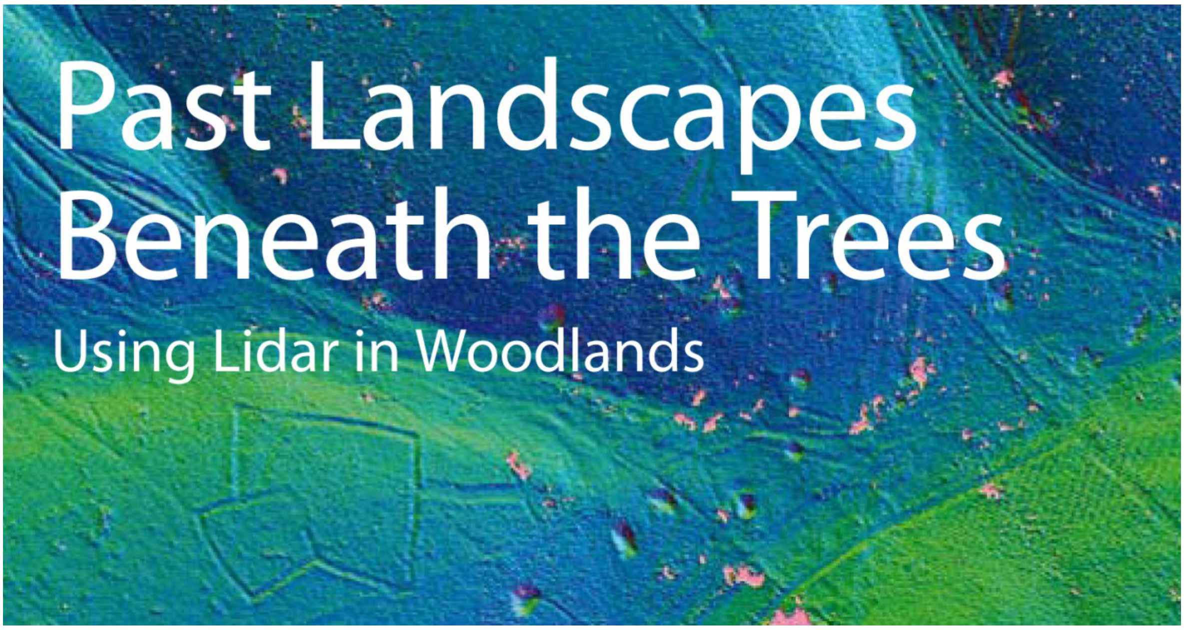

Proceedings of a one-day conference at The Park Campus, University of Gloucestershire, September 2010

Morning Session

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Forward

Jan Wills, County Archaeologist, Gloucestershire County Council

The origins of this conference lie in the long collaboration between the Forestry Commission and the Archaeology Service of Gloucestershire County Council in exploring the historic environment of the Forest of Dean. We began the first stage of the Archaeological Survey of the Forest of Dean in 2001, in a complex, little understood landscape of great archaeological potential. Discussions, workshops seminars and conferences have informed the progress of this project, and the last conference that we organised in 2003 on the subject of woodland survey (GCCAS 2003) brought together techniques and experiences in walkover surveys in woodland from across England. Although this conference took place only seven years ago, lidar did not feature at all in these discussions.

Very shortly afterwards work by the Cambridge Unit for Landscape Modelling (Devereux *et al* 2005) began to demonstrate the enormous potential of this technique for exploring the archaeology of England's woodlands. One of the pilot sites featuring in the article - Welshbury hillfort - was from the Forest of Dean and demonstrated graphically how lidar could be used to record accurately known complex earthworks, and to discover entirely new sites; in this case the extensive field systems surrounding, and at least partly earlier than, the Iron Age hillfort. We went on to commission a lidar survey of the central Forest of Dean and are currently using the results to undertake more detailed exploration of a small sub-set of the more than 1000 sites that the survey has revealed.

Time, therefore, for a review of the use of lidar in archaeological survey, to bring together the experience of the rapidly increasing number of projects countrywide that are exploiting this technique.

The papers given at the conference at Cheltenham in September 2010 are presented here, together with brief notes of the questions to the contributors and the discussion. We are grateful to our co-sponsors of the conference, the Forestry Commission, for their interest in the archaeology of the woodland they manage and their stewardship of this resource. I should also like to thank all of the contributors to a successful conference, and English Heritage who provided financial support towards the web-publication of these papers.

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Contributors

Peter Crow, BSc, MSc: Peter Crow works for Forest Research, where he leads the Forestry Commission's historic environment research programme, providing advice and research to both forestry and historic environment colleagues on the management of heritage in wooded landscapes. As part of this work, Peter has helped to pioneer and publish research on lidar methods for woodland heritage and has subsequently managed various surveys on behalf of others, including colleagues presenting at this conference

Simon Crutchley, BA: Simon Crutchley is a Senior Investigator in the Aerial Survey & Investigation Team at English Heritage. He has a special remit looking at new technology and applications for archaeological research and has been working with lidar across various landscapes since 2001. He has recently published a set of guidance notes (http://www.english-heritage.org.uk/publications/light-fantastic/) on the use of airborne lidar in archaeological survey. Specifically dealing with lidar in woodland he has worked closely with Forest Research and Jon Hoyle on the initial survey in the Forest of Dean and more recently with Forest Research in the survey of Savernake Forest.

Tom Dommett, BA, MA, PIfA: Tom Dommett works for the New Forest National Park Authority as a Heritage Landscape Officer. His work primarily involves the analysis of the data acquired through the National Park's lidar pilot survey. This combines the mapping of historic environment features with the application of techniques for processing and analysing lidar data to enhance archaeological prospection and to inform SSSI restoration projects and veteran tree studies.

Frank Green BA MPhil MSc MIfA IHBC: Frank Green works for the New Forest National Park as their Archaeologist where he is developing the Authority's archaeological research programmes and evidence base to inform the wide range of land management requirements of the National Park. To further this work Frank has developed a number of successful projects that have rapidly increased our understanding of the density and character of surviving archaeological and landscape features. The New Forest lidar project now forms part of the collaborative work between the National Park's Higher Level Stewardship partners to inform restoration schemes and land management of the open forest managed by the Forestry Commission and the Verderers.

Jan Wills FSA, BA, MIFA: Jan Wills is County Archaeologist in Gloucestershire, and manages the County Council's Archaeology Service. She developed the Forest of Dean Archaeology Survey as a response to the paucity of information about early landscapes across west Gloucestershire, in particular in the forested core of this area. Over the last nine years this research and survey project has been one of the Archaeology Service's most important strategic projects, contributing not only to the development of techniques for woodland survey but to also strategies for the management of the historic environment of the Forest of Dean and other woodlands

Helen Winton MA: Helen Winton is a Senior Investigator in the Aerial Survey & Investigation Team at English Heritage. She is a specialist in analysis of archaeological and historic landscapes, in particular on projects involving interpretation and mapping from aerial photographs. Currently she runs the National Mapping Programme (NMP) for the south of England. This involves overseeing English Heritage and contracted project teams who work on this national archaeological survey. Helen has worked on NMP projects since 1992 and has a remit to develop the methodology for NMP, including the use of lidar, for landscape archaeology projects. See www.english-heritage.org.uk/aerialsurvey for more details on projects.

Tim Yarnell BA: After a few years of fieldwork Tim moved into the area of heritage conservation through roles as a Sites and Monuments Record Officer, County Archaeologist and for the last twenty years working as the historic environment specialist within the Forestry Commission (FC). His work with the FC has brought him into contact with many aspects of heritage conservation ranging from the planning of new native woodland in the Scottish Highlands to establishing new Community Forests in Greater London.

Morning Session

Chair: Jan Wills, County Archaeologist, Gloucestershire County Council

Introductory Remarks

Tim Yarnell, Forestry Commission

Why are we here? This is not an invitation to embark upon a philosophical discourse but rather an opportunity to briefly outline why there is a need to see and understand 'Past landscapes beneath the trees'.

Great Britain has a long history of woodland which has seen periods of expansion and contraction and today we have a legacy of the history of the woods and the land that they occupy. For a long time we have been familiar with the terms 'archaeology in' and 'archaeology of woods'. More recently there has been an increasing awareness; we have become more aware of the 'bio-cultural heritage' of individual trees and what they can contribute to an understanding of the history and role of trees and woods in the landscape. Trees and woods are of course an excellent means of learning about the past, sustainable management and ecological history. Ancient woodland, parkland, designed landscapes, more recently established forest, all have a story to tell.

The significance of the historic environment elements of woodland has been accepted for some time and guidance issued on securing long term conservation as part of an ongoing management regime. The conference held here a few years ago (GCC 2003) addressed some of the particular challenges associated with the conservation process. The logistical effort required for survey, time, finance and even finding competent field workers were all identified as significant issues that had to be tackled. I would not claim lidar is a magic wand that we can wave and all the problems disappear but as the speakers will no doubt demonstrate it does open up a whole new world of opportunity.

The timing of the development of lidar and its use in heritage management coincides with a number of initiatives that will affect the historic environment of woods and forests. There is of course the routine management associated with harvesting and restocking of forests. Increased recreational use of forests brings its own special requirements for site planning. As we know earthworks are susceptible to erosion and damage from activities including walking, horse riding and cycling. Formalised routes for these activities require planning over large areas of ground, and lidar is proving exceptionally useful in this respect.

Improving the nature conservation value of woodland is a long established goal of many individuals and organisations. We are of course aware of the long established coincidence of interest between nature and heritage conservation but are also aware that activities associated with one can impact upon the other. Currently there are two major initiatives underway in woodlands where the outcome for the heritage assets could be hugely beneficial but does require an element of heritage input to ensure that the operations necessary to deliver the nature conservation benefits do not have significant impacts upon the historic environment. The first of these relates to the restoration of native woodland on Plantations on Ancient Woodland Sites (PAWS). This involves the removal of non-native, usually conifer, species from Ancient Woodland. Most PAWS will contain evidence of former woodland but also other activities from earlier land uses. The ability to identify these features and present them to owners and managers in a way that they can readily appreciate is an excellent starting point for ensuring longer term management.

The second initiative concerns the restoration of former open habitats that currently under tree cover for a variety of reasons. Many of these locations are former heathland which are often the repository of a diverse archaeological heritage often including significant prehistoric sites and deposits. Selecting which locations to restore may depend upon on many factors, but identifying locations where combined benefits for habitat and heritage can be secured is a priority. It is hoped that lidar evidence can make a significant contribution to this process.

One other aspect of current woodland use deserves a special mention and that is wood fuel. There is considerable interest in renewable energy at the moment and wood is an obvious choice. Indeed for much of their history many woods were utilised in part as a source of fuel. Attention is likely to focus on woods that may not have seen much management activity in recent times and are therefore disengaged from conservation and planning processes.

To conclude these opening remarks I would like to emphasise the contribution that I believe lidar will make to informed conservation but equally hope that the enormous potential for increasing knowledge and understanding of the historic environment at the landscape scale is realised. The capturing of data for several former medieval forests is an avenue of research that I hope is pursued.

References

GCC., 2003. Proceedings of a one day conference organised by Gloucestershire County Council Archaeology Service in June 2003 to discuss methods for archaeological prospecting in woodland. http://www.gloucestershire.gov.uk/index.cfm?articleid=7181)

Illuminating woodland heritage: The technical specifications and limitations of lidar

Peter Crow, Forest Research

Abstract

In recent years there has been significant interest in the use of airborne lidar to map the historic environment. Whilst the technique has been successfully applied to mapping open areas such as Stonehenge, it is without doubt its potential for revealing the historic environment previously hidden beneath wooded landscapes which is generating the greatest interest. However, compared to mapping treeless landscapes, attempting to obtain a reliable model of a woodland floor is much more complex. Like all remote sensing techniques, lidar has its limitations and will neither work through all vegetation types nor reveal every feature. Indeed there are many survey, data and image processing variables which can alter the effectiveness of a survey. For example, the complexity and severity of any sloping ground and the types and abundance of vegetation present will significantly influence the effectiveness of a survey. Equally, survey parameters such as the resolution, scan angle, laser power and the type of data recording system used, will also influence the chances of the laser passing through the vegetation and mapping the woodland floor. Perhaps the most important variable is how the data is subsequently processed to filter out and remove the vegetation, allowing the best 'bare earth' model to be produced and delivered in a usable format. Understanding and interpreting the results from wooded areas can also be problematic, as patterns in vegetation or past forestry practice can appear as interesting archaeological features. To those who are unfamiliar with lidar, it is all too easy to acquire or commission data which gives poor results or ultimately shows nothing but woodland canopy. This paper will briefly highlight some of these variables and potential hurdles, as it is impossible to cover all aspects in depth. For this reason, anyone considering the acquisition of lidar data to research the historic environment under woodland is advised to consult with Forest Research.

Lidar method and products

Ever since the first aerial photographs were collected early in the 20th century they have shown many archaeological features throughout the rural landscape. However, woodland has always been a hindrance to this process, preventing a clear view of any archaeological evidence hidden beneath. Many archaeological features are nonetheless known to occur within woodland and a few have been mapped in detail. Systematic surveys of archaeological sites within woodland do occur, but they are few in number when compared to the woodland cover of the UK. The vast majority of sites are either unmapped, or completely unknown. The history of many UK woodlands is, therefore, often poorly understood and as such they have been referred to as one of the UK's last potentially untapped archaeological resources. For this reason, there is considerable excitement at developments with the Remote Sensing technique of Light Detection And Ranging (lidar) (Bewley *et al*, 2005; Devereux *et al*, 2005) which is unmasking many hidden features.

Lidar technology

An airborne lidar system is typically incorporated into the underside of an aircraft that is flown over a survey area in a series of parallel flight-lines. As the aircraft travels forward, a laser is fired in very rapid pulses (many thousands of times a second) towards the land below. These laser pulses are scanned in an oscillating pattern or arc which allows a wide strip of landscape (hundreds of metres in width) to be surveyed with a single pass of the aircraft. As the laser strikes a solid surface, such as a building or road, the pulse is reflected back to a detector built into the lidar system on the aircraft. Because light travels at a known speed, differences in the reflected signal time to an aircraft at a constant altitude will be directly related to changes in the height of the landscape below (or objects on it). In reality, it is impossible to fly an aircraft so precisely, but sophisticated Global Positioning Systems (GPS) and flight sensors (which measure the pitch and roll of the aircraft) compensate by recording the aircraft's position. When combined with the return times collected from the lidar pulses, the data is used to calculate 3-dimensional co-ordinates for the surface that reflected the laser. The vertical accuracy of the data is typically in the decimetre range (10-15cm), but relative values may be better (often 7-8 cm). Millions of these 3-dimensional co-ordinates can be produced by a survey, creating a ‘point cloud’ of data points that represent the surface of the landscape surveyed. These data points can also be joined together by computer software to form a continuous, 3-dimensional, surface model.

When the lidar is used over a porous surface (such as woodland) some of the laser energy is reflected back from the canopy, but some may also pass through, creating many reflections from branches, understorey vegetation and potentially the forest floor. From a single laser pulse passing through vegetation, the lidar detector on-board the aircraft therefore receives a range of reflected signals. There are different types of lidar sensors in operation, some of which will only record the first and last part of this reflected signal. Others will also record intermediate reflections. For the purpose of this paper, only the time taken for the first part of the reflected signal (typically from the canopy) and the last part of the reflection (potentially from the ground surface) will be predominantly discussed.

Lidar products

A lidar survey may result in a variety of data types, some more useful than others. Many are immediately usable within Geographic Information System (GIS) mapping environments, however they can be very large computer files that will significantly slow the performance of the average desktop PC. Access to powerful computers and specialist software required for data processing and analysis therefore prevents everyday use of lidar data for many potential users. However, many of the derived products may be more accessible. Some data types, processes and derived products are outlined in this paper.

A Point Cloud is usually the first product, calculated from the laser reflections and aircraft position to produce 3-dimensional points, geo-referenced to a national grid system. In many cases, this initial data is in the form of simple text files, with each row containing the X (easting), Y (northing), Z (height above mean sea level) co-ordinates of the first and last part of the reflected signal (see Table 1). Because these are simple X, Y, Z values, they can be loaded into appropriate software and displayed as 3-dimensional points in space – a point cloud. A useful way to imagine a point cloud is to liken it to snow, with flakes covering a landscape (resembling the X,Y,Z co-ordinates of the reflected laser points). Some snow will settle on trees, hedges and fences, and some will also reach the understorey vegetation and possibly the ground. If you mentally remove everything except the snow, you are left with a cloud of flakes (or lidar points) floating in 3-dimensional space (see Figure 1). Table 1 also shows the intensity of the two reflected signals, which will be discussed later in this paper. A final column was added post-survey, to show the difference in height (m) between the first and last reflections. Values highlighted show where the laser pulses struck an impenetrable surface as there is no realistic vertical difference between the two reflections.

Last Return				First Return					
x	y	z	Intensity	x	y	z	Intensity		Difference
480003.52	142000.37	102.95	20	480003.64	142000.91	108.98	43		6.03
480005.70	142000.50	106.64	14	480005.80	142001.13	113.92	35		7.28
480006.76	142000.36	106.58	4	480006.89	142001.23	116.05	43		9.47
480011.54	142000.30	103.79	4	480008.93	141998.61	117.35	38		13.56
480019.77	142000.18	104.35	14	480018.18	141999.20	112.17	26		7.82
480021.22	142000.04	106.15	14	480022.81	141999.11	116.81	34		10.66
480022.93	142000.25	104.73	17	480020.45	141998.75	116.79	52		12.06
480023.99	142000.29	104.83	60	480022.06	141999.12	114.14	6		9.31
480024.76	142000.12	105.02	4	480024.66	142001.32	118.21	47		13.19
480026.58	142000.20	116.65	79	480026.58	142000.20	116.66	79		0.01
480035.18	142000.14	106.37	98	480035.18	142000.14	106.37	98		0.00
480044.53	142000.01	107.15	3	480044.16	142001.22	120.09	43		12.94
480000.25	142000.66	112.23	74	480000.25	142000.66	112.24	74		0.01
480000.71	142000.69	112.46	65	480000.71	142000.69	112.46	65		0.00
480001.09	142001.09	112.61	84	480001.09	142001.09	112.64	84		0.03
480002.12	142000.60	114.36	92	480002.12	142000.60	114.36	92		0.00

Table 1: An example of the data generated by a typical lidar survey. Each row shows the data calculated from a single laser pulse

For every lidar survey, two Digital Elevation Models (DEMs) are usually produced by creating surfaces from the point cloud data. The Digital Surface Model (DSM) is created from the first part of the reflected laser pulse and thus maps the surface of the woodland canopy (Figure 2a). This provides the perfect elevation model over which an aerial photograph can be draped and includes all surface features such as buildings and vegetation. Conversely, a Digital Terrain Model (DTM) or ‘bare earth’ model is created from sophisticated computer processing which uses the last reflection part of the laser pulse to attempt to filter out above-ground data points and model only the true ground surface beneath (Figure 2b). It is this potential ability to model the ground and any archaeological earthworks upon it which is of interest to heritage and land managers alike.

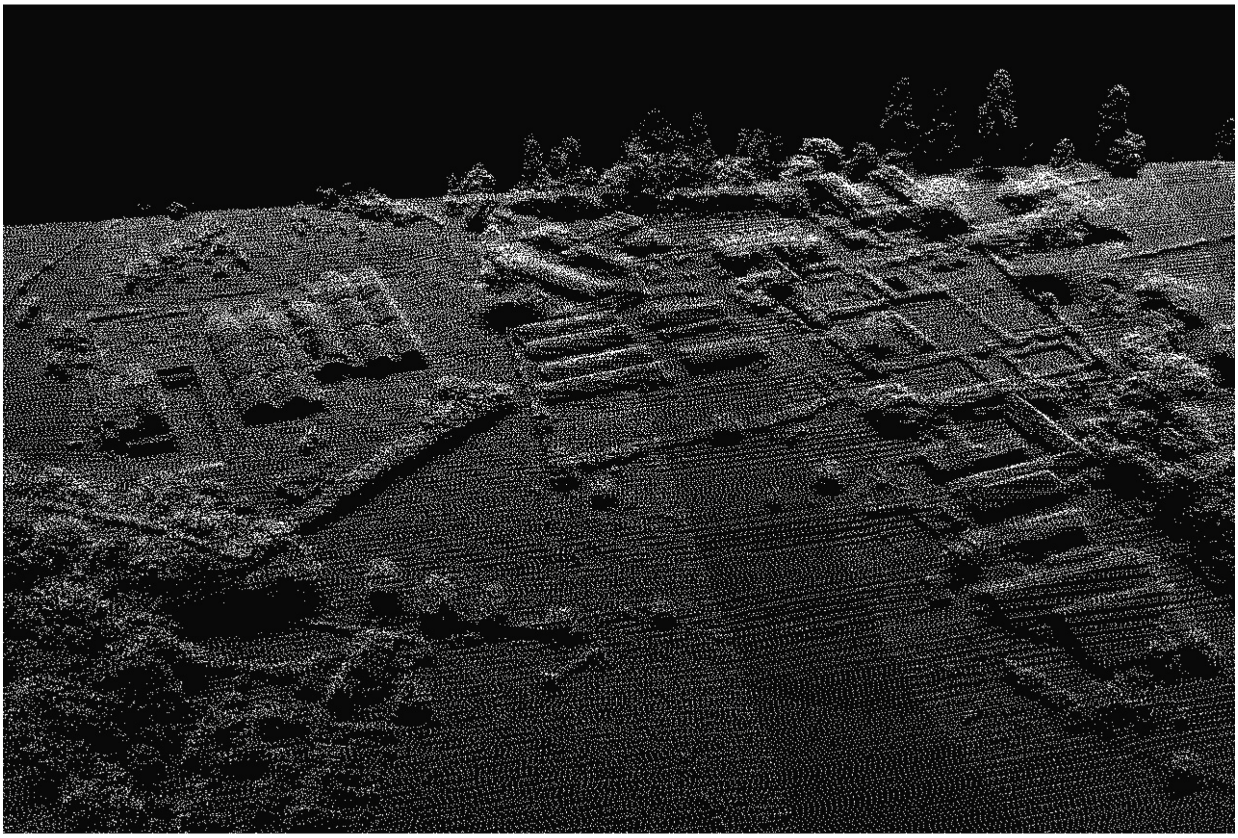
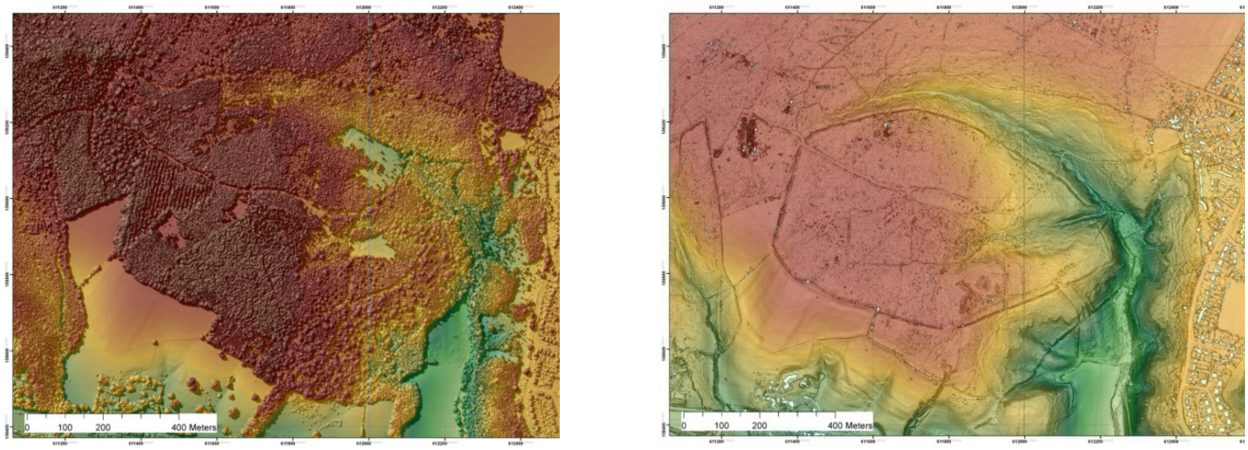


Figure 1: An image of a point cloud

DEMs are often produced as Rasters, a geo-referenced image, formed from a grid of cells of a defined dimension (e.g. 1.0m^2) which relates to a unit of area in the survey. Using the X,Y data from the point cloud, each raster cell is allocated the Z value that falls within it. Any empty cells are filled via interpolation of those adjacent. The smaller the cells of the raster created from the point cloud data, the greater resolution of the image. However, care is needed over the creation of a raster, as specifying cells of a larger size than the resolution of the point cloud data will result in a loss of valuable information. Equally, whilst using a smaller cell size than the resolution of the original data capture may produce 'sharper images', the interpolation required to fill empty cells will create artificial data which may or may not represent the true surface and therefore reduce the DEM accuracy and that of any products derived from it. Rasters can be loaded directly into GIS software where the cell values within a defined range can be assigned a specific colour. This process allows elevation maps to be displayed which use different colours in place of contours to represent changes in height (see Figure 2).

Elevation models offer a very powerful tool for the forest design planner, allowing 3-dimensional views of archaeological features or sites as they may once have looked in an earlier, perhaps treeless landscape. This informs decisions on visually connecting associated historic environment features within the landscape, or changing the setting of individual monuments. Recreational access routes to and around historic environment features can also be sensitively planned to raise their profile within the woodland, thereby enhancing the cultural value. This 3-dimensional data also enables detailed analysis of individual archaeological features, allowing measurements of area, but also cross-sectional interpretation, showing changes in height and degrees of slope across any earthworks.



a b

Figure 2: Examples of a DSM (a) and DTM (b) of the same area. These models were coloured to indicate changing levels of height

The differences in elevation values between the DSM and DTM can be used to produce a further raster image of vegetation height. This is something which may be of interest to forest managers for both productivity assessments and habitat mapping. Similarly, the DSM can be used to map individual ancient or veteran trees or the structure and distributions of ancient woodland. Ancient trees with a large diameter trunk may also be identified in the last return data. For example, when a survey is carried out over a mature broadleaf woodland with sparse understorey, there should be little to prevent the laser from reaching the forest floor. Under such conditions the large trunks of any ancient trees present can block the laser, creating elevated points that allow them to be mapped. With further developments in lidar technology, it may soon be possible to map fallen dead wood, understorey vegetation and, eventually, full forest structure with potential applications in assessing biomass and carbon storage.

Data visualisation

When viewed within a computer, an elevation model shows little surface detail. To make any topographic changes more apparent, an artificial sun is modelled within the computer which can be placed at a low elevation to create an artificial sunrise or sunset event. Any upstanding features on the model surface are then disclosed by the creation of highlights on the face closest to the illumination source and shadows on the opposite face. Features that appear to have their face closest to the illumination source in shadow and their furthest one highlighted will be sunken artefacts such as ditches. This process crates a new hillshaded raster, but rather than each cell containing an elevation value, it contains a grey-scale value ranging from 0 (black) to 255 (white). Figure 2 shows more detail than would be apparent from just the DEMs, because semi-transparent hillshaded images were placed over the top, allowing the height colouration from the DEM to remain visible.

These hillshaded images are the most common product of a lidar survey and may be offered to interested parties for existing data sets. This can have the advantage of acquiring survey derived products without the need for purchasing more expensive elevation data or commissioning new flights. When hillshaded images are obtained from a third party, they are typically produced using illumination from the northwest. Whilst these images are very good at displaying subtle changes to the surface of a DEM, they can have limitations. When features are located on a southeast facing slope, they can remain hidden in its shadow (see Figure 3a). Equally, linear features orientated in the same direction as the light source will show up poorly as there is a smaller surface area showing either highlight or shadow. Because the DEM is held within the computer, running a second hillshade analysis from a different direction and elevation can show objects hidden in the first image (see circled features in Figure 3b). It is possible to build a composite view of several hillshaded images either by overlaying them within a GIS environment (Figure 3c) or by the use of statistical analysis (which can create a composite from any number of hillshaded images generated from a wide variety of illumination directions and elevations) to show the majority of features from each (Devereux *et al* 2008) as shown in Figure 3d.

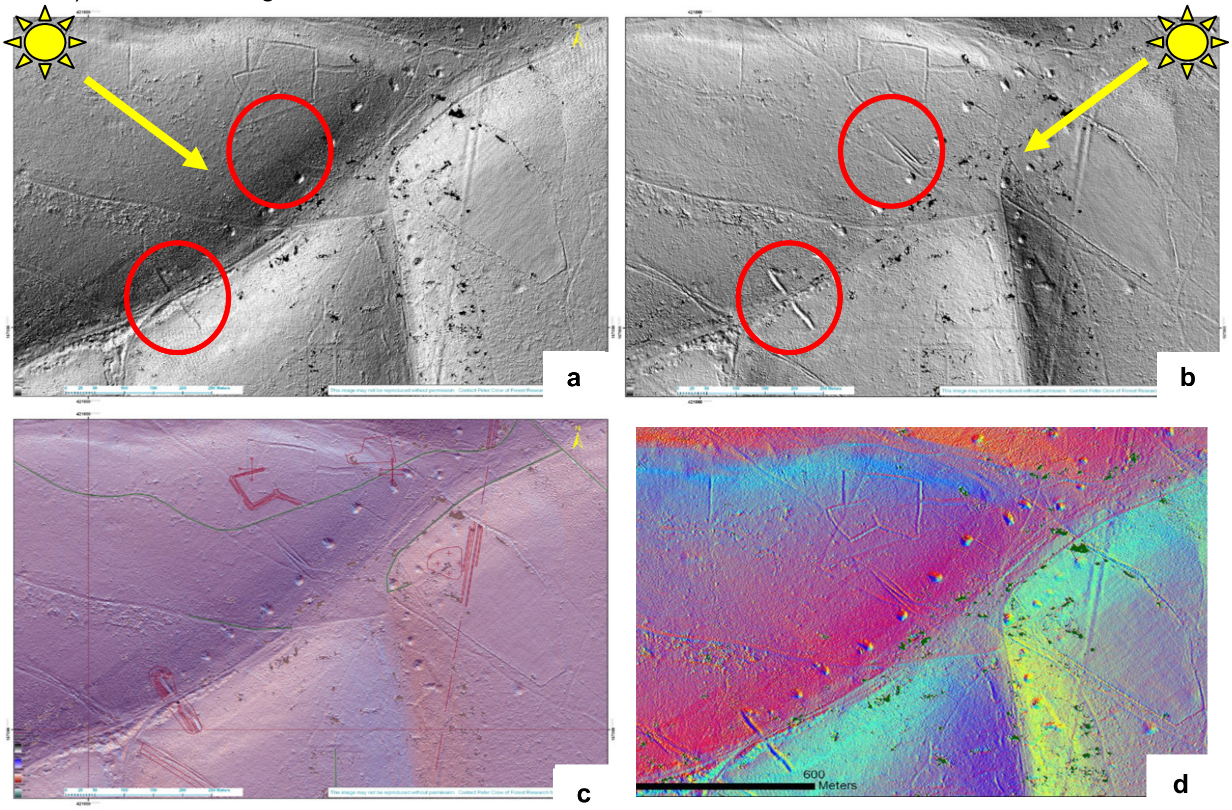
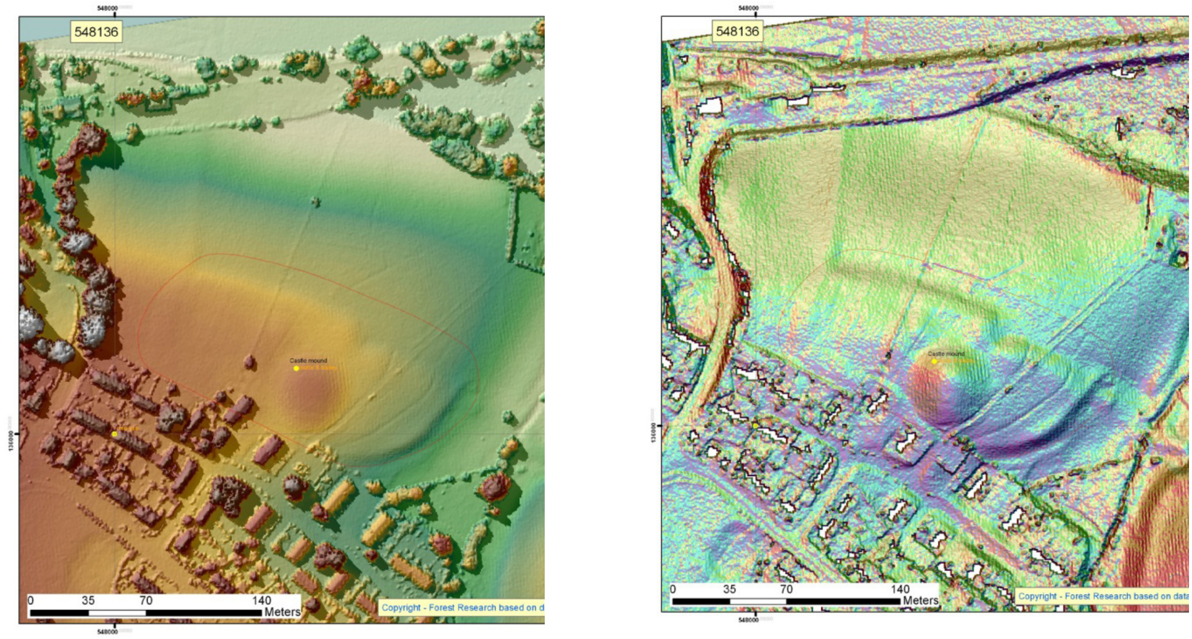


Figure 3: Two different hillshaded views (a and b), a GIS composite (c) and statistically produced image (d) of the same area of a DTM. The sun symbols indicate the direction of illumination used in images a and b

In addition to hillshading, other analytical techniques can be applied to elevation models. Slope analysis creates a new raster in which each cell is populated by a measure of slope from the corresponding area for the elevation model being analysed. When displayed as a grey-scale image, each cell is tinted so that the steeper the slope, the darker the shading. Unlike hillshading, this type of analysis is not influenced by compass direction and features within the elevation model will not be hidden in shadow. However, unlike hillshaded images, the intensity of shading is dependent on the slope, regardless of whether it is rising or falling. In other words, it can be difficult to discern whether disclosed features are raised or sunken, which can complicate interpretation. Slope analysis is particularly effective where archaeological features are detected by a change in slope from that of the surrounding natural topography. For example, where charcoal hearths are shown as levelled areas cut into a natural slope. These sudden, but often very localised changes, in slope can become very clear following slope analysis.

Aspect analysis created a raster where cells can be coloured depending on the compass direction the DEM slopes towards at that point. For example, all cells which correspond to those on a DEM that face northeast are allocated one colour, whilst those sloping east are given another. Any flat areas with no degree of slope can be left colourless. Some very broad, gently sloping earthworks can be difficult to detect with slope analysis or hillshading, as the gradual changes do not provide sufficient contrast to the surrounding topography. However, even very gentle slopes or broad features can exhibit a change in aspect when compared to their surroundings and this can be used to highlight them (see Figure 4). Aspect can also be useful in the identification of sites with potential archaeological interest such as settlements, which are often associated with a south-facing slope. This type of information can therefore be useful when targeting areas for other research purposes.



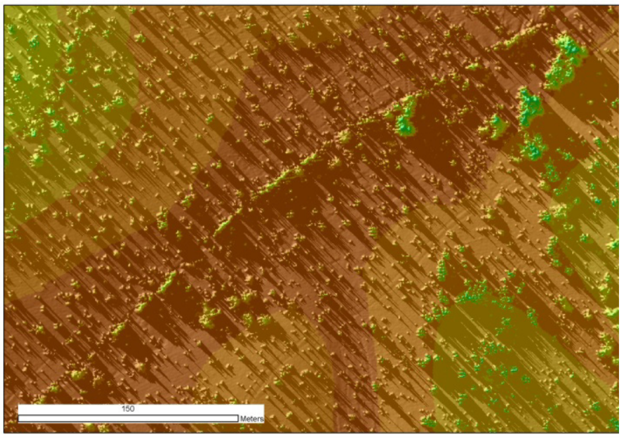
a **b**

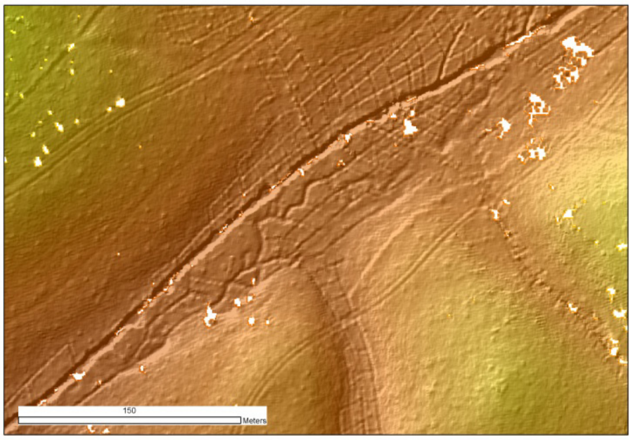
Figure 4: The same area using conventional height and hillshading (a) and slope and aspect analysis (b). The earth mound is more prominent in the latter

The complications of woodland

In open landscapes, the first part of the reflected signal may be suitable for the identification of archaeological remains. However, most of these features will be known from aerial photographs. The greatest potential for lidar therefore lies in wooded landscapes where the use of algorithms to filter out vegetation allows the detection of features beneath the canopy. However, there are many mechanisms by which vegetation can influence the ability of the laser to be successfully reflected from the ground and complicate the production of a quality DTM (Crow *et al*, 2007). For example, as the laser passes through any vegetation (both leaving and returning to the aircraft), some of the laser energy is scattered, reducing the strength of the reflected signal. Higher-powered lidar systems are therefore better for penetrating woodland. Similarly, lidar surveys commissioned for historic environment surveys of woodland are flown during the winter months when deciduous vegetation is devoid of leaf cover and laser penetration to the forest floor would have the greatest likelihood. However, significant areas of dense, young woodland regeneration or unthinned conifer plantation will still greatly restrict the potential of the survey and may prevent it from being a viable option.

A DTM can be generated directly from the last return data, but everywhere that the laser has been unable to reach the ground due to vegetation, structures will be generated in the model, representing the height and size of the object that blocked the laser. Depending on the density and type of the woodland, these DTMs can be very difficult to examine for archaeological features. For example, if the DTM is hillshaded, the above-ground points will create many extra shadows, many of which may mask more subtle, ground-based features of interest (see Figure 5a). To get around this problem, the data is passed through various computer programs which identify these above-ground points and remove them from the data before a DTM is produced (Figure 5b).



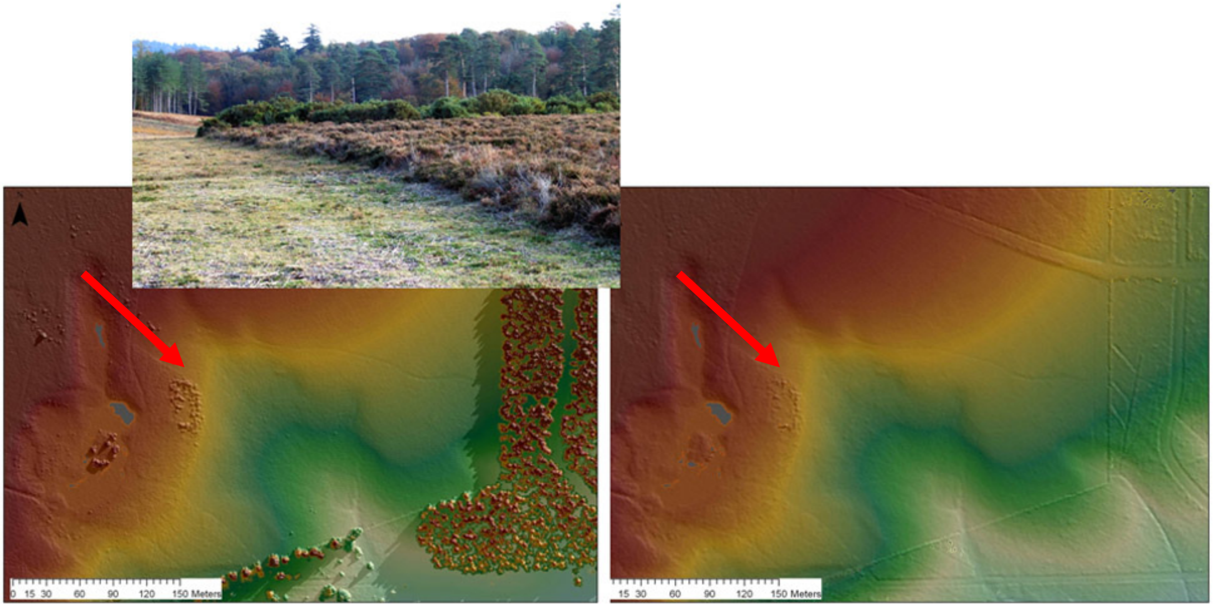


a **b**

Figure 5: Hillshaded images of the same area, but with DTMs created both without (5a) and with (5b) the vegetation removal processing

There are different types of computer processes, ‘algorithms’, which can be used to filter out the above-ground points and create a DTM. Equally, there are often variables which can be applied to these algorithms. Successive algorithms may also be applied to a single data set to ‘refine’ the vegetation removal process. Some algorithms function by passing a ‘window’ over the last return data. Where individual Z (height) values are significantly above their neighbours (using a defined threshold), they are assumed to be ‘above-ground’ points, reflected from impenetrable vegetation or a building. These points can then be excluded from the terrain modelling. An alternative method may start by identifying the lowest points recorded in a survey and assume they are true ground points. These are then used to help identify other likely ground points and the model slowly added to and built ‘from the ground up’. Some vegetation removal processes are highly automated, whilst others require stages of human intervention. To prevent the creation of false features within the DTM from understorey vegetation, the process can be configured to leave ‘gaps’ under above-ground data rather than smoothing the area over or forcing the data to be used in creating an unreliable surface. In areas of dense conifer or understorey vegetation such as holly, the resulting DTM will be dominated by the gaps, making a survey of these areas ineffective. Leaving gaps in the DTM helps to highlight areas where the survey has not been fully effective and further fieldwork may be necessary.

In addition to dense vegetation, areas with short plants can also be difficult to remove from a DTM as the algorithms used will be less confident about distinguishing them from genuine ground values. For this reason, open landscapes dominated by vegetation such as gorse, heather or broom can be difficult to survey through. Because such vegetation may not be fully removed during processing, any changes in height due to different areas of vegetation may persist into the DTM, potentially creating an artificial feature. One example is shown in Figure 6, where vegetation management has left linear edges to areas of heather, creating linear features in the DTM. Figure 6 also shows how the trees on the right-hand-side of the DSM were more effectively removed than the shorter vegetation. Where the laser is able to penetrate to the forest floor and the vegetation removal produces a DTM with few gaps, the real benefits of the survey become apparent, revealing the archaeological features previously hidden beneath the woodland canopy. However, given the complications outlined above, careful site selection and awareness of vegetation is essential to ensure cost-effective surveys are commissioned.



a b

Figure 6: Low vegetation visible in the DSM (6a) is still evident in the DTM (6b) following the successful removal of the trees

Lidar is indiscriminate and whilst it can potentially show features of archaeological interest, it will also record many others. In addition to vegetation, natural changes in soil or geology can manifest themselves as tantalizing features or areas to be targeted for further research (see Figure 7). Similarly, natural water channels can resemble route-ways or drains. False archaeological features may also result from more recent human activity and confusion in lidar interpretation may result from objects such as golf course bunkers, earthworks associated with levelling car parks or enclosing animals. In wooded environments, roadside timber stacks, piles of brash (branch and foliage residue after felling) or extraction routes, all have the potential to appear as interesting archaeological objects. To help eliminate these from further investigation, comparing the lidar products to other existing data sets such as past and present maps or aerial photography may enable the identification of some features and their removal from any further investigation.

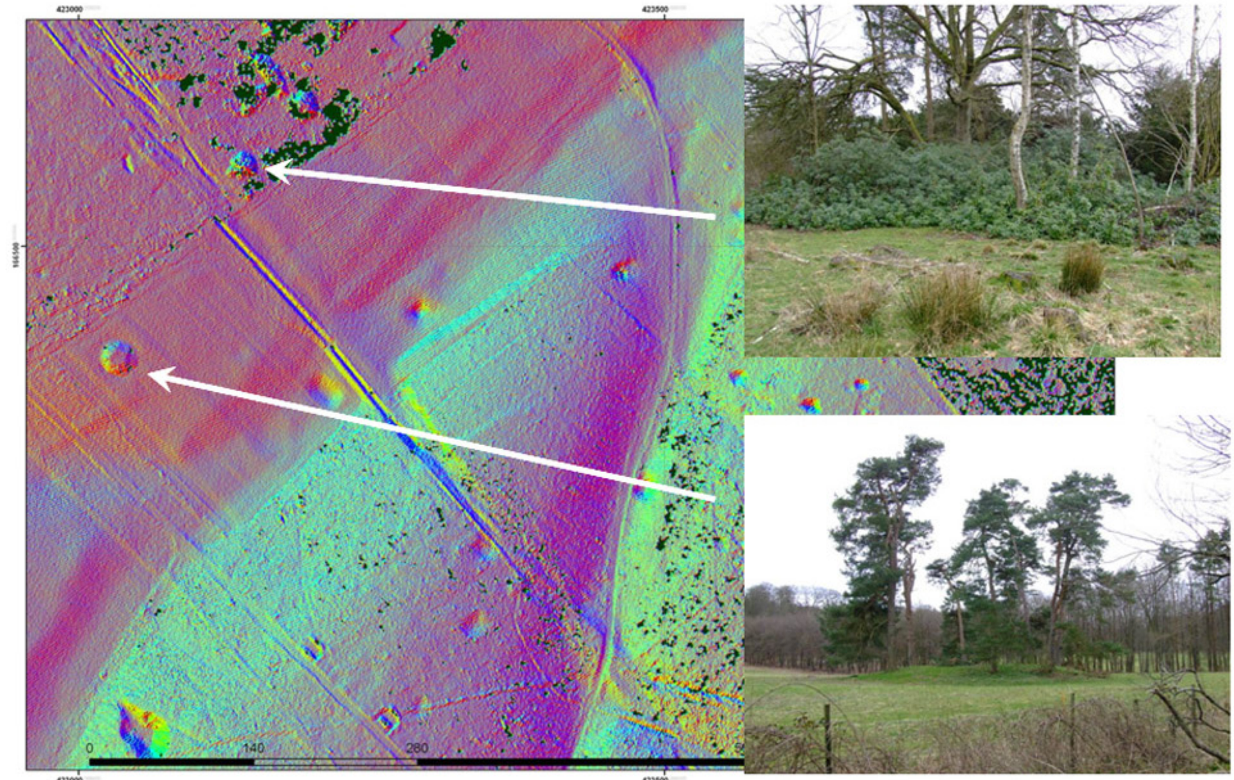


Figure 7: Non archaeological features (e.g. vegetation) can resemble those of genuine antiquity (a burial mound)

Not all surveys are the same

Clearly, different survey and processing parameters can have a significant impact on the quality of lidar results. One extreme, but known, example was when a survey was commissioned to map heritage hidden under a broadleaf woodland, but was captured in mid-summer. Perhaps, not surprisingly, it was impossible to construct a usable DTM from the results. When either acquiring existing data or commissioning a new survey, it is therefore necessary to consider the objectives, the expectations and the limitations of both the technology and site. If a project aim is to map a single site, in an open setting and in great detail, then a higher resolution will be required than that for capturing entire open landscapes, but either may be acquired any time of year. If a large wooded area is to be surveyed, then a compromise on the resolution may be necessary that will maximise the chances of the laser reaching the ground to produce a usable DTM, whilst being cost-effective when capturing an entire landscape. A winter flight will also be necessary for the latter. Similarly, for steeply sloping landscapes or woodland plantations where the trees are located in well-defined rows, the direction of survey flight, laser scanning arc and survey height may all influence the ability of the laser to reach the ground.

There are just as many variables in lidar derived products. If hillshaded images are provided for a specific area, they are likely to be lit from a single direction (usually the northwest) and the user should be aware of the limitations described above. Data products may also be provided in a variety of formats, which may or may not be accessible by the user, depending on the software being used for its display or analysis. It is therefore important to ensure that data is sourced in user-specified formats.

It is essential for any user who is analysing lidar-derived products to be aware of the parameters used for data acquisition and processing, as this will help inform its limitations. For example, whilst a survey resolution may be expressed as a number of laser hits per square metre, it must be remembered that these are typically quoted as average values and whilst for many areas the density will be higher, there will be occasions when it is less. It is therefore possible that objects of only two or three times the size of the survey resolution may not be recorded by the laser.

It must also be remembered that this technology is still being refined and developed, with both new systems and data processing mechanisms becoming available. Some systems now have duel-beam lasers, operating at different wavelengths with differing abilities to penetrate and map below water. Others offer intermediate returns between the first and last data points. When displayed as a point cloud, these extra points may show more information on the types of vegetation the laser is passing through, but the extra data may also make manipulating and interpreting the cloud more difficult. A further data set that may be available is the intensity of the reflected signals. This is shown in Table 1 and is dependent partly on the area and angle of the surface the laser struck, but also its colour, composition and texture. Exactly how the reflected signal is influenced by these latter variables will partly depend on the wavelength of the laser in use, but differences in vegetation colour and soil moisture have been recorded.

One developing area of potential archaeological interest is that of full waveform lidar. These systems observe the reflected signal continuously, potentially equating to hundreds of measurements for every single laser pulse. The data is typically displayed as a plot of reflected intensity against time for every returning laser pulse (see Figure 8). With individual laser pulses fired typically between 30,000 and 200,000 times a second, this generates huge quantities of data and as yet the ability for computers and software to use such data is limited. However, where the method has the greatest archaeological potential is in its ability to improve on the vegetation removal process and produce a more reliable DTM. When a pulse strikes a solid surface, it is returned as a single reflection producing a very narrow waveform peak. Conversely, as the laser passes through vegetation, or a similar porous surface, the many, smaller reflections result in a broader peak being recorded by the waveform system. The shape of these recorded peaks can therefore be used to help clarify what has reflected the laser pulse informing the production of a more reliable DTM.

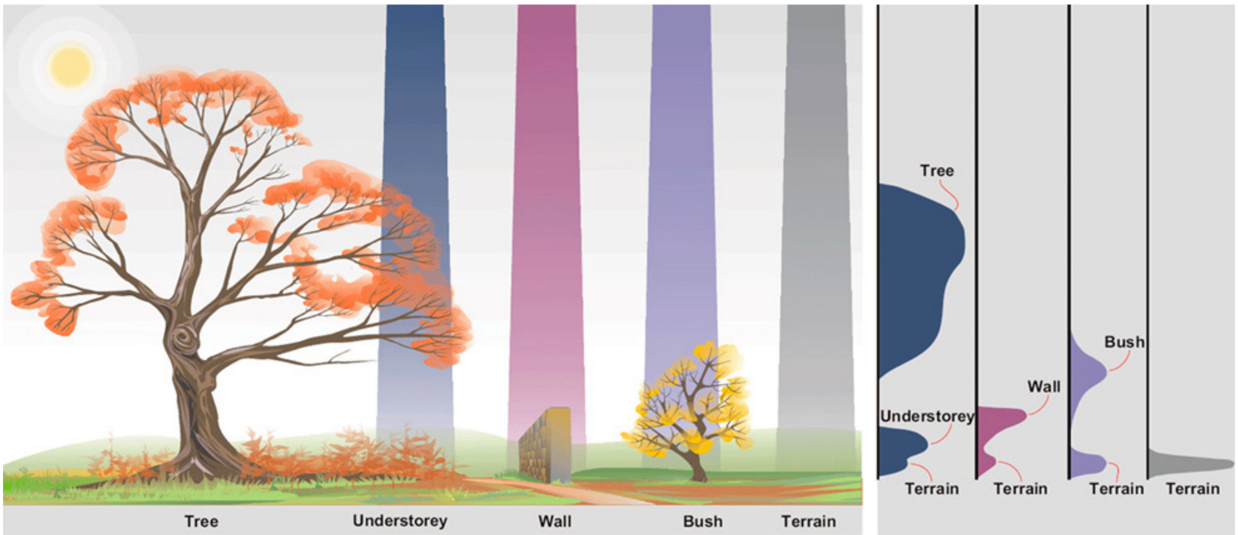


Figure 8: Full waveform digitisation can help distinguish between the types of landscape features struck by the laser. ***Image courtesy of English Heritage***

Conclusions

Lidar allows the rapid survey of large areas of forest and woodland dominated landscapes, often revealing the hidden terrain beneath. The best results are obtained from mature broadleaf canopy with little understorey vegetation when surveyed in winter. Under these optimum conditions, the surveys can reveal some very subtle changes in ground surface allowing many archaeological features to be seen. The best results are obtained between January and March, when the previous season's vegetation has died back and been compressed by possible snow falls and before the foliage once again becomes inhibitive. However, the occurrence of suitable weather conditions during this period to allow the surveys to take place can be very limited. The method is most effective at revealing linear features and even very subtle earthworks can be shown, many of which are difficult to see on the woodland floor. Examples include earthworks of field systems, other boundary banks, lynchets, route-ways and drainage channels. When used over optimum vegetation types, smaller, more discrete features such as charcoal platforms have been mapped.

But, lidar will not show every historic environment feature and will not work in all woodland types. Whilst the technology will work through mature, thinned conifer and has shown linear earthworks, quarries and pits under such conditions, younger, dense conifer plantations will greatly reduce the quantity of laser energy able to penetrate to the forest floor. However, even where canopy penetration is perceived to be good, dense layers of understorey vegetation such as bramble, bracken, gorse or holly can still inhibit the laser from reaching the true ground surface. Indeed gaps in the lidar derived DTMs caused by understorey holly have been used to map its distribution. Knowledge of the vegetation types through which the survey is expected to work is therefore essential in considering potential areas for lidar survey or analysis results.

Lidar is a very powerful tool and when applied to appropriate wooded landscapes has the potential to map both known and previously unrecorded historic environment features. Many may provide information about a woodland's history and, in turn, guide its future management. Nonetheless, it is not an instant solution to discovering every aspect of a woodland's heritage and is best employed in combination with other sources of information. Because it is most economical to apply the technique at the landscape scale, costs of commissioning surveys will inevitably be considerable. However, such surveys should be looked upon as a long-term investment as the data, models and images can be useful for a wide range of planning, management, environmental, ecological and public engagement activities.

Copyright and acknowledgements

 Forest Research wish to acknowledge the University of Cambridge, the Forestry Commission, the Weald Forest Ridge Landscape Partnership, the New Forest National Park Authority, the Castle Neroche Partnership Scheme and the Blean Partnership who contributed to the surveys used in the illustrations. Thanks are also given to English Heritage for permitting the use of their image in Figure 8.

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For further information, contact peter.crow@forestry.gsi.gov.uk or see:

Crutchley, S. And Crow, P., 2009, The light fantastic: Using airborne laser scanning in archaeological survey. English Heritage, Swindon.

Questions for Peter Crow:

Q. Can you comment on the need for ground truthing?
A. Lidar data needs to be treated with caution and, although it is generally accurate, it does not always produce results which can be taken at face value, for example where dead bracken has collapsed over a wire fence it can appear to be a bank. Ground truthing is currently the simplest method of sorting these issues out although future developments in data processing or our understanding of these issues may make it increasingly less important.

Q. Can you comment on the quality of commercially produced data which is available as tiles?
A. Whether commercial data is suitable may depend on what the aim of the project was and what time of year the survey had been undertaken. In open landscapes relatively low resolution lidar flown at any time of the year may provide suitable results. In woodland the survey would need to be undertaken in the winter months (preferably January to March and ideally at a higher resolution (2 points per square metre or better) than much of the existing commercial data. Also the way in which the data is processed is a crucial issue when dealing with woodland.

Q. Why are images illuminated from the north-west?
A. That's the current commercial standard, although lidar can be illuminated from any direction. There are, however, perception issues with hillshaded images illuminated from the south. Whilst individuals can perceive images in slightly different ways, images lit from a northern direction tend to provide a more reliable representation of the topography, whilst those illuminated from the south can appear inverted with mounds becoming hollows and banks becoming ditches.`

Q. Can lidar be used for surveys of designed landscapes e.g. parkland to identify monuments, former designs etc.
A. Yes, if woodland is surveyed in winter and the features being searched for survive as earthworks.
Comment from the floor. There are currently two English Heritage projects using lidar in surveys of designed landscapes, and Archaeology South East is currently undertaking a project at Sheffield Park.

The New Forest National Park Authority and Forestry Commission lidar pilot survey 2009

Frank Green and Tom Dommett, New Forest National Park Authority

Abstract

The New Forest, in particular the Crown land managed by the Forestry Commission and some 45% of the total area of New Forest National Park, is predominantly a lowland heathland landscape with areas of woodland pasture and formal forestry inclosures. The Crown Land is surrounded by additional areas of heathland commonage and the enclosed cultivated landscape, all of which possesses many characteristics unique to the area. With the creation of the New Forest National Park Authority (NFNPA) rapid assessments were made to establish the extent of the existing archaeological evidence base. It became clear that to locate sites and landscape features on the Crown Land and open forest would take about 140 years at the then rate of field survey.

It was therefore decided that using techniques such as lidar might be able to focus field work and ground truthing and potentially would speed up the development of the National Park's archaeological evidence base to inform development and landscape management decisions. In conjunction with the Local History and Archaeology Group, and with advice from the Forestry Commission, led by Peter Crow, a sample transect across the open forest and woodland inclosures was selected. This involved 34km^2 running from Woodgreen in the northwest to Burley towards the southeast. The work was jointly funded by the NFNPA and the FC.

The primary objective was to see how efficient lidar might be in identifying sites on the 'soft' geologies of the Hampshire basin deposits and at the same time to establish the range of sites that might be identified. Some parts of the lidar sample transect area had already been extensively surveyed using traditional techniques and these areas were included so that it would be possible to contrast the two sources of information.

From the outset of the project the expectation was that lidar would be successful in locating additional archaeological sites and landscape features and it would also provide the ability to plot the true extent of some sites with a greater degree of accuracy than had been possible using traditional field techniques.

This paper provides a brief overview of the success of the project and future developments. The lidar survey will be extended in 2010-2011 to cover the 19,000 hectares of Crown Land as part of a 'special project' within the New Forest Higher Level Stewardship scheme.

Background

With the creation of the New Forest as a National Park taking up its full powers in 2006, it was recognised that the evidence base to inform decision making for the historic environment needed to be rapidly expanded. In simple terms the new National Park was some sixty years behind other national parks in collecting data for its evidence base. It was necessary therefore to rapidly enhance the available historic environment data sets. This is an on-going process and the lidar pilot study is only one element of the Authority’s programme of enhancing the available evidence to inform land management and planning decisions. The work will strongly influence appropriate management outcomes and strategies for the historic environment in the New Forest.

The new National Park faces many challenges; one of these is the area’s easy accessibility, located in central southern England close to motorway systems from London and its suburbs. This, combined with its close proximity to the urban centres of Bournemouth, Poole, Southampton and Portsmouth, can result in very large numbers of day visitors estimated at about thirteen and a half million day visitors per year. To this has to be added the resident population of some thirty four thousand people. The sheer volume of visitors to this National Park presents both a risk to the archaeology and an incredible opportunity to engage a wide audience with their local, regional and national cultural heritage, examples of all of which are represented within the New Forest.

The Crown Land, the open common land of the forest, contains nearly half of all the public open space in the entire southeast of England to which the public have access. The forest has a range of habitats from heathland characterised by heather, bracken and gorse through woodland pasture, ancient woodland and commercial forestry plantations. This last aspect of the working landscape of the New Forest also poses significant threats to the protection of archaeological sites. Timber felling and extraction is an intensive and potentially destructive process (see Figure 1) – even when the utmost care is taken to avoid known sites, those that have not been recognised are at considerable risk. There are also areas of enclosed landscape. Although these mainly surround the open forest, there are some small enclosed areas within the open forest.

Figure 1: Deep ruts resulting from felling works

Nearly half of the National Park is covered by nature conservation designations with the largest area of lowland heaths and bogs in Europe and some of the best deciduous and ancient woodlands in southern England. The New Forest is also well-endowed with a wealth of historic environment features. There are over 3,300 sites recorded in the Archaeology and Historic Buildings Record (AHBR), among which are numbered nearly 10% of all the Scheduled Monuments (SMs) in the southeast of England with several hundred more that have been assessed and meet the criteria for scheduling. Within the Forestry Commission's national estate the New Forest contains about 25% of the SMs in their care.

There has been a long tradition of archaeological and antiquarian work within the New Forest from the eighteenth century onwards, such as the mid-nineteenth century excavations of John Wise. Many of the pioneers of field archaeology such as Williams Freeman, Heywood Sumner and OGS Crawford significantly increased our understanding of the area.

In the twentieth century the use of palaeoenvironmental work through pollen and other studies has helped establish sequences of change. To this must be added the current and recent work of many dedicated individuals, local societies, and academic institutions. Current research interests and priorities have assisted our understanding of Bronze Age barrows, boiling mound sites, Iron Age settlement sites and Roman pottery kilns. At the other end of the time scale there are medieval and post medieval woodland activities including saltpetre and gunpowder production. Brick kiln and twentieth century military and wartime installations proliferate throughout the Forest.

However, some traditionally accepted views about how the landscape developed in the past and was influenced by man's activities can now be questioned. The impact of man on the landscape within the New Forest is potentially more complex and of greater time depth than perhaps previously considered.

As with all National Parks, the New Forest has a statutory duty to meet the curatorial obligations enshrined within the purposes of the park:

- To conserve and enhance the natural beauty, wildlife and cultural heritage of the Park.
- To promote opportunities for understanding and enjoyment of its special qualities.
- In addition the National Park Authority has a duty to foster the social and economic well-being of local communities.

As part of the Authority's historic environment needs assessment, the possibility of using lidar seemed to have considerable potential to speed up field survey and allow quick and accurate plotting of archaeological sites and landscape features. It had been variously estimated by the New Forest

History and Archaeology Group that it might take 140 years to complete a survey of the New Forest given current resources and traditional techniques.

The use of lidar was considered to be appropriate in the absence of National Mapping Programme (NMP) data coverage for most of the National Park area (see Figure 2). Areas around the periphery of the Park have been subject to NMP projects undertaken by Cornwall County Council's Aerial Survey team funded through the Aggregates Levy Sustainability Fund along the Avon Valley and parts of the New Forest Coast. The rest of the National Mapping Programme along the New Forest coast has been undertaken as part of the Authority's Rapid Coastal Zone Assessment project. However, Figure 2 shows that the majority of the National Park lacks such (NMP) coverage - the current indication is that English Heritage have considered funding the remaining 400km^2 requiring NMP work once the lidar data is available.

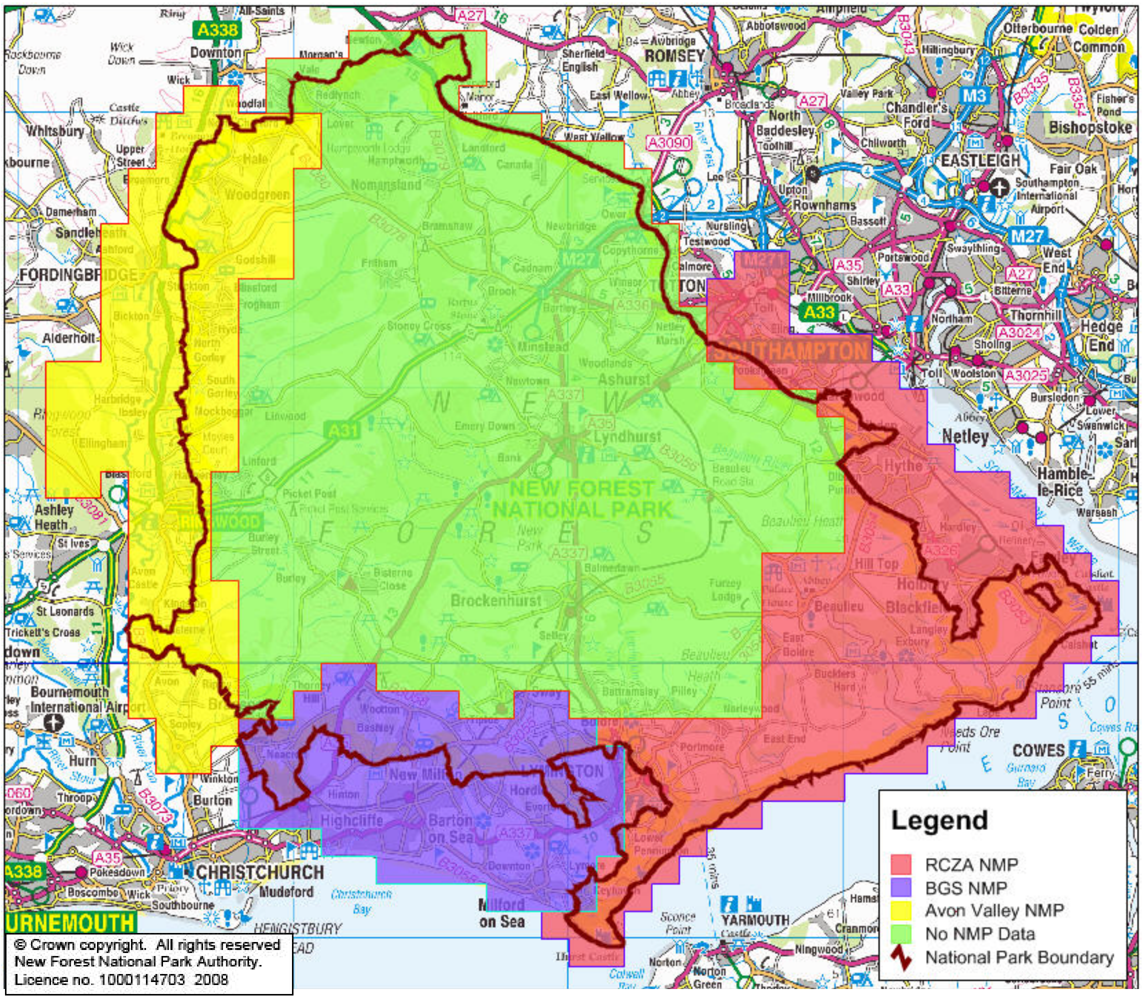

Figure 2: National Mapping Programme coverage for the New Forest National Park

To aid the New Forest National Park's assessment the results of other lidar surveys (cf. http://www.forestry.gov.uk/fr/INFD-6FKHFE) were reviewed in 2007 with colleagues from the Forestry Commission, in particular the evidence from the Forest of Dean. This showed the very real potential to view archaeological sites and landscape features beneath tree cover on a hard geological landscape. Given the substantial areas of woodland within the National Park, this offered an opportunity to vastly improve on the results of NMP aerial photographic analysis alone. However, the New Forest with its Hampshire Basin soft geology of clay gravels and sands, and the absence of stone for construction purposes, presented quite a different environment. It was essential to establish that the collection of lidar data from the New Forest would be of benefit and as such a pilot lidar survey was needed to provide a robust assessment for the use of lidar within the New Forest.

Initially existing sources of lidar and other remote sensing data for the New Forest National Park were examined for their suitability for archaeological and landscape purposes. Of these the Environment Agency coverage (cf. http://www.geomatics-group.co.uk/GeoCMS/Order.aspx) seemed to have the best potential. However, the available data sets were specifically geared to flooding along the coastal margin and the river systems of the Avon and Test Valleys. The core area of the New Forest, the Crown land, was only partially covered by data sets lacking the resolution required for the analysis of archaeological features under woodland canopy. Added to this was the need to purchase the Environment Agency raw data sets. After assessing the availability of data sets and associated costs it was determined that these were not specifically geared to the National Park's archaeological and landscape requirements, and in conjunction with the views from our partner colleagues at the Forestry Commission, it was decided to fund the pilot survey.

The potential survey areas were discussed with the chairman (Anthony Pasmore) of the then New Forest Section of the Hampshire Field Club and Archaeological Society and an agreed transect involving $34km^2$ was selected. The transect ran from Woodgreen in the northwest of the National Park, southeast to Burley. This area encompasses a wide range of landscape types, predominantly dry and wet grassland, dry and wet heath and also inclosure woodland (Figure 3), allowing the effects of different New Forest vegetation to be assessed. The transect was chosen to cover areas that had previously been surveyed in the later 20th century using traditional techniques of field survey and other areas of open commonage and inclosed woodland that had not been the subject of field survey. The objective was to test the data against known evidence and at the same time to provide data that could be verified for areas not previously surveyed by traditional means to establish exactly what the lidar data was capable of providing.

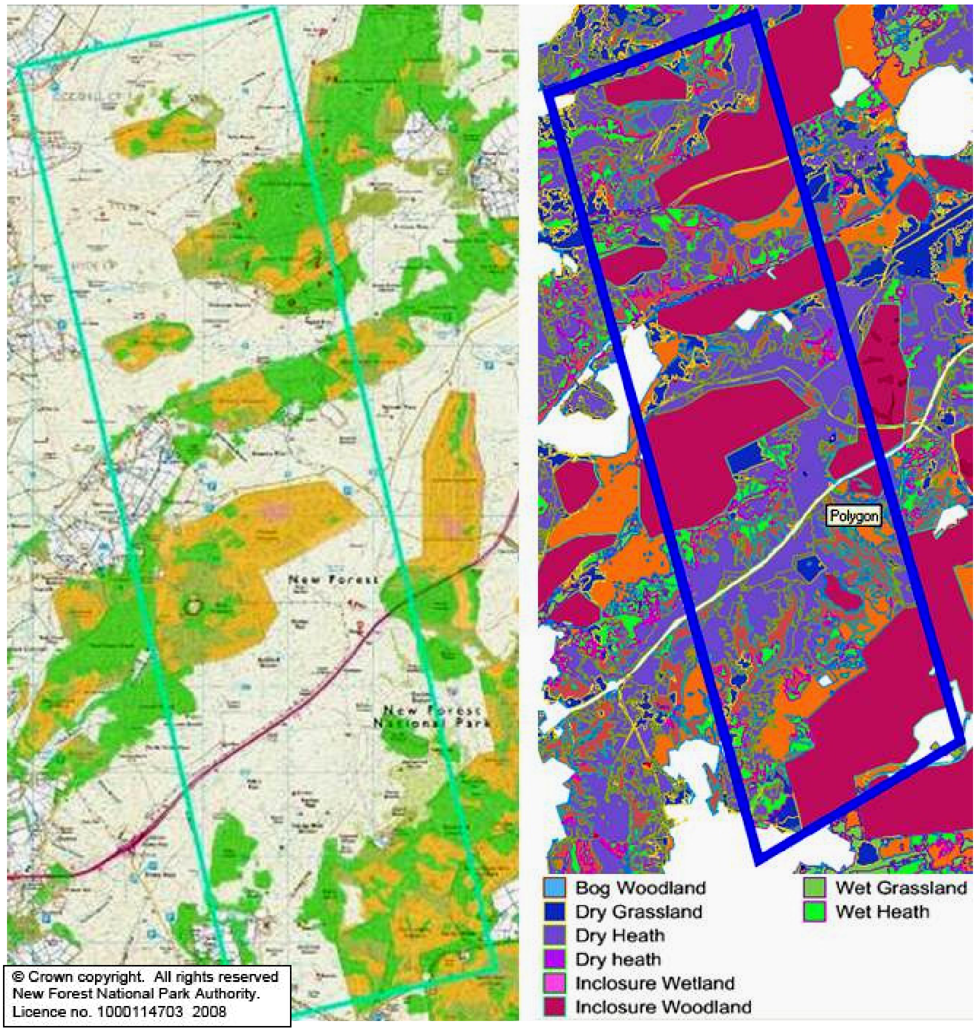

Figure 3: Location of the lidar pilot survey (left) and vegetation types (right)

The lidar work was commissioned through the Unit for Landscape Modelling in Cambridge via Peter Crow at the Forestry Commission. The $34km^2$ were flown with a view to achieving a resolution of 0.5m, or two hits per square metre. Once the data was gathered it was processed to produce a Digital Terrain Model (DTM), Digital Surface Model (DSM), a series of hillshaded images and a Principal Component Analysis image.

As part of this work it was recognised that lidar could provide more than just data to inform the historic environment. It was recognised that there are other obvious avenues of application for lidar data. The ability to model the terrain would be of benefit to inform stream, mire and habitat restoration projects that otherwise had the ability to destroy or damage archaeological sites. Similarly lidar could better inform commercial forestry operations and recreational developments, car parks, camping sites and routine engineering operations. It was considered that there might also be benefits for locating veteran trees and, combined with infra-red data, might help with categorising vegetation types and assisting ecological research and monitoring across the New Forest. Using vegetation heights derived from the lidar (DSM - DTM) it has been possible to extract trees of a desired width and height from within known areas of ancient woodland and subsequently, through cluster analysis, to extract trees with a certain crown width to produce likely candidates for veteran or ancient trees (Figure 4). Infra-red imagery would then potentially allow targeted species to be extracted from this group.

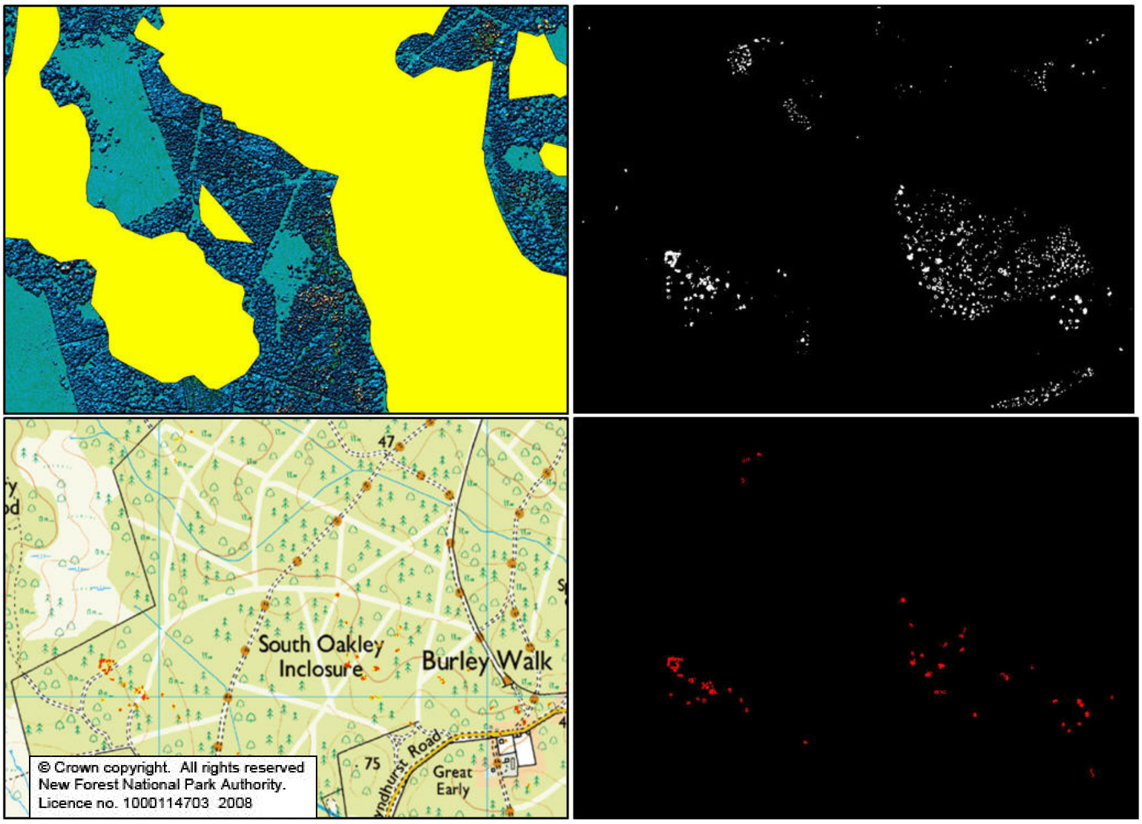

Figure 4: Vegetation height and ancient woodland polygons (top left) used to extract trees based on height (top right) and filtered for crown width (bottom right), with the results overlain on OS mapping (bottom left)

It was recognised at the outset that lidar data would not provide anything of benefit for studying the Palaeolithic gravels and former landscapes beneath the Forest within the Quarternary deposits. It was also considered that a wide range of smaller ephemeral sites associated with open commonage and woodland management might also difficult be to identify from the lidar data (Crutchley and Crow 2009, 34). Sites such as pig pounds, charcoal pits and bee gardens might not show because of their low profile or because through erosion they had become indistinguishable from the rest of the landscape (Figure 5), while boiling mound sites are often only identifiable on the ground by scatters of calcined flints, and as such would largely be invisible to lidar.

Figure 5: Circular charcoal pit in Church Moor. Ranging rods indicate the slight circular bank of the feature

There was, however, every expectation that linear features, field systems, barrows, settlement sites, and twentieth century military sites and structures (Figure 6) would be located unless they were covered in dense pine plantations, dense rhododendron cover, stands of holly or other vegetation that lidar could not penetrate (Crow 2008, 4). The data would also provide the landscape setting of features to be investigated (Forest Research, 2010) and allow the recording of feature dimensions through analysis of the DTM (Figure 7). It was also clear at the outset that on-the-ground verification (ground truthing) would be a requirement to establish the exact character and nature of newly located sites – for instance, to distinguish between sites that might be barrows and those which might be Second World War light battery emplacements. Verification would also be necessary in order to eliminate sites which represented modern detritus such as timber stacks or natural features such as tree throws.

Figure 6: An aerial photograph and lidar image of the same area in Bratley Inclosure. An Iron Age or Romano-British field system, cut by the A31, is revealed by the lidar beneath mixed woodland

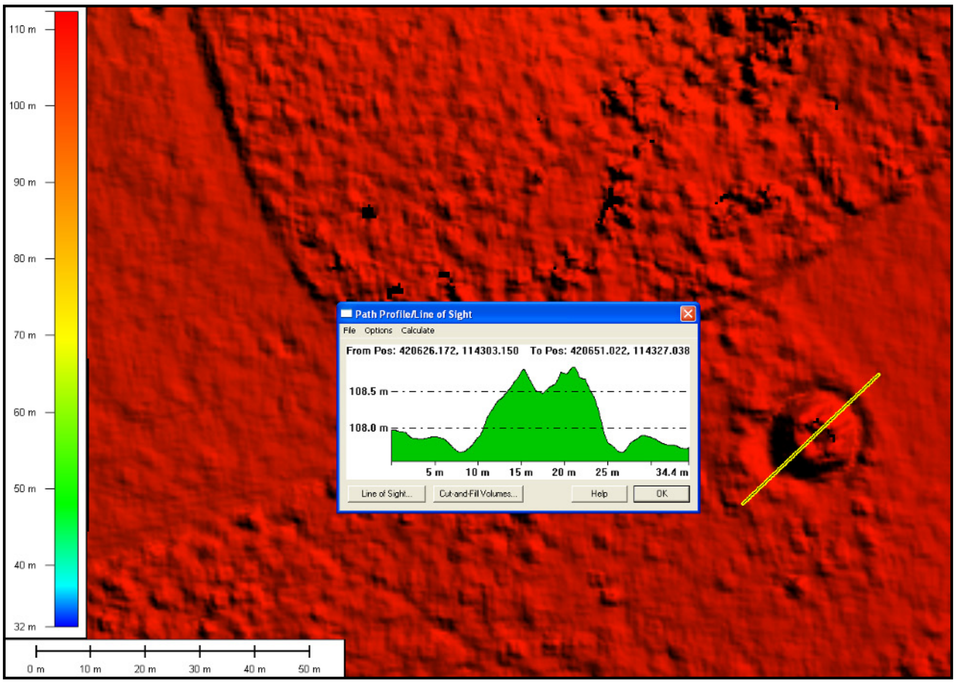

Figure 7: A section drawn through the bowl barrow at Ashley Cross shows the monument in profile and provides an accurate record of its state

To facilitate the additional workload and specialist nature of the work involved with the acquisition of the lidar data the New Forest National Park applied for and was awarded an Institute of Archaeologists (IfA) historic landscape bursary placement. The work of processing and analysing the lidar data since the initial receipt of data from the Forestry Commission has been undertaken by the placement holder.

Future work

The success of the pilot survey has been widely acknowledged by the New Forest National Park's partner agencies. In 2009 a decision was made that the Crown Land Countryside Stewardship Scheme, that the Verderers managed, should be replaced with a Higher Level Stewardship Scheme. As with all such schemes this required the historic environment data to be acquired by the National Park from the Historic Environment Record (HER) managed by Hampshire County Council and recommendations for monument and site management to be made. Given that potentially eighteen thousand hectares were involved it was determined that the agreed National Service Standard for supplying data could not be easily applied.

Through discussion with the County Archaeologist and the Natural England Historic Environment Specialist for the southeast it was decided to divide the Crown land area into fourteen zones and provide historic environment data for each zone. Within the zones the sites and monuments were marked and colour coded according to their potential and/or significance. Red polygons represent SMs, orange polygons for unscheduled sites of national importance (many of which are eligible for SM status) and yellow polygons for sites where archaeological remains survive that are of regional or local importance. Green points were used to identify sites which have been ascribed some archaeological significance or potential on the basis of site type (e.g. Roman villa, Saxon cemetery) but where the extent remains are undefined.

This particular Higher Level Stewardship (HLS) agreement relies on the implementation of a range of work and the enhancement of the Historic Environment Record to include the results of a lidar survey and field work programmes.

The stewardship agreement requires the following information to inform management procedures and prioritise the management of historic environment features:

- Nationally important monuments whether scheduled or not (Red and Orange on the accompanying HER response maps) must be positively managed.
- Regionally important monuments should be positively managed (Yellow on the accompanying HER response map). The criteria used to assess importance are based on those used to assess ancient monuments for scheduling (see Annexe 4 of PPG16) Locally important monuments (Green on accompanying HER response map) would benefit from positive management. This would be beneficial, particularly where the management of these features would also contribute to other HLS outcomes.
- The actual management of HER features is to be based on Forestry Commission management plan guidelines for managing the historic environment in the New Forest. These may be supplemented by other guidance where circumstances occur which are not covered by the FC plans e.g. managing stock animals on HE features.
- Actions resulting from the HLS agreement must not needlessly or thoughtlessly result in the destruction or damage of archaeological and historic environment features or sites (including point features identified on the accompanying HER response map).
- Any works carried out under the HLS agreement with the potential to have an impact on the historic environment must be subject to a consultation procedure to be determined in the first three months of the HLS Scheme.
- For work carried out under the HLS agreement, where landscape restoration and other conservation needs have the potential to destroy, damage or to alter a site or monument, it will be necessary for archaeological recording to take place to mitigate the loss of archaeological information.
- All archaeological recording and any mitigation strategies resulting from HLS agreement works are to be approved by the historic environment lead agency to ensure that specifications and project designs are fit for purpose and meet national standards.
- The NFNPA will be consulted in all cases where ground works as part of the HLS agreement will take place and where new route ways for machinery and spoil handling as a result of the HLS agreement are required to service the open forest and the needs of the inclosures.

Within the New Forest HLS scheme the following historic environment data management conditions were also imposed:

- ‘Any data that is obtained or generated as part of the HLS agreement must be publicly available. In practice this means that that data must be deposited in the relevant HER, who will determine issues of data sensitivity and public disclosure.’

This HLS scheme also requires the undertaking of a lidar survey and the following are the management requirements:
- A lidar survey should be carried out across the whole of the FC managed Crown lands. It should be carried out during the first 15 months of the Scheme. This will be paid as a capital work.
- Following the lidar survey there must be a systematic programme of data processing; ground truthing and data sharing with HER for all features identified. This must be completed during the period of the agreement. The programme for this needs agreement and resourcing.
- A programme of management of existing and newly identified historic features must be agreed annually with NE (and EH for Scheduled Monuments) and be subsequently implemented subject to availability of funding (which may be from the annual payments, or from additional capital funding depending on the nature of the works). See also part 3 of the agreement.
- The work will meet the requirements laid out in the historic environment objectives of the New Forest HLS Scheme. This will include standardised recording of archaeological sites through lidar transcription, GPS plotting and photographic survey to aid in the provision of comprehensive historic environment consultation data, including information from existing records, lidar and other remote sensing data analysis and field survey.
- The production of monument condition assessments, based on English Heritage methodology, and implementation of positive management options on non-scheduled monuments will be undertaken.

The work will also involve digitising the main habitat types of the New Forest HLS area to inform the calibration and verification of habitat studies.

The funding has been approved through the Scheme for the area of this HLS to be subject to a program of lidar, infra-red and aerial photographic data collection. It is anticipated this data will be acquired in the spring of 2011. This data will be used in conjunction with historic mapping, available archaeological historic environment records and ground verification. The lidar work will specifically inform consultation procedures and monitoring of the scheme in advance of conservation, restoration and management projects within the New Forest HLS Agreement land and to inform other schemes within the New Forest HLS area.

Acknowledgements

The authors would wish to particularly acknowledge the following colleagues: David Hopkins and Tom Sunley at Hampshire County Council; Peter Crow at Forest Research, The Forestry Commission; Ruth Garner, Des Sussex, Rachael Bailey and Jackie Kelly, Natural England; Colin Draper, New Forest Verderers; Anthony Pasmore, New Forest History and Archaeology Group; Chris Caswell HLS manager and all our colleagues and partners involved with the implementation of the New Forest HLS scheme that have provided help, data and advice in developing and assisting with the work in establishing the lidar project.

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Questions for Frank Green :

Q. Can you confirm the relationship between Natural England and the Heritage Lottery Fund in the funding of your project?
A. The New Forest was divided into twelve areas and we applied for funding from the Heritage Lottery Fund with the cooperation of Ruth Garner from Natural England. The key issue was to make sure we met all the Heritage Lottery Fund objectives. Natural England is only really interested in the lidar data itself, and archaeology is only one of the end uses of this. The funding for archaeological interpretation will need to be derived from other sources.
Comment from the floor. Heritage Lottery funds are also being used at Ashdown Forest. Natural England will not fund research but they will provide funds for management (subject to availability).

Q. Are you finding many new sites?
A. Ten new sites per square km on average.

Q. Are you undertaking ground truthing before putting information onto the Historic Environment Record?
A. Natural England will not fund ground truthing so we are looking for other sources of funding for this. The Historic Environment Record will need to decide whether they want to admit unvalidated lidar information.

Using lidar in conjunction with other investigation techniques in Savernake Forest, Marlborough

Simon Crutchley and Helen Winton, English Heritage

Abstract

The Aerial Survey and Investigation team of English Heritage have been looking at the use of lidar data for the recording and interpretation of archaeological features in the landscape for a number of years. The team have substantial experience of working with aerial photographs and since 1990 have run a program of systematic interpretation and mapping known as the National Mapping Programme (NMP) that has now mapped over 40% of England. One of the most recent projects to make use of lidar data covered the area of Savernake Forest near Marlborough. With its ability to ‘see through the trees’ lidar has been shown to have particular benefit when working in a wooded environment and this was seen as an excellent opportunity to assess the advantages of this relatively new technique. The project area was mapped using both lidar and standard aerial photography and the results compared.

As expected the lidar revealed a lot of features not previously recorded within the forest, but systematic and careful analysis of all the aerial photographs showed that a number of features ‘discovered’ by lidar had in fact been visible on photographs for twenty, thirty and in some cases over seventy years! Furthermore because the forest had been an important military site during the Second World War there were features visible on the wartime photographs that have left no physical trace and were hence not picked up from the lidar, but which are vital to understanding the full history of the area. The survey showed that whilst various techniques will reveal certain features, to get a full understanding of a landscape you need to take advantage of as wide a combination of sources and techniques as possible.

Lidar data alone cannot provide all the necessary information to understand the historic landscape, but when it is combined with more traditional techniques, as at Savernake, it can prove a very valuable tool.

Summary

The English Heritage survey of Savernake Forest explored the use of non-invasive techniques to improve knowledge of the archaeological landscape in and around the forest. Aerial photography, lidar data, analytical earthwork survey and secondary source materials were used. The survey produced detailed systematic results showing that no single technique or source was able to give a full picture of activity within the forest area. The project contributed to ongoing research on the use of lidar for archaeological survey, published as The Light Fantastic: Using airborne lidar in archaeological survey (Crutchley & Crow 2010). The results from the Savernake project are available as a PDF download on the English Heritage website (Crutchley, Small and Bowden 2009).

Project location

Savernake Forest is an area of woodland about one mile (2 km) southeast of the historic town of Marlborough. The Forest is a Site of Special Scientific Interest (SSSI) and is situated within the North Wessex Downs Area of Outstanding Beauty (AONB). The North Wessex Downs was designated in 1972 and is the third largest AONB in England.

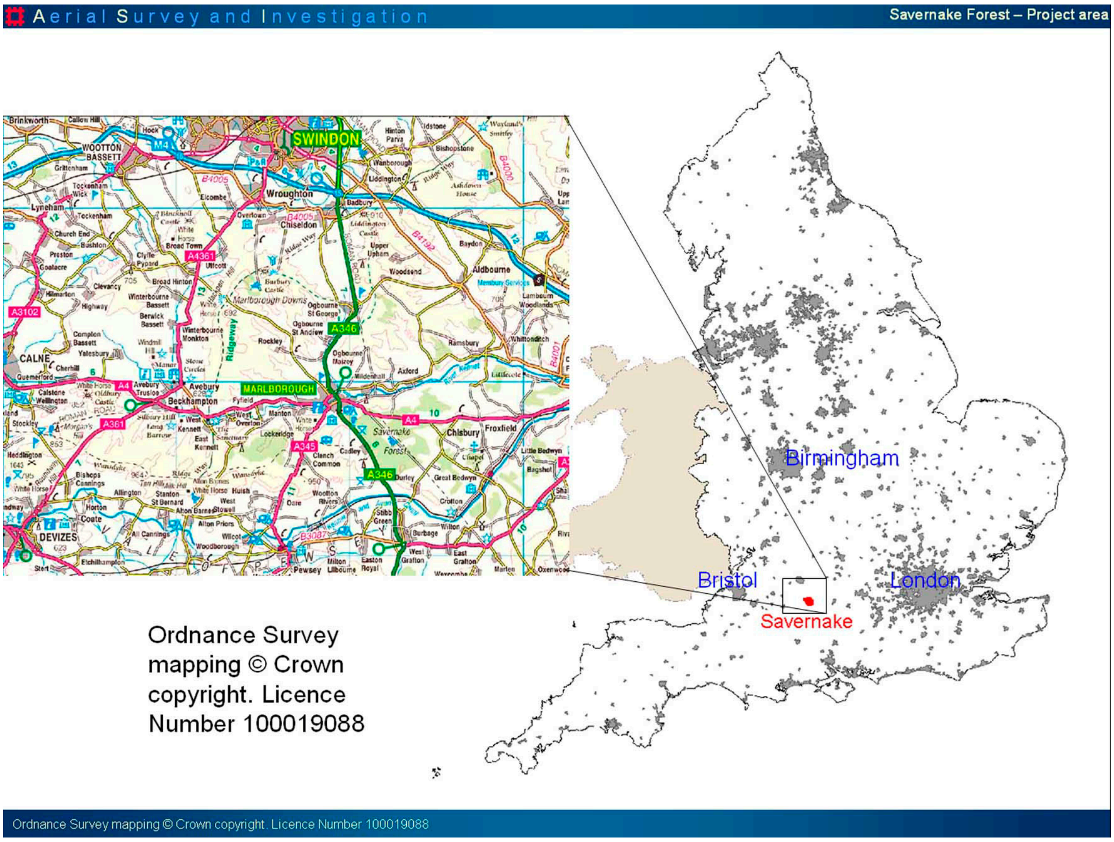

Figure 1: Location of the project

Background

Savernake Forest is one of the oldest woodlands in England and the first known reference to ‘the wood which is called Safernoc’ occurs in a charter referring to a grant of lands at Oare by King Athelstan to Wilton Abbey in 993 AD. It was established as a royal hunting forest by the time of the Domesday survey. Wardens managed the forest on behalf of the crown for centuries but it passed to private ownership on the death of Catherine Parr in 1548, when it reverted to Edward Seymour, Duke of Somerset, a former warden. It was passed down, through inheritance and marriage, and remains private property leased to the Forestry Commission who manage the Estate.

The impetus for the English Heritage Project came when the Forestry Commission began the preparation of a Management Plan for the Forest. In particular, this included a lidar survey commissioned from the Cambridge University Unit for Landscape Modelling. Forestry Commission staff realised that the processed lidar data revealed a large number of previously unknown features within the boundary of the Forest. Therefore, English Heritage was contacted to carry out an archaeological survey of the Forest. This provided a chance to test the latest methodology for using lidar data within a framework of traditional aerial photographic survey, in this case the National Mapping Project (NMP) (Bewley 2001, Winton and Horne 2010).

Project area

The project area covers 54 complete kilometre squares of which 41 kilometre squares were covered by the lidar survey. Just under half of the project area is covered by trees. The forest lies on the Savernake Plateau, a high plateau of rolling downland dissected by small valleys, founded on Upper Chalk overlain with deposits of Clay with Flints.

The Forest consists of extensive tracts of semi-natural ancient woodland, wood pasture with majestic veteran trees, and 18th and 19th century beech plantations, as well as more modern coniferous plantations. The southern end of the project area is dominated by the historic parkland and designed landscape features within Tottenham Park, containing permanent pasture, parkland trees, avenues and rides. The Forest sits within a wider woodland farmland mosaic that includes open arable areas knitted together by hedgerows with many hedgerow trees.

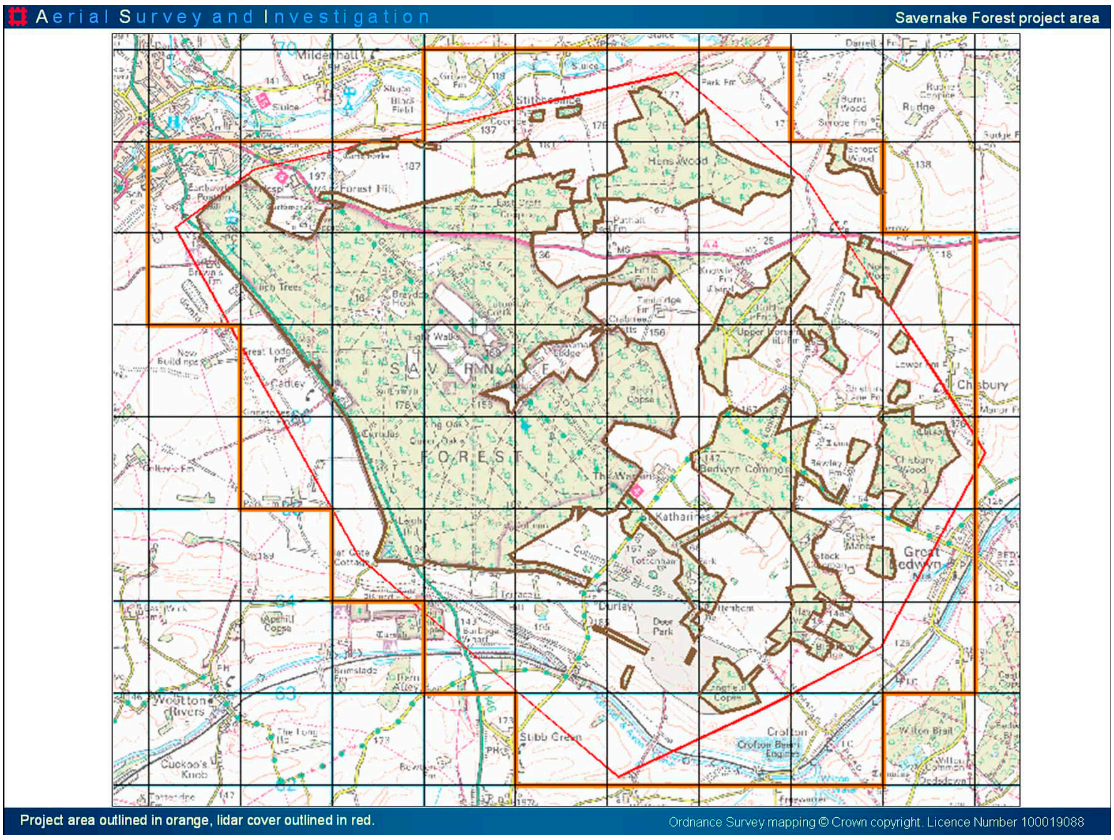

Figure 2: Project area

Combining Techniques – survey from aerial photographs and lidar

One of the main reasons behind the English Heritage Savernake project was the opportunity to test the latest methodology for using the lidar data within a conventional aerial photographic survey project. The 'usual' focus of the work of the aerial survey department of English Heritage includes using aerial photographs as a main source to create archaeological maps with interpretations in a GIS format. The resulting data sets are principally for use by local and national government bodies for understanding, visualising, and quantifying the archaeological resource. The main applications of this data are research (mainly targeting further work) and, perhaps more importantly, use in heritage protection, such as local and regional planning or farm environment schemes.

Although originally NMP only looked at readily available aerial photographs, and other secondary sources, it has been using lidar routinely in the last couple of years where there is readily available data; this is usually in the form of Environment Agency jpeg images, of which we have a set for use on NMP projects. Note these are the image files only, not interactive data. These have proved useful but they have limited coverage and are of variable quality, and although in wooded areas they are usually provided as last return, they have not been processed or filtered to produce a bare earth DTM. The lidar used for the Savernake project was fully manipulatable data and is discussed in greater detail below.

For the Savernake project it was decided to map everything twice; once from the lidar and once from aerial photographs. In this way, it was hoped that it would be possible to compare the relative value of the two sources. After comparison, the two sources were combined into a single set of maps and monument descriptions that are available from the National Monuments Record and Wiltshire Historic Environment Record (HER).

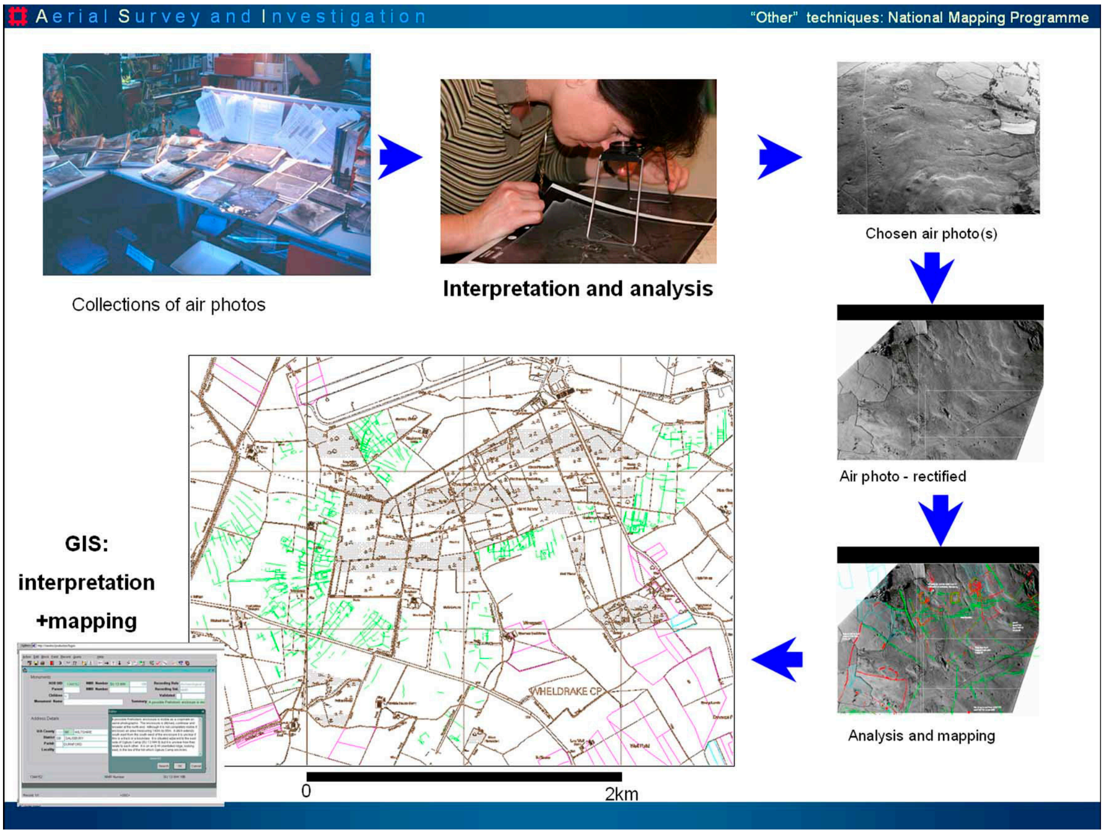

Figure 3: NMP survey

Combining techniques – analytical earthwork survey and lidar

Fieldwork following on from desk based lidar assessment has generally concentrated on confirming the presence or absence of features on the ground (Hoyle 2005, Doneus *et al* 2008; Sittler 2004). The Savernake project also aimed to confirm presence or absence of features recorded on lidar images, but, in addition, detailed analysis was carried out over a chosen site using traditional measured survey and this was compared with the information derived from the lidar data. This compared both the geometric accuracy of the plotting from the lidar derived imagery with the ground survey and the level of interpretation achievable with each technique. The analytical earthwork survey was carried out by staff from the English Heritage Archaeological Survey & Investigation team.

Figure 4: Analytical earthwork survey

Combining techniques – different scales, complementary approaches

Combining techniques is of course nothing new – for example, the same methodology was used during a number of surveys of AONBs, most recently during the Mendip Hills survey, combining aerial survey, field survey, and architectural survey to produce a record and analysis of the landscape at a number of different scales (Bowden 2005; Riley 2006; English Heritage forthcoming).

The Mendip Hills survey also integrated analysis of lidar data but, unlike Savernake, the survey area mainly comprised an open, unwooded landscape (Truscoe 2008; Dickson and Priest 2009). English Heritage has shown the benefits of aerial survey, using the NMP approach, in some wooded areas, such as the survey carried out of the Forest of Dean (Small & Stoertz 2006). The Savernake Forest project offered an opportunity to carry out a systematic analysis of the value of using fully interactive lidar data in a wooded area.

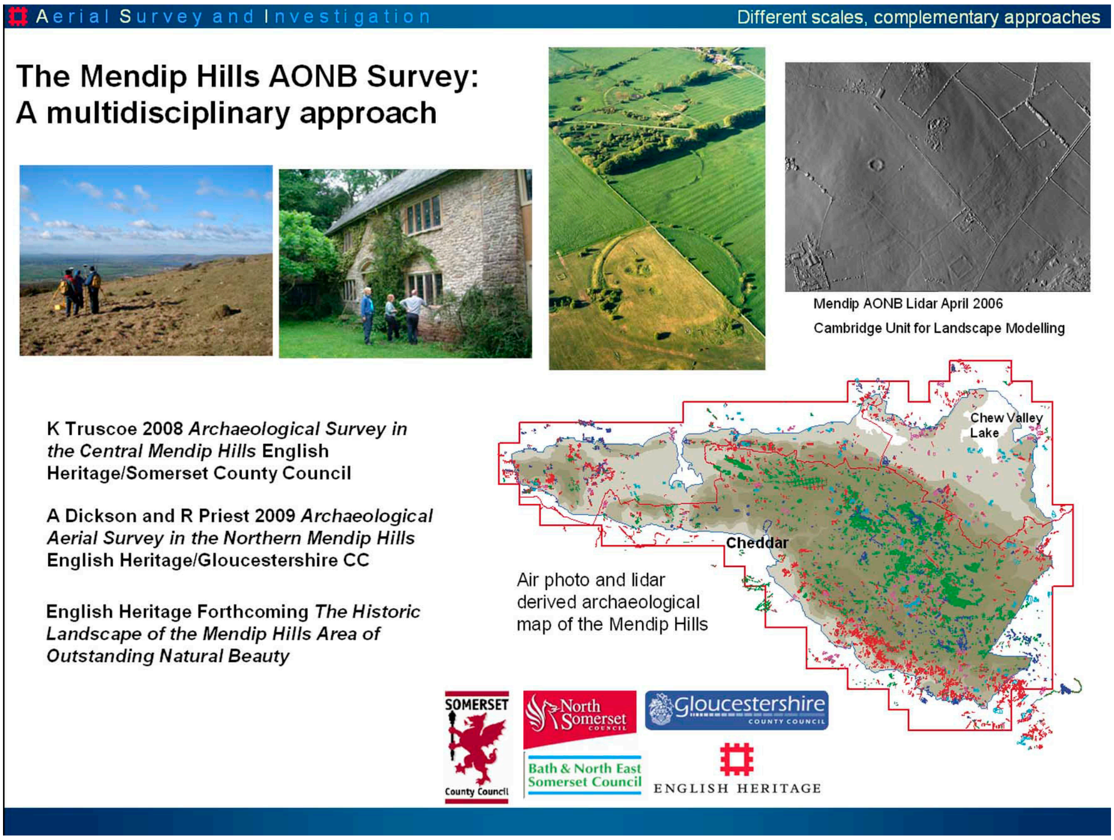

Figure 5: The Mendip Hills AONB survey

Analysis of lidar

The lidar survey of Savernake was flown by the Cambridge University Unit for Landscape Modelling for the Forestry Commission. This was supplied as first and last returns and as a filtered digital terrain model. The latest versions of Autodesk Map (2007 onwards) include the facility to view raster surfaces with interactive hillshading defined by a user-controlled light source together with height exaggeration. Placing these facilities within the CAD environment means that it is now possible to combine the mapping elements of CAD with the 3D facilities that allow the enhancement of lidar data, which are so crucial in its interpretation. It was hoped that using fully interactive lidar data would produce a more accurate and detailed plotting of features than had previously been possible using flat 2D imagery, such as the EA jpeg tiles.

Comparison was carried out between the different lidar data sets; not surprisingly, the first return data was only useful in open land without tree cover. Whilst the last return data was an acceptable source for interpretation in some wooded areas, the presence of the remainder of tree trunks etc. made this much less useful than the filtered DTM. There was also a brief analysis of those areas where the lidar data was less useful such as regions where the data for the forest floor was incomplete or degraded due to lack of penetration through the forest canopy. Comparison with the Forestry Commission records for the forest showed that with a couple of exceptions the worst areas of pixilation, and hence lack of penetration, were found over Corsican Pine, Douglas Fir and Norway Spruce, all coniferous species; in most cases these areas also lay over examples of these species planted within the last 20 - 25 years. This is something that Peter Crow at the Forestry Commission has done more detailed research into; his analysis of the effects of different species and undergrowth on the viability of lidar has shown that these types of trees, especially when in their pre-thinned state are very restrictive of lidar penetration and the examples in Savernake seemed to fully support his findings.

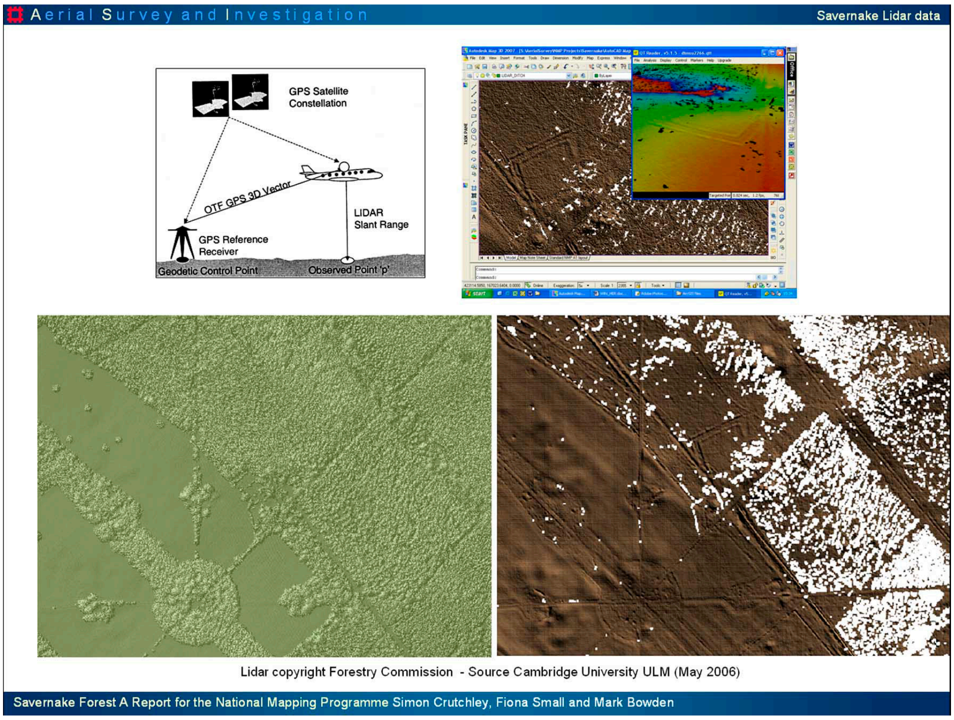

Figure 6: Savernake lidar data

Previous work

There has been extensive documentary research on the Forest, in particular by Graham Bathe, and there is considerable local interest in the history and archaeology of the area. Previous work is summarised in the English Heritage Research Department Report Series (Crutchley, Small and Bowden 2009)

It is striking how few monuments are recorded in the wooded areas of Savernake Forest. Apart from the Roman roads, it is clear that most large features have been found outside the wooded areas (outlined in brown on Figure 7). The data from the English Heritage National Monuments Record (EH NMR) and the Wiltshire Heritage Environment Record (HER) illustrates this. The linear features include railway lines and modern roads following former toll roads. The magenta areas marked out by the NMR within the forest marks the extent of the parkland associated with Tottenham house.

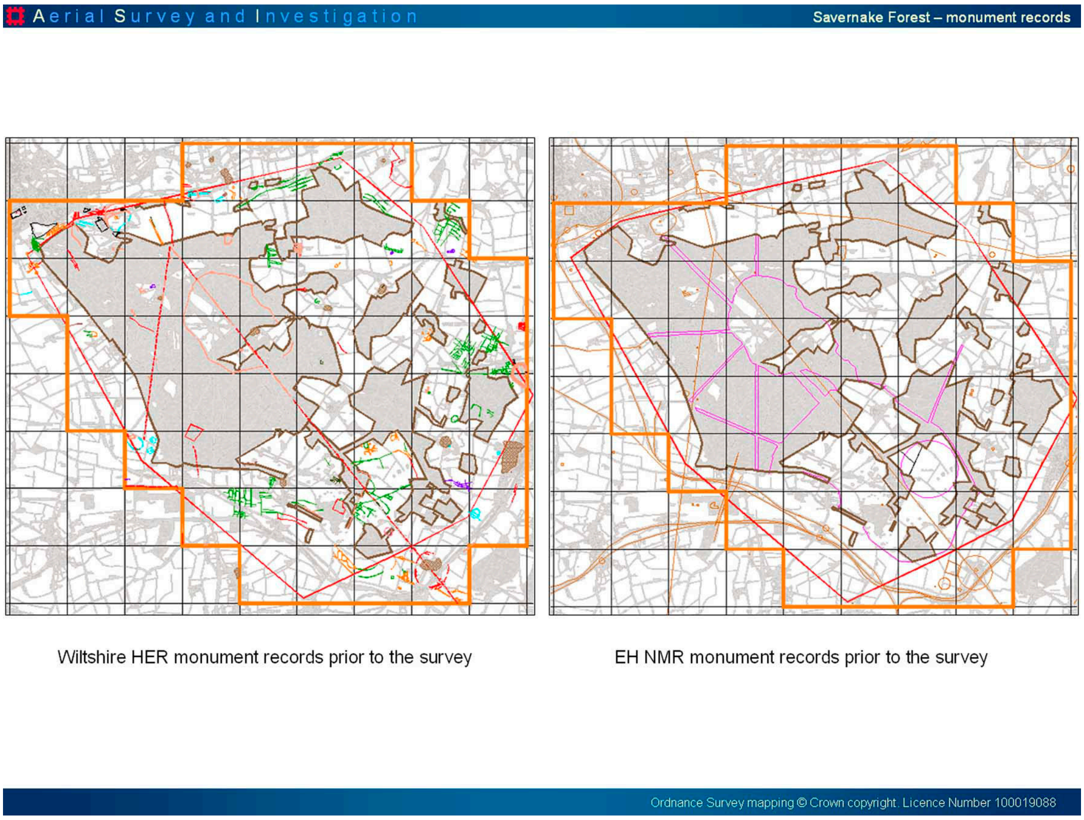

Figure 7: Distribution of known monuments prior to survey

Project results – distribution of archaeological features

During the survey, 315 new sites were recorded in the EH NMR - more than doubling the previous number of records; amendments were made to a further 38. Of the *c.*350 monuments 166 (47.5%) were recorded from lidar, 131 (37.5%) from traditional aerial photographs and 53 (15%) from both. Most individual features recorded from the lidar during the survey were in the woodland, but many sites were recorded outside the woodland including extensive field systems to the south of the project area (Figure 8). In contrast most features recorded from aerial photographs were outside the woodland; however, note the extensive spread of twentieth century military features shown in purple on Figure 8 and discussed further below. One of the reasons for mapping from the different sources and then comparing them was to assess how much was actually visible on traditional photographs.

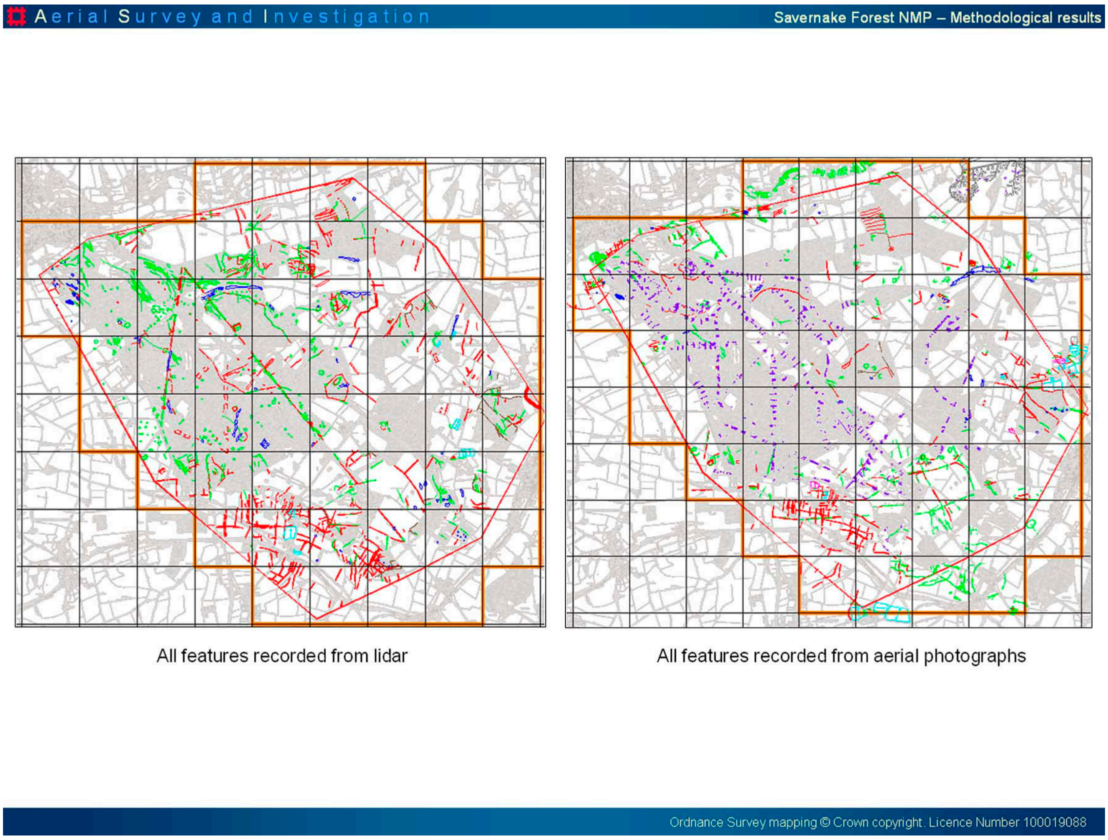

Figure 8: Distribution of features from aerial photographs and lidar

Comparison of lidar and aerial photographs

Figure 9 shows a lidar surface model lit from the northeast that highlights features in Hen's Wood. These include a probable late prehistoric enclosure (middle right) and field boundaries of medieval date visible as parallel boundaries extending across the image from left to right. The white spots that occur across the image, but are particularly evident in the bottom right corner, represent those areas where no data was recorded due to the laser pulse failing to penetrate the tree canopy.

An RAF photograph, held in the NMR archive and showing the same area, was taken in December 1952 after a period of tree clearance (Figure 10). The prehistoric enclosure is somewhat clearer on the aerial photograph than on the lidar derived imagery.

Periods after tree harvesting or woodland clearance are sometimes fortuitously recorded on historic aerial photographs. These photographs can be a very useful source when lidar data is either not available or unclear as they may reveal archaeological sites previously hidden beneath the trees (see Small & Stoertz 2006, 24, Figure 4 for an example in the Forest of Dean). Aerial photographs when used alongside lidar data can help confidence in interpretation, particularly when there has been a change in condition or land-use of the monument being examined.

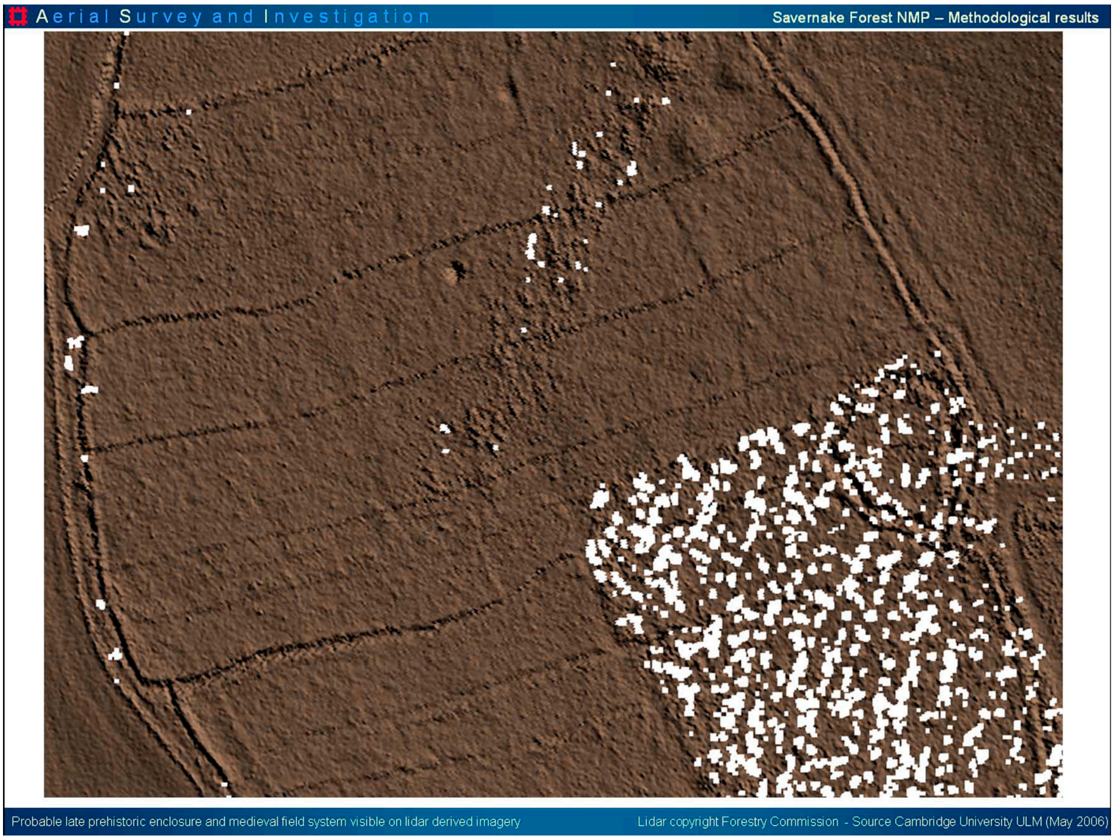

Figure 9: Hen's Wood lidar image

Figure 10: Hen's Wood aerial photograph

In contrast to the example in Hen's Wood, the lidar data has been the primary source for certain sites, even though fragments of a site may already have been explored on the ground or recorded on aerial photographs (Figure 11). The enclosure near Braydon Oak was excavated in 1934 by boys from Marlborough College who recovered large amounts of Iron Age C pottery. Parts of the site were surveyed by the Royal Commission on the Historical Monuments of England (RCHME) in November 1974 and depicted on the Ordnance Survey map. During the EH NMP survey, examination of a range of aerial photographs ranging in date from 1944 to 1970 revealed that the north and eastern edges were visible and could have been recorded from these sources. The lidar image, however, gives by far the most complete and easy to understand picture of this site as it now survives.

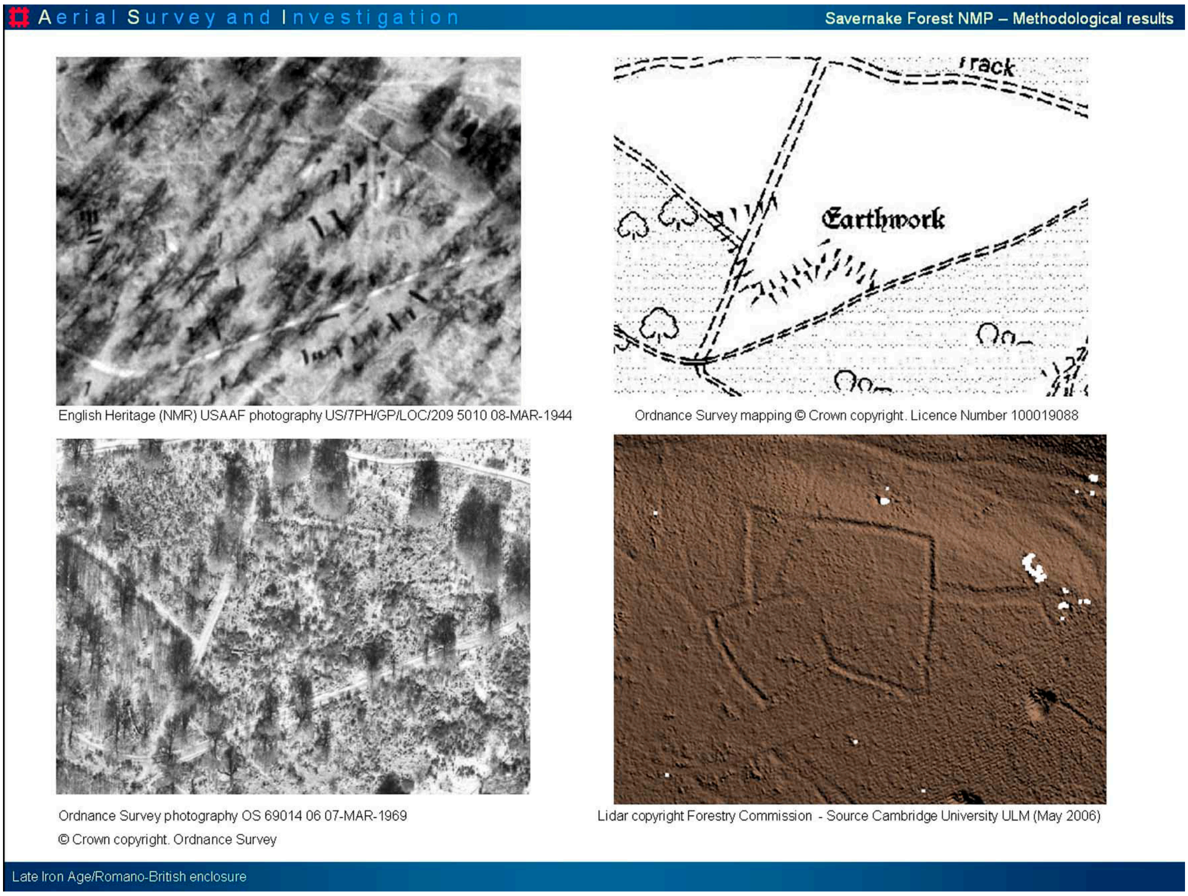

Figure 11: Braydon Oak enclosure

The lidar data does not record all the archaeological information available on the 1944 aerial photographs including the rectangular storage shelters seen here (Figure 11, top left) and recorded across much of the Forest (Figures 12-13). At the beginning of July 1940, the forest was requisitioned by the War Office, which quickly set to work turning it into an ammunition dump that eventually became one of the largest of its type. It saw occupation by the Royal Army Ordnance Corps and the American Army, both of whom used it for storage including for large numbers of conventional and chemical weapons (Day 2007). Storage was concentrated along the main tracks and avenues, presumably to ease issues of access. Stores generally came in blocks of 8-10 shelters, often spread evenly on either side of the road. In Savernake at War, R Day reports that no more than 18 shelters were ever to be grouped together to avoid chain reactions should any ordnance explode. It is clear from Figure 13 that there were an awful lot of these shelters.

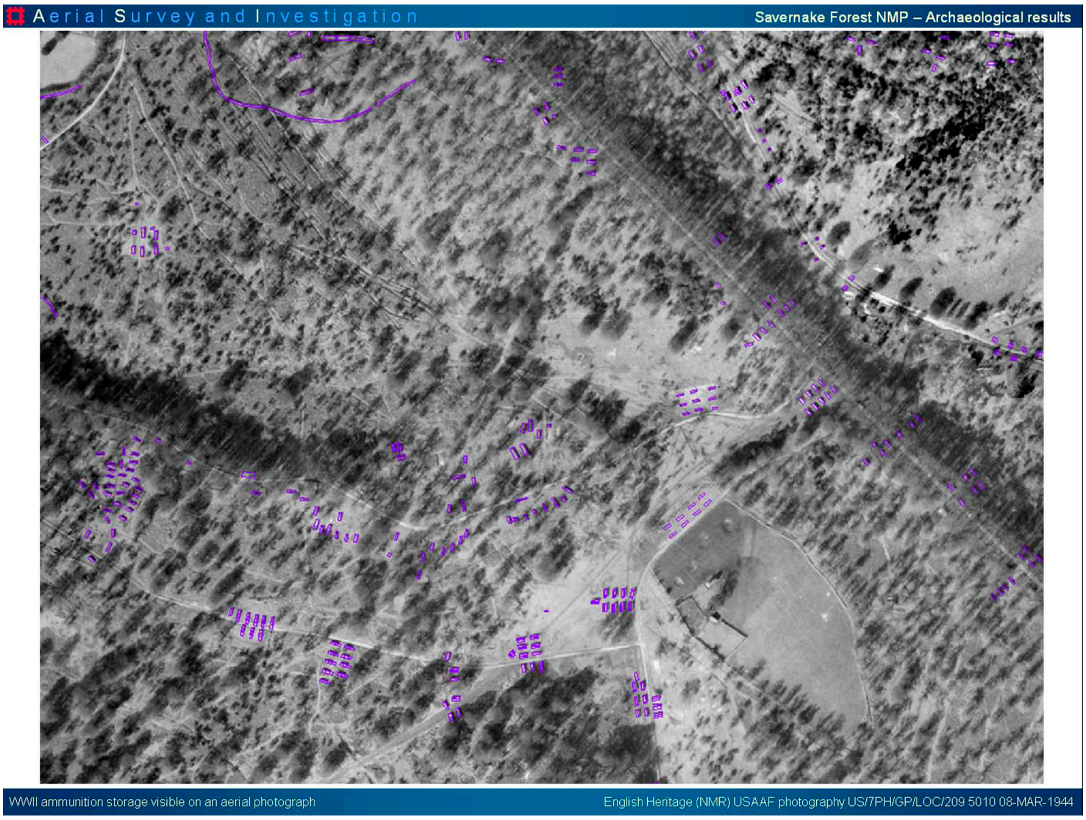

Figure 12: Ammunition storage in Savernake Forest

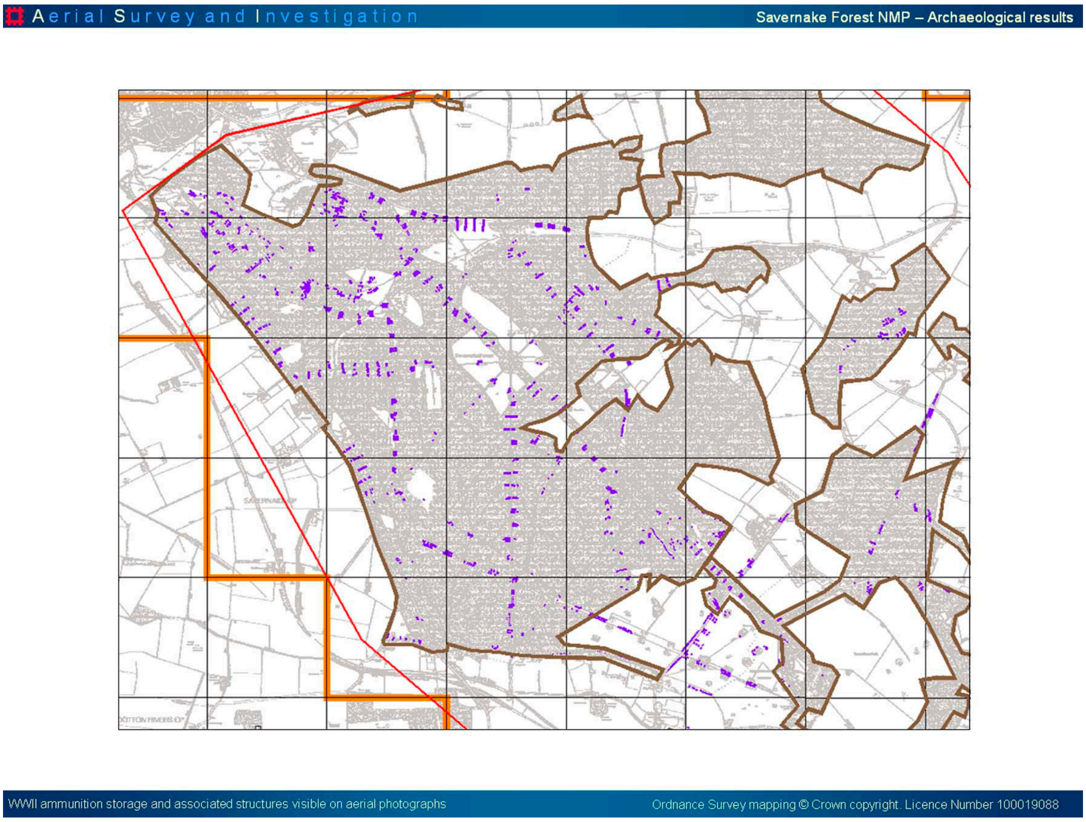

Figure13: Ammunition storage in Savernake Forest

The lidar data also showed a series of strange irregular banked areas that were placed symmetrically across the tracks and especially avenues. Examination on the ground revealed these to be very irregular in form and without evidence for any ditch. They were therefore interpreted as areas of clearance, possibly by bulldozers levelling the ground prior to the construction of shelters. Comparison of their location with those of the storage shelters visible on the wartime photographs (Figure 14) suggests that there is a relationship but unfortunately they do not appear on the photographs showing the shelters. The fact that they do not appear on these photographs that show the actual shelter suggests an alternative explanation; that is that they are the result of levelling ground after the shelters were removed, possibly filling in any trenches that may have been dug at the same time. In this case it is only the use of a combination of sources that has helped to partially resolve a puzzle.

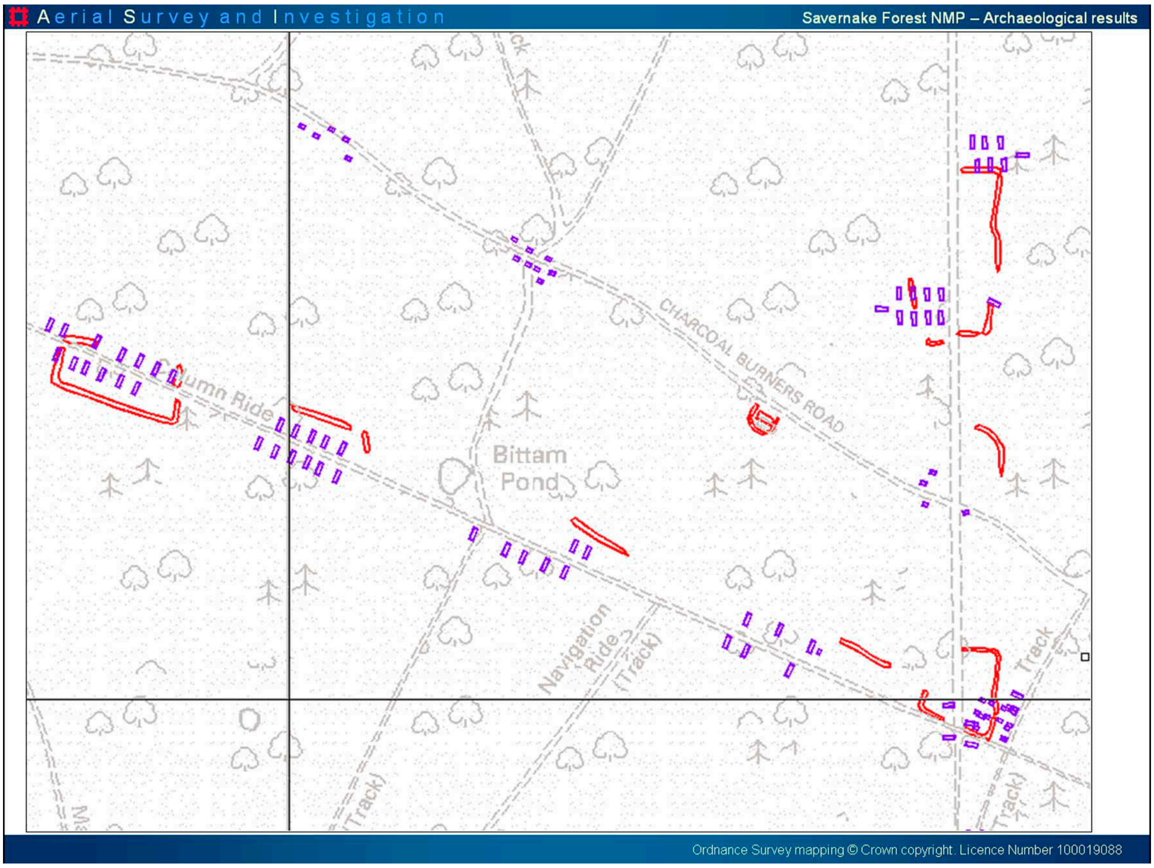

Figure14: Banks (shown red) and storage shelters (shown purple) in Savernake Forest

Another example of the used of combined sources came with the Roman roads leading to *Cunetio*, the modern Mildenhall. The NMR recorded the probable route of the Roman roads from Old Sarum (*Sorviodun*um) and Winchester (*Venta Belgarum*) to Mildenhall (*Cunetio*) as combining just on the edge of the forest and heading in a direct line for *Cunetio* down a steep scarp (marked in orange on Figure 15). Evidence from aerial photographs suggests that in fact the Old Sarum road joins the Winchester road which continues in its original direction (marked in green and red on Figure 15), skirting the possible Iron Age *oppidum* at Forest Hill. Any direct route towards *Cunetio* is therefore unclear although there are several terraces and hollow ways that head down the scarp.

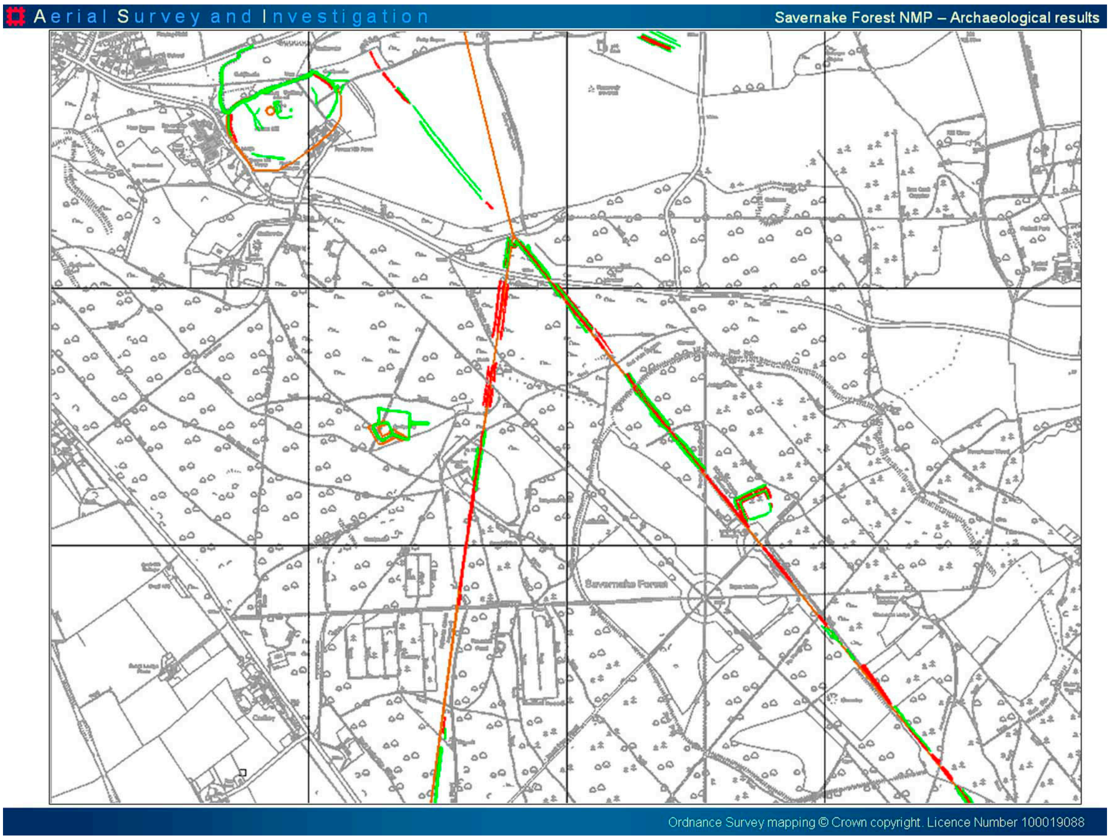

Figure 15: Roman roads

The above examples demonstrate the importance of using combined sources when carrying out surveys of archaeological landscapes. However, there were a number of examples where the lidar was the only source. Possibly the most exciting of these has been a new enclosure lying just north of Luton Lye Cottages (centre right on Figure 15, and Figure 16). When first discovered, its size (*c.*130m x 100m) and regularity suggested that it might be a parkland feature of relatively recent date. However, closer examination showed that its southwestern corner appears to be cut by the Roman road to Winchester. Clearly, unless the Roman road has itself been rebuilt later, which is not impossible, then this feature has to pre-date the building of the road. This would place it as late Iron Age or early Roman in date and given such a date, the most likely interpretation, given the multiple banks and ditches, is that this is a temple complex. There are other examples similar to this in England at Thetford, Blagdon Wood and a newly discovered site on the Lambourn Downs, but this is unusual in that it survives as a comparatively well preserved earthwork.

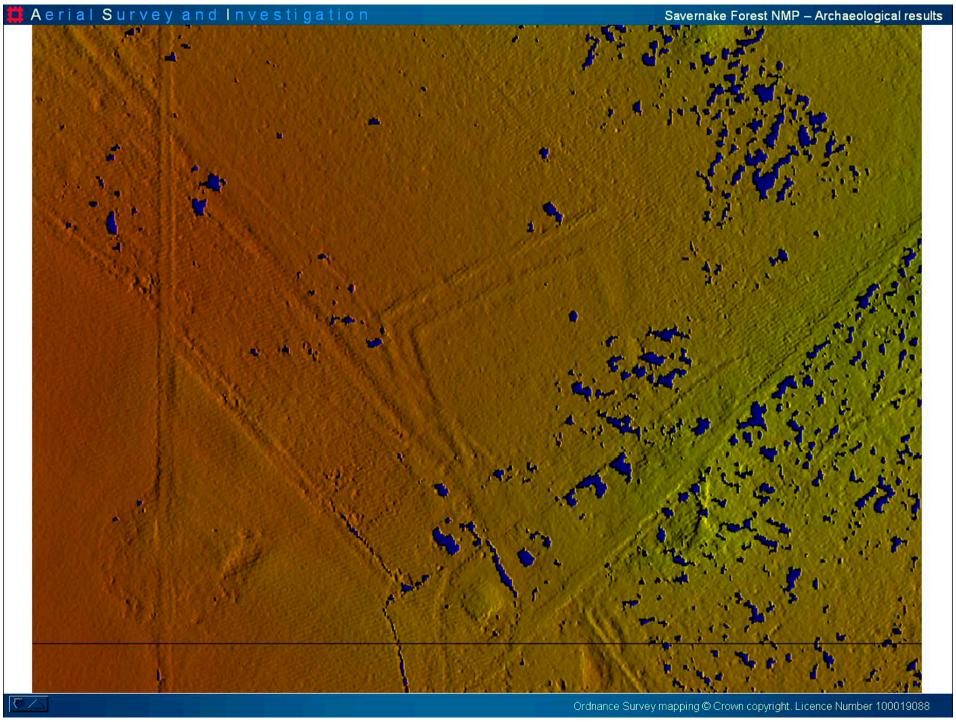

Figure 16: Enclosure at Luton Lye Cottages

Unfortunately, the exact area where the enclosure and the Roman road overlap or intersect has been damaged by modern activity and so their precise relationship is impossible to assess on the ground. Figure 17 shows the general state of the vegetation on the ground near the enclosure, showing how difficult it is to survey. Dave Field is standing in the ditch.

Figure 17: Enclosure at Luton Lye Cottages on the ground

Another of the enclosure complexes newly revealed by lidar was chosen for large-scale analytical field survey in order to test the metrical accuracy and interpretation of the features as mapped from the lidar plot (Figure 18). A group of features on the line of Church Walk was identified as being suitable for this purpose because of its relative complexity and intrinsic archaeological interest. The site occupies a level area on a spur with the ground dropping away gently to north, east and south. It comprises a sub-oval late prehistoric enclosure and, possibly contemporary or later, elongated enclosure. The large quarry is probably a clay pit belonging to a documented brick maker.

As well as the interpretative plot produced from the lidar derived imagery, the lidar imagery itself was also examined during the course of the ground survey to analyse other features that might cause confusion during interpretation and to assess the nature of anomalies on the ground. The image was provided as both a simple hillshaded surface and as a surface with the plotting overlaid. In both cases, the model was lit from the northeast at an elevation of 25˚ with a vertical exaggeration of three times the actual.

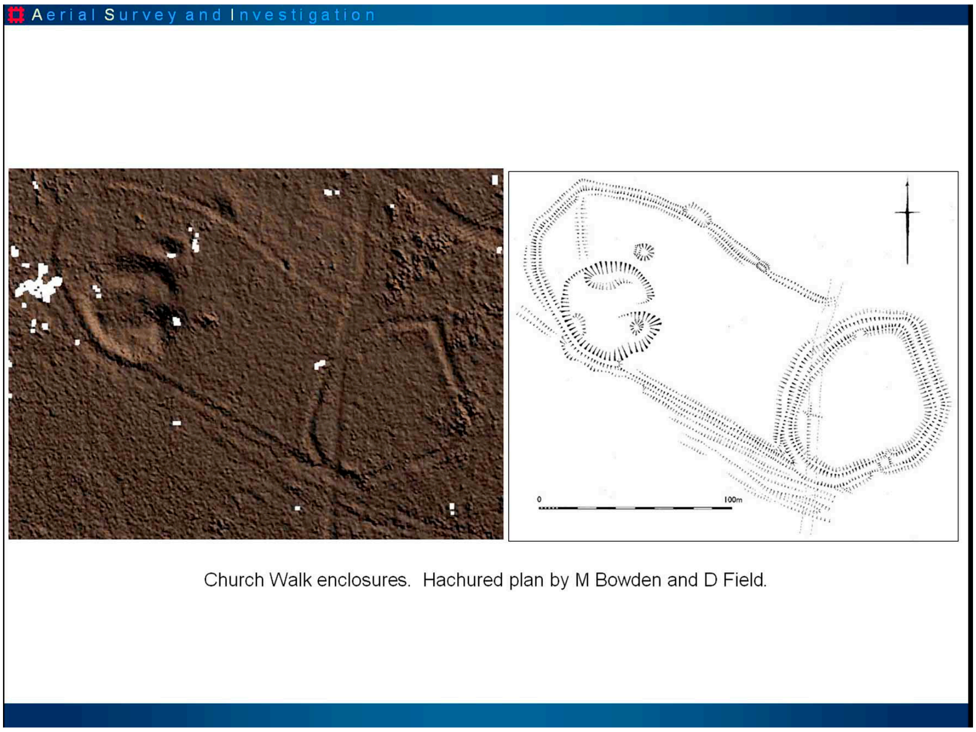

Figure 18: Church Walk enclosures, lidar and metrical survey

Comparison of the lidar image and plot with the ground survey plan reveals almost exact agreement over the location, size and shape of the archaeological features; given the ‘soft’ nature of the earthwork detail involved, the representations could be regarded as ‘identical’ in terms of accuracy. However, the ground survey shows extra detail that is not visible in the raw lidar data and includes an interpretative element. The quality of the lidar derived image is such that, even when enlarged to 1:1000, it presents a readable and usable representation of the ground surface. A suitably experienced archaeologist could, with data of this quality, create an accurate large-scale interpretative plan of a site directly from the lidar derived image, without the need to undertake a control survey. However, the archaeologist would have to be aware of several limitations in the data set, especially false features caused by vegetation response and related factors, and the lack of definition or absence of very slight features on the lidar imagery.

Conclusion

There are two key conclusions from the Savernake survey. The first is that there is no doubt that the use of lidar data when surveying any area that has a substantial degree of woodland cover is essential, as its ability to penetrate the tree canopy and reveal features on the ground is unrivalled. Whilst it is true that there are some forms of vegetation where it is less successful, specifically densely spaced coniferous woodland, it is also true that under such conditions any form of traditional ground survey, either walkover or more detailed GPS recording, would be equally ineffectual, if not more so. Even in these areas of less responsive vegetation, with careful image manipulation and analysis it is still possible to tease out data that would have been virtually impossible to record by any other means.

The second conclusion is that whilst lidar is of great benefit in a wooded area it is not a universally applicable survey methodology and will not record all features in the landscape. Specifically if there is no surface indication of any given feature then lidar will be unable to record its presence. Therefore in any landscape with a combination of wooded and non-wooded areas it is imperative to use a combination of sources, including a structured examination of all readily available aerial photographs, if you wish to gain a full picture of the archaeology.

Projects in Savernake Forest and the Forest of Dean have demonstrated the exceptional quality of archaeological sites preserved in our woodlands. There is a clear need for an audit of the heritage assets in woodland throughout England and a strategy to help prioritise effective and targeted survey for those areas most at threat. Lidar will have a key role in these surveys alongside other techniques.

Acknowledgments

Grateful thanks to the staff at the Unit for Landscape Modelling at Cambridge University who carried out the lidar survey and to those at Forest Research who commissioned it and have worked closely with us in interpreting the data.

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General discussion

Q. How much does a lidar survey cost?
Helen Winton. English Heritage gets the data at cost.
Frank Green. The New Forest survey cost £15000 for $34km^2$ area. Additional software to manipulate the processed lidar data cost a further £12,000. The New Forest data is being analysed by an IfA bursary student which reduces the overall cost of the project.
Peter Crow. It is more cost effective to get a larger area surveyed, but shape of an area also plays a part.
Tim Yarnell. The costing of lidar surveys is not simple. The Savernake survey (an area of *c.* 54 km^2*)* cost £12000 flying time plus £5000 processing by the Cambridge Unit for Landscape Modelling (who flew the survey) plus the cost of Peter Crow to undertake further processing of the data. In addition to that allowance must be made for the cost of analysing the data.

Q. Is there a national repository for lidar data?
Helen Winton. Not yet.
Peter Crow and Tim Yarnell. In general much of the lidar coverage in the country exists as a series of discrete surveys. The Environment Agency have almost national coverage which is available, but there is no access to the raw data due to copyright issues, so it cannot be manipulated further, and the resolution or date of acquisition may not be suitable for all purposes.

Q. Have you had feedback on the success of identifying veteran trees from lidar?
Frank Green. Not yet but the New Forest project will begin to roll that out in the next 2-3 years.

Q. How effective is lidar for identifying veteran trees?
Frank Green. Work on this is ongoing as part of the New Forest Project. The targeting criteria are fairly crude and are essentially identifying those trees in ancient semi-natural woodland which stand out as they are taller or have a greater crown width. This technique has successfully identified veteran trees in areas of ancient woodland, but it is anticipated that it will be continually refined as the project progresses and also by other projects.
Peter Crow. Veteran trees can also often be identified where the surrounding woodland is thinned out around them to give them space (Halo-thinning). Such circular breaks in an otherwise continuous forest canopy can make the veteran trees very obvious.

Q. What are the optimum parameters for data capture for woodland survey? What are the issues surrounding the relationship between altitude and resolution?
Peter Crow. There are a whole range of variables governing data capture in different situations and a wealth of published information about this issue. There is not really time to discuss this at great length here.
Jan Wills. There are a number of commercial companies who offer lidar services and could advise on what is best for your project.
Peter Crow. There are perhaps a dozen or so companies, but the processes they use are very variable.

Q. What are the other uses of lidar?
Peter Crow. It is extensively used in the analysis of levels in flood plains. The Highways Agency and utility companies use lidar to identify trees which may interfere with roads or services.
Helen Winton. English Heritage is using lidar for the analysis of coastal stability and also to inform understanding of landscape change over time; it is being used for this in Ironbridge Gorge.

Q. Has waveform lidar been used?
Helen Winton. Yes it has been used in Austria by Doneus and Briese who are based in Vienna.
Peter Crow. It is currently too complex for landscape-scale processing but data is being captured for future analysis.

Q. Is lidar effective on soft geology?
Frank Green. Yes. In the New Forest it is revealing between eight and ten new sites per kilometre square in open landscapes over a soft geology. Combining infra red, lidar and conventional aerial photographs may give good results in identifying palaeochannels in the future.
Peter Crow. Waveform lidar can pick up palaeochannels, especially where the intensity data records changes in moisture content. Examples of this were very clear in a lidar survey of the Second World War anti-glider defences on the coastal area of Culbin Sands near Inverness, Scotland.

Q. Are there any initiatives to re-assess old lidar data?
Tim Yarnell. Yes, local authorities.
Helen Winton. Analysis of lidar data is similar to looking at aerial photographs in that new information is identified every time you look at them.
Jan Wills. Every time we get a new technology we identify a lot of new features, the challenge is determining their significance.
Frank Green. This can create problems with management as we need to understand the importance of sites before we can manage them correctly. The amount of new sites turning up in the New Forest is worrying land managers.

Q. Should there be restrictions on forestry in areas where lidar has identified archaeological features, particularly as there appears to be good survival of earthwork features in woodland?
Tim Yarnell. Where there is existing tree cover there is not necessarily any reason why that should not be maintained. Bear in mind that these features have already survived a range of woodland management regimes often over many years. Their survival indicates that forestry is far less destructive to archaeological features than many other landuse regimes such as agriculture although the introduction of more mechanized management practices should cause some concern. What is needed is sensitivity towards the management needs of features in woodland, and the implementation of forestry operations which do not compromise those needs.
Helen Winton. Lidar is increasingly demonstrating that areas of woodland have the potential to be islands of relatively well preserved archaeological features, similar to other areas which have not been extensively cultivated, such as Salisbury plain.
Frank Green. Lidar can also identify areas where archaeology has been destroyed either by forestry operations or other activity.

Q. Does lidar have a role in the creation of new woodland? There is a private afforestation scheme in Warwickshire, where the landowner is sympathetic towards archaeology. Can lidar be used to inform the planting of a new area of woodland?
Peter Crow. lidar can pick up very subtle differences in areas of open ground particularly if the illumination is changed so that it is lit from a number of different directions.
Helen Winton. Lidar has had spectacular results in the North Pennies and a large number of sites have been identified.
Frank Green. Dense heather can cause problems for lidar in open moorland conditions. There is already a consultation process for any development or landscape changes affecting National Parks who are already consulted on any development or change in their areas.
Tim Yarnell. The value of lidar in open landscapes has already been flagged up. Organisations should work towards greater pooling of resources and data to ensure that all available information is accessible when decisions are made.

Q. Have local groups at Savernake been helping ground truthing to feed back into interpretation?
Helen Winton. To date, local groups have not been involved in validation in Savernake.

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