APPENDIX

Technical Guidance Sheets for Monitoring

1.0 HYDROLOGY

The frequency and duration of tidal inundation is a key factor in determining many aspects of site development, including sediment delivery and deposition, and vegetation colonisation. However, the frequency and duration of inundation at a given elevation above ordnance datum varies between sites, even those close together. Wave climate (and wave generated currents) can also be a major factor in the sediment-transport cycle.

Where freshwater enters an intertidal site, it effectively becomes estuarine, with the volume and timing of freshwater entering the site controlling variations in low tide salinity and creek depth. Variations in salinity and low tide water depth have implications for flora, fauna and sediment transport. Low-tide rainfall on intertidal areas may also impact on sediment stability and transportation.

High levels of nutrients, such as nitrate, phosphate and ammonium, may indicate poor water quality and increase the risk of saltmarsh erosion. Many realignment projects are carried out on nutrient enriched agricultural land, and the sites may be further enriched by nutrients from other sources, such as upstream water treatment works and diffuse run-off.

REMOTE SENSING – AERIAL

The obvious advantage of Satellite imagery, LiDAR and sUAV (small Unmanned Aerial Vehicle – drone) methods is their high spatial resolution. These methods are especially useful for larger sites or inaccessible areas where the technology can be used to determine the inundation area, extreme wave or high freshwater flow data. These methods are not generally used for short-term observations of hydrological aspects, however, with increasing numbers of satellites and improving drone technology, aerial observations are starting to be used for long-term observations. These types of surveys collect large quantities of data, which would need to be processed for interpretation.

WATER COLUMN AND SUBMERGED BED

Hydroperiod (depth): There are networks of tidal gauges and buoys around many coastlines, which, if sited close to the site, may provide adequate data to estimate the hydroperiod within a site. However, these monitoring points are often off-shore, meaning their data do not take account of near-shore changes to hydrodynamics. It is especially important to understand how the hydrodynamics alter within a managed realignment site, for example, when water enters through a relatively narrow breach into a depth-limited intertidal site. Even more inaccuracies are introduced when there is freshwater flow through a site. Therefore, it may be necessary to introduce localised monitoring, which can then be calibrated with off-shore monitoring equipment. Local changes in depth can be monitored by recording observations against a benchmark, either by eye or using static photography. Pressure sensors can be installed (attention needs to be made for variations in air pressure) to monitor changes in tidal and freshwater depth.

Waves: Offshore waves tend not to propagate into enclosed intertidal sites because of the narrow entrance, so data captured by off-shore wave buoys may not be representative of conditions at a restoration site. Waves within enclosed systems develop across areas that are depth and fetch-limited, therefore waves are generally extremely high frequency. An appropriate pressure sensor, coupled with an Acoustic Doppler Velocimeter (ADV), is an example of an appropriate way to capture wave data within an enclosed site. With the increasing availability of low-cost sensors and data-loggers, it is also now possible to construct inexpensive and open-source tools such as 'mini buoys' in house by following published design guidelines.

Freshwater input: Freshwater input can be estimated by monitoring salinity, either by collecting bottled samples for laboratory analysis or by installing salinity sensors.

Velocity and currents: These are created by the saline water, the fresh water and waves, and impact on the sediment regime of the system and therefore the geomorphology. Although not very accurate, spot measurements can be made by using biodegradable floating objects. Other options include types of Acoustic Doppler Current Profilers (ADCP) and Acoustic Doppler Velocimeters (ADV) (which can be adjusted for shallow water velocity and current measuring) or low-cost 'mini-buoys' constructed in house.

Surface water quality: Bottled samples for salinity and other chemical and/or biological analyses (for example, to quantify pollutant concentrations or bacterial communities) can be taken back to the laboratory for accurate analyses. Hand held meters can give immediate spot readings for some determinands of interest, and probes can be attached to sondes for longer, more regular sampling. Laboratory analyses are generally more accurate. It is worth checking if water quality data is already available for the area of interest from other organisations, for example, data may be collected for regulatory purposes or as part of state of the environment monitoring. However, checks would need to be made to the suitability of the data collection method (especially the sample timings and the sampling frequency) as well as what data has been collected.

TERRESTRIAL SURFACE

Rain and wind gauges can be used to provide more detailed data to estimate freshwater input and waves.

Carrying out a water features survey as part of a walkover survey would help to identify natural water features, including ponds, stream channels, spring lines and artificial water features, before starting construction work on a restoration scheme. It may also be helpful to incorporate a bench study of local geology to check for presence and depth of aquifer units. At realignment schemes, it can be beneficial to repeat the walkover survey after the sea defence is breached, when the die-off of flora may expose more features.

SUB-SURFACE – TERRESTRIAL

Groundwater will control the freshwater seepage points, but it is also critical in understanding if the new intertidal system will increase risk of saline intrusion to the aquifer. To monitor groundwater, boreholes would need to be drilled, with at least one borehole drilled down to the depth of the aquifer/bedrock. After a sea defence is breached, any existing borehole water extraction points close to the limits of the intertidal site should be monitored to check for saline intrusion. Installing an array of piezometers, positioned in boreholes, would enable fluctuations in sub-surface hydraulic head within the sediment to be continually measured. A set of shallow tube well sampling points could be installed to collect samples of pore water, ready for laboratory analyses.

2.0 SEDIMENT AND GEOMORPHOLOGY

Sediment accretion and erosion are very important to monitor for a range of reasons depending on the type of restoration scheme and the project objectives, including:

a) at recharge sites, where sediment retention will determine the project success

b) at low sites, where sedimentation would be needed to raise elevations if vegetation is to colonise

c) to help assess impact of scheme on water quality or blue carbon objectives, because sedimentation rates strongly influence burial of carbon and pollutants

d) to predict how the topography of the site will develop, including formation of creeks, which are important to plants and fish

e) to help identify potential changes in the wider estuary, for example, possible erosion to existing flood defences or movements of navigation channels

REMOTE SENSING – AERIAL

On a regional scale, coastline changes and turbidity can be monitored using satellite imagery. At a large scale, such as at the site/estuary scale, LiDAR and sUAV (small Unmanned Aerial Vehicle – drone) can be used to create digital elevation models of topography, and if these are taken at regular intervals, rates of sediment accretion and erosion can be derived. Structure-from-Motion (SfM) elevation models, using multi-spectral sensors, can produce high-resolution (<3cm xyz) outputs.

WATER COLUMN AND SUBMERGED BED

Moving water sculpts the morphology of intertidal environments, so being able to predict and understand the hydrological processes in a site is a fundamental basic in understanding how the site will develop. Sediment is transported by water, so measuring the volumes of sediment transported and the chemical/mineral composition of sediment can help to understand sediment pathways and sources. Mixed in with, or bound to, the sediment are also seeds, micro-flora, fauna, bacteria and fungi; together they are termed as Suspended Particle Matter (SPM). All elements of SPM are important for the development of intertidal environments.

Volumes of SPM vary with tide, weather and seasons, and the concentration (volume of sediment to water ratio) also varies along and across any channel sampled. Therefore, single point SPM samples are almost meaningless. Instead, consider designing a programme for SPM monitoring. Plan the sampling locations, sample frequency and the duration of the monitoring programme to capture the variability of SPM across the system, both spatially and temporally. At managed realignment sites, include sampling sites towards the breach, at extremities and possibly at intermediate sites. Extend the sampling campaign to cover at least a spring/neap cycle and, if possible, repeat over different seasons. Optimum sample frequency will depend on the chosen methods, but data should be comparable, that is to say, at the same state in a tidal cycle and at the same elevation from the bed. It may be helpful to profile the water column over individual tides to gather data to inform a three-dimensional understanding of a system. Other parameters, such as depth, salinity, conductivity and dissolved oxygen could be collected at the same time.

Bottled samples can be collected regularly by hand or by automated systems, and gravimetric analyses performed in a laboratory to establish SPM concentration levels. Turbidity probes can be used as a proxy for concentration measurements. This method would need seasonal calibration from a site by comparing results to bottled samples to produce an algorithm to calculate concentration. This is particularly important in muddy environments where floc-size may vary. Acoustic Doppler Current Profiler (ADCP) can be boat or bed-mounted and, as with the turbidity sensors, would need calibration.

TERRESTRIAL SURFACE

Although aerial imagery can provide site-scale measurements of the sediment accretion and erosion, the vertical and horizontal precision is usually lower than in situ measurement. To take single point measurements of sediment accretion/erosion, install the monitoring equipment where it will be representative of the data that you would like to capture. Sediment pins, elevation plates or tables are cheap to install and data are recorded by hand periodically during low-tide. However, sediment accretion may exceed the level of the pin, therefore this technique may only be effective over the short-term, especially if sedimentation rates are very high. This technique may also not be suitable in areas of very significant erosion or sedimentation because such locations may not remain accessible after restoration.

Submersible Altimeters (ALTUS systems), which use acoustic measurement, are self-logging, can be set at high frequency and can continually measure depth, and possibly wave data, over extended periods. Fixed-point photography may also be deployed, as long as there is a fixed subject which can be used for accurate scale.

Traditional land-surveying techniques, such as Differential Global Positioning Systems (DGPS) or 3D laser scanning could be used to record whole topographic features, and data on accretion and erosion could be collected by carrying out repeat surveys.

Measuring the strength of the sediment surface can help to understand its erodibility potential or consolidation state, and could help to identify sources and sinks of sediment. On site, a shear vane can be used to measure the undrained geotechnical shear strength, and a Cohesive Strength Meter (CSM) can be used to assess the resistance to erosion by water.

SUB-SURFACE – TERRESTRIAL

Understanding the fabric and structure of the soil/sediment (for example, how erodible, how able roots are to penetrate the sediment and how water drains from the sediment) is important to predict how a site may evolve. Sediment that has poor drainage can inhibit flora and fauna colonisation and growth, and in extremes become anoxic. Pore water is the means by which nutrients and gasses pass through the sediment to and from the roots of the plants. In intertidal environments, pore water is generally dominated by tidal water, however interaction with freshwater sources, such as springs and aquifers, rainwater or even relic clay land drainage systems, can impact on chemistry, which in turn can impact on site development. To assess structure and geochemistry, sediment cores can be analysed with methods such as XRF, XRD, ICP-OES/ITRAX and TOC. Nutrients could also be assessed by extracting pore water from the cores, using centrifugal force or rhizon technology.

In realignment sites, the contact horizon between the old agricultural soil surface and the newly deposited intertidal sediment, often visible from visual inspection of a core, may act as an aquiclude (a formation that hardly transmits water), resulting in sediment waterlogging. Therefore, it is advisable to take core samples from different depths to encapsulate structure either side of the contact horizon. CT scans of sediment cores can be used to help quantify the soil/sediment structure. Physiochemical properties, such as bulk density, grain size, Eh/pH and porosity, that impact on the ecosystem and stability of the sediment, can be assessed vertically through the soil layers by analysing core sections at selected depths.

Sub-surface water features/groundwater flow, buried drainage features and any other buried objects will also impact on geomorphological evolution, therefore Ground Penetrating Radar (GPR) may be helpful to deploy, however GPR does not work on clays.

3.0 FLORA AND MICROBES

The presence of vegetation defines saltmarsh compared to mudflats and is therefore likely to be a critical aspect of monitoring schemes. The vegetation communities that form are also likely to be important to monitor at sites restored to provide compensatory habitat. Some plants, for example, Phragmites australis or Spartina anglica may be undesirable, and monitoring their distribution may be an objective of the monitoring plan.

Different saltmarsh plants contribute in different ways to ecosystem functions and properties such as wave attenuation and sediment stability, and so measuring the presence and abundance of plants may also help to assess the ecosystem services provided by the developing saltmarsh.

REMOTE SENSING – AERIAL

Earth observation data from satellite and/or sUAVs using multi-spectral imagery sensors (for example, Compact Airborne Spectrographic Imager (CASI), Red Green Blue (RGI), Red-Edge and Near Infra-Red (NIR)) can be used to identify broad plant communities (pioneer, Spartina dominated, mid/low, upper and reedbeds) and could therefore be used for some aspects of monitoring. However, spectral signals from a given plant community vary with a range of factors including season, nutrient enrichment and how recently the plants were tidally inundated (leaves may be covered with sediment after recent tidal inundation). Therefore, classifications of plant communities to spectral signals must be site and time-specific, and some ground-truth data would need collecting every time; data for ground-truthing should be collected as close in time as possible to the spectral image collection).

Imagery from drones can be very high resolution and is therefore useful to identify plant communities. However, collection of imagery is restricted to snapshots of relatively small areas due to time, battery, cost, and data processing implications. In contrast, imagery from satellites is more frequent (for example, Sentinel-3 is every 27 days) but at a lower resolution (pixel sizes of >10m x 10m). Satellite imagery may provide useful tools to identify broad-scale patterns, for example, proportion of site vegetated, or may help identify sites that need additional ground surveys.

WATER COLUMN AND SUBMERGED BED

Microbial communities of the incoming tidal waters could be assessed (see below) but, as with all monitoring, there should be a clear purpose for this.

TERRESTRIAL SURFACE

Permanent quadrats can be used to identify when vegetation becomes established National Vegetation Classification (NVC) communities, although developing communities fit NVC poorly. Additional vegetation surveys would be needed to identify the presence of rarer communities or species, or to specifically monitor transplant survival or growth.

Species distribution models that relate existing vegetation data to environmental variables (such as elevation and topography, derived from digital terrain models) can be used to predict the presence of a particular species. Artificial turf has been used to assess seed rain (number of seeds reaching an area) in saltmarshes, although the benefit of doing this for monitoring purposes may be low because collected seed tends to be dominated by species that colonise quickly.

Local natural saltmarshes (ideally more than one site) should be sampled to provide reference vegetation communities for comparison. When selecting reference sites, consider the salinity (of both of the incoming tidal waters and any local flushes, seepages) and local management (for example, grazing intensity and history, and grazer community) because these factors strongly influence the composition of the plant community.

SUB-SURFACE – TERRESTRIAL

Roots of saltmarsh plants provide stability to the sediment and this could be monitored if desired. This can be done by taking cores, washing off the sediment and then making measurements of the root mass, length and structure. Alternatively, CT scanning can be conducted on cores to provide models of root structure.

Bacteria and fungi: These are currently understudied in restored saltmarshes and further research into community development and resulting ecosystem function (for example, nutrient cycling) would be beneficial for future projects, especially to help understand their influence on plant establishment and carbon storage. Bacteria and fungi DNA can be extracted from soils for community analysis and their functioning assessed.

4.0 CULTURAL HERITAGE (ARCHAEOLOGY)

The impact of any restoration scheme on heritage assets must be fully assessed and, if necessary, mitigated before starting ground work. For large realignment schemes, an appropriate archaeological team should be involved from the start of the process to assess, through desk-based studies and field evaluation, the likely scope of impact on designated and non-designated heritage assets. This team should include geoarchaeological experts with expertise of working in coastal and intertidal contexts. At some stage in the planning process, a full geoarchaeological and surface archaeological survey is likely to be required for major restoration schemes. However, with some consideration and planning, synergies may be found across the full multidisciplinary team, which could provide useful data for the archaeological evaluation and, overall, provide scope for cost-savings.

Understanding the historical geological development and anthropogenic use of a site is also important for predicting and understanding how the site will develop, including where creeks may form and flora establish.

REMOTE SENSING – AERIAL

Cultural heritage and geoarchaeological features can often be identified by capturing topography or revealing subsurface features through vegetation colour contrast, using remote sensing technology, such as satellite, LiDAR or sUAV (small Unmanned Aerial Vehicle – drone). Photogrammetry, using fly-over photographic mosaics geo-referenced to hard survey points, enable images to be converted into rectified accurate maps and 3D topographic models. Timing of such surveys is important because some features, such as old channels, may only be visible during low tides, following a scour caused by a storm event or during the summer growing season. If aircraft or drone surveys are being carried out for other reasons, it would be beneficial to liaise with the archaeological team to maximise useful data capture from those surveys.

WATER COLUMN AND SUBMERGED BED

At managed realignment sites, the hydrodynamics will change outside of the breach area, and may result in scour and changes in geomorphology. Hidden historical geo-features provide important evidence that can be used when predicting how the site could develop. Changes in bathymetry may also impact on nearby cultural heritage sites. Bathymetric surveys would provide detail of the inundated landscape. Sharing this information with the archaeological team and comparing with relevant models can be beneficial to help gain an appreciation of the scale and likely impact of those changes.

TERRESTRIAL SURFACE

Geo-physical surveys, such as resistivity, palaeomagnetism and ground penetrating radar, along with walk over surveys before, during and after site construction can provide information on areas of interest and back up remote sensing data. While the archaeological team will want to carry out such work to meet specific purposes, there may be scope to combine surveys or share data with other disciplines.

SUB-SURFACE – TERRESTRIAL

Geotechnical ground investigations, using a mix of mechanically dug test pits, cable percussion boreholes, window sample cores, hand augurs and hand dug test pits, are routinely commissioned near the start of major projects. These surveys provide useful geoarchaeological data. Attendance by a qualified geoarchaeological team would add value. Such specialists can develop first order deposit models for those areas covered (deposit models use existing information to map the distribution of buried deposits of archaeological interest across a site), take spot samples for dating and palaeoenvironmental assessment (palaeoenvironmental processing involves washing soil samples to separate microscopic material for assessment and analysis), and advise on any artefacts or structures encountered. This information may allow areas of the site to be characterised as low potential very early on in the process and would commensurately reduce the scope and costs of later work.

The scope of a purposive geoarchaeological field evaluation would also use the range of interventions outlined above. Part of this work would be to attempt to collect intact cable percussion cores (to record deposits in detail), palaeoenvironmental samples (for pollen, mollusc, micropalaeontology and small vertebrates) and dating samples. Most commonly, sediments are dated through Carbon14 and Optically Stimulated Luminance (OSL), dating the last time quartz grains were exposed to sunlight. This work would allow specialists to develop a full deposit model of the site and characterise each major sedimentary unit in terms of age, depositional contexts (colluvium, gelifluction, alluvial, lacustrine, intertidal and marine) and past ecology (for example, pasture, woodland, saltmarsh and near-shore marine).

This would allow for targeted archaeological mitigation and, most crucially, would allow on-going changes to the coastline to be understood within a well-established geoarchaeological framework.

5.0 FAUNA

If a restoration scheme will have a significant direct effect on protected species (often, but not exclusively, great crested newts, water voles and badgers), monitoring of these species would be required before the scheme can be carried out. These species have standardised surveys that will not be described here and best practice monitoring for these species should always be conducted.

As many saltmarshes are created as compensatory habitat, collecting data on how birds use the restored site is a common monitoring objective. Monitoring the benthic invertebrate communities that establish in restored saltmarsh can also help to study its suitability for wading bird communities. Monitoring of other invertebrate communities (such as ground beetles and spiders) is rare, even in research projects.

Use by fish, particularly by juveniles of commercially important species, is an important ecosystem service of saltmarshes, but more information is needed on how, when and by which species on both natural and restored saltmarshes. Each site is unique and provides novel opportunities to study the success of site design and evolution for fish utilisation over time.

Otters do use saltmarshes and surveys for this may also be beneficial to include.

REMOTE SENSING – AERIAL

Fish: Understanding how the flows move across the site during the whole tidal cycle would provide important information on which to build an efficient fish sampling regime. The hydrology can be studied using remote sensing, such as uAVs, together with walk over surveys (see Sheet 1. 'Hydrology'). Both should be conducted at periods so that when combined together they span the whole tidal cycle.

WATER COLUMN AND SUBMERGED BED

Fish: When we understand how fish move across the site throughout the tidal cycle, we can develop a robust fish sampling regime. Passive methods, such as fyke nets and block nets, can be set in drainage channels to intercept fish as they either access or egress the site. Active methods, such as seine nets, can be applied to standing water bodies at either high or low water when flows are minimal. Small light weight dredges can be drawn through shallow water bodies at low water. With a full understanding of how and when the tidal streams move across the site, a complete programme of active and passive sampling methodologies can be applied across a single tidal cycle.

Fish utilisation of intertidal habitats is very seasonal and highly dynamic, making quantitative studies very difficult. Long-term monitoring programmes would be needed to develop robust estimates of fish production in situ. Long-term studies would also help to describe how physical site evolution influences fish utilisation over time. Development of acoustic monitoring is increasing and has been employed in other environments, for example, to monitor eels. Gut content analysis of captured fish can indicate active feeding on restored sites.

Underwater video monitoring can provide important observations on how fish interact with habitat features such as channel topography and vegetation stands.

Fish and other vertebrates: The presence of a particular species (for example, otter, water vole, a commercially important fish) and whether its use is increasing could be investigated using eDNA, however eDNA cannot provide clear evidence of the absence of a species.

Phytoplankton and zooplankton: Phytoplankton and aquatic invertebrates in pools on saltmarshes are rarely surveyed, likely due to their largely ephemeral nature. However, larger, more permanent pools or lagoons, for example, in regulated tidal exchange sites, may have interesting communities. These communities could be surveyed by taking water samples, for example, cylinder surveys.

TERRESTRIAL SURFACE

Birds: Wader and wildfowl counts are stochastic, varying seasonally and across the tidal cycle. Integrating with the existing Wetlands Birds Survey (WeBS) would allow changes in site counts to be put into a wider population context. Additional winter counts would inform an understanding of site use across the tidal cycle (roosting and feeding areas), and dedicated surveys would be needed for wintering passerines and breeding birds (for example, redshank).

Non-benthic invertebrates: Non-benthic invertebrate communities are understudied and research surveys of these would be beneficial. However, monitoring of invertebrates must consider the time and expertise required in their identification if the value of the data is to be realised. DNA metabarcoding of samples can be used to estimate species richness, but establishing abundance with these techniques is in its infancy; furthermore, relatively few species may be in sequencing databases, reducing the ability to put a name to species. Lui *et al.* (2019)[1] provide a practical review of the values of metabarcoding to invertebrate sampling.

Ground beetle and spider assemblages can be sampled effectively with groups of pitfall traps, which can also assess amphipod abundance, although these need to be deployed between tidal inundations. Sweep netting and/or suction sampling can be used to assess invertebrates on low vegetation (for example, flies, bugs and other spiders). There are a wealth of other sampling techniques for invertebrate communities and Sutherland (2006)[2] has summarised the pros and cons of these.

Ungrazed saltmarshes support important pollinator populations and monitoring of these would be interesting. There are standardised pollinator transect methodologies, although transects alone sample fewer species of solitary bee and hoverfly compared to the additional use of pan traps (see O'Connor *et al.* (2019)[3] for a review of pollinator survey methods).

Some invertebrate species are specialists of saltmarsh plants, for example, larvae of the micromoth, *Aristotelia brizella* feed on sea pink and sea lavender. Relatively little is known about these species, particularly in restored saltmarshes where sea pink and sea lavender are infrequent compared to natural saltmarshes, and taxon-specific surveys would need to be designed if studying them is within the monitoring plan. In addition, there are specialist coastal species (for example, Fisher's estuarine moth, *Gortyna borelii lunata*) for which specific surveys may be desirable.

SUB-SURFACE – TERRESTRIAL

Benthic invertebrates: These give an indication of food available for birds, but surveys are labour intensive so may be best deployed if bird populations are not using the site as anticipated. Benthic invertebrates are sampled by taking cores (or other sediment samples) and wet-sieving to remove the sediment and collect the invertebrates. Core size should be tailored to the invertebrates targeted, with large polycheate worms needing larger cores dug fast to prevent their escape.

[1] Liu, M., Clarke, L. J., Baker, S. C., Jordan, G. J., & Burridge, C. P. (2020) A practical guide to DNA metabarcoding for entomological ecologists, Ecological entomology, 45(3), 373-385.

[2] Sutherland, W. J. (Ed.). (2006) Ecological census techniques: a handbook. Cambridge University Press, Cambridge, UK.

[3] O'Connor, R. S., Kunin, W. E., Garratt, M. P., Potts, S. G., Roy, H. E., Andrews, C., ... & Carvell, C. (2019) Monitoring insect pollinators and flower visitation: The effectiveness and feasibility of different survey methods. Methods in Ecology and Evolution, 10(12), 2129-2140.

6.0 CARBON STOCK AND SEQUESTRATION

Carbon sequestration is an important ecosystem service performed by saltmarshes. To quantify the amount of carbon stored in the sediments of restored saltmarshes we need to assess: i) the net amount of sediment the site has accumulated (accretion minus erosion) and ii) the amount of carbon in that sediment (accounting for the density of the sediment). It would also be beneficial to understand the source of the carbon accumulated; does it originate on site, upstream or from the marine environment. Saltmarshes may be substantial producers of greenhouse gases (particularly methane and nitrous oxide) and so, if a full carbon budget is desired, these should be quantified or estimated with a suitable proxy, although the latter is not currently available (elsewhere in the world, vegetation indicators of gas fluxes have been identified).

Quantification of the carbon in the biomass (above and below ground) of the plants that have colonised may also be desirable. For a full carbon budget, the carbon 'spent' in the construction of the site would be needed. Some agencies, for example, the Environment Agency, have carbon calculators to help quantify this.

REMOTE SENSING – AERIAL

Net sediment accumulation can be quantified using digital terrain models (DTMs) derived from regular LiDAR or sUAV surveys. However, these should be taken at intervals that consider both the error of the LiDAR elevations and the likely amount of sediment accumulation. Baseline images taken immediately before restoration and before construction would be valuable.

Some studies have been able to estimate above ground biomass by coupling ground-truthing field data with satellite imagery (Normalised Difference Vegetation Index (NDVI)). However, these plant communities have been typically monocultures and the applicability to more mixed communities will be reduced

WATER COLUMN AND SUBMERGED BED

Non-available at time of print.

TERRESTRIAL SURFACE

As described above, additional in situ measures of sediment accretion and erosion would help confirm the LiDAR-derived DTMs. Above-ground biomass of plant matter can be assessed by collecting all above ground material in a given area, then drying and weighing it.

Fluxes of greenhouse gases may outweigh sediment carbon burial in some saltmarshes and so are an important measure. These can be measured in situ with a portable greenhouse gas analyser or samples can be taken for later analysis in the laboratory.

SUB-SURFACE – TERRESTRIAL

The proportion of carbon in the sediments/soils can be assessed by laboratory analyses of samples. If changes in the proportion of carbon between the pre-restoration soils and the post-restoration sediments are of interest, cores can be taken and divided before analysis. The total carbon fractions of the soil/sediments can be assessed with elemental analysis. The organic carbon fraction can be quantified by first decarbonating the samples.

Isotopic analysis and/or identification of certain biomarkers can provide indications of the source of the carbon.

Below-ground biomass is a component of the potential carbon stored in the sediments and so may be a useful measure. This can be quantified through the removal of a known volume of sediment with root matter, washing off the sediment, and drying and weighing the root matter.