Interpretation of high resolution coastal and marine monitoring data for shoreline management and geohazard risk mapping

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Introduction

The demand for high quality coastal and marine-related spatial information has become increasingly apparent in recent years at a European and national (UK) scale, due to a wide range of increasing pressures. The Defra-funded National Network of Regional Coastal Monitoring Programmes of England (Bradbury et al, 2002) provides important quantitative long-term coastal and nearshore marine monitoring data to improve understanding of coastal processes, rates and trends of coastal change, and enables robust shoreline management and engineering decisions to be identified with confidence.

Temporal and spatial analysis of such datasets enables assessment of: sediment transport studies; coastal slope stability and landslide risk; coastal erosion and sea flooding risk; the performance of beach management plans and coastal engineering works; and the impact and recovery of managed beaches from storm events. Integrating monitoring of physical processes with a range of marine surveys also enables modelling of biological, geological and oceanographic interactions.

Data Collection Programmes

The National Network of Regional Coastal Monitoring Programmes of England comprises six regional programmes and is coordinated and delivered under the Open Government Licence by the Channel Coastal Observatory (CCO) (Bradbury, et al. 2002). The CCO data management centre is hosted by New Forest District Council, in partnership with the University of Southampton and is based in the National Oceanography Centre Southampton. The network of monitoring programmes is managed through a series of lead authorities on behalf of the Coastal Groups and provides a regionally consistent and integrated approach to evidence gathering, delivers strategic actions, maximises the use of data and provides best value.

The principal monitoring and analytical tasks of the regional coastal monitoring programmes include topographic surveys (cross-section profiles, baselines, control network, post-storm and emergency incident recovery surveys of beaches, cliffs and landslides); bathymetric surveys (multibeam and single beam surveys); network of coastal wave buoys, tide gauges and meteorological stations); ecological mapping; aerial photography and photogrammetry; airborne Lidar (Light Detection And Ranging). Data are freely available via CCO website and free web service delivery under Open Government Licence (NFDC, 2010). The regional coastal monitoring programmes have embraced recent advances in land-based topographic monitoring and marine acoustic survey technologies, which has resulted in increasingly cost-effective data acquisition in coastal zone areas.

In order to maximise efficiencies under the ‘gather once, use many times' principle, effective pan-governmental agreements have also been successfully established. The UK Marine Environmental Mapping Programme (MAREMAP) was originally launched in 2010 by the Natural Environment Research Council centres of British Geological Survey (BGS), the National Oceanography Centre Southampton (NOCS), and the Scottish Association for Marine Science (SAMS), and aimed to improve seafloor and shallow geological mapping to achieve national objectives such as habitat mapping, Quaternary science, coastal and shelf sediment dynamics and the assessment of human impacts and geohazards in the marine environment. The programme expanded rapidly with a broadening of the partnership to include the CCO, Universities of Southampton and Plymouth, the Maritime and Coastguard Agency (MCA) principally through the Civil Hydrography Programme, the Centre for Environment, Fisheries and Aquaculture Science (CEFAS), and the Marine Scotland Science (MAREMAP, 2013). These collaborations are resulting in efficient integration of swath bathymetry survey planning, analysis and delivery of marine environmental data, and have resulted in seabed survey data of unprecedented detail being brought together for approximately 40% of UK Waters.

Data Types

This paper will focus primarily on swath bathymetry, topographic laserscan and aerial photography data and present examples of integrated datasets from these data collection and mapping programmes, taken from southeast, southwest and northeast England.

Swath bathymetry

Until relatively recently, the most effective method for capturing bathymetric data within shallow coastal waters was with single beam echo sounders; this involved gathering one profile line at a time, but even when the line spacing is fairly close (~50m) such surveys provide poor spatial resolution and may fail to identify large and potentially important seabed features (Colenutt et al, 2013). High resolution multibeam echosounder systems collect a swath of georeferenced bathymetric soundings and can efficiently map large areas of the seafloor at metre-scale horizontal and centimetre-scale vertical resolution. The widespread application of such systems has meant that it is increasingly economically-viable to achieve 100% sea floor coverage in the nearshore zone, which has opened up new opportunities to understand and address a range of coastal engineering and shoreline management issues as well as contributing towards wider scientific initiatives (Mason et al, 2012). The regional monitoring programmes are increasingly utilising swath bathymetry technology to survey the nearshore zone from approximately Mean Low Water Springs (MLWS) to about 1km offshore, ensuring an overlap with aerial photography, Lidar, and beach topographic surveys (Figure 1). Data have been converted from Chart Datum to Ordnance Datum using the most appropriate vertical offsets and projected to British National Grid on OSGB36 datum in order that the monitoring programme can provide a seamless Digital Terrain Model of the coastal region (Mason, 2012).

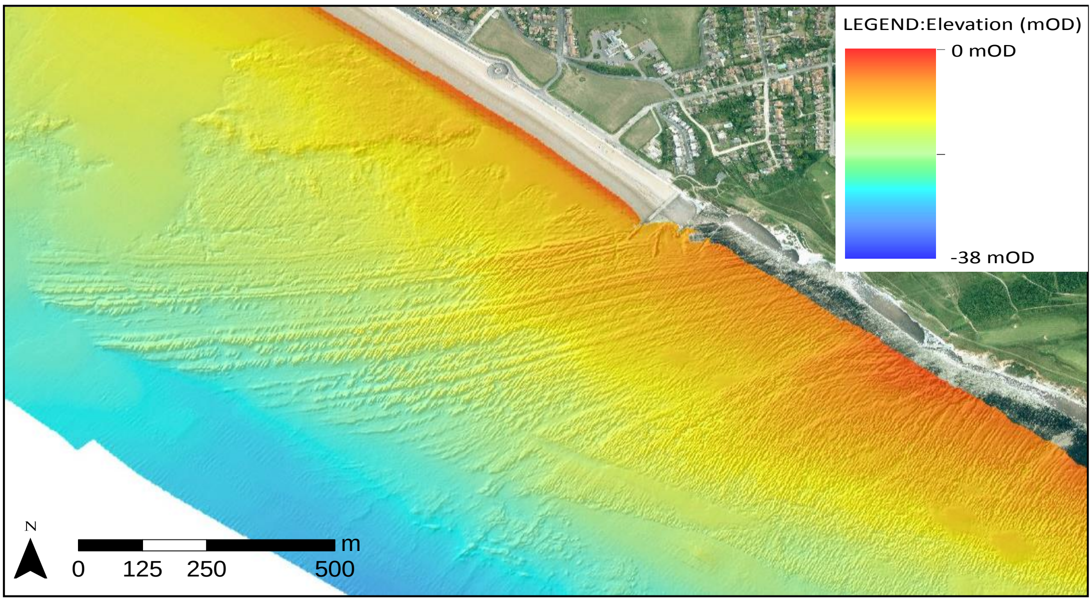

Figure 1. Swath bathymetry and aerial photography data integrated to produce comprehensive coverage of the coastal zone. Seaford, East Sussex

Due to the collaborative partnerships and pan-government agreements that have been developed through the publicly-funded hydrographic survey community, there is an increasing consensus for the gathering of swath bathymetry data to comply with the MCA’s Civil Hydrography Programme's Survey Specification, which ensures data collection and processing achieves the International Hydrographic Organisation Order 1a Standard (IHO S44 Edition 5), which is applicable for depths shallower than 100m. It requires detection of all features larger than 2m in depths up to 40m, and of features larger than 10% of the depth in deeper water. Sediment samples are also obtained for seafloor characterisation and sediment texture analysis. The Specification also requires backscatter data to be collected. Backscatter is a measure of how much power is lost in a sonar beam during its passage from the survey vessel to the seabed and back; the intensity and reflectivity of the returning acoustic signal provides information on the nature and composition of the seabed e.g. a flat rock seabed will reflect the sound beam well whilst, in contrast, mud substrate tends to absorb sound energy (Le Bas and Huvenne, 2008).

Using this Specification ensures that the data is truly multi-purpose since surveys conducted for safety of navigation are automatically suitable for a wealth of other purposes, whilst the converse is not necessarily true.

Terrestrial laserscanning

The Southeast regional coastal monitoring programme have been using terrestrial laserscanning techniques, in addition to existing Real Time Kinematic (RTK) Global Positioning System (GPS) techniques, for monitoring beaches, cliffs and landslides for a number of years. Advances in technology and data processing have made the terrestrial laser scanning technique a viable technique in terms of cost, mobility of equipment on site and advances in computing power. The systems employed have relatively long range data acquisition capabilities, approximately 200-300m, with typical individual data point accuracy of 10-15mm. Digital colour photography can also be captured simultaneously with the laserscan data thus providing red-green-blue values for each point measurement, improving visualisation and thus interpretation of the data. Ground-based laserscanning technologies, combined with Lidar and aerial photography, are being used increasingly to focus on specific issues in the coastal zone, such as onshore-offshore bedrock mapping, and slope instability in cliff-dominated areas. Consistent and repeatable monitoring techniques allow improved understanding and temporal analyses of active landslide and coastal retreat mechanisms. Figure 2 shows a continuous elevation surface generated from integration of Lidar and swath bathymetric data, overlain in part with a higher resolution point cloud generated from a ground-based laser-scanning survey. The latter adds important surveying detail in the lower, near-vertical cliff section, that may not necessarily be adequately defined by Lidar alone.

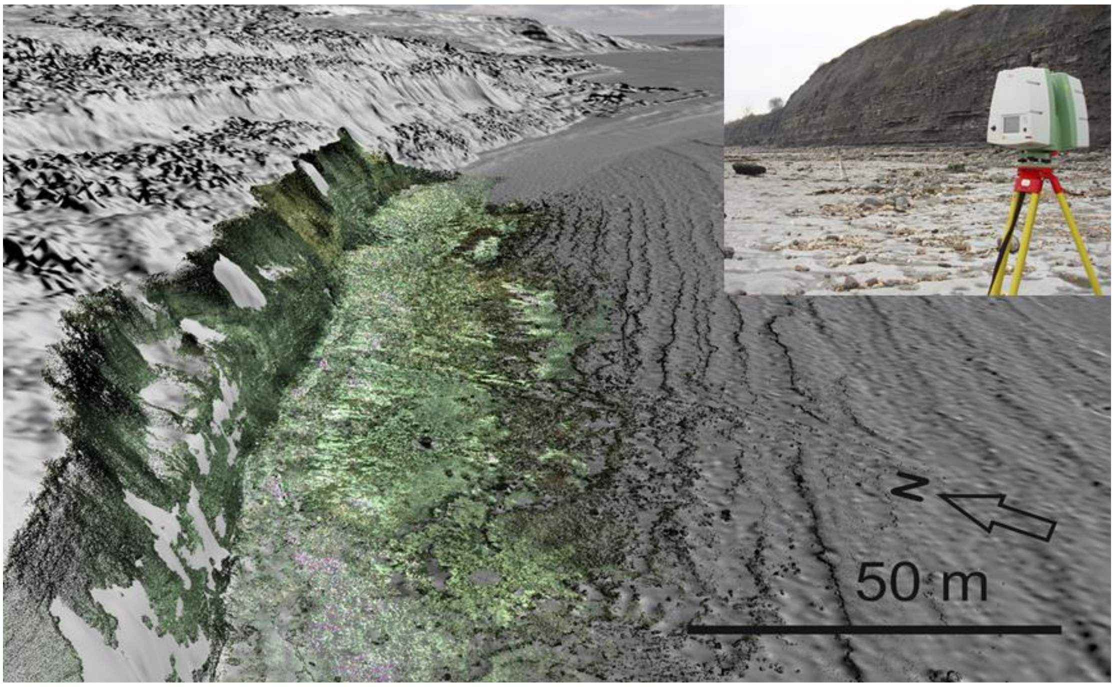

Figure 2. Features of coastal landslides in Monmouth Ledges, Lyme Regis, West Dorset. Inset: Laserscanner mounted on tripod.

The coastal slope in this area is formed by interbedded limestones and mudstones and is actively landsliding and retreating through a combination of mudflows, rotational slides and cliff falls, enhanced by wave action at the cliff base. Narrow beach deposits can be seen at the base of the cliff and widening towards further to the east where they form a significant storm beach.

Digital aerial photography

Digital aerial photographs are images acquired of the ground surface using a nadir-pointing large format digital camera mounted on an airborne platform. The camera calibration properties are used in conjunction with a detailed elevation model to perform geometric correction in photogrammetry, generating a series of orthophotos that are commonly used in geographic information systems (GIS) as contextual overlays draped onto digital elevation models to simulate 3D landscapes.

Applications

Substrate Mapping

Interpretation of the bathymetry and backscatter data, integrated with ground-truthing data provided by a range of other partners, has produced a series of detailed thematic maps including surficial substrate, broad-scale marine habitats, anthropogenic features and marine geology. These are derived through analysis and interpretation of a series of GIS layers. Generating a Hillshade layer, which is a form of artificial sun-illumination applied to the bathymetry, highlights and enhances depth changes and features in the bathymetry. This layer is particularly useful for displaying areas of bedforms and rocky seabed where there are numerous depth changes across relatively short distances. The hillshade and bathymetry layers can be displayed together so that the depth values can be viewed with the desired colour map. The seabed slope layer calculates the angle of slope of the seabed by using a central cell and comparing its value to those around it.

The processed backscatter data can aid the definition of the general distribution of coarse and fine sediment textures and differentiate between surficial sediment and exposed bedrock. Figure 3 clearly illustrates the boundaries in backscatter denoting variability in seabed sediments that are not detectable solely from bathymetry data. There are many environmental factors that affect the backscatter values, and it requires technical expertise to process and interpret the mosaic of backscatter tiles

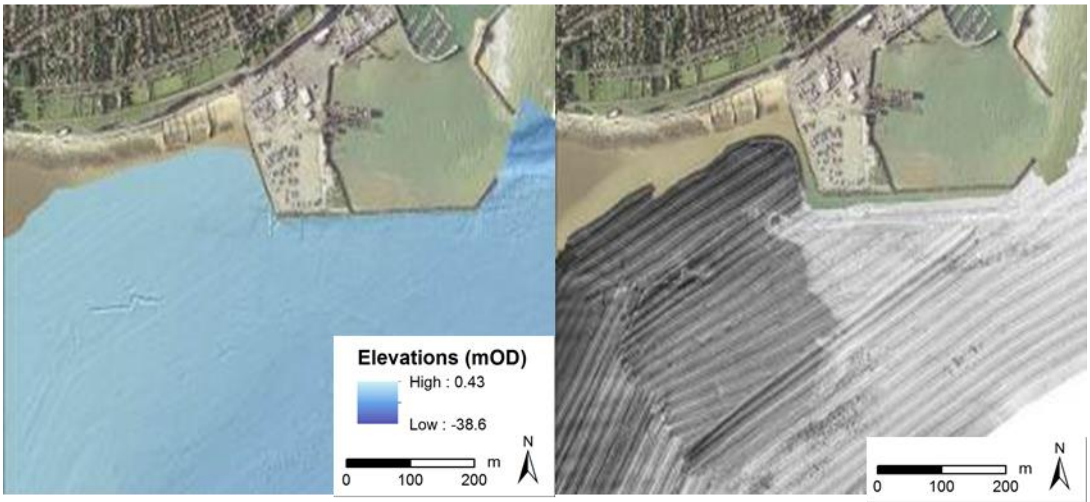

Figure 3. Seabed substrate differentiation and detection from [a] bathymetry and [b] backscatter datasets (Ramsgate, Kent, UK).

The relative importance of these seabed layers varies with seabed terrain and substrate. For example in areas with rocky seabed, rock platforms can be readily identified from the bathymetry, with the aid of the slope layer. In contrast, on a featureless seabed, careful interpretation of the backscatter is needed to infer a change in sediment composition. The type and extent of indicative seabed environments will depend on a range of factors, such as the depth of water, the underlying rocks, the thickness and type of substrate material, the direction and velocity of tidal and seabed currents, and exposure and influence of waves.

The identification of zones of exposed bedrock and surficial deposits of coarse, fine and mixed sediments as shown in Figure 4, provide spatial detail of seabed features, such as sand waves, rock outcrops, pinnacles and scour, and informs future monitoring programme requirements.

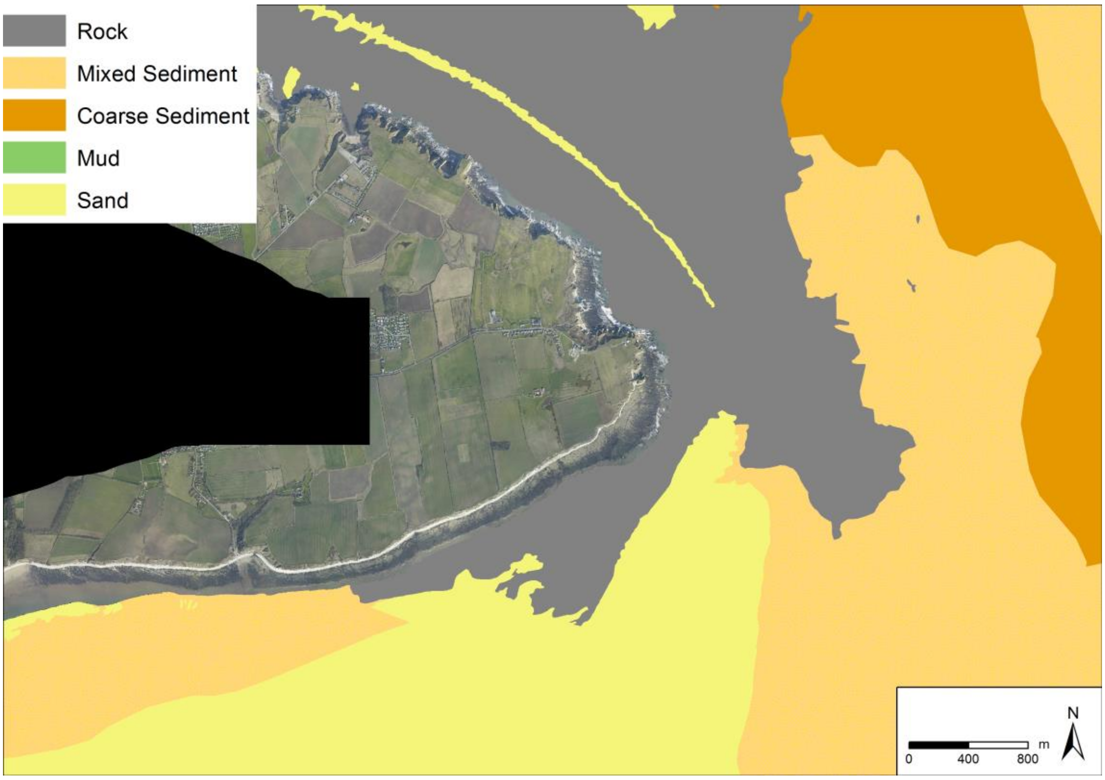

Figure 4 Substrate mapping, Flamborough Head, East Riding of Yorkshire.

Anthropogenic Features

Identifying location, type and condition of anthropogenic features such as pipelines, cables and trenches, wrecks, or trawl marks may provide useful information for marine planning, and indicate levels, type and concentration of marine activities and condition of marine assets. Identification of such features can provide information on mobility of sediment, for example, sediment plumes downstream of obstructions and wrecks, and rates of sediment transport by channel infilling and scouring. Assessing environmental impact or recovery of a site may contribute towards scientific evidence base, and for example, may support pragmatic conservation measures to be implemented or enable offshore developments to progress.

Coastal Stability and Landslide Risk Mapping

A further application of integrating swath bathymetry, terrestrial laserscanning, aerial photography, and seabed mapping data is the improvement in geomorphological and geological surveys (Westhead et al, in press). When combined with innovative 3D mapping techniques and visualisation technologies. These advances are allowing data collected during earlier mapping programs to be reinterpreted in much greater detail. Seamless high resolution surveys of the coast and nearshore zone have been achieved, and permit offshore extensions of onshore geological maps to be produced. This new generation of geological maps and science outputs provide important information about seafloor composition and structure, physical properties and geohazards.

In addition, the correlation of offshore relict landslide deposits with active onshore slopes, as illustrated by the example in Figure 5, has the potential to improve prediction and modelling of the most active areas of coastal retreat, and informs the mechanisms of failure and mass movement, geomorphological mapping and shoreline evolution studies, sediment inputs, geotechnical assessments. At this example site, 7 km to the east of Lyme Regis in Dorset, the cliffs are topped by more resistant sandstones of the Upper Greensand Formation, underlain by weaker mudstone-dominated formations (mainly Lias Group).

This combination of geological layers produces an actively landsliding and retreating coastal slope. The nearshore platform provides a record of this retreat through preserved ‘boulder arcs’ (mapped here with black lines) formed at the toes of former landslides. These are interpreted as recording former positions of the coastal cliff line and sea-level, and extend to at least 700m offshore and to 10 m below current sea-level. Such information will underpin future research into coastal evolution, which in turn could contribute to better predictive coastal management, and hazard and risk mapping.

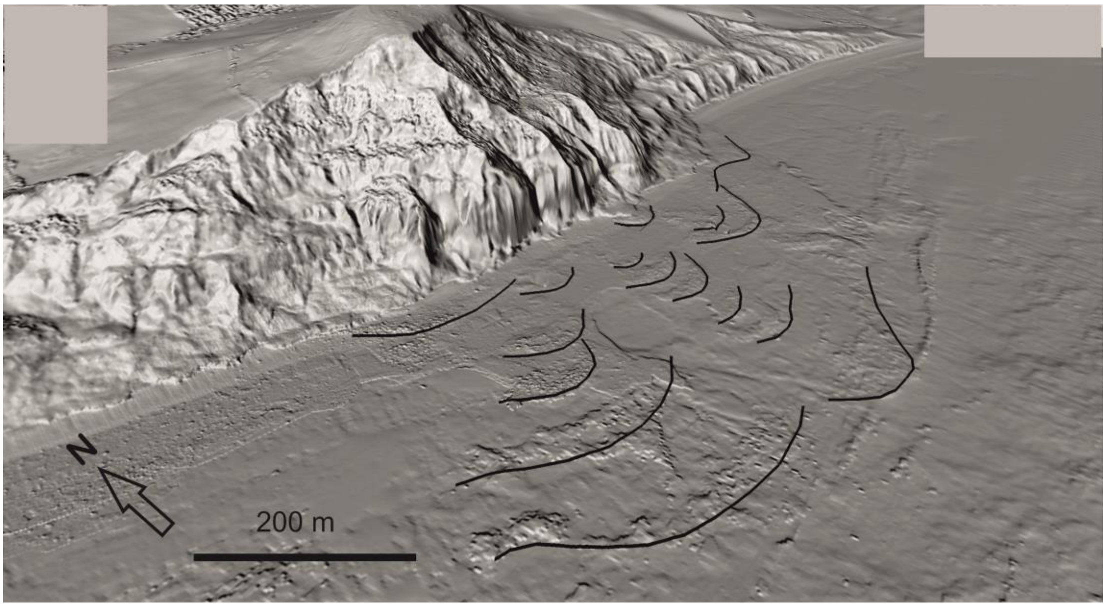

Figure 5. Former coastal positions, landslide features, 3D Golden Cap, Charmouth, Dorset

Sediment Transport Studies

Providing information on seabed texture and micro-scale nearshore and seafloor topography can be useful for management of nearshore zones. Such information, considered with other sources of evidence indicated from other seabed and anthropogenic features, can then be integrated with coastal monitoring data to further enhance the modelling of sediment transport within the coastal zone, which may indicate the mobility or stability of the seabed sediments. The regional coastal monitoring programme's robust, consistent and repeatable data acquisition methodologies enables rates, volumes and directions of shoreline and sub-tidal sediment transport to be assessed and quantified. Sediment budget analysis informs the design, operational performance and post-project appraisal of managed beach frontages, the management of coastal erosion and coastal instability risks, assessment of interaction between coastal processes and defence and offshore structures, and identification of potential sources of sediment that could be available for beach renourishment and recycling operations.

Conclusions

Advances in data capture technologies and techniques, and improvements in consistency of data quality, coverage, availability and interpretation of coastal and marine-related spatial data directly contribute to multi-disciplinary baseline conditions, and have the potential to better inform shoreline management planning and coastal engineering, by providing a more robust scientific evidence base.

To enable planning authorities to consider and assess the impacts of developments at the coast or that contain connections between offshore development and shore-based works there is also an urgent requirement to integrate the overlapping terrestrial and marine planning regimes that cover the inter-tidal zone. It is clearly beneficial to regulators, developers and land and marine-area users to have access to the improved scientific evidence and analytical interpretation to underpin decisions (Westhead et al, in press) and development of pragmatic policies that aim to improve the management of the coast and marine resources.

Coastal management authorities could benefit significantly from interpretation of the nearshore bathymetry datasets to identify sediment types, direction and rates of alongshore and off-onshore sediment transport pathways, and potential nearshore stores and sinks of suitable sediment for future beach management operations. In the longer-term, with further surveys it may be possible to quantify sediment transport budgets in dynamic sub-tidal and nearshore zones. The availability of such marine spatial information may enable more-efficient and cost-effective management measures to be implemented and be of value in terms of evaluating scheme design and performance of structures and beach management operations.

High-resolution substrate mapping through innovative use of bathymetric and backscatter data can better define baseline conditions for monitoring of marine ecosystems. Integration of new nearshore seabed topographic and texture interpretations with nearshore monitoring data can provide improved definition of sediment mobility and stability mechanisms important in subtidal engineering and beach management activities.

Improved mapping of seabed anthropogenic features and their interaction with the environment (e.g. scouring) can support more pragmatic installation of conservation measures and engineering structures at the coast or further offshore. New techniques for repeated, high-resolution measurement of coastal morphology (e.g. repeated ground-based laserscanning) can improve prediction of coastal retreat rates and mechanisms, enabling more effective coastal management works. Innovative geological bedrock and landslide mapping using seamless elevation surfaces through the coastline have the potential to contribute to better predictive coastal management, and hazard and risk mapping.

Within the UK the availability of such high quality data informs the management of tidal flooding and coastal erosion risk and geohazards (Westhead et al, in press), enhances the integration of terrestrial and marine planning regimes, and sustainable use and conservation of coastal and marine resources (Colenutt et al 2013). Such work will have multiple benefits, including: better-informed environmental impact and economic assessments for coastal and marine developments; more effective coastal defence and offshore installations; improved identification of coastal hazards; improved identification and condition assessment of marine heritage features; and improved assessment of seafloor environments and management of resources.

The repeatable, consistent and standardized approach to data collection, analysis and interpretation, coupled with making the publicly-funded data and resulting GIS layers freely available, are significantly contributing towards meeting the requirements of EU Directives, and the UK's legal environmental obligations, and contributes towards improving the scientific evidence base for policy development.

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