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Dynamic Coast

Enhanced Change Analysis

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The cover image shows: (Top) Storm waves reflecting and undermining artificial defences at Golspie, Highland. Copyright: A. MacDonald (2020). (Bottom left) coastal erosion of the beach crest adjacent to the World Heritage Site at Skara Brae, Bay of Skaill in Orkney. Copyright: A Rennie / NatureScot (2019). (Bottom right) an oblique aerial image of the Splash play park at Montrose looking north. In the 1980s the play park was set-back within the dune, due to the subsequent coastal erosion, now it is in a more exposed position relying on artificial coastal defences. Copyright: F. McCaw (2021).

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Contents

WS3 Enhanced Change Analysis (Technical Annex)

Context

The Dynamic Coast research delivered in 2017 was based on changes in the position of Mean High Water Springs (MHWS) over time; chosen as MHWS is one of the few available coastal datasets recorded and mapped at a national level. This national availability resulted in widespread use in underpinning the legal boundaries of the coast and, despite a change of name (from HWMOST to MHWS), it has been mapped by Ordnance Survey (OS) for over a century. However, it remains that MHWS is not readily seen and identified on the beach and so coastal scientists have employed other features to help track changes in the position of the coastal edge both at the time of MHWS mapping and between such surveys taking place. On some open coasts, experiencing high wave energies, MHWS is located within an active zone which means strong seasonal variations can mask longer-term trends. We have chosen to use the 'vegetation edge' (as an additional approach to MHWS analysis) as the most recognisable and easily identifiable feature both on the ground and within remote sensing imagery (satellite, aerial and drone). It is also the line that most people identify as the coastal edge or, at least, the point where "useable, productive and asset-filled" land ends and the mobile coast begins. Whilst there are some methodological complexities, the analysis of the vegetation edge is intended to complement the changes further down the beach at MHWS and (if available) alongside MLWS. Whilst these methods are presented separately, a richer understanding of coastal changes can be achieved when multiple methods are employed and compared in parallel, as has been done for the Dynamic Coast supersites.

Methods

Changes to the vegetation edge position at various time intervals were established in three main ways:

1. **Aerial imagery:** NatureScot's back catalogue, supplemented by the University of Glasgow's licensed imagery through the EDINA air-photo catalogue was also used to manually digitise and provide a collection of time-lapse vegetation edge datasets over 36 locations, with a total length of 482 km over all epochs (approximately 2000-2021). On eroding shorelines, the vegetation edge is often clear but on stable and accretional shores (such as saltmarsh) there can be a diffuse or fuzzy boundary; not easily summarised into a sharp-edged line. In these situations, a 50% threshold was employed (where vegetation occupied >50% of the area) and a comment is inserted within the data set to reflect an indicative accuracy attached to the line position.
2. **Ground survey:** A key benefit of using the vegetation edge is that it is readily identified on the ground and so our time-lapse aerial survey data has often been supplemented, with ground surveys at multiple dates, to add further detail. We employed a sub-metre GNSS receiver (EoS Arrow 100) to ensure a comparable level of locational precision between the survey approaches. The EoS Arrow 100 typically provides an accuracy of ca 15cm, comparable with the pixel size of standard air photography. Comparing ground survey and aerial-derived lines works best on rapidly eroding coasts but given uncertainty between methods care must be used on more static coasts where two methods have been used, where actual change may be smaller than measurable differences with each method.

Figure 1 Picture of EOS Arrow being used to survey vegetation edge at St Cyrus National Nature Reserve (North of Montrose Bay, Angus). © A.Rennie/NatureScot.

3. **Satellite imagery:** the Dynamic Coast project collaboration agreement with Ordnance Survey explored the use of unsupervised classification (rule-based) of high-resolution satellite images to identify the vegetation edge. Whilst the full report is annexed here a summary is provided below. Satellite derived Earth Observation (EO) data as an alternative to airborne or terrestrial methods has the potential to efficiently and cost effectively observe coastal changes over large areas and time. In the 1970's the freely available optical EO Landsat 1 (Campbell & Wynne, 2011) imagery that was commonly used had a spatial resolution of 80m, with later satellites from Landsat onwards typically reaching 30m in the spectral bands, and 15m for the panchromatic band. This is often too coarse to be of use in large scale mapping situations in Scotland. However, this changed with the increased availability of 10m visible bands and Near Infra-Red bands for Sentinel-2 data and sub-metre EO data from commercial companies such as Airbus, Maxar (formerly DigitalGlobe) and Earth-i. Using the seaward vegetation edge as a reference, a metric is needed to observe spectral changes in ground cover using EO data, such as Normalised Difference Water Index (NDWI) and Normalised Difference Vegetation Index (NDVI) (Maglione, et al., 2014). Using these indices to provide estimates of the vegetation edge position, the EO derived data was compared with ground survey and aerial photography data for the selected dates of satellite imagery acquisition at St Andrews. NatureScot's early method statement was developed by Ordnance Survey and indicative results are shown below.

The utility of using vegetation edge position can be seen in Figure 4 to Figure 11 where the vegetation edge was used to identify areas of increased erosion in a variety locations and coastal types. Greater analytical understanding is possible when the change to vegetation edge is compared with changes to high and low water marks, or to volumetric changes across the foreshore and dune face. When comparing vegetation edge changes with high water projections, it is important to recognise the horizontal offset between MHWS and the vegetation edge.

Indicative Results

The value of vegetation edge assessments lies at the local / detailed scale, the Dynamic Coast project has undertaken manual assessments across 36 locations, many of these as time-series datasets (Figure 2). This provides a preliminary network of monitoring sites which is being enhanced by Earth Observation analysists at NatureScot, to automate vegetation edge extraction from Colour InfraRed (CIR) imagery alongside standard (RGB) photography. Such analysis could be supplemented, on a case by case basis, with aerial imagery from earlier periods where these are helpful / indicative. The National Collection of Aerial Photography (https://ncap.org.uk/) may be helpful in this regard.

A key benefit of plotting time-series vegetation edge positions (however derived) lies not only in the visual impact of annual or sub-annual mapped updates of the coastal edge, but also in the utility of using the distance between each dated survey line and the elapsed time, to calculate rates of change. Figure 4 shows this for 2007-2020 at Montrose and can be used to identify increase in the rate of coastal edge recession over time. These are published on the Dynamic Coast web-map site (Dynamic Coast Webmap – to view these please turn on the 'Vege Edge (all sources)' layer). At Montrose, this data is now augmented by a series of oblique ground images taken from two fixed points at the south and north ends of Montrose Bay and collected into a usable dataset of coastal edge change (navigate the map to Montrose Bay within www.spotteron.com/coastsnap). The photos are collected by members of the public and help consolidate awareness of coastal erosion among the local community. Exemplars of the use of the vegetation edge data are reproduced below.

Figure 2 Location map of the network of 36 sites for vegetation edge surveys from all sources (including satellite/aerial/drone imagery and ground survey).

Figure 3 Montrose Links CoastSnap post which allows members of the public to take and share fixed point photography. Such citizen science complements ground and aerial analysis. © J.Adams / D.Pender {TBC}.

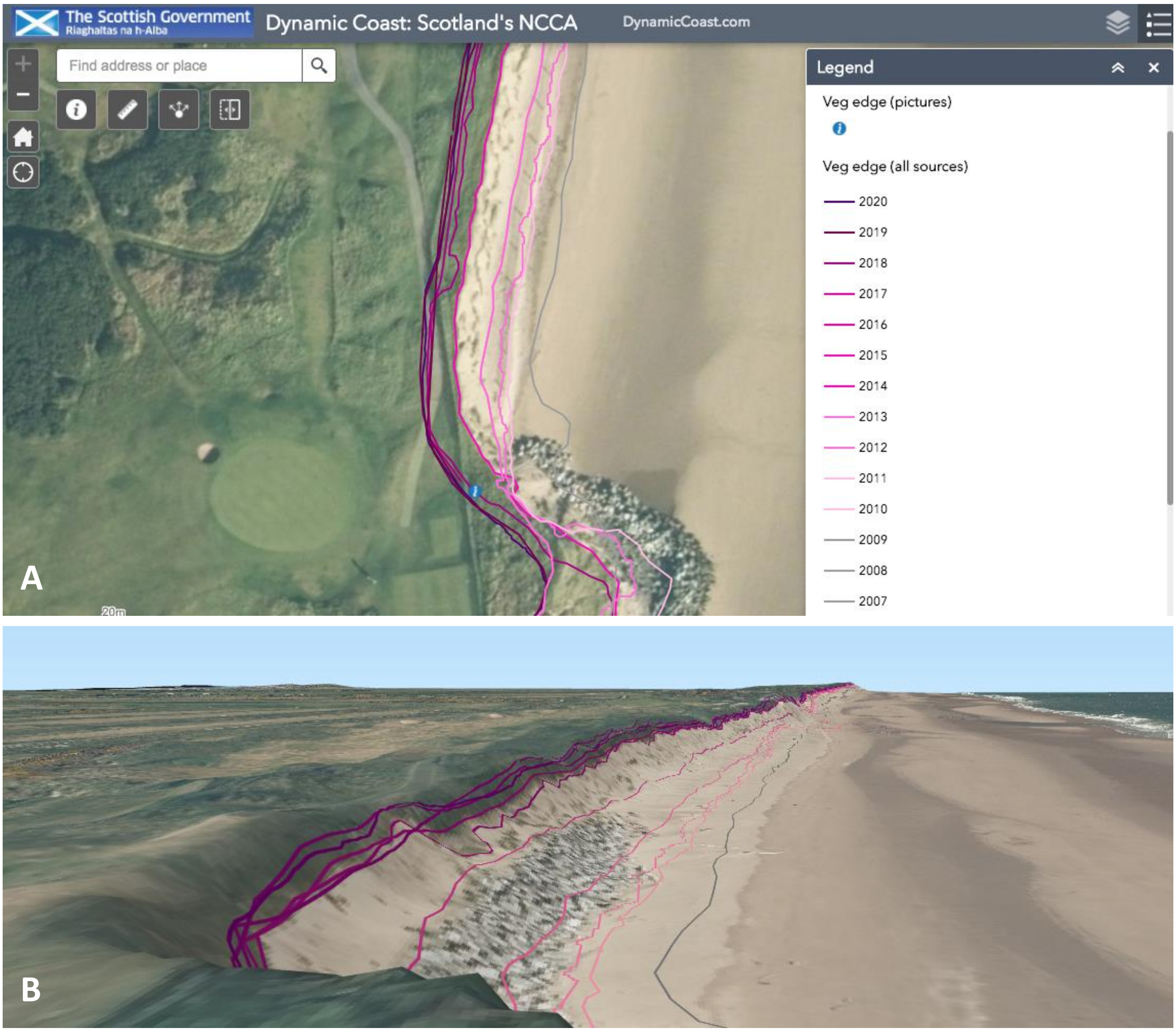

Figure 4A: Extract from Dynamic Coast web map showing the vegetation edge lines and coincident fixed-point photography (from seaward to land: grey 2007, pink 2011, 2012, 2013, darker pink 2015, and 2018, 2019, 2020 in dark purple). B: Oblique view of Figure 4A looking north.

At Montrose Bay Figure 5 below shows time-series observed changes in vegetation edge positions based on recent aerial photography and ground survey. The vegetation edge at the southern section of the bay shows consistent erosion, which is typically associated with undercutting of the dune toe due to incident wave action occurring during high spring tides. Figure 6 shows ground surveys from mid-January 2020 that captured erosion of the Vegetation Edge caused by Storm Brendan (13 Jan 2020). Figure 6 shows rates of change of the Vegetation Edge, High Water and Low Water tidelines, at a representative transect near the southern section of dunes. Whilst this shows variability over time in the rate of Vegetation Edge erosion, with variability in MHWS and MLWS obscured due to the lack of data for intervening years, the overall erosional trend of Vegetation Edge and MHWS is clear. Landward movement of MLWS has slowed over the more recent period, perhaps partly due to gain of sediment eroded from the upper beach and dunes. Nevertheless, the overall trend is for erosion of all three indices and attendant foreshore lowering.

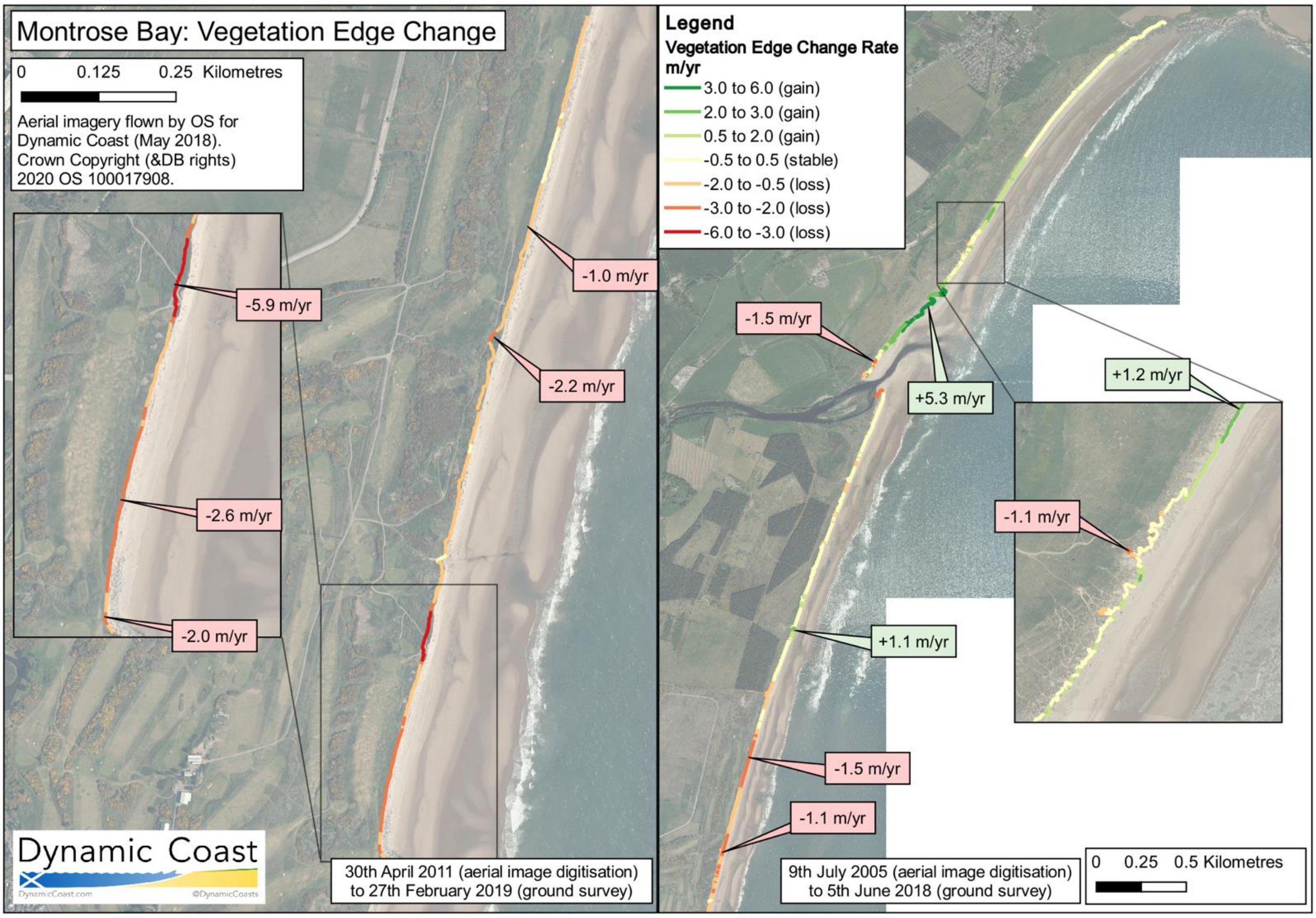

Figure 5 Past vegetation edge change maps of Montrose Bay (2011 to 2019 and 2005 to 2018) where landward erosion is shown in red colours, little change in yellow and seaward gains are shown in greens. Note the -5.9 m retreat, reflects the retreat of the vegetation edge following the removal of the rock armour at this location

Such up-to date change intelligence on recession of the vegetation edge is of great benefit to coastal managers and Local Authorities and allows them to be reactive in the short-term to protect key low-lying areas from erosion and potential flooding and pro-active in the medium and long-term to put in place strategies to cope with future, and possibly accelerated, erosion trends. At Montrose this is already under way with Angus Council and Montrose Links Golf Club employing Dynamic Coast data and forward look intelligence to enhance coastal resilience by planning for the future.

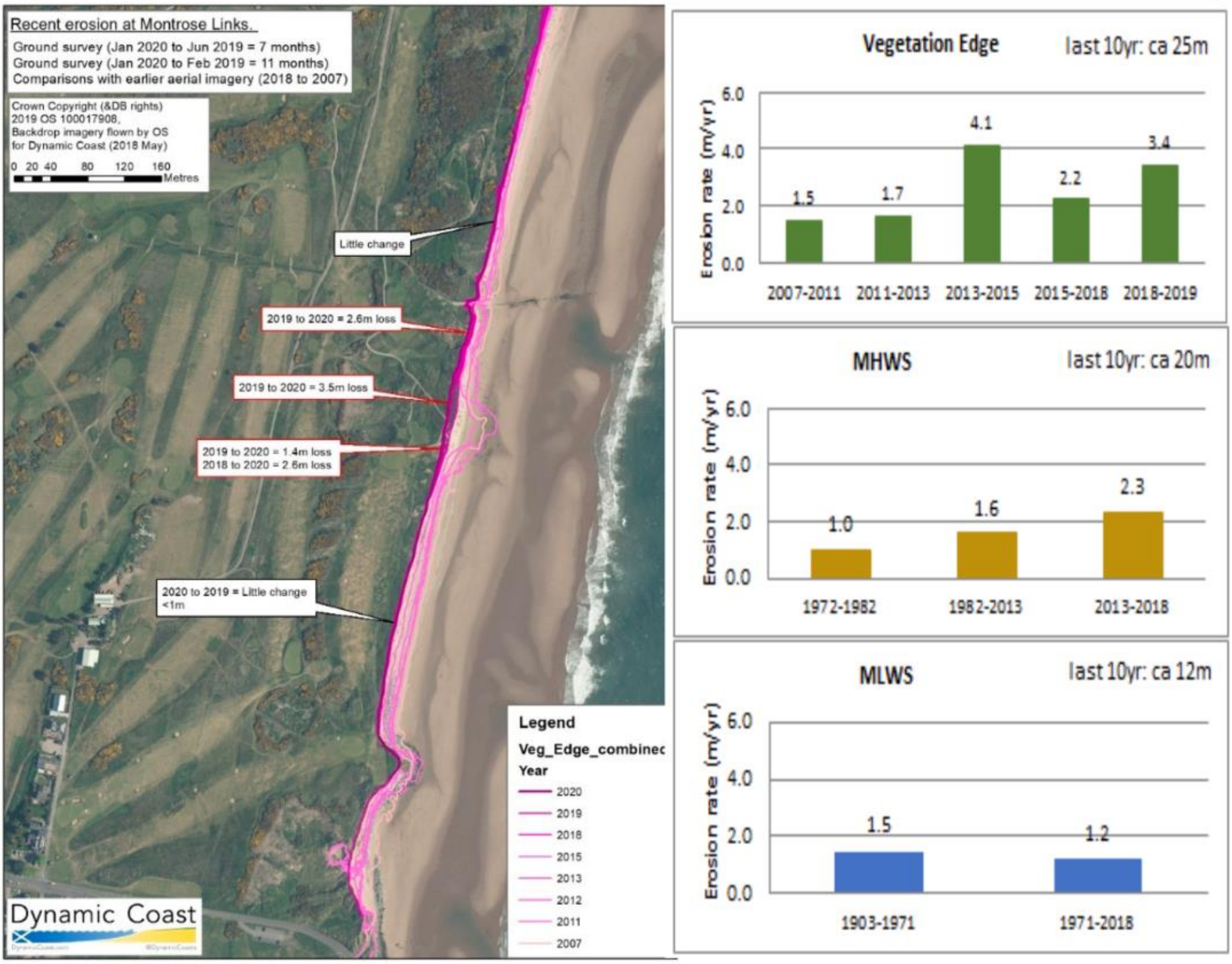

Figure 6 (left) Detailed vegetation edge changes following Storm Brendan (ca. 12th to 14th January 2020) of Montrose golf links compared with recent ground survey and aerial photography analysis. (right) Comparison of rates of change – Vegetation Edge, Mean High Water Springs and Mean Low Water Springs.

At St Andrews Figure 7 below shows time-series observed changes in vegetation edge positions between 1850 and 2018 at St Andrews Links, based on early mapping updated with recent aerial photography and ground survey. It is important to note the substantial works undertaken by SALT and FCCT over the last decade, where extensive areas have been fenced, planted and pressures removed. The trends shown largely mirror the changes in MHWS positions and shows gains along the West Sands, gain at Out Head and relative stability along the Eden Shore, but some recession of the vegetation edge south of Out Head. These planimetric changes, showing gains and losses of MLWS, MHWS and vegetation edge, greatly help inform volumetric changes in the intertidal zone and dunes and set the scene for informed management decisions such as locations and volumes of sediment required for any beach nourishment scheme.

Whilst the above analysis is useful, the destination and fate of the eroded sediment may not be fully resolved until a full assessment of volume gains and losses is made of the entire coastal cell, or at least this section of the sub cell. At

St Andrews, the northward export of eroded sediment has certainly resulted in local accretion beyond Outhead and ongoing transit north toward Tentsmuir, Tentsmuir Point and Abertay Sands. Since much of this potential accretionary activity is subtidal, the volume gains remain unknown and will remain so until a full bathymetric or marine LIDAR survey is conducted and linked to the terrestrial survey above MLWS.

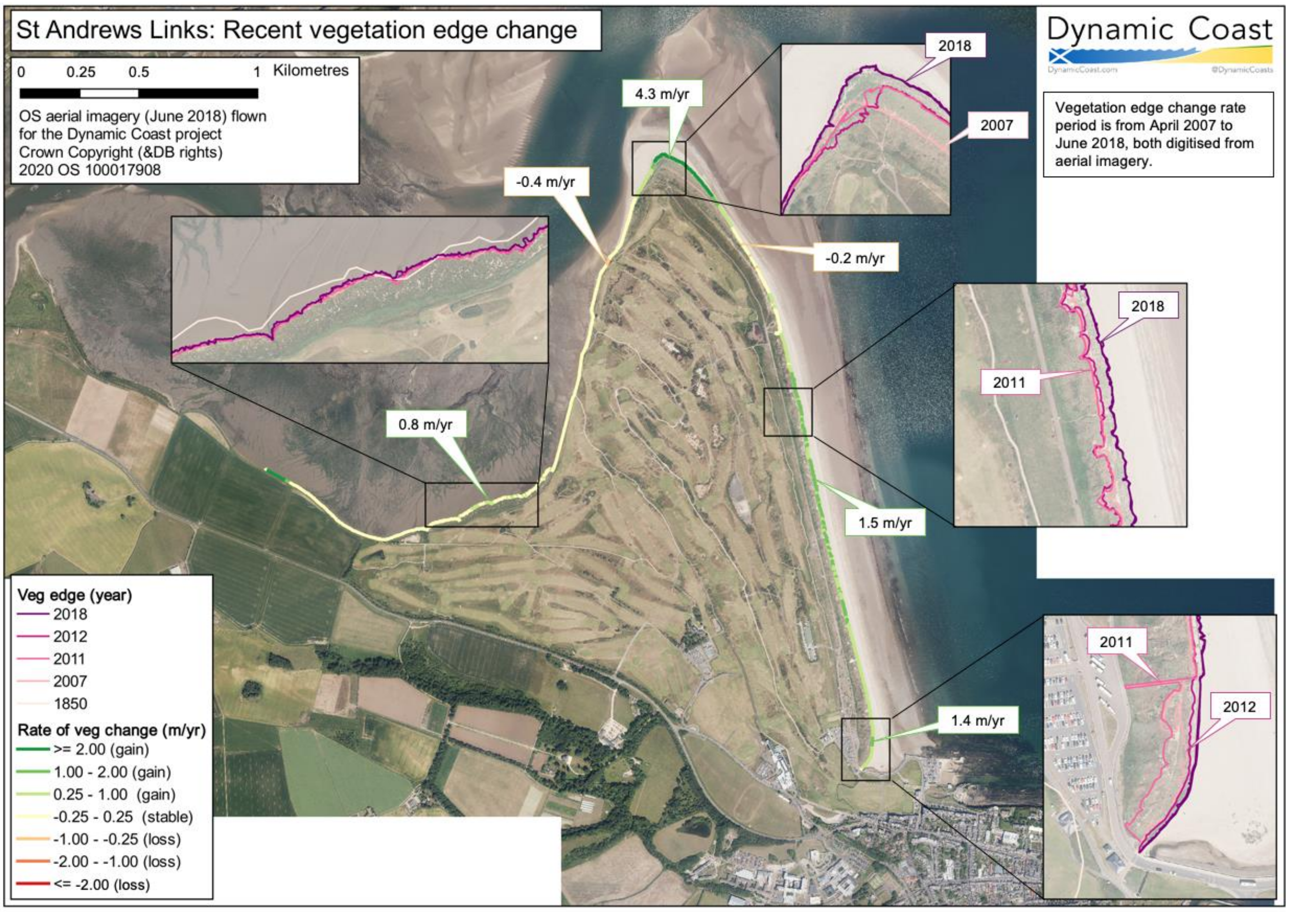

Figure 7 Vegetation edge change maps of St Andrews Links showing observed edges from 1850, 2007, 2011, 2012, and 2018 and the rate of change expressed as horizontal distance between 2007 and 2018.

Using the vegetation edge time-series data alongside data that displays height changes, such as acquired using Differential-GNSS ground survey or LiDAR imagery, an even greater understanding of volumetric change on the beach and dunes can be gained, as shown at St Andrews in Figure 8.

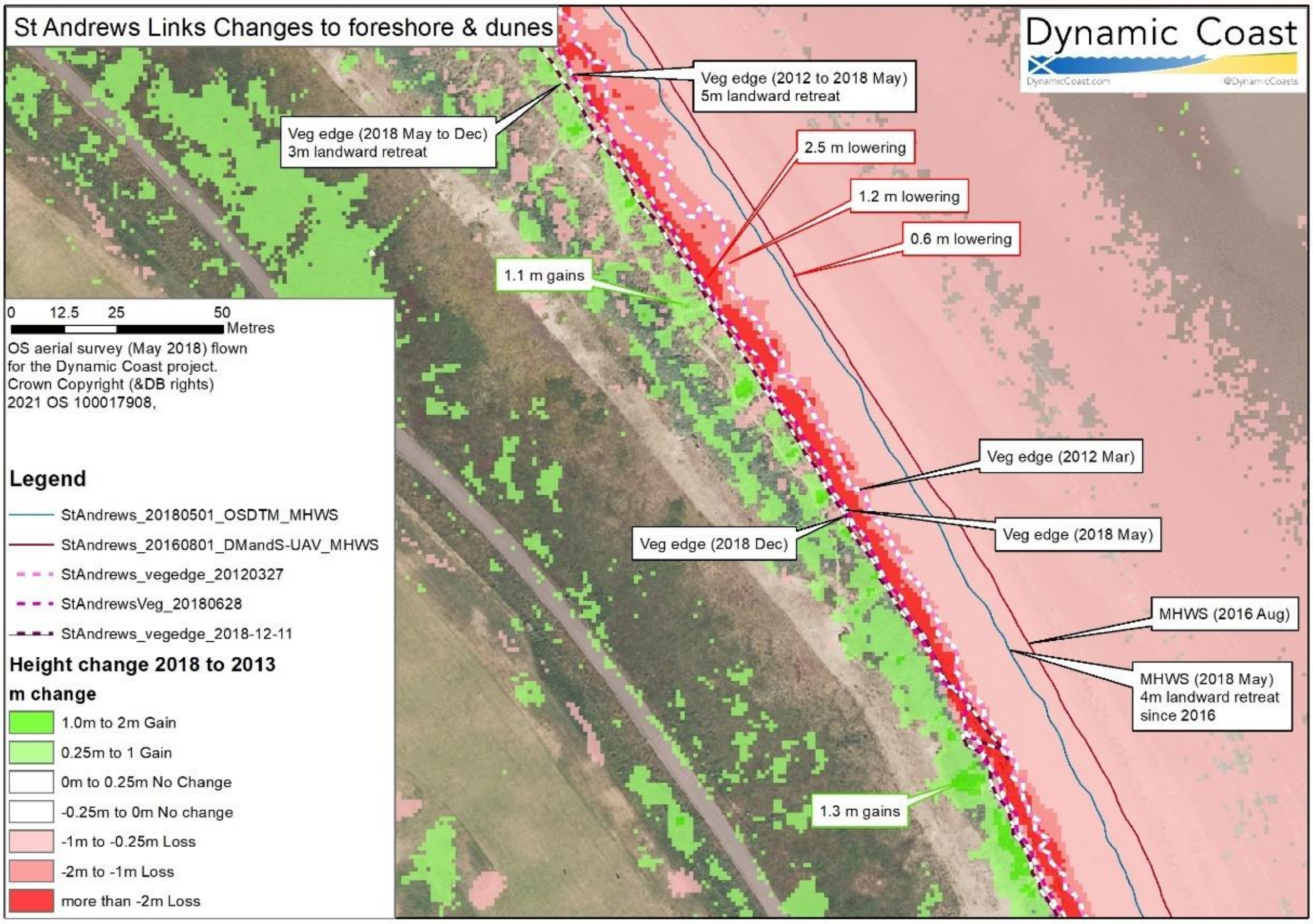

Figure 8 Vegetation edge lines (Dec 2018 ground survey, May 2018 aerial analysis & 2016 aerial analysis) alongside MHWS changes (May 2018 to August 2016) and volumetric change (2018 May to 2013) annotations highlighting the gains and losses.

Further exemplars are available within the Super Site Reports.

Where detailed and site-specific vegetation data that is not universally available at the number of time steps required to allow a fully informed view, the use of Earth Observation (EO) methods provide additional potential. This is particularly so if the regular acquisition of EO at a national level can be automated or semi-automated, hugely reducing the time, effort and cost attached to more traditional survey methods.

Figure 9 shows a comparison between Earth-i (0.8m pixel), Maxar (WorldView2, formerly Digital Globe (2m pixel) with Airbus Spot (6m pixel) and Sentinel imagery (10 m pixel). Whilst higher resolution imagery was made available by OS, the inset shows the comparable aerial image (0.25m pixel) from Ordnance Survey. It is self-evident that the accuracy of the discernible vegetation edge reduces as pixel size increases.

Figure 9 comparison of remote sensed data and vegetation edge extracted from Earth-I image (top left) 0.8m pixel size (pan sharpened) compared with (nominal multispectral resolution) 2m pixel (top right from Digital Globe), 6m (bottom left from Airbus Spot6) and 10m pixel (bottom right from Sentinel 2b) inset shows OS aerial imagery (0.25m pixel size).

Irrespective of the method of vegetation edge data acquisition, the utility of the vegetation edge data can be seen in Figure 4 to Figure 11. The vegetation edge clearly identifies areas of increased erosion (the red call-out text boxes) along a beach and dune coast at Coul Links in the Dornoch Firth and provides a clear way of assessing the underlying current erosion risk along this shore. Figure 10 shows the vegetation edge positions along this coast to be mainly moving landward at variable rates over time. Such data are useful but are more usefully deployed in conjunction with other data, such as MHWS data. For example, to establish the anticipated future positions of both lines based on either current rates of landward recession or any expected accelerations due to climate change. Using the anticipated position of the MHWS and vegetation edge into the future brings the issue into much sharper focus. This is because there exists a clearly defined horizontal offset between the position of MHWS (changes in which can be absorbed by the beach itself) and its impact on the vegetation edge (when erosion of the "land" (land loss) is popularly perceived to occur). In other words, erosion and loss of land occurs well before MHWS actually arrives at, and impinges on, the "land". Figure 11 clearly shows the land losses depicted by the vegetation edge positions that lie well landward of the MHWS positions of the same future date.

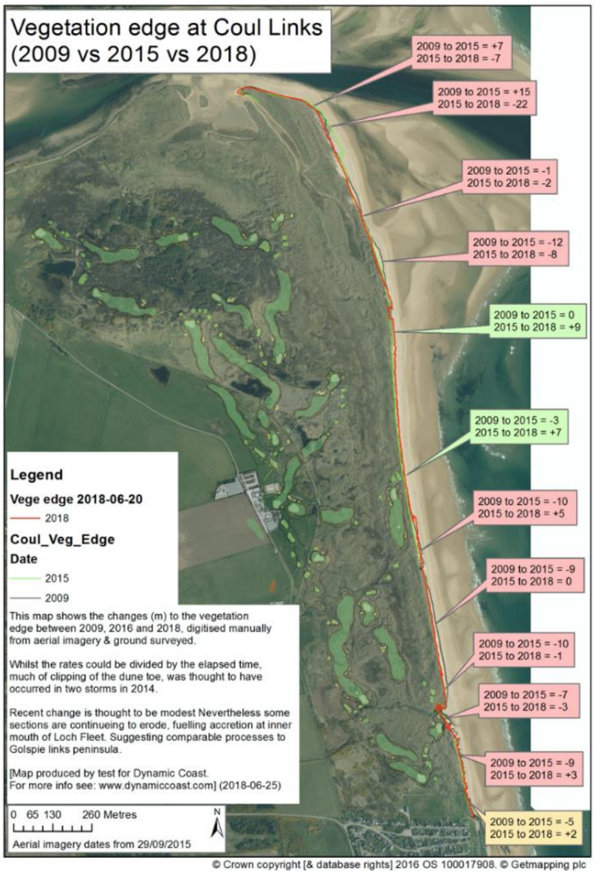

Figure 10 comparison of remote sensed data and vegetation edges within each.

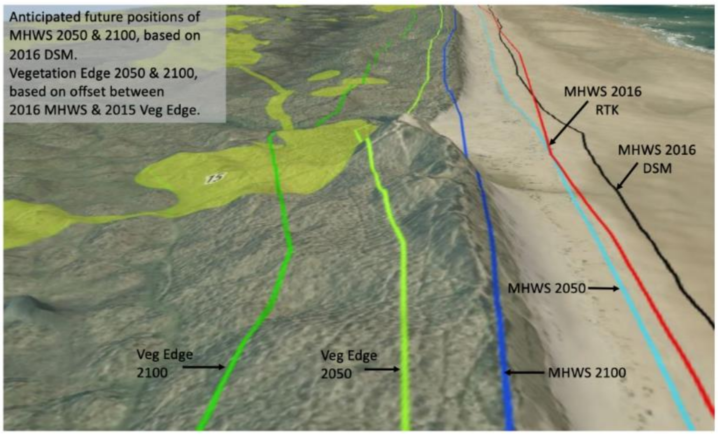

Figure 11 comparison of remote sensed data and vegetation edges within each.

Figure 11 shows MHWS positions in 2016 derived from two survey methods: a Real-Time Kinematic (RTK) Differential GPS survey and a digital surface model (DSM) from aerial photography. When projected forward to 2050, MHWS remains on the intertidal beach. However, the anticipated vegetation edge for 2050 (based on current horizontal offsets between existing MWHS and vegetation edge) shows a substantial loss of land and an even greater anticipated loss by 2100. This vividly demonstrates the utility of the vegetation edge data as key information for future planning decisions related to the proposed use of land lying behind a shoreface anticipated to be located well inland of its current position in the future.

See the link below for an interactive web-map of the results:

Browser link
www.dynamiccoast.com/webmaps.html

Supplementary Reports

Report	Link
OS EO review at St Andrews Links	https://gla-my.sharepoint.com/:b:/r/personal/ali_rennie_glasgow_ac_uk/Documents/_DC2%20Consultation%20Docs/_WS3%20Veg%20Edge/OSReport_SNH_VegetationEdge.pdf?csf=1&web=1&e=PLjbyk
Dynamic Coast webmap showing vegetation edge data	http://www.dynamiccoast.com/webmap.html
Written Guide	– https://gla-my.sharepoint.com/:b:/r/personal/ali_rennie_glasgow_ac_uk/Documents/_DC2%20Consultation%20Docs/_WS3%20Veg%20Edge/Veg%20Edge%20-%20Arrow%20-%20Setup%20Guidance%20v8%20-redacted.pdf?csf=1&web=1&e=SyxPaF
Video 1– Arrow surveying device	https://youtu.be/fbPw9cPcRiY
Video 2 – How to survey a line	https://youtu.be/tb7qVtwQumQ
Link to Super Site Reports showing how Veg Edge analysis is used alongside other analysis.	{Link to be inserted when available)

End.