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Sedimentary Dynamics and Coastal Changes on the South Coast of Ireland

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ABSTRACT

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Sedimentary studies of coasts sensitive to erosion in the south of Ireland are presented. Over 50 monitoring stations established in two bay-estuary systems (representing intertidal sandflats, pioneer to mature saltmarsh and extensive mudflats) incorporated sedimentation pins and buried plates to measure monthly surface elevation and linked sediment accretion changes. These measurements are supported by EDM Total Station and *d*GPS transect surveys from the outer coastal areas to enable the quantification of contemporary net sedimentary movements and the analysis of the systems' sedimentation patterns. Results indicate significant localised beach profile adjustments (≥50cm annual vertical change) in the outer bay / estuary mouths. However, volumetric analyses indicate that only small (<5%) total beach volume changes are evident, thus suggesting that profile changes are a result of seasonal adjustments and exchange of sediment between profiles. Lateral erosion rates of local to regional soft shorelines within and adjacent to the study areas commonly exceed 1m yr^{-1}. Estuary mudflats and saltmarshes in the systems are influenced by climatic seasonality and local morphologies, with averaged sedimentation rates of 6.0-6.5mm $yr^{1.}$ Sediment accretion at these inner coastal locations is possibly influenced by vegetation growth, particularly by *Spartina* spp., together with other local physical environmental factors (*e.g.*, creek meandering). Results form part of an initial 30-month study, designed to investigate relationships between the long-term regional drivers of coastal change, and the contemporary functioning of these southern coasts of Ireland.

ADDITIONAL INDEX WORDS: *Intertidal areas, sedimentation rates, estuarine hydrodynamics.*

INTRODUCTION

Despite numerous studies of short-term spatial and temporal intertidal accretion trends (*e.g.*, RANWELL, 1972; LETZSCH and FREY, 1980; ALLEN and DUFFY, 1998), the processes that contribute to these sedimentation patterns remain poorly understood at local - regional scales (REED and CAHOON, 1992) and are seen as complex (FREY and BASAN, 1978) . The need for an improved understanding of intertidal and linked wider coastal sedimentary changes, however, is increasing, particularly as the managed realignment of marshes has become a more attractive and potentially feasible coastal protection option (CAHOON *et al*., 2000a). Although process parameters combine in different ways to drive intertidal sedimentation, these relationships are complex and site specific in nature. This has tended to force researchers to isolate and study the individual processes involved, such as hydroperiodicity, wave energy (CAHOON *et al*., 1995) and the impact of vegetation on sedimentary patterns (SÁNCHEZ *et al.*, 2001). Driving parameters, such as these, have been examined in the context of marsh survival and development (BAUMANN *et al*., 1984; JANSSEN-STELDER, 2000); to quantify impacts upon wave attenuation (MÖLLER *et al*., 1996); to monitor impacts upon ecological zonation; and to quantify beach morphological change (e.g., MASSELINK, 1998).

To date, a spatially and thematically separated series of sedimentary and coastal process studies have been produced for Ireland's coasts. These include storm frequency and magnitude analyses (LOZANO *et al*., in press), coastal morphological responses to storm forcing (e.g., WHEELER *et al.*, 1999; DUFFY and DEVOY, 1999), Holocene sea-level changes (e.g., DEVOY, 1983; CARTER *et al.*, 1989; SINNOTT, 1999), studies of dunes and coastal barriers (e.g., CARTER *et al*., 1992), estuarine geochemistry (GALLAGHER *et al.*, 1996) and baseline coastal inventories (e.g., CURTIS, 1991; CURTIS and SHEEHY SKEFFINGTON, 1998). Approximately half of Ireland's c.7,500km coastline is estimated to be sensitive to coastal erosion under climate warming (DEVOY, 1992, 2000). Research upon Ireland's southern coasts in particular (SWIFT *et al.*, 2003) is in progress to assess the impacts of these climate change-linked storm and erosion risks (VIJAYKUMAR *et al.*, 2003). This paper presents an aspect of this wider research that aims to establish the principal drivers of sedimentation within the different composite elements of two bay - estuary systems typical of Ireland's southwest central coastline (Figure 1). Extensive process (tidal, hydrodynamic, climatic) and morphometric data (elevation change, sediment deposition and loss, sediment composition changes) have been collected. This paper reports on representative data from over two years of monitoring of the sedimentary elevation changes recorded from these systems.

PHYSICAL SETTING

Ireland's southwest - central coastline has a strong geological control, characterised by east west aligned anticlinal structures (SLEEMAN and PRACHT, 1994). The region has also been heavily modified by glacial/ice action (DEVOY and SINNOTT, 1997). The study sites of Courtmacsherry Bay and Womanagh Estuary are exposed to southerly - southeasterly and southeast - easterly wind-wave actions respectively. Extensive inner mudflat and saltmarsh complexes here are protected by the

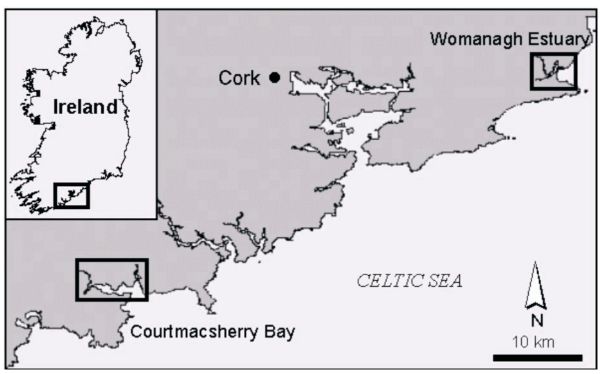

Figure 1. The study region and the two monitored study sites.

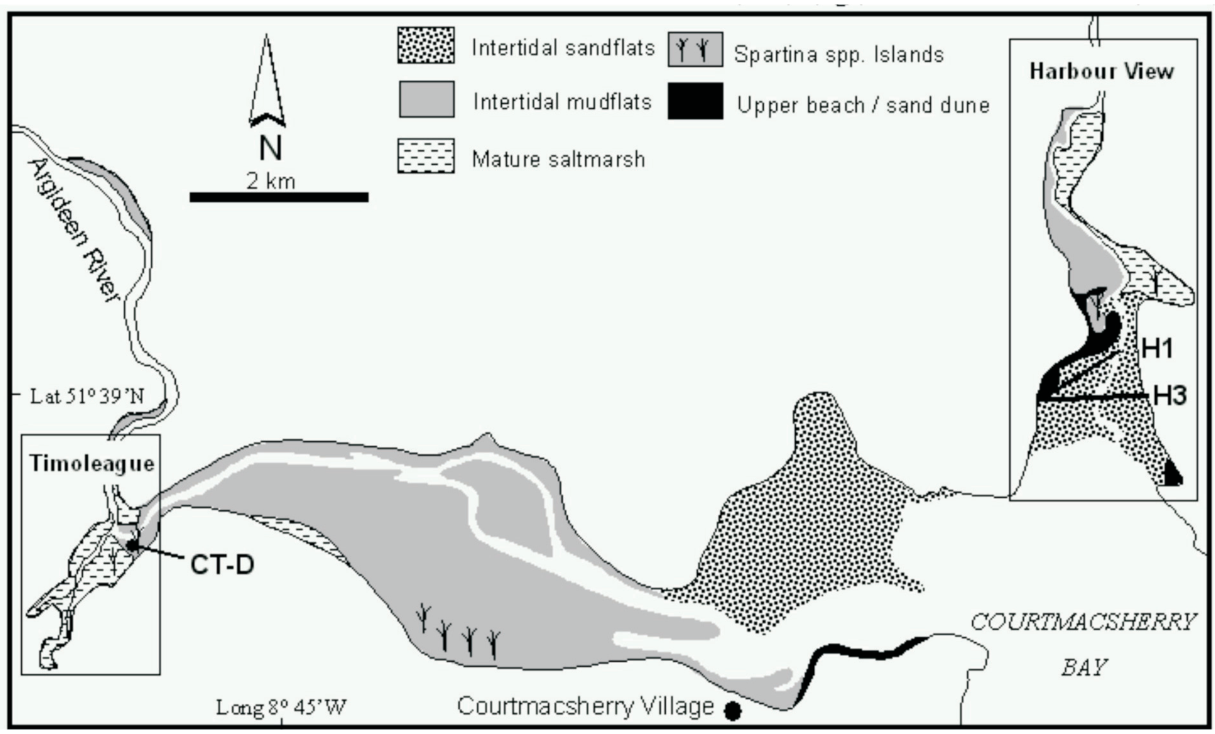

Figure 2. Courtmacsherry Bay, west County Cork showing the study locations. H1 and H3 are EDM repeat levelling transects (see Figs. 7 & 8), CT-D is a long-term monitoring station 1995-2002 (see Fig. 6).

Development of high-energy, open coast gravel-based spit and barrier structures. These coasts experience a semi-diurnal, high mesotidal regime (mean spring range = 3.7 m; neap range = 1.9 m), generating maximal inner estuary currents of approx. 1 ms^{-1} (SWIFT *et al.*, 2003). The prevailing south-westerly winds typically average c. 15 knots, with maximum gust speeds of c. 80 knots during winter.

Courtmacsherry Bay is fed by two river - estuary sources (Figure 2). Timoleague is situated at the head of the Argideen estuary and is channel dominated, with flanking channel edge mud and sandflats. These are backed by an upper mudflat bench and fringing high marsh, which support a summer vegetation assemblage of *Puccinellia maritima, Spartina spp., Limonium vulgare, Spergularia marina, Aster tripolium, Triglochin maritima* and occasional *Atriplex spp.* and *Salicornia perennis* (DEVOY *et al.*, 1996a). Harbour View is characterised by a wide, ultra dissipative medium-sand beach (typical mean grain size = 300μm) backed by a dune sand barrier and intersected by a riverine/ebb dominated tidal channel. Landward of the barrier, progressively finer sediments form substantial 'semi-quiescent' intertidal mudflats (typical mean grain size = 40-80μm) colonised in part by *Spartina spp.*. At the head of the estuary, the upper mudflats are backed by mature saltmarsh (laterally eroding c.10-20 cm a^{-1}). In both areas *Enteromorpha spp.* coverage can reach 100% during the summer months.

The Womanagh estuary (east County Cork) is a distinctive 'lagoon estuary' (CURTIS and SHEEHY SKEFFINGTON, 1998). The environment is river dominated, (low tide salinity is c.1-5 ppt, SWIFT *et al.*, 2003), due to extensive physical protection by sand - gravel barrier structures that support small-scale sand dunes except at the tidal channel intersection. Wide sandflats dissipate wave energy seaward of the barriers. Within the estuary, extensive channel incised mudflats are backed by pioneer saltmarsh, mature saltmarsh and formerly reclaimed land that has reverted to saltmarsh.

METHODS

Inner Estuary Intertidal Elevation Change

In recent years, small changes (+/- 1.5 mm) in sediment surface elevation have been successfully measured in a number of tidal and riverine marsh environments using the sedimentation-erosion table (SET) (e.g., BOUMANS and DAY, 1993; CAHOON *et al.*, 2000a). However, the high initial overheads and limited spatial coverage (BOUMANS and DAY, 1993) of the SET compelled the consideration of alternative options for this particular research.

Although sequential levelling surveys (e.g., by Electronic Distance Measurement [EDM] Total Station) can detect large-scale (>1 cm) elevation changes over time (ANDERSON *et al.*, 1981; PETHICK and BURD, 1996), most saltmarshes exhibit rates of surface elevation change below this magnitude (CAHOON *et al.*, 2000a). Consequently, 'reference frames', most recently used by HAZLEDEN and BOORMAN (1999), were employed to measure intertidal elevation changes in relation to a bar placed across pairs of fixed points (sediment pins) (DUFFY and DEVOY, 1999).

A total of fifty-seven sediment pin stations were installed

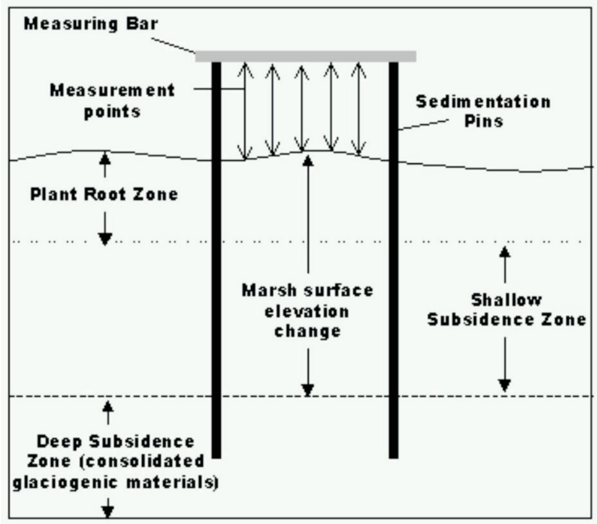

Figure 3. Concept and measurement of sedimentation pins (after CAHOON *et al.,* 2000b).

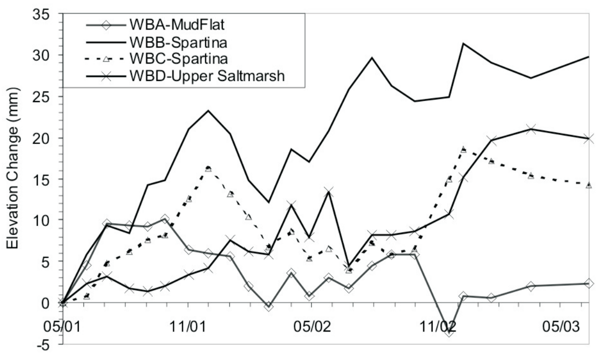

Figure 4. Cumulative elevation change at four sediment pin stations, Womanagh estuary.

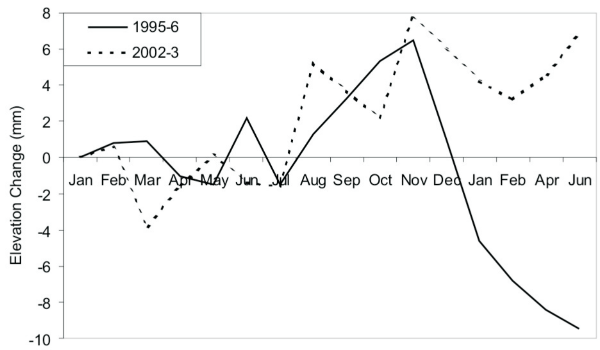

Figure 6.Cumulative elevation rates at station CT-D, Timoleague (*Spartina spp*. mudflat), Jan 1995 - Jan 2002.

(Thirty-six at Courtmacsherry and twenty-one at Youghal Womanagh). All stations were resolved to national Ordnance Datum, Malin (ODM) using an EDM Total Station. Each sediment station comprised two light metal pins (2.25-2.5m long, 1cm diam.) driven one metre apart into the sediments and anchored in the 'lower subsidence layer' (CAHOON *et al.*, 1995). This fixes the pins into position (to the point when refusal of the pin to further downward movement occurs), allowing the measurement of elevation changes: as the combined effects of compaction-consolidation / sediment expansion (i.e. 'ground breathing') of the upper subsidence layer and the vertical gains or losses of sediment (Figure 3) (DUFFY and DEVOY, 1999).

Previously, sediment pins have been used to measure vertical accretion / erosion alone. In this study the consolidated glaciogenic materials underlying the sites enabled the measurement of the upper sedimentary layer's subsidence as well. This 'reference frame' approach can be limited when used in deep soft sediments (CAHOON *et al.,* 2000a), due to the potential for the pins (or especially heavier pipes, if used) to sink over time.

Monitoring was conducted each lunar month (29.5 days) between April 2001 and July 2003. A specially designed wooden bar was fitted across the two pins to provide a repeatable datum, from which a stainless steel rule was placed onto the sediment surface (visually defined) at five equidistant points (Figure 3). The mean of these distance measurements between the datum and sediment surface, enables the calculation of yearly sedimentation rates and the identification of any seasonal patterns in sedimentary changes.

This method of measurement has some practical problems. The sediment surface cannot always be easily defined, particularly with liquid-mud, or heavily vegetated (either in situ [e.g., *Spartina spp*.] or transient [e.g., *Enteromorpha spp*.]) surfaces. Trampling adjacent to each station was a necessary 'evil' of monitoring that sometimes affected vegetation growth, although the repercussions of this on sedimentation changes are uncertain. The affect of wave scour on the sediment pins was found to be minimal; probably due to the relatively low energy of these inner-estuary areas.

Outer Estuary Topographic Change

A 'pilot' deployment of sediment pins on the medium-high energy Harbour View sand flats indicated that substantial (>10 cm per week) elevation changes occurred in such outer estuary - beach areas. This allowed topographic surveys to be used as a valid, repeatable and safe (the beach is often used for water sports) alternative means of recording sedimentary changes in these environments. A *Sokkia* SET4010 EDM was used to conduct topographic surveys of transects arranged in a 'radial' array. Heights were calculated to ODM, using differential GPS, and beach 'volumes' were determined above an arbitrary base level of 2 m ODM using *SURFER 7.0* (Golden Software). In this study data are presented from Harbour View, one of four outer estuary sandflats monitored between 2001-2003.

RESULTS

Inner Estuary Elevation Changes

Particle size analyses from these areas show the dominance of fine sized sediments (mean sediment grain sizes typically < 75µm), characteristic of low-energy regimes (DUFFY and DEVOY, 1999).

At the study sites it is likely that the individual recording stations, even within an otherwise homogeneous environment, will be subject to different forcing parameter combinations (e.g., fetch, proximity to channels, position within the tidal frame). However similar net trends in surface elevation change were often observed at different recording stations (Figure 4). These included seasonal pattern changes and were particularly evident at stations with similar morphological attributes and vegetation cover (e.g., sites dominated by *Spartina spp.*). The patterns of elevation changes also follow the same or similar trend on a regional basis. The average cumulative elevation changes from all the Courtmacsherry stations are closely comparable to those of the Womanagh stations (Figure 5), exhibiting annual rates of elevation change of c. +6-6.5 mm yr^{-1} (2001-2003). These rates of elevation change from the

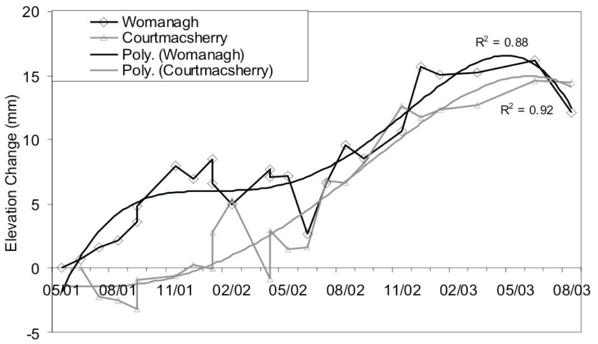

Figure 5. Average cumulative elevation changes from all Womanagh and Courtmacsherry sediment pin stations (4th order polynomials trendlines have been added).

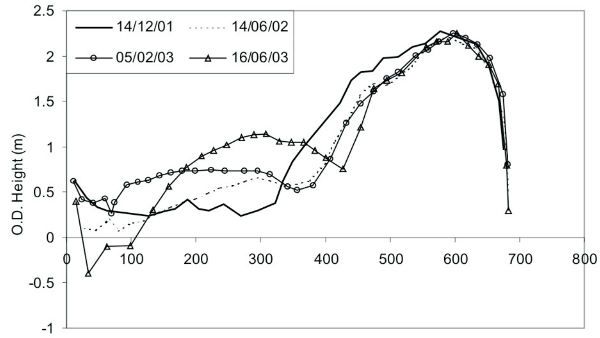

Figure 7. Vertical elevation changes at transect H1, Harbour View (see Figure 2 for the transect location). Note that the westward channel bank remains static throughout.

Courtmacsherry sites have also been compared with those from an earlier 18-month study (Jan 1995 July 1996) at Timoleague (Figure 2) (DEVOY *et al.*, 1996a). A number of sediment pin stations used in that study remain in position unchanged and have allowed direct comparison of sedimentary trends between the two time periods (Figure 6). Whilst the monitored sediment elevation levels for the two study periods are independent of each other, results show similar time trends and mean annual sediment accretion rates, of c.6 mm y^{r-1}.

Differences do exist, most noticeably the sudden loss of elevation for station CT-D shown to commence at the end of November 1995. DEVOY *et al.,* (1996a) attributed this trend to rapid erosion of the sediment surface by localised increases in wave energy as a result of the seasonal prevalence of north easterly winds coincident with the maximum fetch for these stations.

Outer Estuary - Beach Elevation Changes

Contrasted with the inner estuary areas, of fine sediments storage and predominantly low wave energy regimes, are the wave exposed higher energy, open coastal study sites. These are dominated by sediments of medium - coarse sands and gravels.

The intertidal sediment transects from the Harbour View area display significant temporal adjustments. For example, transect H1 (Figure 7) shows substantial (>50 cm) vertical accretion over a 4-month period (February 2003 June 2003). This pattern of change appears to be continuous (as opposed to cyclical) over the short study period (Figure 2). The main channel position has remained static, however, during this time. In contrast, transect H3 (Figure 8) exhibits distinct vertical and lateral sediment movements, driven in part by migration (~100 m/yr) of the shallow ebb-tidal channel, and vertical elevation change in excess of 1m (June 2002 - February 2003). This may be due to the affect of persistent southerly winds at this location during the winter period.

In spite of the apparent substantial beach height adjustments recorded over some transects, sediment volumetric (above 2 m ODM) change at sites appears as relatively small (<5%). This may indicate the remobilisation and redistribution of sediment within and between the surveyed profiles, rather than net gains or losses of sediment from the beach system as a whole.

The opposing trends of accretion and erosion between transects H1 and H3 in the same area (Figure 9) illustrate this and also intimate to sediment redistribution within the Harbour View sand flat.

DISCUSSIONS

Factors that influence sediment accretion and erosion, as measured by changes in sediment elevation, are mainly driven by variations in wind-generated waves and currents and by tidal currents (ANDERSON *et al.*, 1981). Variations in sediment supply over time are also important. Records of these sediment elevation 'fluxes' require cautious interpretation due to the strong localised differences that will exist between both individual recording stations and between study areas. It should be noted that intertidal sedimentary flat environments display trends and patterns on a number of spatial and temporal scales and do not respond to forcing factors in a simple and uniform way (ALLEN and DUFFY, 1998). Further, for marsh - mudflat, low energy areas sedimentation is not a continuous process (REED, 1989).

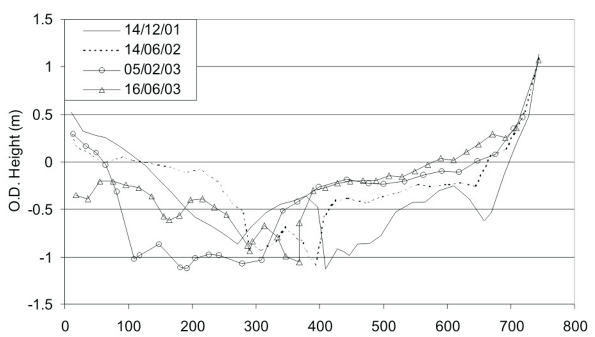

Figure 8. Vertical elevation changes at transect H3 (see figure 2 for transect location).

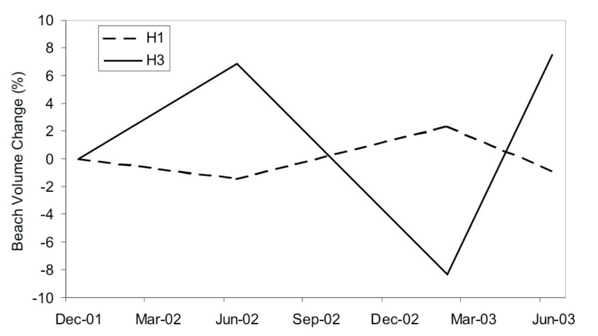

Figure 9. Percentage volumetric change (above ODM 2m) of transects H1 and H3.

Consequently, although valid in itself, this two-year study of such coastal sites is hardly sufficient to define the longer-term patterns and causes of sedimentation. In this study overall inner estuary elevations have been shown to be increasing at a rate of c.6 mm yr-1, which is consistent with earlier results from the same areas. Reasons for this trend at the Timoleague - Courtmacsherry site may include the factor of river water extraction (Argideen river), with consequent strengthening of tide dominated sediments influx. For both sites intensive agriculture in the river catchments feeding the coasts contributes sediment-rich runoff into the estuaries from significant exposures of seasonally unvegetated land. Further, the impact of Spartina spp. colonisation, which has occurred since 1967 at Timoleague and the Womanagh estuary, may be leading to accelerated elevation gains in the pioneer marshes (SÁNCHEZ et al., 2001).

As with the earlier work of DUFFY and DEVOY, (1999), the pattern of maximum sedimentary accretion in the current studies appears to show some cyclicity - seasonality for the marsh and other low energy areas (e.g., Figure 5). DEVOY *et al.*, (1996a) report that the sediment surfaces at these and comparable coastal marshes in Ireland generally attain their highest elevations during the winter to early spring, and their lowest during the summer to autumn. Causes for this, as observed more widely (DUFFY, 1994), are probably due to winter sediment accretion from storm events and the summer consolidation of sediments through 'ground breathing'. DEVOY *et al.,* (1996a) found that storm events may be most significant for those marsh stations that exhibited a positive sedimentary accretion relationship with wind-wave climate. Conversely, exposed sandflats and degraded saltmarsh had an opposite (sediment loss) relationship, being lower in the tidal frame and experiencing increased wind-wave induced shear stresses. In the present study these patterns are less clear for some of the monitored locations. In this work the intertidal flat stations are generally small-scale and lie close to riverine channels, and are perhaps less dependent upon storm events to gather inorganic material (CAHOON and REED, 1995).

The similarity in rate and pattern of average elevation changes in the two estuaries, 62 km apart, is an interesting result. Could this be coincidental, or are regional - wider factors responsible (LOZANO *et al.*, in press)? The similar rates of change observed between the two Timoleague studies (for 1995 and 2003) indicate an ongoing medium-term sedimentation rate (mean elevation increase) of c.6mm yr^{-1}. The comparison of these studies (Figure 5) does also show that phases of erosion, due to wind-wave activity and storminess, can 're-zero' the sediment surfaces virtually instantaneously. These contemporary accretion rates contrast with a lower long-term averaged accumulation rate of c. 2mm yr^{-1}, as reconstructed from the radiocarbon dating and palaeoenvironmental analyses of the longer Holocene sedimentary sequences at such sites (DEVOY *et al*., 1996a; DEVOY *et al*., this volume). This may suggest that a different 'suite' of process parameters is now operating at the study sites, causing more rapid environmental changes to occur (e.g., from human impacts, storminess and climate change linked causes). However, the estimation of sedimentation rates based upon the dating of cores can be problematic, often providing only 'tentative' results (REED, 2002). The processes of sediment compaction-consolidation and extreme event / geological averaging of the coastal sedimentary record will cause an inbuilt environmental distortion (underestimation) of reconstructed sedimentation rates from the past (DEVOY *et al*., 1996b).

In the present day, the observed contemporary infilling of navigation channels, the increasing extent of intertidal flats (linked to habitat changes), and the apparent increase in Enteromorpha spp. during the summer months highlight the importance of human-induced environmental management issues in ongoing coastal sedimentation. Other factors of importance for continued sedimentary changes include those of relative sea-level rises (RSL) and storminess, as linked to coastal geometry. Relative sea-level rise may trigger marsh initiation (PETHICK, 1980; ALLEN, 2000) and can be important in determining the timing of their development cycles. However, although marshes have been shown to accrete at a faster rate than RSL, if there is sufficient sediment input and in situ soil formation (DAY et al., 1998), models of marsh development generally indicate that accretion rates decrease as marsh height increases (PETHICK, 1980). Given these observations it is unlikely that the current rate of RSL along Ireland's south coast (1-2 mm yr^{-1}) will be responsible for all of the elevation increases observed at the study sites.

The influence of changing storminess patterns may also be reflected in the site data. The magnitude and rapid nature of the changes shown at some study locations, for example, by the Harbour View sandflat (Figures 7 and 8), may in part be a response to episodic, high energy events, as seen on the Ireland's west coast (DUFFY and DEVOY , 1999; WHEELER *et al.*, 1999). The geometry of both study sites ensures that the inner estuary areas are afforded protection from the effects of storminess. This has resulted in lower energy levels within the main estuarine bodies and sedimentological partitioning of the inner and outer estuary systems. Although separated by a matter of only a few metres, monitoring of suspended sediment flows has shown that coarse sediments rarely move landward of the protecting coastal barrier, whilst few fines escape from the main estuary.

CONCLUSIONS

This paper has presented a selection of representative results from a wider, ongoing study of coastal functioning along the south coast of Ireland. More questions have been asked than answered at present, though some clear patterns of short - medium term changes are apparent for the sites, at both the local and inter-site (regional) scales. It is the aim of further work to show more accurately the combination of processes that drive the large scale, rapid patterns of outer estuary sedimentary movements and the steady elevation increases (c.6 mm yr^{-1}) of the inner estuary mudflats and saltmarshes on these coasts.

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