Littoral 2010, 06004 (2011)
DOI:10.1051/litt/201106004

Management Implications of Flood/Ebb tidal dominance: its influence on saltmarsh and intertidal habitat stability in Poole Harbour

Sarah Gardiner[1], Prof. Robert Nicholls[1], Prof. Trevor Tanton[1]
[1]School of Civil Engineering and the Environment, University of Southampton, Southampton, SO17 1BJ, UK. Tel: 02380 595459, (scg@soton.ac.uk)

Abstract

Saltmarshes are important habitats and have historically declined in the south of the UK and as sea-level rise is predicted to accelerate these losses are expected to increase.
In order to explore estuary morphodynamics with relation to accretional and erosional trends at an estuary and sub-estuary scale, historic aerial photography were analysed with saltmarsh changes from 1947 and 2005 quantified. Using the Telemac model developed by HR Wallingford, tidal asymmetry of peak tides and slack duration was mapped and correlations between tidal asymmetry and saltmarsh change examined. Results indicate that there is a significant relationship between areas of flood dominance and the historic accretion of saltmarsh. However, there is no statistical correlation between areas that had experienced erosion and ebb dominance, indicating other dominant drivers of erosion processes. Results using hypsometric calculations suggest that the whole harbour behaves as an ebb dominant system and therefore tends towards erosion. However, when split into a sub-estuary scale, different creek systems show varying morphology and the hypsometry changes. This may have serious management implications where estuaries are manipulated through dredging and development, leading to significant effects on the surrounding intertidal habitats. However, managed realignment planning could also exploit the potential for enhancing flood dominance and hence accretion wherever possible.

Keywords: *Saltmarsh, Estuary, Tidal asymmetry, Coastal habitats, Poole Harbour*

1. Introduction

Habitat loss through modification and fragmentation is considered as one of the most serious global diversity threats (Sih, *et al.* 2000). Habitat loss has been particularly severe and prominent in the coastal zone through land reclamation, development, overfishing and pollution, with European losses being estimated at exceeding 50% of the original area (Airoldi and Beck, 2007). Estuarine habitats, including saltmarshes, mudflats and seagrass beds are important habitats, both as protected areas for wildfowl and fisheries stocks as well as providing an important component of coastal protection via wave dissipation, (Moller and Spencer, 2002). As an acknowledgement of the ecological functions estuaries perform, large areas have been designated under the EC Habitats and Species Directive including; saltmarshes and mudflats. However surveys led by English Nature within the Stour and Orwell Estuaries, Hamford Water, Blackwell Estuary, Thames Estuary and Marshes, the Solent and Portsmouth Harbour, have found that despite European protection, salt marsh areas are still declining, (Gardiner *et al*., 2007), (Pye and French, 1993), (Royal Haskoning, 2004). Saltmarshes have also declined in other locations worldwide, particularly the USA (Kennish, 2001) and as sea-level rise is predicted to accelerate, these losses are expected to increase and near-total loss of saltmarsh in many coastal areas is not inconceivable by the end of this century, (Nicholls *et al.,* 1999). Hence understanding the processes which affect saltmarsh and intertidal areas and the services they provide is vital. One such estuary that has experienced saltmarsh loss in the UK is Poole Harbour, a large tidal estuary situated on the south coast of Britain, Poole Harbour will be examined as a case study.

In light of the importance of estuaries, both environmentally and commercially, understanding the processes which drive them, including hydrodynamics, tides and sediment transport and the consequences for morphological change is crucial in order to better manage these areas and conserve the habitats situated within them. As well as giving insight into the changes that may occur in these areas with future development and anthropogenic influence.

2 Methodology

Estuary morphodynamics with relation to accretional and erosional trends at an estuary and sub-estuary scale and specifically the role of tidal asymmetry with relation to saltmarsh change was explored. In order to examine these issues, a saltmarsh change analysis was performed using historic aerial photography to observe saltmarsh trends within the harbour. A hydrodynamic model was used to assess tidal asymmetry within the harbour and the harbours morphology was studied using bathymetry datasets in order to further investigate the role this plays in habitat distribution.

2.1 Historic Saltmarsh Analysis

Aerial photography was acquired for 1947 and 2005 from the Environment Agency, UK. The 2005 data was supplied as one single, georectified, colour image. However, the 1947 data was supplied as individual black and white, non-rectified images. Using ArcGIS, these images were georectified against the 2005 aerial photography. Throughout this process the RMS (root mean square) errors of the georectification points were monitored to ensure that accuracy was maintained and error was minimised. Saltmarsh extent was then digitised for both datasets. This was aided using data supplied by Dorset Environmental Records Centre, showing generalised saltmarsh, reedbed and intertidal habitat extent in 2003. Issues included the incomplete coverage of aerial photography, the 1947 dataset has a 73% coverage of the Harbour and the 2005 dataset a 96.6% coverage. The digitised saltmarsh areas for 1947 and 2005 can then be compared, to observe saltmarsh trends.

2.2 Telemac Model

With permission from HR Wallingford and Poole Harbour Commissioners, a Telemac model for Poole Harbour provided depth averaged tidal flow vectors under present conditions, indicating areas within the harbour that are flood and ebb dominant and potential correlations with saltmarsh and mudflat erosion from the historic analysis.

The underlying tin mesh varies with accuracy throughout the Harbour, as the model was developed to investigate possible effects of dredging in the main channels, reported in (HR Wallingford, 1993), therefore it is these areas that have the greatest resolution. However it is hoped that model outputs will give insight into other areas of the Harbour also, particularly the southern intertidal shore and Wareham Channel. The model was calibrated using flow data collected from current meters at 7 locations within Poole Harbour and 6 tidal diamonds. A grid of points was created in ArcGIS, with a spatial scale of 500m. At each point, data was extracted from the Telemac model and processed in matlab, the data included x and y coordinates, time, velocity U m/s, velocity V m/s, water depth and velocity magnitude m/s. These are supplied for every 20 minutes over the 12.5 hour tidal cycle for a neap or a spring tide. From this data peak flows for flood and ebb stands can be observed across the estuary.

2.3 Estuarine Morphology

Hypsometry is the way in which the plan area of a drainage basin varies with elevation, variations in this form can alter the way the tide propagates and can change the flood and ebb properties, (Townend, 2008). Several studies have investigated the application of empirical formulae to hypsometrical relationships, including Strahler, 1952 and Boon and Byrne, 1981, hypsometry is used to describe the morphology and 'maturity' of an estuary. This method was applied to the Dee estuary (Moore *et al*, 2009), usually categorised as flood dominant. However, it was found that it could be switching towards being ebb dominant or is reaching morphological equilibrium and in future this will lead to a decrease in accretion. Hence, this method may give some insight into the future sediment trends within an estuary and thus saltmarsh distribution.

Hypsometric curves can be calculated using equations (1-3):

$$a/A = G/(r+G(1-r) \quad (1)$$

$$\text{where; } G=(1-h/H)^{\gamma} \quad (2)$$

$$r=A_{min}/A \quad (3)$$

Where h=height above minimum basin elevation, H=height between maximum and minimum basin elevation, A=total/maximum basin area, A_{min}=minimum basin area, a=basin area lying below contour at height h, and γ=factor controlling the area below the hypsometric curve (i.e. the volume of sediment in the basin) The parameter γ is unknown and can be estimated using graphical solutions, this can be used to describe the morphological state of the estuary. An estuary where γ=3.5-5.0, will be little in-filled and flood dominant, while an estuary where γ= 1.8-2.5 and will be ebb dominant. Hypsometry can be simply observed by plotting x= a/A and y=h/H.

3 Results

3.1 Saltmarsh Change

A net loss of saltmarsh has occurred within Poole Harbour between 1947 and 2005. Saltmarsh loss through land claim was calculated to be 51 ha, with development in Holes Bay accounting for 37ha and land claim for agriculture in Middlebere Lake, 14 ha. The types of saltmarsh erosion were then identified, these are; 1) island erosion, 2) frontal erosion and 3) creek erosion, figure 1, in a similar manner to (Downs *et al.*, 1994), in order to link loss to possible drivers and hence assess the relative importance of the possible loss mechanisms. Island erosion was classified where islands of marsh, unconnected to the mainland with no elevation over HAT have partially or wholly eroded, frontal erosion was classified as where areas on open or semi-open saltmarsh had retreat landwards from the front edge. Creek erosion was classified as any erosion that had taken place within sheltered creek systems. The drivers for the erosional processes may be the same, for example where saltmarsh islands have retreated exposing frontal saltmarsh which has also retreated. Similarly the process of frontal erosion may be due to the same processes within creek systems. Accretionary processes were similarly classified, with creek accretion and frontal accretion. However it is important to note that no island accretion was observed.

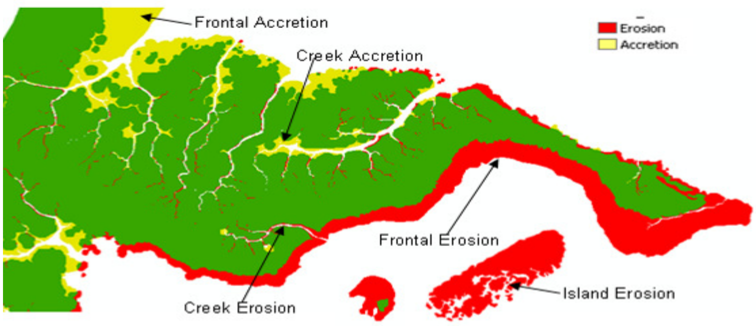

Figure 1. *Definition sketch for the different types of saltmarsh erosion and accretion used in this research*

The Harbour area was split into 20 different polygons, Figure 2, according to dominant saltmarsh processes, from the historical analysis, with saltmarsh loss and gain calculated. Unfortunately some areas were not covered by the aerial photography for one or both years, these areas have been left out of the comparison. Areas where an overall loss in saltmarsh has occurred are highlighted in red, areas where an overall gain has occurred, are in blue.

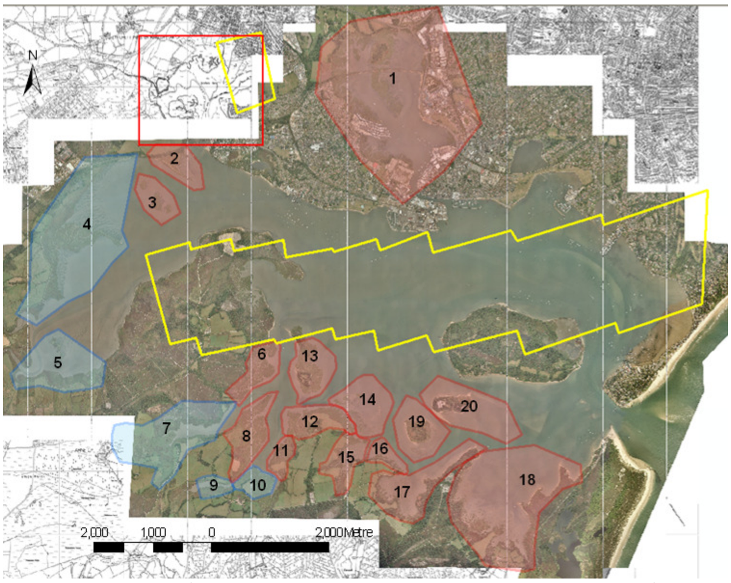

Figure 2. *Poole Harbour Regions used for saltmarsh analysis (Boxes show areas of missing aerial photography)* 1) Holes Bay, 2) Wareham North, 3) Wareham Islands, 4) Wareham West, 5) Wareham South, 6) Grip Heath, 7) Middlebere Lake, 8) Wych Lake North, 9) Wych Lake South, 10) Wytch Farm, 11) Wych Lake East, 12) Fitzworth North, 13) Long and Round Islands, 14) Fitzworth Islands, 15) Ower Bay, 16) Cleavel Point North, 17) Newtown Bay, 18) Brands Bay, 19) Green Island, 20) Furzey Island

Location	Saltmarsh (ha)		Net Change	% Change	Erosion (ha)			Accretion (ha)		
	1947	2005			island	frontal	creek	island	frontal	creek
1) Holes Bay	87.5	52.7	34.8	39.8	10.08	24.71	5.65	0	0	5.71
2) Wareham North	9.1	7.0	2.1	23.1	NP	2.13	0.12	NP	0.15	0.05
3) Wareham Islands	11.0	4.5	6.5	59.1	NP	6.76	0.05	NP	0.09	0.16
4) Wareham West	62.9	66.0	-3.1	-4.9	0.11	6.58	0.51	0	6.47	3.90
5) Wareham South	9.9	18.2	-8.3	-83.8	0.04	0.56	0.06	0	8.38	0.64
6) Grip Heath	21.7	19.9	1.8	8.3	NP	1.10	1.00	NP	0.13	0.30
7) Middlebere Lake	25.9	35.3	-9.4	-36.3	NP	0.06	0.16	NP	2.38	7.22
8) Wychlake North	31.3	30.2	1.1	3.5	NP	1.39	1.12	NP	0.89	0.45
9) Wychlake South	5.3	7.4	-2.1	-39.6	NP	0	0.02	NP	1.98	0.14
10) Wytch Farm	12.9	14.1	-1.2	-9.3	NP	0	0.28	NP	1.28	0.17
11) Wychlake East	10.3	9.6	0.7	6.8	NP	0.77	0.27	NP	0.07	0.26
12) Fitzworth North	19.9	17.6	2.3	11.6	0.48	2.49	0.49	0	0	1.15
13) Long and Round Island	24.2	15.2	9	37.2	0.99	7.33	0.87	0	0	0.16
14) Fitzworth Island	22.2	1.5	20.7	93.2	20.81	0	0	0	0	0.05
15) Ower Bay	13.2	11.1	2.1	15.9	0.15	1.81	0.66	0	0	0.53
16) Clevel Point North	6.3	2.5	3.8	60.3	1.65	1.79	0.46	0	0	0.02
17) Newtown Bay	18.1	7.6	10.5	58.0	4.79	5.95	0.28	0	0	0.54
18) Brands Bay	67.7	22.8	44.9	66.3	30.60	11.34	3.25	0	0	0.30
19) Green Island	15.7	3.4	12.3	78.3	7.77	4.51	0.10	0	0	0.06
20) Furzey Island	20.5	2.4	18.1	88.3	13.42	4.64	0.13	0	0	0.03
Total	495.5	348.9	146.6	29.6	90.89	83.92	15.48	0	21.82	21.84

Table 1. *Saltmarsh area (ha) by location, overall change in area and percentage change and erosional and accretional processes by region (NP denotes not possible at this location)*

The majority of regions experience an overall loss of saltmarsh area between 1947 and 2005, (***Table 1***), with the main drivers differing between sites. Brands Bay lost the most amount of saltmarsh at 67 ha, (44ha net loss), however in terms of relative loss, Furzey Island has lost 88% of its saltmarsh area. Five areas within Poole Harbour have, however, experienced overall saltmarsh gain, with Middlebere Lake gaining the most with 9 ha or 36 % area gain. Wareham South gained the most in percentage terms, 8 ha or 88% area gain. Wychlake South and Wytch Farm regions appear to have experienced very little erosion of any kind with 6ha lost through frontal erosion in Wareham west, whereas, elsewhere in the Harbour, towards the south-eastern creeks, very little accretion has occurred and it is confined to within protected creeks. It is clear from these results that trends in saltmarsh accretion and erosion occur across the Harbour, with accretion occurring in the creeks to the west of the estuary.

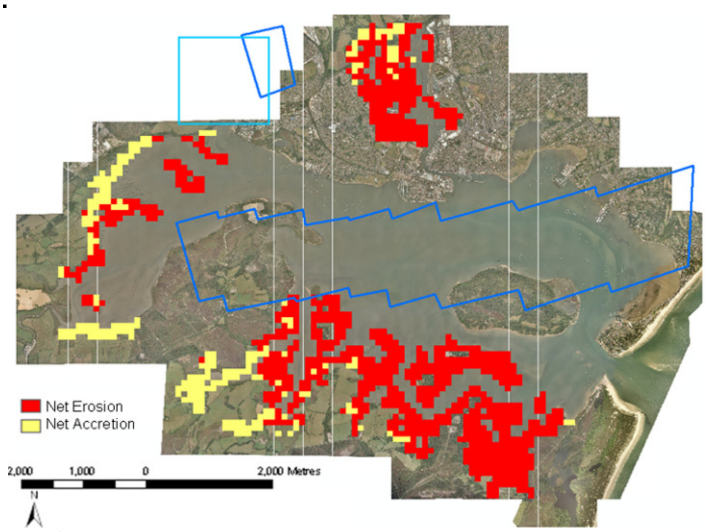

Figure 3*. General trends of saltmarsh change in Poole Harbour (100m cell size). (Boxes indicate where aerial photographic data is missing).*

Figure 3 illustrates the general trends of the saltmarsh within Poole Harbour by taking the original data and depicting accretion or erosion, over a 100m cell. Areas of accretion occur predominantly in the west or the Harbour and up the creeks at the top of the tidal frame, whereas saltmarsh erosion occurs within the open estuary and the east of the Harbour.

3.2 Tidal asymmetry

Figure 4 shows peak flows on flood and ebb with an imposed slack threshold of 0.2m/s, used to illustrate the potential effects on sediment transport, after (Mantovanelli *et al.*, 2004). The key has 7 categories, 1) peak flows occurring on flood and both flood and ebb flows below 0.2m/s, 2) peak flows occurring on ebb but both flood and ebb flows below 0.2m/s. In these situations sediment transport would not be expected to occur. 3) peak flood flow is higher than 0.2m/s and the peak ebb below 0.2m/s, 4) peak ebb flow is higher than 0.2m/s and the peak flood below 0.2m/s. In these situations sediment transport would be limited to the flows where they are higher than 0.2m/s, therefore showing strong tidal asymmetry. 5) peak flow is on flood, but peak flows on flood and ebb are both above 0.2m/s and 6) peak flow is on ebb, but peak flows on flood and ebb are both above 0.2m/s. In this situation sediment transport occurs on both flood and ebb but to differing extents. In only one area the model output gave the flood and ebb peak flows to be the same, however, the flows were below 0.2m/s and so would not contribute greatly to sediment transport.

Data from Figure 4, of peak flows during ebb and flood dominance and data of dominant saltmarsh accretion or erosion, Figure 3, averaged over 500m cells, were combined. A chi-squared test was performed, to assess statistical significance between areas where flood dominance and saltmarsh gain were present and saltmarsh loss and flood dominance were present. For saltmarsh gain a $p>0.05$ was calculated thus indicating that where saltmarsh is accreting, the tidal asymmetry is of significant importance. For saltmarsh loss a $p<0.05$ was calculated indicating that where saltmarsh is eroding the tidal asymmetry may not be the driving factor and these issues require further assessment.

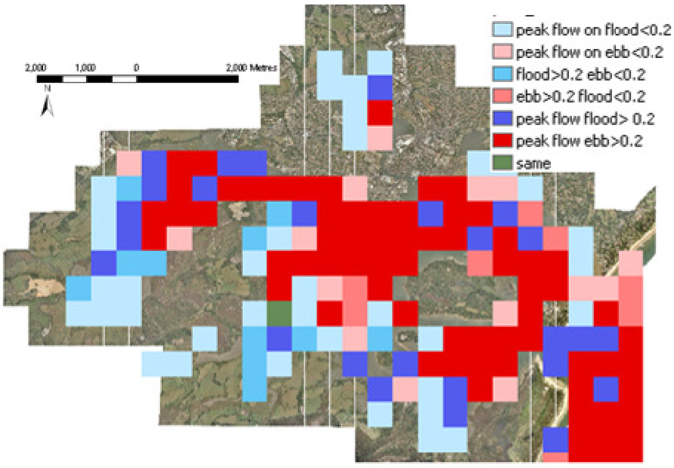

Figure 4. *Telemac model output showing ebb and flood dominance of peak flows over spring tidal cycle, with a slack threshold of 0.2m/s.*

3.3 **Hypsometry**

By combining the Lidar data from 2006 and Bathymetric charts from 1987 showing the main channels in detail, a digital terrain model of the Harbour has been created. From this, cross sectional area at given heights could be evaluated and plotted to observe the hypsometry. Where H is the total height of the basin, A is the total area of the estuary and a is the cross sectional area at given height h. These profiles can then be compared to empirical hypsometry curves derived in Strahler, 1952 and Boon and Byrne, 1981. Parameters from these curves can then be calculated to indicate whether these areas are behaving as mature or immature estuaries. The parameter γ can be used to describe the maturity of the estuary. An estuary where γ=3.5-5.0 will be little in-filled and will be flood dominant, while an estuary where γ= 1.8-2.5 will be ebb dominant.

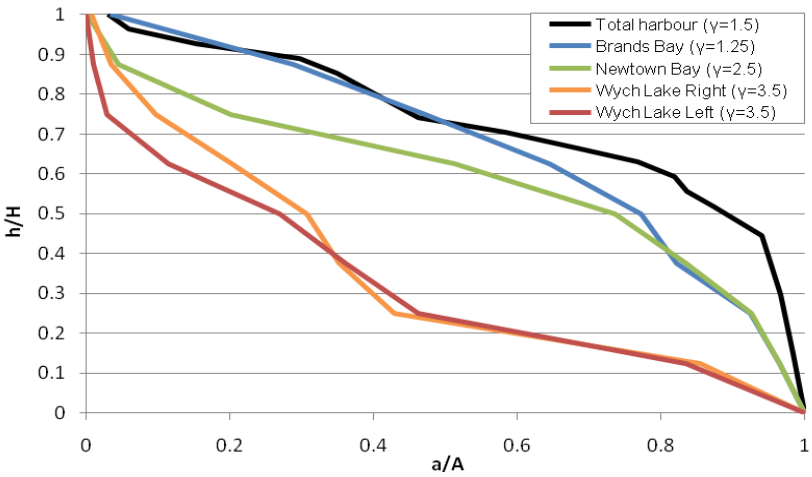

Figure 5*. Hypsometry plots for Poole Harbour and selected regions*

Figure 5 shows the hypsometric plots for Poole Harbour and selected areas within it, the varying morphology is clear to see with Wych Lake Left and Right having a γ value of 3.5

indicating an association with flood dominance, (Boon and Byrne, 1981), these areas have experienced net accretion between 1947 and 2005.The data for Newtown Bay suggest a value of γ=2.5, a γ figure of 2-3 which suggests varying states of medium infilling and this area may be in an intermediate stage where it will switch from flood to ebb dominance. The plot for the whole of Poole Harbour suggests from the shape of the curve that Poole Harbour may have an overall γ value of around 1.5, and Brands Bay a γ value of around 1.25. Both Brands Bay and Newtown Bay have experienced losses of saltmarsh, which may be due to the export of sediment from these regions due to ebb dominance in the tidal asymmetry.

4 Discussion

Saltmarsh in Poole Harbour has experienced a net loss since 1947, however, in addition to 190.3 ha of loss, an accretion of 43.7 ha has also been observed. When the harbour is broken down into separate zones some experience a net gain of saltmarsh. This more variable behaviour has not been identified in any preceding studies, e.g. (Born, 2005) where habitat change within Poole Harbour was focused on large scale changes. Small scale creek accretion therefore has been missed leading to an overestimation of historic erosion, and the assumption that erosion is the dominant process and will be the long term trend in the future. Previous studies have also not investigated or tried to specifically link how hydrodynamics may affect these processes. Initial results from studying the morphology show the hypsometric curves for the whole harbour and regions within it, the curves vary greatly from one another, with curves of areas of accretion being of a different form to those of areas where erosion has occurred and of the whole estuary. Examples of hypsometric curves within the results also suggest a correlation between areas of accretion with areas that exhibit a higher value of γ, and a tendency for flood dominance. Areas with a low value of γ and a tendency for ebb dominance appear to be associated with areas that have experienced saltmarsh loss. Other driving factors of change may be due to the tidal asymmetry within the harbour. This includes erosion, due to high current velocities, with tidal asymmetry affecting sediment transport and therefore the net export or import of sediments. Preliminary results of peak tidal flows from the Telemac model outputs indicate that areas that have experienced accretion from 1947 to 2005 and areas of flood dominance are statistically correlated. However, this is not true for areas of erosion and ebb dominance. Therefore, it is suggested that the hydrodynamics are one of the primary drivers of accretion within the harbour but it is not the primary driver of erosion.

5 Conclusions

The morphology of an estuary is intrinsically linked to the habitats located within it, as the morphology is changed through either natural or manmade pressures the habitats will be affected. This study has attempted to link the historic saltmarsh changes within Poole Harbour and its morphology and resultant tidal asymmetry. In order to do this a historic analysis of saltmarsh change has been conducted alongside the analysis of tidal flows from the Telemac model of Poole Harbour and studies of the morphology via bathymetry data.

It has been found that saltmarsh loss in the harbour is less than suggested in previous studies, where creek systems were not investigated in detail, thus missing small scale creek accretion, and when split into sub-estuary areas some exhibited net saltmarsh gain. The initial hypsometry calculations suggest that the harbour as a whole tends towards being ebb dominant, however, as creek systems are observed individually the hypsometry changes, with areas where accretion has occurred tending towards flood dominance. Comparing peak flows during a spring tidal cycle, extracted from the Telemac model, and saltmarsh change within the estuary, suggests that there is a correlation between flood dominance and accretion. However there is no statistical correlation between areas of erosion and ebb dominance. Suggesting that flood dominance may be a driver for accretion but ebb dominance may not be the main driver for the erosion that has been observed. These findings better inform how the harbour may behave in the future with the dominant processes causing change identified.

At a wider scale these findings have implications for management within estuaries, particularly where dredging may change the morphology and could potentially shift an accreting, flood dominant system to an eroding ebb dominant system or vice versa. These findings could also be used within managed realignment schemes to maximise the habitat resources created by ensuring the bathymetry will favour a flood dominant, accreting system.

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Acknowledgements

EPSRC, HR Wallingford, Poole Harbour Commissioners, Dorset County Council, Environment Agency, Natural England, NOC and Dorset Environmental Records Centre.