Assessing Habitat Compensation Requirements in Estuary Environments

Paul Canning, Atkins Limited, Bristol, UK.
Nigel Pontee, Halcrow Limited, Swindon, UK.

Summary

In the UK, the EU Habitats and Birds Directives have provided a legal requirement to protect a range of designated conservation sites from deterioration. This applies whether deterioration is due to natural or anthropogenic causes. The development of strategic plans for the management of flood and coastal risk management (FCRM) assets therefore needs to consider the implications on habitats. Some early estuary FCRM strategies, developed by the Environment Agency set out to compensate for all habitat loss regardless of the causes. More recently, Defra guidance has suggested that FCRM plans only need to compensate for those losses that are due FCRM actions, although they should seek to identify all losses. This approach leads to the requirement to define extents or habitat change and identify those changes that could be due to FCRM activities.

This paper is concerned with evaluating the extents and causes of past and future losses of habitats within estuaries. It is specifically concerned with determining a) natural change which occurs in response to sea level rise or other natural causes, and b) anthropogenic changes caused by FCRM activities or other anthropogenic assets and activities. The determination of these causes is a critical element in deriving appropriate habitat compensation targets for habitats that might be affected by FCRM assets. Implementing these targets is often both costly and difficult to achieve, and hence appropriately assessing the cause and extent of change is of significant financial value to society, especially during times of austerity. This paper describes a methodology to quantify existing losses, decide on the causes of these losses and extrapolate the potential future losses.

Introduction

In the UK, the EU Habitats and Birds Directives have provided a legal requirement to protect a range of designated conservation sites from deterioration. This applies whether deterioration is due to natural or anthropogenic causes. The development of strategic plans for the management of flood and coastal risk management (FCRM) assets therefore needs to consider the implications on habitats. Some early estuary FCRM strategies, developed by the Environment Agency set out to compensate for all habitat loss regardless of the causes. More recently, Defra guidance has suggested that FCRM plans only need to compensate for those losses that are due FCRM actions, although they should seek to identify all losses. This approach leads to the requirement to define extents or habitat change and identify those changes that could be due to FCRM activities.

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times of austerity. This paper describes a methodology to quantify existing losses, decide on the causes of these losses and extrapolate the potential future losses.

Identifying Causes for Habitat Change

Previous work highlighted that there are a number of factors that combine to cause variations in retreat rates and habitat zones at individual locations (Pontee, 2011). Habitat change caused by FCRM activities is often referred to as coastal squeeze. However, this term has been overused and coastal squeeze is more precisely defined as '*one form of coastal narrowing, where intertidal habitat is lost due to the high water mark being fixed by a defence (i.e. the HWM resides against a hard defence such as a sea wall), whilst the low water mark migrates landwards in response to sea level rise.*' As such, there is a need to clarify the various causes for changes in coastal habitat extent over various timescales.

At an estuary strategy level it would be inappropriate to undertake the detailed studies necessary to appraise all of the potential contributory factors for habitat changes. Instead a high level approach is needed to identify those habitats whose future evolution may be affected by the presence of man-made assets. This paper describes a method that screens out those habitats whose future evolution is believed to be independent of anthropogenic assets. This is based on identifying habitat with a) significant spatial or process connection to natural coastline, b) significant spatial or process connection to FCRM or other anthropogenic assets and activities and, recognizing the complexity of some areas, c) uncertain or partial spatial or process connection to FCRM/anthropogenic assets or activities.

Determining Habitat Change

The quantification of changes in habitat, particularly over the decadal timescale, has large uncertainties attached, especially those due to sea level rise. The method relies on a sound understanding of geomorphological and hydrodynamic processes within the estuary, and involved the following steps.

1. Development of an estuary scale sediment budget and conceptual model. This was based on expert geomorphological analysis, including analysis of historic and recent mapping, volumetric surveys (LiDAR, beach profiles, bathymetry charts), aerial photography, scientific/grey literature review and 2D modeling.
2. Prediction of future estuary bathymetry based on estimated vertical and lateral rates of erosion or accretion.
3. Zoning of the present day intertidal habitats using astronomic tide levels (RSPB, 2005). This identified the present day distribution of mudflat, saltmarsh and transitional habitats. The results of this analysis were checked against available BAP habitat mapping and field observations for validity.
4. Prediction of future astronomic tidal levels based on future sea level rise predictions (Environment Agency, 2011) for a range of climate change scenarios, supported by 2D modeling.
5. Prediction of future intertidal habitat extent based on the future estuary bathymetry and astronomic tide levels. The results of this analysis were considered in light of historic observations.
6. Identification of those changes occurring within and without the existing SPA, SAC and Ramsar.

The above method was applied to the Severn Estuary (Atkins, 2012), Exe Estuary (Atkins Halcrow Alliance, 2012a) and Poole Harbour (Atkins Halcrow Alliance, 2012b), in relation to their respective FCRM strategies. These locations represent a range of tidal (micro, macro, and hyper) and wave conditions (from exposure to swell and wind waves, to significantly fetch-limited wind waves), as described in Figure 1. A summary of the review and usage of the available datasets for each of the estuaries is given in Table 1.The quantified analyses were considered in the context of historic habitat changes, future sea level rise scenarios, and wider causes of habitat change (such as those arising due to biological reasons), to indicate the level of uncertainty the methodology and predictions could have.

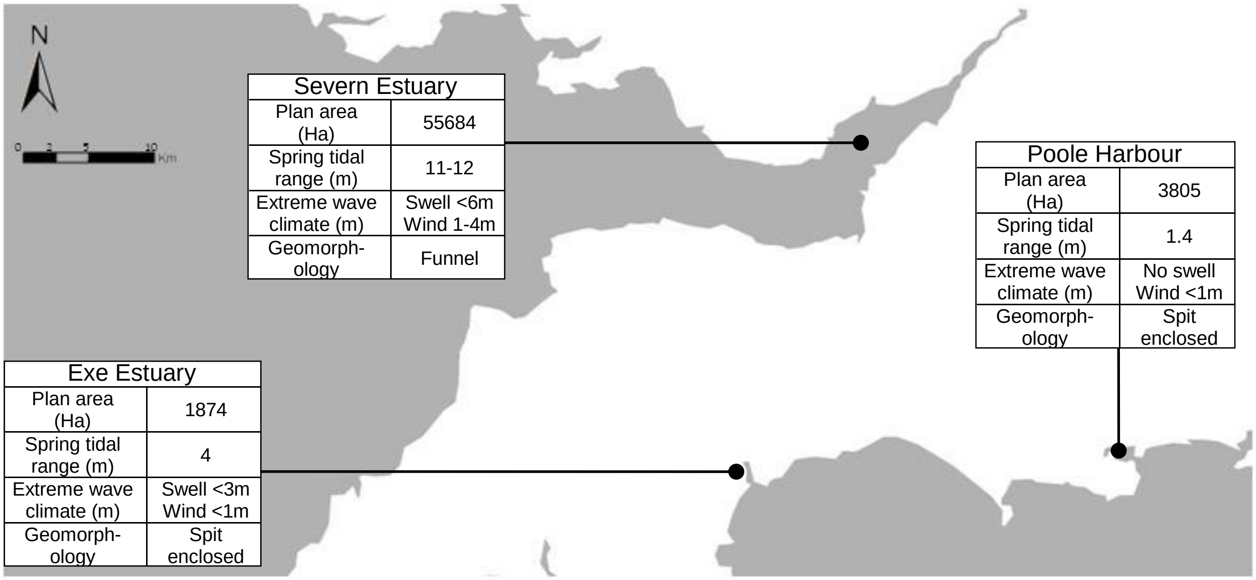

Figure 1. Overview of location and main features of the estuaries.

Table 1. Summary of data review and usage within expert geomorphological assessment.

Data	Severn Estuary	Exe Estuary	Poole Harbour
Volumetric surveys	**Review:** LiDAR and bathymetry surveys available. Intertidal relevance is reasonable (although tending to focus on navigation channels and fringing intertidal) historical temporal and spatial coverage across the whole estuary is inconsistent. **Usage:** Localised to corroborate or otherwise other datasets.	**Review:** LiDAR, beach profiling and bathymetry surveys available. Intertidal relevance is variable, and historical temporal and spatial coverage is good at the estuary mouth. **Usage:** Estimating sediment transport linkages and volumetric exchanges.	**Review:** LiDAR, beach profiling and bathymetry surveys available. Intertidal relevance is variable, and historical temporal and spatial coverage is variable. **Usage:** Identifying sediment transport linkages and order of magnitude volumetric exchanges.
Aerial photography	**Review:** Historical spatial coverage is focused mainly along the coastline, with in-channel features not covered. Temporal coverage is good between 1940 and 2000, although there are uncertainties around intertidal relevance. **Usage:** Limited.	**Review:** Historical spatial and temporal coverage is focused mainly along the coastline. Temporal coverage is good between 1940 and 2000, although there are uncertainties around low water relevance. **Usage:** Investigating lateral movements and evolution of large-scale features (sand spit, ebb/flood deltas).	**Review:** Historical spatial and temporal coverage is variable. Temporal coverage is good between 1940 and 2000, although there are uncertainties around low water relevance. **Usage:** Investigating lateral movements and evolution of fringing intertidal.
Ordnance Survey mapping	**Review:** Intertidal relevance was reasonable, although not the particular focus of OS mapping. Historic spatial and temporal coverage across the whole estuary was high with consistent data quality. **Usage:** Wide-scale to estimate lateral movements of features (fringing and in-channel mud-sandflats), and identify sediment linkages.	**Review:** Intertidal relevance was reasonable, although not the particular focus of OS mapping. Historic spatial and temporal coverage across the whole estuary was variable. **Usage:** Localised corroboration or otherwise of other analyses.	**Review:** Intertidal relevance was reasonable, although not the particular focus of OS mapping. Historic spatial and temporal coverage across the whole estuary was variable. **Usage:** Localised corroboration or otherwise of other analyses.

Modelling	**Review:** Hybrid 1D-regime CHaMP modeling of the whole estuary, and 1D ISIS modeling upstream of the Severn Crossings was available. Temporal and spatial coverage of the models and runs is good, being estuary-wide and 2010 through to 2110. **Usage:** Wide-scale prediction of intertidal evolution, and impacts of FCRM asset management.	**Review:** 2D hydrodynamic modeling of the estuary, and 1D modeling of the rivers Exe and Clyst was available. Temporal and spatial coverage of the models and runs is good, being estuary-wide and 2010 through to 2110. **Usage:** Wide-scale prediction of impacts of FCRM asset management. Localised prediction of potential erosion-accretion trends.	**Review:** 2D hydrodynamic and sedimentological modeling of the harbour was available. Temporal and spatial coverage of the models and runs is variable, being estuary-wide, but focused on 2010 and 2110 only. **Usage:** Wide-scale prediction of impacts of FCRM asset management. Wide-scale prediction of potential erosion-accretion trends.
Literature	**Review:** Extensive scientific literature, and grey literature including FutureCOAST, BMAPA, Severn Estuary SMP2, Severn Tidal Power feasibility study, various FCRM strategies, Gwent Levels FMP, Severn Estuary CHaMP, site specific dredging studies. **Usage:** Localised to indicate feature specific evolution, sediment linkages and corroborate or otherwise other datasets.	**Review:** Scientific literature, and grey literature including SDAD SMP2, Exe Estuary CMS, Lower Clyst studies, Dawlish Warren studies, SCOPAC sediment transport study. **Usage:** Wide-scale to corroborate or otherwise sediment transport linkages, Localised to corroborate sand spit evolution.	**Review:** Scientific literature, and grey literature including Two Bays SMP2, Wareham studies, PHC dredging studies, SCOPAC sediment transport study. **Usage:** Wide-scale to corroborate or otherwise sediment transport linkages.

Development and Application of Geomorphological Models

For the Severn Estuary, geomorphological models are described in the literature (e.g. Parker and Kirby, 1982), with quantitative detail being provided by the CHaMP and successor studies (ABPmer, 2006, Atkins/ABPmer, 2009). For the Exe Estuary and Poole Harbour the geomorphological models were developed during the strategy studies (Canning et al, 2011; Atkins-Halcrow Alliance, 2013), shown in Figures 2 and 3 with indication of trends, magnitudes and confidence.

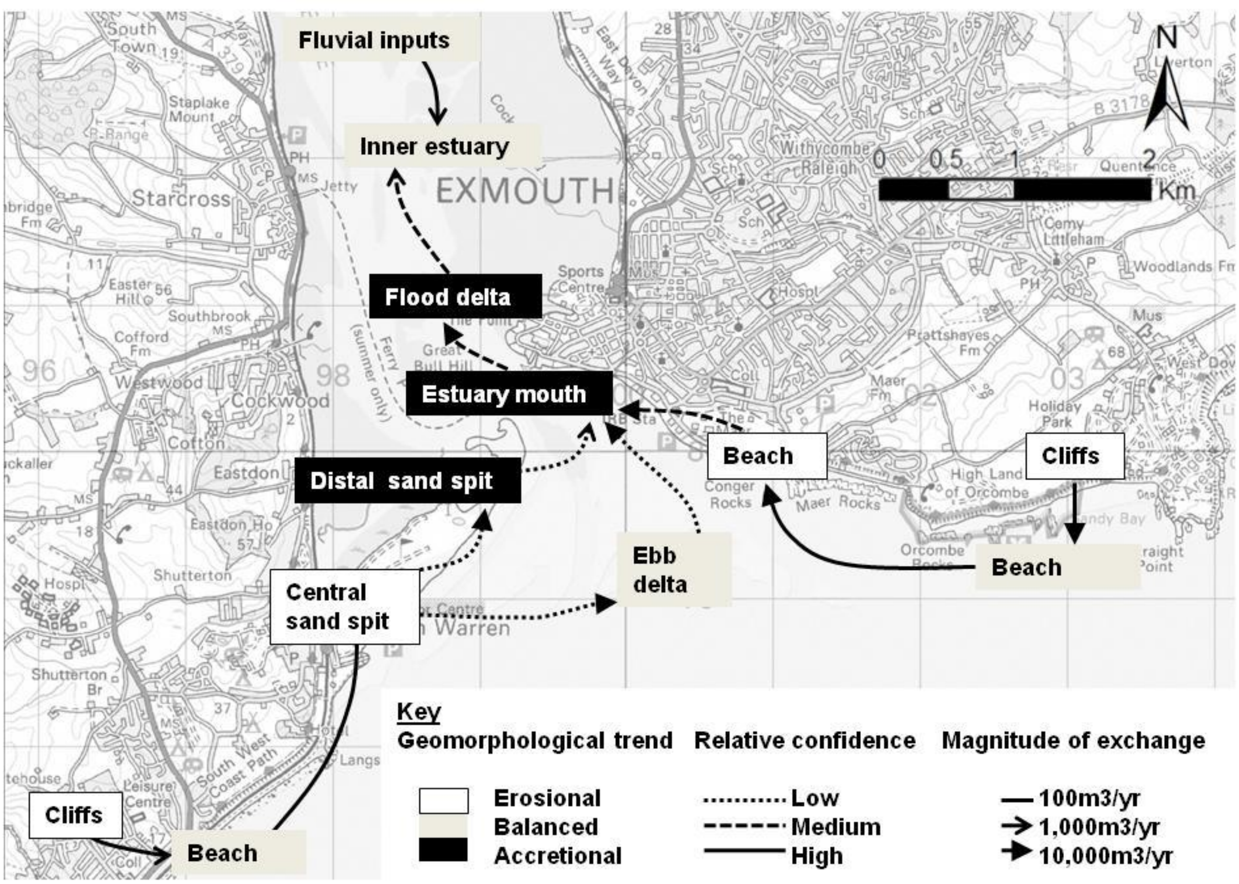

Figure 2. Conceptual model of the Exe Estuary.

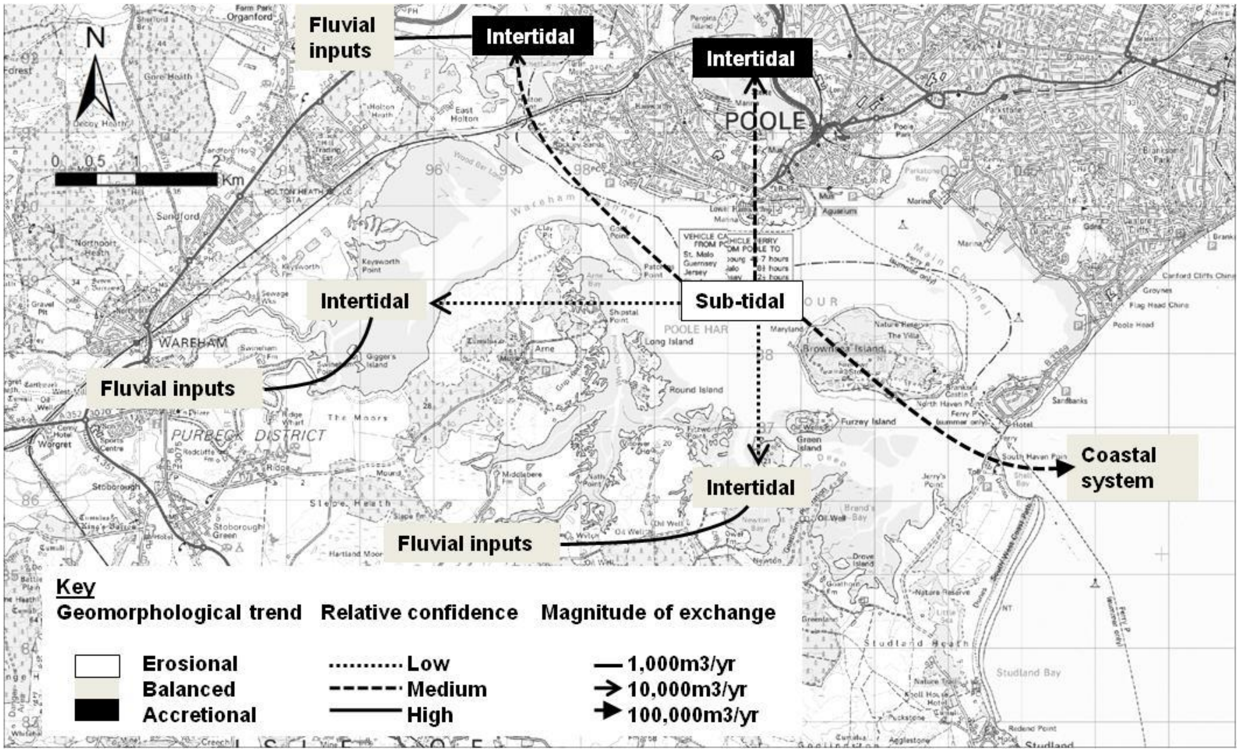

Figure 3. Conceptual model of Poole Harbour.

Allocation of habitat change

A summary of the allocation of habitat change within the study sites is given below, based on interpretation of the conceptual models. For the Severn Estuary, collation of historic OS mapping and bathymetry since the 1970s identified the in-channel features shown in Figure 4, as well as the definition of habitat behaviour units (ABPmer, 2006). For the Exe Estuary and Poole Harbour, the estuary units were based on the conceptual models.

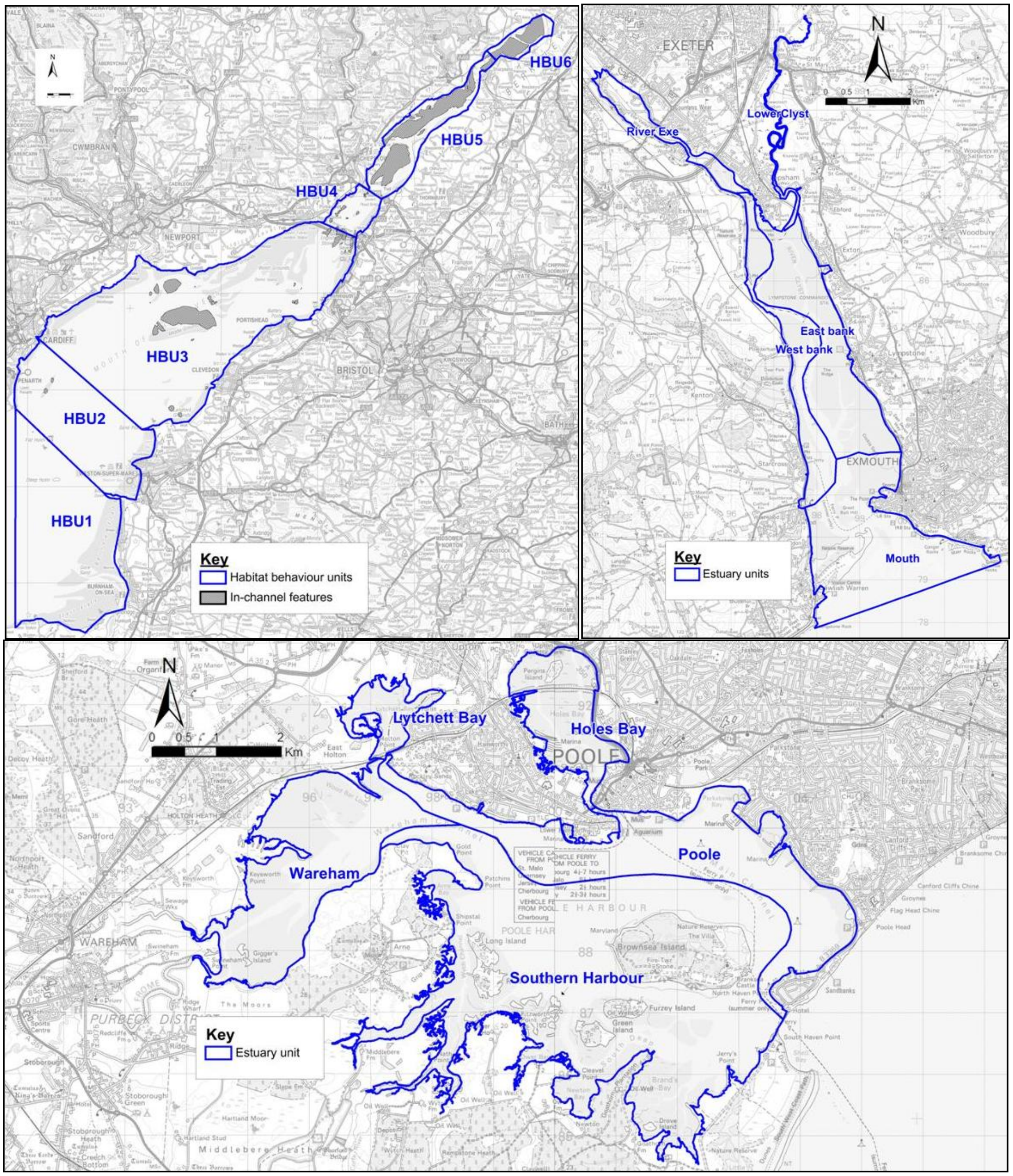

Figure 4. Overview of estuary units.

Severn Estuary overview

Previous work in ABPmer (2010) identified the proportion of fringing intertidal habitat adjacent to natural (cliffed) coastline or FCRM assets. Further consideration of this study identified that in-channel mud-sandflats and rocky outcrops were included within this proportional assessment. This suggested that the more detailed assessment of the evolution of these features could provide clearer evidence of natural and FCRM influences.

Consideration of the estuary-wide historic OS mapping, corroborated with bathymetry since the 1970s, identified three broad groups of in-channel features; (i) small scale mud-sandflats intermittently distributed near the coastline downstream of the Severn Crossings, (ii) large mud-sandflats situated in the central estuary and surrounded by the main sub-tidal channels, and (iii) large complexes of mud-sandflats up-stream of the Severn Crossings. Consideration of the historic evolution of these features, and the existing literature, suggested that the majority of small scale mud-sandflats, and large mud-sandflats in the central estuary exhibit limited influence from FCRM assets. Furthermore, the large complexes upstream of the Severn Crossings were seen to be strongly influenced by channel-switching, which is influenced by the FCRM assets that constrict the estuary channel in this area.

Exe Estuary Overview

The estuary mouth region includes the ebb-flood deltas and sand banks, Dawlish Warren sand spit and Exmouth beach. The conceptual model in Canning (2011) indicates that this is a dynamic area with strong linkages to other areas, including inputs from coastline to the east and west, and net output to the inner estuary also. Historic mapping and photography clearly show the mobility of ebb-flood deltas and near-shore sand banks, with no man-made assets present. However, Dawlish Warren sand spit and Exmouth beach do have man-made assets present. The construction of the mainline railway, and existence of the Langstone Rock and groyne, have also restricted the input of sediment spit from the west. Additionally, the presence of the FCRM assets (revetments, gabions and groynes) has had a significant influence on the continued existence of the spit. In a similar manner, the existing seawalls and promenade along the Exmouth coastline have also constrained the ability for the beach to receive increased sediment input. These analyses suggest that there are both anthropogenic and natural influences on habitat evolution, suggesting an uncertain spatial or process connection to FCRM assets or activities.

The conceptual model indicates that the rivers Clyst and Exe, and the estuary east and west banks, are less dynamic in comparison to the estuary mouth. There is a limited sediment transport linkage from the estuary mouth (specifically Bull Hill Banks) as well as the rivers Exe and Clyst. This sediment supply allows some vertical accretion of the mudflats, however this is believed to be less than the coincident sea level rise. For the rivers Clyst and Exe, and the estuary west bank, there are a range of assets along the shoreline (including the Exeter canal, the mainline railway, quay walls and FCRM embankments) and the majority of the immediately landward topography would enabling intertidal habitats to exist if these assets were not present. In addition to this the man-made assets enable the existence of landward freshwater habitat. These analyses suggest the habitat extents in this area are predominantly influenced by FCRM assets or activities. For the east bank of the estuary, although there are man-made assets (the branch-line railway), the topography immediately landward rises and precludes the ability for intertidal habitats to translate further inland. Thus in this area it is likely that habitat extents are predominantly controlled by natural processes.

Poole Harbour Overview

The Poole frontage includes the limited vegetated and non-vegetated intertidal along the mainly developed frontage from Sandbanks to Rockley Sands, including Holes Bay. The fringing intertidal habitats along the northern coastline are separated from the wider estuary intertidal by the wide sub-tidal areas (Main and Wych Channels). Consideration of the analysis by Gardiner et al. (2011) suggests that the historic rate of saltmarsh loss in this area was less than 1Ha/year. The landward topography restricts the inland migration of intertidal habitats in the present day, but the influence of sea level rise could theoretically enable allow this towards 2110. Consideration of these findings suggests that the future cause of change is related to FCRM assets and the historically reclaimed ground levels which constrain landward habitat translation. The above evidence indicates that the habitats in this area are predominantly influenced by FCRM assets or activities.

In Lytchett Bay and Wareham within the western harbour, the fringing intertidal habitats are separated from the wider estuary intertidal by the Wareham Channel. This sub-tidal area has expanded in size significantly since the 1880s. Within Lytchett Bay itself, historic OS mapping indicates that the intertidal and sub-tidal areas have been stable since 1880. Consideration by Gardiner et al (2011) of historic saltmarsh change around Wareham suggests a slight saltmarsh expansion, with consequent mudflat loss. Analysis of available recent LiDAR data also indicates a trend for intertidal accretion, potentially matching coincident sea level rise rates, which generally corroborates these findings. There are FCRM assets present along the majority of this section of coastline and the tributary rivers. These defences prevent the landward translation of the intertidal habitats and this indicates that the habitat extents in this area are predominantly influenced by FCRM assets or activities.

The fringing intertidal habitats along the southern harbour and island coastlines are separated from the wider estuary intertidal by the Wareham Channel, South Deep, Ramshorn Lake and White Ground Lake sub-tidal areas. These sub-tidal areas have expanded in size significantly since the 1880s. Previous analysis (Gardiner et al, 2011; Royal Haskoning, 2010) has indicated an overall historic rate of saltmarsh loss of 2Ha/year. There are no FCRM assets present along the majority of the coastline and fringing intertidal habitats are able to translate landwards in most places unless constrained by natural rising topography. Overall, this indicates that habitats in this area are predominantly influenced by natural processes.

Predicted Future Habitat Change

The prediction of habitat change and the allocated cause of the change are shown in Figures 5 to 7, covering the range of sea level rise within the low 50%ile, medium 95%ile and upper end climate change scenarios (Environment Agency; 2011). These show the absolute magnitude (please note different vertical scales) of habitat change, as well as proportion of the total intertidal area. Consideration of the relative proportion of habitat loss in the study sites highlights that percentage loss increases with reducing tidal range (approximately 16% in the Severn Estuary, 25% in the Exe Estuary, and 34% in Poole Harbour). This would be expected as predicted sea level rise drowns out a progressively larger proportion of the tidal range for hyper, macro and micro-tidal estuaries, although this would partly also be influenced by predicted accretion and erosion. The impact of allocating the cause of habitat change is also evident. Anthropogenic causes of change are estimated as approximately 54-67% (Severn Estuary), 11-22% (Exe Estuary) and 15-35% (Poole Harbour) of the total change, varying with magnitude of sea level rise.

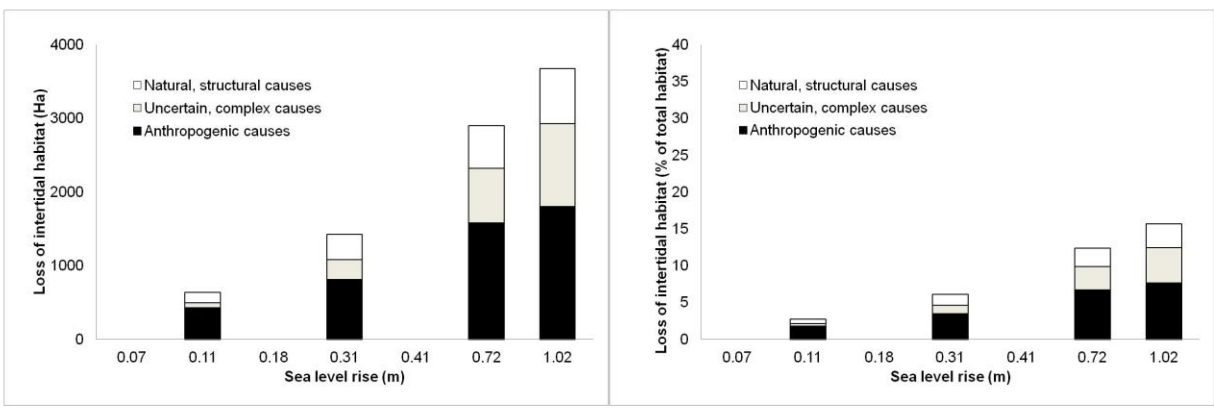

Figure 5. Intertidal habitat loss predictions in the Severn Estuary.

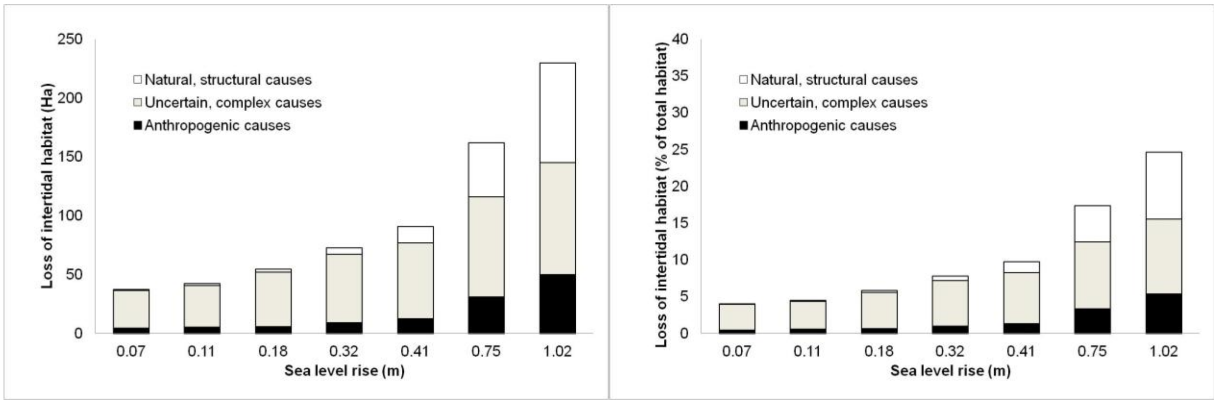

Figure 6. Intertidal habitat loss predictions in the Exe Estuary.

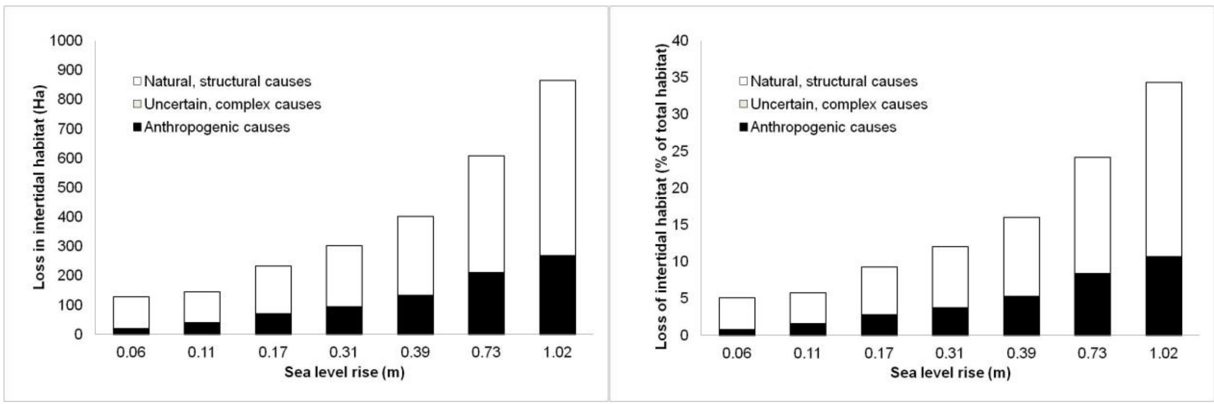

Figure 7. Intertidal habitat loss predictions in Poole Harbour.

Discussion

Within the Severn Estuary, Exe Estuary and Poole Harbour FCRM strategies the financial saving of developing a habitat compensation strategy for the next century to deal with anthropogenic causes alone, as compared to one to address all causes of habitat change, is considerable. Analyses carried out within the strategies estimate that for the Severn Estuary potential cost saving would be £5 million over the next 10 years. Over the wider 100 year programme, the potential cost saving would be a Present Value (PV) £19 million, equivalent to an undiscounted cost of £100 million. Similarly for the Exe Estuary, over the 100 year programme the potential cost saving would be a PV of £13 million (undiscounted cost of £120 million). Potential cost saving for Poole Harbour is less certain, but would have a similar order of magnitude as for the Severn and Exe estuaries. Wider benefits of a reduced habitat compensation strategy also include the avoidance of unnecessary physical and ecological disruption to the designated sites. Additionally, the reduced landowner and political complexities mean that there is an improved chance of successful delivery.

The analysis described herein was based on the strategy level application of a developing methodology. Whilst the relevant strategic geomorphological models have provided quantified estimates of sediment exchange, significant uncertainties remain. Overall, for all three sites, the predictions are accurate to an order of magnitude. This level of uncertainty in sediment exchange translates through to uncertainty in habitat prediction to different extents for the different estuaries, as other uncertainties may be more significant (such as sea level rise amount). In addition to this, there are a number of improvements that are immediately clear:

- Other anthropogenic causes of habitat change. These could include activities less directly related to FCRM, such as dredging or tourism. For the present study sites, dredging would be more relevant to the Severn Estuary and Poole Harbour, whilst tourism would be more relevant to the Exe Estuary and Poole Harbour.

- Other natural causes of habitat change. The process of biological ‘die-back’ is well documented (SCOPAC, 2004) in Poole Harbour as influencing saltmarsh evolution.
- Further detailed analysis of geomorphological processes with a wider selection of models and datasets. The analysis herein was undertaken at a broad strategic level. Further consideration of geomorphological influences may indicate areas of greater or lesser FCRM influence than already identified.

The analyses have also identified the need for future monitoring, based on existing datasets at least partly collected through the relevant coastal observatories (for the study sites herein, the Plymouth and Channel coastal observatories, and Welsh Coastal Monitoring Centre). Salient monitoring activities and their aims would include:

- Enabling and strengthening quantified geomorphological predictions. This will require continued collection of LiDAR, bathymetry, aerial photography and habitat survey. Within the estuary-level strategy studies, a key requirement is strong temporal and spatial overlapping of datasets covering the whole estuary. Broad, overlapping datasets are preferred to detailed, localised datasets.
- Confirming/revising cause of change. A key dataset to support this is high quality tide gauge monitoring, currently overseen by POL. This will confirm the rate of sea level rise, and in conjunction with observation from spatial/volumetric datasets, would enable validation of the quantified geomorphological predictions. Whilst present in the Severn Estuary to some extent, the tide gauge network in the Exe Estuary and Poole Harbour would require extension and improvement.
- Impact of managed realignment sites. Where managed realignment sites are constructed, monitoring could be undertaken of the likely ‘zone of influence’, to provide a database of actual impacts of managed realignment on, for example, fringing intertidal, sub-tidal channels and sandbanks. Monitoring of topographic and habitat change within the management realignment sites themselves would enable confirmation or otherwise of any modeled predictions.
- Wider, qualitative observations. Further datasets of use would, for example, include Natural England’s condition assessments of designated sites. Whilst localized, if carried out at key indicator sites, these assessments could provide valuable information that would not be captured via other monitoring.

Conclusions

In England and Wales the Environment Agency is responsible for developing strategic plans to manage the flood and coastal erosion risks within coastal and estuary areas. These plans need to consider the impacts of FCRM actions on a range of designated habitats. Where these actions lead to deterioration of SPA, SAC and Ramsar sites there is a requirement to provide compensatory habitat. This paper has described a high level approach that can be used to identify those changes in habitats that could be due to FCRM actions. Considerable cost savings are possible if FCRM strategies compensate for only those losses due to FCRMS actions, as opposed to all changes in habitat. The method requires sound understanding of coastal processes in order to be able to identify the likely influence of FCRM actions and also to make predictions about future changes in habitat.

There are many uncertainties in predicting habitat losses and also in predicting the habitats that will form and evolve within managed realignments over the long term. Given these uncertainties, and the fact that long term projections are subject to increased levels of uncertainty, it is suggested that a pragmatic approach to implementing habitat compensation is to compensate for losses that occur in the short term (the next 20 years), whilst drawing up plans for possible solutions in the medium and long term (20 to 100 years). This approach allows for future predictions to be revisited in the light of improved understanding of the rates of sea level rise, the geomorphological response of estuarine habitats and the influence of FCRM actions compared to other drivers.

Acknowledgements

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