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Assessing the relation between the distribution of salt-marsh communities and the sediment budget of the North Norfolk coast

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Abstract. Very high resolution imagery from an airborne multi-spectral scanner has been used to estimate the distribution of different salt-marsh communities along a 30-km stretch of the North Norfolk coast. Field observations have been used to develop a mathematical relationship between the vegetation, physical environment and sediment accumulation. This relationship has been used to produce provisional sediment accretion maps for the North Norfolk coast.

Keywords: Inter-tidal zone; Multi-spectral scanner; Spatial model; Vegetation type.

Abbreviations: BIOTA = Biological Influences On inter-Tidal Areas; CASI = Compact airborne spectrometer instrument; DTM = Digital terrain model; SDSS = Spatial decision support system.

Introduction

The inter-tidal zone is very dynamic and changes occur on every tide. In addition to these frequent but gradual changes, occasional extreme events can significantly alter the shape and character of the 'landscape'. This dynamism is part of what makes the inter-tidal zone such an interesting area of study, but it also generates problems in quantifying changes. It is important to remember that the inter-tidal zone provides a number of valuable 'environmental services'; in particular salt marshes protect land and housing from flooding, act as a nursery for fish and shellfish and are a place of recreation.

Work on this contribution arose from the activities of the BIOTA (Biological Influences On inter-Tidal Areas) programme within LOIS (Land Ocean Interaction Study). A description of the aims and objectives of the BIOTA programme and especially the development of a prototype spatial decision support system (SDSS) can be found in Brown et al. (1997). In this contribution we concentrate on the development of a spatially articulate model to fit within the SDSS framework to allow users to investigate and describe the accumulation of sediment on the vegetated parts of a salt marsh.

Methods

Structure of the model

A mathematical model based on the analysis of field data has been constructed to estimate the rate at which sediment accumulates on a salt marsh. The model has been designed to fit within the SDSS framework to allow a variety of users to investigate the sensitivity of the assumptions made and to investigate the possible effects of sea level rise. Analysis of field observations was carried out using stepwise linear regression for a variety of vegetation types independently. In each case the depth of sediment accumulated on a single tide was found to be significantly positively correlated with the length of time an area is submerged and the amount of sediment in the water and negatively correlated with distance from the nearest creek and the density of the sediment. These individual equations were then combined to give the form shown below. Considering accumulation per unit time the vegetation coefficient (v) can be shown to have units of area. This implies that, all other things being equal, species with a large or complex cross-sectional area trap sediment more efficiently than smaller or less complex species.

The final form of the model is:

$$\Delta h = \frac{v * t * s}{d * \rho} \tag{1}$$

where Δh = the depth of sediment accumulated (m), v = is a constant dependent on the type of vegetation, t = time submerged (s), s = concentration of sediment in the water column (kg.m^{-3}), d = distance from the nearest creek (m), r = sediment density (kg.m^{-3}).

Assembling the necessary data for the model requires the integration of remotely sensed and ground based surveys with predictions of tide height.

Data sources

Vegetation type

Estimating the vegetation cover on the inter-tidal zone has been carried out using classified data from the CASI (compact airborne spectrometer instrument). Data were collected with an approximate resolution of 5 m. The CASI image used here is shown in Fig. 1. Additional flight lines cover the remaining parts of the Norfolk coast as well as the whole of the Wash and Lincolnshire coast as far as the Humber Estuary, however, these have not yet been classified.

Classification was performed using a supervised clustering technique to produce 13 classes; classification and verification were described by Thompson et al. (1996). The abundance of the different classes is shown in Table 1.

The problems with geo-correcting imagery collected from scanning instruments mounted on aircraft should not be underestimated as it is necessary to know the exact location and orientation of the instrument every 50th of a second. To confound matters there is very little 'fixed' detail in the inter-tidal zone which can be used for ground control. The image used in this study has a root mean square error of ca. 25 m.

Duration of submergence

As the predicted rate of sedimentation is directly related to the length of time an area is under water it is important to be able to estimate the elevation of any point. Other groups within LOIS are employing a subtle method to develop an inter-tidal DTM (digital terrain model) based on remotely sensed radar information and a hydrodynamic model of the sea – see Mason et al. (1997) for further details. Unfortunately this subtle DTM is not yet available and recourse has been made to the beach profiles collected by the NRA (National Rivers Authority, see acknowledgements). These have been collected at intervals of 1 km along the entire coast of the East Anglian region (from Lincolnshire to Essex). By combining the profile information with the CASI imagery the relationship between the shape and stability of the beach and the vegetation can be revealed.

Fig. 2 shows a profile across Scolt Head Island. Note the dunes and shingle ridges protecting the salt marsh, and the stability of the profile over a 3-yr period. Fig. 3 shows a more exposed profile 1 km to the east of the town of Wells where a single minor ridge is sufficient to protect stable salt marsh vegetation, which is, however, conspicuously different from that at Scolt Head Island. Fig. 4 shows a profile mid-way between Wells and Blakeney Point where the vegetation is very similar to the Scolt Head profile, however, the bare sediment is much more dynamic than in the other two profiles.

It is interesting to observe the very narrow and consistent range of elevations within which the different species exist; this has been used to refine a DTM based on the NRA profiles. Construction of the DTM followed a two stage process. First the profiles were 'stitched' together to form a surface using a triangular irregular network approach. Obviously with profiles so far apart any form of interpolation will miss many major topo-

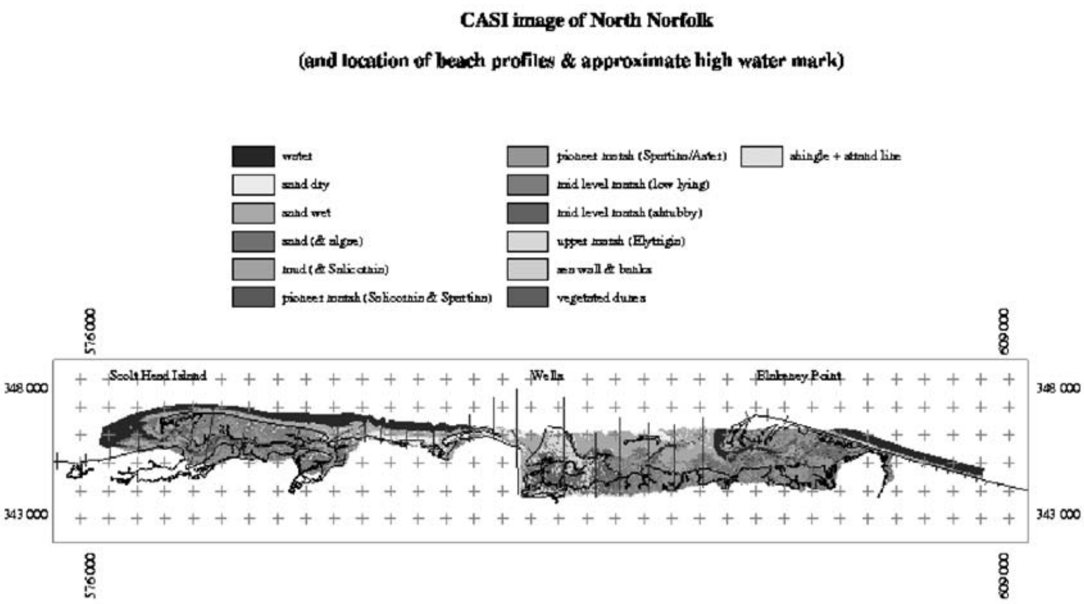

Fig. 1. CASI (compact airborne spectrometer instrument)image of North Norfolk (and location of beach profiles and approximate high water mark).

graphical features (rivers, sand banks and so on). The initial surface was then refined by exploiting the relationship between ground cover and elevation along the observed profiles. For each cover type the mean and standard deviation of the elevation was used to generate a range of 'expected' values to use as an 'adaptive filter'. Each point in the DTM was examined in turn and where the interpolated surface was much higher or lower than might be expected (given the cover type), the elevation was adjusted. Where the interpolated elevation was within the expected bounds it was not altered.

The level of the tide has been calculated using the Admiralty harmonic method. One secondary port, Wells, is within the study area, but the predicted tidal range is very low due to the convoluted nature of the channel to the harbour. Fortunately two other secondary ports, Hunstanton and Cromer, are respectively to the west and east of the region. Tidal heights from these two ports are used to interpolate values in between.

By combining information about the elevation of each point with the predictions as to the height of the tide, it is possible to estimate the duration of submergence at any point.

Table 1. Classes defined from the CASI compact airborne spectrometer instrument imagery

Class ID	Description	Area (ha)	Area (%)
1	Water	755	15.7
2	Dry sand	180	3.7
3	Wet sand	1078	22.5
4	Sand and algae	391	8.1
5	Mud & *Salicornia*	0	0
6	Pioneer marsh (*Salicornia* and *Spartina*)	227	4.7
7	Pioneer marsh (*Spartina* and *Aster*)	731	15.2
8	Mid-level marsh (low lying vegetation)	672	14.0
9	Mid-level marsh (shrubby vegetation)	379	7.9
10	Upper marsh (*Elytrigia*)	266	5.5
11	Sea walls and banks	14	0.3
12	Vegetated dunes	63	1.3
13	Shingle and strand line	49	1.0
	Total	4805	

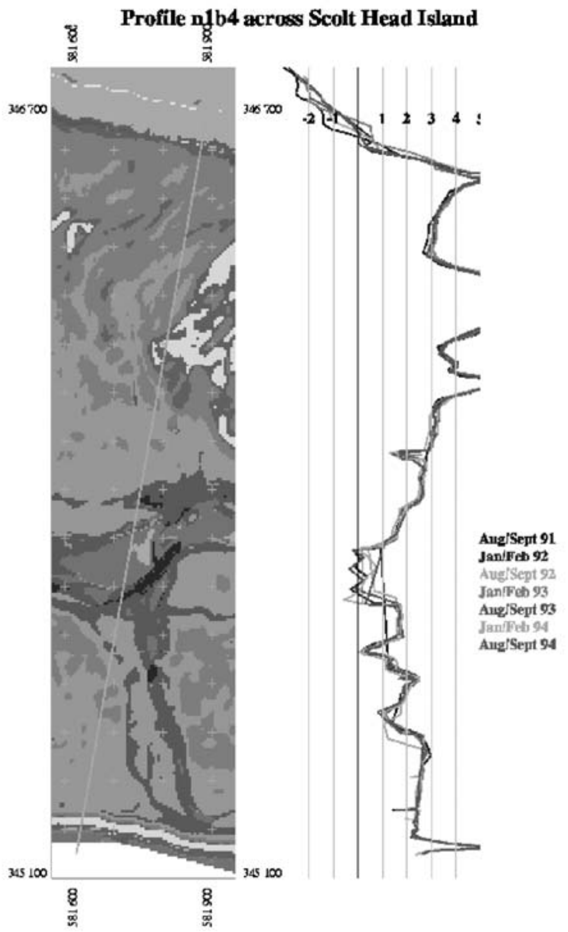

Fig. 2. Profile n1b4 across Scolt Head Island.

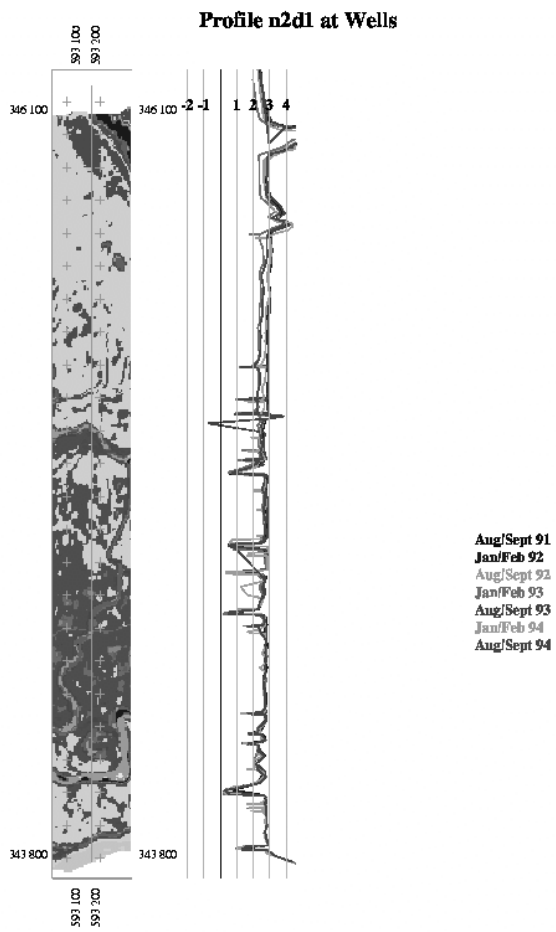

Fig. 3. Profile n2d1 at Wells.

Distance from the nearest creek

The distance from the nearest creek has been estimated by reclassifying the image to try and identify creeks and then apply a buffer around them. Note, however, that even a resolution of 5 m is rather coarse for the complex topography of the typical salt marsh, this may explain why the mean distance to a creek (80 m) appears rather high by this method.

Sediment trapping by vegetation

Sediment accumulation by different species is based on a series of short-term (single tide) observations. Filter papers are fixed horizontally within the different types of vegetation before the tide approaches. After the tide recedes the filter papers are collected, dried and reweighed to estimate the amount of sediment trapped. Environmental data around each filter paper, such as the elevation and distance to the nearest creek, is measured as well as the sediment concentration on the incoming tide.

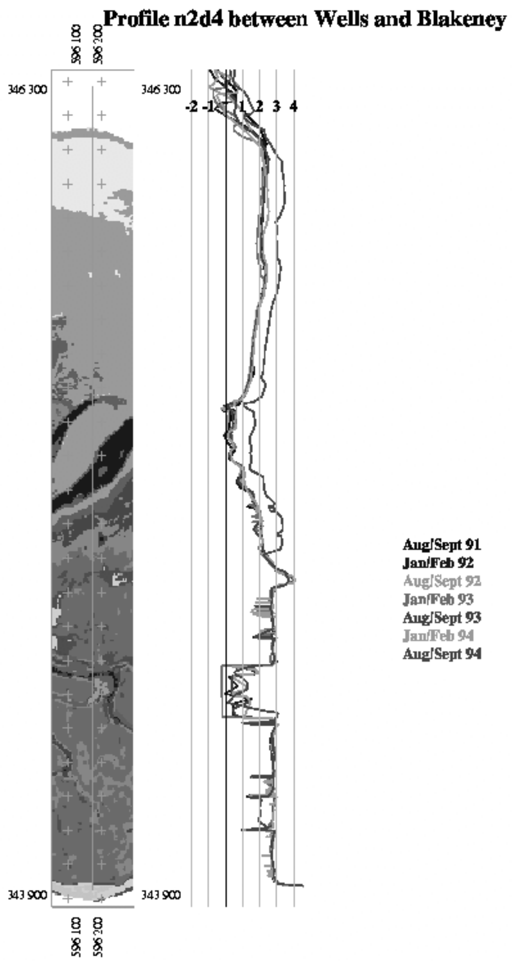

Fig. 4. Profile n2d4 between Wells and Blakeney.

Results

Fig. 5 shows the predicted accumulation of sediment for 1995 using a sediment concentration in the water of 1 kg/m^3 and a sediment density of 400 kg/m^3. Users of the model can select and alter these figures according to their own knowledge and experience. The average accumulation rates are relatively low, averaging only about 3 mm.yr^{-1} over the vegetated part of the marsh. This still represents a significant volume of sediment (ca. 48000 m^3). Note that the figures for accumulation are rather lower than the predicted rate of sea-level rise, which by some estimates (Warick & Oerlemans 1990) may exceed 10 mm.yr^{-1} over the next 100 yr.

Rigorous validation of the model is still being carried out, but, initial results can be compared to rates reported in Steers (1960) along three transects at Scolt Head Island. Accretion was measured three times over

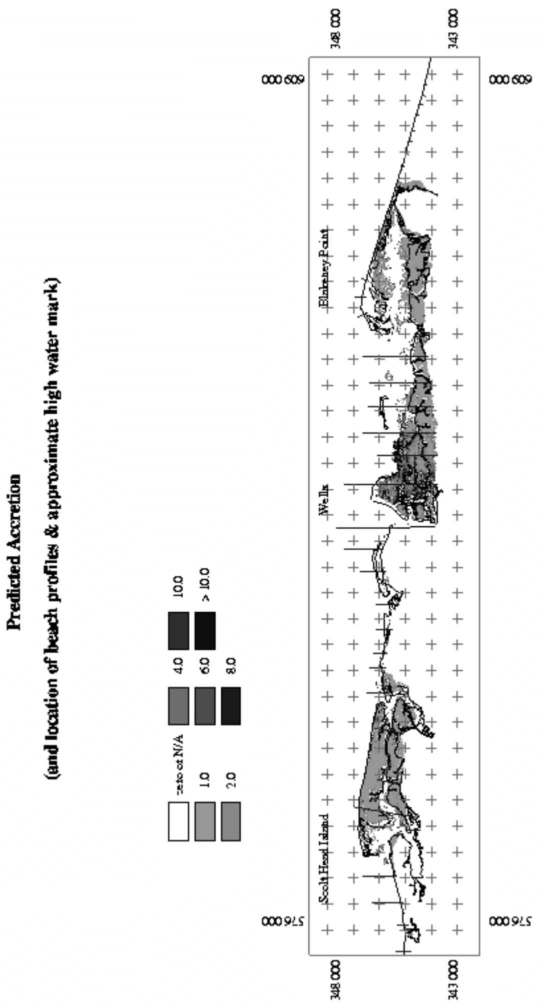

Fig. 5. Predicted accretion (and location of beach profiles and approximate high water mark).

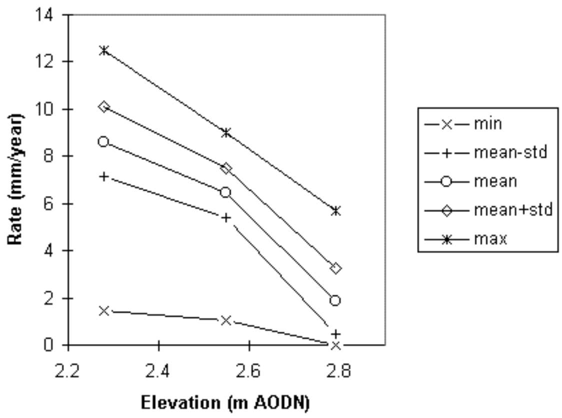

Fig. 6. Annual accretion rate Missel Marsh between 1935 and 1957 Stn. 1 at 2.28m AODN (source Steers 1960)

a 22-yr period. Unfortunately, there is no information about the vegetation and only the only elevation data is for the first station on each transect. Rates of accretion varied from zero to 12 mm.yr^{-1}. This was measured in relation to patches of sand spread on the marsh surface. Current practice is to use fine white clay that may more safely be assumed to be neutrally buoyant in the surrounding sediment. Little systematic variation can be seen along individual transects or over time. Fig. 6 shows the data from the lowest transect, Missel Marsh, for the 17 points (out of the original 37) which could be found in all years. Whether the missing sites represent erosion or other changes is unknown, so that conclusions about the net accretion over the whole marsh are difficult to draw. Fig. 7 shows the data from all three transects plotted against the elevation of the first station on each transect it demonstrates how relatively minor differences in elevation can have a major influence on the rate of accretion.

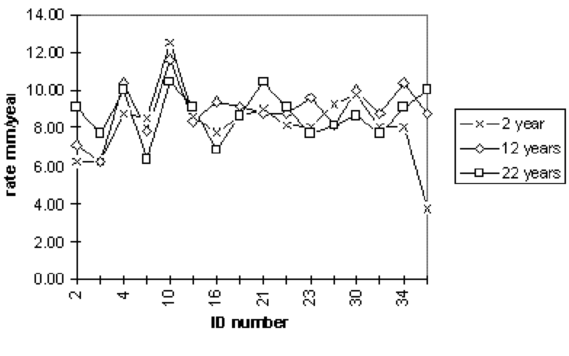

Fig. 7. Averaged accretion rates at Scolt Head 1935 to 1957 (source Steers 1960).

Discussion

The results of this analysis should be taken as indicative of what is possible. It should be noted that the results presented in this contribution are ‘typical’ and are not expected to reflect the best possible fit with observed values. There are several deficiencies with the approach which are currently under active review. At the moment comparisons between the model and long-term observations appear to indicate that the model over-predicts at low elevation and under-predicts at high elevations.

Constructing a DTM from filtering an interpolated surface by ground cover provides a certain amount of circularity in the argument. In addition, problems with geo-referencing the image and the way in which the profiles record every creek mean that there is an unknown uncertainty with the final predicted elevations. The method for identifying creeks is possibly deficient and will lead to underestimates of deposition away from the front edge of the marsh.

One of the most difficult parameters to estimate is the concentration of sediment in the water column, and how much of it represents ‘new’ sediment and how much is being transported around on the local scale. The Admiralty method of predicting tidal levels is designed for particular ports, the physical characteristics of many parts of the coast are likely to lead to rather different tidal behaviour. Use of a hydrodynamic model which takes into account the bathymetry would be preferable. Basing long-term predictions from short-term observations are likely to lead to compounded errors. In particular the importance of occasional rare events is impossible to capture in such an approach.

Conclusions

This contribution reports initial attempts to estimate accretion rates across a large area of vegetated salt marsh. Although there are significant uncertainties about the approach, there appear to be few practical alternatives. To rely on digging up markers as in the experiment reported by Steers (1960), introduces problems with extrapolating net accretion due to the steady loss of sites. Attempts to use ground survey to describe the shape of the surface to the required degree of accuracy (to within a mm) implies very high costs as well as the practical problem of deciding exactly where the surface of wet mud is. These initial findings will help to quantify the flux of materials between the land and the ocean and help to assess the impacts of pressing environmental problems such as sea-level rise.

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References

Brown, N.J., Cox, R., Pakeman, R., Thomson, A.G., Wadsworth, R.A. & Yates, M. 1997. Development of a spatial decision support system for the BIOTA project within LOIS. In: *Proceedings CoastGIS'97 Aberdeen, 29th-31st August 1997*. University of Aberdeen, AB24 3UF, Scotland, Aberdeen, UK.

Mason, D.C., Davenport, I.J., Flather, R.A. & Gurney, C. 1998. A digital elevation model of the inter-tidal areas of the Wash produced by the waterline method. *Int. J. Remote Sens*. 198: 1455-1460.

Steers, J.A. 1960. Physiography and evolution. In: Steers, J.A. (ed.) *Scolt Head Island*, Chapter IV, pp. 29-32. W. Heffer & Sons, Cambridge, UK.

Thompson, A.G., Eastwood, J.A., Fuller, R.M., Yates, M.G. & Sparks, T.H. 1996. Remote sensing the intertidal zone in the LOIS project. RSS96 Remote Sensing Science & Industry. In: *Proceedings of the 22nd Annual Conference of the Remote Sensing Society, 11th - 14th September 1996*, pp. 298-303. University of Durham, Durham, UK.

Warick, R.A., and Oerlemans, H. 1990. Sea Level Rise. In: Houghton, J.T., Jenkins, G.J. & Ephraums, J.J. (Eds.) *Climate Change: The IPCC Scientific Assessment*, pp. 257-282. Cambridge UP, UK.