossible to test larger areas. The soil maps therefore had to be divided into smaller segments. CultSearcher now has several parameters that the user may change. Therefore, it was decided to experiment on three smaller areas only, so that suitable values for these parameters could be established. Two of the test areas were within the previously mentioned area of interest, whereas the third was located further to the north, centred on UTM32 E:572140, N:6589715 (Figure 28).

4.2 Testing

The first round of testing concentrated on the larger area to the south. This area, covering 4.5 km^2, encompasses a smaller area with highly visible crop marks. Here, the simple parameter settings (Figure 6) in CultSearcher were used. Only the strictness parameter could be changed, the six possible values being *very strict, strict, fairly strict, fairly relaxed, relaxed* and *very relaxed*.

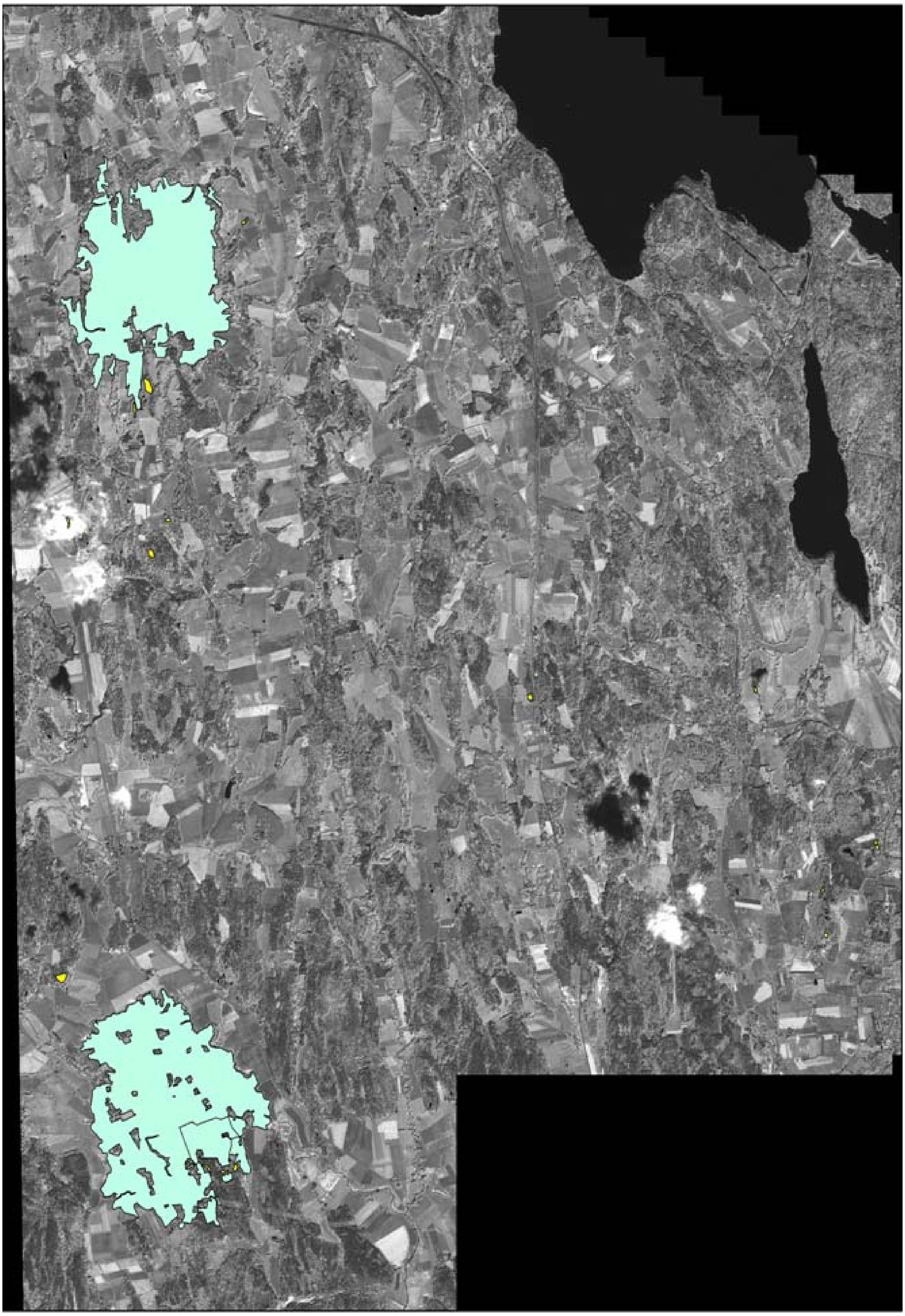


Figure 28. The three test areas of investigation, in cyan. The two test areas at the south are adjacent, one being much smaller than the other

1. Using v*ery strict* resulted in 60 ring detections. 3 of these were of potential interest, one of which was a visually detected crop mark.
2. *Strict* resulted in 142 ring detections. 4 of these were potentially interesting, one of which was a visually detected crop mark
3. *Fairly strict* resulted in a total of 295 rings. 7 of these were potentially interesting, but still only one of the visually identified crop marks was detected by CultSearcher.
4. Using *fairly relaxed* resulted in 586 rings. 10 of these were potentially interesting and CultSearcher also managed to detect two of the visually identified crop marks.
5. *Relaxed* gave a total of 1184 ring detections. Testing of the predefined settings was at this point terminated, and the *very relaxed* setting was not tried as it was felt that this would return far too many detections.

Further testing was carried out using the interactive mode with advanced parameter settings (Figure 7). This allows the user to specify the search parameters according to, e.g., maximum and minimum ring size as well as to which ring filter is to be used. Several sets of parameters were tested on the smaller area in order to find the most suitable set. The following parameters seemed to produce the most promising results:

Minimum radius: 60	Ring similarity: 35
Maximum radius: 200	Ring filter: 1
Radius steps: 10	BPF: 1

With this set, CultSearcher managed to detect 4 out of the 5 very clear crop marks within the smaller area, whilst the number of false detections was reasonably low. Interestingly, a fairly similar set of parameters was discovered by the archaeologist working from the other end of the satellite data set (see Section 3). It is felt, however, that even with the added functionality of being able to manually adjust the parameters, it is still extremely difficult to find a balance between detecting too many features and too few. In the area where the highly visible crop marks could be seen, for instance, none of the tested parameters managed to detect all of the crop marks, unless they were set to a level where the software detected but anything with differences in contrasts in the area.

As for the Ikonos satellite images, it has become clear that even this type of relatively high resolution data is not suitable for the task at hand. This manifests itself in the fact that CultSearcher tends to falsely detect clusters of pixels that bear little or no similarity to rings.

5 Improvements of the CultSearcher software and algorithms

During 2008, NR has made a number of improvements of the CultSearcher system:

1. Improvements of detection algorithm
2. Improvements of user interface
3. Initiated the production of a frequency map of a large area in Vestfold

Each of these aspects is discussed in detail below.

5.1 Improvement of detection algorithm

The purpose of the detection algorithm is to find traces of possible cultural heritage sites, with the ultimate goal to detect new sites, and to do so with less human effort than in traditional manual methods. In previous years, a software prototype, *CultSearcher*, has been developed for this purpose. CultSearcher is a semi-automatic system, where the system identifies a list of candidate locations, which are subsequently checked by an archaeologist as "interesting" or "not interesting" for further verification *in situ*.

The current version of CultSearcher is tailored to detecting ring-shaped marks in agricultural fields. In 2008, considerable effort has been spent on improving the algorithm for ring detection. The main challenge has been that the rings have low contrast to the surrounding agricultural fields.

In order to be able to improve the algorithm, some rings had to be identified manually in test images. In two Quickbird satellite images, archaeologists identified 35 rings that they would like the system to detect. These rings are termed "true rings" in the description below.

At the start of 2008, the algorithm had the following steps:

1. Import the panchromatic satellite image and a mask of agricultural fields.
2. Compute a local contrast-enhanced image.
3. Template matching, using ring-shaped templates of varying size.
4. Segmentation of possible ring candidates by extracting sub images
5. Computation of features, that is, numerical values describing various aspects of each sub image.
6. Classification of feature vectors into "rejected ring candidates" and "ring candidates to present to an archaeologist"
7. Manual verification by an archaeologist.

Steps 2-6 have been subject for algorithm improvement.

5.1.1 Computation of local contrast enhancement

Several experiments were conducted in an attempt to improve this processing step. Local contrast enhancement is performed by computing, for each pixel, the mean pixel value in a local neighbourhood centred on the pixel, and the standard deviation in the same neighbourhood. The new pixel value is obtained by subtracting the mean value from the old value, and dividing by the standard deviation.

To optimize this step means to optimize the size of the local neighbourhood. If the neighbourhood is too small, then almost no variation, or contrast, remains in the image. If the neighbourhood is too large, then local contrast enhancement has almost no effect.

The results of the experiments were:

1. If local contrast enhancement is skipped, then none of the true rings were detected by the subsequent steps.
2. A local neighbourhood size of 21-by-21 pixels seemed to work quite well. The exact value was not critical, for example, 15 or 35 also worked quite well.
3. If the local neighbourhood was too small, then the texture of the field was too exaggerated.
4. The local contrast in a field is suppressed in a buffer surrounding very bright or very dark objects. The width of this buffer is half the size of the local neighbourhood.
5. A compromise has to be found to balance the negative effects of items 3 and 4 above.

In conclusion, local contrast enhancement is vital, the neighbourhood size was set to 21, but we still have some problems close to very bright or very dark objects.

5.1.2 Filtering in the frequency domain

A popular approach in one-dimensional signal processing is to Fourier transform the signal into the frequency domain. In the frequency domain, the information in the frequencies that contains the signal is kept, whereas information in other frequencies are considered as noise and removed. This technique can be used on images as well, by using the two-dimensional Fourier transform followed by band-pass filtering in the frequency image. Then, inverse transformation should give an image with less irrelevant information.

We experimented with different cut-off frequencies for the band pass filter, and found that the best filter for our purpose had cut-off radii 100 and 800.

The result of the band-pass filtering experiment was that:

1. Local contrast enhancement still has to be done after the band pass filtering.
2. The same number of rings was detected by the subsequent detection steps, but a few rings were found that were not found without band pass filtering, and *vice versa*.

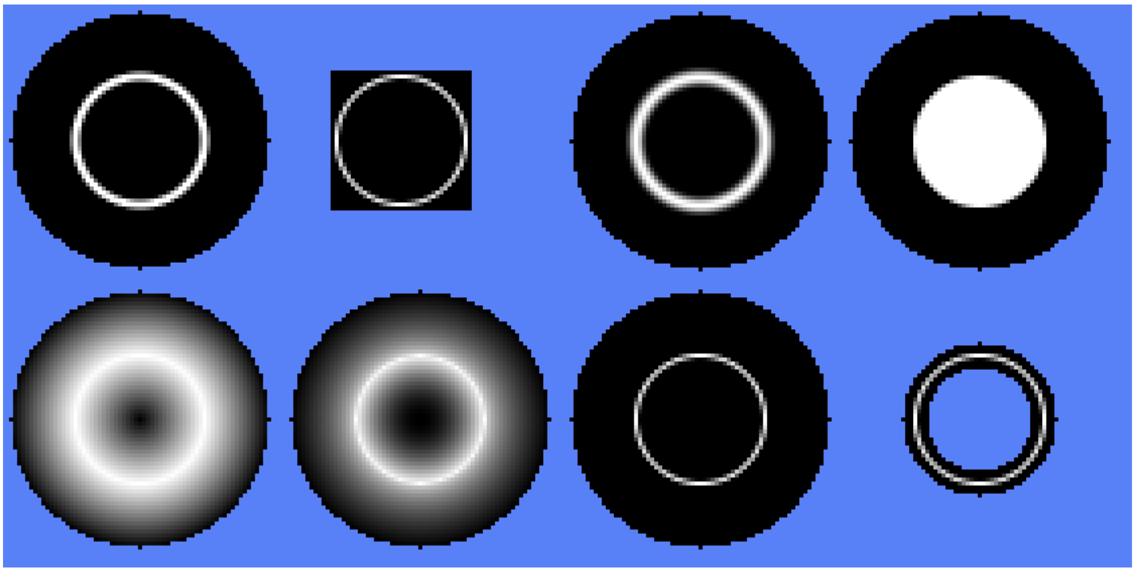


Figure 29. Ring filter shapes currently supported in CultSearcher.

In conclusion, no improvements were made in overall recognition performance, but band-pass filtering provides an alternative approach that could be useful in some settings. It is not included in the current version of CultSearcher.

5.1.3 Template matching

The purpose of the template-matching step is to find locations in the image which closely resembles the shape of the template, in our case, a ring. Different ring shapes have been tested (Figure 29), in which the ring thickness has been varied, and also the smoothness of the ring shape. A disc has also been tried.

Once a template shape has been selected, ring templates of various radii are constructed. Each template is then *convolved* with the contrast-enhanced image. The resulting correlation image indicates, for each pixel, how well the image resembles the ring template in that location. A high positive value indicates a bright ring, and a high negative value a dark ring. Ring candidate locations are identified by thresholding the correlation images. Detections less than a few pixels apart are merged.

Each ring candidate carries the following information:

1. x- and y-coordinates of the ring centre
2. ring radius
3. dark or bright

By setting a high threshold value, only a few detections are made, and by setting a low threshold value, many detections are made.

5.1.4 Feature extraction

For each ring candidate, a 4*r*-by-4*r* sub-image is extracted, where *r* is the detected ring radius. The sub-image is extracted from the original panchromatic image. A binary version of the sub-image is also used.

A number of different feature extraction methods have been tried:

1. Ring cover, that is, overlap between binary image and a binary version of the ring template
2. Mean value of binary image.
3. Hu-moment invariants, for both the binary and the panchromatic images
4. Real-weighted Fourier moments, for both the binary and the panchromatic images

For the details of the computation of these features, please see (Amlien et al., 2008). The result of feature extraction is to assign a feature vector to each ring candidate.

5.1.5 Classification

The purpose of the classification step is to discriminate between true rings and false rings based on each ring's feature vector.

Since the number of true rings was quite low, we could not use a statistical classifier. Instead, a decision tree was used. For each feature in the feature vector, a minimum and maximum value was set. In order to determine the minimum and maximum values, scatter plots of all the features were made. The conclusion was that none of the features were able to discriminate well between true and false rings, and experiments showed that combinations of the best features did not give reliable recognition. It was better to use a high threshold value in the template matching step and drop feature extraction and classification.

5.1.6 Scientific publication of algorithm

The improved algorithm has been presented at two international conferences in 2008 (Larsen et al., 2008; Trier et al., 2008), and described in a paper which is accepted for publication in Archaeological Prospection (Trier et al., 2009). The work has also been presented at the CAA-Norge conference in Oslo, 20-21 October, 2008. Further, we have been invited to submit a less scientific version to the Aerial Archaeology Research Group's newsletter AARGnews.

5.2 Improvement of user interface

The user interface has been adjusted to reflect the improved algorithm, to hide advanced details from less experienced users, and to facilitate efficient use. The previous user interface is described in (Amlien et al., 2008), and the below changes are relative to that report.

5.2.1 The main menu

In the main menu (Figure 30), the old "interactive processing" has been replaced by "interactive search amorphous" and "interactive search rings". Also, "restore default ring search parameters" has been added, so that the values originally suggested by NR may be restored.

Note that even though the old functionality for detecting amorphous objects is still present in the use interface (Figure 30), it is not being used at the moment.

5.2.2 The "processing – rings" dialogue

By selecting "interactive search rings" in the CultSearcher menu, the "processing – rings" dialogue appears (Figure 31). Earlier, there was only one "processing" dialogue, which was common to detection of amorphous objects and rings. Since feature extraction and classification are now left out in the ring detection algorithm, a separate dialogue for ring detection is needed.

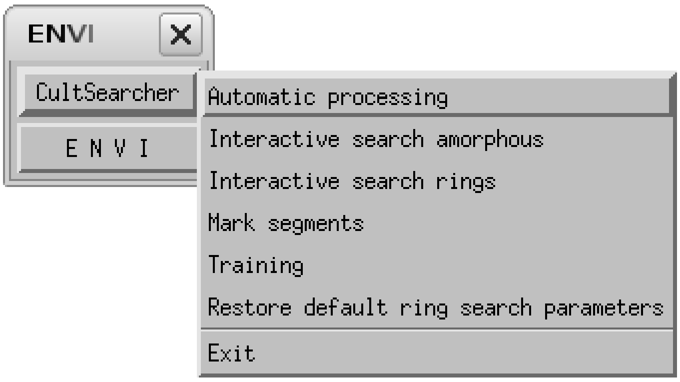
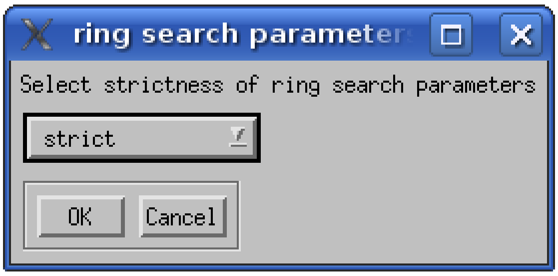


Figure 30. The main menu in CultSearcher.

Figure 31. The "processing – rings" dialogue.



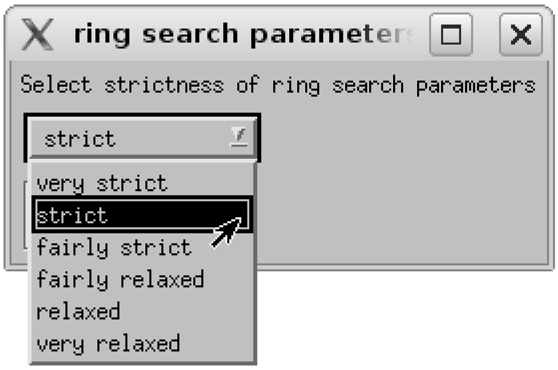


Figure 32. The simple variant of the ring-search parameters dialogue. The single parameter may be changed by selecting from a dropdown list.

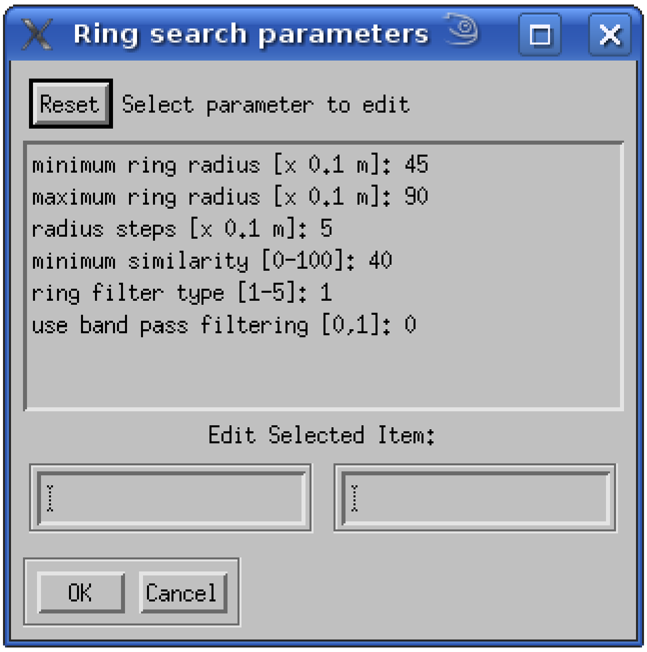


Figure 33. The advanced variant of the ring-search parameters dialogue.

A new processing option appears at the right-hand side of the dialogue: "advanced parameter settings". This option is used to control which version of the "ring search parameters" dialog (Figure 32 – Figure 33) that will be used. In the "processing – rings" dialogue (Figure 31), if the interactive step "3. Search for rings" is selected, and the user clicks on "Start", then the user is prompted to select three input files: The panchromatic image, the mask and the contrast-enhanced image. After that, the ring search parameters dialogue is opened.

When the user clicks "OK" in the "ring search parameters" dialogue, the selected parameter values are stored, and will be used the next time the ring-search parameters dialogue is opened. The processed files are assigned names which contain the selected ring-search parameters. In the case of the simple ring-search parameters dialogue, this part of the file name may be "_strict", whereas in the case of the advanced dialogue, the six different parameter values will be embedded in the file name.

5.2.3 Validation

In the validation process, the user is guided through all detected rings, and prompted if the ring should be deleted or not (Figure 34). This validation process has been improved graphically to avoid confusion.

For each detected ring, the application zooms the satellite image to the ring in question. Previously, all detected rings were displayed, so it was sometimes hard to tell which ring the system asked about. Now, only the ring in question is displayed, in red if it is a bright ring and in green if it is dark. If the ring is deleted, then it is removed, otherwise, it is displayed in dark blue. After all rings have been validated, the colour of each ring is restored to red for bright and green for dark ring.

Figure 34. The user interface for the validation step.

5.3 Various bugs

Various bugs in the software have been fixed.

5.4 Recommended improvements for 2009

As observed by the archaeologists, the software is not precise enough in identifying interesting ring shaped patterns in the images. This is especially true for Ikonos images, which has 1.0 m ground pixel size in the panchromatic band. The software worked much better with Quickbird images (0.6 m pixels), still several interesting patterns were missed.

For 2009 we recommend the following improvements:

1. Make priority of higher resolution imagery for ring detection, like Quickbird images.

2. Improve the pattern recognition module.

For item 2, we have several ideas which may be tried. This list of ideas is subject to change:

1. Study the correlation images resulting from the template matching step. Experiment with various ring template shapes, and see how the correlation image is affected. Use this to find the best template shape. Template variations may include:
   a. One template for the inner edge of the ring, and one for the outer. Should have matches for both (at different radii). Should be invariant to ring thickness.
   b. Combine templates of different shapes. Currently, eight different ring template shapes are supported (Figure 29), and more shapes may be implemented. Can have levels of templates.

3. Compute features that measure the deviation from the ideal ring. All the below alternatives are dependent on finding the circle centre:
   a. Convert to polar coordinates (angle, radius), and make a profile as a function of radius. A well-defined circle should have a narrow, high peak centred on the average radius, whereas a broad, lower peak indicates a substantial deviation from the ideal circle.
   b. Start from the centre and find the strongest edge, in all directions.
   c. Dynamic contours.

4. Use a statistical method to find the threshold for the correlation image. Matches in the template matching may be regarded as deviations from the null hypothesis

5. Improve the decision tree classifier:
   a. Gradual refinement, this means that the order of the if-tests will be important.
   b. May use features that are expensive to compute only for the few remaining patterns.
   c. Different features/methods depending on radius

6. Extract features from the original image instead of/in addition to the local contrast-enhanced image, or another transformed version of the image.

7. Study grey-level variability along the ring. Is it random noise or dashes?

8. Fourier transform to remove stripes in fields, on a per-field basis.

6 Frequency map

In order to get an idea of where new cultural heritage sites may be hidden, it would be interesting to see if CultSearcher could produce a frequency map, which could indicate individual agricultural fields for further investigation. The idea is to run ring detection with a strict threshold in the template matching step, which would result in few false detections, but possibly also some true rings being missed. The hope is that the detected rings are mainly true detections, and the number of detections per area could give an indication on where to look for rings manually.

6.1 Frequency map experiment

A moderately large test area in the Vestfold County has been selected for producing a frequency map (Figure 35). This area is covered by an Ikonos image that was acquired on 30 June 2006 at 11:12 AM. The area is also covered by a digital map in the form of an agricultural dataset (markslag, FKB, Larvik and Sandefjord municipalities), which can be used to extract masks of agricultural fields, excluding areas used for growing trees.

Unfortunately, the satellite image is not properly co-registered with the digital map, and local shifts of a few metres are observed. By creating an agricultural mask directly from the digital map, many false detections were made along the border between field and forest, whenever the agricultural mask overlapped forest in the satellite image.

To overcome this, a low standard deviation mask was generated from the satellite image and combined with the agricultural mask from the digital map. The combined mask includes areas that are included in both the standard deviation mask and the agricultural mask. The combined mask (Figure 36) was used when running ring detection.

To generate the frequency map, the following steps were taken:

1. Run CultSearcher on the Ikonos image, using the combined mask as the mask file.
2. One of the output files from CultSearcher is a binary image with '1' at all detected ring centres, and '0' elsewhere. This file was converted to an image file suitable for input to ArcInfo.
3. The Krieging function in ArcInfo was used to produce a continuous frequency map over the test area (Figure 37).

As a last step, the combined mask (alternatively, the agricultural mask from the digital map) could be used to remove values outside agricultural land. This has not been done in the example frequency map (Figure 37).

The legend of the frequency map is difficult to read in Figure 37, an enlarged version appears in Figure 38. Note that the frequency map is only an illustration of the method of making a frequency map, and should not be taken literally, since the detection result is not reliable.

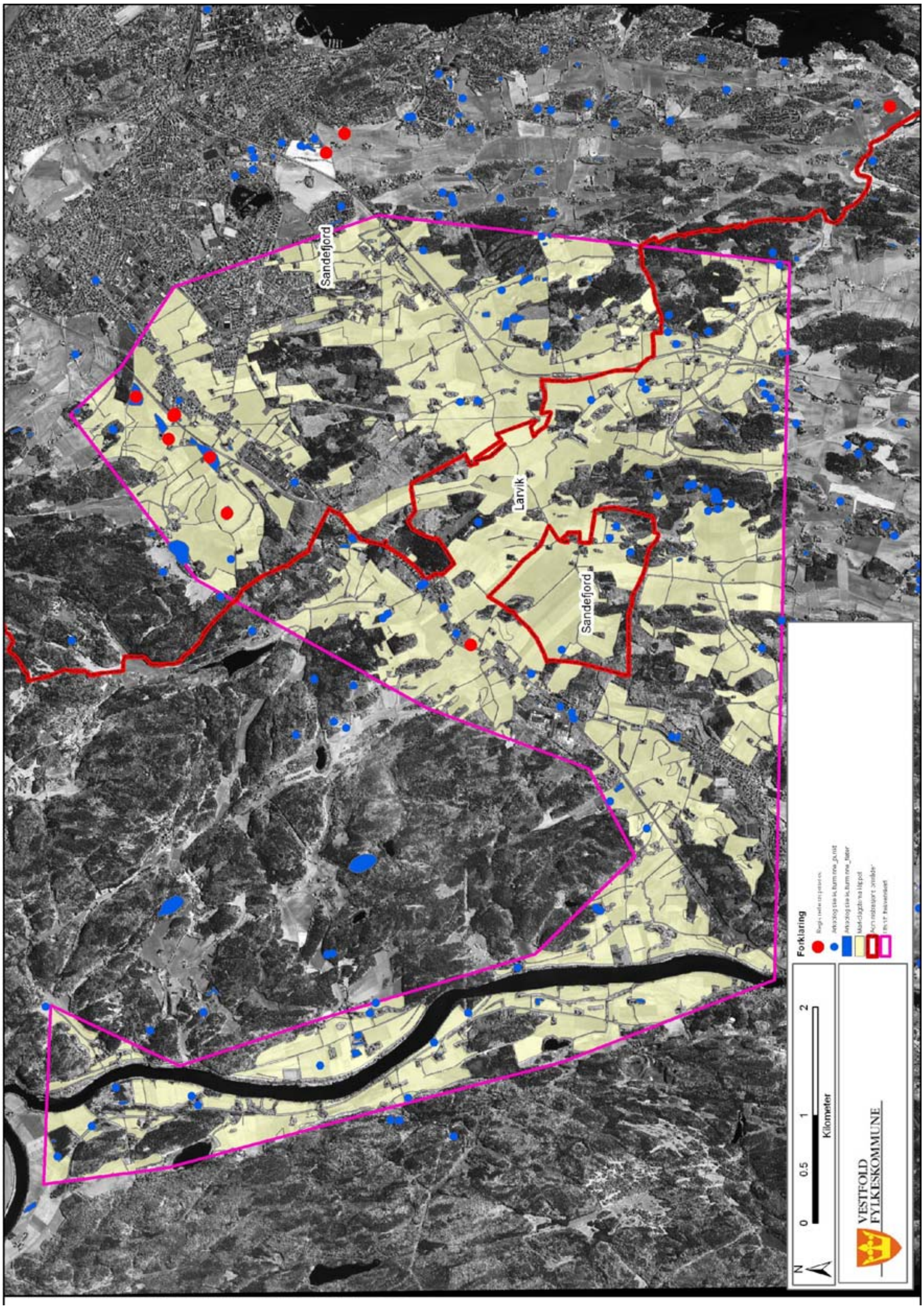


Figure 35. The test area in Vestfold County, used for producing a frequency map

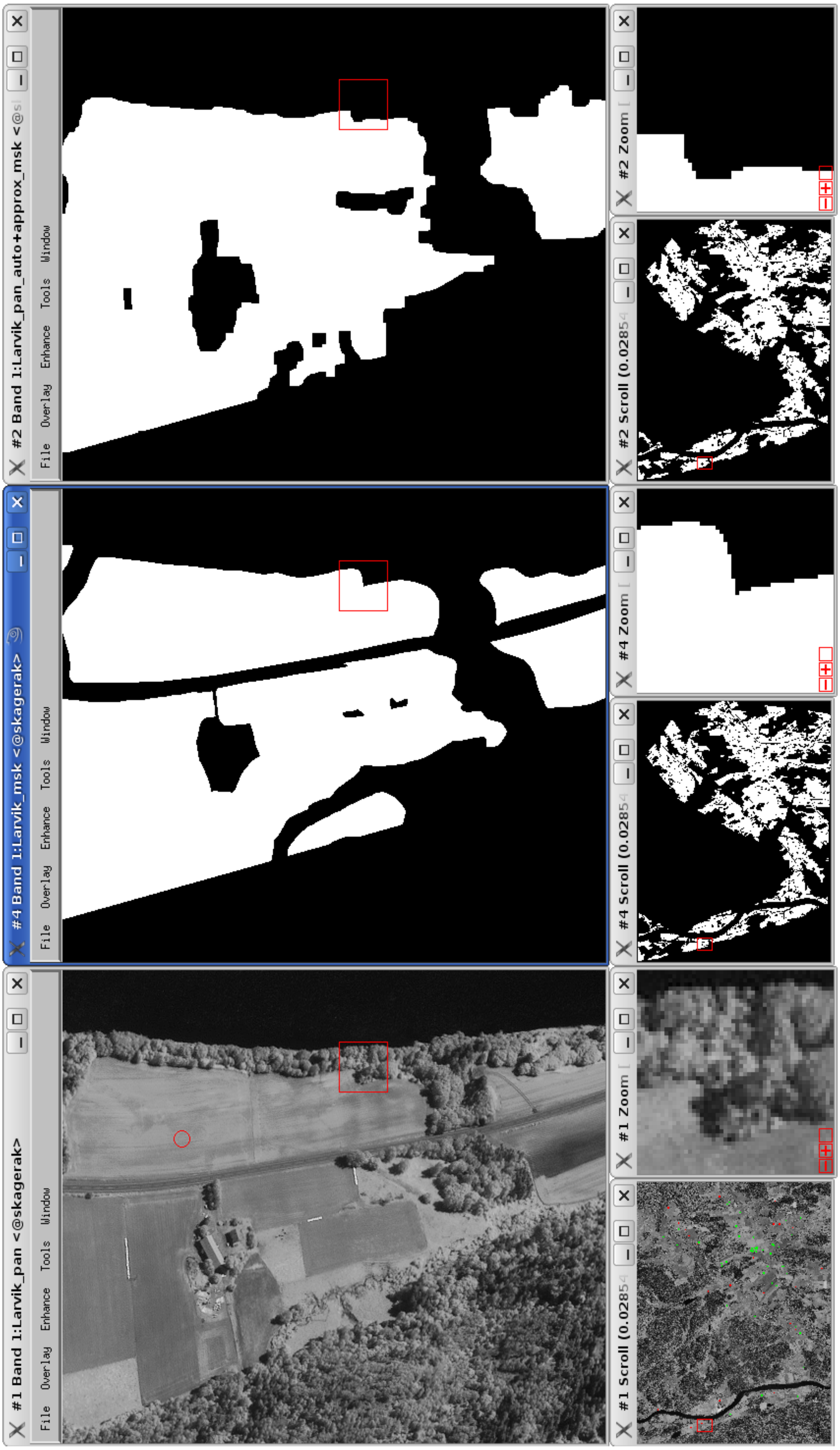


Figure 36. Bottom: original image. Middle: agricultural mask, generated from digital map. Top: combined mask.

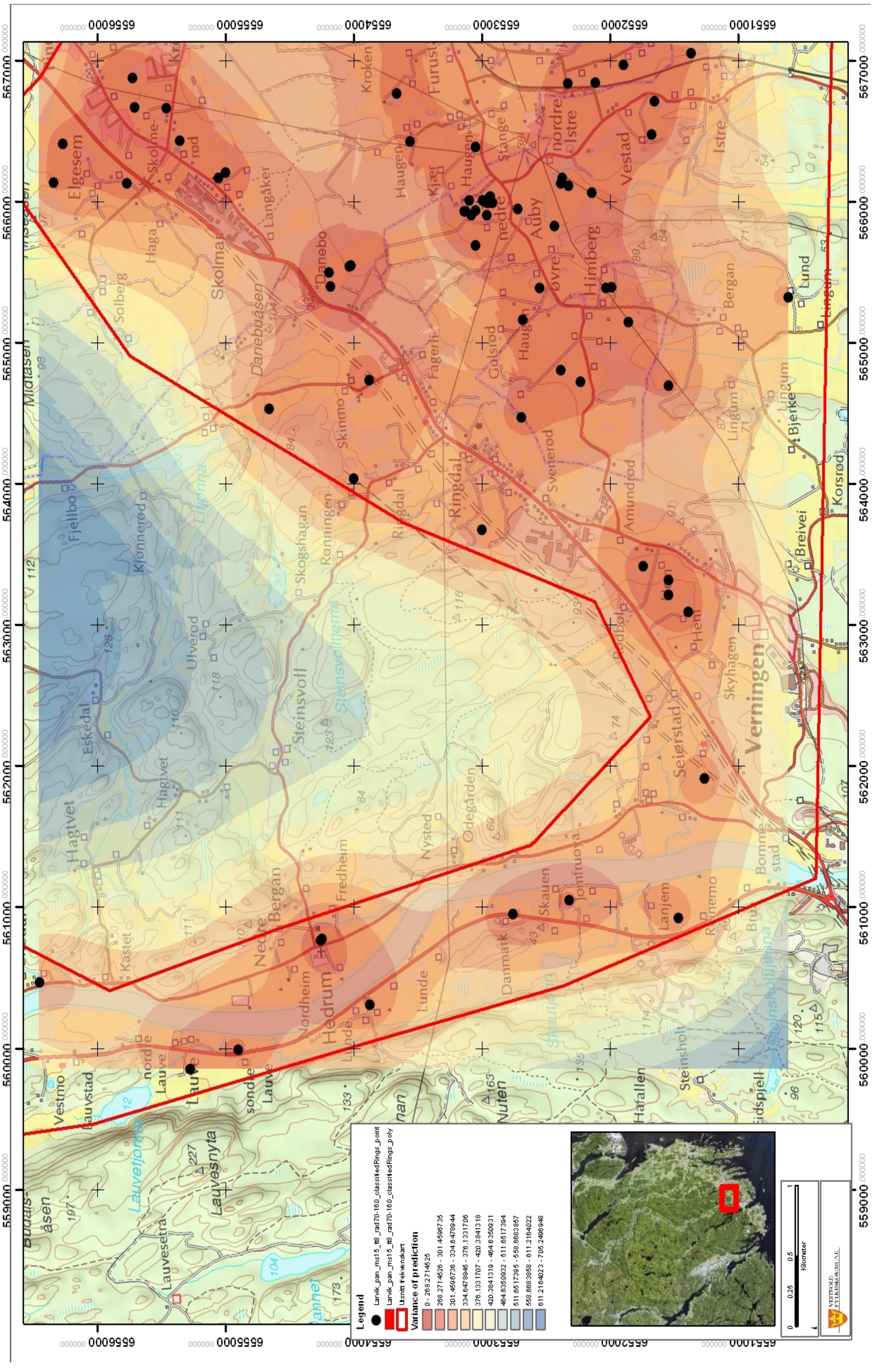


Figure 37. An example of running Krieging on the detection result from CultSearcher.

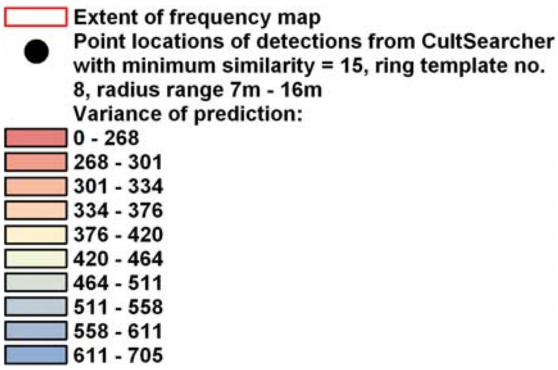


Figure 38. Legend of the frequency map.

6.2 Detailed procedure for creating the agricultural mask

Tools: ESRI ArcMap 9.2, and CS tools (Capita Symonds Toolset 1.21 (www.capitasymonds.co.uk)).

Data: Agricultural dataset (Markslag) from FKB (Felles kartbase) available for partners in Norway Digital (in Norwegian, "Norge digitalt"; http://www.statkart.no) for Larvik and Sandefjord municipalities.

Method: Mapview for frequency map was limited with an Esri shape file in cooperation with NR on March 11, 2008. This Esri shape file was used as a clipping theme for the agricultural dataset (markslag) in Larvik and Sandefjord municipalities.

For the batch clip procedure we used the ArcMap extension CS Tools 1.21. This enables ArcMap to use one Esri shape file as a cutting template for other Esri shape files.

After the batch clip procedure the clipped shape files were joined together by copying over info from one theme to the other. Finally a definition query was performed in ArcMap 9.2 on the new clipped and joined theme. By selecting all areas containing information about arable land (in the column 'jord'), everything else was deleted. An additional procedure was necessary to eliminate areas that were classified as arable forestland (e.g., Christmas tree production). By selecting all areas containing information about forestry (in the column 'askog') and deleting, the finished mask for the frequency map was produced (Figure 35).

7 Summary and conclusions

The main focus of the 2008 project was to cover most of the Vestfold County with satellite images and carry out large-scale application and evaluation of the CultSearcher system analysing these data. This has given important experience with the system and a broader overview of obstacles, which is crucial for further improvement of the ring detection algorithm.

NR made a number of improvements of the CultSearcher system in 2008: Improvements of detection algorithm, improvements of user interface and initiated the production of a probability or frequency map of ring structures of a large area in Vestfold. The user interface has been adjusted to reflect the improved algorithm, to hide advanced details from less experienced users, and to facilitate efficient use.

The idea of a probability or frequency map is to give an overview indicating where archaeological sites, in this case ring structures, are frequent. A frequency map could then be a tool where to proceed with further investigation. The procedure used was to run CultSearcher on the Ikonos image, flagging detected ring centres, and finally using Krieging to produce a continuous frequency map over the area. The frequency map approach was this year only an illustration of the method of making such a map, and the result should not be taken literally. More careful tuning of the detection algorithm is necessary to make a reliable map.

In order to make comprehensive satellite coverage of the Vestfold County, four new archived Ikonos images were ordered and applied together with four other Ikonos images bought previously. Selected parts of these images were investigated intensively by Vestfold County Administration (VFK) and Norwegian Institute for Cultural Heritage Research (NIKU) in order to test CultSearcher on a larger number of known ring structures as well as regions where undiscovered ring structures might be present. These experiments also gave NR valuable input for improvements of the detection algorithm as well as the user interface.

For 2008, VFK focused on the CultSearcher functionality, testing out the software and weeding out bugs and weak spots while doing a practical search for ring-shaped structures on well-known cultural heritage sites in the Vestfold County. The acquired Ikonos satellite images were primarily acquired during the harvest season (July-August) in order to secure the best possible conditions for crop-mark detections. Despite these considerations, the hotspots of historically documented ring ditches/graves were quite difficult to spot in the satellite images. Reasons for this might be changes in crops in some fields, seasonal variability, disturbed soil due to deployment of water pipes etc., and that the 1-m spatial resolution of the Ikonos satellite images is too coarse in many cases.

The tuning of CultSearcher focused on cultural heritage sites in which undisputable ring ditches were recognized in the Ikonos imagery. When using the "Advanced parameter settings" options, refined parameter tuning was possible. This tuning process eased the phase of interpreting the detections greatly. Trying to use Cultsearcher on a large data set proved difficult. The original plan was to use a large vector data set when applying masks for arable land. This data set is readily available to Vestfold County Administration through the *Norway Digital* (Norge Digitalt) organization. The Ikonos images are geographically rectified but not with sufficient accuracy to use them together with the vector dataset for arable land. An alternative approach was chosen, creating smaller masks which consisted of arable land close to the historically known sites.

The tuning of CultSearcher was then performed on four sites, in which we had a good visual confirmation of over-ploughed ring ditches in the Ikonos imagery. For three of these sites, we had good visual confirmation of ring ditches in other data. On the fourth site we only had visual confirmation of ring ditches in the Ikonos image. The four sites were Lauve, Vølen, Reinemo and Hole Vestre. For the remaining 24 sites, 17 were either not covered by Ikonos images that we had ordered, or could not be seen in the Ikonos images for various reasons. The seven remaining sites had potential (correct crop, correct contrast) when looking at the Ikonos images, but there were no crystal-clear ring ditches. Nevertheless, CultSearcher was tested on these seven sites, building on experience from the four sites that had been used for tuning. In addition to the Ikonos images, available orthophoto series from Norway Digital were studied. This was done if the ring ditches were visible in the orthophoto, in which case a better insight into the geographical extent of the sites could be obtained. When no rings were visible, true detections could then not be expected. The detections that CultSearcher flagged did, as expected, not confirm previously reported but currently not visible rings.

NIKU tested CultSearcher for an area in Vestfold County located in the municipalities of Horten and Re. This area is rich in both cultivated areas and previously recorded scheduled monuments. Although the current version of CultSearcher is a marked improvement over previous versions – both in user-friendliness and in its capability for detecting archaeological features – it is felt that a substantial amount of work remains to create a working tool for archaeologists. The main concern is that the software in its default setting detects far too many features for the archaeologist to validate, or, if the settings are tightened, far too few.

Furthermore, finding a suitable parameter set manually has also proven difficult. These concerns are well illustrated by the testing performed in the area where known crop marks were present. With certain settings all the crop marks could be detected, but the amount of false detections around these was far too high for an efficient use of the program. Similarly, if the settings were tightened, only a few of these highly visible features would be detected. It has also become apparent that the Ikonos satellite imagery is not sufficiently suited to this type of work, and that satellite imagery with higher resolution might yield better detection results.

As concluded by the archaeologists, the CultSearcher software needs improvement in order to be an operational tool. This might include improvements of the template matching step, the use of a statistical method to find the threshold for the correlation image computing features that measure the deviation from the ideal ring, improved decision tree classifier, and extraction of features from the original image instead of/in addition to the local contrast-enhanced image or another transformed version of the image. We focussed on Ikonos imagery (1.0 m pixel resolution) this year as this satellite had the best coverage of Vestfold. However, previous experiments with Quickbird (0.6 m pixel resolution) indicate that this resolution is better for ring detection, which was confirmed by the experiments in 2008. Fortunately, there are now several satellites in orbit providing 0.5-0.6 m panchromatic imagery.

8 References

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