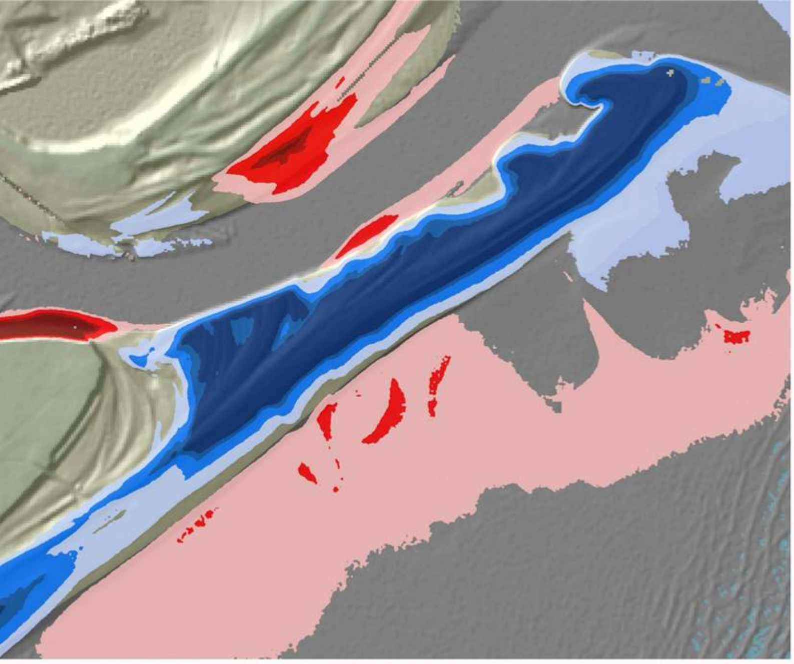


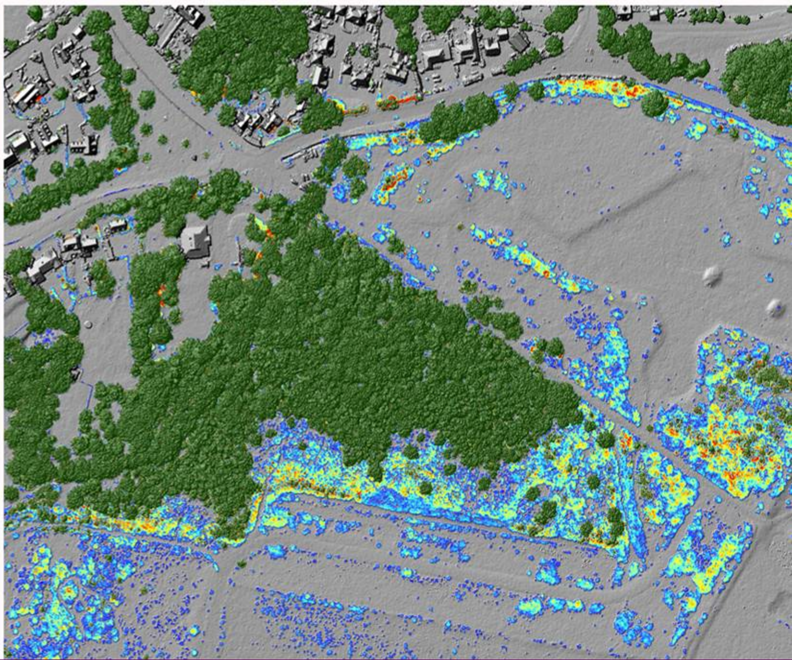

Natural England/Environment Agency Collaboration: Operational use of Remote Sensing for Environmental Monitoring

Joint report - November 2011

Operational use of Remote Sensing for Environmental Monitoring

Authors	Sarah Petchey, Kyle Brown, Crispin Hambidge, Keith Porter and Sue Rees
Authorised by	Alison Matthews and Keith Porter
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Contact details:

Sarah Petchey, Kyle Brown and Crispin Hambidge
Environment Agency, Geomatics Group
Lower Bristol Road
Bath
BA2 9ES
01225 487637
sarah.petchey@environment-agency.gov.uk

Keith Porter
Natural England
3rd Floor Touthill Close
City Road
Peterborough
PE1 1XN
0300 060 0673
keith.porter@naturalengland.org.uk

Geomatics Group

NATURAL ENGLAND

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Glossary of Terms

Accuracy:

How close the data value is to the true value. The vertical accuracy of Environment Agency LIDAR data has typically been ± 6 cm over the last five years

Compact Airborne Spectrographic Imager (CASI):

Airborne multispectral imaging sensor, which measures the reflected light from the Earth's surface

Digital Surface Model (DSM):

Elevation data that includes surface objects such as buildings and vegetation.

Digital Terrain Model (DTM):

'Bare earth' elevation data that has had surface objects filtered out.

Light Detection and Ranging (LIDAR):

An airborne mapping technique, which uses a laser to measure the distance between the aircraft and the ground. From this a highly accurate 3D elevation model can be created.

Resolution:

The size of a pixel on the ground. Determines the smallest feature that can be distinguished. For example an object that is 1 m in size will be visible in a 50 cm resolution LIDAR dataset, but not in a 2 m resolution dataset.

1. Executive summary

This report summarises key products from collaborative working between the Environment Agency and Natural England and its predecessors. The intention of this work has been to apply data collected from sensors mounted in aircraft, to create operationally useful products. The application of remotely sensed data has been discussed at length for many years, but rarely has this led to any consistent, cost-effective use of such data in an operational agency.

The work reported here covers almost 10 years of joint working and takes us from first attempts to reconcile the technical expertise of the Environment Agency and the ecological and operational needs of Natural England. All examples were initiated by a request from Natural England staff and were needed to address real problems encountered as part of delivery or development work. The vast majority have been used to support condition assessment of features, casework or reporting. Many products could not have been developed without this approach, or at best would have cost far more in staff time or resources. Wherever possible the products have been derived from data already secured as part of other requirements, particularly around assessment of floodplains and coasts by the Environment Agency, or aerial photography licensed by Natural England.

The strength of this work has been the marriage of technical remote sensing skills and techniques and the ecological knowledge of Natural England staff. Experience has shown that the combination of these two disciplines has been critical to delivering innovative products that would not otherwise have been possible. The exchange between these two disciplines has often provided a strong challenge to both parties; data analysis and interpretation requires clear, consistent definitions of features and ecologists have had to rethink this in many cases.

Most of the examples presented here are essentially technical products that require further context and interpretation. During the collaboration both sides have grown in confidence in both applying and understanding the potential of these type of data. The intention now is to explore how to cement this experience in new ways of working across Government bodies in order to make even greater use of existing and future data.

2. Introduction

Environment Agency Geomatics Group and Natural England have a long history of partnership working and since 1999 a wide variety of collaborative remote sensing projects have been undertaken. Initial projects focussed around coastal mapping and surveillance, particularly within saltmarsh habitats. Over time this work has expanded and joint working is now investigating new ways of using remotely sensed data for environmental monitoring, for a wide range of intertidal and terrestrial habitats. The aim being to provide Natural England with operationally useful products.

Geomatics Group have a substantial archive of Light Detection and Ranging (LIDAR) data, which are used to create these operational products under the collaboration. As of the end of December 2010, Geomatics Group had LIDAR data for more than 62% of England. Figure 1 shows the extent of archive data coverage, coloured by the year the data were acquired.

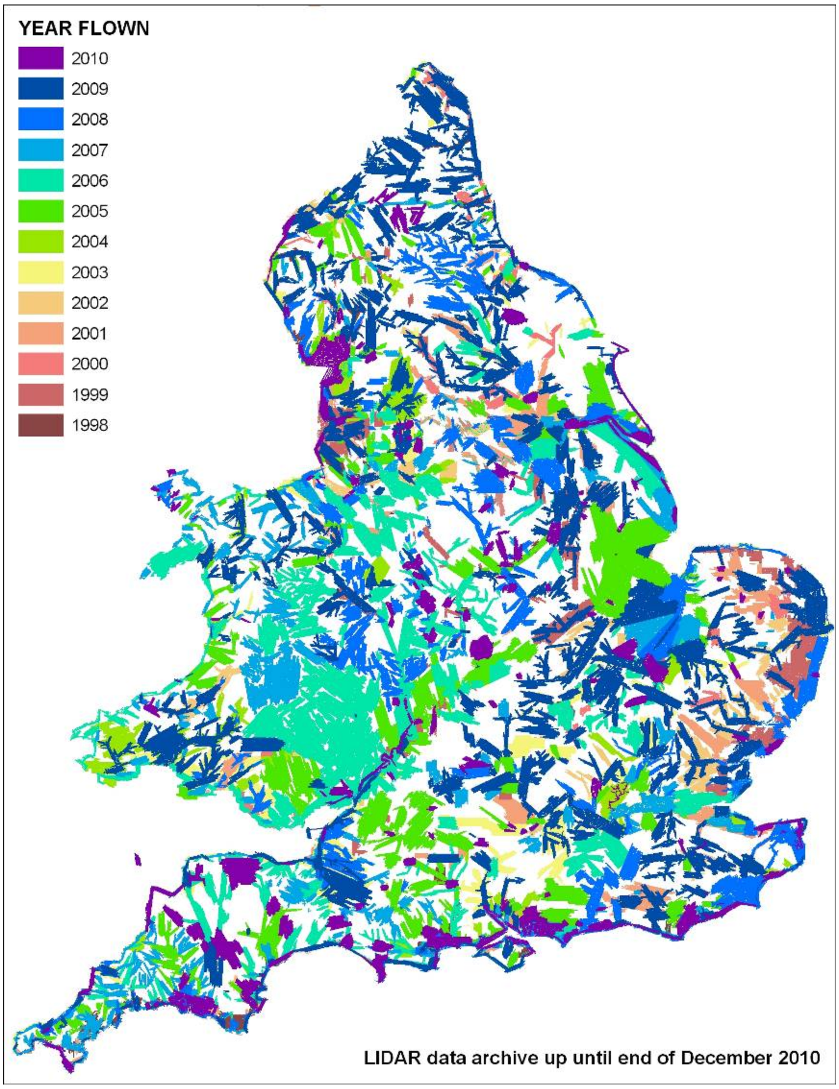

Figure 1 Geomatics Group LIDAR data archive for England and Wales

These archive data were acquired from 1998 onwards at varying resolutions from 25 cm to 2 m. The resolution here refers to the horizontal distance between measurement points on the ground. Data capture has focussed mainly on coastal and floodplain areas, with the majority of the data commissioned by the Environment Agency for flood risk management purposes. However, once the data are acquired they can also be used for many other potential applications. Other datasets, including aerial photography and multispectral Compact Airborne Spectrographic Imager (CASI) data are also available for use within the collaborative work.

Although having access to a variety of remotely sensed data is important, the most valuable part of this agreement is the collaboration and knowledge sharing between the two organisations. Environment Agency Geomatics Group have a wealth of remote sensing and GIS expertise, but to produce a meaningful product, this needs to be combined with the ecological knowledge held within Natural England. The importance of this will be demonstrated through the case studies presented here.

This joint report will outline the breadth of analysis that has been undertaken over the last ten years under the collaboration. It presents products generated for a range of coastal and terrestrial applications, all of which have been developed and led by the operational needs of Natural England. Many of the outputs that were developed as part of a pilot study have subsequently been turned into operational tools. They are now used to help understand change and give advice for sites all around England. All operational products that were created between March 2010 and March 2011 are included at the end of the relevant section.

3. Describing coastal sediment changes

The coastal environment presents particular problems to ecologists in that the features can be extremely dynamic, sometimes changing with every tide. Natural England are particularly interested in how the natural dynamics operate, to understand how topography influences the maintenance of different elements of habitats, for example on sand dune systems. These processes operate at relatively large scales and there need to be ways of capturing all the information for entire sites to see the picture across multiple coastal cells.

Remote sensing is particularly good at providing data across large areas over different time periods and thus provides the ideal tool to look at dynamic change over long stretches of coastline. LIDAR enables spatially continuous elevation data to be acquired rapidly and accurately, in areas that may be too sensitive or inaccessible from the ground. The Environment Agency Geomatics Group have LIDAR data for more than 95% of the coast of England (as of the end of December 2010). For many of these areas there are multi-temporal LIDAR datasets, making it ideal for monitoring coastal change.

3.1. Monitoring coastal features, Cley-Salthouse shingle ridge, Norfolk

Change products derived from LIDAR data can be used to help inform coastal management plans. The shingle ridge at Cley is part of the North Norfolk coast SAC and SPA. In the winter of 2006, the Environment Agency and Natural England agreed a beach management plan to stop all artificial profiling of the ridge as a flood risk management measure, which had been previously carried out using heavy machinery. This approach was considered to be unsustainable and a return to a more natural beach profile would recover the condition of the site features, coupled with other management and habitat restoration. The significant ecological importance of this feature, as well as its value as a natural sea defence for the surrounding low-lying area, meant that the impact of this management decision needed to be recorded and monitored.

This was made possible by the availability of archive LIDAR data from before the change and several surveillance flights commissioned by the Environment Agency over the next couple of years. These data, acquired 9th September 2006 (50 cm resolution), 11th April 2007 (25 cm resolution) and 12th January 2008 (25 cm resolution) were used to derive a series of products to assess changes of key condition indicators:

- Height of the ridge;
- Width of the ridge;
- Elevation along the ridge;
- Shingle volume change.

3.1.1. Defining the 'extent of the shingle ridge'

It is difficult to define the boundaries of a shingle ridge, as they are dynamic and transient features within the continuous coastal zone (Figure 2).

Figure 2 Cley shingle ridge, North Norfolk Coast (looking east). Photo courtesy of Sue Rees, Natural England

The first challenge was to establish a consistent and robust way to define what was being described as a shingle ridge. This is necessary to enable accurate repeat monitoring over time and needed expert input from ecologists and geomorphologists. For this project, the seaward extent was defined by the average Mean High Water Springs (MHWS) height, taken from Admiralty Tide Tables, adjusted to Ordnance Datum Newlyn. The landward extent was defined as the point at which the slope of the ridge flattened out to the level of the low-lying backshore. Natural England requested the inclusion of areas where the ridge had collapsed, forming overwash fans (Figure 3).

Figure 3 Overwash fan at Cley (looking north-west). Photo courtesy of Sue Rees, Natural England

These ridge extent parameters were used to create a mask for the subsequent analysis of the ridge. Figure 4 shows the distance along the ridge every 1000 metres.

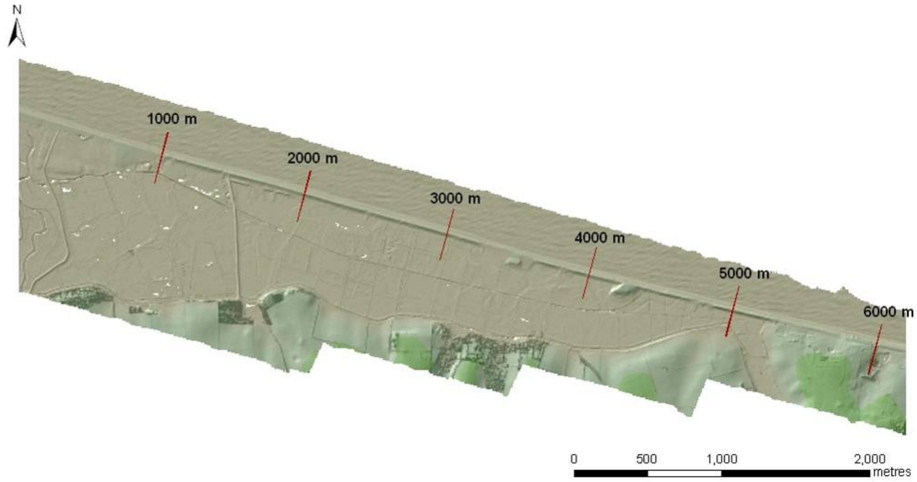

Figure 4 Distance along the ridge (north-west to south-east), as referenced in the following graphs in this section. Underlying imagery is the 2008 LIDAR data

3.1.2. Ridge height change

The maximum height of the ridge at 2 m intervals was determined for each of the LIDAR datasets (Figure 5). Additionally, the spatial location of the maximum height of the ridge in each year was identified (Figure 6). The position of the ridge peak indicates that steady linear, landward migration of the ridge has been occurring since 2006 (Figure 6, image A), except in areas where the shingle has rolled back as overwash fans. At these locations, the highest point of the ridge is actually slightly further seaward, but the width of the ridge is greater (Figure 6, image B and C).

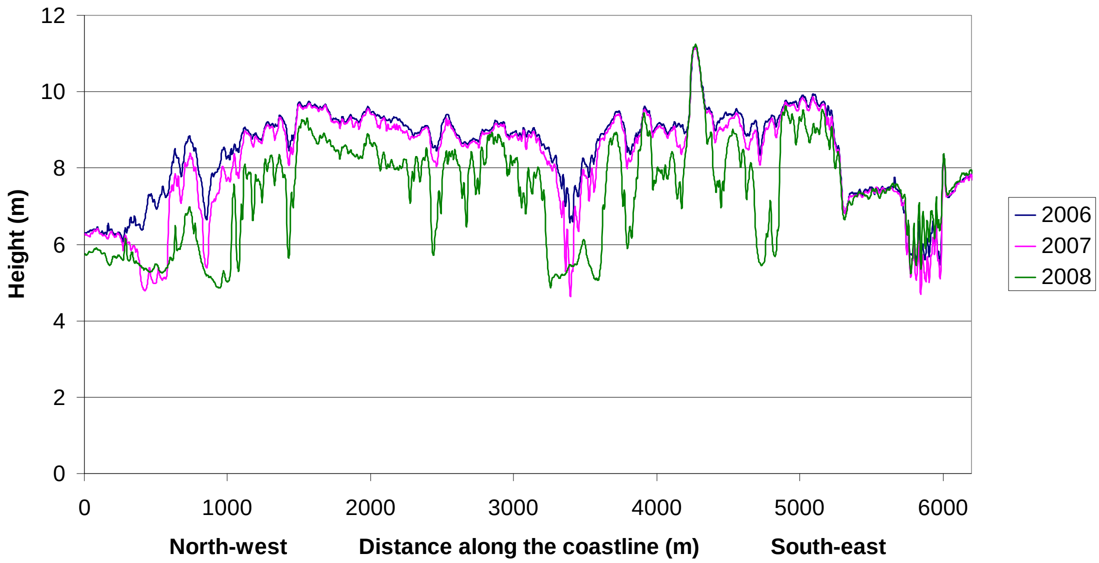

Figure 5 Changes in the maximum height of the shingle ridge between 2006 and 2008 (calculated at 2 m intervals along the coastline)

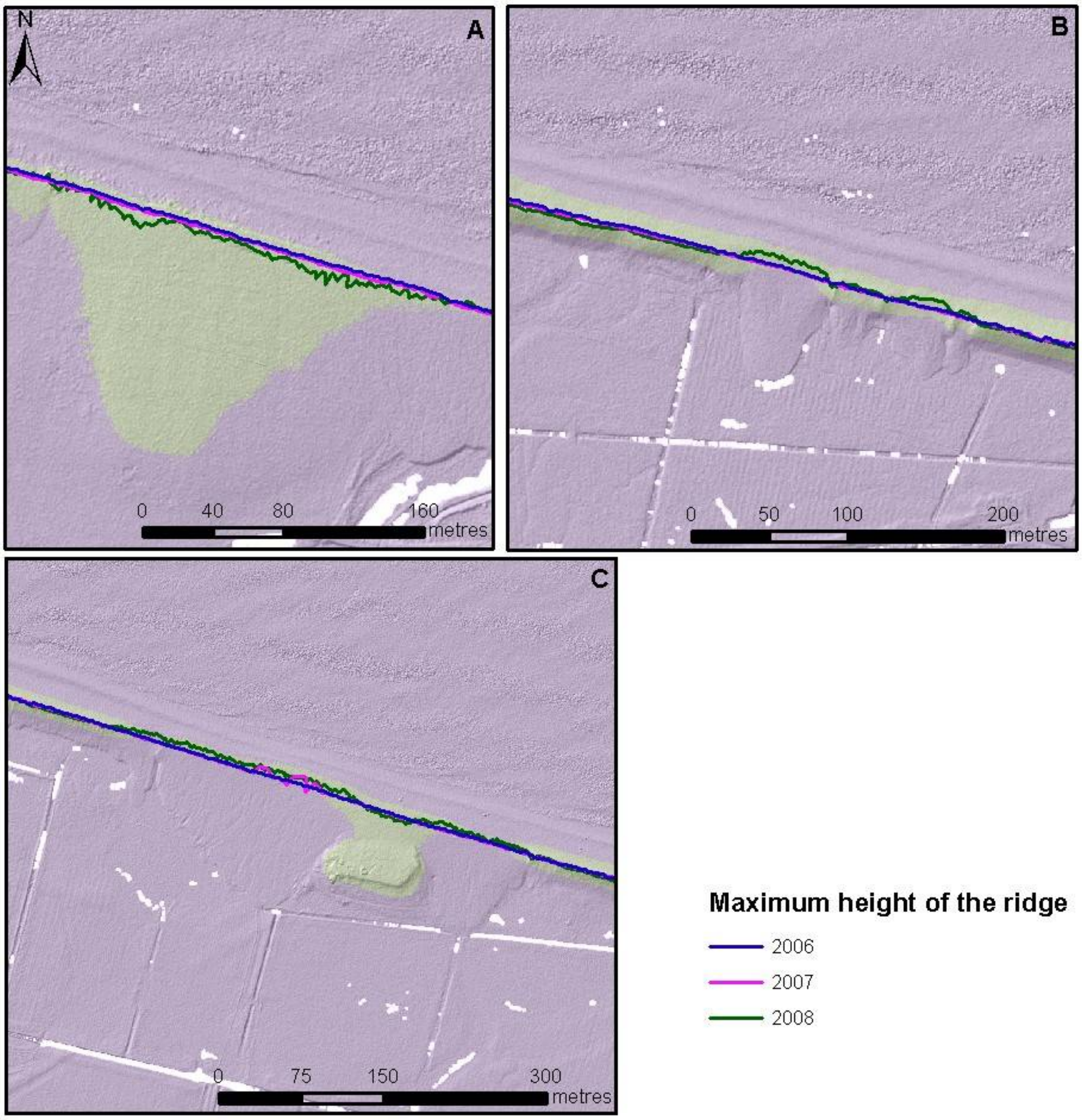

Figure 6 Location of the maximum height of the ridge between 2006 and 2008 for three small sections of the ridge. The imagery is the LIDAR data for 2008

3.1.3. Ridge width change

The ridge extent for each year was used to determine the change in ridge width over time (Figure 7). Figure 8 shows how far the landward extent of the ridge has migrated between 2006 and 2008, specifically at each 2 m interval along the ridge. Comparing the absolute changes in ridge height and width provides important information about the ridge evolution. Having a time series of data also means that the rate as well as the scale of change can be analysed.

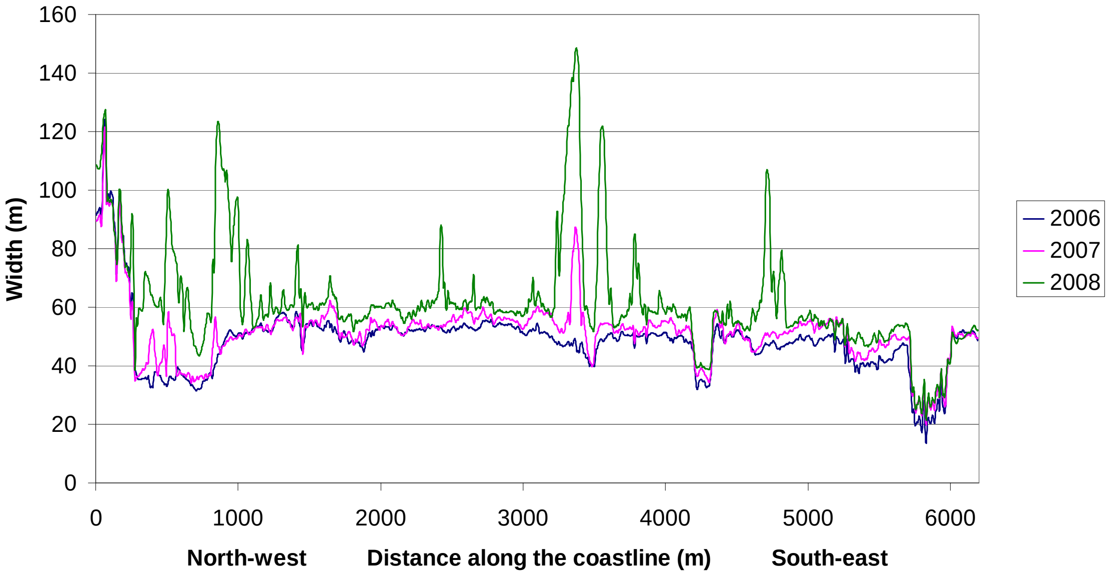

Figure 7 Changes in the width of the shingle ridge between 2006 and 2008 (calculated at 2 m intervals along the coastline)

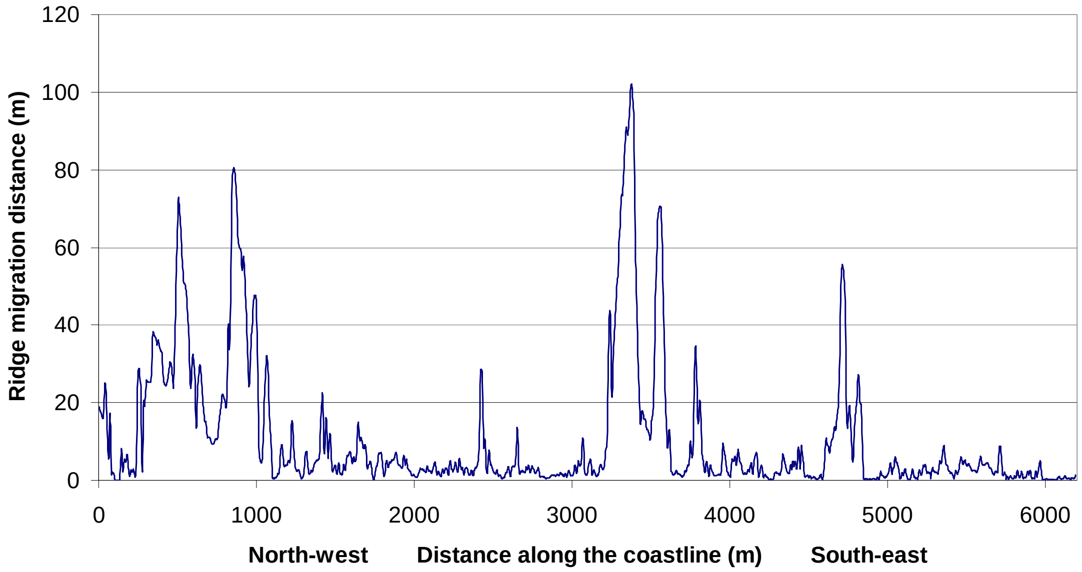

Figure 8 Migration of the landward extent of the shingle ridge between 2006 and 2008 (calculated at each 2 m interval)

3.1.4. Elevation change

LIDAR data were used to continuously map the relative elevation changes along the ridge between 2006 and 2008 (Figure 9). The elevation change identifies the reduction in the peak height of the ridge as areas of erosion (red). The blue areas of accretion show where shingle has been pushed landwards by the sea, forming overwash fans.

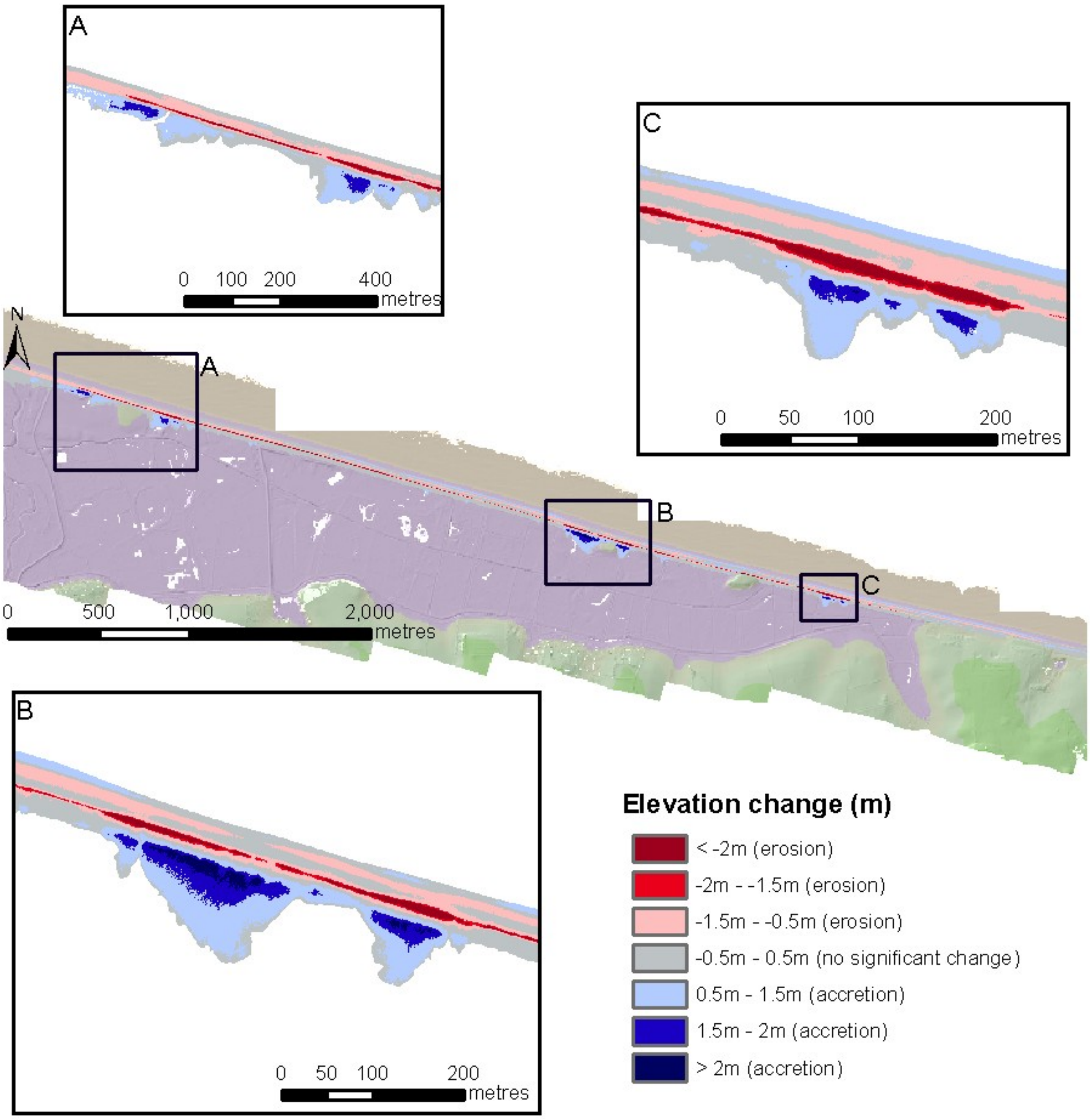

Figure 9 Elevation change of the Cley shingle ridge (2006-2008). The imagery is the LIDAR from 2007

3.1.5. Volume change

As part of this assessment, Natural England needed to be able to judge whether shingle was just being redistributed along the ridge or if sediment was actually being lost from this section of the coastline. To facilitate this, volume change was also undertaken for this site, calculated on a series of 20 m virtual quadrats set up along the ridge. The results are shown in Figure 10.

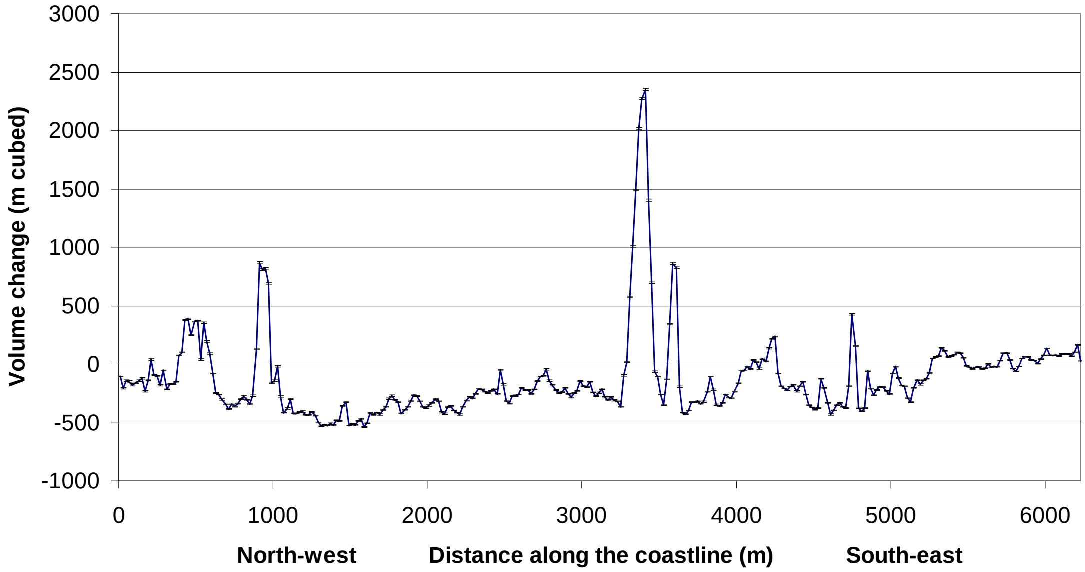

Figure 10 Shingle ridge volume change (2006-2008), calculated at 20 m intervals along the coastline. Error bars are 95% confidence intervals

In addition to providing answers to operational questions, such as understanding how the ridge function is being restored, the products lend themselves well to visual manipulation. Figure 11 shows the continuous elevation change overlaid on some CASI imagery. The LIDAR data have been used to provide the height values that give the image a 3D appearance.

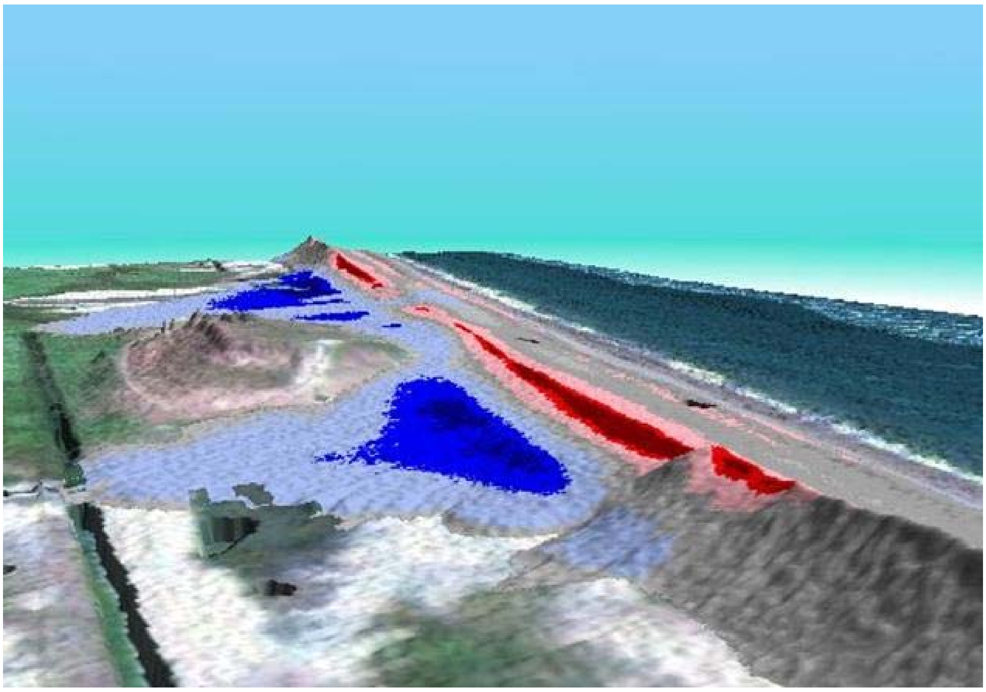

Figure 11 3D visualisation showing the elevation change at Cley

Striking visual tools like this have been used to help explain the coastal processes acting on the site to local people, visitors and other partners. They have also been used within Natural England to underpin coastal training exercises for staff and students to promote understanding of coastal evolution.

3.1.6. Ridge definition uncertainty

As previously mentioned, in order to monitor precise coastal changes over time, robust definitions need to be set for the target feature. This ensures that there is something constant against which changes can be identified and measured. However, natural features are rarely so clear cut, as one coastal unit tends to blend into the next. This work stimulated thinking about the environment in a different way and led to some interesting ecological discussions.

For this study, the landward limit of the shingle ridge was defined as the point at which the steeper gradient of the ridge met the flat, low-lying land behind it. The seaward extent was more complicated. It was agreed that because the ridge is directly influenced by the sea, the seaward limit of the ridge should be defined by a height value corresponding to a position in the tidal cycle. However, after discussions with Natural England ecologists, it became apparent that any position between Highest Astronomical Tide (HAT) and Mean Low Water (MLW) could be legitimately used. For this study, the average height for the MHWS level was used to define the seaward extent, with the key aim to be consistent between different studies.

Further analysis was undertaken to see whether using alternative reference sea level measures would alter the conclusions. The ridge was re-defined, with the same parameters setting the landward boundary, but using the HAT and MLW tidal heights to define the seaward boundary. The volume and width change between 2006 and 2007 were calculated based on these two new definitions. Figure 12 shows the results for the volume change analysis.

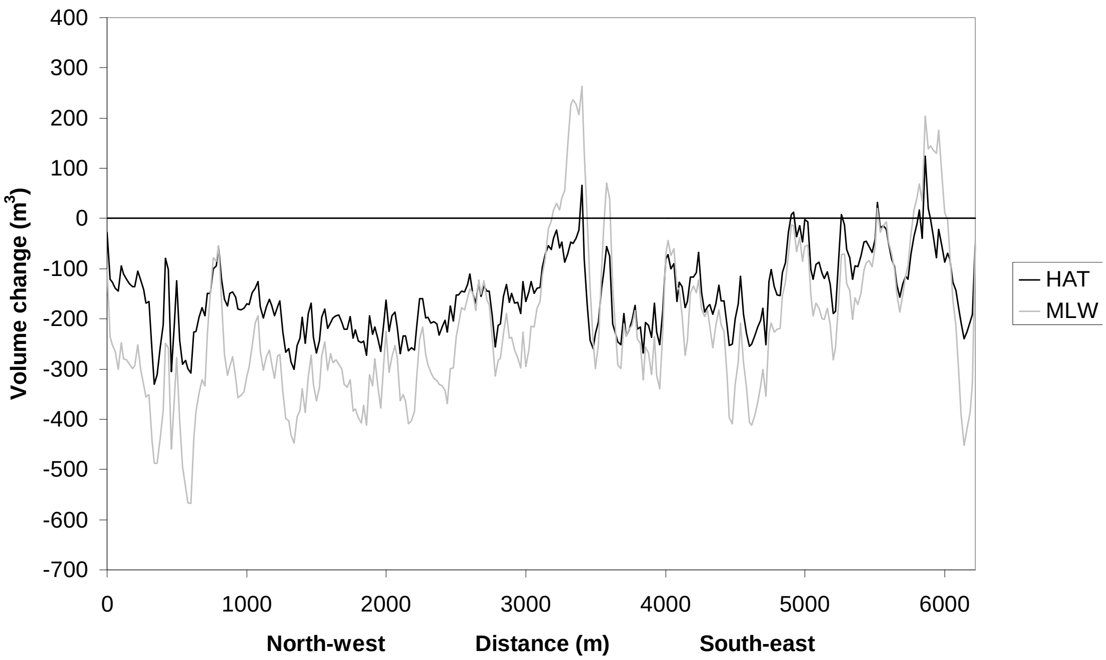

Figure 12 Volume change between 2006 and 2007, using HAT (black line) and MLW (grey line) to define the seaward extent of the ridge

These results record different levels of volume change along the ridge, with the lower tidal limit generally showing a greater amount of sediment loss. At some points the analysis records completely different volume trends. Part of the centre and south-eastern sections are recorded as undergoing net accretion or erosion, depending on how the seaward boundary is defined.

The same procedure was undertaken for calculating the width change. The results are shown in Figure 13.

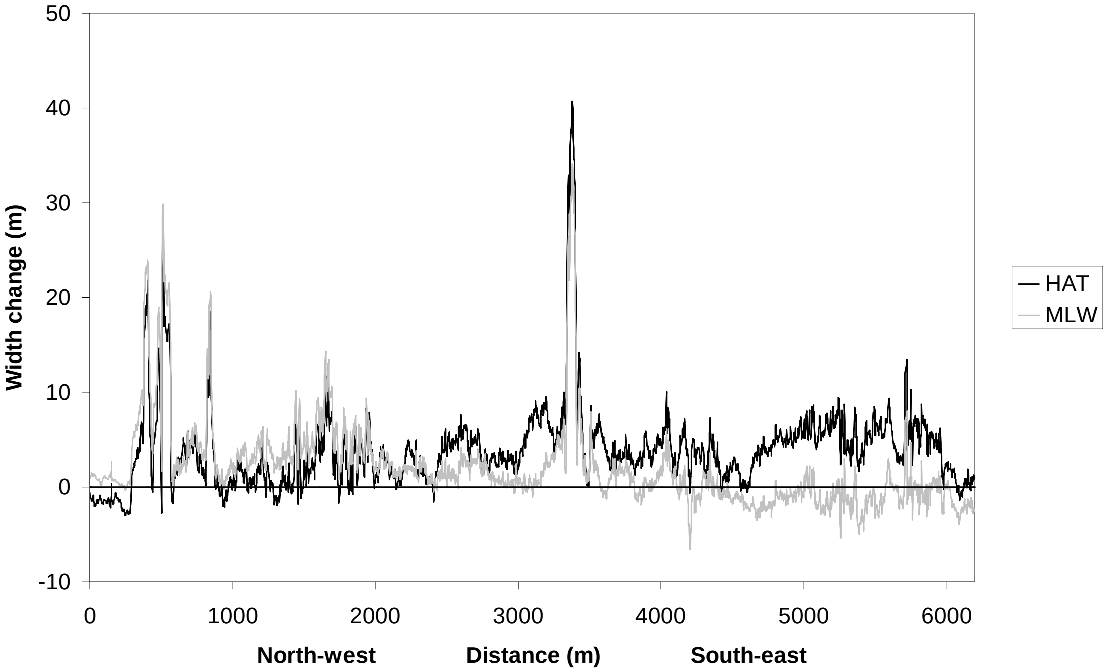

Figure 13 Width change between 2006 and 2007, using HAT (black line) and MLW (grey line) to define the seaward extent of the ridge

As with the volume change analysis, depending on the definition used for the seaward boundary, the same section of ridge is recorded as both widening and narrowing. There also appears to be more variation within the width change results compared to the volume change. This is probably because the definitions are more influential in the width analysis. Width change is directly calculated from positional variations in the ridge boundaries, whereas ridge extents are merged when calculating volume change.

This is a good example of where it is essential that the geomorphological expertise within Natural England is passed to the remote sensing analysts. For the results to have practical meaning they need to be justified by sound ecological reasoning. It is equally important that ecologists not only understand the methods used to generate the outputs, but also the uncertainties associated with them. The different results shown in Figure 12 and Figure 13 might lead to two very different management plans being drawn up if considered in isolation. The results indicate a need to fully understand the system and processes in order to make management decisions.

For this analysis, the shingle ridge was defined using 'hard mapping' techniques. This requires a cell to be defined as either belonging or not belonging to the ridge, drawing hard boundaries. This was done so that clear change results could be reported, however it is not the only way to approach this analysis. Within the academic environment 'soft mapping' or 'fuzzy mapping' techniques are more commonly used for mapping vague geographical features, incorporating the uncertainty of the feature boundaries. However this method has some limitations when applied to operational monitoring, some of which are explored in section 5.2.

More in-depth analysis of the Cley shingle ridge and the uncertainty associated with monitoring vague geographical features was presented at the Remote Sensing and Photogrammetry Society (RSPSoc) conference in 2009. Details of this work were published in the RSPSoc conference proceedings (Petchey, S and Brown, K (2009). *What is a shingle ridge? The importance and difficulty of defining vague landforms for monitoring change*, RSPSoc conference proceedings). Further analysis has been carried out and a paper is being prepared for submission to a peer reviewed journal.

3.2. Assessing coastal change, Pagham Harbour, West Sussex

The change analysis requested for Pagham Harbour on the South coast was a reactive rather than planned monitoring exercise. It was apparent from the ground that the spit across the harbour entrance was rapidly extending and Natural England needed to be able to quantify these changes to support casework advice. Archive LIDAR data, acquired on 27th November 2004 (2 m resolution) and 31st January 2009 (1 m resolution), were used to map spatially continuous elevation changes over two time periods five years apart (Figure 14). Changes of up to 6 m were recorded in some areas.

As the spit was clearly extending and depositing a significant amount of sediment into the harbour entrance this whole area was kept in the analysis, despite the presence of water in 2004. However, it is important to note that as a result, the LIDAR height values in 2004 will lead to an underestimation of the amount of change. Therefore, the change product will only show the minimum amount of accretion that has occurred and it is likely that the actual amount of accretion will be greater.

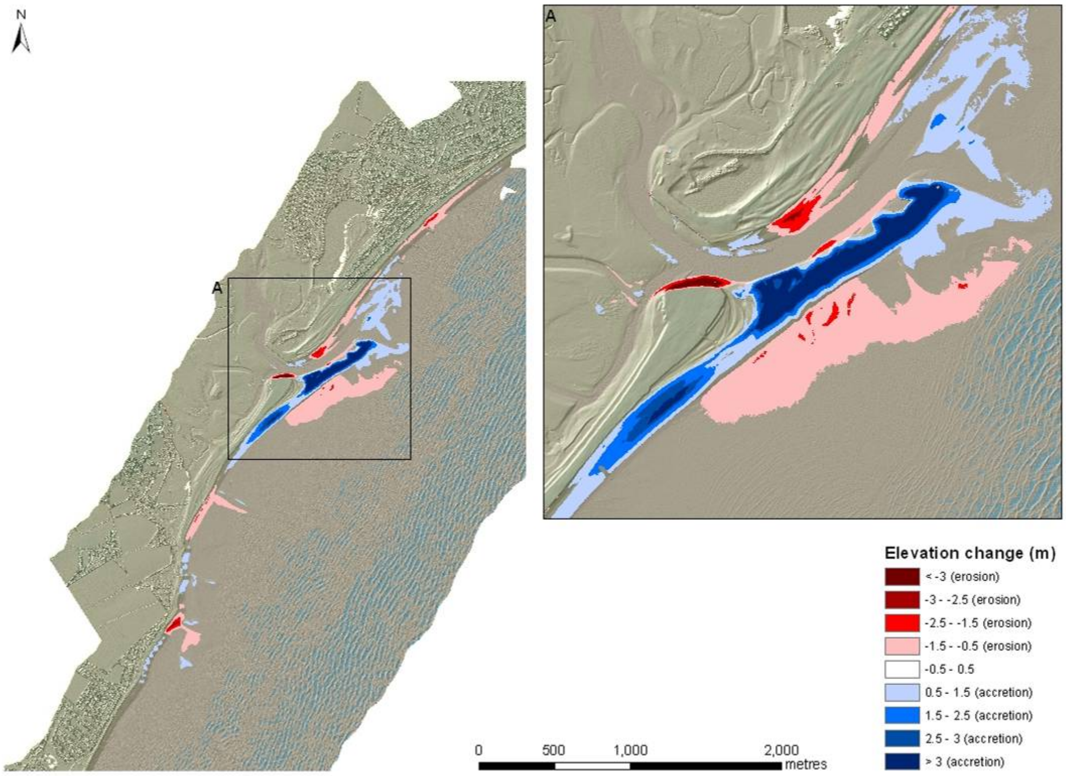

Figure 14 Elevation change for Pagham Harbour (2004-2009)

Natural England have used this product to help advise the local authority and work with their consultants. By having a clear analytical process, supported by data, the local authority was able to make an evidence-based decision. The aim was to prevent any unsustainable use of the newly deposited shingle.

3.3. Benefit of using LIDAR over traditional techniques for assessing coastal sediment change

The traditional approach to change monitoring usually involves establishing a series of transects and routinely collecting ground-based data along them over a period of time. One of the benefits of using LIDAR for change monitoring over these traditional techniques, is that these data can be used to extract continuous changes across large areas. LIDAR is a non-destructive method for acquiring data over sites that may be difficult or dangerous to access, such as intertidal mudflats or military sites.

The high resolution of the LIDAR data acquired for Cley shingle ridge (section 3.1) enabled a detailed set of condition indicators to be extracted. Precise information on height and width was calculated every 2 m along a site that spanned over 6 km. It would have been virtually impossible to have undertaken analysis to a similar level of detail using traditional ground-based methods.

Another limitation of using transects for monitoring is that they will only provide a snapshot of the change happening at that specific location. If the transect is not suitably placed or unexpected change occurs elsewhere, then it will not be recorded in the transect. Figure 15 illustrates the advantage of using LIDAR for change monitoring over traditional techniques.

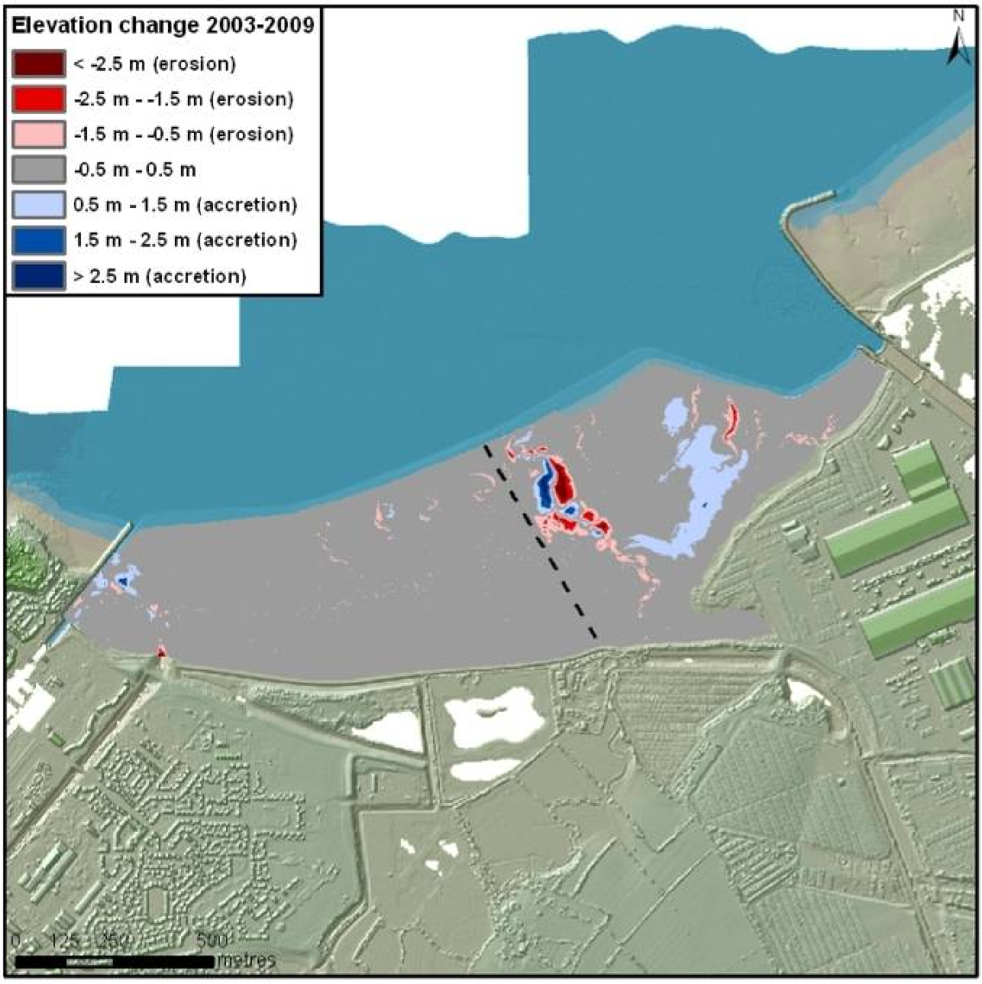

Figure 15 Elevation change analysis for a pilot site along the Severn estuary (2003-2009). Hashed black line shows the transect location

Figure 15 shows part of the analysis that was undertaken for a series of pilot areas located around the Severn estuary. For each area Natural England requested continuous elevation changes derived from LIDAR data and change extracted along a single transect. At the site shown in Figure 15, the location of the transect suggested by Natural England staff completely missed the area of most change, identified by the LIDAR analysis of the wider area.

LIDAR offers a repeatable methodology that can be used to monitor changes across large or small timescales. The data are acquired regularly and in a standardised way, which means that once they are captured they can be re-visited and re-analysed at any time. This is important, since some changes are evident over a couple of years, but others may take 10 or 20 years to show. A key feature of data acquired by the Environment Agency is that for coastal work it is collected at low tide when the greatest amount of the intertidal zone is exposed. This is not necessarily the case with other sources.

At Pagham Harbour, the availability of archive LIDAR data acquired over several years, was essential to understanding the dynamic coastal processes taking place. These data were not originally flown for this purpose, however once they are acquired they can be used for multiple applications. Even if historical transect data were available for this site, it is unlikely that it would have been as useful, since it does not provide a continuous dataset and would not have been acquired with the knowledge of the large scale changes that were going to take place. Furthermore, as the majority of the change involved newly deposited shingle extending seawards, this area would not have been easily accessible for ground measurements, whereas it could be captured by LIDAR acquired at low tide.

3.4. Operational products

Due to the advantages that LIDAR data offer for coastal surveillance and monitoring, a variety of requests were made for change products to support operational reporting and casework needs by Natural England staff. Change analysis has been done for various sites across England and Figure 16 shows sites where operational coastal change monitoring has been undertaken under the collaboration.

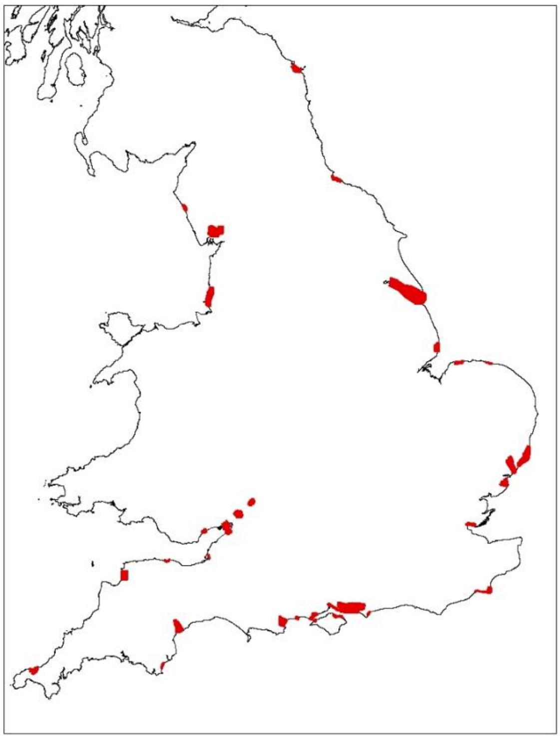

Figure 16 Red areas show where coastal change monitoring has been carried out operationally

The following projects in this section outline the coastal change analyses that have been undertaken between March 2010 and March 2011.

3.4.1. St. Ives Bay (Upton Towans), Cornwall

As part of reporting on change at this site, work was commissioned to map the intertidal and frontal dune elevation change between 30th-31st March 2003 (2 m resolution) and 10th March 2009 (1 m resolution), using the LIDAR Digital Surface Model (DSM) (Figure 17). A DSM shows the height of all features on the land, including trees, buildings and other structures.

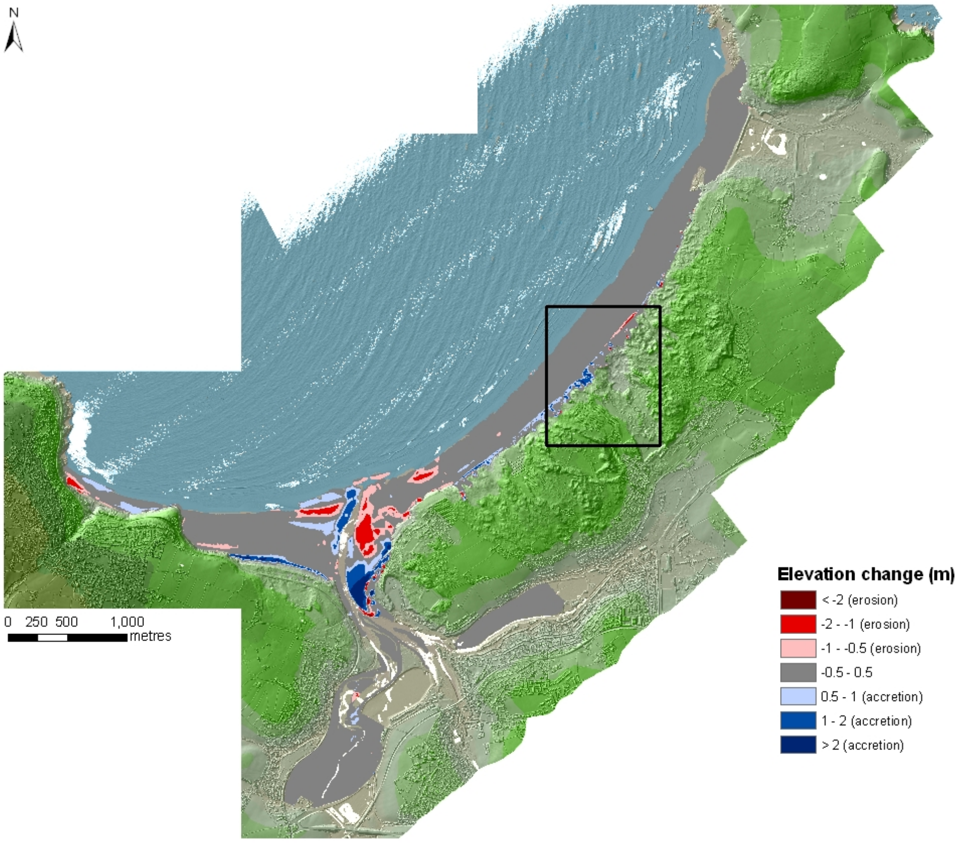

Figure 17 Intertidal and frontal dune elevation change for St. Ives Bay (2003-2009). The black extent box shows the location of Figure 18

Figure 18 shows a 3D visualisation of the elevation changes across the frontal dunes at Upton Towans. The local perception of this section of the coastline was that the dunes might have been experiencing erosion around the front of the holiday camp (to the right of the image). However this routine surveillance exercise revealed that the dunes were actually accreting here. This has been very useful to inform casework and management of this site.

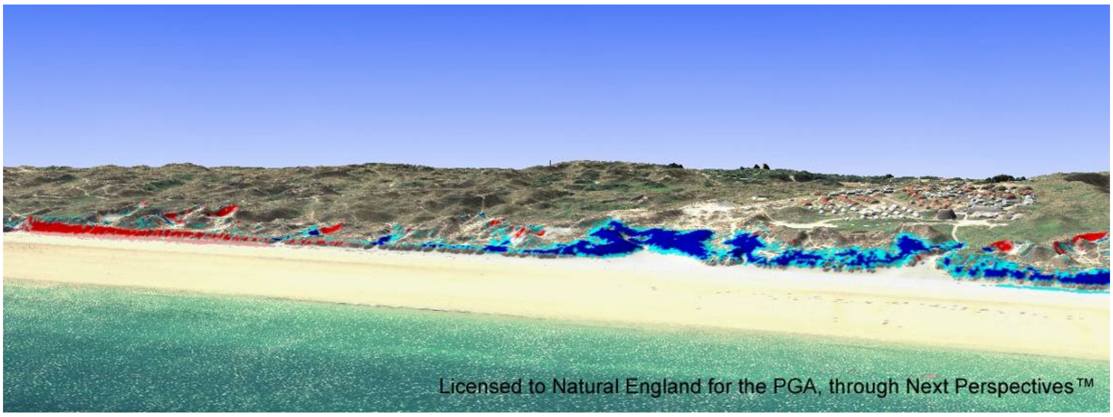

Figure 18 3D visualisation of the elevation change along the frontal dunes at Upton Towans. Red and pink are erosion and blue is accretion

3.4.2. Porlock Bay, West Somerset

Porlock Bay is a site where a breach of the shingle ridge occurred during a storm in 1996. The breach was left to evolve naturally and provides a nationally important site showing the evolution of new intertidal areas and the beach ridge. Documentation and study of this location is a vital element of increasing scientific understanding of coastal change and will help with planned or natural change at other sites. The elevation change (Figure 19) and calculated volume changes (Figure 20) between 20th April 2007 (1 m resolution) and 16th October 2009 (1 m resolution) were mapped for Porlock Bay, using the LIDAR DSM.

The LIDAR analysis shows changes on the shingle ridge and the breach site, as well as elevation changes of the intertidal area behind it where sediment is deposited by tidal water. This updates previous change analysis between 2003 and 2007 and will contribute to our understanding of how the saltmarsh and ridge are developing, including variations in rates of deposition over time.

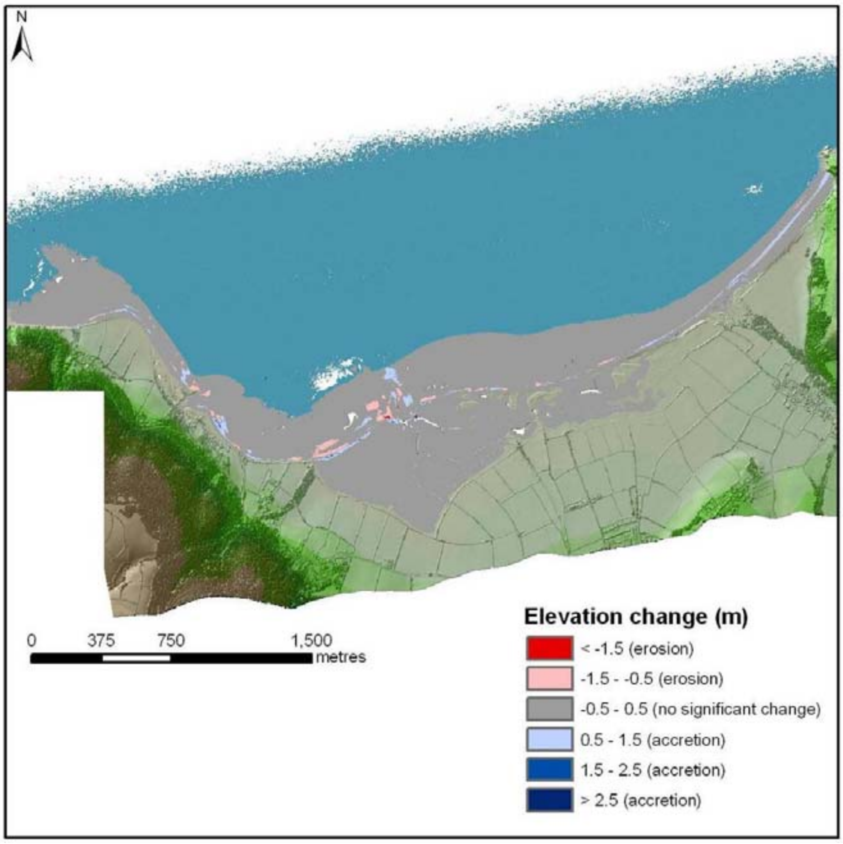

Figure 19 Intertidal elevation change for Porlock Bay (2007-2009)

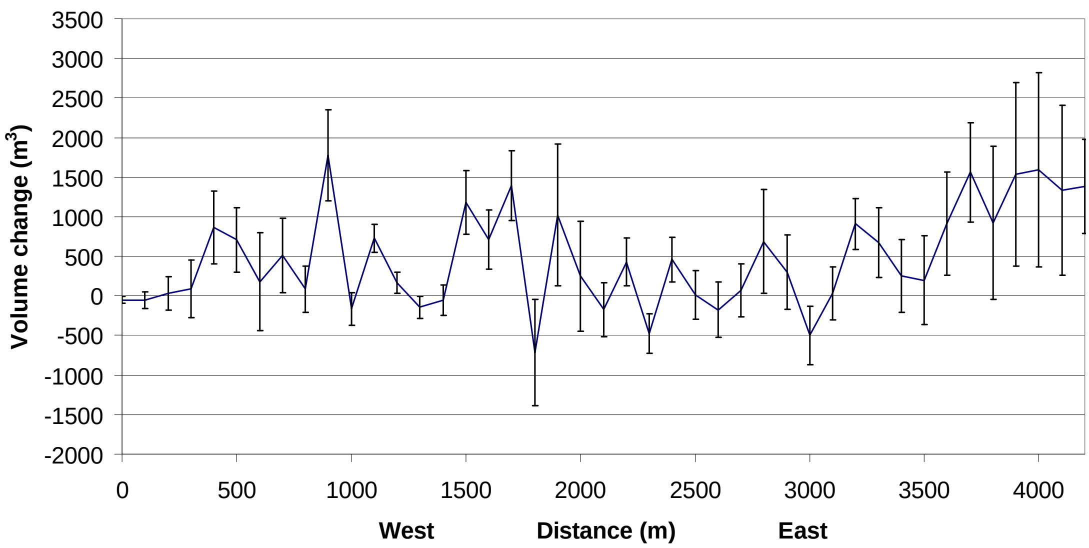

Figure 20 Volume change analysis for Porlock Bay (2007-2009). Error bars are 95% confidence intervals

3.4.3. Dungeness, Kent

Dungeness is the largest cuspate foreland in Britain, which has evolved over the last 5000 years. The foreshore is still changing in response to coastal processes, but the presence of human assets, including a nuclear power station, has led to programmes of shingle recycling and re-profiling as part of flood risk management measures. In 2008, a beach management plan was agreed between the Environment Agency and Natural England, as a condition of consent for management of the ridge. Monitoring was essential to enable the impact of the works to be kept under review. In addition, from 2007, the recycling of material from the eastern shore was reviewed, with only limited amounts of material added from other sources. This study was to explore whether the available data would be suitable as a complementary source of information to the regular ground-based transect monitoring and will be used to illustrate the types of changes that may occur. However, data coverage only extended into part of the foreshore, which limited the potential of the results.

The elevation change of the shingle beach ridge was mapped (Figure 21) and volume changes calculated (Figure 22) between 25th May 2005 (2 m resolution) and 16th October 2009 (1 m resolution), using the LIDAR DSM. Analysis was also undertaken to determine the difference in maximum height of the shingle ridge between 2005 and 2009 (Figure 23).

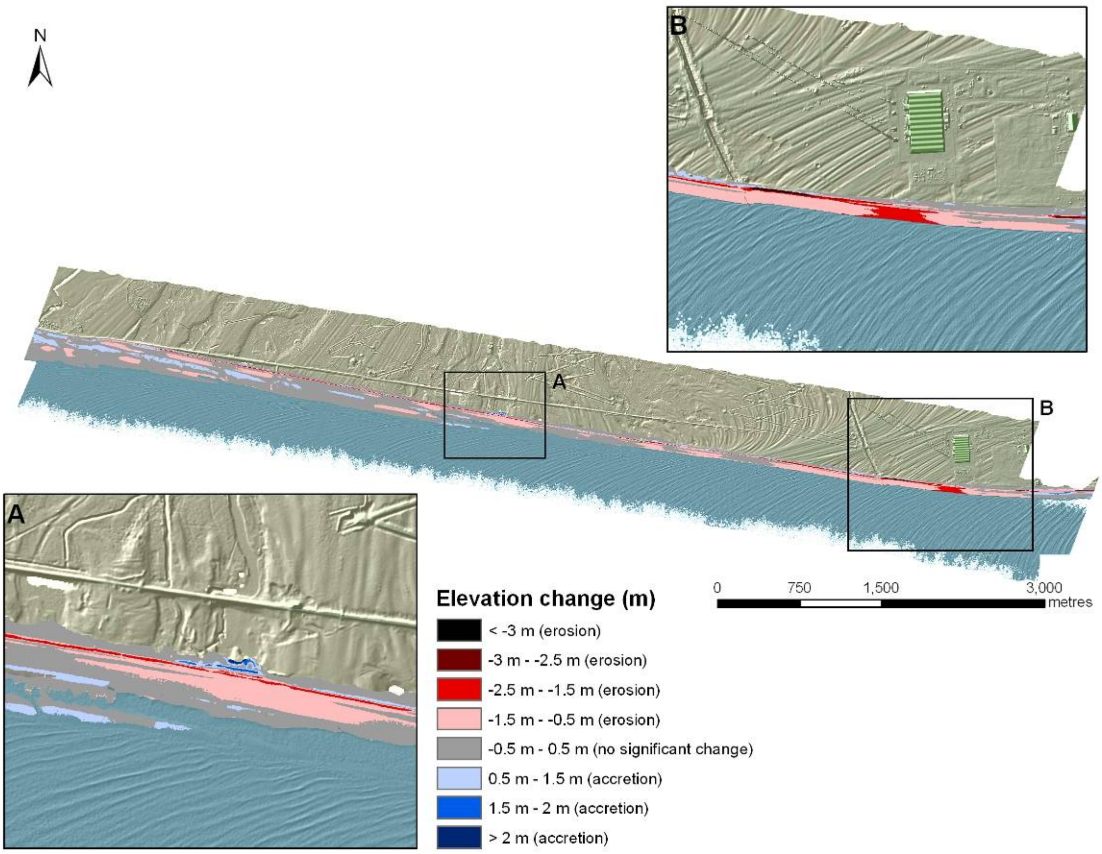

Figure 21 Elevation change analysis for Dungeness (2005-2009)

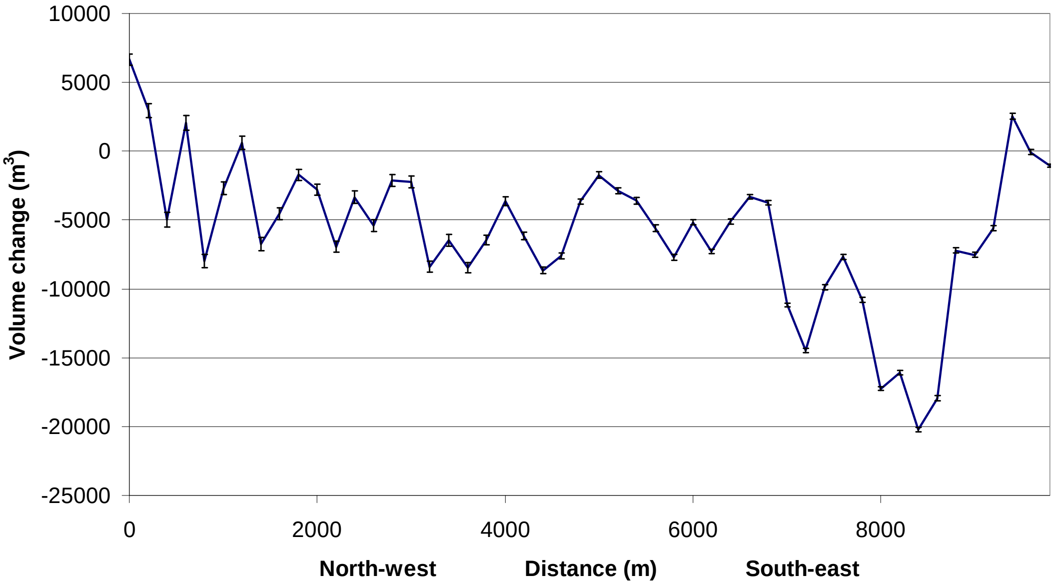

Figure 22 Volume change analysis for Dungeness (2005-2009). Error bars are 95% confidence intervals

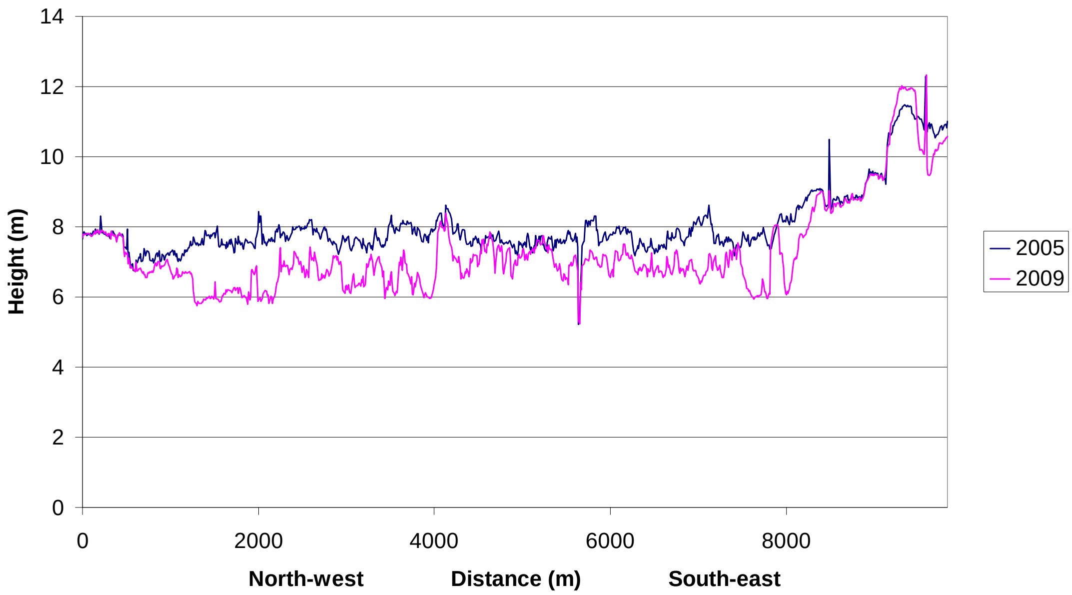

Figure 23 Change in height of the peak of the ridge along the Dungeness coastline 2005 and 2009

In the future, it would be recommended that full LIDAR coverage is planned for sediment process systems, where longshore drift from one area feeds another, or where artificial recycling has been part of a management programme.

3.4.4. Seaton Carew dunes & South Gare sands - Cleveland

The relationship between the beach plain and sand dunes is important as the beach is the source of sand that feeds the dunes. The following two examples in Cleveland and in Sussex aimed to investigate changes in the beach plain elevation over time, where there was a need to better understand dune processes. The long timescales between data sets do not enable representation of seasonal or storm-related changes. In the Seaton/South Gare sands study, accretion of sediment behind South Gare can be clearly seen in the enlarged section A. Further analysis of the topography of the frontal dunes is described in 4.3.1.

The elevation change for the intertidal zone was mapped (Figure 24) between 17th January 2000 (2 m resolution) and 25th August-9th September 2009 (1 m resolution), using the LIDAR DSM.

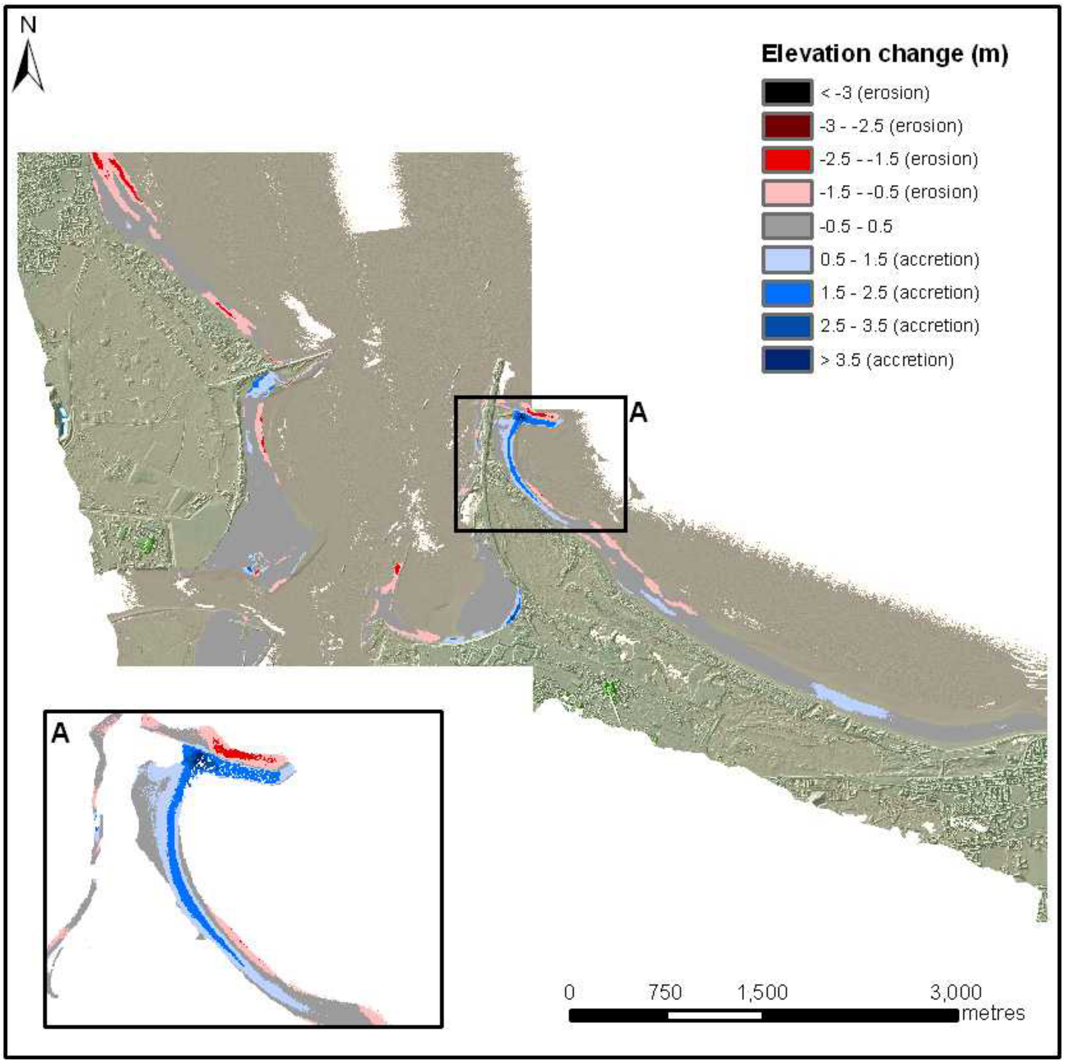

Figure 24 Intertidal elevation change for Seaton (2000-2009)

3.4.5. Camber Sands, East Sussex

Camber Sands is an area of beach plain and dune and is part of the Dungeness complex. Perceived changes in the volume of sand moving landward through the dunes led to the need for better understanding of the sediment processes at this location. This is known to be a dynamic site, with the dunes having developed in their present form since the construction in the 1920s of the current terminal groyne to the west to keep the river mouth open. To support more detailed advice on the dune an analysis of elevation of the beach plain was carried out using available data. The elevation change for the intertidal zone was mapped (Figure 25) between 16th June 2000 (2 m resolution) and 20th March-6th April 2009 (25 cm resolution), using the LIDAR DSM.

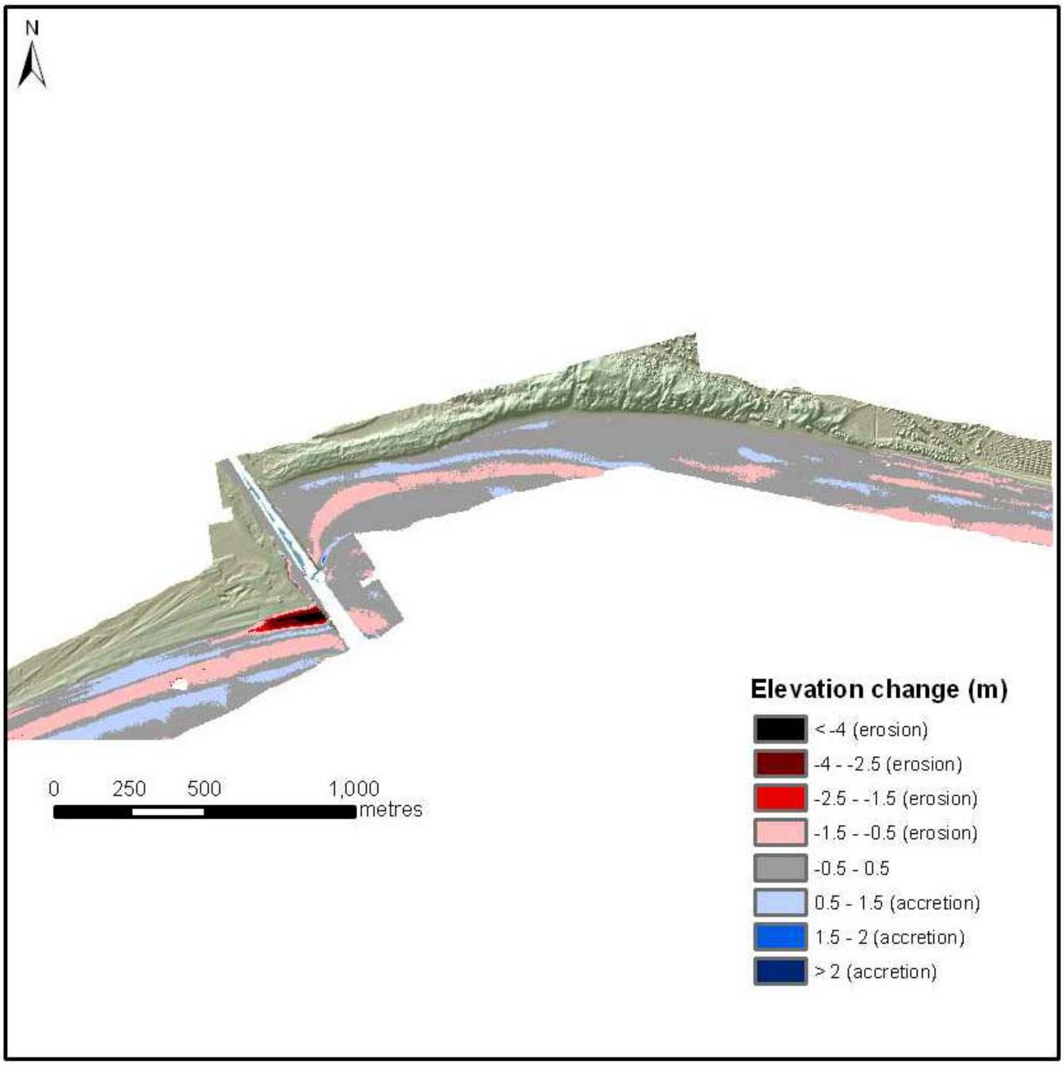

Figure 25 Intertidal elevation change at Camber Sands (2000-2009)

It should be noted that at this site there are consented recycling operations, which take material from the terminal groyne area for placement further west. Some of the larger erosional changes shown by this analysis of the two datasets are very likely to be a result of artificial extraction of deposited shingle between these dates. As with the Seaton/South Gare example, seasonal and storm-related changes cannot be identified from this analysis. Further geomorphological evaluation of this data would be needed in conjunction with intermediate data sets from beach monitoring transects.

3.4.6. Morecambe Bay, Lancashire/Cumbria

Morecambe Bay is a very active and dynamic intertidal area, which changes dramatically over time. Sites such as this are particularly difficult to assess in terms of condition, due to the ever changing location of the sediments. This is seen in the example here using two LIDAR datasets collected at different times. Although both datasets were captured during a low tidal window, areas that were previously sediment in one year, have become water filled streams in another year. To make the maximum use of the data and not discard areas where water was present in either year, two change products were produced for this site.

The elevation change for the intertidal zone was mapped between 28th November 2004 (2 m resolution) and 30th January 2010 (2 m resolution), using the LIDAR DSM.

A mask was generated to remove all areas of water and the elevation change for the sediment only areas was calculated (Figure 26).

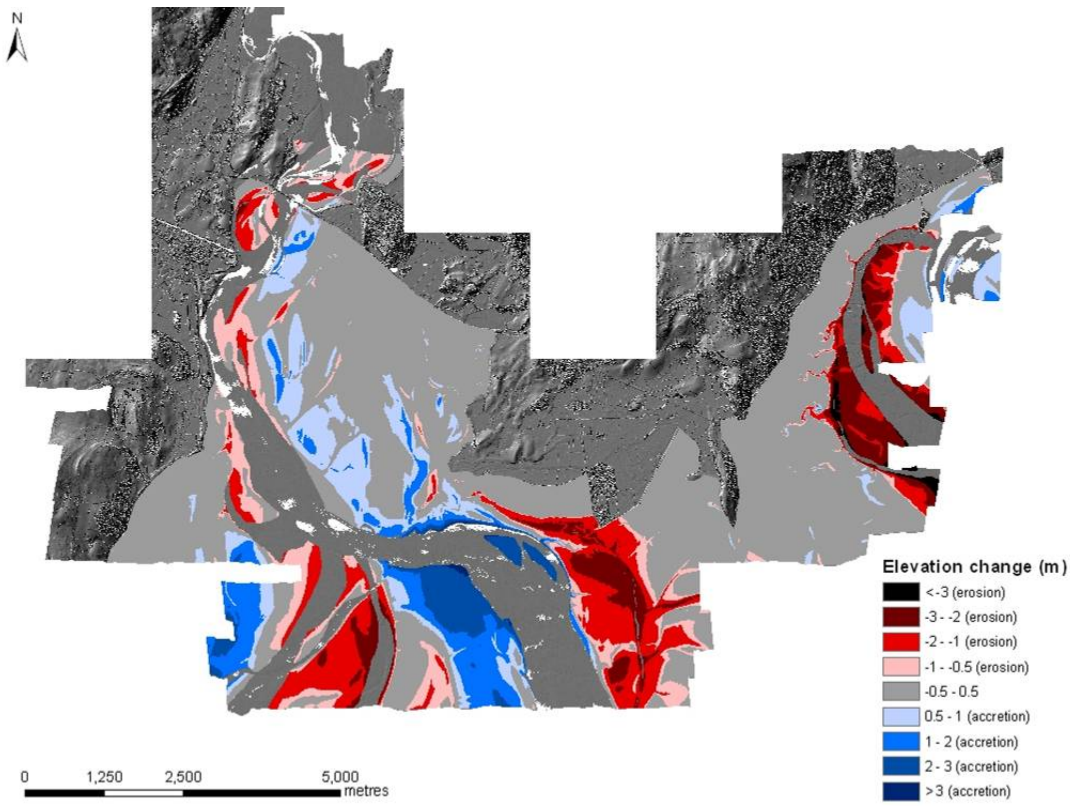

Figure 26 Intertidal elevation change for Morecambe Bay (2004-2010) only for areas where there was sediment in both datasets. Underlying image is the LIDAR hillshade

A second product was also produced to capture the changes that have occurred outside of these sediment only areas. It was important that errors were not incorporated into this product though, by including changes caused by different water levels rather than actual changes. To prevent this, the mask was classified to show whether the water was present in the 2004 or 2010 dataset and both masks were then considered separately. Areas where water was present in 2010 and change detection indicated erosion were included in the analysis, since the 2010 sediment surface must be somewhere below the water height (Figure 27). Both the 2004 sediment surface and the 2010 water surface are known, so it is possible to say that there has been at least this much erosion.

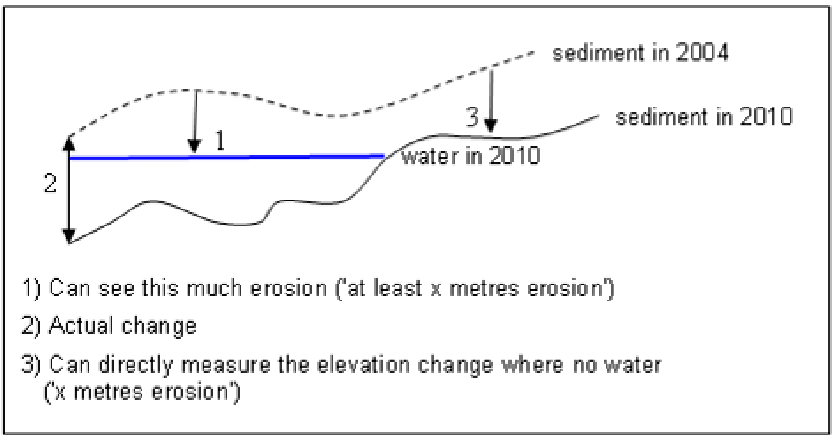

Figure 27 Profile through the intertidal zone. In areas where water is present in 2010, there will be at least this much erosion

Conversely, areas where water was present in 2010 and change detection indicated accretion were removed from the analysis. In these areas it is impossible to know whether the sediment level in 2010 was above or below the level in 2004 (Figure 28). It could be that it was actually below the 2004 sediment level, so if water was not present the change analysis would actually record erosion.

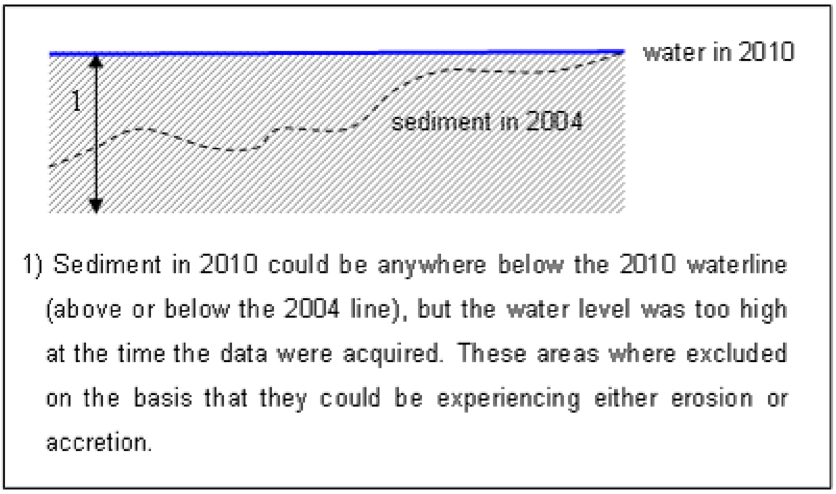

Figure 28 Profile through the intertidal zone. Presence of water makes it impossible to determine the direction of change

The same principles were applied to areas where water was present in 2004 and the results used to calculate the elevation changes in these dynamic areas (Figure 29). This product shows the minimum amount of change that took place between 2004 and 2010.

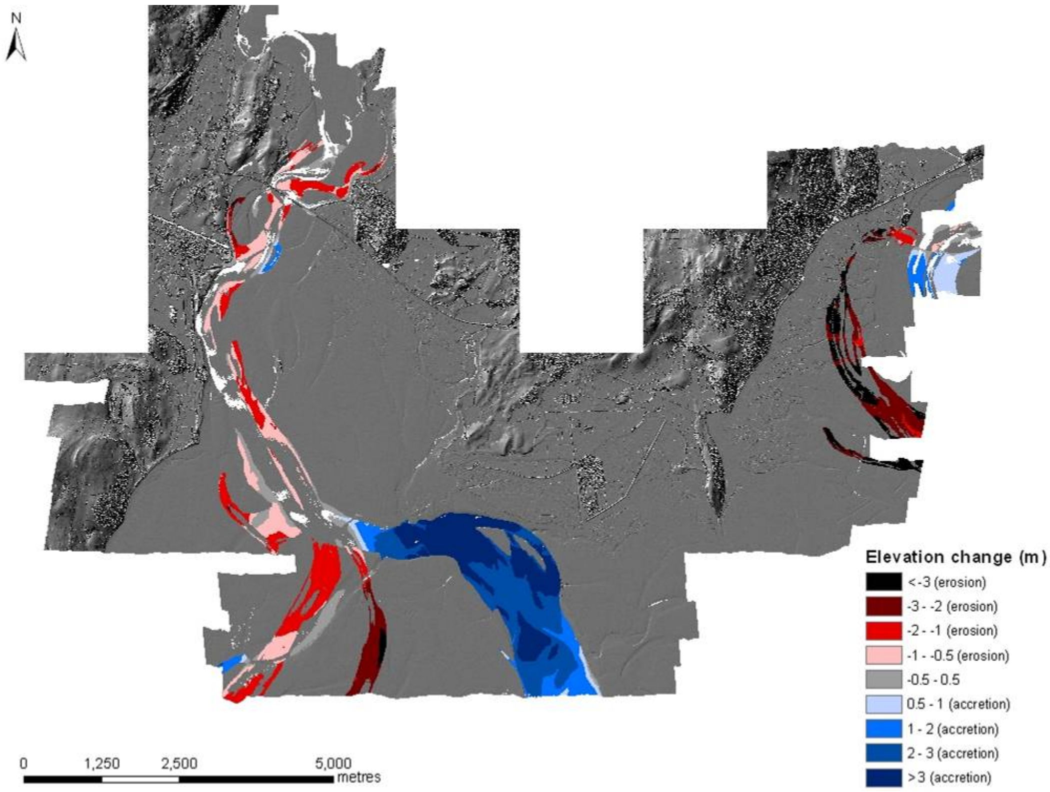

Figure 29 Intertidal elevation change for Morecambe Bay (2004-2010) for areas of sediment in one year and water in the other. Underlying image is LIDAR data

3.5. Comparing LIDAR with other elevation datasets, Ainsdale Dunes NNR, Sefton coast

As well as analysing changes between LIDAR datasets, it is also possible to compare LIDAR data to other remotely sensed elevation datasets. For this project at Ainsdale sand dunes LIDAR data acquired in 1999 were analysed alongside 1982 photogrammetry data.

It was widely acknowledged that the sand dunes were experiencing significant erosion, but not so well known that further along the coastline the dunes were also accreting. This analysis was requested to prove that reserve managers could demonstrate the dune evolution with evidence that could be shared with the local community.

The ability to analyse the development of the dunes over a 17 year period allowed a comprehensive overview to be produced and meant that changes as great as 10 m and 25 m (erosion and accretion) were identified (Figure 30).

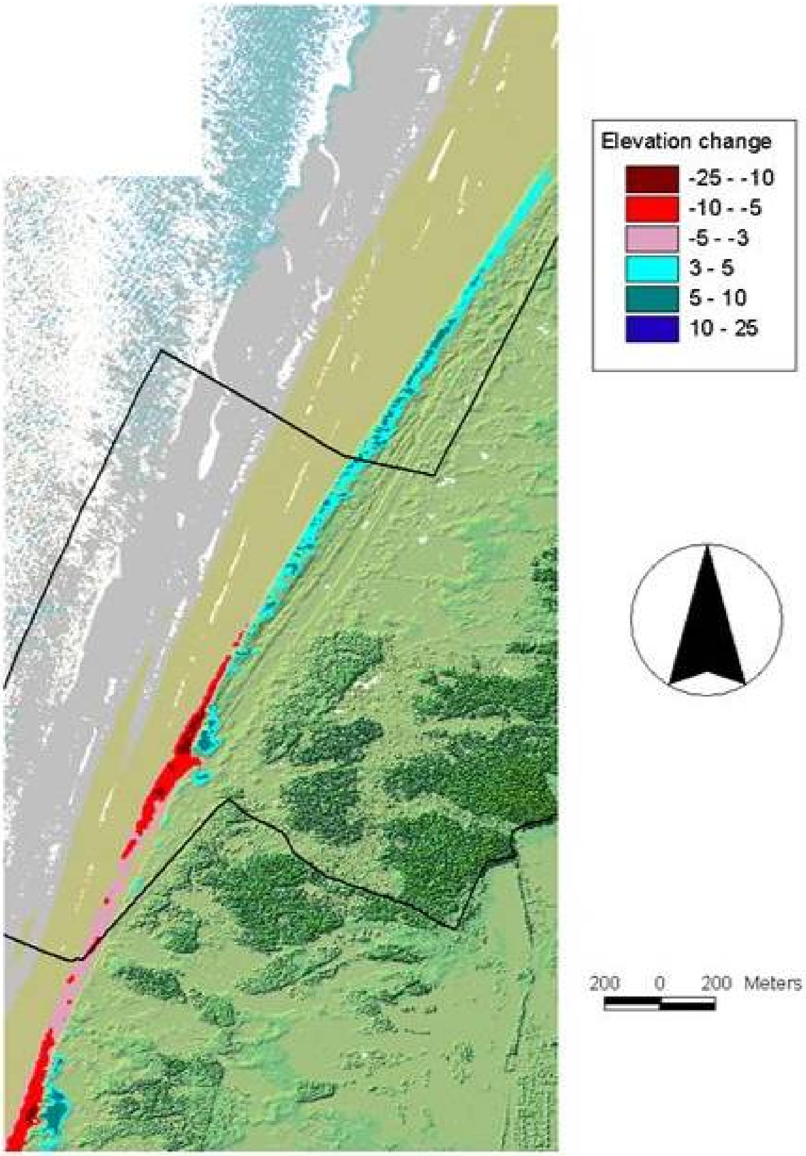

Figure 30 Elevation change analysis for Ainsdale NNR sand dunes, using LIDAR (1999) and photogrammetry (1982)

Where they were available, a series of additional LIDAR datasets were also used to analyse changes between 1998 and 2001. Figure 31 shows the advancement of the frontal dune edge, confirming that sections of the dunes were continuing to actively accrete.

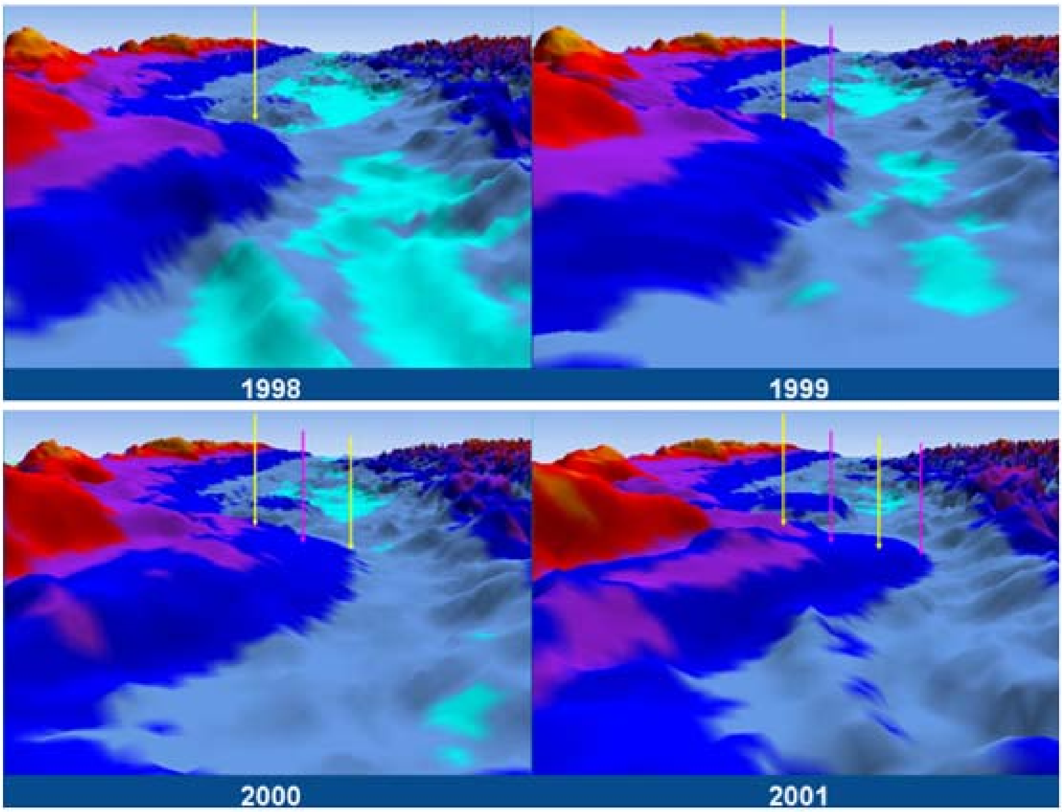

Figure 31 LIDAR data from 1998, 1999, 2000 and 2001 showing sand dune accretion at Ainsdale. Arrows indicate dune edge in each year. Colours relate to height, with red to blue indicating high to low

These products were presented to the local community and used to help explain the coastal processes acting at this site. Visualising the evolution of the NNR dunes in a wider context of the whole system on a larger scale, helped clarify that erosion was not the only process occurring along this coastline.

Additionally, this information is relevant to the development of the Shoreline Management Plan for the whole frontage. The same information also contributes to site condition reporting where dynamic change is a key attribute and also helps target vegetation monitoring to assess continuity of interest features.

4. Habitat mapping

A key requirement for Natural England is to be able to map and monitor change in habitat extent. This is important both in setting conservation objectives and assessing site condition. The application of remotely sensed and satellite data has been explored many times with varying degrees of success. Through our joint working we have tried to create repeatable, credible views of habitat extent where the technology has been appropriate.

An additional need is to identify and characterise habitats as defined by the Habitats Directive and those described under the Biodiversity Action Plan (BAP). This is particularly acute for coastal features where multiple Annex 1 Habitats Directive features can fall within a single BAP category, within a sand dune environment for example.

The main focus of these products has been on coastal features, partly due to data availability and partly because of the dynamic nature of these features. Many coastal features can be described in terms of morphology or vegetation cover, or a combination of the two.

4.1. Bare sand mapping within sand dunes, Sefton coast

Natural England requested analysis for the Sefton coast to map areas of bare sand from aerial photography. The balance of bare sand to vegetated areas can indicate succession between the different phases of dune vegetation. It would normally be expected that bare areas would gradually colonise over time, but also the creation of dune slacks by sand erosion down to the water table, provides new habitat types important for a range of species. Mapping changes in bare sand also helps to plan management, for example in relation to coastal change or for access-related restoration. This analysis was undertaken for two separate datasets and then the extents compared to infer change (Figure 32).

Figure 32 Change in the extent of bare sand along the Sefton coast (1996-2005)

Figure 33 is a zoomed in image of the results in Figure 32, showing areas of no change, areas that have been colonised by vegetation and areas where vegetation has been replaced by bare sand.

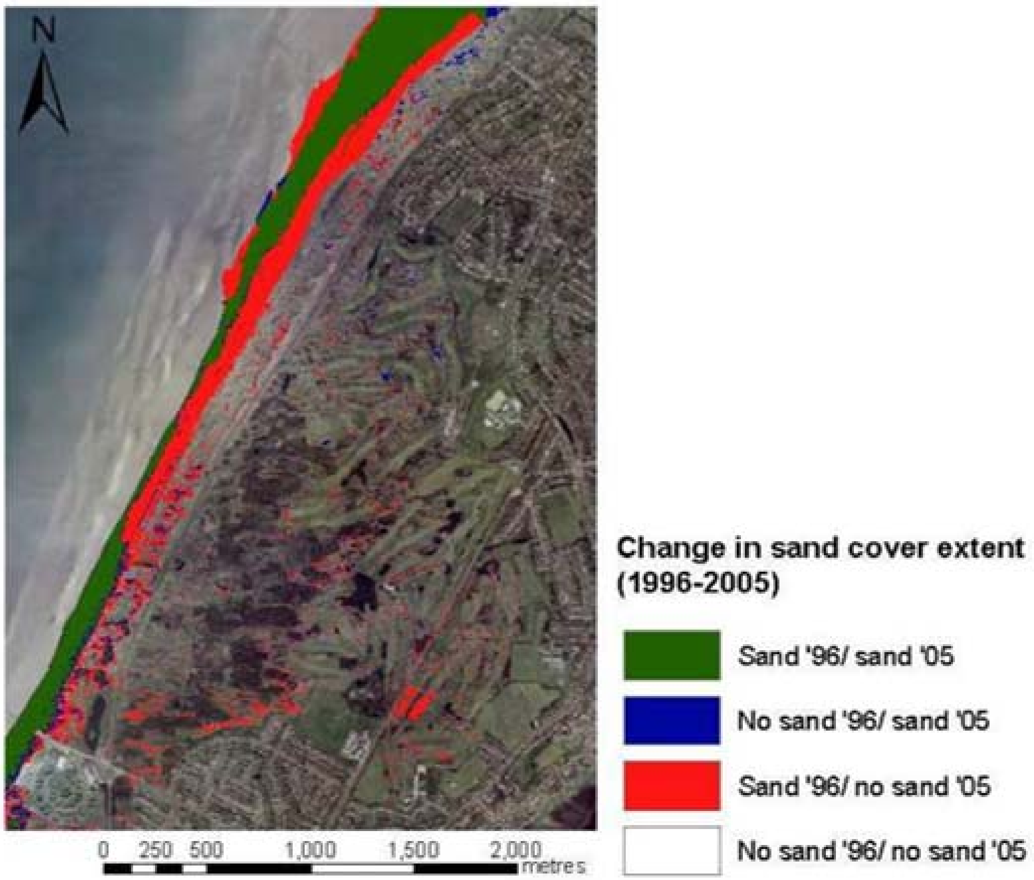

Figure 33 Zoomed in image of the bare sand extent change for the Sefton coast

This information is relevant to access management on dunes, as well as monitoring the effects of management. The apparent increase in vegetation on parts of the fore dunes during the 10 year period, will also allow targeted monitoring of newly-formed mobile dunes and areas within the dunes which have re-colonised. In this example, the current limited extent of bare sand within the dune system indicates that the system is becoming more stable, perhaps with the exception of some small areas of the golf course to the north. There may be an application for this type of analysis for monitoring the new coastal access measures around England.

4.2. Targeted change monitoring, Humber estuary

The project case studies presented in section 3 showed the change analysis that is possible using LIDAR data. This analysis can also be targeted at a specific part of the intertidal zone. In this particular project along the Humber estuary, Natural England wanted to be able to map the elevation changes expressly within the mudflat areas in order to inform reporting on condition of the estuary system and casework affecting the intertidal zone.

How do you define the limits of a mudflat? The problem of applying hard boundaries to map geographical features without fixed boundaries was explored in section 3.1. In order to be able to monitor changes over time, the target feature needs a clear definition that is transferrable between datasets and over time. In this case, height values corresponding to tidal limits were used to define the mudflat extents. Using these parameters, elevation changes between 2000 and 2005 were calculated. Figure 34 shows these elevation changes along one section of the estuary.

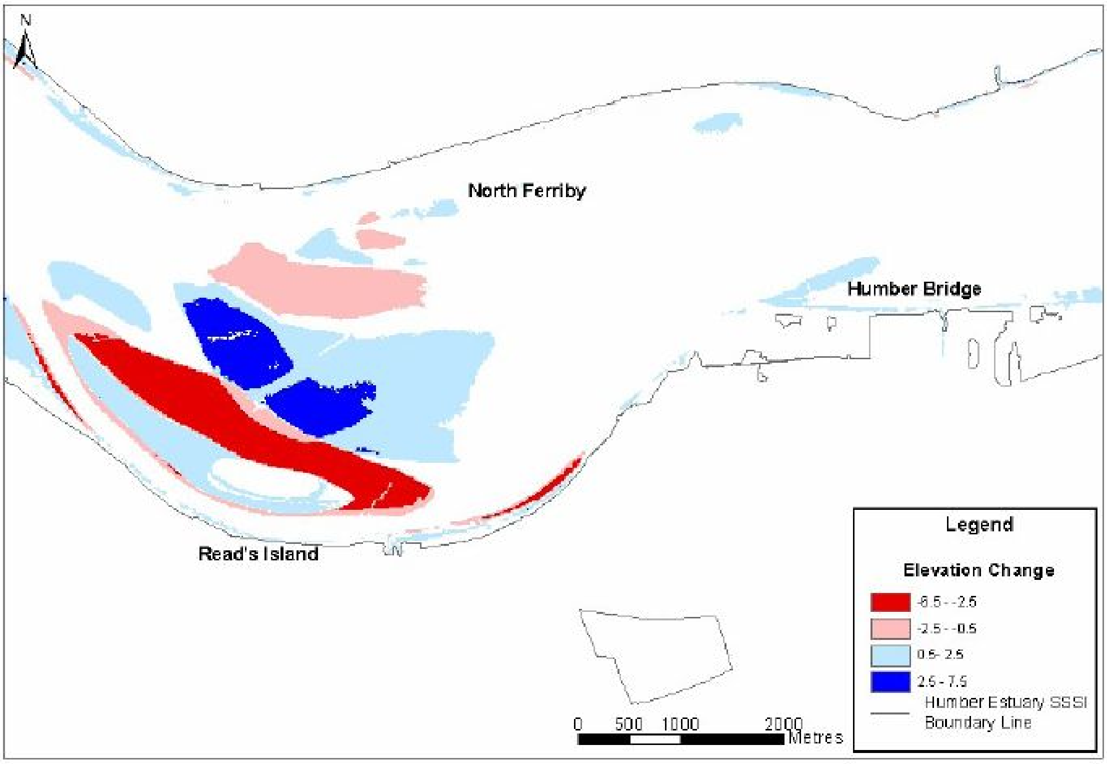

Figure 34 Mudflat elevation changes for a section of the Humber estuary (2000-2005)

4.3. Operational products

The following projects in this section outline the targeted analysis that has been undertaken between March 2010 and March 2011.

4.3.1. Seaton sand dunes, Cleveland

This product is related to the case study in 3.4.4, which was linked to both reporting on condition and extent of fore dunes and recent casework associated with restoration of the dune features after installing a pipeline.

Elevation and volume change analysis was undertaken for the frontal dune system. The location of the frontal dune zones is shown in Figure 35. Elevation change for the dunes was calculated between 17th January 2000 (2 m resolution) and 25th August - 9th September 2009 (1 m resolution) (Figure 36). Volume changes were calculated separately for each dune zone, within the same time period (Figure 37, Figure 38 and Figure 39).

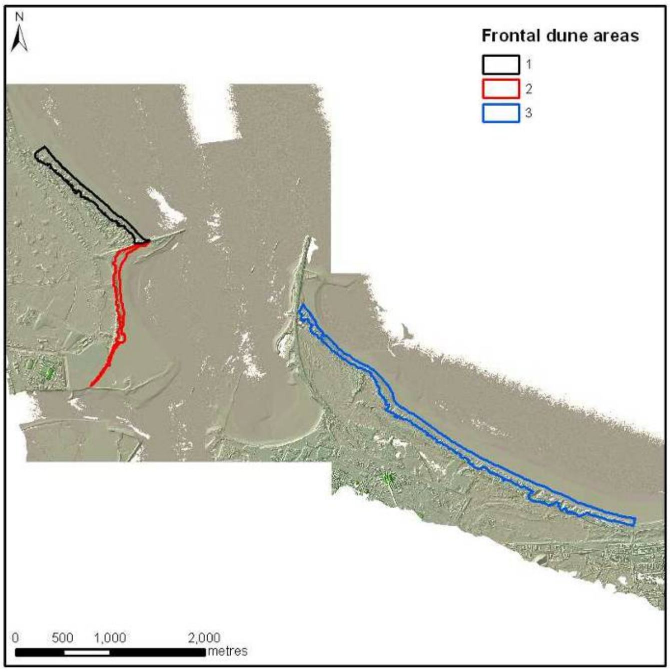

Figure 35 Location of the frontal dune zones at Seaton

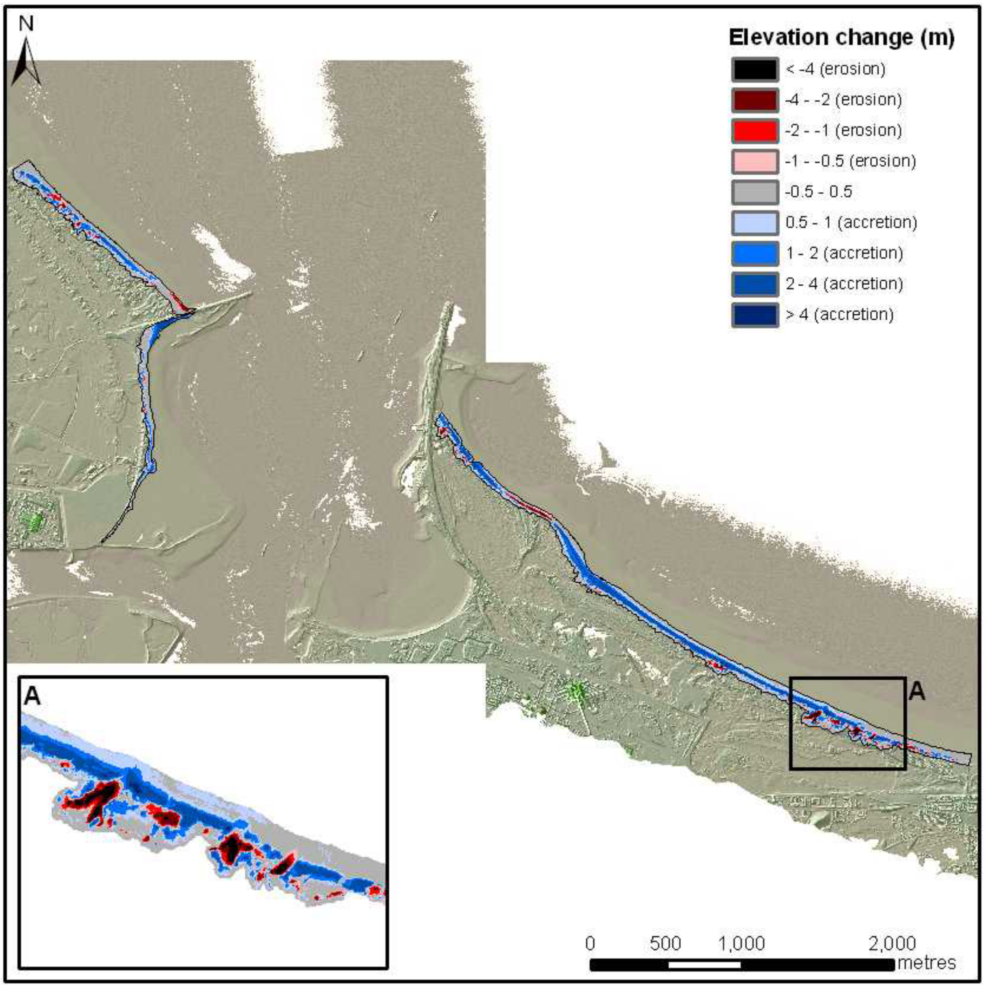

Figure 36 Frontal dune elevation change at Seaton (2000-2009)

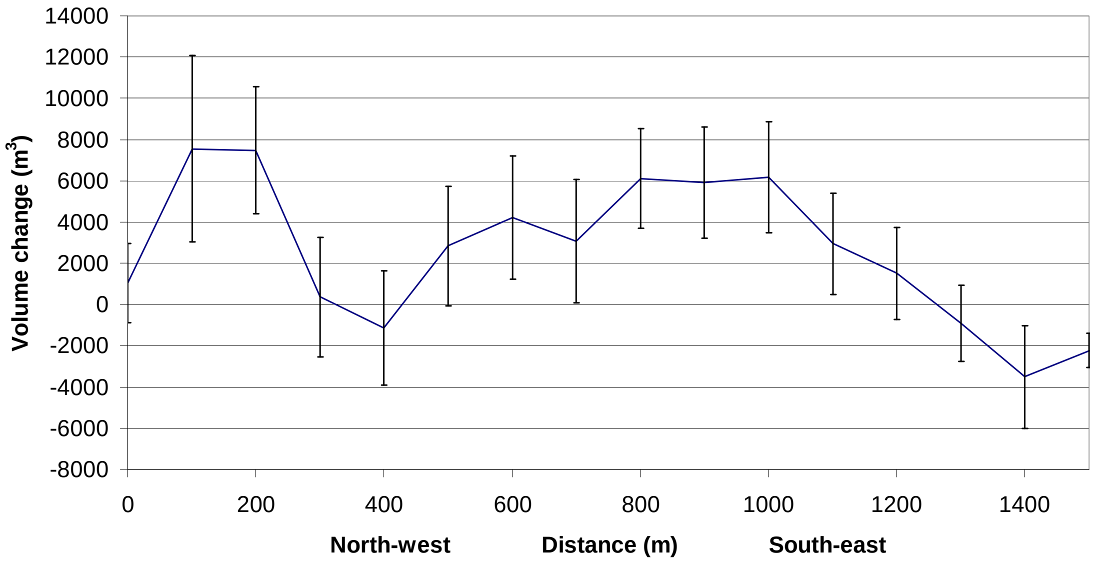

Figure 37 Frontal dune volume change for area 1 (Figure 35). Error bars are 95% confidence intervals

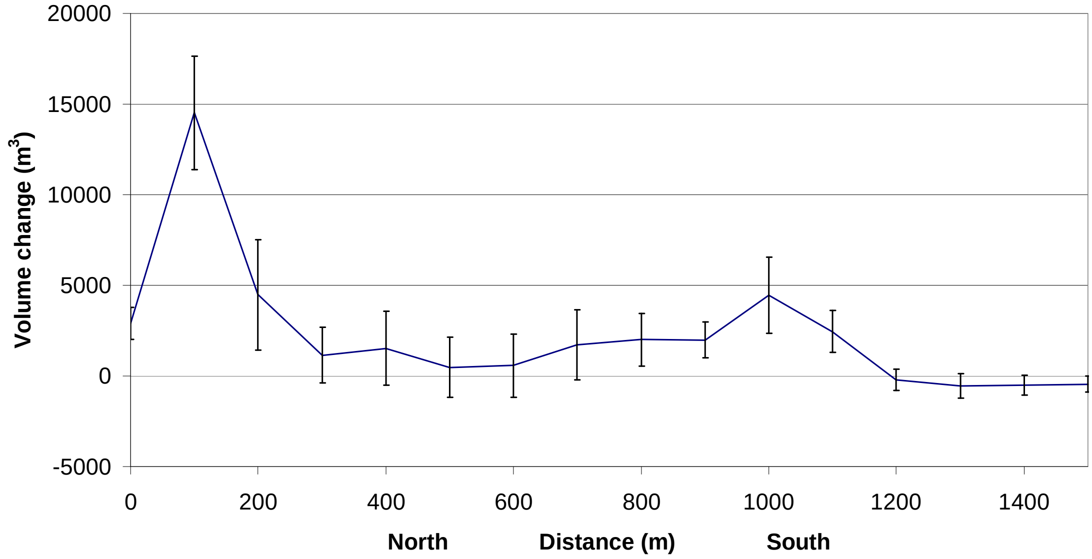

Figure 38 Frontal dune volume change for area 2 (Figure 35). Error bars are 95% confidence intervals

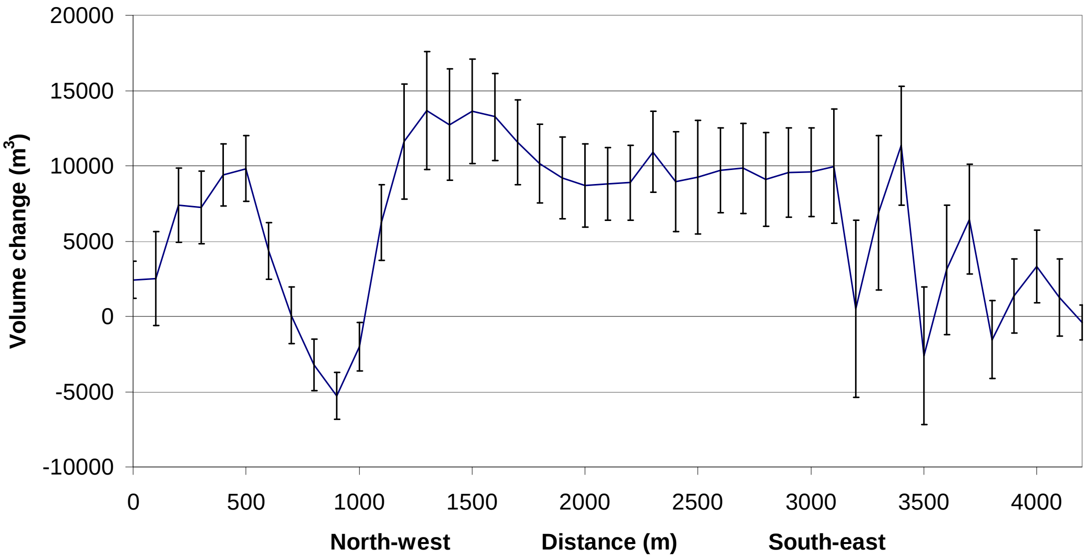

Figure 39 Frontal dune volume change for area 3 (Figure 35). Error bars are 95% confidence intervals

4.3.2. Camber Sands sand dunes, Kent

Elevation and volume change analysis was calculated for the frontal sand dunes. This is linked to the issue introduced in 3.4.5. Elevation change (Figure 40) and volume change (Figure 41) was calculated between 16th June 2000 (2 m resolution) and 20th March - 6th April 2009 (25 cm resolution).

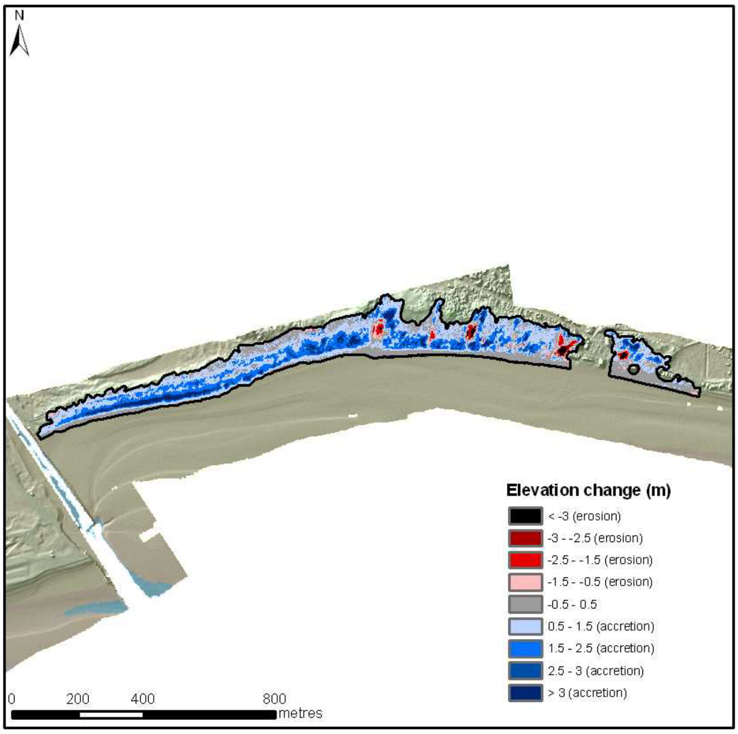

Figure 40 Elevation change for the frontal dunes at Camber Sands (2000-2009). Black line shows the extent of the frontal dune zone

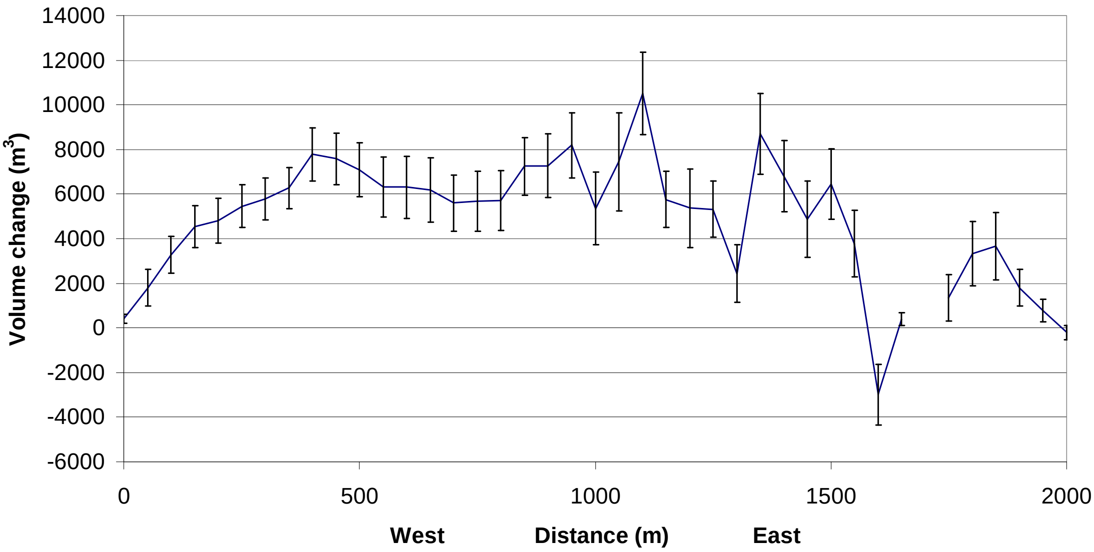

Figure 41 Volume change for the frontal dunes at Camber Sands (2000-2009). Error bars are 95% confidence intervals

This analysis shows that the sand dunes are still actively accreting with the exception of a few small erosion areas around access points and buildings (it is known that some of the sand accreting around buildings is removed artificially). This provides data to inform the condition assessment and to help inform Natural England's management advice.

5. Habitat quality assessment

In assessing feature condition we make use of many physical attributes of vegetation structure, including scrub extent and height and the presence of bare ground. Mapping scrub has always been a challenging task in nature conservation, due to the difficulties in locating position accurately or even identifying where the scrub starts and stops. Human error in mapping can give misleading information and two different observers are likely to produce two different maps and assessments of condition. Using detailed topographic data to define scrub offers an alternative approach that removes human bias and can be repeated at intervals to show the trends in change.

Scrub is a natural part of the succession from open grassland or heathland to woodland. Maintaining the balance between open habitats and scrub is a key task in site management, with the proportion of scrub used to measure overall feature condition. The occurrence of scrub around or within open ground contributes to the overall structural heterogeneity and is strongly related to species richness. Remote sensing offers a way of describing and monitoring change in scrub cover and density in order to inform management planning and reporting on condition.

5.1. Scrub mapping, Berkshire

The disused airbase at Greenham Common near Newbury is of high ecological importance, having the largest surviving area of open heathland in Berkshire. Following closure of the airbase and removal of the concrete runways, much of the area was rapidly colonised by pioneer heathland. In turn, this is being rapidly colonised by gorse and birch scrub. Natural England wish to map the extent of this scrub encroachment as part of condition assessments. Having a precise scrub boundary will enable targeted management actions and detailed future analysis of scrub extent change over time.

Natural England commissioned Environment Agency Geomatics Group to acquire high resolution, 25 cm LIDAR data for this site. First return DSM, last return DSM, Digital Terrain Model (DTM) and intensity data were processed. A pilot study was then undertaken to see if LIDAR data alone could be used to map the extent of the scrub vegetation.

Standing water and surface objects, such as buildings and cars were masked out of the analysis. The first return DSM and the DTM were then used to estimate the height of all vegetated areas (Figure 42).

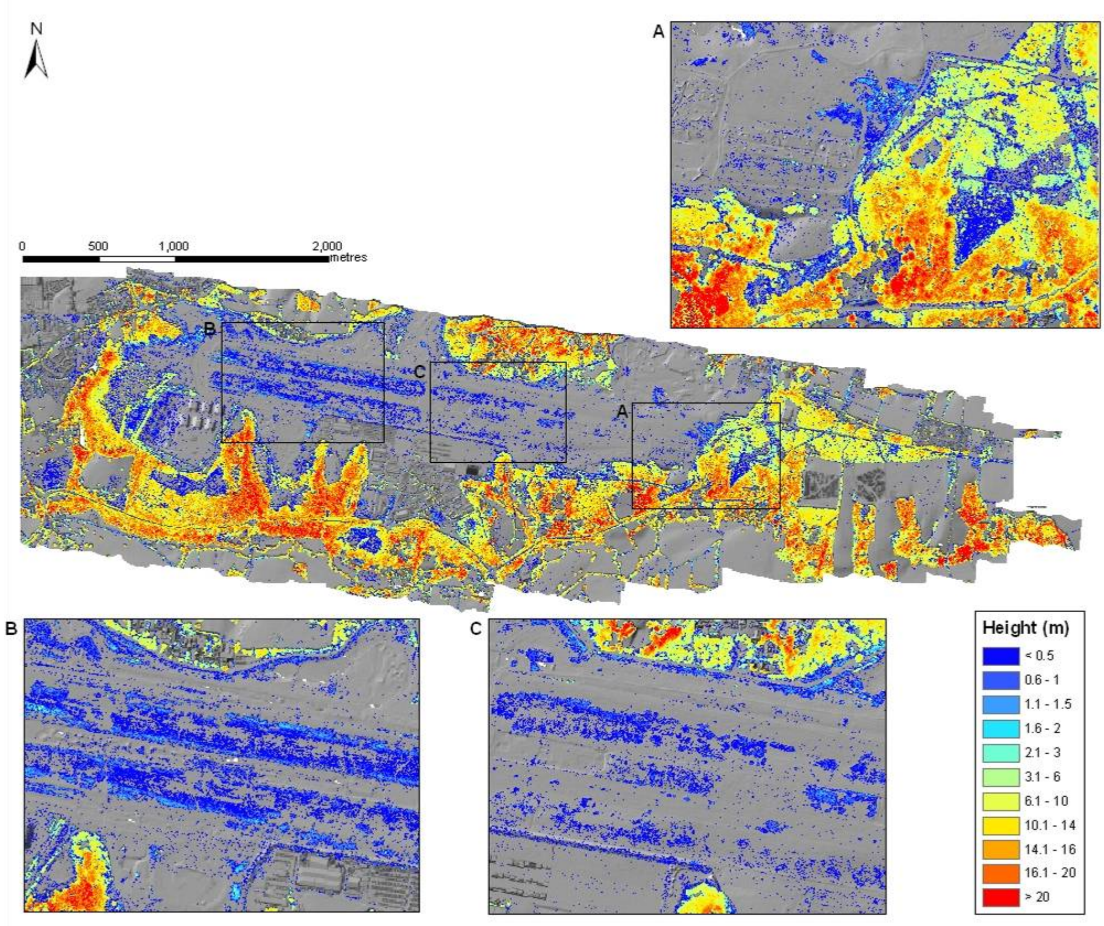

Figure 42 Height of vegetation at Greenham Common

A site visit was undertaken prior to the LIDAR analysis. Ground data gathered during this fieldwork was used to define the parameters for delineating scrub. The height product shown in Figure 42 was used in conjunction with the intensity data to produce a classification of scrub, deciduous tree and evergreen tree (Figure 43). If more information about vegetation species was required then additional data, such as aerial photography, multispectral data such as CASI or ground data would be needed.

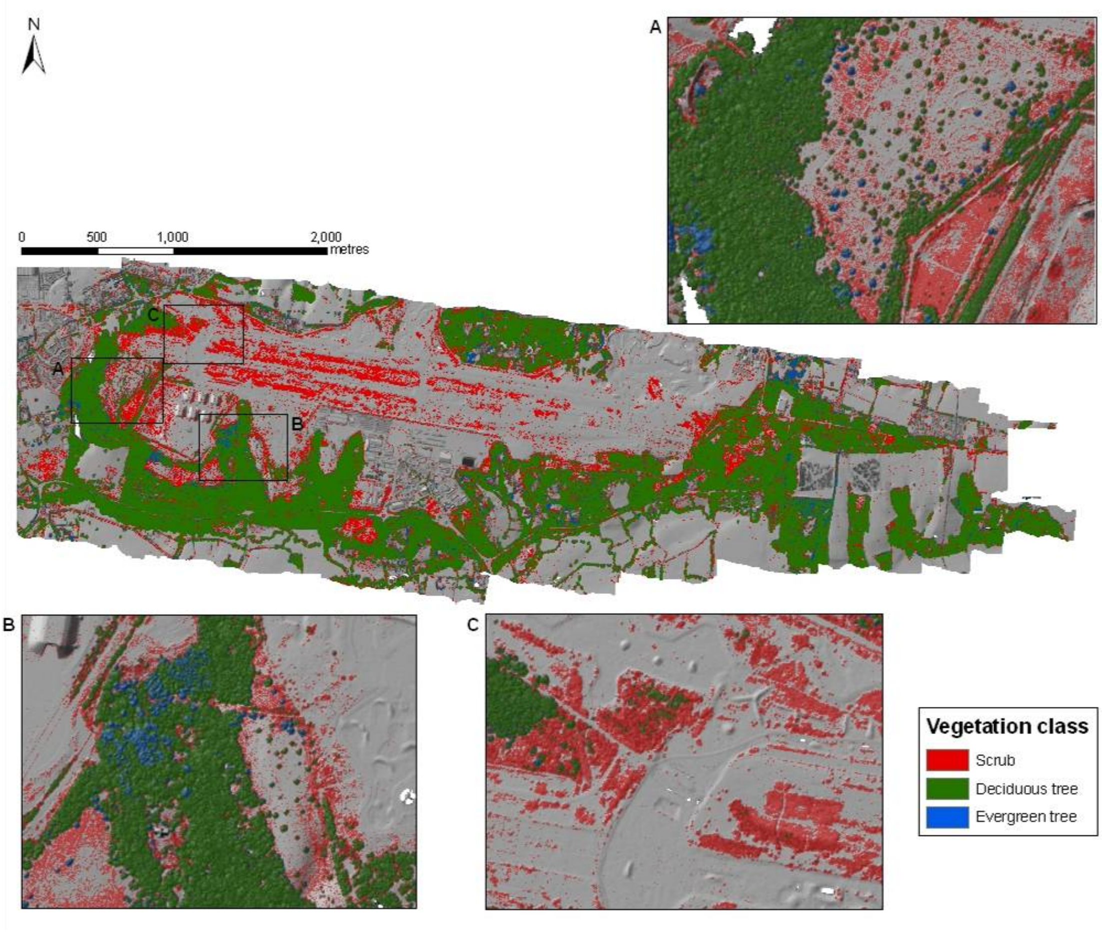

Figure 43 Scrub vegetation classification at Greenham Common

Using LIDAR data for this task means that a highly detailed scrub extent map can be produced very quickly. Remotely sensed data such as LIDAR is a far more time effective option than an alternative GPS ground survey for this type of spatial mapping exercise.

At this site it was possible to directly compare these two techniques, since a GPS survey had been undertaken a few years previously to produce an equivalent scrub extent map. Figure 44 shows the level of detail that was achieved by each method.

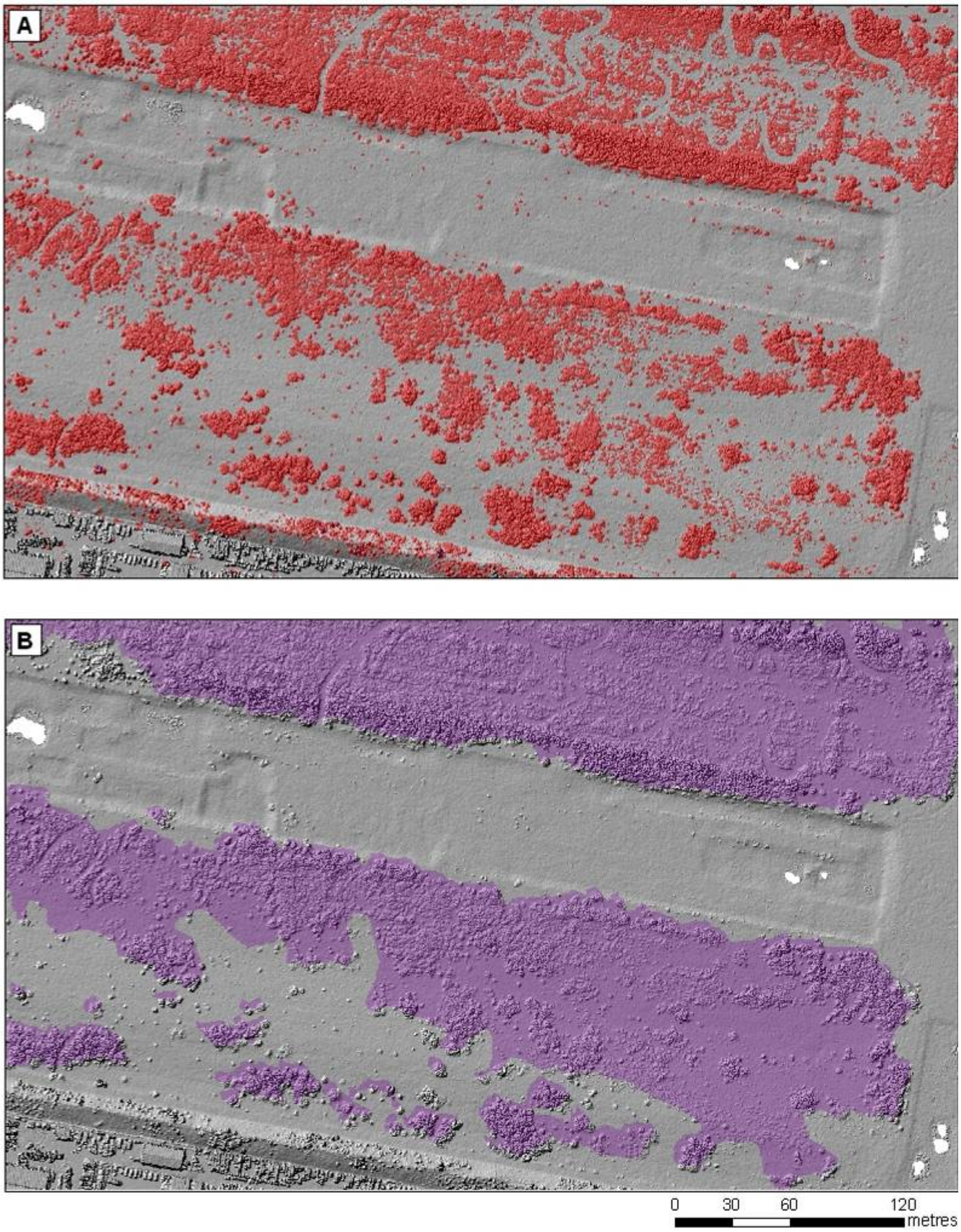

Figure 44 Scrub extent map, derived from LIDAR (A) and GPS ground survey (B). In box A the scrub is mapped in red. In box B the scrub is mapped in purple

The LIDAR analysis was able to achieve a very high level of detail. The complexity of the scrub areas would make it extremely difficult to get the same level of detail efficiently using a ground based approach. Only generalised areas of scrub were mapped using GPS and it took roughly two weeks to generate this map. In contrast, it took about three days to do the same exercise using LIDAR data, including ground survey to customise the classification. Although it is useful to have such a detailed map of scrub vegetation extent, the true value of this product will be when comparing it to future extents looking for change.

5.1.1. Accuracy assessment

To make a quantitative assessment of the classification accuracy and scrub border precision, further fieldwork was undertaken. Survey grade GPS was used to collect ground data points for scrub and non-scrub areas (Figure 45). Where applicable the height of the scrub at each point was also recorded.

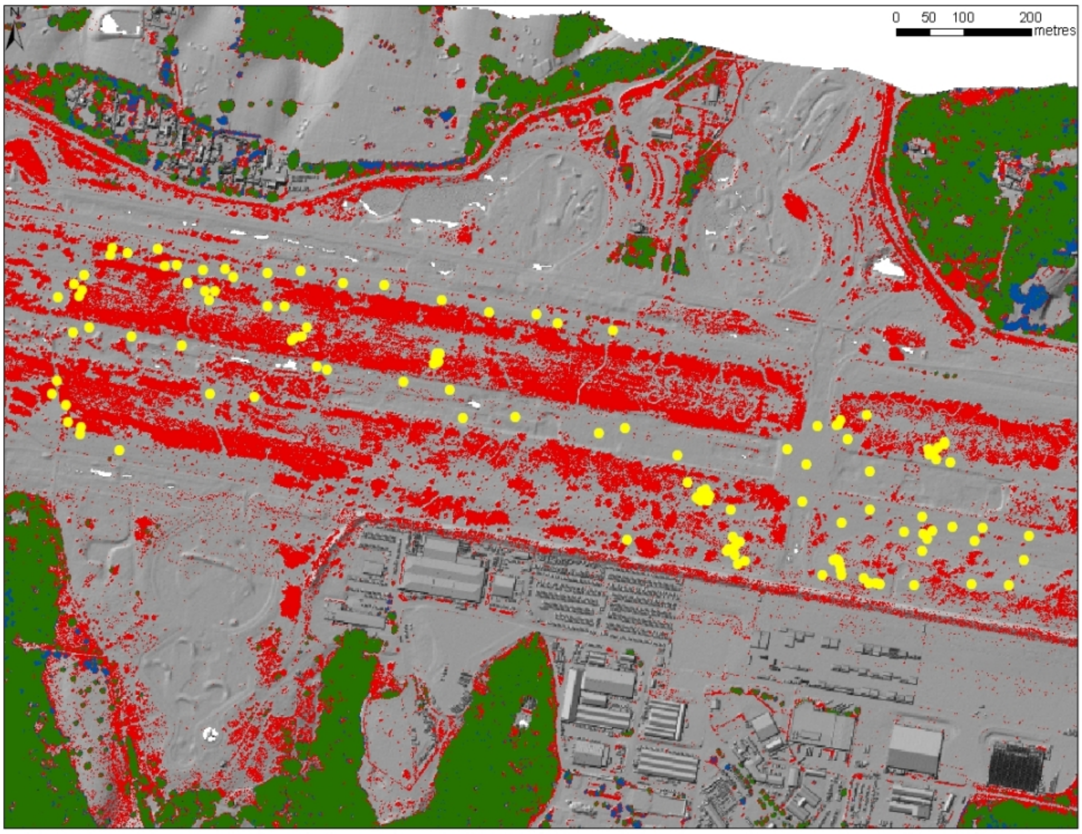

Figure 45 Map showing the location of the GPS scrub and non-scrub ground data (yellow points). Red areas are scrub, green is deciduous tree and blue is evergreen tree. The underlying imagery is the hillshade for the first return LIDAR DSM

These GPS points were compared to the scrub classification to produce a measure of classification accuracy. The results of this analysis are shown in the confusion matrix table (Table 1).

		Ground data		
		SCRUB	NON-SCRUB	*User's accuracy:*
Classification data	SCRUB	64	0	1.00
	NON-SCRUB	6	58	0.91
	Producer's accuracy:	0.91	1.00	

Overall accuracy:	**0.953**

Table 1 Confusion matrix showing classification accuracy

Overall the scrub classification was 95% accurate. The confusion matrix shows that all of the non-scrub ground data points were correctly classified as non-scrub. The user's accuracy reveals that the non-scrub class was over classified by 9%. In other words, several scrub points were wrongly classified as non-scrub. Overall this resulted in a 91% user's accuracy for classifying scrub. Figure 46 shows the scrub classification accuracy against the scrub height.

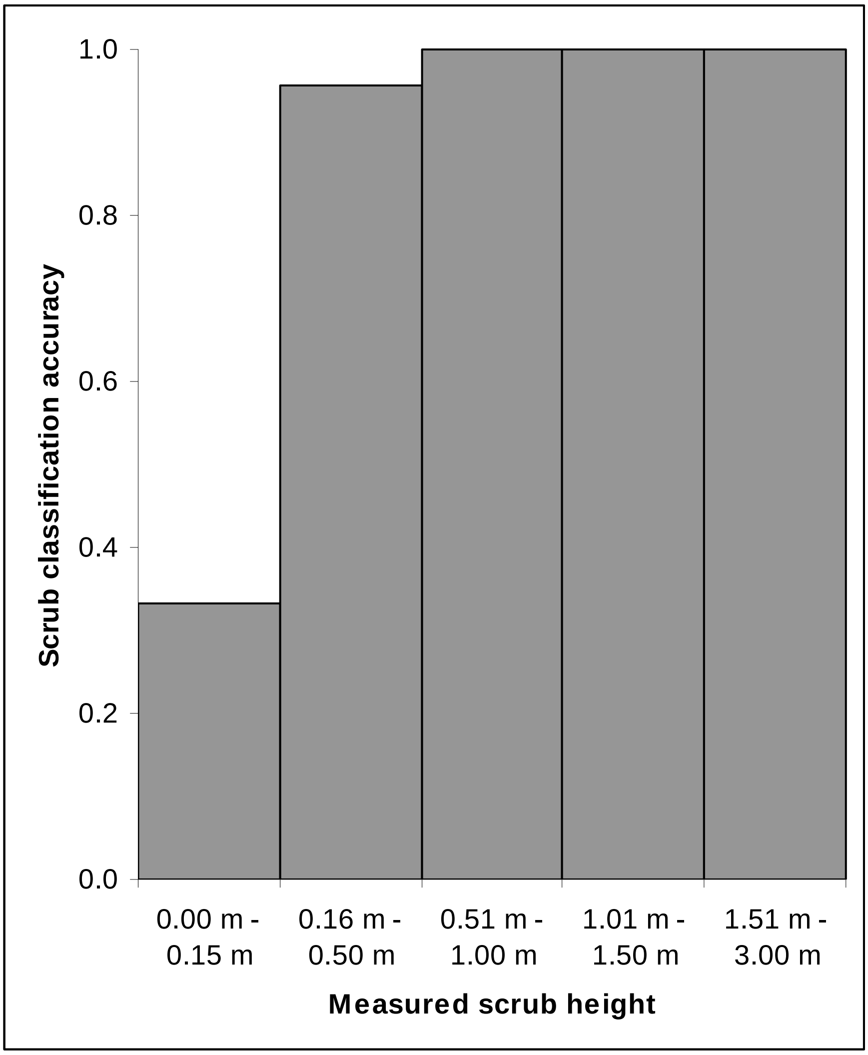

Figure 46 Scrub classification accuracy as a function of scrub height

Even with limited ground data, the results shown in Figure 46 indicate that most of the classification errors occur when the scrub vegetation height is between 0 and 15 cm. It is therefore likely that this error is reflecting the sensitivity limits of the LIDAR. The official vertical accuracy that is quoted for LIDAR is ±15 cm (although it has routinely been around ±6 cm over the last five years) and almost all of the classification errors fall within this error band. This shows that for scrub heights in excess of 16 cm this method was very accurate in predicting scrub occurrence at this site.

The scrub vegetation heights estimated in the field were also plotted against the vegetation heights derived from the LIDAR data (Figure 47).

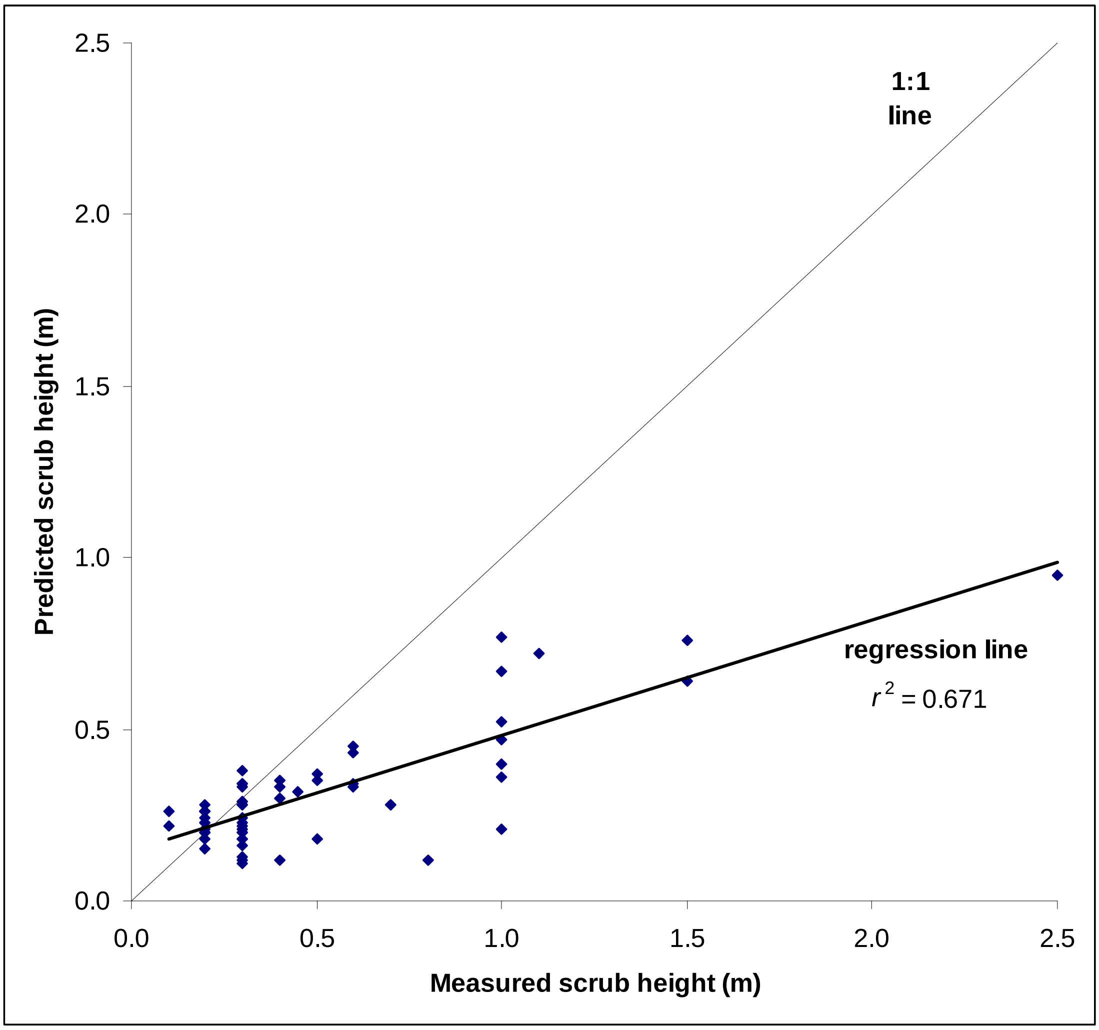

Figure 47 Scrub height regression analysis

This regression analysis produced a strong correlation between measured and predicted scrub height (r^2 =0.67), however the associated slope value (0.336) suggested that it was not possible to directly measure scrub vegetation height using LIDAR data alone. Gorse scrub has a very open, spiky canopy. This can result in the laser penetrating part of the canopy and so not returning hits from the highest part of the vegetation. Where this happens, the LIDAR will underestimate the scrub height. One important point to note though, is that the ground data were collected a year after the LIDAR data were acquired. It is possible that natural vegetation changes may have also introduced errors.

The final part of the assessment was to calculate the precision of the scrub extent boundaries. GPS points were collected around the borders between scrub and non-scrub. Figure 48 shows the location of some of these GPS border points in relation to the scrub extent classification.

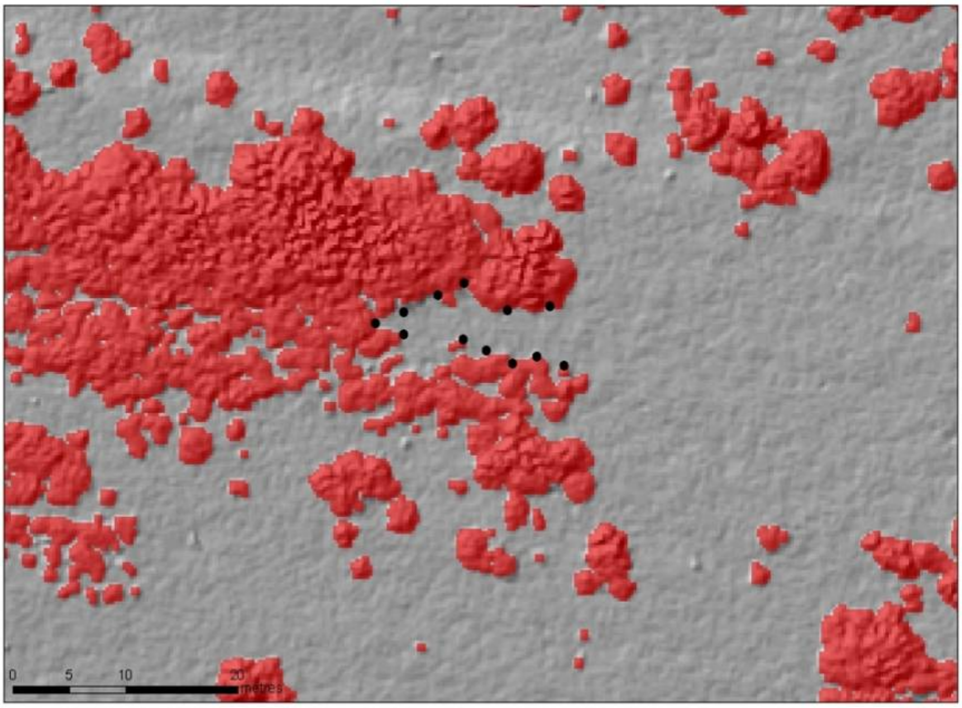

Figure 48 Location of some of the GPS border points (black points) collected on the boundary between scrub and non-scrub. Areas of scrub are coloured in red

The precision was determined by calculating the average distance between the GPS points and the nearest scrub extent edge. Though the number of ground points was limited, the resulting RMSE of 34 cm indicates very precise location of scrub boundaries. This is particularly impressive considering that the scrub extent was classified using automated mapping techniques.

Further work is currently underway looking into the relationship between LIDAR resolution and classification accuracy. Some ecologists believe that in order to map scrub vegetation accurately and precisely, the LIDAR data must be of the highest resolution. Coarser resolution datasets are normally acquired for heathland environments. The availability of a 25 cm dataset for this site though, allows the impact of resolution on the accuracy of scrub mapping to be tested.

The LIDAR data were re-sampled to produce coarser resolution datasets and the same classification was undertaken for each. The ground data was then used to assess the accuracy and precision of each scrub extent map. The findings from this investigation were presented at the Remote Sensing and Photogrammetry Society (RSPSoc) conference in September 2011.

Using LIDAR data alone does have limitations though. It was not possible to differentiate between common gorse, dwarf gorse and dwarf heather using only LIDAR data. If more information on scrub species is required, then additional datasets would be needed. Remote sensing is not a substitute for experienced ecologists visiting the site. An approach combining the LIDAR derived scrub extent with detailed ecological notes would produce the most meaningful product.

This pilot study has proved that it is possible to map scrub vegetation using a single LIDAR dataset. However, this type of mapping needs to be considered on a site by site basis, as each environment will present new challenges. The old runways at Greenham Common are very flat, which aided in identifying the scrub vegetation. Other terrains may make this process more difficult, requiring the method to be modified.

5.2. Mapping sand dune habitats, Cornwall

There is a requirement under the Habitats Directive to provide indications of how the extent and quality of sand dune habitats are changing over time. Monitoring of these factors is required at a national level to inform Habitats Directive reporting and to aid management, both at a local and national scale. While remote sensing is not able to provide information on some specific species in sand dune habitats, previous work carried out by Geomatics Group for Natural England (Brown, K, Hambidge, C and Matthews, A (2003). *The development of remote sensing techniques for marine SAC monitoring*, Environment Agency, Bath) indicated that remote sensing could play an important part.

Natural England required two output products: one showing invasive scrub and one showing the Habitats Directive classes, such as mobile dunes. This pilot study investigated the potential of using Pan Government Agreement (PGA2) aerial photography and LIDAR data to generate these products. Both these datasets have national or close to national coverage, so if successful, this technique could be rolled out to other sites in England that have data available.

5.2.1. Invasive scrub mapping

The study site for this pilot was Gwithian to Mexico Towans Site of Special Scientific Interest (SSSI) in Cornwall. The techniques used to map scrub for Greenham Common (section 5.1) could not be applied to this coastal environment as sand dunes have large variations in topography over small distances. This makes it much more difficult to discriminate between sand dune features and scrub vegetation using LIDAR data alone. Some height information could be extracted for scrub vegetation, but it would be much less sensitive than the level achieved at Greenham Common.

One of the objectives was to map sea buckthorn as a scrub category, as it is an important feature identified in the Habitats Directive. However, sea buckthorn is not considered native in UK away from the East coast, so at this site in Cornwall, it is not formally considered part of the overall range of the feature. The project at Gwithian sand dunes will contribute to our understanding of how to assess this feature.

An object-based classification was carried out on the PGA2 aerial photography to map the classes shown in Table 2. These classes were used as they provided the maximum discrimination easily achievable using the aerial photography available. The 'Deep Shadow' class was included as there were areas in the imagery where it was not possible to discriminate the cover type due to shadowing effects.

Green grasses	Gorse
Senescent Grasses	Other scrub (Privet, Bramble, Elder, etc)-low
Non-Vegetation- exposed sand, etc	Other scrub (Privet, Bramble, Elder, etc)-high
Bracken	Red Valerian
Sea Buckthorn	Deep shadow

Table 2 Classes used in scrub mapping for Gwithian to Mexico Towans SSSI

The final scrub vegetation classification is shown in Figure 49. Some manual editing of the output was required for polygons that had been misclassified, which was the most time consuming stage. It would take an estimated 2 days per km^2 to provide these classes, but this could be greatly reduced if some of the invasive species classes were merged.

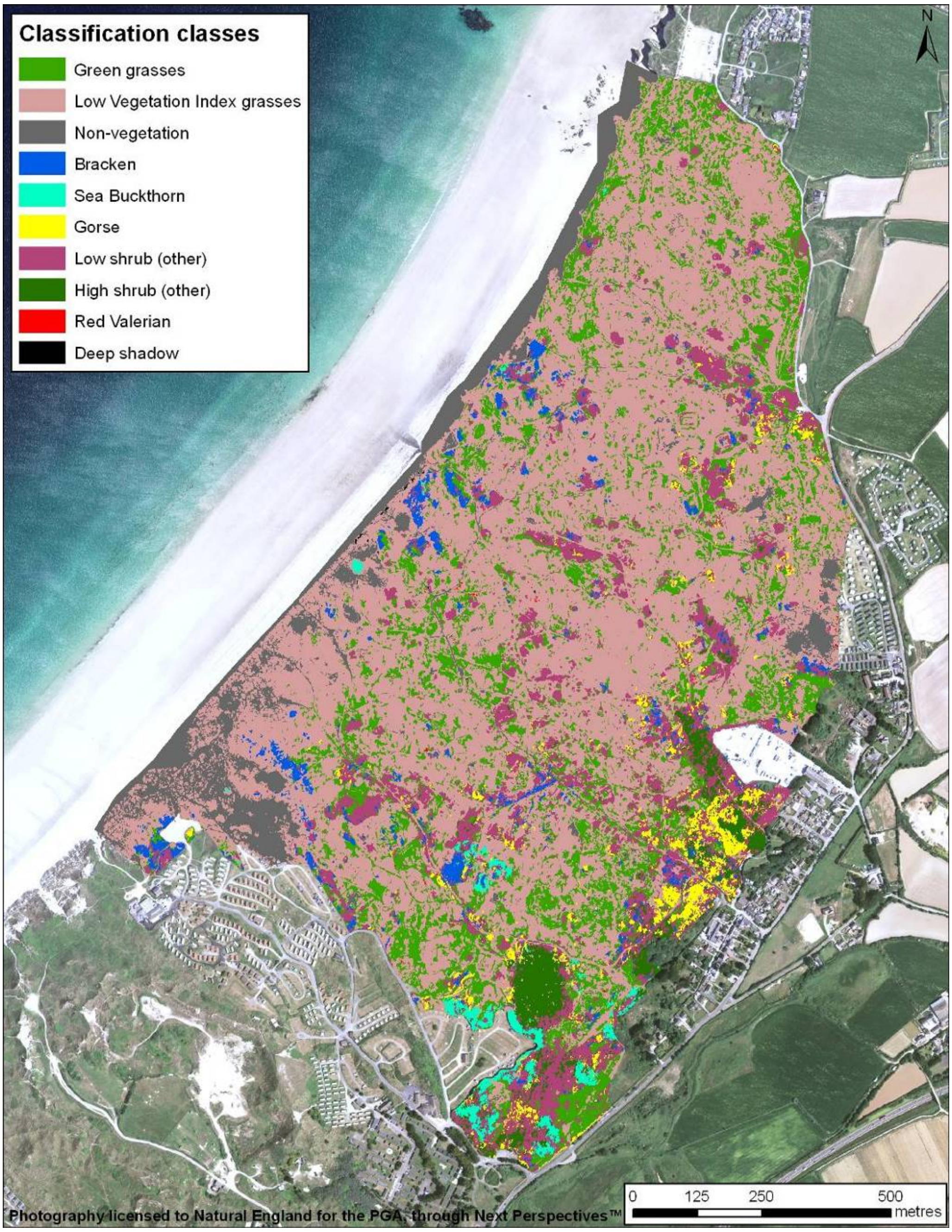

Figure 49 Scrub classes for the northern section of Gwithian to Mexico Towans SSSI

Visual inspection of the output suggested the map was consistent across the photography. Further work and additional ground data are required though, if the accuracy needs to be quantified. Ground data could not be easily acquired during the winter of 2010/2011, but there is the possibility of acquiring future ground data during a growing season.

5.2.2. Mapping Habitats Directive classes

Within the Gwithian to Mexico Towans SSSI there were two main Habitats Directive classes; mobile dune and fixed dune. Other classes present on the site; dunes with S*alix repens* and humid dune slacks, were limited geographically (believed to be less than 1 ha) and so were not included in the mapping. Mobile dunes could be distinguished by the percentage of bare sand and height; they are generally higher than fixed dunes.

A similar object-based classification method was attempted to try and delineate the boundaries of these classes using the aerial photography data, but in the time available it was not possible. An interpretative approach to mapping the classes was taken instead and the output map is shown in (Figure 50).

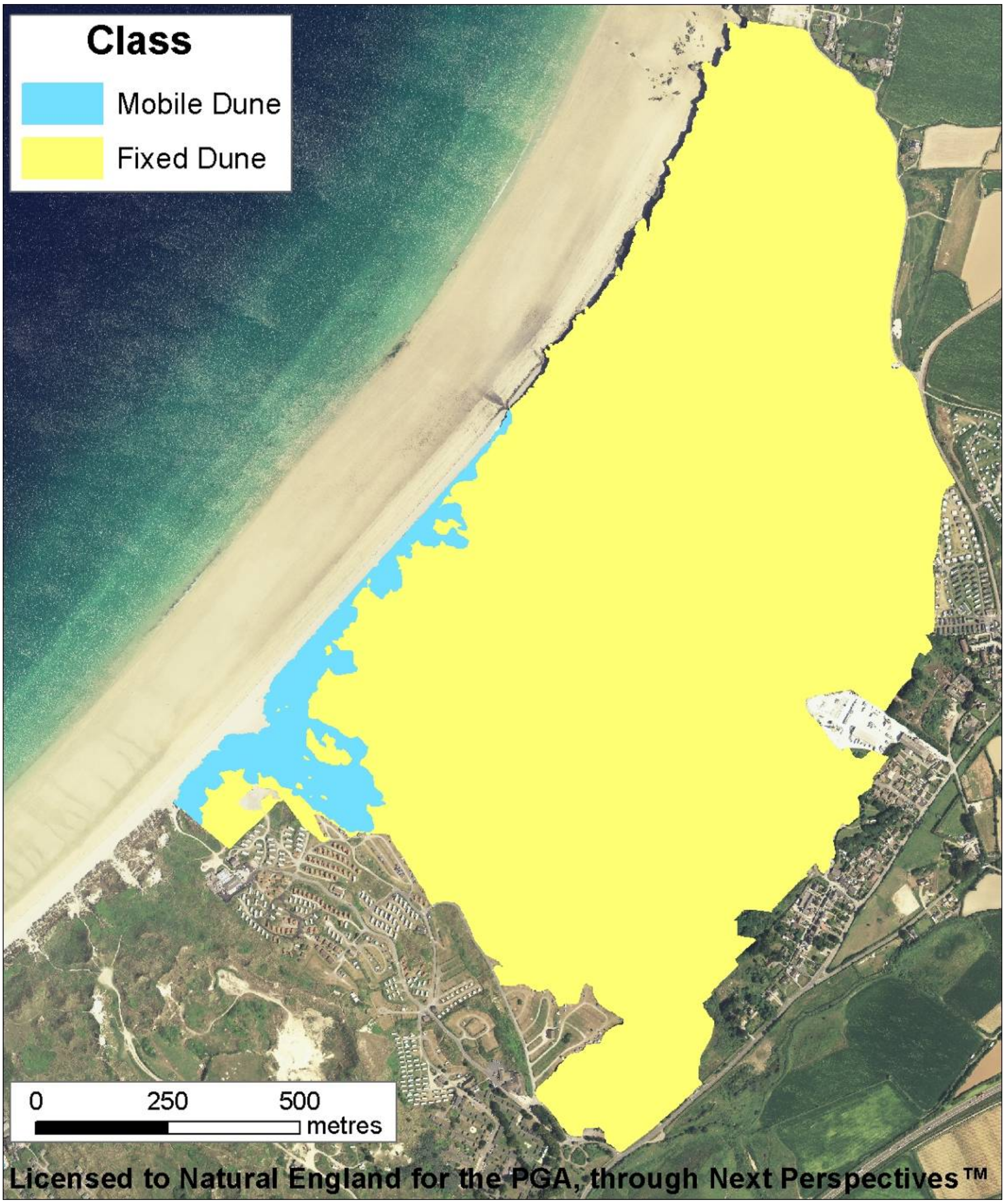

Figure 50 Habitats Directive classes for Gwithian to Mexico Towans SSSI

The boundary between fixed and mobile dunes had also been mapped from the ground by the local area team during a site visit. Figure 51 shows a comparison of the boundaries derived using these two methods. The general trends are similar, but there are differences.

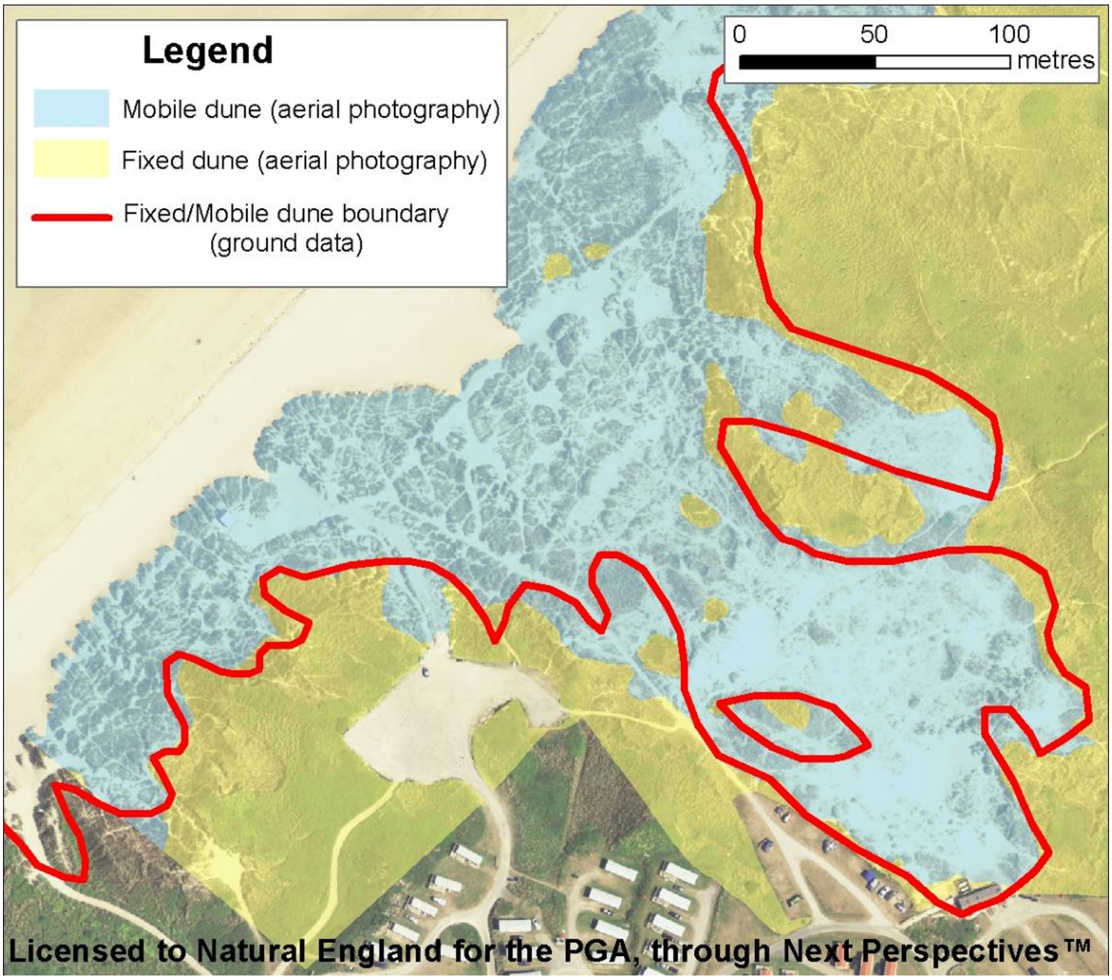

Figure 51 Comparison of ground based interpretation of mobile/fixed dune vegetation boundary with aerial photography interpretation

There would also be differences between interpretations from different analysts using the same method and even from the same analyst at different times. This means that it would become very difficult to monitor change, as it is highly likely that the largest differences between maps would be due to differences in interpretation, rather than actual differences. Additional work needs to be carried out to find ways to minimise the impact of errors in classifications and interpretation.

5.3. Ecotones and uncertainty

Uncertainty in mapping within this type of environment is very common. Asking several interpreters to undertake the same habitat mapping exercise using the same data will generally result in many different output maps. Variations in interpretations are partially due to uncertainty in the interpreter's mind as to exactly where boundaries between habitats may lie. In some cases the interpreter has high certainty that a particular area belongs to a certain class. However, there will be areas where this certainty is greatly reduced, sometimes to the point where the interpreter believes that the area could potentially occupy one of several classes.

This uncertainty can be the product of two main issues. The first and most obvious is the uncertainty of the interpreter, mainly due to inexperience. Another issue is that the boundary between classes may be a gradual transition, an ecotone (Figure 52), rather than a hard boundary where the class suddenly changes from one to another. This is very likely in coastal environments, where boundaries may move about over time as well. Within the ecotone there will be more than one class present, so there will be uncertainty as to which class is most appropriate. When drawing a boundary the ideal position would be where each habitat type makes up 50% of the cover, but this is very difficult to do on the ground, let alone from data acquired at 800 m above ground level.

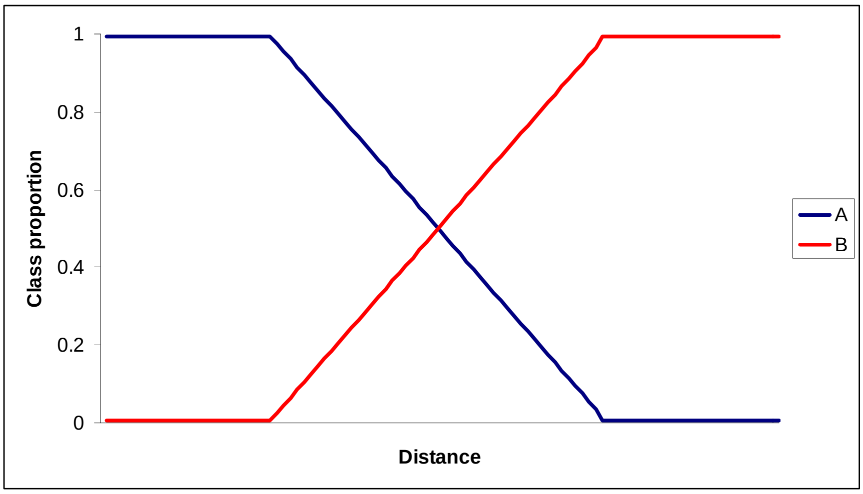

Figure 52 Simplistic example of an ecotone with two classes, A and B

The process of mapping where a point can only belong to one class is called ‘hard’ mapping. This was the method used to define the extent of the shingle ridge (section 3.1) and to derive the two products for this pilot study (Figure 49 and Figure 50). When mapping ecotones, not only does hard mapping not represent the uncertainty in the interpreters mind, it also does not necessarily represent reality.

If, when an interpreter maps a boundary, that boundary is contained within an ecotone, one could interpret the map to be correct. However, it is unlikely that two interpreters will map the boundary in the same way, i.e. the position of the line through the ecotone will vary (Figure 53(b) and Figure 53(c)). This would result in an error when data between years are compared (Figure 53(d)).

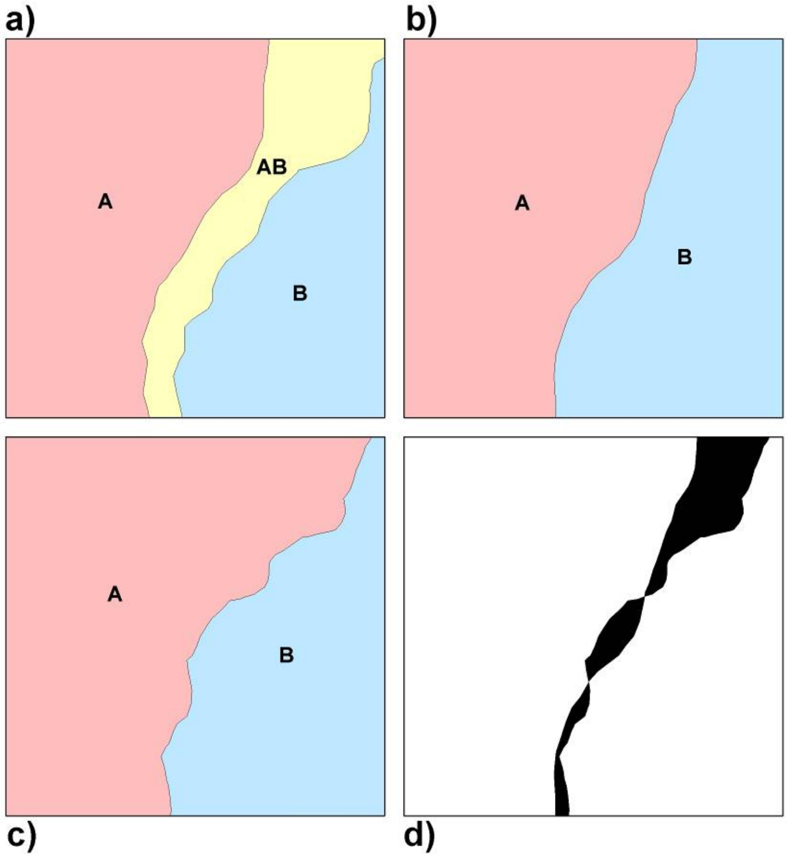

Figure 53 Hard interpretations of the same reality. A) Actual ground classes A and B, with ecotone (AB) between them in yellow. B) One photo-interpreter's map. C) Other interpreter's map output. D) Areas of difference between interpretations in black

For ecotone mapping it may be more accurate and representative to map points as belonging to multiple classes (Figure 54).This approach is known as ‘soft’ mapping and will reduce errors when change detection is carried out, as errors at boundaries should be reduced (Figure 54(d)). An additional benefit will be where the interpreter is unsure of the habitat type. This may happen through lack of experience, the presence of an unusual species, or complications within the imagery such as shadows. If a hard approach was taken, a boundary would have to be drawn, and all points would only be allowed a single class. If multiple classes were allowed, then uncertainties can be incorporated within the map.

Using a soft approach does have disadvantages. It is more complicated to carry out and may take more time. There is a danger that multiple classes are allocated in areas where only a single class is actually present. This may be because the interpreter is uncertain about what they are seeing or because it is the easy option involving the least amount of decision making. The resultant map would be much less useful for change detection. It is also more difficult for people who are used to traditional maps to understand and analyse maps that include uncertainty.

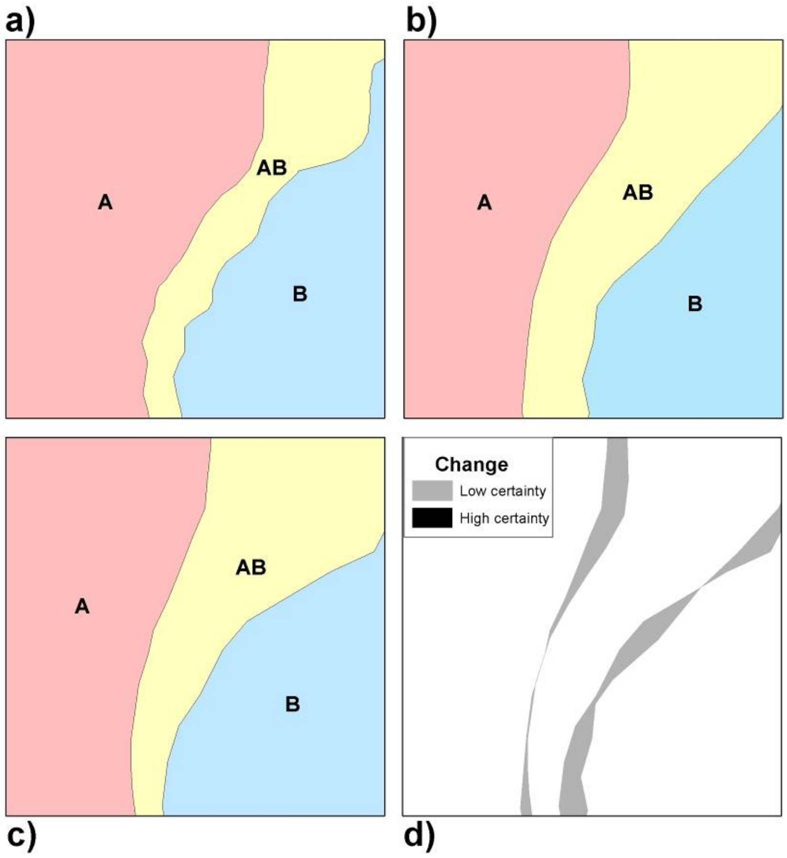

Figure 54 Soft interpretations of the same reality. A) Actual ground classes A and B, with ecotone (AB) between them in yellow. B) One photo interpreter's map with ecotone. C) Other interpreter's map output with ecotone. D) Areas of difference between interpretations in grey. All areas of predicted change are assumed to be uncertain, but have a low uncertainty (grey polygons)

It is recommended that the issues surrounding soft mapping are considered further. This could be part of the sand dune mapping work and should try to identify practical methods that can be used to overcome the issues created by ecotones and uncertainty in aerial photography classification. From the perspective of habitat mapping and monitoring it is important to minimise the impact of errors associated with the interpretation, especially when considering change over time.

5.4. Moorland burning, Broomhead, Sheffield

In 2006, a pilot study was undertaken to see if satellite data could be used to map moorland burning. This work formed part of a larger feasibility study to test the capabilities of the data.

One of the pilot areas for this project was a site at Broomhead, west of Sheffield. Landsat data for this site were used to derive a Normalised Burn Ratio (NBR), using the near infrared (NIR) and shortwave infrared (SWIR) channels. This ratio was used to identify areas that have experienced burning and the initial results are shown in Figure 55.

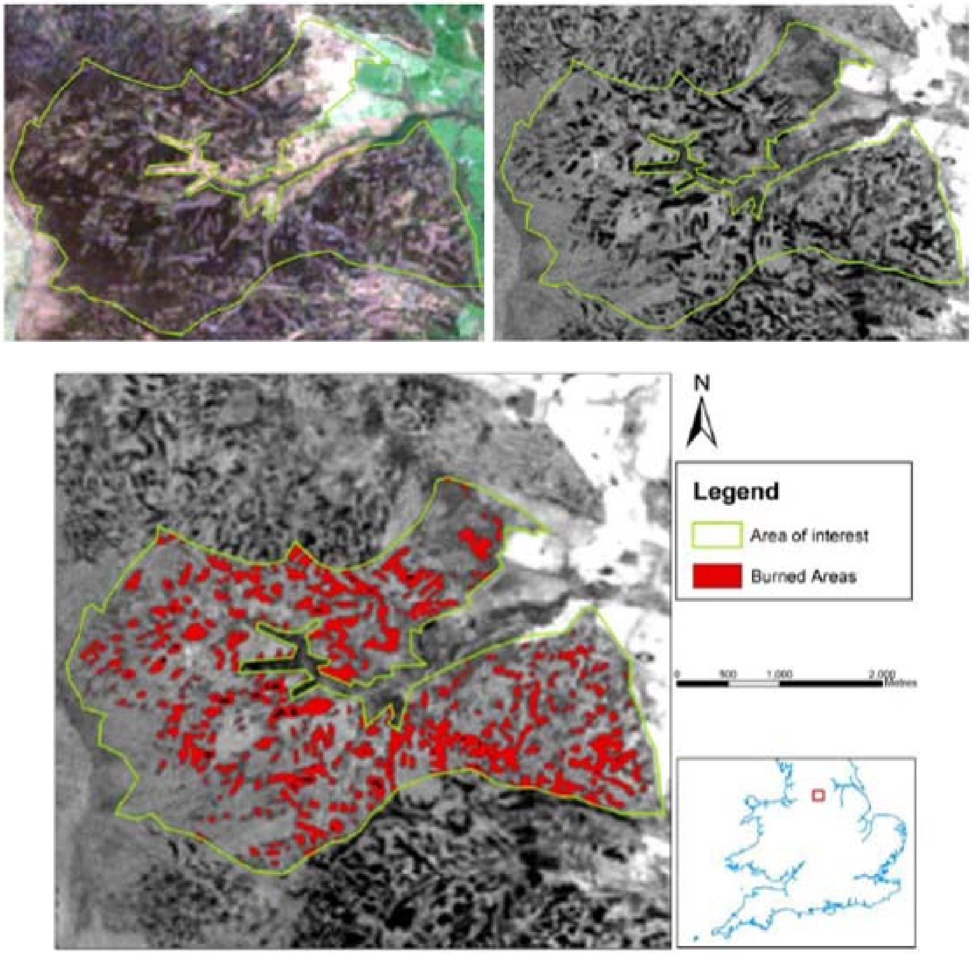

Figure 55 Classification of burned areas using a single image approach. Top left image is the true colour Landsat data. Top right image is the NBR index. Bottom image is the classification, with burned areas coloured in red

This single image approach proves that NBR can be used to detect burned areas. However, using a single dataset can result in confusion between regenerating areas and other high productivity regions. To improve the classification, a multi-temporal approach was adopted. Separate NBR's were produced for Landsat data acquired before and after a burn. These ratios were subtracted (dNBR) and the resulting output used for the classification. The dNBR is hypothesised to correlate to the magnitude of environmental change, thus providing a measure against which recently burned and high productivity areas can be discriminated. The results using this multi-temporal method are shown in Figure 56.

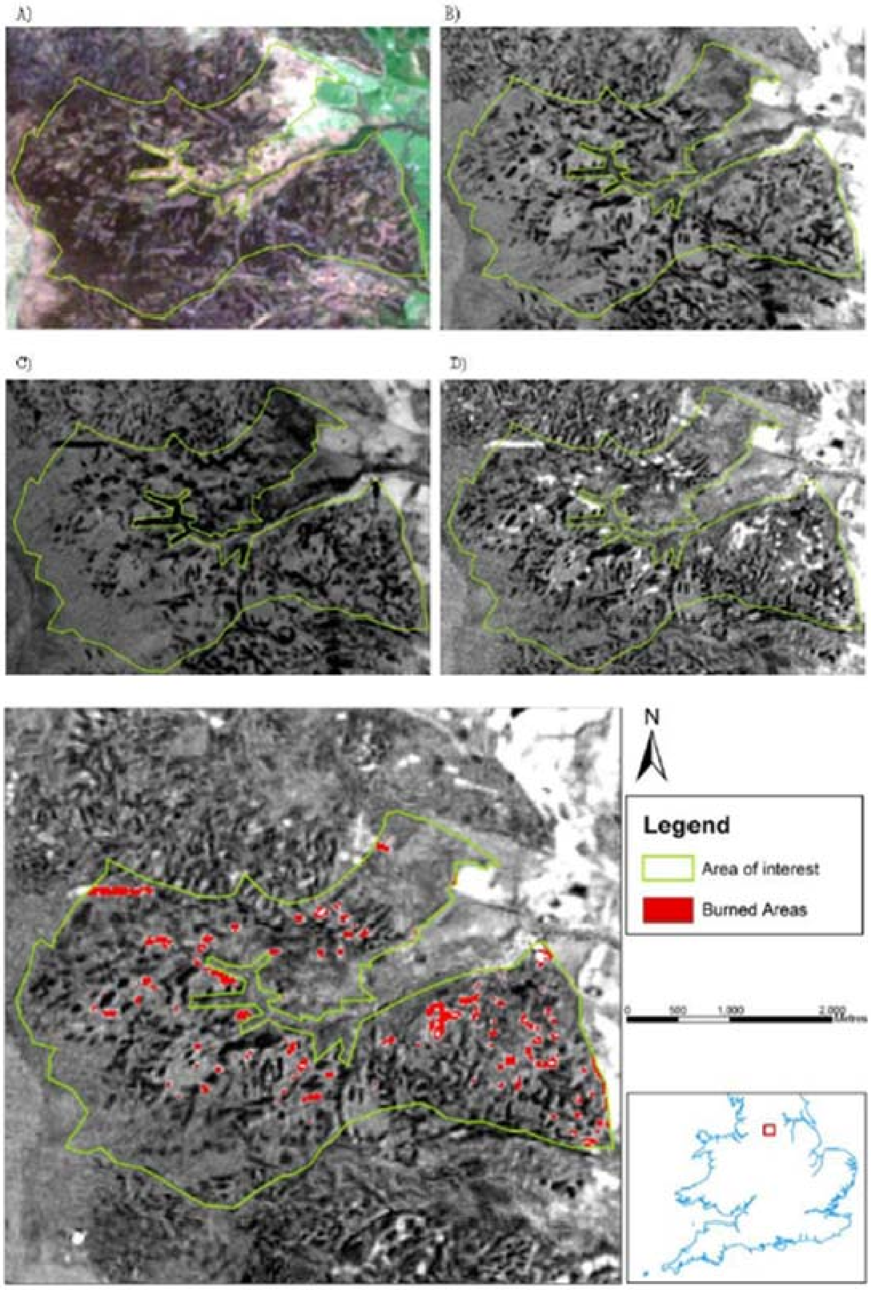

Figure 56 Classification of burned areas using a multi-temporal approach. A) True colour Landsat data (2001), B) NBR index for May 2001, C) NBR index for April 2002 and D) difference between the two NBR outputs (dNBR). The bottom image is the classification, with burned areas coloured in red

Comparing the classified image in Figure 56 with the same classification in Figure 55 shows the benefit of using a multi-temporal over single image approach. By incorporating an additional dataset, false positive results have been removed from the classification, producing a more realistic representation of recently burned areas.

This pilot study was crucial in proving that satellite data could be practically applied to mapping areas of moorland burning. As a result of these findings, this project received GIFTSS funding. The GIFTSS project has now reached a successful completion, which might not have been possible without this initial research stage.

5.5. Vegetation shading along rivers

As part of the collaboration, Natural England asked for some initial work to develop a tree shading product. The rationale behind this was to identify sections along a river bank that were cooler due to the surrounding vegetation. This product was not pursued by Natural England in the end, but the Environment Agency showed an interest and followed up the project. Figure 57 shows one of the outputs from the resulting pilot study, undertaken by Geomatics Group.

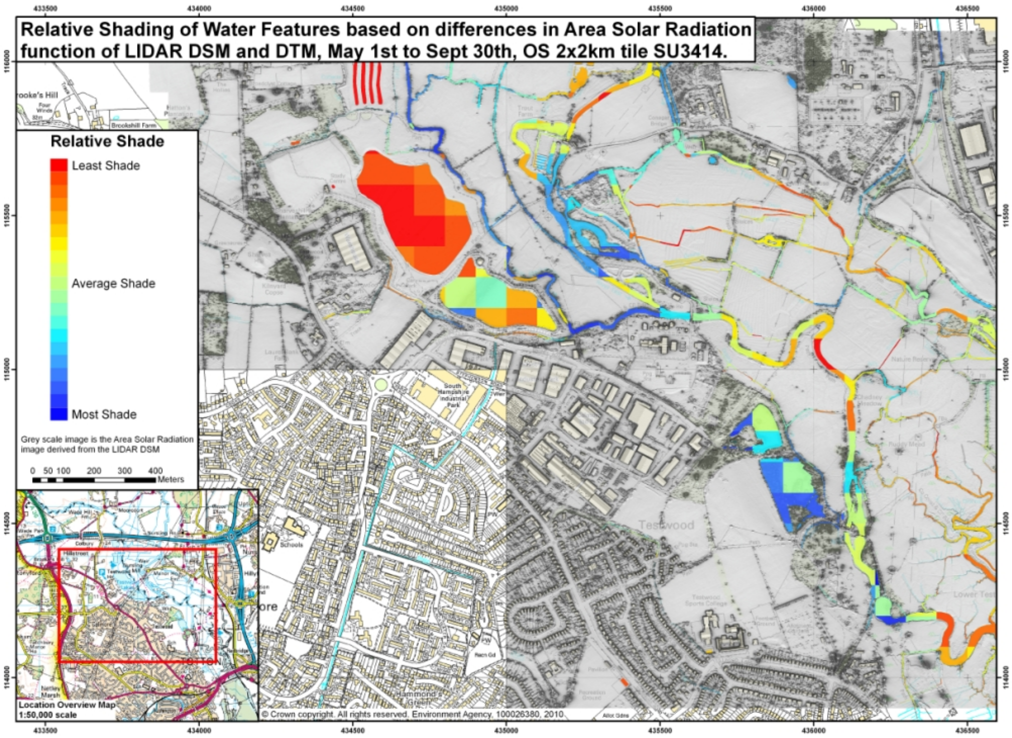

Figure 57 Relative shading product for the River Test, Hampshire. Colours relate to sections receiving the most shade (blue) and least shade (red)

The amount of solar radiation received by water features was calculated for both the LIDAR DSM and DTM. The difference between these two outputs was used to infer the relative shading caused by surface features such as vegetation. The water features were divided into 100 m blocks and an average relative shade value was taken, which is why the colours appear 'blocky' in Figure 57. This is an arbitrary value and could be reduced if a more detailed product was required.

As a result of this initial pilot study, the Environment Agency is now looking into undertaking this work on a national scale. These products will be used to help identify areas where vegetation shading may produce cooler spots, where fish could take refuge. It will also help locate exposed sections along the river that might benefit from targeted tree planting.

6. Habitat re-creation assessment

We anticipate many changes at landscape scale as climate change and human activities introduce new habitats or force changes on existing ones. Again operational practicalities require large scale analysis to inform an overall condition assessment. This type of application has only briefly been investigated so far and the following example shows what can be done in coastal situations where there is an identified need for long-term adaptation to accommodate dynamic features.

6.1. Identifying new habitat re-creation sites, Cley, Norfolk

The change analysis carried out for the shingle ridge at Cley suggested that the ridge is migrating landwards now that artificial profiling has stopped (section 3.1). Consequently, the saline lagoons in the low-lying land behind the ridge will eventually become overwhelmed, completely or partially, by shingle. These percolation lagoons depend on the ridge to regulate their sea water intake, so will need to adapt alongside the ridge evolution. Natural England requested LIDAR analysis to identify the options for transmigration of this Priority Annex I habitat further inland. These could include allowing natural influx of saline water, or by artificially managing this change.

Natural England provided the key criteria for potential new sites based on an expert understanding of the structure and function of saline lagoon habitats. These included parameters on height, area, slope and distance to the existing lagoons on the site. LIDAR data acquired 12th January 2008 (25 cm resolution) were used in this analysis. The results are shown in Figure 58.

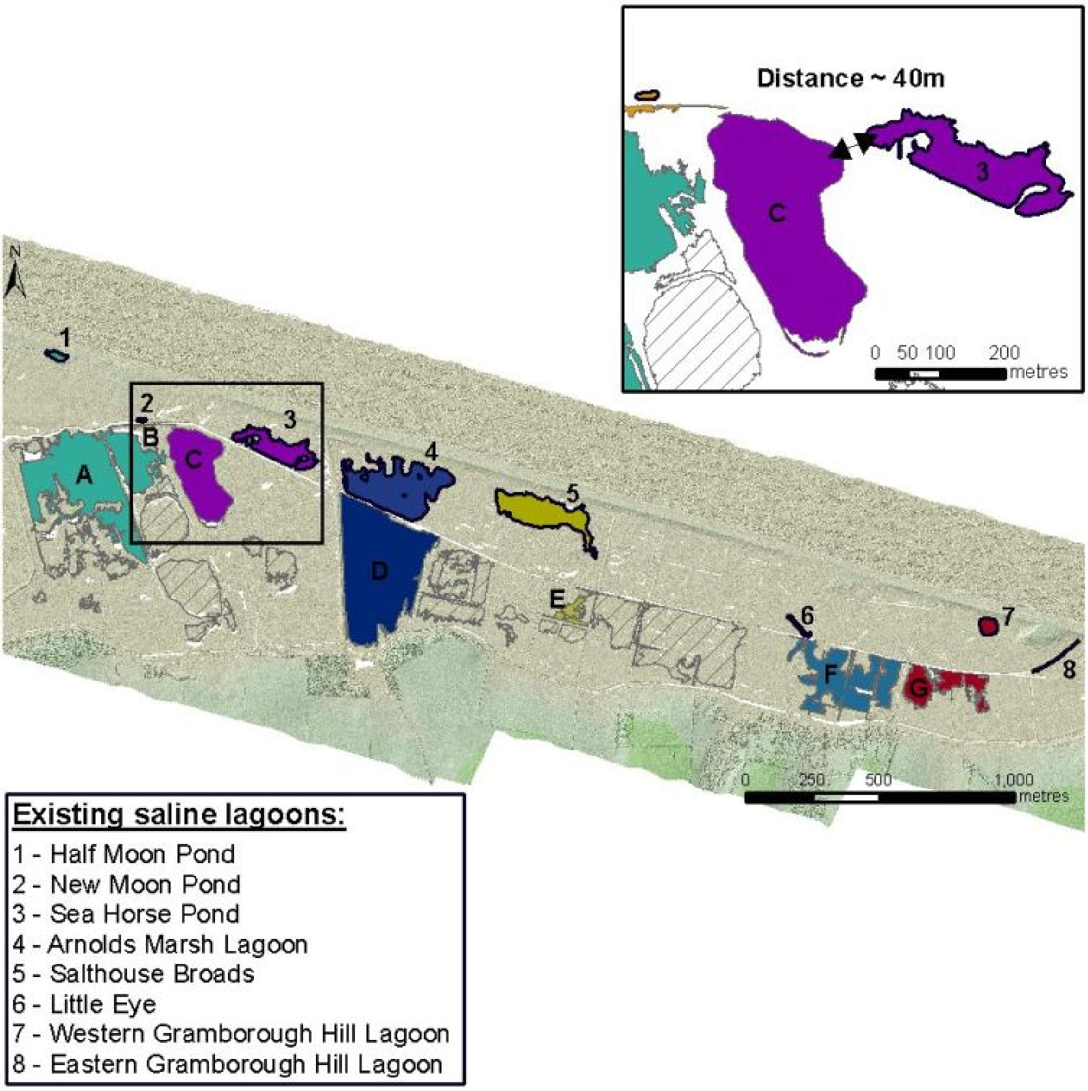

Figure 58 Optimum locations for saline lagoon development at Cley. Numbered polygons show the location of existing lagoons on the site. Lettered polygons are the most suitable new areas that are closest to the existing lagoons

Each existing saline lagoon was allocated the potential new site that was closest to its current position. The hatched polygons in Figure 58 are areas that met all the criteria outlined by Natural England, but were not the closest option. These may however be of interest in the longer term management of this site.

The zoomed in example in Figure 58 shows that the nearest re-location area for Sea Horse Pond lagoon is around 40 m away. The mechanisms by which natural colonisation of lagoons happens are not fully understood, therefore Natural England's view was that a maximum distance beyond which species would be able to migrate could not yet be defined. The distances to the nearest new sites for each existing lagoon are shown in Table 3.

Existing lagoon	Nearest potential site (letter)	Area of potential new site (ha)	Shortest distance between edge of existing lagoon and the edge of the nearest potential new site (m)
Half Moon Pond	A	12.6	256
New Moon Pond	B	0.1	8.6
Sea Horse Pond	C	5.1	40
Arnolds Marsh Lagoon	D	12.8	4.6
Salthouse Broads	E	0.65	121.8
Little Eye	F	5.6	10
Western Gramborough Hill Lagoon	G	2.6	149.4
Eastern Gramborough Hill Lagoon	G	2.6	162.7

Table 3 Distance between existing lagoons and the nearest appropriate new site

6.2. Topographical height maps

One product that is regularly requested through the collaboration is a topographical height map. Natural England require these maps mainly for Higher Level Stewardship (HLS) options, SSSI condition assessments and BAP habitat improvement or creation. Figure 59 shows a typical topographical map produced for Bassenthwaite, Cumbria. This map was generated from post-flood LIDAR DTM data acquired 4th-10th December 2009 (1 m resolution).

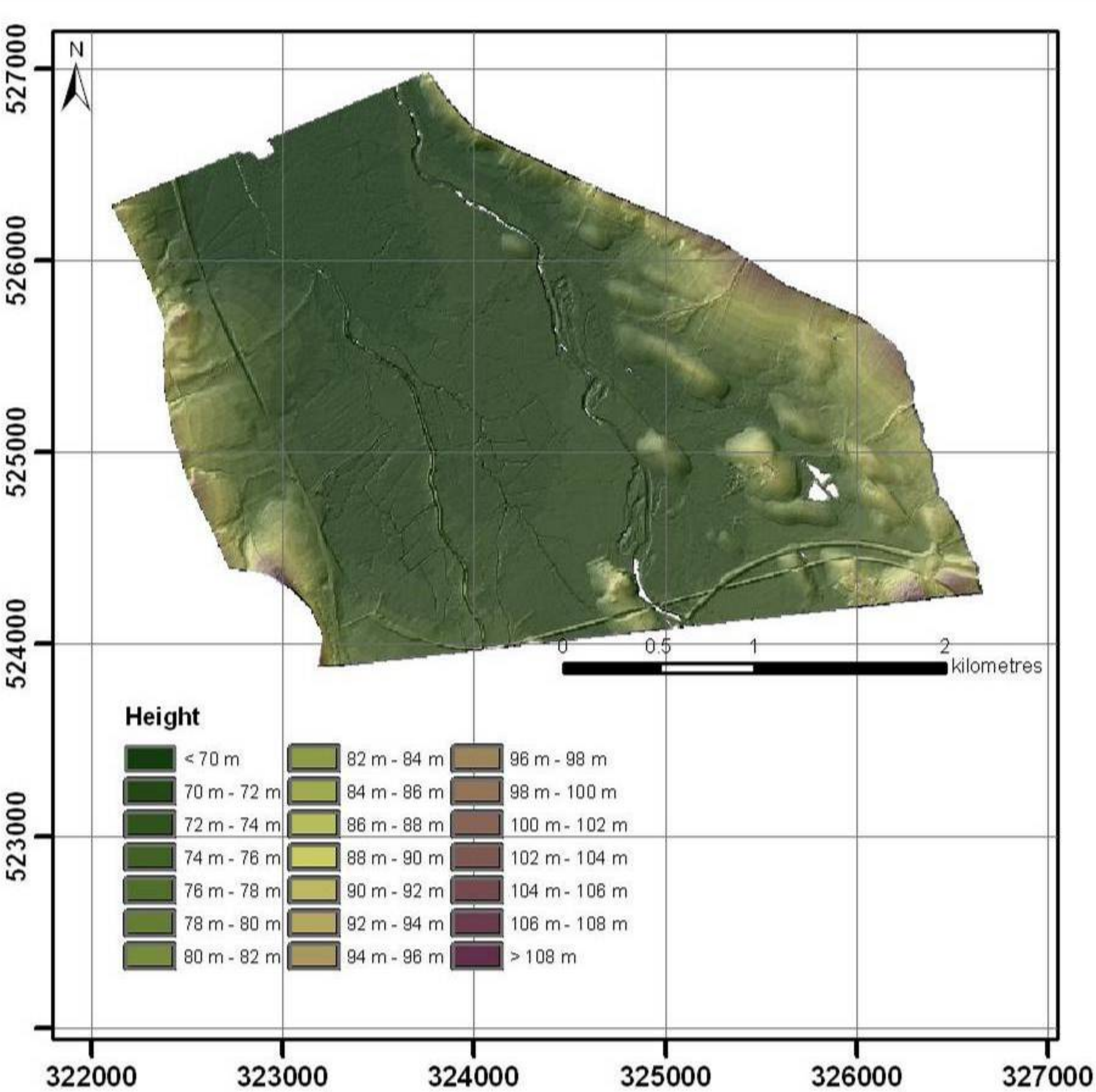

Figure 59 Coloured topographical height map for Bassenthwaite. The LIDAR DTM data are classified into regular 2 m height intervals

This particular site has areas of high quality purple moor-grass rush pasture (PMGRP). Natural England requested this analysis to identify optimal locations for dipwells, which can collect hydrological data around these high quality areas. This information can then be used to aid the restoration of this habitat both here and elsewhere in England. To further facilitate the process, contour data were also derived from the LIDAR DTM (Figure 60).

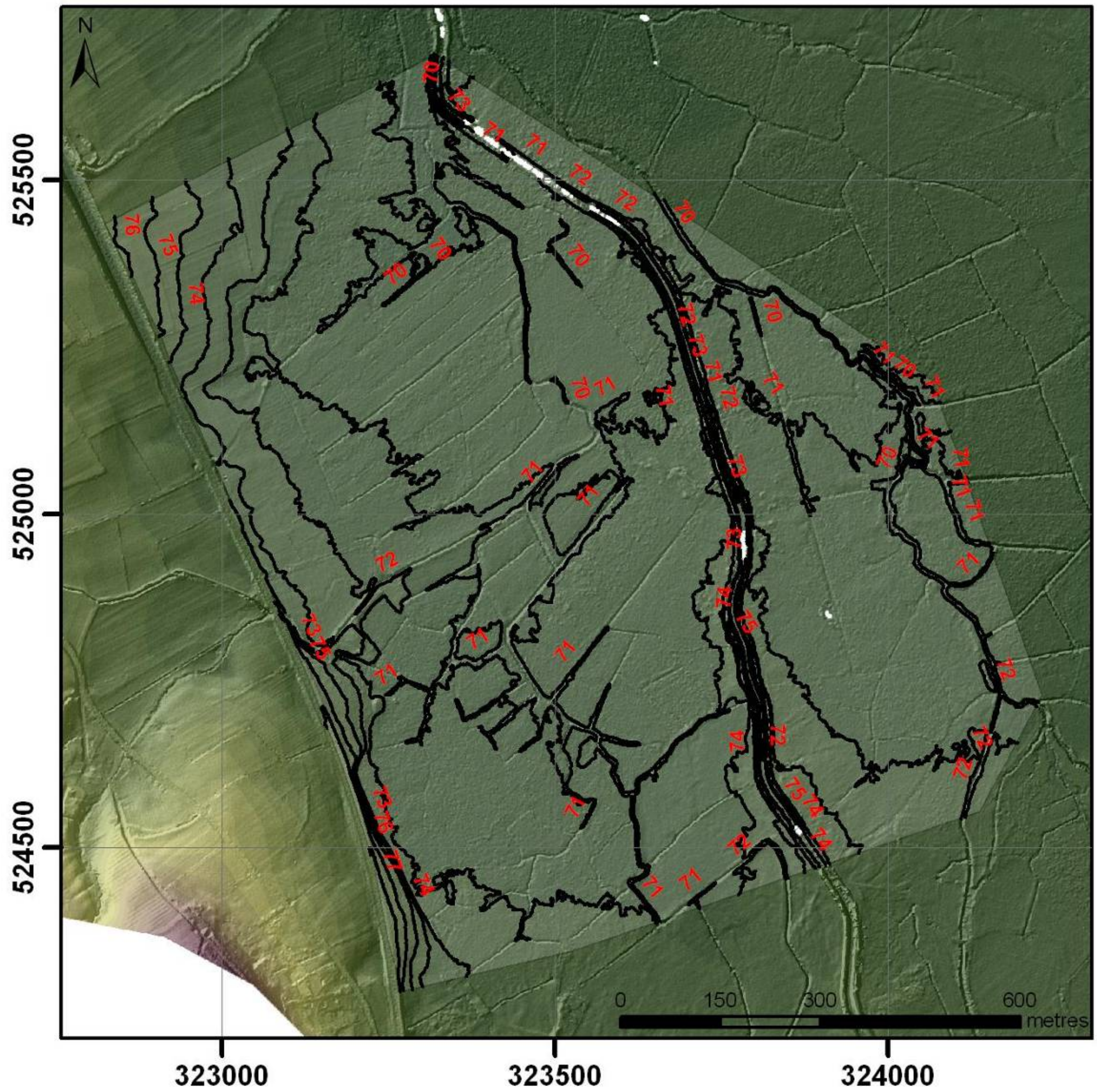

Figure 60 Contours (1 m spacing) for a subset of the larger Bassenthwaite site

Natural England have used these specific products during an on-site workshop to inform dipwell placement. They can also be used to help estimate the potential extent of winter flooding and so the duration that floodwater would influence the site.

Currently, these types of products are either created through the collaboration using LIDAR data, or they are generated from bespoke GPS surveys undertaken by Natural England. It is widely recognised though that LIDAR would often be the quicker and more efficient option.

6.2.1. Benefits of LIDAR over GPS for topographical height maps

It has been possible to directly compare the relative merits of these two data collection techniques for the generation of topographical height maps. Table 4 shows the comparison based on several key criteria. The details for GPS data collection were provided by Natural England and the equivalent information for LIDAR was provided by Geomatics Group.

	GPS	**LIDAR**
Data collection time	30-50 ha per day - rough grassland. 70 ha per day - flatter grass and arable land.	Large areas can be collected in a single flight.
Resolution	25-35 m - rough grassland. 35-50 m - flat grassland. 75 m - arable land.	Between 2 m and 25 cm (any land type).
Accuracy	1-2 cm horizontal. 2-3 cm vertical. Produce 10 cm height intervals.	15-20 cm horizontal. 15 cm vertical. Produce 10 cm height intervals.
Costs	More cost effective if covering a single, very small area.	More expensive to commission small new flights. Archive data often available.
Complications	Difficult to collect data around forested areas.	Trees can be removed during processing and a continuous data surface interpolated (unless very dense canopy).

Table 4 Comparison between GPS and LIDAR

It takes much longer to collect data using GPS compared to LIDAR. Roughly extrapolating these figures, it would take approximately three weeks to acquire 10 sq km of GPS data. In contrast the same area could be easily captured by a single LIDAR flight of less than two hours.

The process of capturing LIDAR data is also much more standardised. During a LIDAR survey between 50,000 and 100,000 points per second are generally acquired, at a resolution of between 2 m and 25 cm. GPS data collection is not as consistent. The resolution acquired is dependent on the land cover type. If specific features within a landscape are important then more GPS data will be collected around them. As each GPS survey is tailored to the type of site and the specific application requirements at the time, it makes it difficult to compare GPS surveys. In contrast, the uniformity of LIDAR capture means that data acquired many years apart can be analysed to look for changes and data originally acquired for one purpose can be used for many more.

GPS data are slightly more accurate than LIDAR. However, for the application of topographic height map generation, both datasets can be used to create a product classified at 10 cm intervals. If appropriate archive LIDAR data are available for a site, a product can be made in as little as an hour. One thing that could affect GPS accuracy is if an area is heavily forested, as this will reduce the satellite visibility. Forested areas are generally not a problem when acquiring LIDAR data, as the system will usually return some tree and some ground hits. During the data processing stage the trees can usually be removed and the ground height underneath interpolated using the ground points that were returned. Some problems can arise when the tree canopy is very dense. When looking to produce a DTM, the optimal time for acquiring LIDAR data is during the winter, when most of the trees are bare.

New LIDAR data capture can be expensive. If data were required for a single field and archive data were unavailable, then it would probably be most cost effective to acquire these data using a GPS survey. However, several small sites can be grouped together and flown on a single flight. Some forward planning would be required to come up with a programme of sites like this, which might involve changing the way this work is approached. It would ultimately be a more effective use of money and resources though.

6.3. Operational products

The following projects in this section outline the topographical height map products that have been delivered between March 2010 and March 2011.

6.3.1. Lugg Meadow, Hereford

A colour-coded topographical map was produced using the LIDAR DTM data gathered 6th-10th April 2006 at a resolution of 2 m (Figure 61). This product was required to help inform a wetlands project.

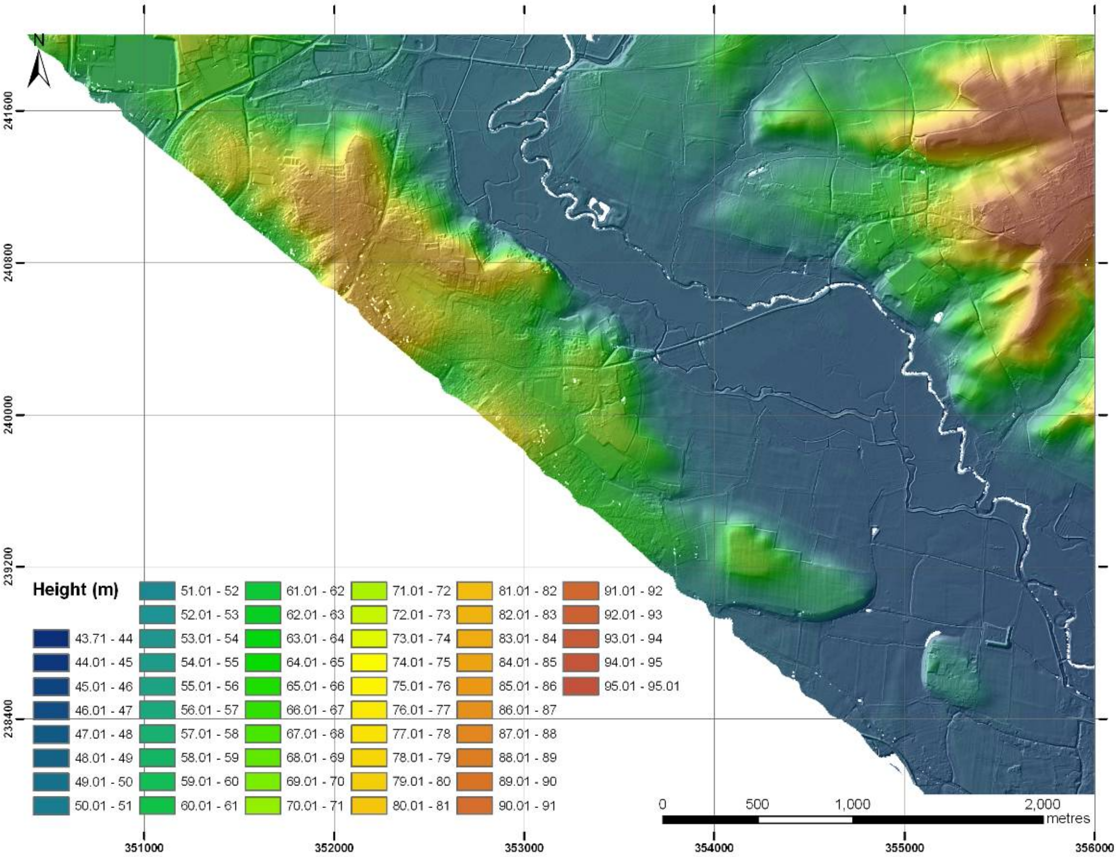

Figure 61 Coloured topographical map for Lugg Meadow, classified into 1 m height intervals

6.3.2. Crose Mere and Sweat Mere, near Shrewsbury

Two colour-coded topographical maps were produced for this site using the LIDAR DTM. LIDAR coverage was available only in the western and eastern sections of the site. The western map was produced using LIDAR data gathered 4th March 2006, at a resolution of 1 m (Figure 62). The eastern map was produced using LIDAR data gathered 2nd-4th February 2008, at a resolution of 2 m (Figure 64). Contours were also generated using the western (Figure 63) and eastern (Figure 65) data. These products were required to investigate wetland restoration options and assess the potential impacts of raised water levels on local farmland.

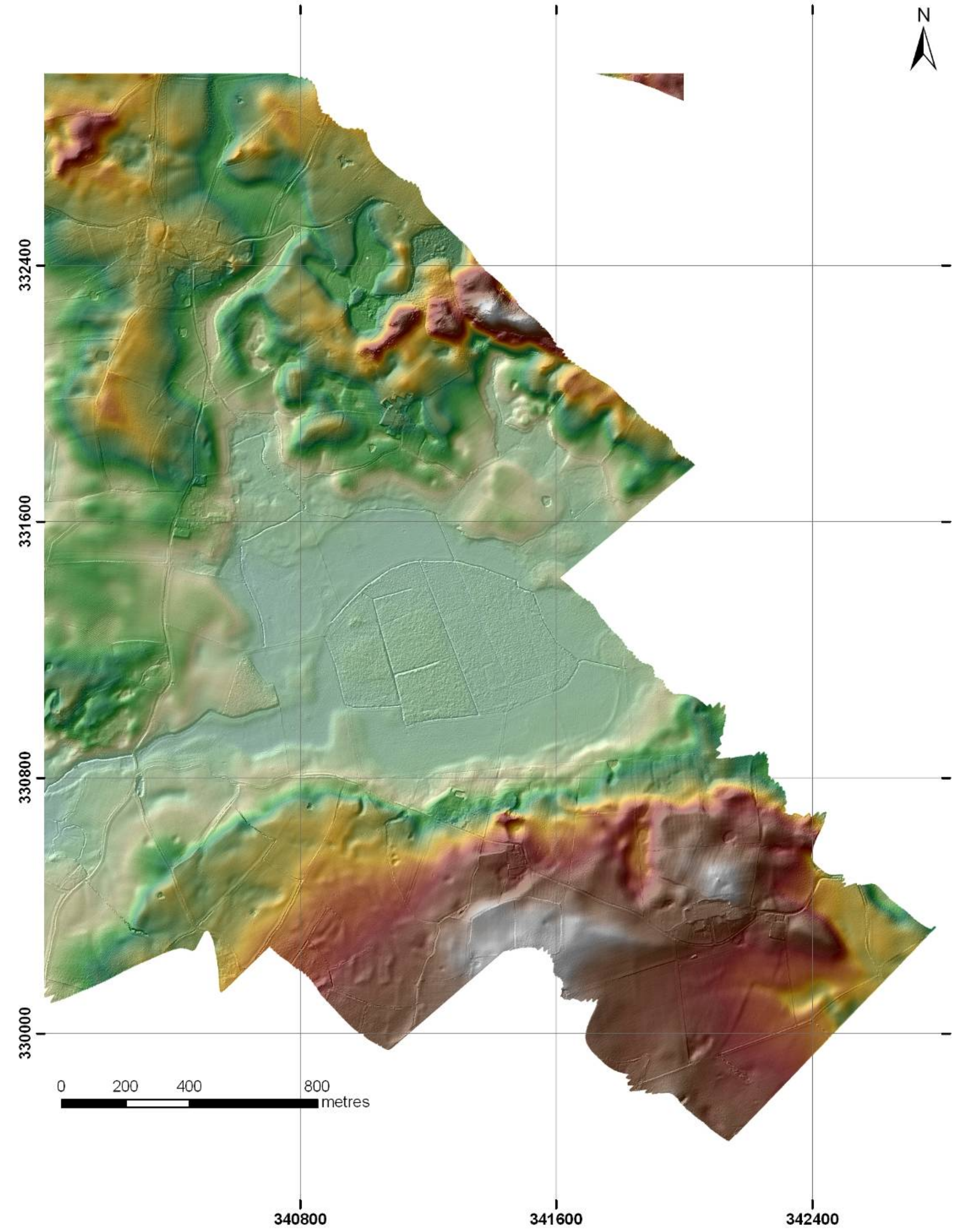

Figure 62 Coloured topographical map for the western section of Crose Mere and Sweat Mere (2006), classified into 15 cm height intervals. A detailed legend was provided with the product (height ranged from 79.03 m to 130.35 m)

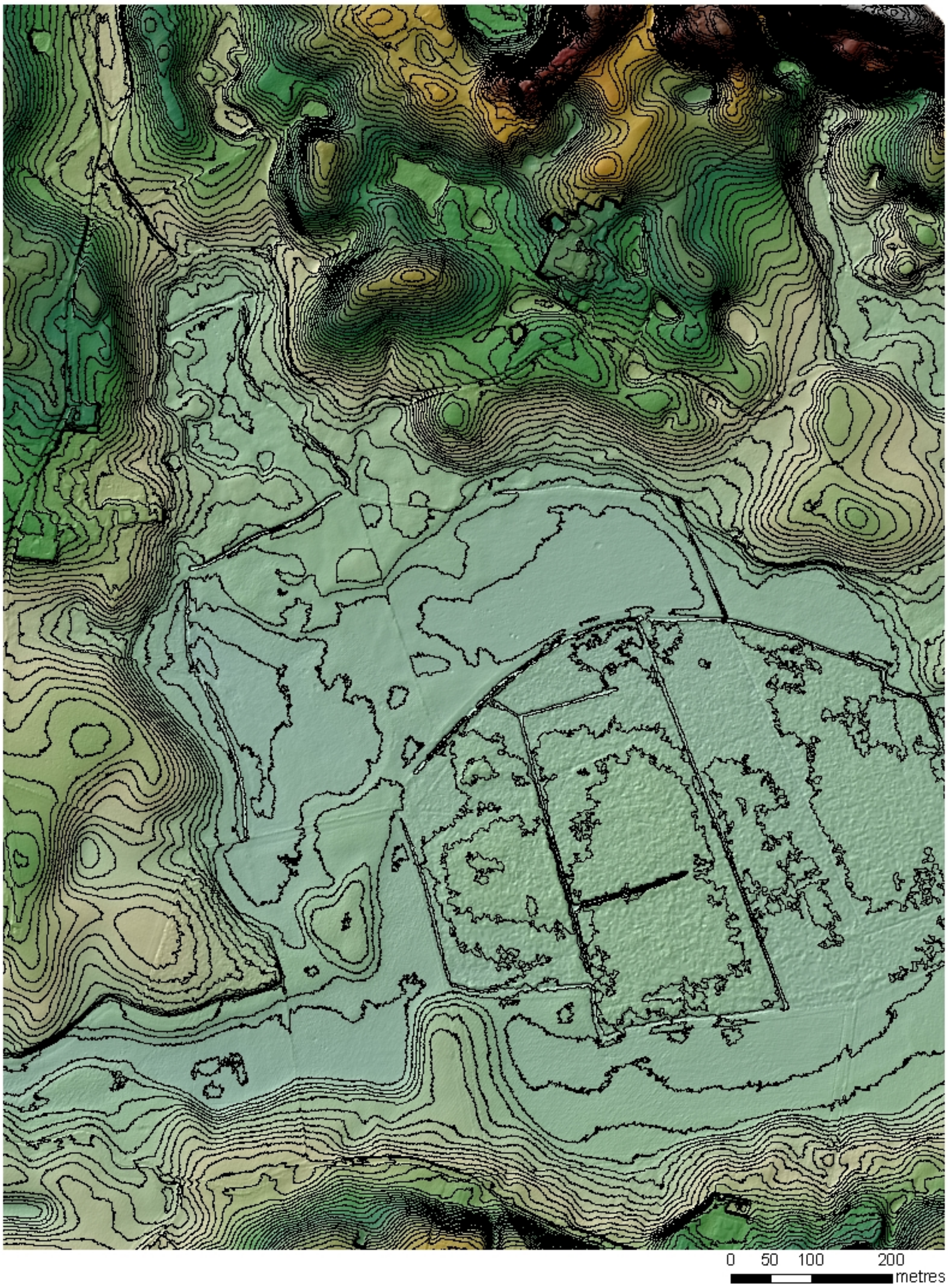

Figure 63 Subset of the contours produced for the western section of Crose Mere and Sweat Mere (2006), 50 cm spacing

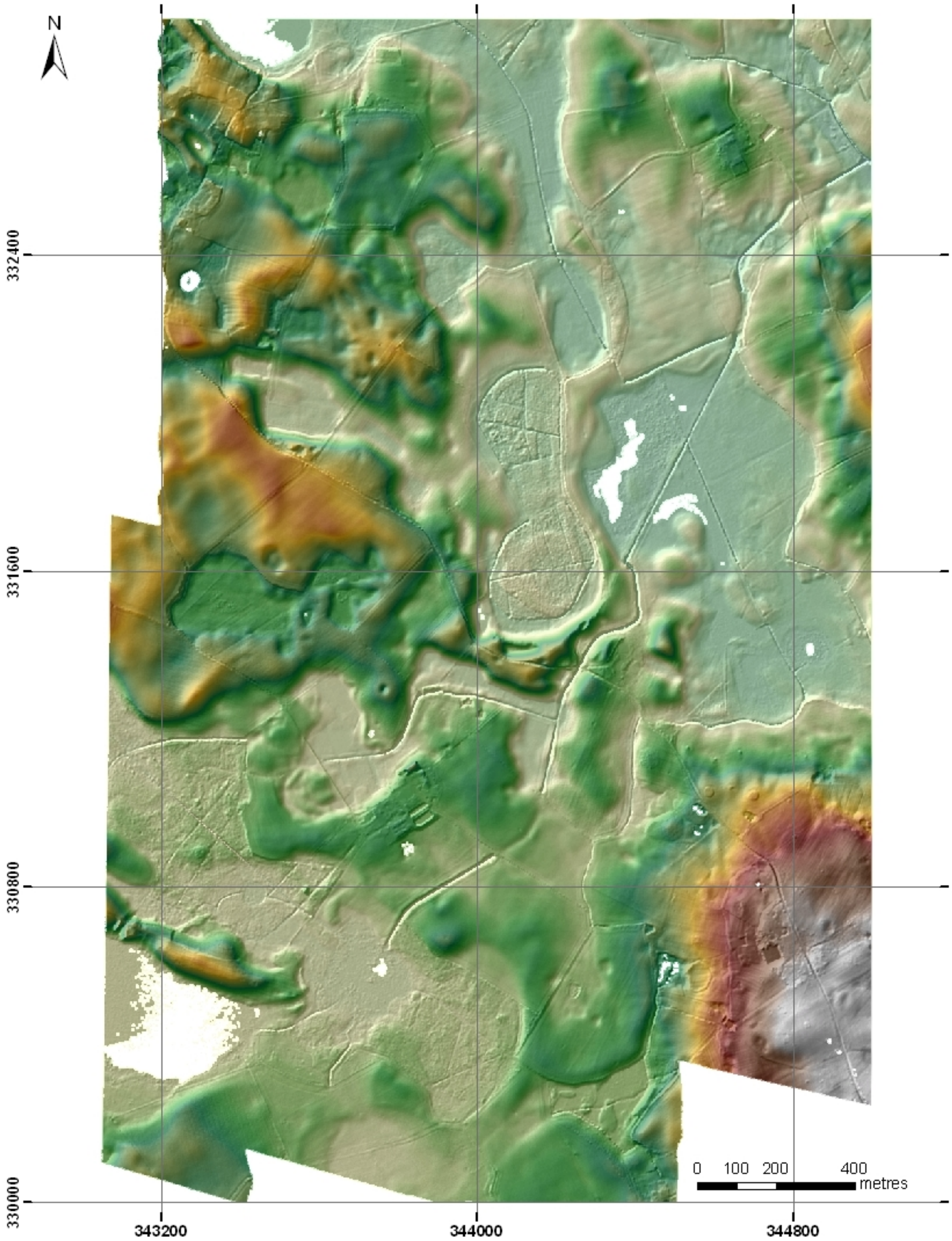

Figure 64 Coloured topographical map for the eastern section of Crose Mere and Sweat Mere (2008), classified into 15 cm height intervals. A detailed legend was provided with the product (height ranged from 82.02 m to 118.2 m)

Figure 65 Subset of the contours produced for the eastern section of Crose Mere and Sweat Mere (2008), 20 cm spacing

6.3.3. Jones' Mill, near Marlborough

A colour-coded topographical map was produced using LIDAR DTM data acquired 3rd-4th November 2005 at a resolution of 1 m (Figure 66). This product was needed to provide information about the hydrological patterns on the site, in order to identify the optimal locations for dipwell installations.

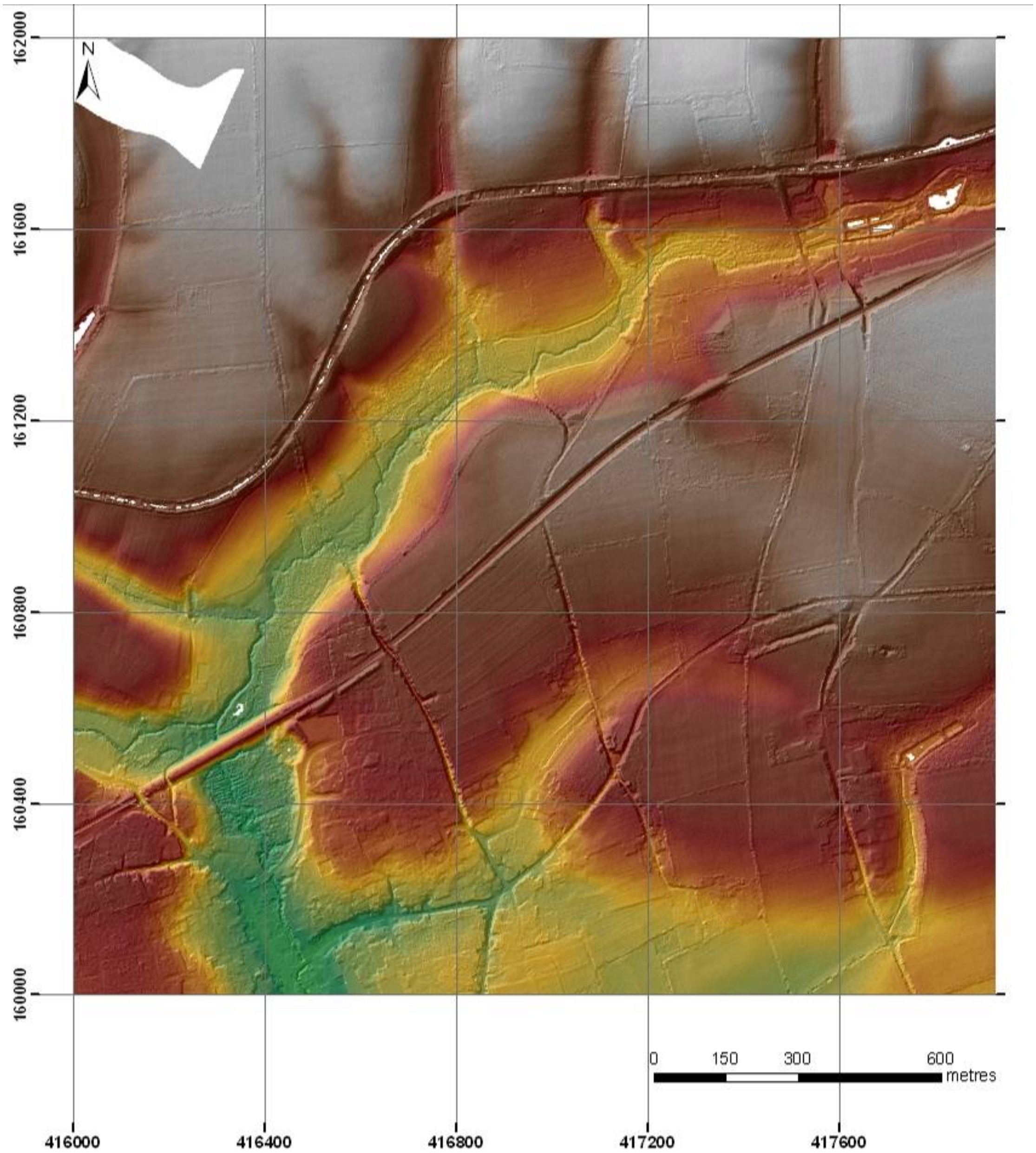

Figure 66 Coloured topographical map for Jones' Mill (2005), classified into 25 cm height intervals. A detailed legend was provided with the product (heights ranged from 97.51 m to 142.92 m)

6.3.4. Dungeness, Kent

In addition to the change analysis described in section 3.4.3, a colour-coded topographical map was also produced for the wider area of interest at Dungeness (Figure 67), using LIDAR DTM data acquired on 11th November 2008 (1 m resolution).

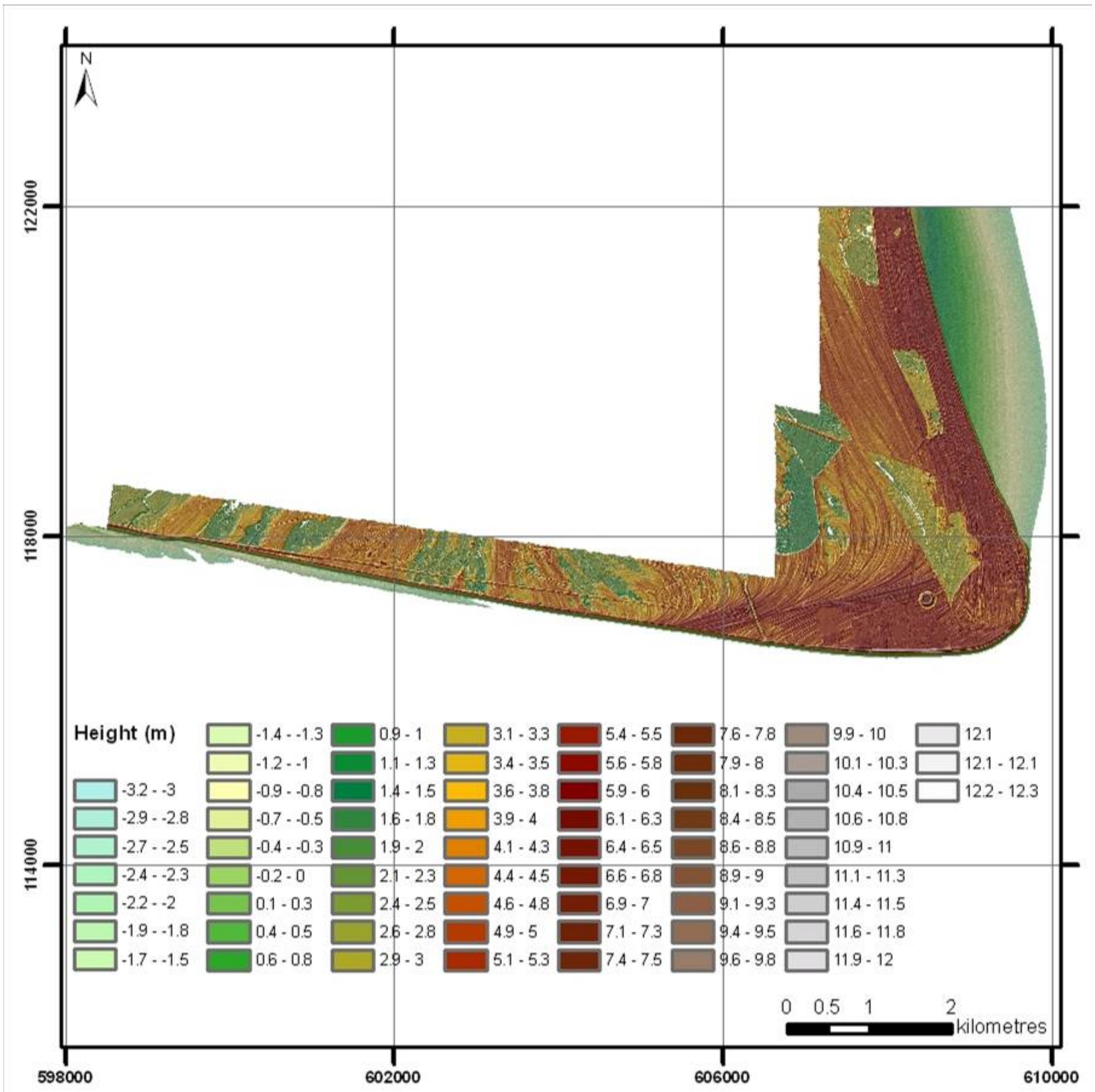

Figure 67 Coloured topographical map for Dungeness, classified into 25 cm height intervals

7. Erosion prediction

A specific area of interest for Natural England was trying to predict where erosion will occur using information about current and past erosion. This will be used to inform management planning and design of access routes to reduce any impacts. The following example was a complex query that required close working between the requesting officer and the analysts. Other examples show the potential of using remotely sensed data in operational situations.

7.1. SSSI condition improvement, Brecon Beacons

Brecon Beacons National Park Authority is working with Natural England to improve the condition of this SSSI. One of the challenges for this area is to manage and restore erosion scars that were originally caused by wildfires. These scars are vulnerable to sediment erosion by water running down the mountainside. The decision on how the scars should be restored has already been made, but the size and scale of each site makes it difficult to design an appropriate strategy for implementing the work.

To facilitate this, Natural England requested some LIDAR analysis for the Black Mountains, southern erosion scar. Two products were required to meet the operational needs, a hydrological analysis and a visibility analysis, both of which were derived from LIDAR data acquired 5th April 2006 (2 m resolution).

7.1.1. Hydrological analysis

One aspect of the management strategy is restoration of the scar to prevent further sediment being washed away. In order to do this, a better understanding of the hydrological paths across the whole site is needed. The LIDAR DTM data were used to predict the likely routes for surface water runoff away from the scar. Figure 68 shows these flowpaths, coloured by the direction the water would be travelling.

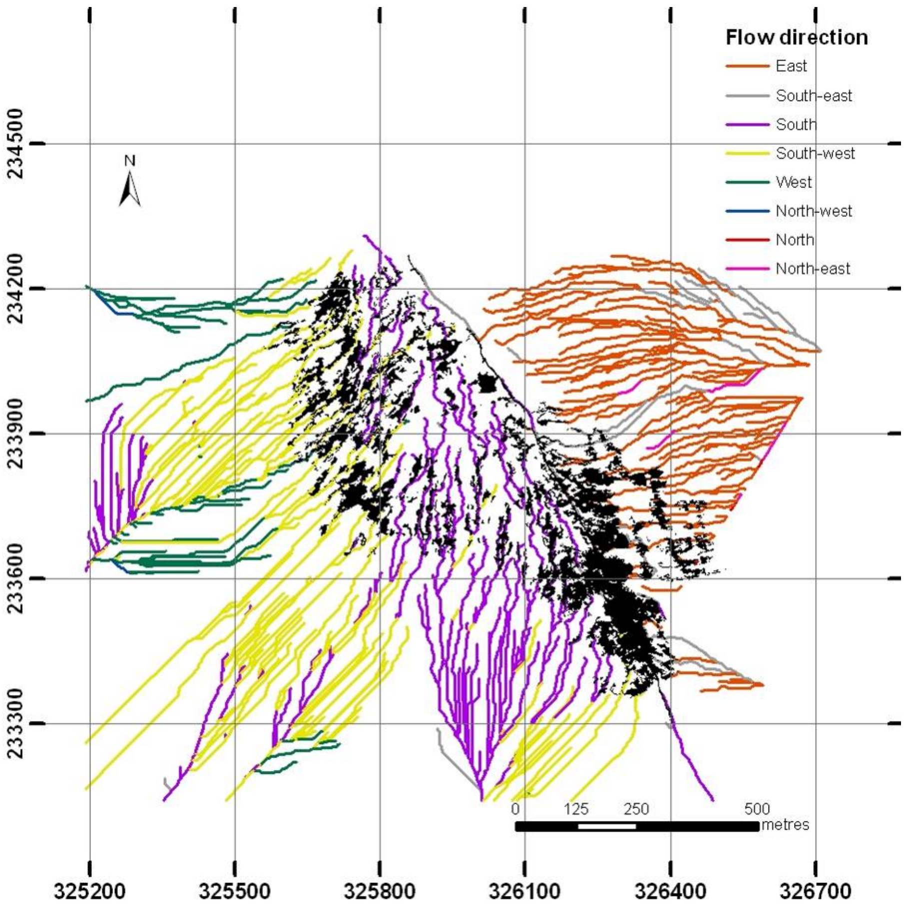

Figure 68 Predicted surface water flowpaths away from the southern erosion scar (coloured in black), Black Mountains

The size of the southern scar (at around 40 ha) makes the cost of restoring the whole scar at once prohibitive. Therefore there needed to be a way to divide the scar, targeting most 'at risk' sections in a phased restoration approach. To facilitate this, a second hydrological product was created, using additional parameters like slope to identify which flowpaths could potentially cause the most erosion (Figure 69).

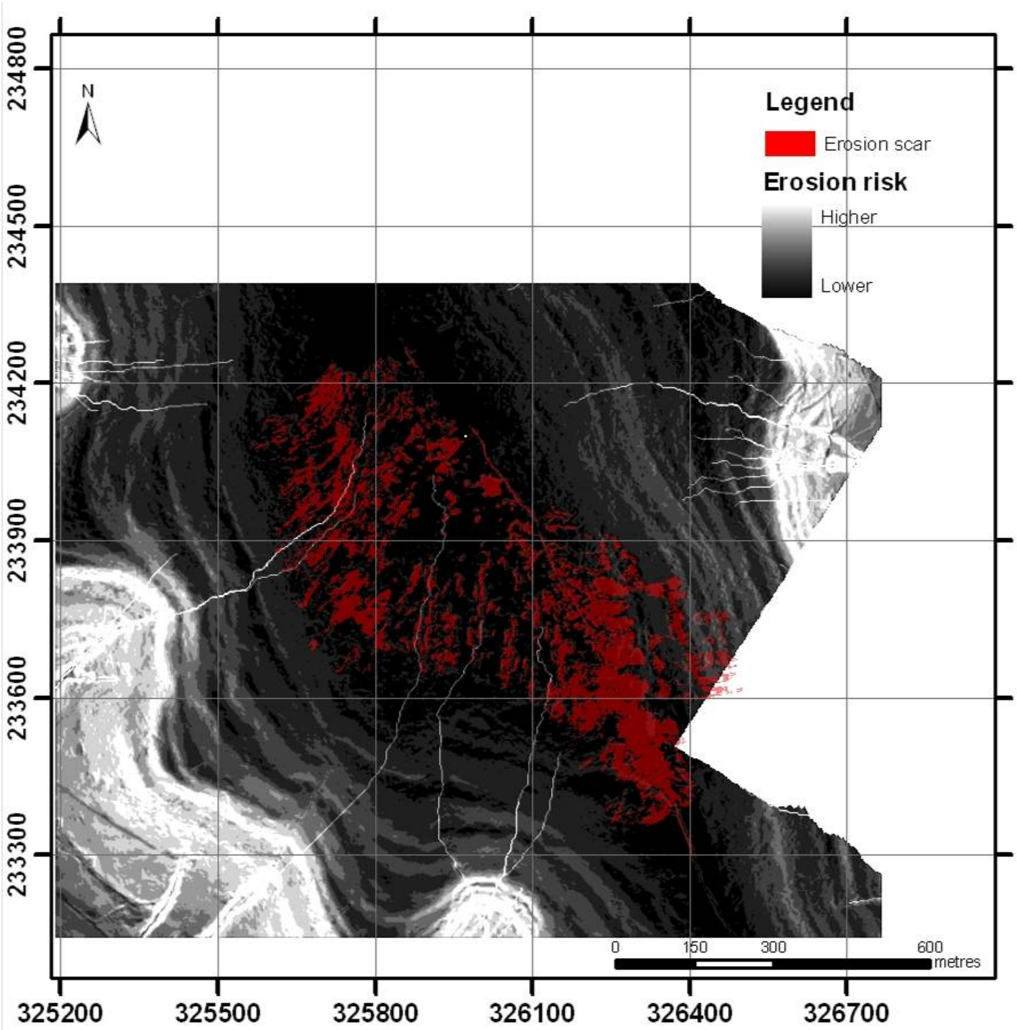

Figure 69 Erosion 'risk' map, identifying flowpaths that have a higher potential of transporting sediment away from the scar

These parameters are only one way of identifying the areas most prone to erosion. This product does not constitute a detailed hydrological model, which would require additional information for factors such as amount of rainfall and soil type.

These products have enabled the scar to be divided into four or five discrete zones. These zones have been prioritised for phased restoration, focusing on sections that are deemed to be at most risk of erosion. It would have been very difficult to have acquired the same level of detail from the ground at a whole site scale.

There is also the potential for further analysis work, assessing what impact the first stage of restoration has on the hydrology across the whole scar. Alternatively, the LIDAR data could be used to virtually restore the first zone and assess the impacts, prior to any work actually being carried out on the site.

7.1.2. Visibility analysis

The second part of the management strategy involves tighter regulation of sheep grazing to allow the vegetation around the scar time to recover. To achieve this, it has been decided that a fenceline should be put up around the scar. However, any fenceline would need to be hidden from view as much as possible for people walking along Offa's Dyke trail path, which runs right through the centre of the scar.

To facilitate this, a visibility analysis was undertaken using the LIDAR DTM, to determine the optimal positioning for the fence. The results are shown in Figure 70.

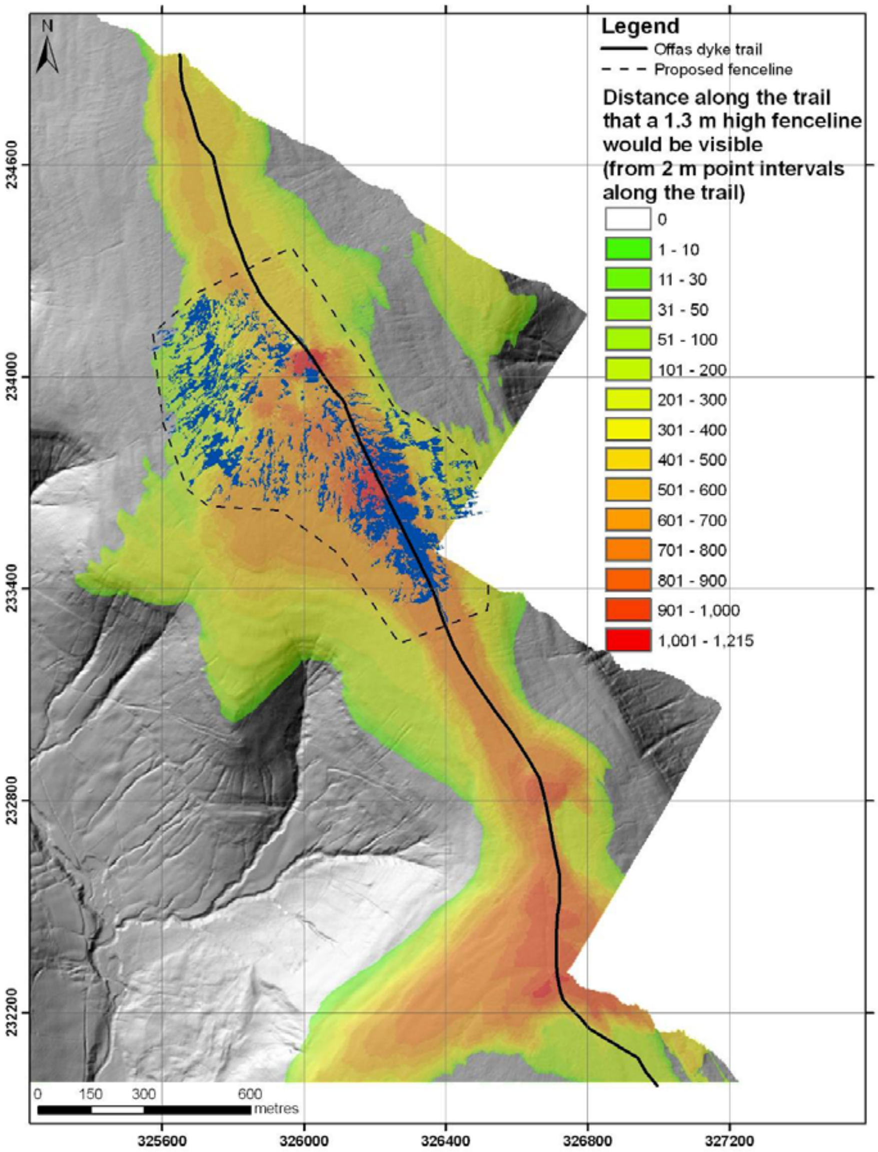

Figure 70 Visibility analysis for the proposed enclosed fenceline around the erosion scar (coloured in blue). The black line is Offa's Dyke Trail. Colours indicate areas where the fenceline would be most visible (red) through to hidden from view (transparent showing grey hillshade)

The best location for a fenceline would be anywhere where the grey of the LIDAR hillshade is visible, as a fenceline here would not be visible from any part of the trail shown in Figure 70 (black line). Areas coloured in yellow and green would be hidden from most sections of the trail, whereas orange and red areas indicate high visibility.

The hashed black line shows one fenceline option. Having undertaken the visibility analysis it is evident that some sections of the proposed fenceline only need to be moved slightly further away from the scar to become completely hidden from view. There will be some parts that cannot be concealed, for instance where the fenceline crosses perpendicular to the trail. Figure 71 shows a 3D visualisation of the proposed fenceline at the northern end of the site, where it crosses the trail.

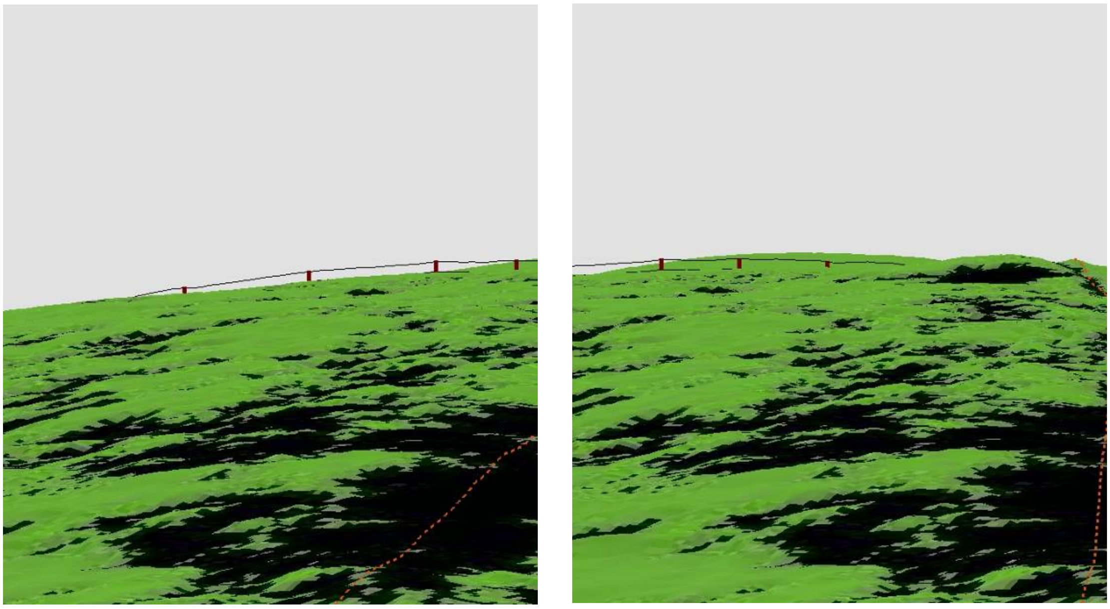

Figure 71 3D visualisation showing the visibility of a fenceline around the scar (area in black) from Offa's Dyke trail (hashed red line). Left hand image is looking north-west; right hand image is looking north

These impressions show what the fenceline would look like to someone walking along Offa's Dyke trail (hashed red line). Part of the fenceline is visible as it crosses in front of the trail, but then disappears from view down the side of the mountain.

Fencing on common land is subject to legislative control and a consultation process. This visibility analysis provides a very powerful tool for visual demonstrations when trying to make or justify a decision. This product can show possible visual impacts and help explain them to the key consultees.

7.2. Gullying and vegetation erosion, Dartmoor

An individual remotely sensed dataset is a valuable data source, but combining multiple datasets can produce a very powerful monitoring tool. A pilot study undertaken for Dartmoor National Park investigated the capabilities of combining LIDAR data (50 cm resolution) and multispectral CASI data (1 m resolution) to facilitate a condition assessment. The project was not part of this collaboration, but involved Geomatics Group, Natural England, Dartmoor National Park Authority (DNPA) and Southwest Water.

Part of the analysis involved assessing the scale of erosion and gullying occurring around footpaths, bridleways and vehicle-ways. LIDAR data can be used to accurately measure the amount of erosion taking place. Figure 72 shows profiles extracted from the LIDAR data across a footpath. The same process could be done with future LIDAR datasets and the graphs compared to estimate the rate of erosion.

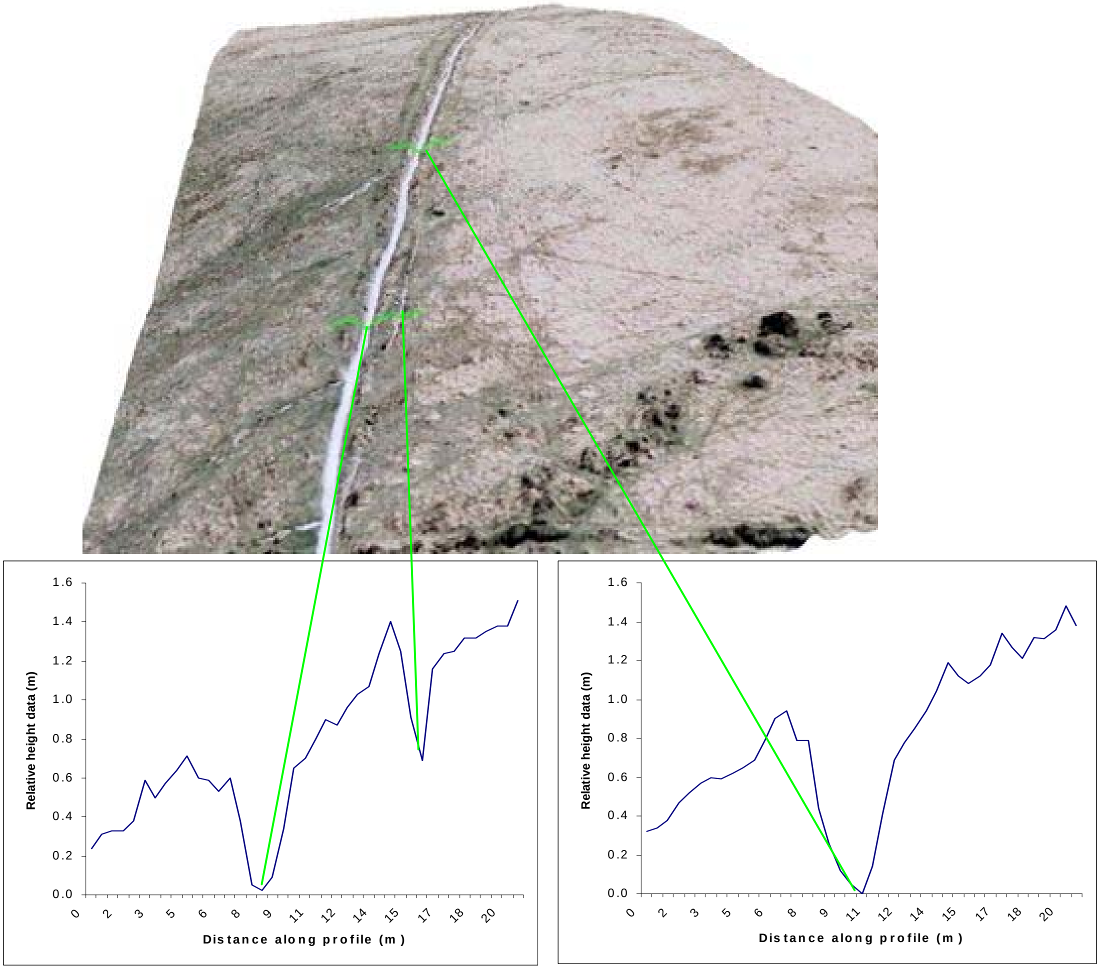

Figure 72 LIDAR profiles extracted perpendicular to the footpath between Nun's Cross Farm and Eylesbarrow tin mine, Dartmoor. Green lines shows the location of the profiles

In addition to monitoring the erosion within the known footpaths, this analysis also identified a secondary footpath that is forming parallel to the first. This is clear in the left hand graph in Figure 72, where a second trough occurs further along the profile. This new feature can now either be monitored or restored.

CASI data was very useful in detecting signs of early stage erosion, as it is very sensitive to bare ground. Figure 73 shows how inspection of the CASI data for the same section of footpath revealed vegetation disturbance deviating away from the main footpath area.

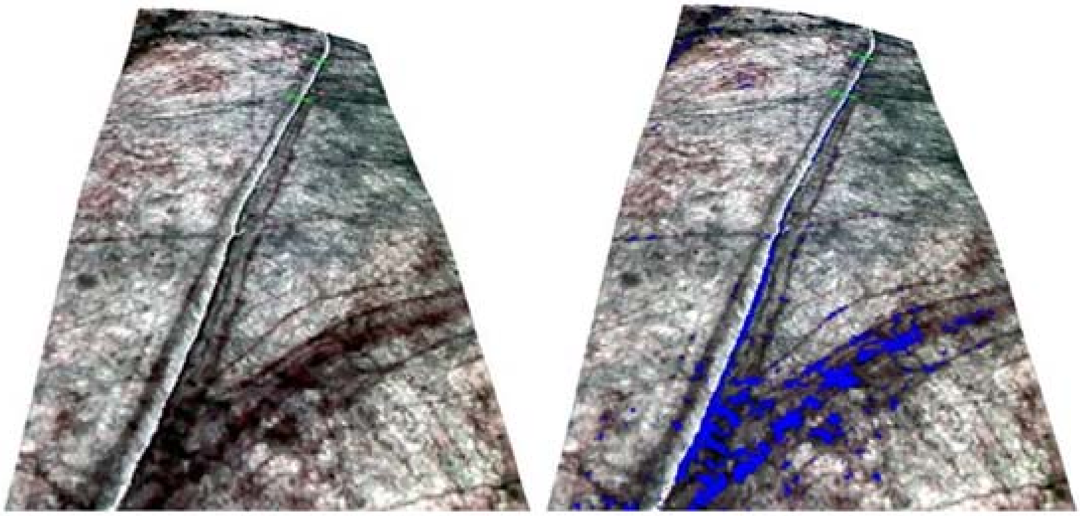

Figure 73 Early stage erosion detection. Left hand image is the CASI data. Right hand image shows areas of bare ground classified in blue

DNPA went on site to investigate these findings and saw evidence of quad bike usage (Figure 74), confirming the possibility of using these data for detecting early stage erosion, before it becomes a full scale erosion problem. Now this area has been identified as vulnerable, erosion of sediment could be monitored using LIDAR data.

Figure 74 Photograph taken by a DNPA field officer. Vehicle tracks are evident veering off from the established path

Although only a few of the outputs of this pilot study are presented here, they show the powerful analysis that can be achieved by integrating several remotely sensed datasets. These data can be used to identify areas susceptible to erosion in addition to routine monitoring and surveillance exercises. Further information about this pilot project can be found in the project report (Hambidge, C and Petchey, S (2010). *Dartmoor National Park Authority Remote Sensing Pilot Project,* Environment Agency Geomatics Group, Bath).

8. Summary

The partnership between Natural England and the Environment Agency Geomatics Group is long standing, with a proven track record. For over ten years this collaboration has facilitated the development of remote sensing products that meet Natural England's operational needs. It is an excellent example of how co-operation between government agencies can produce valuable tools for delivering reporting and monitoring responsibilities.

The success of this collaboration is a direct result of regular communication between specialists throughout each project. This ensures that the final product is fit for purpose and meets the requirements laid down at the outset. The value of this collaboration is not that it is just a mechanism to be able to give away raw data; it is about providing a relevant, timely service. Geomatics Group has the remote sensing and GIS skills in-house to be able to undertake complex analysis, adding value to the raw data. Likewise, Natural England have the ecological and other expertise such as hydrology and geomorphology, that can be applied to the products, giving them meaning and a practical application. It is the combination of both these skill sets held within each organisation that makes the products so valuable.

From a resources perspective, the collaboration enables Natural England to take advantage of the IT network and software that Geomatics Group already have in place for processing and analysing large volumes of data. Set up costs alone to buy the software and hardware would add up to several tens of thousands of pounds and then all this would need to be regularly maintained. Having this collaboration means that Natural England can have all the benefits of using remotely sensed data without a lot of the hidden expense.

Looking to the future, there are many ways in which this collaboration can be taken forward. Innovative applications are always being suggested and explored and new uses for remotely sensed data are constantly being found. Significant advancements have been made over the last few years, but it is likely that many more will follow.