

DOCUMENTATION AND ANALYSIS OF ARCHAEOLOGICAL SITES USING AERIAL RECONNAISSANCE AND AIRBORNE LASER SCANNING

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ABSTRACT

For the last 4 years, an area covering 700 km² along the river Leitha 30 km southeast of Vienna has been investigated in two research projects. This paper presents the preliminary results and tries to demonstrate the potential of an integrated approach using aerial reconnaissance, targeted field walking, and ALS, and shows the high-quality information that can be gathered using new photogrammetric techniques applicable even in forested areas. It is argued that only an integration of different prospection methods will enable effective heritage management.

1. INTRODUCTION

Our cultural heritage is under constant threat. Since its General Assembly in Mexico in 1999, the International Council on Monuments and Sites (ICOMOS) is running the Heritage @ Risk program. According to its website, this program tries to identify threatened heritage. It presents typical case studies and tries to develop suggestions for solving problems related to all kinds of threats to our cultural heritage. The reports, which can be accessed on the ICOMOS website (www.icomos.org), dramatically show the annual destruction of a broad range of heritage.

This paper deals with the major part of archaeological heritage, namely those archaeological sites, which are hidden in the sub-surface. Most of these sites are still unknown, and therefore difficult to protect. To be able to take adequate measures of protection, the archaeologist has to know the exact position and dimension of a site. Therefore, archaeologists need fast and low cost methods that are able to show the extents of a whole site and provide a detailed mapping of its features.

Currently, archaeologists use only two prospection methods for the systematic (i.e. not coincidental) discovery of archaeological sites: field survey and aerial archaeology. Aerial archaeology is a very cost-effective method for site discovery, but often does not provide details about individual structures of a site (as for example posts or palisades) or dating evidence. A detailed plan can be provided by geophysical prospecting techniques, while field walking can provide the archaeologist with information on the physical conditions on the ground and with dating evidence for a site. All of the mentioned methods come to their limits in forested areas, which results in the fact that we usually know only large and well-preserved sites in these areas (Devereux et al., 2005). Over the past few years, Airborne laser scanning (ALS) has turned out to be a potential tool for recognising and measuring topographic earthwork features in wooded areas (Ackermann, 1999; Kraus, 2004; Wehr and Lohr, 1999), but can only render a limited range of types of archaeology, which is still surviving in (micro-) relief.

For the last 4 years, an area of 700 km² along the river Leitha 30 km southeast of Vienna has been investigated in two research projects. The aim of the first project was to demonstrate the value of aerial archaeology both to detect and document archaeological sites in a mainly arable region and to provide detailed mapping of all relevant

archaeological structures and features within that area. Because of the limitations of aerial archaeology over forested parts of the project area, a second project was started in 2006 to test the applicability of airborne laser scanning (ALS) for archaeological reconnaissance in woodland.

This paper presents the preliminary results and tries to demonstrate the potential of an integrated approach using aerial reconnaissance, targeted field walking, and ALS. It is argued that only an integration of different prospection methods will enable effective heritage management.

2. RESEARCH AREA

The research area is situated 30 km southeast of Vienna, covering a 10 km wide corridor along the valley of the river Leitha and the adjacent area of the Leitha mountain range (Fig. 1). The river Leitha comes from the eastern Austrian Alps, running northeast towards the important Roman site of Carnuntum, which it passes in a west-east direction some 5 km south of the ancient town. The southern part of the project area is more or less flat. It lies in a climatically favourable transition zone between the Eastern European and Central European climatic areas, with an average temperature between 9° and 10° Celsius and an annual total of approx. 600 mm of precipitation. It is intensively cultivated and therefore usually a worthwhile target for aerial archaeology. The northern part of the project area is dominated by the so called "Leitha mountain range", whose heights are 200 to 300 m higher than the valley of the river Leitha. It is covered by a forest of mixed deciduous trees, mainly oak and beech with varying degrees of understorey. Altogether, the research area has a size of about 700 km². In the course of the research, a detailed archaeological map of the total area will be produced. During the first project (2003-2005), the roughly 500 km² agriculturally dominated part was investigated using aerial archaeology in combination with targeted field surveys. The second project (2006-2008), which is still running, will investigate the remaining forested region using ALS.

3. METHODOLOGY

Through a partnership with the *Austrian Bundesdenkmalamt, Abteilung für Bodendenkmalpflege* (federal commission on historical monuments, department for archaeology), we could get access to the database of monuments and sites.

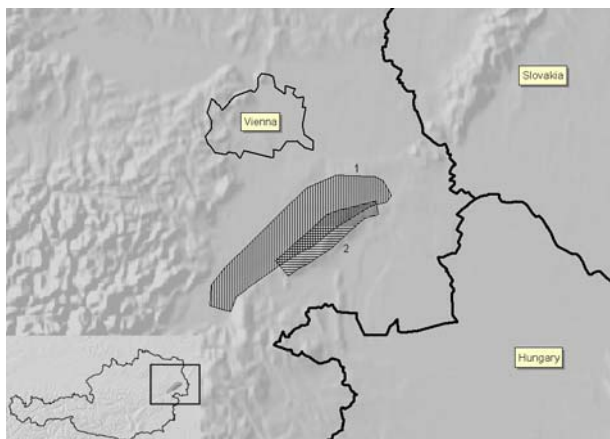


Figure 1. Map showing the project areas. (1) aerial archaeological project in the Leitha valley (600 km²), (2) ALS project in the “Leitha mountain range” (200 km²).

From this dataset, we could use a little over 300 sites, which were precisely locatable. This was our basis to start from. Besides searching through the relevant literature, collecting information from old maps, and visiting the regional museums, different prospection methods were applied.

Our main method to investigate the project area was aerial archaeology. To verify new discoveries, targeted field surveys were undertaken. Soon it became clear that aerial archaeology would uncover little that is new within the wooded areas of the adjoining Leitha mountain range; this was the reason for the second project, a pilot study to test the application of full-waveform airborne laser scanning.

3.1. Aerial archaeology

In aerial archaeology, one gains a raised, remote viewpoint (airplane) which provides an overview of an area and its archaeological traces. Archaeological traces can appear in various ways on the earth's surface. Different colours in the fields or in the vegetation, shade, or areas of snow cover that melt earlier, are the sort of indications of archaeological sites hidden in the soil that can be recognized from the air.

Aerial Archaeology is one of the most efficient methods of prospection. Both vertical and oblique aerial photos are used for interpretation. Above all, repetitive observations conducted over a period of several years - if possible, in different seasons - draw new details again and again from the soil. These can be joined, like pieces of a puzzle, into an extensive overall view of an archaeological landscape (Doneus, 2003).

An important task is to transfer the archaeological information visible on the vertical and oblique photographs to composite maps that are sufficiently accurate and readable for other archaeologists to use. The mapping of the archaeological landscape enables archaeologists to choose their special area of interest for a closer investigation in the form of excavations or other, more costly prospection methods (e.g. geophysical prospecting).

Between 2003 and 2005 several reconnaissance flights (altogether 35 hours) were carried out. Through a contract with an Austrian military air base we have free access to all of their vertical photographs made using a Zeiss RMK with a format of 23 by 23 cm. Their scales range between 1: 30.000 and 1: 5.000, but a scale of about 1: 8.000 is preferred and mostly available. More than 2.000 vertical aerial

photographs, made by the Austrian air force in Langenlebarn, were archaeologically interpreted (Doneus et al., 2001).

If not made digitally, the aerial photographs are scanned using the Vexcel Ultra Scan 5000. Using its automatic roll film unit, a film is scanned automatically at high resolution. All of the aerial photographs and sites were input into our GIS based archive (ArcView 3.3); this integrates our aerial archive, the sites record, the digital image database, and the interpretations.

Before a detailed interpretation of the archaeological features could take place, all of the relevant aerial photographs (over 400) had to be rectified. First a recent vertical coverage of the area was oriented using aerotriangulation and rectified using the Leica Photogrammetry Suite (LPS). The resulting orthophotographs were then used to provide secondary ground control information for the rectification of further vertical, and the oblique, aerial photographs.

LPS was also used to rectify the other relevant vertical aerial photographs. Ground control was obtained from the already rectified orthophotographs and the DTM. While the rectification of vertical aerial photographs usually should not cause too many problems, mapping from oblique photographs can be a more difficult task (Doneus, 1996; Scollar et al., 1990). Problems are mainly due to perspective distortions, that are the result of the oblique viewing angle and the topography of the site, use of non-calibrated cameras, lack of well distributed ground control information, and an often missing stereo partner. At least two specialist programs have been written for aerial archaeologists to overcome some of these difficulties (Haigh, 1993; Scollar, 1998). Using photogrammetric principles, both of them provide the archaeologist with the possibility to rectify single oblique photographs. In the project, we were mainly using Scollar's AirPhoto (<http://www.uni-koeln.de/~al001/airphoto.html>). It is easy to use and allows the oblique photographs to be mapped directly on the orthophotographs of the previously rectified verticals. Since most of the sites were located on reasonably flat terrain, most of the oblique aerial photographs could be rectified with errors smaller than +/- 1,5 m (Fig. 2).

Altogether, more than 400 aerial photographs were rectified and consequently interpreted in GIS. The interpretation was done image by image on screen in separate layers using different colours and attributes for different features (Fig. 3). During the process of drawing the interpretation, descriptive values are added in the corresponding database(s). In the attached attribute table, for each drawn feature the information on its description, function, and context, the number of the interpreted photograph, and the interpreter were input.

As a result, more than 640 archaeological sites were identified, many of them multi-period settlements or graveyards. This means that within only 35 flying hours the total inventory of archaeological sites had been doubled (Fig. 4). Altogether, a detailed archaeological map of the 600km² area could be created. During this procedure, more than 30.000 individual archaeological features (pits, houses, graves etc.) and landscape features (mostly old river channels, ditches, and drains) were mapped (Fig. 5).

The resulting data was used as a basis to show the spatial distribution of the individual archaeological phases and to analyze in detail the late iron-age and Roman settlement patterns.

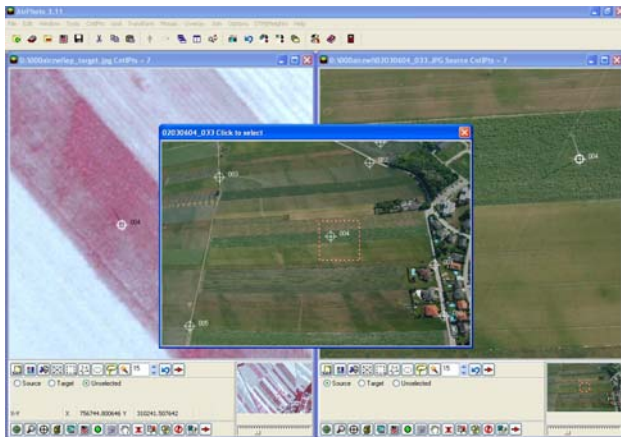


Figure 2. Screenshot during rectification of oblique aerial photographs using the software AirPhoto. Ground control points were measured from the previously rectified vertical photographs.



Figure 3. Interpretation of the rectified aerial photographs as done in GIS. In the attached attribute table, for each drawn feature the information on its description, function, and context, the number of the interpreted photograph, and the interpreter were input.

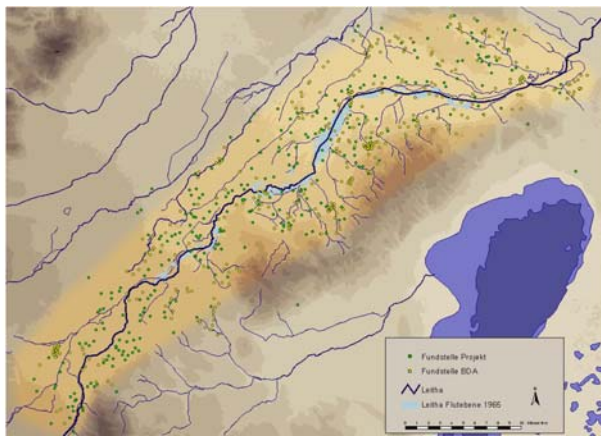


Figure 4. Resulting distribution of 640 archaeological sites. Green points indicate newly discovered sites, while yellow ones mark previously known sites.

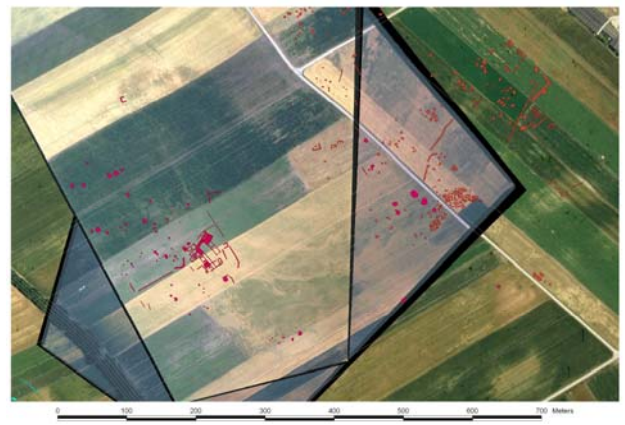


Figure 5. Mapped Roman villa rustica with accompanying cemetery.

3.2. Targeted Field Surveys

Interpretation of aerial photographs is a subjective process and so the resulting confidence will vary from site to site. There are many natural and recent features that could affect the interpretation of the photos. Hence, we may identify non-sites as potential archaeological sites or on the other hand give a natural interpretation to features, which are in fact of archaeological relevance.

Therefore, to evaluate the accuracy of this identification process the ‘potential’ sites discovered through aerial archaeology needed visiting to ascertain whether they were archaeological sites or not and if not what had caused the response. These visits are essential to the production of an image interpretation key.

All of the newly discovered “potential” sites (more than 350) therefore had to be field-walked during autumn and winter 2004/2005. The collected artefacts and ecofacts were typologically and chronologically analyzed.

As a result, around 310 of the newly discovered “potential” sites could be verified as archaeologically relevant and most of them could be dated by the material found during the field-walks. For the remaining 40 “potential” sites, the lack of finds however does not necessarily indicate the site is not archaeological – it is just not “confirmed”. For further analysis, only the confirmed sites were used.

3.3. Airborne Laser Scanning

Although the results from the aerial reconnaissance were better than expected, it became clear that aerial archaeology would uncover little that is new within the wooded areas of the adjoining Leitha mountain range, part of the project area. Systematic detection of archaeological sites in woodland is one of the unsolved problems in archaeological prospection resulting - not only in Austria - in a big deficit of archaeological knowledge of forested areas.

Over the past few years airborne laser scanning, also known as LIDAR (Light Detection and Ranging), has been used to produce high precision terrain models (Ackermann, 1999; Kraus, 2004; Wehr and Lohr, 1999). Its applications in

archaeology are successful although still rare, but it turned out to be a possible tool that can help to solve problems with the recognition and measurement of preserved sites in forested areas. During the first phase of the project, a test scan covering two 4 km² areas was performed. Its main purpose was to assess the potential of the technique for archaeological reconnaissance in forests. The areas were carefully chosen and represent different kinds of canopy (bushes, trees with and without brushwood) above already known archaeological sites (earthworks, tumuli, ruined buildings, stone quarries, and single walls).

The laser scanner is usually mounted below a fixed wing aeroplane or helicopter, where it emits short infrared pulses towards the earth's surface into different directions across the flight path (typically 30,000 to 100,000 pulses per second). Each pulse will result in one or more echoes reflected from various objects along its path (vegetation, buildings, cars, ground surface etc.). The location of each reflecting object is calculated using the angle of the emitted laser beam, the distances to the reflecting object (measured by the time delay between emission and each received echo), and the position of the scanner (typically determined using differential global positioning system (dGPS) and an inertial measurement unit (IMU)).

For archaeological interpretation, a high quality digital terrain model (DTM) has to be derived from the ALS data. This involves a reliable separation of terrain and off-terrain points while maintaining a high point density. Currently, there are two different types of ALS sensor system available: discrete echo scanners (conventional scanners) and full-waveform scanners. Discrete echo scanners detect a limited number of echoes for each laser pulse in real time using analogue detectors. While most detectors deliver only the first and last echo, some can distinguish up to four distinct echoes from multiple targets from a single laser pulse. These sensors can be considered to be "lossy" as the majority of the received signal is discarded by the analogue detectors.

Full-waveform scanners digitise the entire analogue echo waveform for each emitted laser beam (typically with an interval of 1 ns) and convert the signal in a digital data stream, which has to be post-processed (Wagner et al., 2006). During post-processing the full waveform can be modelled as a series of Gaussian distribution functions (Hug et al., 2004; Wagner et al., 2006), each representing an

Full-waveform scanners discard significantly less data than conventional scanners during the data collection process. Different algorithms can be applied to segment the data stream in different ways suited to the users need. This means that the user is not restricted to a group of discrete echoes controlled by a detector but can generate his own algorithms that respond to the physical and biological environments within which the laser interacts.

By modelling the full waveform as a series of Gaussian distribution functions, individual scatterers can be distinguished (Hofton et al., 2000; Wagner et al., 2006). The results are estimates of the location and scattering properties of the individual targets: for each returning echo of a single laser pulse, the estimated coordinates of the scatterer, the echo width, and the amplitude is determined. Using amplitude and echo width, it is possible to investigate the return signal and extract additional ground characteristics. Consequently, much more information is available when classifying the point cloud into solid ground and vegetation cover (Fig. 6). In a recent paper, the usage of a simple threshold operation in order to pre-exclude points situated within low vegetation or other structures as for example clearance piles (consisting of twigs and branches) is demonstrated (Doneus and Briese, 2006a).

In the project, full-waveform ALS was applied. Therefore, a more reliable classification of the laser points and a higher accuracy of the terrain points from full wave in comparison with the conventional LiDAR data could be achieved (Doneus and Briese, 2006a; Doneus and Briese, 2006b). Both analysis and georeferencing of the full-wave data is done in cooperation with the Institute of Photogrammetry and Remote Sensing of the Technical University of Vienna. For the filtering of the data we use the software package SCOP++ where robust interpolation with an eccentric and unsymmetrical weight function is used. A brief description of the technique is given in a recent paper (Doneus and Briese, 2006a). The whole process of filtering is also demonstrated at the EuroSDR Distance Learning Course "Filtering and Classification of Laser Scanner Data", available under:

<http://www.ipf.tuwien.ac.at/euroedr/index.htm>.

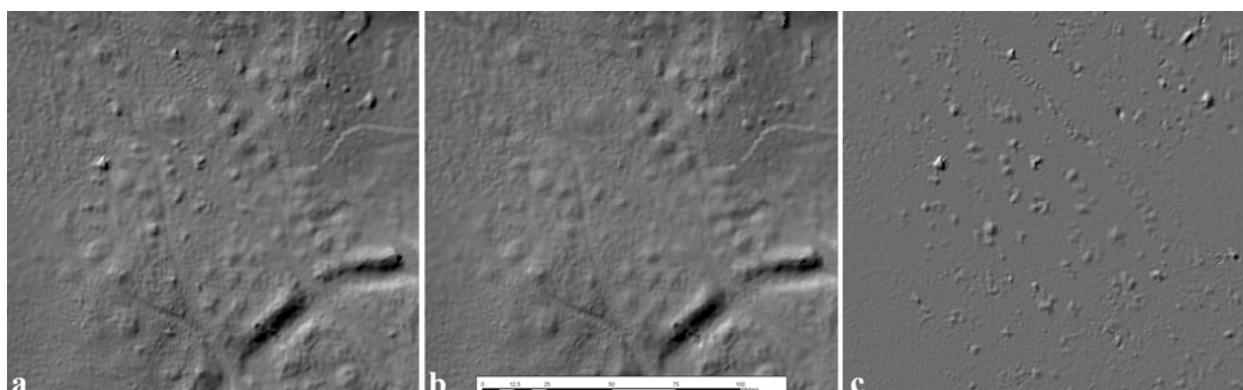


Figure 6. (a) DTM derived from filtered last echo data. Low vegetation and clearance piles are still represented in the DTM. (b) DTM derived from last echo data after removing points with large echo widths and filtering. (c) Subtraction of both images. The elevations indicate removed low vegetation and clearance piles.

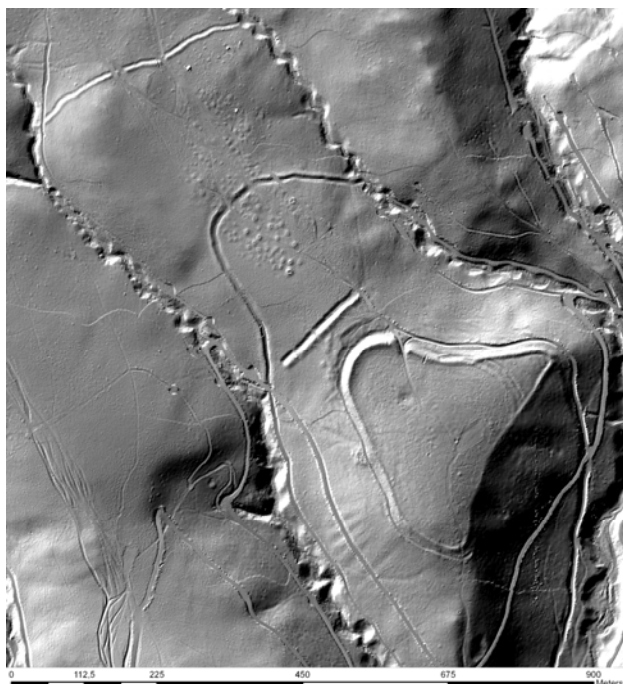


Figure 7. Final DTM of an Iron Age hillfort in the Leitha mountain range after filtering using the theory of robust interpolation. Illumination: northwest. The roughly triangular shaped hillfort is surrounded by a massive rampart. To the northwest, altogether 3 fore-walls cut off the ridge. In-between, the 260 by 100 m large graveyard with c. 100 round barrows becomes clearly visible. The barrows range between 5 and 15 m in diameter and stand to between 0.2 and 2 m in height.

In this way, most of the forest canopy and brushwood covering the archaeological features could be removed. The resulting DTM shows a detailed map of the topography with even faint archaeological structures under the forest canopy and therefore clearly demonstrates the potential of full-waveform airborne laser scanning for archaeological prospection of forested areas. In one of the test sites, an Iron Age hillfort with various ramparts and round barrows can be clearly seen through the forest canopy, with varying structure of trees and bushes. The resulting DTM reveals the entire hillfort with even subtle structures, as for example small shallow depressions on top of round barrows, which result from looting (Fig. 7).

4. DISCUSSION

Although the results of the two projects so far are better than expected, one has to make clear that each of the applied prospection techniques does have limitations and introduces biases into our archaeological data. The field of application varies with each method as does the archaeological content of the mapped information.

Aerial photography is a passive remote sensing technique recording the reflected part of the visible and near infrared range of the electromagnetic spectrum on film or a digital sensor. A photo-pixel is a mixture of all radiation within a certain back-scattering area. During aerial archaeological reconnaissance flights, only a few parameters, as date and time of flight, flying height, direction of view, and type of sensor can be influenced to improve the detectability of sites.

Once an aerial photograph is made, there is only a limited variety of possibilities to enhance it for easier interpretation. The visibility of buried archaeological traces depends on many factors. Therefore, the degree of visibility of different elements of an archaeological site will vary through time depending on climate, vegetation, agricultural regime, etc. Only repetitive observations conducted over a period of several years will reveal a sufficiently complete representation of the buried archaeology of a region. But still there are areas, where aerial archaeology will rarely or even never be successful, as for example built up areas, areas with high alluvium, or forests.

Also, quite often, only major structures of an archaeological site become visible. Even if subtle details, as for example palisades or postholes, can show occasionally in an aerial photograph, this is not the common situation. In some cases, it is possible to provide dating evidence just from the structure and pattern of the visible traces, but very often, this is not the case. Here, additional prospection methods have to be applied.

Field survey can yield dating evidence for sites detected in aerial photographs. But also the visibility of artefacts lying on the surface of a field varies throughout a year. As a result, field-walking an archaeological site does not necessarily result in good dating evidence. Soil is highly mobile and so are the artefacts. The ploughsoil from construction areas is quite commonly moved to other fields before construction work starts. In that way, artefacts from the moved soil can indicate archaeological sites where there never have been any.

Due to its ability to penetrate the vegetation canopy, ALS will have a major impact in the archaeological reconnaissance of vegetated areas. But, as with every archaeological technique, there are some limitations which have to be considered when applying ALS.

The most important constraint is that ALS can document only a limited range of types of archaeology. ALS results in a precise model of the surface, which means that we will only be able to “see” sites and features, which are still surviving in (micro-) relief. There is no way to detect buried features or sites, which do not leave traces in relief.

Other limitations are the type of tree cover and the rather short time-frame available for scanning wooded areas. ALS in principle does yield details below conifer plantations, as can be seen in the publication of Devereux et al. (2005, p. 654 and Fig. 4), but it seems that fewer pulses will penetrate to the ground, which will result in a coarser resolution and therefore will have a negative impact on the DTM quality. The best time for data collection is the dormant period, when deciduous trees and most of the understorey have lost their leaves. There should be no snow (when it is wet), because it will poorly reflect the laser pulses and tends to fill up the shallow depressions archaeologists are interested in. These are just basic recommendations and the effects of conifer plantations on DTM generation and the extent of the time-frame still need further investigation.

Only by integrating various prospection methods into a coherent picture, can some of the limitations be overcome. Aerial evidence can be dated by field-walking, artefact scatters interpreted from air photos, above-ground earthwork sites found in forests etc. But still, for the time being, there is no combination of prospection methods existing, which would allow us to know the “total” archaeological site information of a region. Nevertheless, by combining aerial archaeology, ALS, geophysical prospection and field survey,

archaeologists already have a powerful toolcase to help protecting our cultural heritage by revealing its presence.

5. CONCLUSION

Four years of survey in the Leitha valley have shown how airborne surveying techniques, supported by integrated ground work, can be of great value in heritage management. By undertaking only 35 hours of aerial reconnaissance, and analysing the resultant photographs alongside pre-existing vertical photographs, the total inventory of archaeological sites for an area of 600 km² was doubled and a detailed map was created with more than 30.000 individual archaeological and landscape features. Targeted field surveys gave enough dating evidence of individual sites to provide insights into the historic depth of the landscape. In wooded areas, usually presenting difficulties for archaeological survey, the value of the analysis of full-waveform airborne laser scanning for seeing under the forest canopy was proved with even slight earthwork features revealed.

The results of each survey technique provide valuable information, but each has its own biases and limitations. It is only by combining the techniques in an integrated programme that it is possible to gain a more "realistic" overview of a region's buried archaeology and so allow the effective management of this heritage.

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