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M.Sc. programme in
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CoMEM

The implication of future shoreline management on protected habitats in Poole Harbour under sea-level rise

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July 2009
Thesis work done at the University of Southhampton

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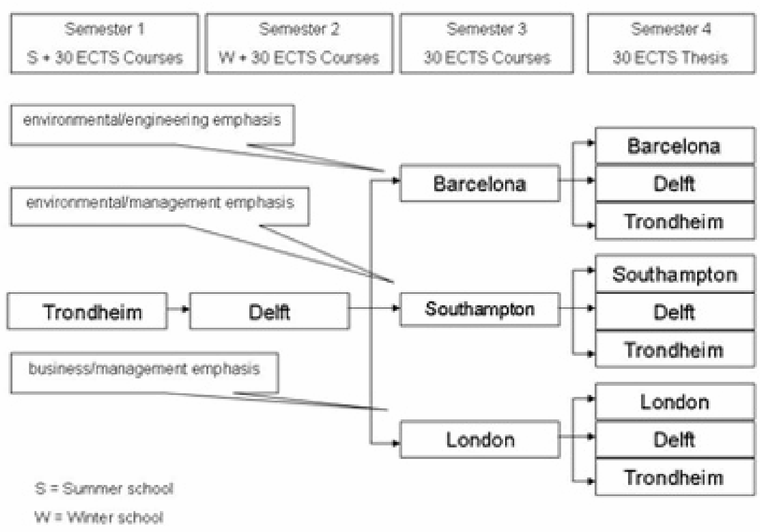

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FACULTY OF ENGINEERING, SCIENCE AND MATHEMATICS

SCHOOL OF CIVIL ENGINEERING AND THE ENVIRONMENT

THE IMPLICATION OF FUTURE SHORELINE MANAGEMENT ON PROTECTED HABITATS IN POOLE HARBOUR UNDER SEA-LEVEL RISE

Mengdan Yu

A dissertation submitted in partial fulfillment of the degree of

MSc in Coastal and Marine Engineering and Management

July 2009

Abstract

Existing Shoreline Management Plan (SMP) for Poole Harbour was the first generation produced in 2004, which is before statutory obligations to protect the natural coastline were fully realised. Under the idea of 'adopting a sustainable policy for the longer-term', at present the second generation of SMP is being produced. This study was conducted to identify changes in coastal habitats under sea-level rise and to inform development of SMP2 in order to comply with the requirement of the European Union Habitats and Birds Directives. The focus was on mudflat and saltmarsh habitats as these are not only the largest coastal habitats of the Harbour, but also immediately under threat from sea-level rise and coastal management decision.

This study involved the use of Geographic Information Systems (GIS) software in a modelling-based approach to study the behaviour of inter-tidal habitats in response to predicted changes in sea level for the remainder of the 21st century. Under the BRANCH project guidelines, ArcGIS was used to model the current and future distribution of habitats in the region. The present state of the habitats was first modelled using three basic inputs- topographical LiDAR (Light Detection and Ranging), tidal data from the Harbour and assumed boundary conditions for the zonation of the habitats with respect to tidal range. The accuracy of this model was verified with available Aerial Photographic Interpretation (API) data. The model was then used to evaluate new distributions and areas for all the habitats for changes in sea-levels by the 2085. Based on the Tidal Elevation Testing results and sediment transport studies the SPM1 management units were refined. Using all above results and considering four specific coastal management options, a feasible management plan for the refined units were derived, keeping in mind the relevant land-use restrictions and other spatial planning issues. The project concluded that the 'flexible and safe' combination of the options of 'Do Nothing', 'Selective Hold the Line' and 'Selective Managed Realignment' were best suited for the coastal habitats in south and west of the Harbour assuming that the sea-level rose according to the DEFRA scenario and taking into consideration the large uncertainties inherent in sea-level rise predictions.

ACKNOWLEDGMENTS

The author extends his gratitude to all those enabling and assisting in this successful research project.

Particular thanks go to:

Sarah Gardiner	**University of Southampton**
Ivan Haigh	**University of Southampton**
Mustafa Mokrech	**University of Southampton**
John Hurst	**University of Southampton**
Katie Born	**Halcrow Group Ltd**
Samantha Cope	**Channel Coastal Observatory**
Travis Mason	**Channel Coastal Observatory**
Claire Pinder	**Dorset County Council**
Chris Doyle	**Environment Agency**

The staff of the Channel Coastal Observatory, and Canterbury City Council (Strategic Monitoring)

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GLOSSARY OF TERMS USED

API	Aerial Photography Interpretation
AR4	IPCC Fourth Assessment Report
CCO	Channel Coastal Observatory
DEFAR	Department for Environment, Food and Rural Affairs
DERC	Dorset Environmental Records Office
DTM	Digital Terrain Model
EDINA	a Joint Information Systems Committee of National Data Centre
HAT	High Astronomic Tide
IHVDT	Intertidal Habitats Vertical Distribution Testing
IPCC	Intergovernmental Panel on Climate Change
LAT	Low Astronomic Tide
LiDAR	Light Detection And Ranging
LTEI	LiDAR and Tidal Elevation Interpretation
MHWN	Mean High Water Neap
MU	Management Unit
NAW	National Assembly for Wales
NNR	National Nature Reserve
OS	Ordinary Survey
RTET	Relative Tidal Elevation Test
SAC	Special Area of Conservation
SCDOs	Strategic Coastal Defence Options
SCOPAC	Standing Conference On Problems Associated
SMP	Shoreline Management Plan
SMP	Shoreline Management Plan
SNCI	Site of Nature Conservation Interest
SPA	Special Protected Area
SSSI	Site of Special Scientific Interest
TAR	Third Assessment Report
UK CIP	UK Climate Impacts Programme

1. INTRODUCTION

1.1 Background

Coastal environment holds a significant role for people and other living creatures, such as plants and animals. In some cases, particular species can only be found in this habitat. This shows how the wetland ecosystem contributes to biodiversity. Another function of wetlands is that it is a natural coastal flood defence, especially when extreme events such as tsunamis and storm happen. For this reason, coastal wetland areas are proved to be ecologically valuable.

Throughout the world, the coastal ecosystem is at risk. With the increasing propensity of human populations congregate in coastal areas, over half of the world's coastlines are threaten by coming with the severe development pressure. With coastal urbanization has come rapid industrial and commercial development which has pit increasing pressure on coastal wetland habitats including estuaries, mudflats and saltmarshes (Dirk Bryant et al, 1995).

Moreover, accelerated sea-level rise due to climate change makes the coastal wetland even vulnerable. With increasing sea-levels the inter-tidal habitats will most probably try and migrate landward. This migration would be stopped however once they come up against the hard structure of the defence, which is called 'coastal squeeze'. However, the EC Habitats Directive requires Member States to take measures to maintain or restore natural habitats and wild species at a 'favourable conservation status', which is appropriate steps to avoid destruction or deterioration of habitats (Council Directive 92/43/EEC).

Under those issues there is always a question that 'How our coastline should be managed?' The answer to it is varied by time and locations. Like most other countries, England has a long history of using hard defence such as dikes and embankments for the coastal protection over the past 10-20 years. Nowadays, the thinking of using 'hard' defence has been gradually shifted to a 'softer' approach which aims to work with nature rather than against, which has led to gradually changes of the spatial planning and its relationship to shoreline management into a more sustainable way in a longer term.

Existing Shoreline Management Plan (SMP) is the first generation produced in1999, which is before statutory obligations to protect the natural coastline were fully realised. It is defined the method by which coastal defences in the harbour should be managed over the next 50 years. At present, the second generation of SMPs are being produced. It is intended that they will cover management potions for the next 100 years, also considering the latest research and encouraging greater stakeholder involvement. (DEFRA, 2006)

1.2 Research Overview: Poole Harbour

Poole Harbour is a large tidal estuary situated within Shoreline Management Unit Cell 5 on the south coast of Britain with an area of 3805ha and an intertidal area of 2050ha. The tidal range of Poole Harbour is less than 2m (micro tidal area) and the intertidal habitats are extremely vulnerable by the SLR.

In Poole Harbour, there are many contrasting and conflicting pressures between natural environment and anthropogenic activity. On one hand it is a large natural estuary which is comprised by many separate channels, bays and inlets and provides extensive mudflats, salt marshes, reedbeds, sand dunes, heathland and islands. Many of these areas are the home to an astounding number of native and migratory birds as well as a reasonable number of terrestrial animals. Thus, they were identified as being protected by SAC, SPA, Ramsar site and an SSSi, along with another 15 National, European and International conservation designations. (Haskoning, 2009)

On the other hand, the harbour is also a busy port, with commercial shipping, ferry traffic and pleasure craft using the water. There are approximately 100 registered fishing boats based at the port and sections of the seabed are used for the cultivation of shellfish. The Harbour is also home to Europe's largest onshore oilfield. In addition there are the major urban centres at Wareham, Poole (the later also a popular tourist destination) and a significant area of light industry at Hamworthy & Holes Bay. (Haskoning, 2009)

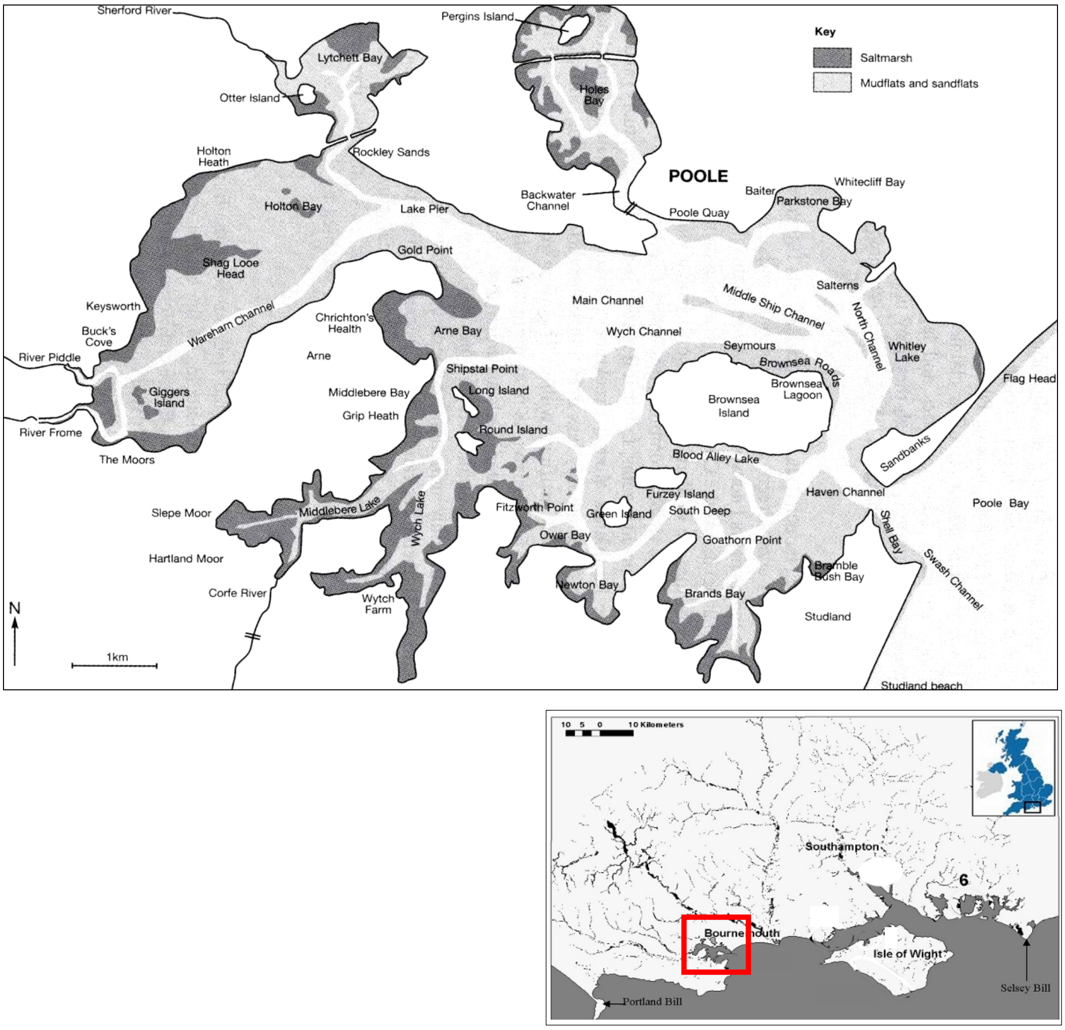


Figure 1.1; Poole Harbour and Coastal Cell 5 (May and Humphreys, 2005b; DEFRA, 2006)

According Haskoning (2009), the most significant long-term trend affecting Poole Harbour is sea level rise, which causes many important intertidal habitats squeeze and ultimately being inundated unless something is done to maintain them. Being designated habitats, the government is therefore under an obligation to either protect the existing habitats or provide compensatory habitats elsewhere. This situation combined with the increasing frequency of overtopping and breaching incidents at the existing defence and steadily increasing maintenance costs have led the local authorities to the conclusion that it would be unprofitable in the long run to maintain the existing situation. The realignment of the defence along one of two alternate, shorter routes is therefore being considered as a means to provide additional land to the inter-tidal habitats to migrate landward, preventing the problem of coastal squeeze by giving back land to the sea and at the same time reducing the length and therefore the maintenance costs of the sea-wall. However, these realignment options would result in a loss of coastal grazing marshes and brackish water marshes behind the existing defence due to inundation by the sea. This results in the conundrum of having to sacrifice one type of habitat for the protection of the other.

A number of pertinent questions have been raised by the public and interested private parties in this regard. Some of the tougher questions are those on what will be happened to these intertidal habitats in the future, which of the habitats are to be sacrificed in order to preserve the other, what the implications are of SCDO to these areas in short term or long term, and which of the options appear more profitable in a cost-benefit assessment that takes all the relevant factors into account. While on the one hand the option of realignment is a move where sea defences are moved landward, resulting in creation of extra natural habitats and is largely regarded as beneficial for this reason – on the other hand, it is recognised that the realignment options would result in a loss of very valuable designated habitats, something that would happen even if nothing were done. So again 'how to manage our coastal line' will be a big challenge for the next generation of SMP.

1.3 Aims and Objectives

As a part of Poole Harbour morphological and ecological changing research, this study aims to identify changes in coastal habitats and to inform development of the 2nd round Shoreline Management Plan (Haskoning, 2009) in order to comply with the requirement of the European Union Habitats and Birds Directives. The focus is on mudflat and saltmarsh habitats as these are not only the largest coastal habitats of the Harbour, but also immediately under threat from sea-level rise and coastal management decision. This will be achieved by:

1. To estimate the current areas of intertidal habitats and investigate their behaviours in Poole Harbour by using aerial Photography

2. To investigate and evaluate the impacts of relative sea-level rise on these salt marsh up to 2085.

3. To consider and investigate briefly possible realignment options and other spatial planning issues related to the protection of these habitats.

4. To investigate how the site under study could be managed, in the light of the large uncertainties associated with sea-level rise projections and correspond saltmarsh changes and to provide recommendations for the second round Poole Harbour SMP

The study made use of the Geographical Information Systems (GIS) software ArcGIS, a package provided by ESRI, an international GIS software developer.

ArcGIS was used to simulate the possible distribution of the habitats in the region using certain accepted rules of thumb. This simulation was checked against available data to ensure its accuracy. The simulated habitats were then modified in response to changes in sea levels and their response to the same was studied and evaluated quantitatively and qualitatively. These conclusions were then used in a brief investigation on the various realignment and coastal management options that were available and their respective pros and cons. Finally, the handling of the inherent uncertainties in sea-level rise projections with respect to long term coastal management in the region was considered.

1.4 Outline of Report

This report is divided into five further sections:

Section 2 is literature review pertains to background information study

Section 3 describe the data and methodology developed in this study

Section 4 presents the result from the simulation

Section 5 discusses the results from presents in section 4 and providing recommendation for the Poole Harbour SMP 2

Section 6 concludes the project

Section 7 is the reference

2. BACKGROUND REVIEW OF LITERATURE

2.1 Hydrology

2.1.1 Tidal Regime

The tidal regime in Poole Harbour is semi-diurnal. The mean tidal range in Poole Harbour is 1.8m at springs and 0.6m at neaps (Bray, 2004). However the range varies with tidal ranges of 1.2 m and 1.6 m reported by Edwards (2001) at Arne and Newton Bay, respectively. Tidal observation data shows 1.97 m at Poole Entrance and 2.19 m at Town Quay. A small double high water occurs in the English Channel between Portsmouth and Lulworth which is transmitted into Poole Harbour. Consequently, there is in harbour always a relatively long stand of high water within the Harbour (about 16 hours per day) (John 2005).

Because of the narrow entrance there is a substantial volume of water retained in the harbour during a tidal cycle. The proportion of the water body leaving the harbour at neap tides is 22%, increasing to 45% at springs. Water remains above mean water level for 16 out of 24 hours (Gray, 1985).

Ebb tidal stream velocities are higher than flood stream velocities, with maximum speeds of approximately 2m/s at the harbour entrance. Tidal flows decrease from the entrance to Lychett Bay and Town Quay. Characteristic velocities in the main channel are 0.5m/s (Bray, 2004).

2.1.2 Waves

The wave within the harbour is dominated by south and south-west winds. Halcrow (1999) modelled extreme wave height by hind casting from local and regional wind data. Based on a 1: 100 year recurrence interval, wave heights varies from 0.5 to 1.2m depending on location. The north and east parts which are exposed to longer fetch from dominant wave are most energetic.

Wave climate is dominated by depth limited locally generated waves as storm waves do not penetrate the main harbour due to diffraction and refraction effects (Bray, 2004). Refraction analysis has shown that wave energy may concentrate at different sections of the coastline depending upon the direction of the wave. Under south-westerly waves, the wave energy tends to focus upon the eastern part of the coastline.

The capability for wave propagation within the harbour has been suggested for the degradation of bluffs around the harbour margins. It is likely waves would have driven some sands from Poole Bay into the harbour (Bray, 2004). However Posford Haskoning (2004) concluded that although wave breaking has a significant effect on the currents in the breaker area, the flow regime of the Harbour and approach channel is dominated by tidal action.

2.1.3 Sea-level Rise

I. Global study

IPCC Assessment Report IV (AR4) has recently been released estimates global (Eustatic) sea level rise (SLR) by 2100 to be between 0.18-0.6 m – which has large uncertainty of the data (Pfeffer, 2008). However, regional studies are mainly based on IPCC Third Assessment Report (TAR) which is similar to AR4 (John 2008). The projections of sea-level rise for the 21st century are shown below.

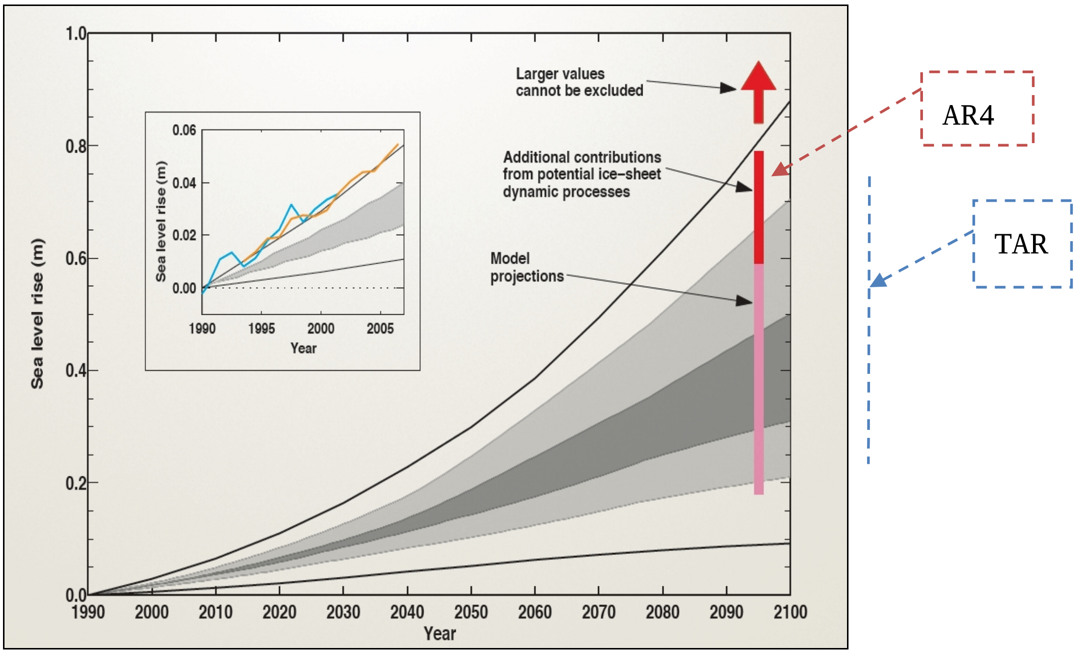


Figure 2.1; TAR and AR4 projections of sea-level rise (source from IPCC)

There would be different effects on temperature and precipitation in different locations so there was a need for higher-resolution models to estimate local variations and plan effective mitigation measures.

II. The mean sea-level trends of south-west England

In the UKCIP02 Scientific Report (Hulme et al., 2002), future changes in regional net sea-level were calculated to be between 0.20-0.80 m by 2080 which based on two components: isostatic changes, which refer to adjustments in the absolute elevation of the land; and eustatic changes, which refer to variations in the absolute elevation of the sea surface caused by variations in the volume of the oceans.

DEFAR UKCIP Guidance Note 2006 projects net SLR of 4mm/year 1990 –2025, 8.5mm/year 2026 – 2055,12mm/year 2056 – 2085 and 15mm/year 2086 –2115. Assumed vertical land movement is -0.8mm/year. (DEFAR, 2006)

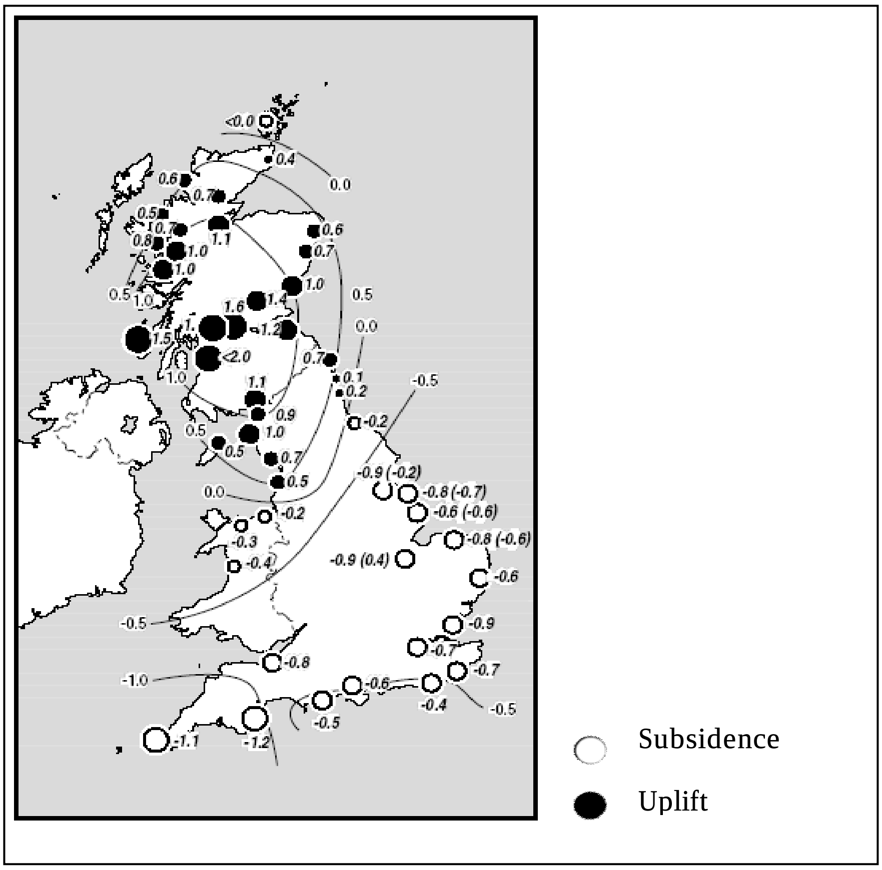


Figure 2.2; UK Geological Observations Of Uplift/Subsidence (source from Shennan and Horton, 2002)

According to Haigh (2008), although data from tide gauges suggest that sea level has risen by 1−2mmyr-1 over the past 200 years, recent satellite measurements show that the rate is now 3 mm per year and rising, exacerbated on the south coast by isostatic sinking of 0.5 mm per year. Observed sea level rise is the sum of the mean sea level, tidal movement, and surges due to weather.

Observations from 15 sites with at least 35 years of data suggest that, contrary to popular belief, there has been no increase in the size of storm surges, but a slightly higher rise in mean high water (2.18 mmyr-1) than mean low water (2.08 mmyr-1) so that the mean tidal range is also increasing. Overall, mean sea level is predicted to rise between 18 and 59 cm between 1990 and 2090, coupled with a sinking of the land by 11 cm, a net change of from 29 to 70 cm.

2.2 Geomorphology

The geomorphology and sedimentation of Poole Harbour are poorly described however there are many localized studies within the harbour. Most of the investigations focused on the accumulation and release of sediments associated with the spread and dieback of Spartina anglica (Bird and Ranwell, 1964; Gray, 1985; Gray et al, 1990; Raybould, 1997) and the sedimentation and dredging of the main navigable channels (Green, 1940; Halcrow Maritime, 1999; Hydraulic Research Ltd, 1990, 1991).

The channel depth at the harbour mouth is about -18 m OD which is the deepest part of Poole Harbour and where the bed is naturally scoured. There are four main channel networks. Middle channel is a regularly dredged navigation channel with the depth of -6m, between the entrance and the port (Hydraulic Research Ltd, 2004). Wareham channel is draining between the port and the Piddle and Frome rivers with the limited depth to a few metres. The Wytch channel system is draining the central/southern area, and the South Deep is draining the area south of Brownsea Island. The channel system is relatively stable due to the islands (which restrict channel migration) and the small tidal range (characteristic of a low-energy system) (Gray, 1985).

The landward edge of the harbour is marked by low bluff (commonly less than 5m in height), eroding cliffs and artificial structures which is mainly concentred at the north east developed areas. To seaward, there are extensive saltmarshes and mudflats or small sand and shingle beaches (May 2005).

The source of sediment to the harbour is from offshore (the most significant), cliff erosion, saltmarsh erosion, beach erosion, channel erosion, and river flows (Halcrow, 2003).

May (1969) has investigated the way of shoreline changes in Poole Harbour, focusing particularly on Holes Bay. It was concluded that change has mainly taken the form of sediment deposition, Cliff erosion, Build-up of marshland as a result of vegetation growth on mudflats (e.g. Spartina) and Human interference.

Especially erosion and deposition are the main factors of the post Holocene shape of the Harbour. The erosion happened at these headlands, particularly along the southern shore, as well as the islands where the shore is exposed to modest wave action within the harbour. Accretion of riverine sediments has allowed extensive mudflats to become established, which have been stabilised by saltmarsh vegetation in places. Coastal sediment transport has caused the narrowing of the harbour mouth due to spit growth creating the Sandbanks and South Haven Peninsulas. Originally over 3.5km in width, the harbour mouth is now reduced to approximately 350m, which prevents large-scale transport of sediment into the harbour (Bray et al, 2004). According to (May, 2005), there was little change in patterns and channels, mudflats and fringing marshes until the end of the nineteenth century. Human interference which is including the construction of seawalls and embankments, dumping of town waste and reclamation of marshland happened mainly at the North and east developed areas.

2.3 Sediment Transportations and Coastal Erosions_

2.3.1 Sediment Transport

Sediment transport in Poole Harbour is a complex system. SCOPAC 2004 research carried out that the harbour naturally operates as a relatively closed circulation system with frequent reversals in current directions. A detailed map of sediment transport within the harbour (Figure 2.3) is shown that littoral drift generally occurs from west to east along exposed shorelines.

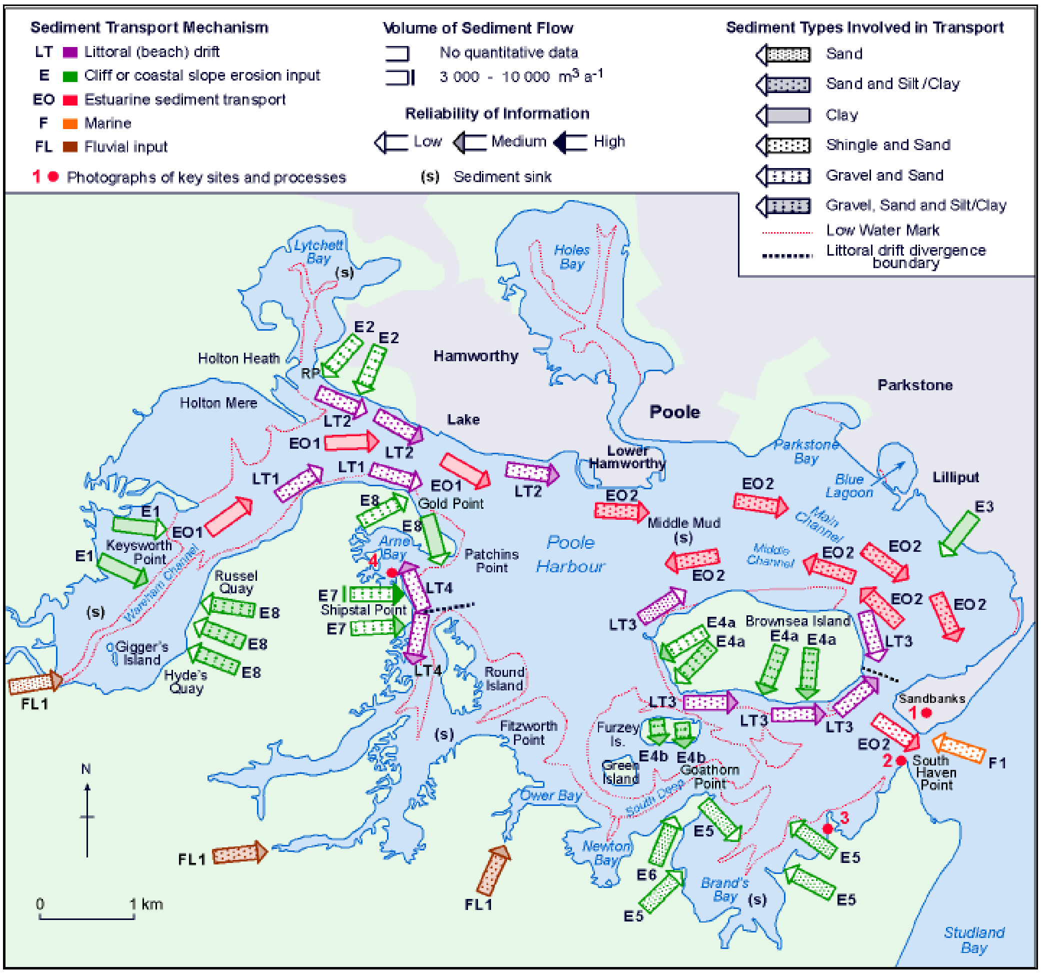


Figure 2.3; Sediment transport in Poole Harbour (source from SCOPAC)

Tidal scour is a dominant influence, and it is thought that material leaves the harbour on ebb tides (Halcrow, 1999).

It is concluded that as sediment inputs in the harbour are comparatively low, and the harbour normally operates as a relatively closed circulation system with frequent reversals in current directions. Although there is a trend for net seaward tidal flushing of sediments, the extent remains uncertain. Sediments may be stored in the harbour's circulation systems, or outputs might be offset by wave driven inputs through the entrance. Tidal scour is a dominant influence,

2.3.1 Coastal Erosion

May (1969, 1976) and Gray (1985) provided a detailed accounts of processes and rate of cliff development in different area of the Harbour. The remaining literature consists of brief inferences or implications of past or present inputs from cliff erosion. SCOPAC (2004) arranged the available evidence and described that Cliffs developed in both the Bagshot outcrop and at the seaward edge of marshes. The Spartina anglica expansion from the late 19th century to the mid or late 1920s reduced significant wave energy at previously cliffed sites. However, at several sites, the trend has been reversed due to Spartina "die back" (Gray, 1985; Raybould, 1997; May, 1998).

Based on the previous research, SCOPAC (2004) provided a number of in specific erosion sites within Poole Harbour.

E1Keysworth Marsh: Low cliffs were eroded between 4 and 75cm in height at the edge of the marsh (Hubbard and Stebbing, 1968; Gray 1985). Several other marsh margins fringing the Upper Wareham Channel are eroding (Ranwell 1964) caused by wave action (May 1969)

E2 Rockley Cliff, West of Lake: The erosion rate is c.0.3mm-1 for an unspecified length of the Hamworthy shoreline. May (1969). The cliff some 10-15m in height and 1km in length erodes

E3 Lilliput to Sandbanks : A low bluff cut into saltmarsh existed in front of the sandy-muddy beach along Shore Road (B3369) (Gray 1985), Erosion proceeded rapidly in the 1980s and 1990s, consequently, there are very little original saltmarsh existing at this location

E4(a) Brownsea Island : A retreat rate of south-west Brownsea coastline is up to 0.45mm-1 between 1886 to1952, (May,1969) Severe erosion happens in the vicinity of the seawall around the north-east quadrant of the island (Bamber and Ranger, 1990). Erosion is more limited on the north coast because of the majority of the steep coastal slopes are vegetated. Former cliff stabilisation at the western end of the island is thought to have reduced beach volumes along the south coast, thus accelerating coastline recession since the mid 1980s. Cliff top erosion, especially in the south-east, is likely to accelerate. Outside areas of active sediment yield from cliff instability, the rest of the island's coastline is comparatively stable (May, 1999).

E4(b) Furzey Island : Active block detachment by weathering and shallow mass movement are recorded at two sites, and photogrammetric mapping by photogrammetry is undertaken although no recession rates are given (Pfaff, 1994). Sound photogrammetric derived maps are presented that would bear comparison with a contemporary survey enabling calculation of recession rates. Given similar rock lithology and wave climate to the south coast of Brownsea Island, the causes and retreat rates of these small scale cliffs on Furzey are probably comparable.

E5 Brand's Bay: Both degraded and active cliffs, up to 4m in height, are cut into a variety of materials including marsh sediments, dunes and in situ Bagshot Sands (Gray, 1985).

E6 Goathorn Peninsula: A sandy cliff up to 10m in height on the western shoreline is eroded (Gray, 1985).

E7 Shipstal Point and Vicinity: Cliffs to the south of Shipstal Point exhibit no contemporary toe erosion, having been removed from the direct influence of waves by saltmarsh growth in Middlebere Bay. A short-term monitoring programme revealed that sub-aerial processes contributed 25m3 of debris during the period April to October 1971; 20% of this total was produced by storm runoff over the cliff face in two weeks in late September to early October.

70% of this amount was removed by waves close to calculated maximum heights in January 1974. Because of major differences in exposure to wave action due to constant changes in coastline plan and orientation, and spatial variation in the extent of fringing mudflat/marsh development, to what extent it is representative of other sectors of the eroding coastline of Poole Harbour is debateable. Therefore, this is no estimate of the longer-term rate of cliff erosion.

E8 Arne Peninsula: It was found cliffs are well-developed between Hyde's Quay and Russell Quay, on the north-west shore cut into Bagshot sands and clays. Recreational pressure accelerated toe erosion and cliff top recession, small slumps and gulleying, which were mapped by student groups from 1978 to 1981 (Leeson House Field Studies Centre, unpublished). Gray (1985) describes this coastline as "strongly eroding" and May (1969) suggests a rate of retreat of between 0.35 and 0.4mm-1, 1886 to 1952. Gray also describes a strongly defined erosional micro-scarp at the seaward edge of the mudflats and marsh in Arne Bay.

2.4 Navigation Dredging

In order to maintain the navigation channels there is regular dredging works, especially in the Main (or 'North') and Middle (or 'Middle Ship') Channels. The majority of dredging operation has been undertaken on a bi-annual basis by trailing a suction dredger. It has caused some displacement of channels, although there has been general stability since the first reliable and detailed hydrographic survey in 1785. Detailed records can be obtained from Poole Hatbour Commissioners Poole (ngineers' and Hydrographic Departments), who are responsible for all dredging operations.

Table 2.1; Historic dredge volumes (Source from SCOPAC)

Date	1969-1975	1975-1984	1985-1990	1990-1997	Total
Volume (m3)	138,618	349,800	2,017,000	1,531,336	4,036,754
Data Source	McMullen (1982 and 1985)	McMullen (1982 and 1985)	Hydraulics Research (1990)	Hydraulics Research (1990)	

The volume of dredged material from various sources is show in Table 2.1, these values is progressively increase because of involving the removal of previously stable sediments to deepen and widen channels to accommodate passage of larger vessels.

Table 2.2; current annual dredge volumes in different location within Poole Harbour according to (source from Posford Haskoning, 2004)

Location	Swash Channel	Middle ship channel	Turning basin	Other Locations	Total
Sediment type	Sand	Predominantly sand	predominantly silt	predominantly silt	
Approx. Volume (m3)	21,000	20,500	13,000	34,000	88,500

The dredged material used to be disposed at South of Swanage Bay which is 7 km from the Harbour basin which caused a sediment input into Poole Harbour as well as a permanent output from there. And now some of the dredged material is used for beach nourishment within Poole Bay and Swanage Bay, thus becoming part of the sediment budget of Poole Harbour.

2.5 Intertidal Habitats

Poole Harbour contains a wide variety of habitats due to its size, estuarine environment and the fact that most of the harbour is intertidal area. Sand dunes, shingle beaches, heathland, mires and grazing meadows are all present, but the dominant habitats are mudflats and saltmarsh.

2.5.1 Mudflats

Extensive clay and silt ("mud") is accumulated in many area of Poole Harbour where wave and tidal energy is low, especially along the southern, western and north-western margins. In the north-eastern harbour, the eroded foreshores limited its horizontal development. The mudflats are sourced from suspended sediments, erosion and reworking of bed deposits. According to SCOPAC (2004), a long-term net imbalance of the sediment budget of the harbour is in favour of accretion due to saltmarsh vegetation. All of these banks are separated by channels, some of which have been regularly dredged over a long period of time for navigation use.

2.5.2 Saltmarsh

According to Drake (2006), saltmarsh currently covers around 300ha, but has been in decline over the past 50 years. According to Born (2005) Salt marsh vegetation is strongly linked to the complex tidal regime, characteristic zones of sediments. It is often classified as three zones (upper, mid and lower saltmarsh), depending on floral tolerance to inundation. However, This is not very obvious due to the due to the small tidal range of the harbour. Over 20 different saltmarsh communities and sub-communities, has been found in Poole Harbour, three of which have been listed into Annex I of the EU Habitats Directive (European

Commission, 1996).

Much of the saltmarsh is dominated by Common Cord Grass Spartina anglica , which originated by chromosome doubling of the sterile hybrid and rapidly colonized several south coast estuaries earlier this century (Gray et al, 1991). It has spread naturally and by planting to aid coastal defence and land-claim (Raybould, 1997). It first started colonizing in the 1890s and spread rapidly to cover 800 ha by 1924 (Raybould 1997). But since the 1920 it has been decreasing which may caused by 'die-back', invasion of other species, wave erosion, sea level rise, deliberate land reclamation and other anthropogenic causes, such as pollution, dredging (Gray and Pearson1984; Gray et al. 1991; Raybould 1997).

2.5.3 Accretion

Spartina salt marshes have stored and continue to store, large quantities of silt and clay. Oliver (1924, 1925) and Goodman et al. (1959) both give figures of 6m as the maximum submergence tolerance for Spartina. Ranwell (1964) calculated a rate of 0.5-1.0 cm vertical accretion across a series of transects in inner Keysworth Marsh based on 7 months observation records in 1962. Hubbard and Stebbing (1968) derived 6cm between January and September 1963, and 14.5cm in 1966 at the same site. For an adjacent site, these authors calculated that Spartina had stabilised some 1.8m of silt and clay, allowing for compaction. According to Raybould (1997), the rate between 70 and 100cm (upper harbour) and 35cm (lower harbour) are possible and they are closely comparable to vertical accretion reates for other areas of healthy Spartina on the southern, southwestern and eastern coastlines of England (Hubbard, 1968). According to Ranwell (1964) that silt and clay accretion in Phragmites communis reed swamp, landwards of the Spartina sward, was occurring at the same rate as for the Spartina sites. It is a strong possibility that the contribution of other wetland species to mudflat development has been under-estimated, as Phragmites, Elymus and Halimone have successfully invaded some areas vacated by Spartina since the early 1960s (Gray, 1985).

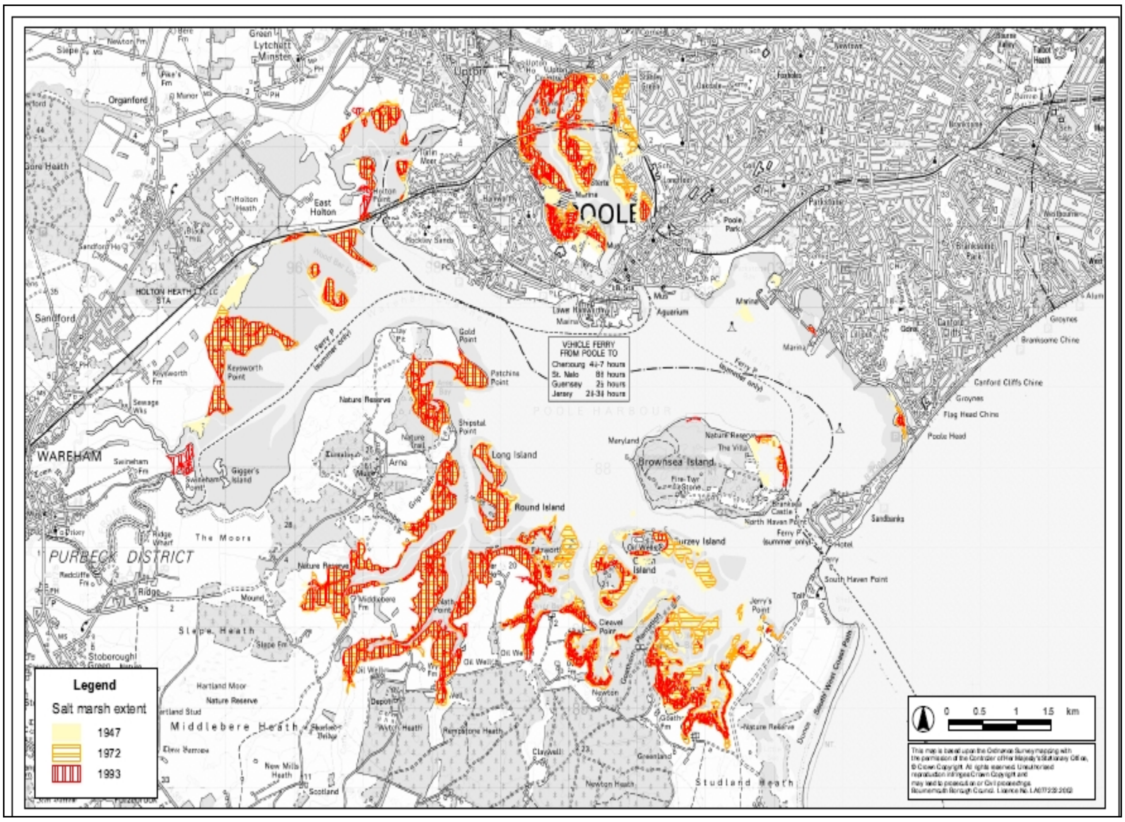


Figure 2.4; Saltmarsh extent in 1947, 1972 and 1993, (Born 2005)

Born (2005) extrapolated historic losses linearly to 2053, found that between 1947 and 1993, the area of salt marsh in the study area decreased from 634 ha to 389 ha, an overall loss of 245 ha (38%).

2.5.4 Designation

The extensive mudflats and salt marshes are home to an astounding number of native and migratory birds, a reasonable number of terrestrial animals as well as a large variety of flora that is rare in other parts of the country. With the increasing interest in the protection of the country's natural heritage, many of them currently fall under a number of designations that serve to give them legal protection from human damage. While most of these regulations, such as the SSSI, SPA and SAC, are national the Marshes also enjoy the international status of a designated EU site for protection under the EU Habitats directive as well as that of a Ramsar wetland site- an international designation intended to ensure the protection of wetlands all over the world. The summary of nature conservation designations of Poole Harbour is shown in Table 2.3. However all the above designations apply to both kinds of habitats in this area – the seaward inter-tidal habitats as well as the landward coastal grazing marsh.

Table 2.3; Poole Harbour nature conservation designations (Adopt from SMP2 Review of Poole Harbour & Islands)

Site type	Locations	Reason for designation
World Heritage	Dorset & East Devon	Landscape
Ramsar	Dorset Heathlands	Ecology-wetland habitat
	Poole Harbour	Ecology-wetland habitat
SAC	Dorset Heaths Purbeck & Wareham & Studland Dunes	Ecology-heathland, dunes and damselfly
	Dorset Heaths	Ecology-heathland
SPA	Poole Harbour	Ecology-birds species
	Dorset Heathlands	Ecology-birds species
SSSI	Poole Harbour	Ecology-varied habitats and rare species
	Arne SSSI	Ecology
	The Moors	Ecology
	Hartland Moor	Ecology
	Ham Common	Ecology/Geology-heathland and retile
	Holton & Sandford Heaths	Ecology
	Luscombe Valley	Ecology-varied habitats and sand lizard
	Rempstone Heaths	Ecology
	River Frome	Ecology
National Nature Reserve	Studland & Godlingston Heaths	Ecology-heathland, dunes and reptiles
Heritage Coast	West Dorset	
AONB	Dorset	Landscape

2.6 Spatial planning and Shoreline management

Spatial planning is a comprehensive framework for policy integration and a process to implement Strategies. It aims better to integrate planning into wider policy delivery and ensure the most efficient use of land by balancing competing demands within the context of sustainable development (ODPM, 2004). Such activities can be support by various enabling frameworks (e.g. European Parliament and Council Recommendation concerning the implementation of Integrated Coastal Zone Management in Europe, Barcelona Convention,) in different scales (e.g. global, regional or EU level).

In the UK coastal area spatial planning includes, the consideration of shoreline management (coastal defences), biodiversity designations and land use pressures (Gardiner et al. 2007). While there are a number of general schemes and techniques listed with regard to spatial planning in and around the Solent and along the south coast of England, order to better understand the coastal environment and plan the future management of these dynamic habitats. They aim to understand how specific habitats have changed over time, and how they are likely to respond to changing climates in the future. Some of these studies and their relevant issues to this project have studied, and are briefly introduced in this section.

2.6.1 BRANCH

BRANCH (Biodiversity Requires Adaption in Northwest Europe under a Changing climate) is an EU-funded project with partners in France, Holland and the UK. The project promotes improved spatial planning, in order to allow habitats to adapt to climate change. The project's recommendations are supported by a range of modelling results, case studies, policy analysis, stakeholder discussions and transferable tools developed by BRANCH. These have been produced by partners coming together to shared experience and knowledge through working groups (Gardiner et al, Guideline 2007). Within the UK coastal part of the project, the coastal work package has investigated the above issues at local to regional scales, focussing on the EC Habitats and Species Directive requirements, which aims to maintain designated habitats in 'a favourable condition' (Council Directive 92/43/EEC). As part of the BRANCH project, Gardiner et al (2007) assessed the potential impact related of sea-level rise on six locations which are representative of the coastal habitats in Cell 5. Besides, they provided assessments of "existing and potential near-future coastal habitats under different sea-level rise and management scenarios" based on a series of GIS approach, which involved using LiDAR tidal elevation interpretation and intertidal vertical zonation analysis in conjunction with aerial photographic interpretation, sea-level rise scenarios and historical trend analysis. They encountered difficulties in meeting the requirements of the EC Habitats Directive at individual case study areas. They found intertidal saltmarsh and mudflat areas decline under all the sea-level rise scenarios in the study areas, and suggested that compensating with similar habitats near the affected areas could be achieved by managed realignment in conjunction with artificial sediment supply to raise intertidal surfaces to levels conducive to vegetation establishment. However, this will reduce the area of coastal grazing marsh, which is also protected by the Directive. Spatial planning offers the potential for future landbanking of these areas, but its implementation may require a reinterpretation of the application of the Habitats Directive. (Gardiner et al, 2007).、

2.6.2 Shoreline management Plan (SMP)

In the UK, the planning of new coastal defence schemes is now carried out within the context of a shoreline management plan (SMP), which is a non-statutory document that provides a wild assessment of the long-term risks associate with coastal processes and presents a policy framework to reduce these risks to people and the developed, historic and natural environment in a sustainable manner. SMPs form an important element of the Department for Environment, Food and Rural Affairs (DEFRA) and the National Assembly for Wales (NAW) strategy for flood and coastal defence. It includes the considerations of existing planning initiatives and legislative requirements and uses the best present knowledge on the possible effects of climate change and sea level rise. (DEFRA 2003)

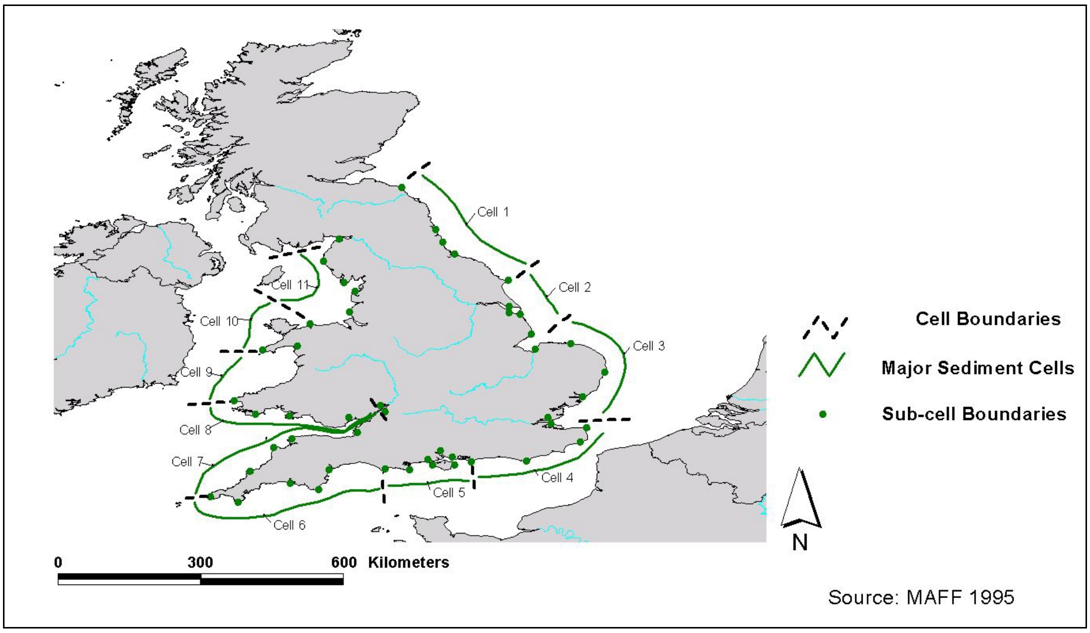


Figure 2.5; Shoreline management units along British coast (source from MAFF 1995)

Within SMP, coastline of England is divided into 11 primary coastal cells based on natural sediment movements and coastal processes, rather than administrative boundaries. And a series of sub cells defines within each primary cell. For each policy unit four coastal defence options is considered (Table 2. 4), which are:

Table 2. 4; Strategic coastal defence options (adopt from shoreline management plan, source from HALCROW MARITIME. 1999)

Policy	Comment
Hold the line	Maintain or upgrade level of protection provided by defences
Advance the line	Build new defences seaward of existing defences
Managed Realignment	Allowing retreat of shoreline with management to control or limit movement
No Active Intervention	Not to invest in providing or maintaining defences

1. *Hold the line:* This method involves maintaining the defences such that the coastline is held at its present position and the habitats behind are protected. In case of hard defence structures, this could result in a loss of inter-tidal habitat seaward of the defence in case of coastal squeeze- a phenomenon where a landward migrating habitat is lost to the sea when its migration is prevented by the presence of a hard structure. Alternatively, the use of soft methods such as beach nourishment or sediment replenishment could help sustain seaward habitats.

2. *Advance the line:* This strategy involves active advancement of the coastline seaward. It requires a combination of land reclamation and provision of suitable defences for the reclaimed land. While it usually results in a loss of inter-tidal habitats, the new land may be used for development of new habitat.

3. *Managed Realignment:* Managed Realignment or Retreat involves a considered setback of the coastal defence line resulting in the creation of inter-tidal habitats

behind the original defence line but simultaneously resulting in the possible loss of backshore habitats. This process is seen as a 'soft' approach to coastal defence where a considered decision is made to let go of assets of relatively low value. While it has the twin advantage of increasing land area under natural habitats as well as reducing future costs of maintenance of extended sea-defences, it could also necessitate provision of compensation for the lost backshore habitats. This option is currently gaining in popularity as it allows for dynamic behaviour of the shoreline, thereby coming closer to mimicking natural coastal processes.

4. No Active Intervention: This method lets the situation remain as it is, with no steps taken that would either increase or decrease the inter-tidal habitats. It is however accompanied by constant monitoring to ensure that habitats are not lost due to human activity or by neglect.

Existing SMP for Poole Harbour was the first generation produced in 2004, which is before statutory obligations to protect the natural coastline were fully realised. It is defined the method by which coastal defences in the harbour should be managed over the next 50 years. At present, guided and funded by DEFRA, the second round of SMP is being produced. It takes of latest information and future challenges with the greater emphasis on Improving links with the planning system, taking greater consideration of the effects on the environment, making longer term coastal policies over a 100 year period and encouraging greater stakeholder involvement.

2.6.3 Other Planning Issues

Higher sea levels and extreme surge levels mean that both the frequency and severity of coastal flooding are likely to increase unless defences are improved to maintain the standards of protection. Wetlands dissipate wave and tidal energy and therefore the defence structures need to be updated for the rise in the sea level to protect the marshes. The sea level in this area is expected to rise between 5 and 13 mm per year with an average of 6 mm used for estimations and models. This would result in a predicted sea level rise of around 50 cm by the year 2080. This implies that unless constant maintenance of the seawall or realignment is not carried out, the current sea wall will be breached during a storm at some point in the future and the marshes and most of Harbour marshes will be exposed to the risk of flooding.

Studies have shown that with increasing sea-levels the inter-tidal habitats seaward of the wall will most probably try and migrate landward in an attempt to keep pace with the change. This migration would be stopped however once they come up against the hard structure of the sea-wall, a phenomenon called 'coastal squeeze'. Ultimately the habitats would get inundated unless something is done to maintain them.

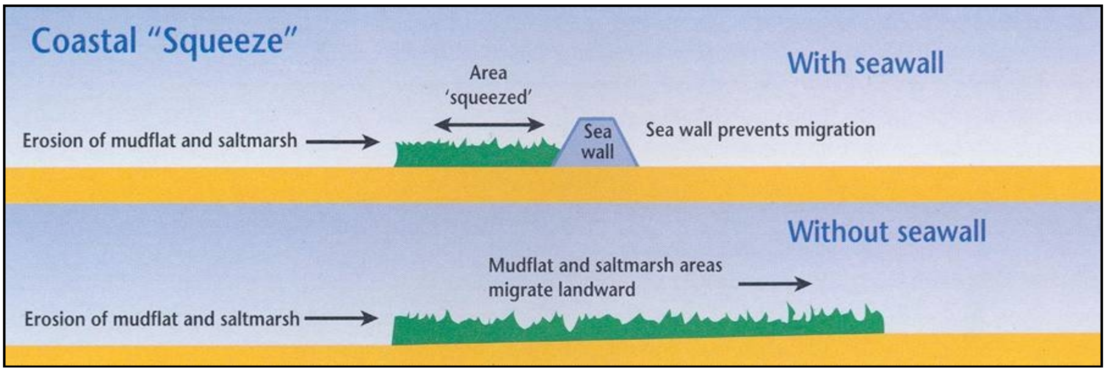


Figure 2.6; Coastal squeeze (Source from Environment Agency)

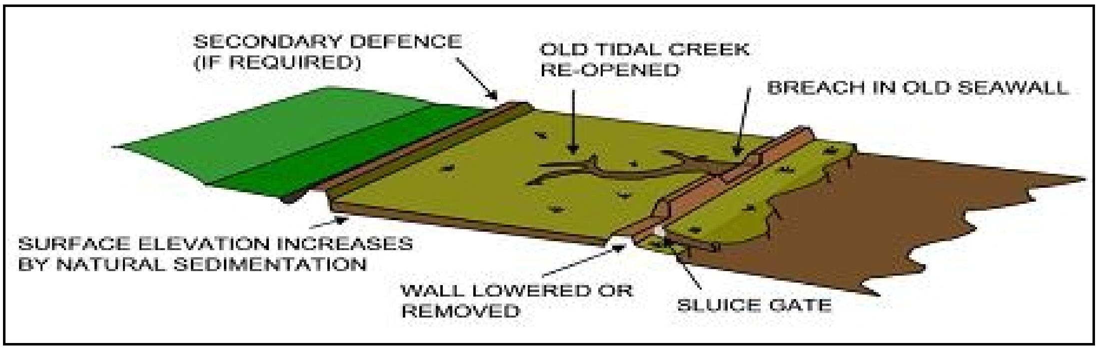


Figure 2.7: Effect of breach in sea wall under present conditions (Source from EA)

Studies estimate that this risk of breaching may happen with more regularity as the sea level rises and will be compounded by the increase in storm activities associated with global warming. Flooding will also bring saltwater into the brackish habitats in the marsh and it could be expected that over time the dominant habitats in the marsh will turn into saltwater habitats. This will lead to a loss of feeding grounds for many of the important bird and plant species that are currently adapted to brackish environments.

3 METHODOLGY

In this study, firstly, the present and future behavior of intertidal habitats was assessed by using ArGIS based on the guidance from BRANCH. Then the spatial planning considerations and correspondent management options of the inter-tidal habitats were analysed based on the options identified within the first generation Shoreline Management Plans (Poole & Christchurch Bays Coastal Group, 1998). The work undertaken comprised a mixture of technical analysis and statutory body 'expert opinion'. Table 3.1 demonstrates the different stages of the study.

Table 3.1 Summary of study approach

Assessing the intertidal habitats behaviours	Stage 1	Present intertidal habitats distribution A technical analysis to estimate the current inter-tidal habitats and investigate their behaviours by using: API LTEI Histogram
	Stage 2	Future intertidal habitats changes A technical analysis to investigate the impact of SLR on the inter-tidal habitats and predict their distribution in the future by using: LTEI
Their impact to shoreline management	Stage 3	Management issues investigation Consider spatial planning issues and investigate the possible shoreline management options by using LTEI RTET Histogram
	Stage 4	Assessment of preferred site management options Investigate how the site under study could be managed by evaluating each strategic option by using the results from previous stages.

3.1 Techniques

3.1.1 LiDAR and Tidal Elevation Interpretation (LTEI)

Tidal inundation relative to the land elevation and gradient is the one of the most important factor controlling the mudflats and salt marsh distribution. Theoretically the mudflats and salt marsh occurs in the certain range of the tidal elevations (table 3.2). In UK, salt marsh is composed of four main salt marsh zones which are pioneer, low marsh, middle marsh and high marsh; and upper transition zone. The latter is usually absent in the area which is restricted by seawalls.

Table3.2; Tidal criteria for modelling vertical zonation of inter-tidal areas (source from BRANCH)

Coastal Habitats	Criteria for habitat occurrence based on tidal level and elevation
Transitional marsh	Highest astronomical tide (HAT) - Mean high water springs(MHWS)
Upper/mid saltmarsh	Mean high water springs (MHWS) - Mean high water (MHW)
Pioneer saltmarsh	Mean high water (MHW) - Mean high water neaps (MHWN)
Mudflats	Mean high water neaps (MHWN) - Lowest astronomical tide (LAT)
Standing water	Lowest astronomical tide (LAT)

Based on these criteria the astronomical tidal statistics data was used to create various tidal interfaces. In this case it was assumed that tidal patterns would not change with a change in sea level. The two created interfaces were then combined with the information on the distribution and classification of the salt marsh habitats, with respect to tidal elevations and an approximation of the corresponded inter-tidal habitats were modelled. Using the Raster Calculator tool of ArcGIS, the criteria for the existence of each habitat were matched against the actual elevation of every cell and thereby the existence of the habitat at that particular location was determined. Once mapped, the current habitat was verified using digitized area shape file from the Aerial Photography Interpretation (API) which was mentioned in the next section to ensure sufficient accuracy. Based on the same methodology the future spatial changes of inter-tidal habitats were predicted by using the available sea-level rise scenarios. This was under the assumption of no vertical sediment accretion. Furthermore in order to provide a more comprehensive simulation a series of accretion scenarios (1mm per year to 6mm per year) was applied to against the large uncertainty of intertidal habitats accretion. The specific process was mentioned in section 3.3.

3.1.2 Aerial Photography Interpretation (API)

In the early stage of LTEI simulation, each intertidal habitat was determined by its vertical elevation. It did not take sea defence, land use, sediment type or other habitats types into account and might predict that habitats would occur, for example, in urban areas or behind the sea defence.

API was used as an additional tool to identify the distribution of existing mudflats and saltmarsh and provide a better understanding of their behaviour. It aims to improve the accuracy of LTEI simulation by comparing and verifying from the API result. The Aerial Photography 1947 and 2005 was obtained with permission from Channel Coastal Observatory (CCO). The saltmarsh extents were digitised using aerial photography supplied by Sarah Gardiner. There were georectified from Ordinary Survey (OS) map, converted into a photo-mosaic and digitised in a GIS. Where there were areas of uncertainty, verification was carried out using ground trusting and comparison with habitat maps.

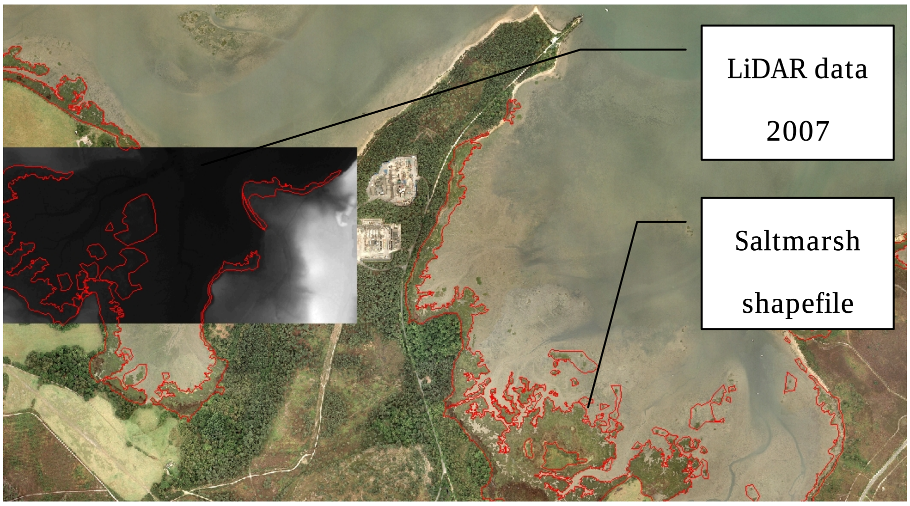


Figure 3.1; Aerial Photography Interpretations Working Principle in GIS

The aerial view can give a good impression of intertidal habitats distribution especially some sites access are not available. However the "raw data" of the aerial photographs requires some processing to be truly useful. At an advanced stage in API procedure the Ordinary Survey (OS) map or filed trip may help to refine the identification and classification of certain picture contents.

The whole process is depends on the human analyst interpretation. The accuracy of this 'eyeball interpretation' result will depend upon the interpreter's ability to disaggregate the contents of the imagery either consciously or subconsciously.

3.1.3 Relative Tidal Elevation Test (RTET)

As it mentioned before tidal inundation is the one of the most important factors controlling the mudflats and salt marsh development. Theoretically the mudflats and salt marsh occurs in the certain range of the tidal elevations (table 3.2). It is important to know the relative tidal elevation and regime in study area. However, the present tidal data was obtained from only two points which respectively located at the Harbour Entrance and Poole Harbour Quay. In order to produce a more accurate simulation of their distribution and better assessment of their behaviour, a method was created to provide the relative tidal elevation to intertdial habitats. It is based on following assumption. The mudflats and saltmarsh is respectively distributed in the range of LAT to MHWN and MHWN to HAT. Theoretically the lower and upper margins of the current mudflat and saltmarsh areas could respectively represent the Low Astronomic Tide (LAT), mean high water neap (MHWN) and high astronomic tide (HAT). The majority of current mudflats and saltmarsh margins are respectively distributed at the Low Astronomic Tide LAT, mean high water neap (MHWN) and high astronomic tide (HAT). Under assumption of the vertical distribution of the intertial habitats is follow table 3.2.

Firstly, this method based on the assumption that the margin of intertidal habitats are just appear at the critical tidal elevation level (HAT, MHWN, LAT). For instance, from figure 3.2, the seaward pioneer saltmarsh margin is just reach the level of MHWN.

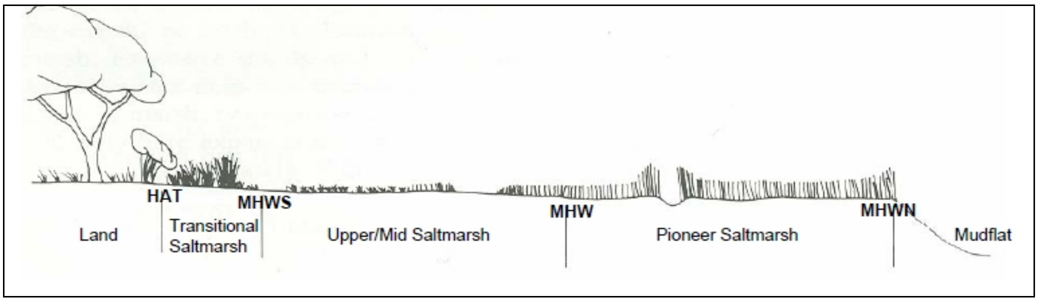


Figure 3.2; Intertidal habitats zonation (Source from BRANCH)

In Arc GIS, a series test points were digitized along the saltmarsh and Mudflats (2005) margin. The elevation information of these points was extracted from LiDAR data. Then this information was analysed. The points whose elevation was within the range were selected into group by using selection tool of ArcGIS Structure Query Langiage (SQL). Finally, the average criteria tidal elevation was determined. For example in Arne Bay there were hundreds of testing points around landward and seaward margin. Assume that the values of testing points on landward side were around HAT which was above 0.8 m. So these points were selected with expression: Raster Value > 0.8m

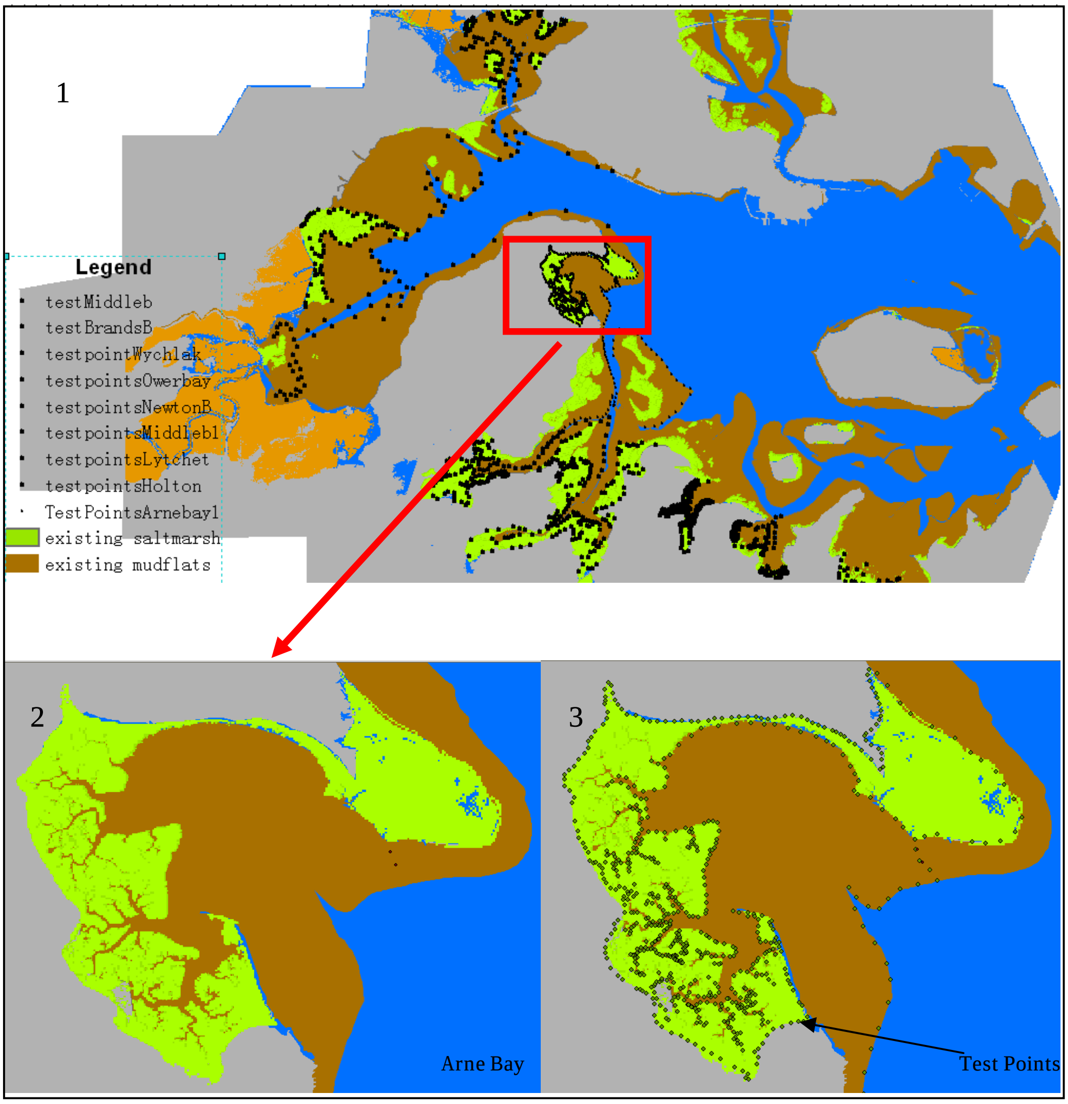


Figure 3.3; (1) Poole Harbour intertidal habitats distribution in Arc GIS; (2) Selected area; (3) Selected area after setting testing points;

The GIS can provide a set of statistical data including the distribution rang the average maximum and minimum value. After a careful selection, it was found the points were mainly distributed between 0.8m to 1.2m. The main value is 1.093m. Therefore under above assumptions the relative HAT in Arne Bay is 1.093m. Assume that the values of testing points on sea side were around MHWN which was lower than 0.8 m. So these points were selected with expression: Raster Value < 0.8m. With the same procedures, it was found the points were mainly distributed around 0 m. The main value is 0.0426m. Therefore under above assumptions the relative HAT in Arne Bay is 0.0426m.

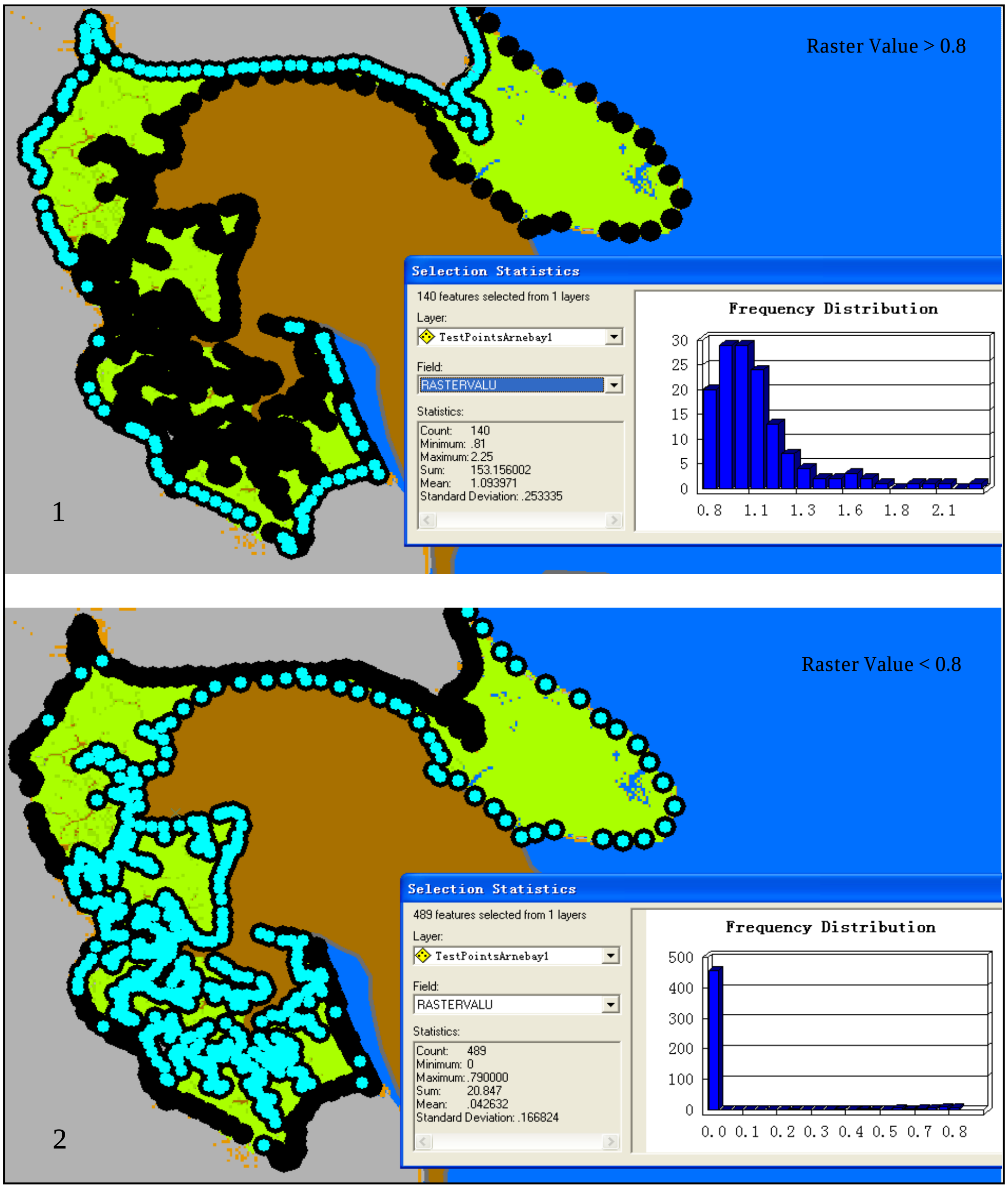


Figure 3.4; Statistical analyses in Arc GIS (1) when MHWN higher than 0.8m; (2) when MHWN lower than 0.8m

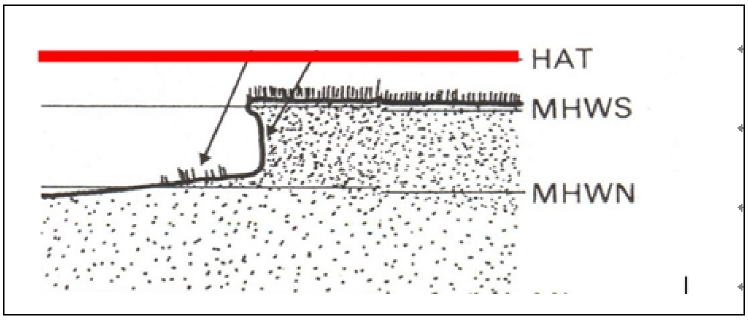


Figure 3.5; The case saltmarsh margin appears at HAT

This method based on the assumption that the margin of intertidal habitats are just appear at the critical tidal elevation level (HAT, MHWN, and LAT). Sometimes, the margin vertically falls between two adjacent critical tidal levels. For instance, figure shows that the saltmarsh landward margin was appear between HAT and MHWS which could lead to great error. Moreover, georectification of the aerial photographs and habitats mapping were estimated to have potentially introduced minimal error. Sensitivity to scientist interpretation was another potential cause of error. The statistical results should compare with the observed tidal data to reduce this error.

3.1.4 Intertidal Habitats Vertical Distribution Testing (IHVDT)

In this study, the LTEI simulation and shoreline management sub-unit classification were all based on the sufficient tidal regime. Due to lack of sufficient tidal information may impact the accuracy of the results. The site histogram of intertidal habitats vertical distribution has been used to check these results and to control their accuracy in an acceptable range. The principle is by using the site histogram to find the relationship between intertidal habitats and the tidal elevation in the interested area. The histogram of simulated result is tested to see whether it is comply with the pattern. It was achieved by following procedures:

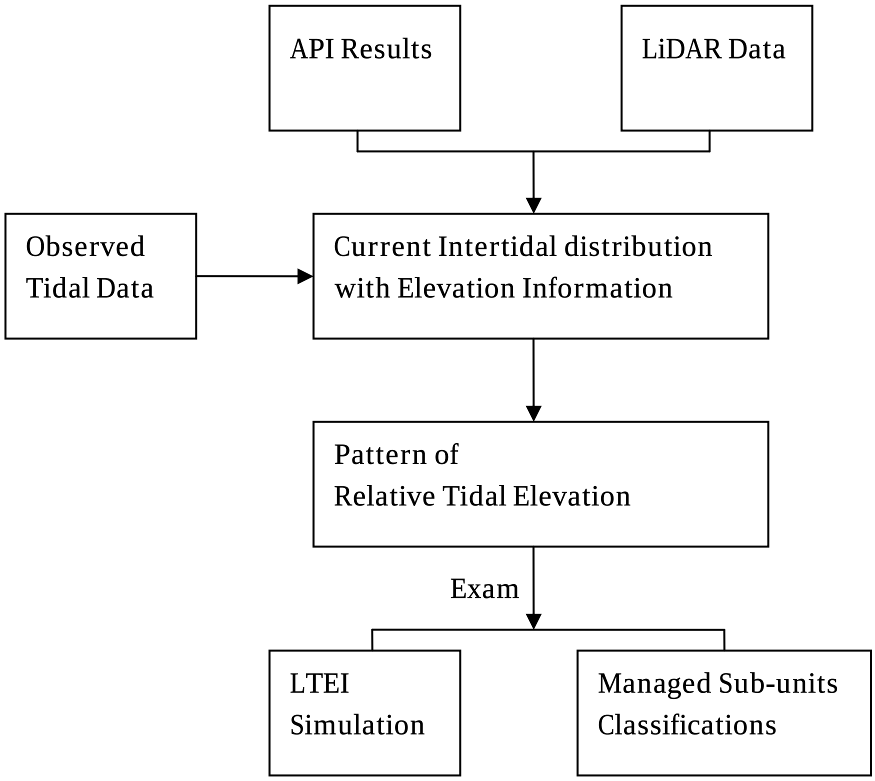


Figure 3.6; Flow chart of RTET and IHVDT process

In ArGIS, API produced a series of current intertidal habitats distributions which then used to extract the elevation information from LiDAR data. Using the histogram tool the statistical vertical elevation distribution was figured out. It shows for each tidal elevation value, the amount of the intertidal habitats grid cells.

One of the tidal gauges is located at Holes bay, thus its intertidal habitats distribution was first checked. Compared with the observed tidal information it is found that the intertidal habitats vertically follow a normal distribution. This was used as a reference to check the LTEI simulation and Sub management units' classification.

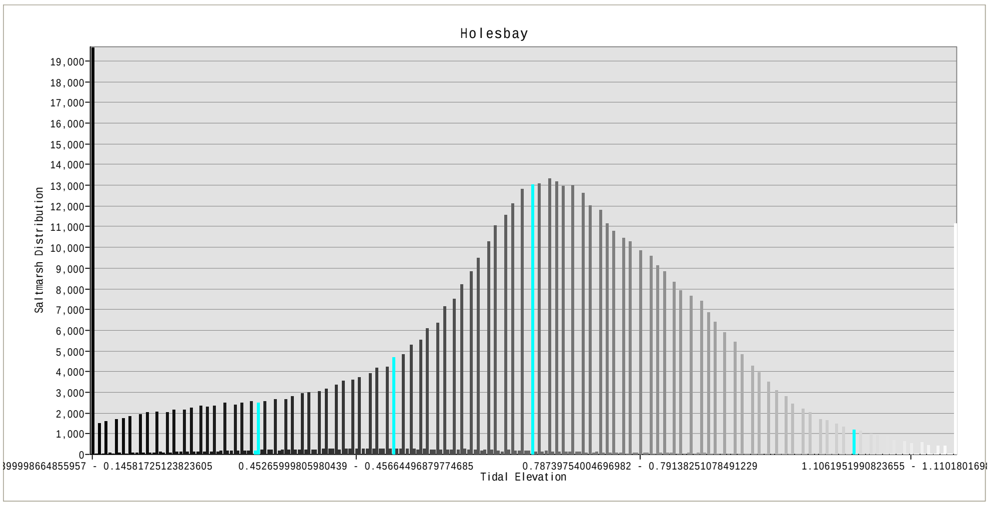


Figure 3.7; Histogram of intertidal habitats vertical ditributions in Holes Bay

Table3.3 The observed tidal data at Poole Harbour Quay (source from the Channel Coastal Observatory, 2007)

Easting	Northing	HAT	MHWS	MHW	MHWN	LAT
401176	90846	1.04	0.66	0.495	0.33	-1.36

In this study the histogram result was only consider as a reference. Due to histogram testing is also based on API result; its accuracy could directly influence the histogram results.

3.2 Data and their Sources

Topographical LiDAR (Light Detection and Ranging) data from the Channel Coastal Observatory (CCO) was used to create the initial Digital Terrain Model for the study area in ArcGIS. A Digital Terrain Model is a computer model that takes data on terrain elevations at specified coordinates as its input and creates a map using this data. This allows the user to visualize the terrain in the form of a topographical map and work on the same.

The next set of data used was the tidal parameters. Tidal data was obtained for two points in the region from tidal measurements dating from 2007, from the Channel Coastal Observatory (CCO). Tidal elevation is very important for the simulation accuracy therefore additional tidal information is needed.

The sea-level rise scenarios were obtained from the UKCIP02 for the region of south-west England and DEFRA 2006 flood management project (Table 3.4). In the UKCIP02 Scientific Report (Hulme et al., 2002), future changes in regional net sea-level were calculated to be between 0.20-0.80 m by 2080s which based on two components: isostatic changes, which refer to adjustments in the absolute elevation of the land; and eustatic changes, which refer to variations in the absolute elevation of the sea surface caused by variations in the volume of the oceans. DEFAR UKCIP Guidance Note 2006 projects net SLR for south-western England of 3.5mm/year 1990 – 2025, 8.0 mm/year 2026 – 2055, 11.5mm/year 2056 – 2085 and 13.0mm/year 2086 –2115. Assumed vertical land movement is -0.8mm/year (DEFAR, 2006). DEFRA values is particular interested in this study.

Table3.4: Sea-level rise scenarios used in the analysis

Time Scale	Sea-Level Rise (cm)			
	UK CIP-Low	UKCIP-High	DEFRA	Haigh et al 2008
2020s	9	19	7.2	
2050s	15	44	27.2	
2080s	20	80	63.2	68.9

Aerial Photographic Interpretation (API) images from the Channel Coastal Observatory (CCO) and Ordinary Survey (OS) map from EDINA (a Joint

Information Systems Committee of National Data Centre based at the University of Edinburgh) were made available. The land-use and coastal defences were identified from them. These identified areas were combined with the 2003 coastal habitats shapefile then used in the verification of the simulated habitats and in consideration of management options. In addition, the 2003 shapefile was obtained courtesy of the Dorset Environmental Records Office (DERC). Information on the annual rate of vertical accretion and horizontal erosion of the marshes was also made available to enable accurate modelling of future scenarios. Finally, information on the schematic distribution of salt marshes with varying tidal elevations was made available for the study

The data used and some of the assumptions made in the project and their sources are described in the table below.

Table 3.5; Summary of the data used and its source

The purpose of use	Description of Data	Source
Historical Study	Aerial Photograph 1947	EA
Current Simulation	LiDAR Data 2005 2007	CCO
	Aerial Photograph 2005	CCO
	Digitized saltmarsh area shapefile 2005	Sarah Gardiner's study
	Intertidal habitats area shapefiles 2003	DERC
	Tidal data 2007	CCO
Future Prediction	Sea-level rise scenarios DEFAR 2006 and UKCIP02	UKCIP and DEFRA
Saltmarsh Behaviours	Vertical accretion scenarios (1-6mm/year)	Born study 2005
	Intertidal habitats vertical zonations (table 3.1)	BLOTT and PYE, 2004
Land use study	Ordinary Survey (OS) map	EDINA

3.3 Data Processing

This section describes in brief the methodology used and assumptions made in this study:

1. Identified the existing saltmarsh area from digitized intertidal habitats distribution shadflies from the API image (2003, 2005). Mudfalts area land use and sea-defence imformation were collected from OS map.

2. The LiDAR data from the CCO was converted in ArcGIS, into a Digital Terrain Model (DTM) model (Annex 1-Fig 1). This allowed the user to manipulate the data within ArcGIS and create different layers that could then be super-imposed and their relationship studied

3. The available tidal data was then used to create various tidal interfaces from Lowest Astronomical Tide (LAT) to Highest Astronomical Tide (HAT). In this case it was assumed that tidal patterns would not change with a change in sea-level.

4. Combined the two created interfaces with the information on the distribution and classification of the salt marsh habitats, the tidal elevations and an approximation of the current inter-tidal habitats was modelled. Using the Raster Calculator tool of ArcGIS, the criteria for the existence of each habitat were matched against the actual elevation of every cell and thereby the existence of the habitat at that particular location was determined [Annex 1-Fig 2].

5. Once mapped, the current habitat was analysed and verified using digitized intertidal habitats distribution shadflies from the API image (2003, 2005) to ensure sufficient accuracy for the purposes of this study.

6. Once the DTM and the method used to simulate the habitats were verified, the next step was to use the available data on sea-level rise scenarios and marsh habitat behaviour along with the existing DTM, apply the same basic methodology used in the creation of the present habitat and simulate the response of the inter-tidal habitats to sea-level rise by the 2020s, 2050s and 2080s.

7. Inorder to quitify the uncertainty of saltmarsh changing by 2080s two sea-level rise scenarios UKCIP -low and high- were considered in this project and separate simulations were run for both. Since the marsh habitat behaviour could be divided into two components, vertical accretion and horizontal erosion, two separate analyses were carried out to represent these and the results of both were then superimposed to study the combined effect.

8. During the modelling, another parameter that had an effect on the results was the presence of a sea-defence. For purposes of comparative studies of the effects of different realignment schemes, two analyses were performed- one that disregarded the sea-defence and another that included its protective effect on the habitats lying behind it.

9. Once considering the sea defence present in the simulation, the assumptions made were that the habitats behind the defence were inter-tidal in nature and would behave in the same manner as the habitats in front of it. While this assumption could result in the incorrect modelling of saline grazing marshes and coastal lagoons as inter-tidal habitats, it served as a useful

tool to study the possible effects of the removal of the defence on the habitats behind it.

10. The presence of the sea-defence was simulated by simply keeping the areas behind the defence static while allowing the rest to change. While this may again not have been representative of actual processes, it served as a good tool to indicate the effects of the process of coastal squeeze.

11. The maps produced from all these analyses could be overlaid on one another and their spatial relationships studied. Additionally, the behaviour of each habitat for all the scenarios could be studied with the methodology adopted in this study, allowing more detailed and specific analyses of the responses of individual habitats.

12. Finally, quantitative data extracted from the attributes of the different layers gave a more accurate insight into the extent to which each habitat was affected. The flowchart shown below summaries the process used (Figure 3.8). The results obtained in this process are discussed in detail in the next section.

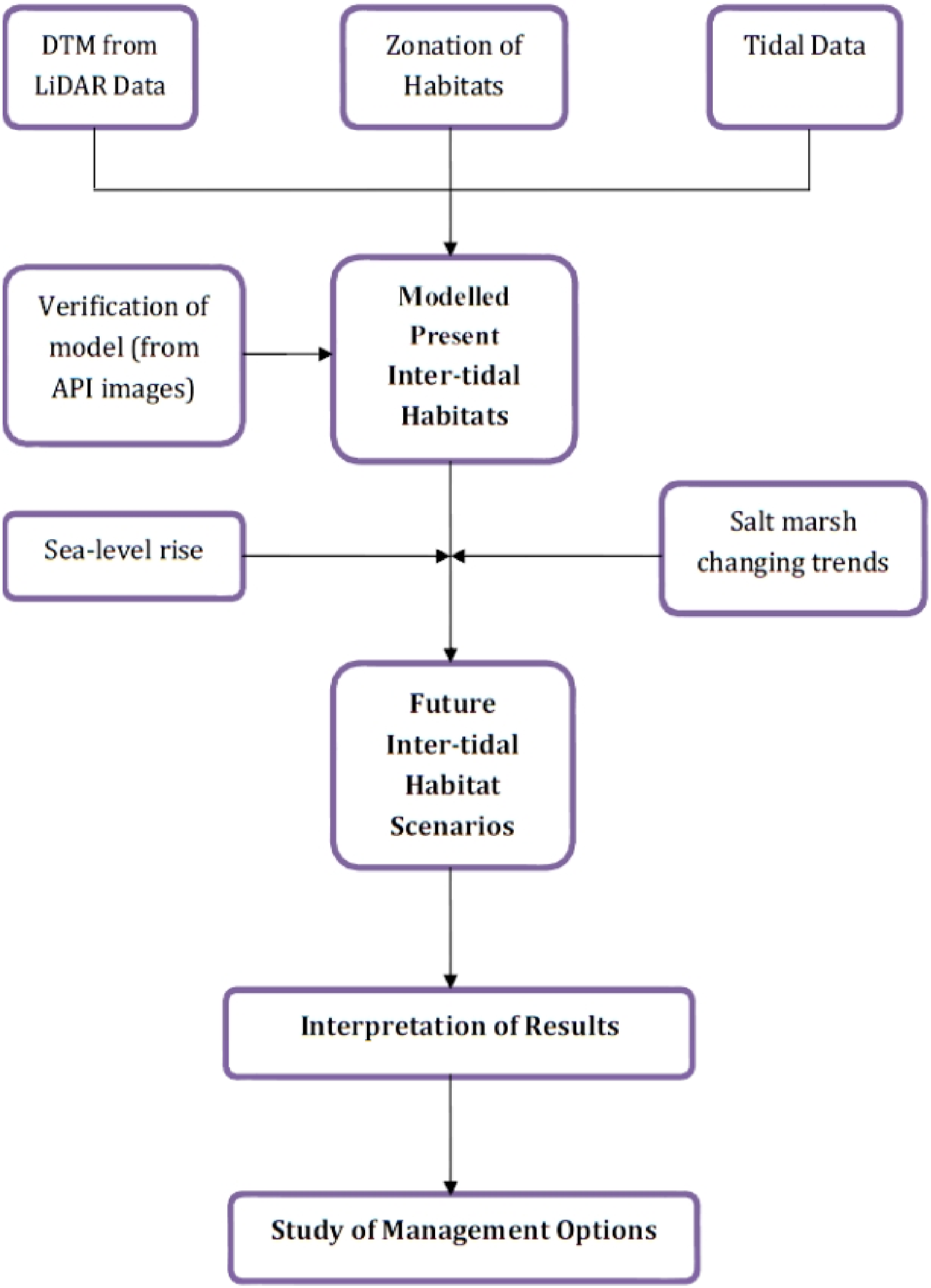


Figure 3.8; Flowchart of modelling and analysis process adopt from BRANCH project

4. RESULTS AND DISCUSSION

As mentioned above [Section 3.3], a serious of simulations was run with ArcGIS in an attempt to forecast the effects on existing habitats given different scenarios, until the 2080s. The simulations that were carried out to demonstrate visually the spatial changes in the distribution of existing and potential mudflat and saltmarsh which could help to indicate how the system could respond to changes in the environment around it and this in turn helped in providing a guideline on where managed realignment should be conducted and how the site could be managed.

4.1 Summary of Results

4.1.1 Present Situation

From the simulation of the present situation (Figure 4.1), the total area covered by the existing intertidal habitats was calculated as being approximately 1930 ha. Among which 80% is mudflats which is distributed all over the harbour. Saltmarsh currently covers approximately 383 ha and most of them located around the south and south-west of the harbour as well as the Lytchett bay, Holes bay.

The initial percentage distributions of the different zones within this 383 ha existing saltmarsh were found to be 5% pioneer marshes, 40% upper-mid marshes, 55 % transitional marshes. The evolution of potential saltmarsh is based on the assumption that sea defence does not exist. Besides, it was also assumed that as long as the land elevation is falling in between the HAT and MHWN levels, an area of land was considered as potential saltmarsh area irrespective of the sediment type of the land. The majority of potential saltmarsh is concentrated around in Holes Bay, Lytchett Bay, around the mouths of rivers Piddle and Frome. This is the case of potential mudflats as well. In Holes Bay and north-east Lytchett Bay the potential intertidal habitats is restricted by the Residential area.

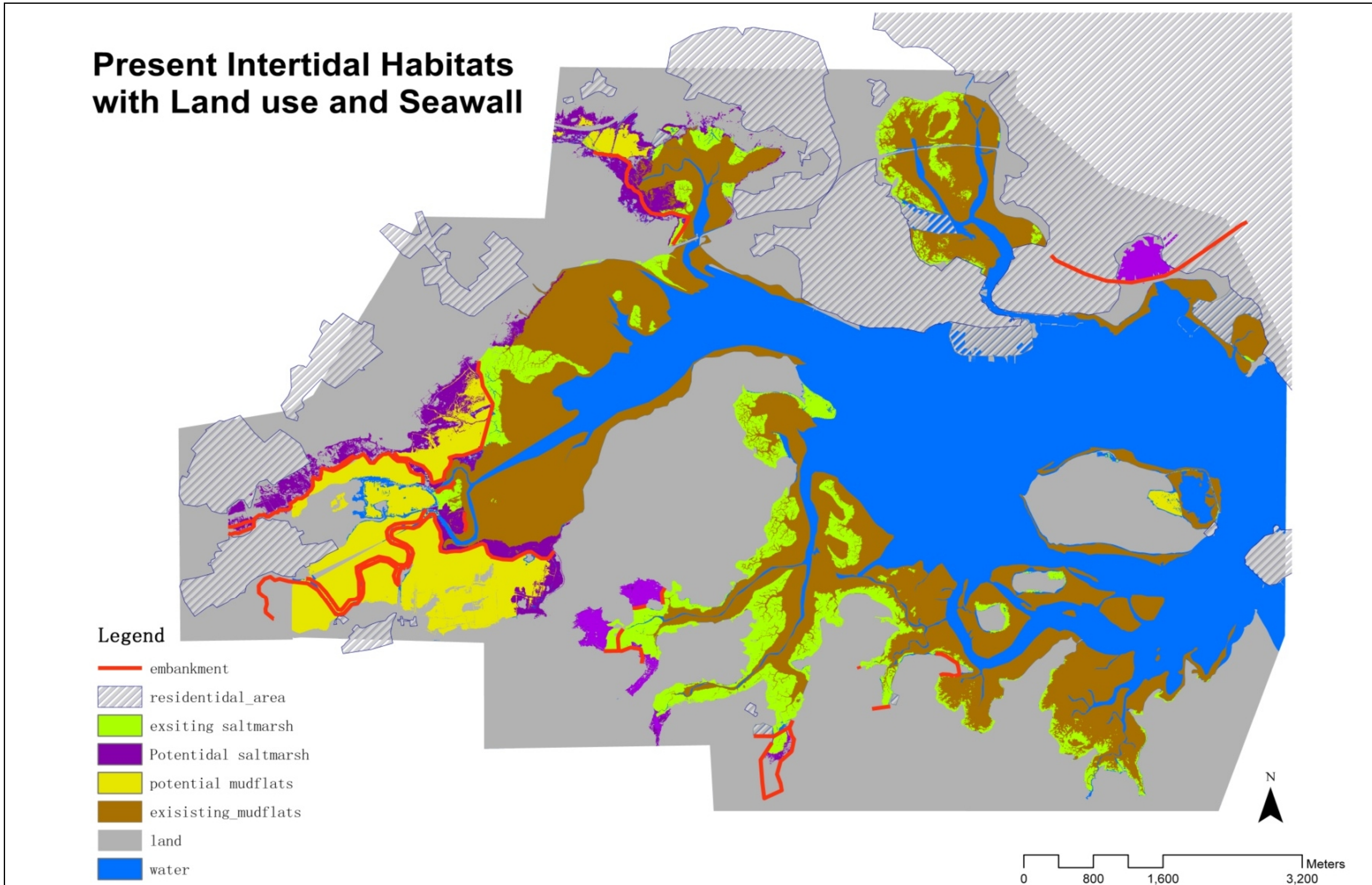


Figure 4.1: Existing and Potential Intertidal Habitats in 2007 (assuming no defence)

4.1.2 Intertidal Habitats Distribution By 2025 2055 and 2085

A series of maps for the change of each habitat for 2025, 2055 and 2085 were produced by using the LTEI model. Figure 4.3 shows the combined scenario of DEFRA sea-level rise and no accretion. Assuming there is no existing sea defence, a significant migration of saltmarsh in landwards direction was observed before 2025. However, the distribution of saltmarsh is stable for the 2055 and the migration of saltmarsh migration between 2055 and 2085 was observed to be less significant if compared to time period between 2025 and 2055. Thus, it can be concluded that there is small cliff of saltmarsh on the seawards margins of saltmarsh. The slope of profile along the coastline is gentler closer to the sea and is steeper at the landwards side.

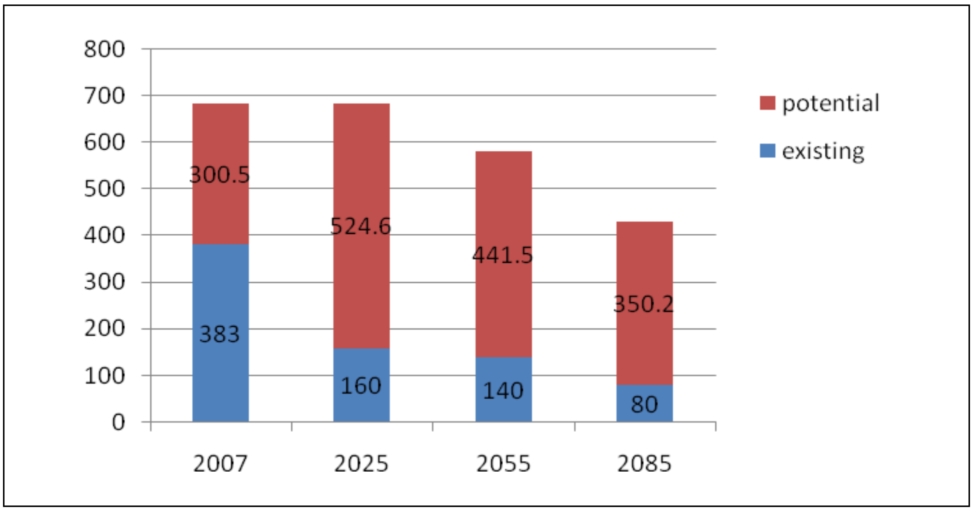


Figure 4.2: LTEI predicted saltmarsh change under DEFAR scenarios and no accretion

Table 4.1; DEFRA SLR guidance levels (DEFRA, 2006)

Year	1990-2025	2025-2055	2055-2085
SLR mm/year	3.5	8.0	11.5

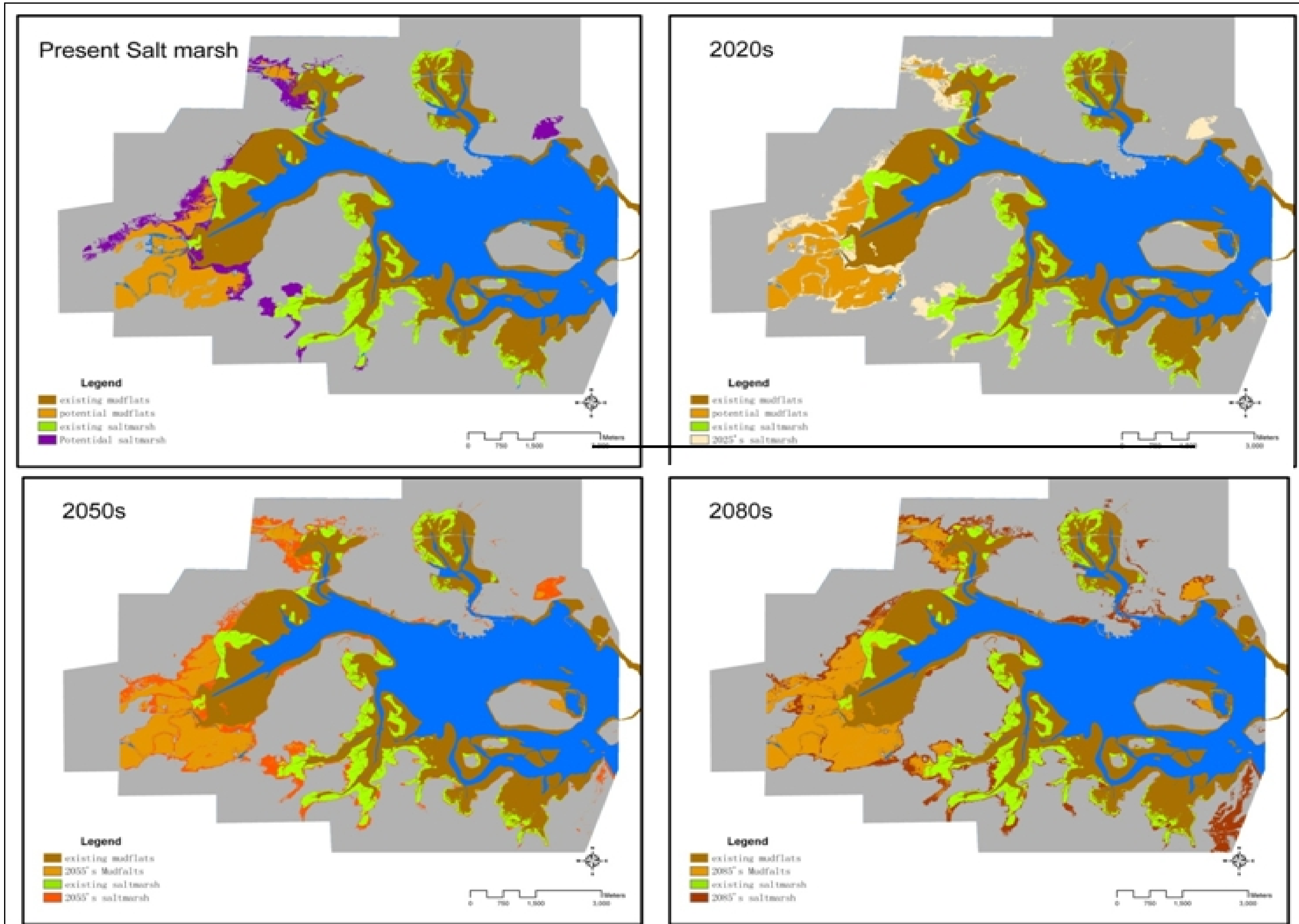
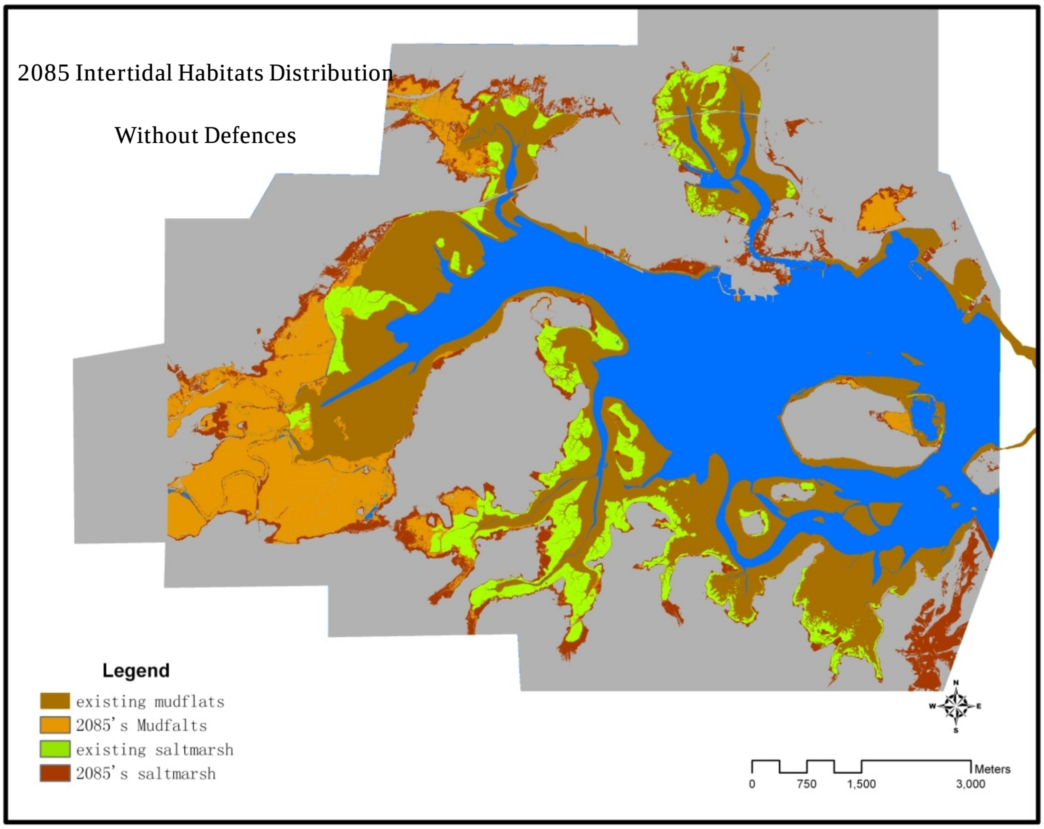


Figure 4.3: Existing and Potential Intertidal Habitats at 2025, 2055, 2085 (assuming no defence)

Figure 4.4 shows the distribution of saltmarsh and mudflats at 2085 after considering sea defence and land use area. Assume existing sea-defence being situated higher than the estimated maximum rise and the habitats behind it were effectively protected. Thus the effects of sea-level rise and dynamic marsh behaviour were localised to areas in front of existing sea defence. A summary of the change in salt marsh areas for these simulations is given in Figure 4.2.

By this time, more than 80% saltmarsh in front of the sea defence is observed being lost. The survived saltmarsh is scattered around the harbour without particular pattern to its distribution. In contrast there is still significant amount of mudflats remains in 2085. It is because of more and more of the land comes within the range suitable for mudflat colonization with increasing amounts of sea-level rise. Mudflats in this stage is mainly concentrated in Holes bay, Lytchett Bay and the west and south of the lower harbour where previously is occupied by saltmarsh colonization.

Potential saltmarsh is mainly located at west Lytchett Bay and around the mouths of rivers Piddle and Frome. This is the case of potential mudflats as well. In Holes bay and north-east Lytchett Bay the potential intertidal habitats is restricted by the Land use. The type of sediment in Studland is sand which is not suit for the existing saltmarsh to migrate inland. Even though the land surface elevation in this area is falling in between the HAT and MHWN levels by the 2080s.



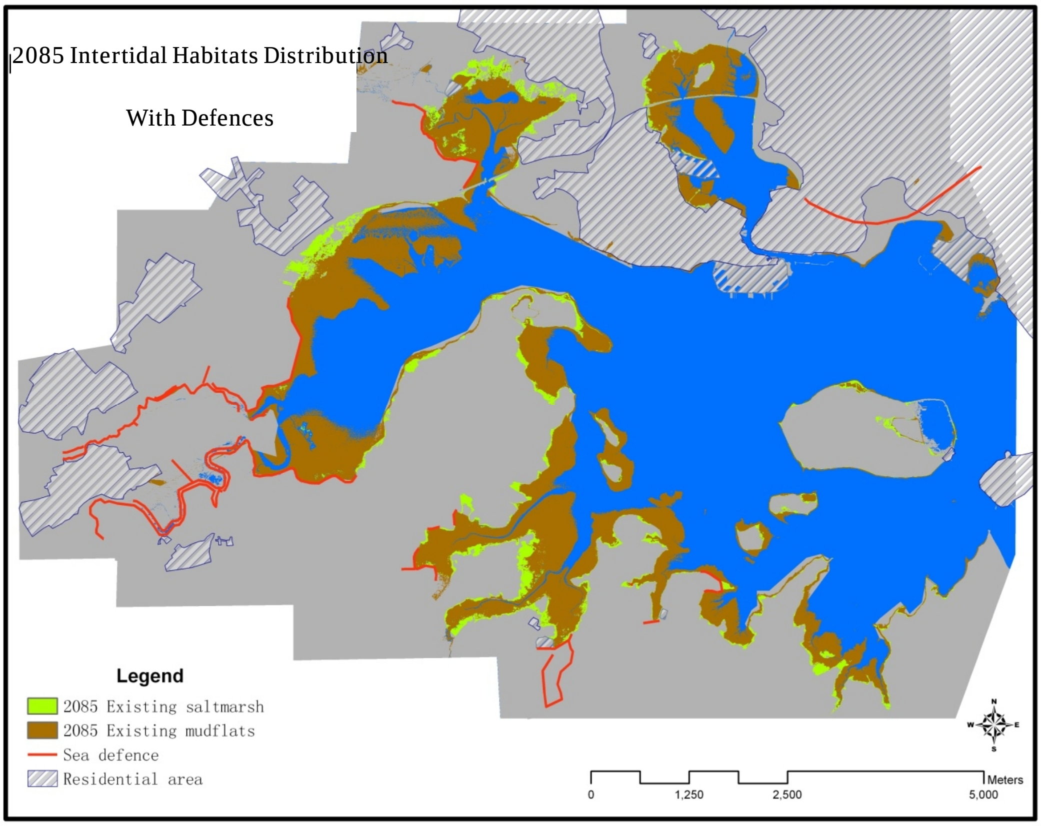
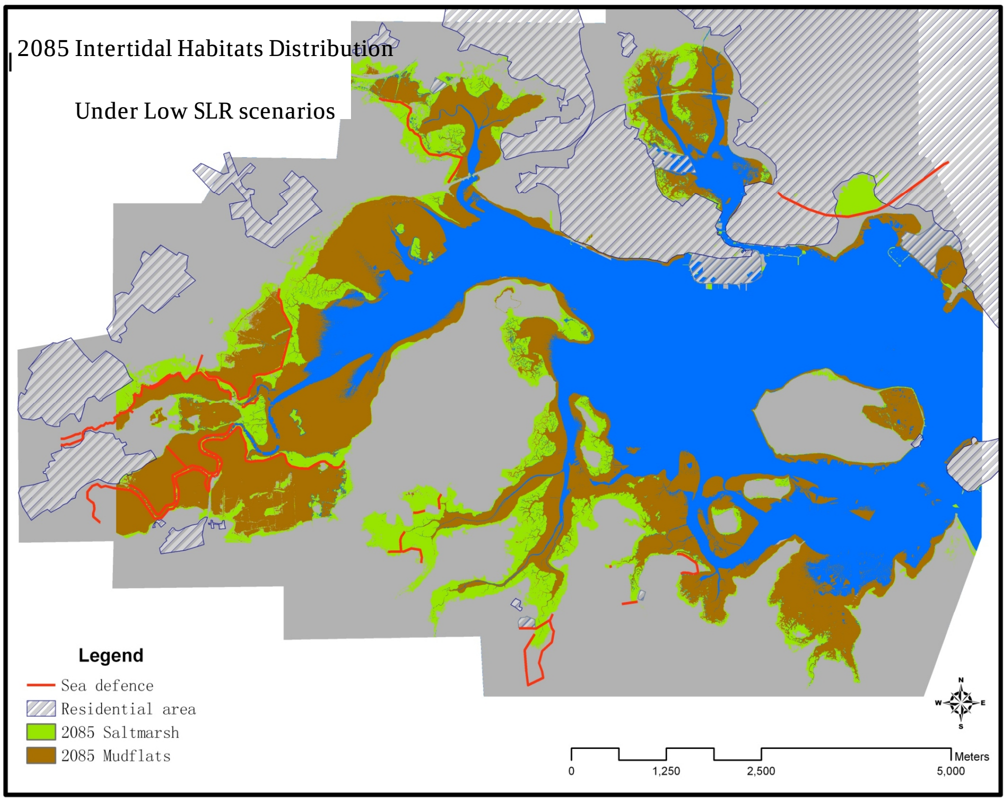


Figure 4.4; Intertidal habitats distribution by 2085 (1) considering defences; (2) without considering defences



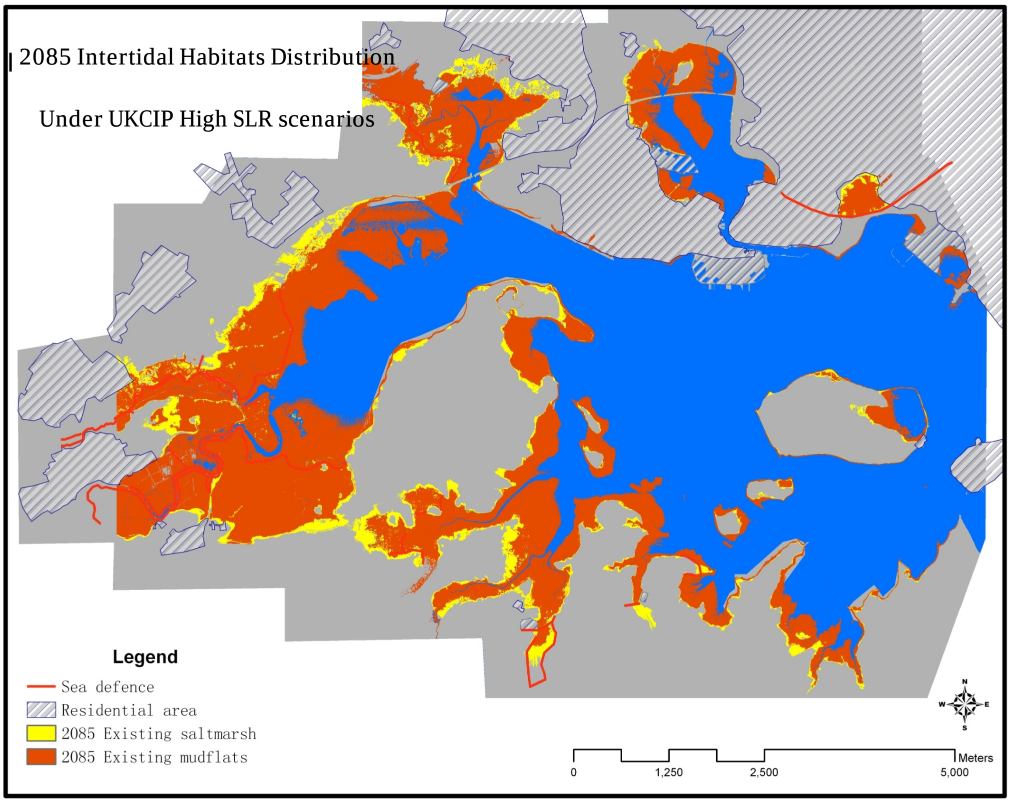


Figure 4.5; Intertidal habitats distribution by 2085 (1) Under Low scenarios (Ivan Haigh); (2) Under High scenarios (UKCIP)

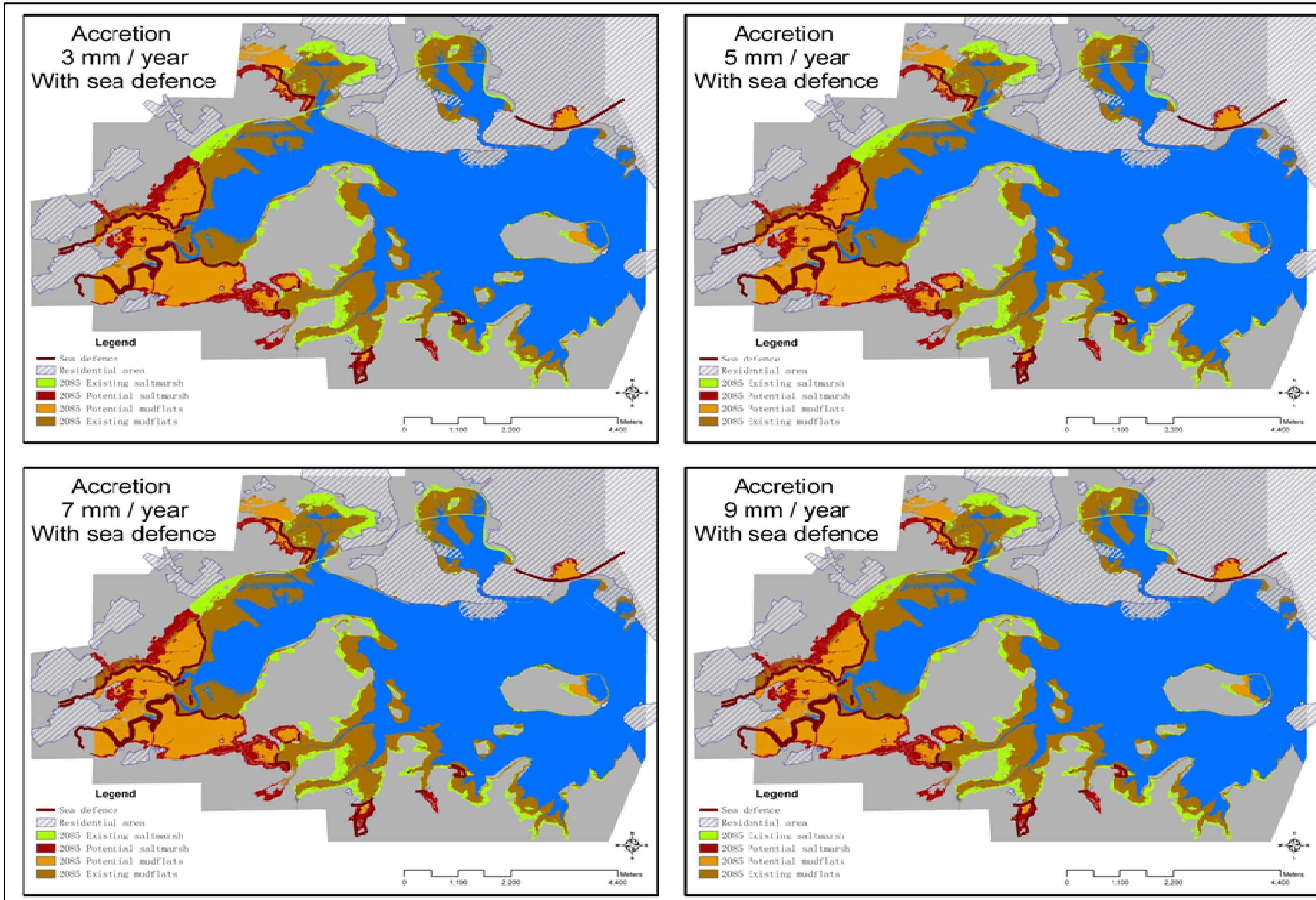


Figure 4.6 Intertidal habitats distribution in different accretion scenarios

4.2 Shoreline Management Options and related spatial planning

While there are a number of general schemes and techniques listed with regard to spatial planning in the UK and world-wide, the underlying philosophy at present is that the closer the scheme is to mimicking dynamic natural processes the better it is. In this study, the spatial planning considerations and correspondent management options of the inter-tidal habitats were analysed by using ArGIS based on the guidance from BRANCH and the options identified within the first generation Shoreline Management Plans (SMP1, 1999).

Contrary to the previous studies which focused on the north and the east of the harbour (developed area), the south west (less developed area) has not been studied extensively. It was fund in SMP1 that total frontage length of management unit PHB4 and PHB5 is 70 times more than average. These two units are located at the south the west of the Harbour with low land assets and high value of natural environment. Their shorelines are very long and complex. Thus previous definition of management units can be refined. Based on the LTEI the PHB4 and PHB5 were divided into 5 sub-units which can be managed in a co-ordinated way. These sub-units were defined from the coastal processing based on tidal regime and sediment transport (figure 4.8). Then the methodology described in Section3 was applied to three scenarios:

i. Maintenance of the current defence line

ii. A managed realignment involving the total removal of the current defences

iii. A selected realignment of appropriate areas.

4.2.1 Refine Management Units

In SMP, the coastline of the Harbour was divided into 17 Management Units with coherent characteristics in terms of coastal processes and land assets (Poole & Christchurch Bays Coastal Group, 1998). Then these MUs were classified by the coastal defence options. From the figure 4.7, it was clearly observed that the f south and west of management units (PHB4 and PHB5) are large, total length is 70 times more than average. The frontage length of PHB4 is 57.406 kms, but the defended frontage length is only 60 m which is much less than the average. The same situation is happened in PHB5. The majority of land in these areas is undeveloped. On the other hand, shoreline in PHB 4 and PHB 5 are very complex with extensive mudflats, salt marshes, reedbeds, sand dunes, heathland and islands are of great importance to wildlife and bird populations, many of which are protected by a raft of national and international conservation designations. It could easily be damaged by inappropriate coastal defences (Poole & Christchurch Bays Coastal Group, 1998). Therefore it is necessary to study these two units and refined into detailed sub units.

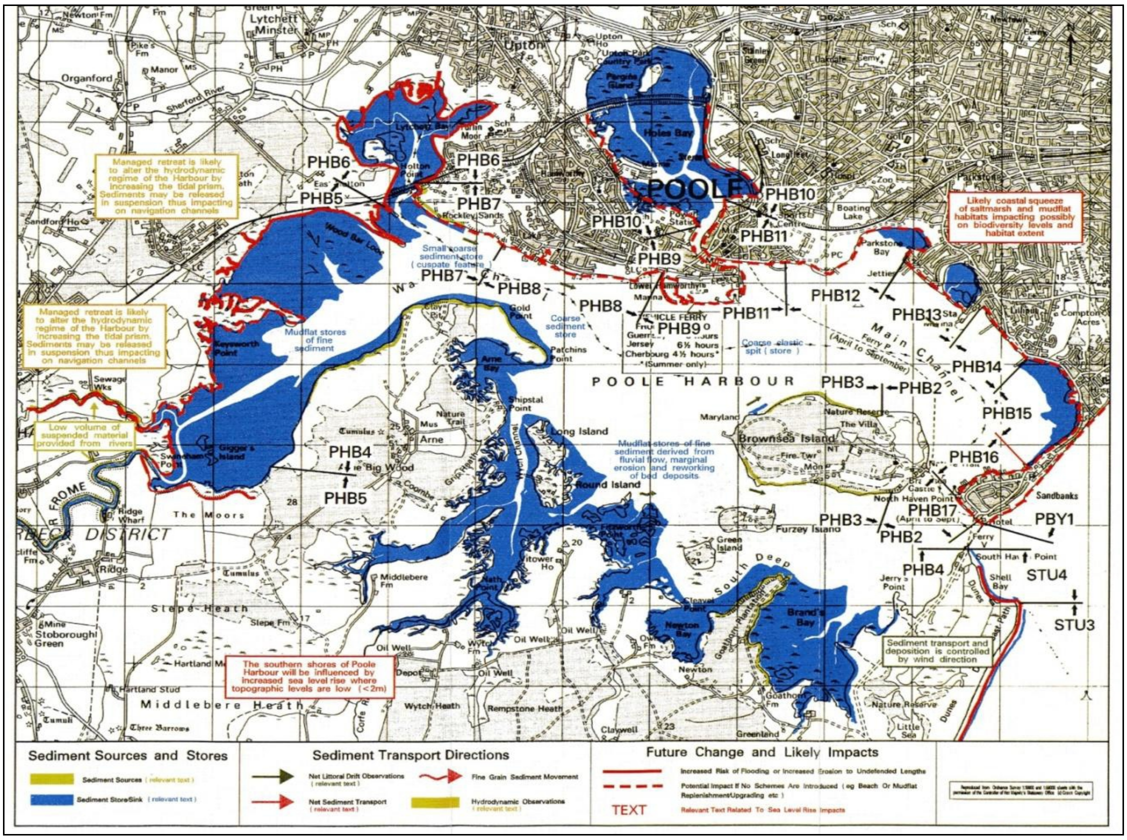


Figure 4.7; Poole Harbour Management Units (Halcrow, 1999)

The sub-units are determined based on the assessment of tidal regime, sediment transport, existing and potential risks of flooding or erosion, etc. Every single bay or estuary within the inserted units was analysed and evaluated. The PHB 4 and 5 are divided into three and two single units respectively.

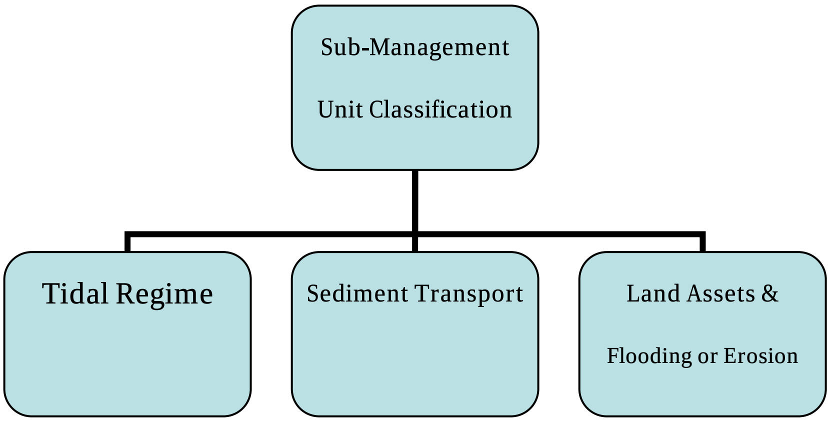


Figure 4.8 Flow chat of consideration process

Tidal inundation is one of the most important factors that control intertidal habitats development. Therefore, it was selected as one of indicators of coastal processes. Tidal regime is very complicated in a multi-inlet bay system. Due to lacking of tidal data, in this study, a set of the relative intertidal habitats elevation data was considered as indicator of the tidal regime. Theoretically, intertidal habitats vertically were distributed in the specific tidal range. Therefore the statistics of relative tidal elevation was got from the current intertidal habitats distribution. The methodology was mentioned in section 3. After comparing the data with observed tidal data, statistical results of relative tidal interface elevation in each bay was determined.

Table 4.2; The tidal interface elevation obtained from RTET

Study area	HAT Range (m)	Average HAT(m)	MHWN Range(m)	Average MHWN(m)	Average LAT(m)
Arne Bay	0.8-1.1	0.99	0.5-0.6	0.551	0.551
Middlebere Lake	0.8-1.0	0.95	0.3-0.7	0.543	0.543
Wych Lake	0.8-1.1	0.945	0.4-0.7	0.555	0.555
Ower Bay	0.9-1.0	0.96	0.2-0.7	0.379	0.379
Newton Bay	0.8-1.2	0.95	0.2-0.4	0.319	0.319
Brands Bay	0.9-1.2	1.08	0.2-0.4	0.318	0.318
Holton Bay	0.8-1.1	0.948	0.4-0.7	0.51	0.51

It was found from table 4.2 that the saltmarsh and mudflats in some adjacent bays and inlets were distributed within similar range. For instance, the saltmarsh in Arne Bay, Middlebere Lake and Wych Lake were vertically distributed between 0.8m and 1.1m, which were selected as a group. On the other hand, in some adjacent bays the situation was different. For instance, the saltmarsh distributed in Brands Bay was slightly higher than Onwer Bay. This probably because of the Brands bay was located closer to the Harbour entrance. Besides, it was wider which reduce the tidal rank. Holten Bay is located at the inner harbour side and two estuaries nearby. Therefore it is considered as one unit.

Sediment budgets and transport is another important indicator. They are useful in creating a holistic approach to studying coastal systems and contribute to both, improving the geomorphologic understanding of the components of the coastal system, and predicting the performance and impacts shoreline management policies and schemes over a sediment cell (Cooper et al, 2001).

After combining many datasets and studies, an insight into recent sediment transport pattern was worked out. The sediment transport and deposition around Brands Bay are controlled by wind direction. The mudflats at the middle harbour stores large amount of fine sediment which derived from fluvial flow, marginal erosion and reworking of bed deposit. The Wytch lake and Middlere Lake are relatively low laying area (< 2m) where will be influenced by increased sea level rise. The Rive Core Piddle and River Frome bring low volum of suspended materials to the southern Holten Bay. And in the Northern Holten Bay large amount of fine sediment is stored in frontage mudflats which also may be realised in suspension thus impacting on navigation channel. Managed retreat is likely to alter the hydrodynamic prime of the Harbour by increasing the tidal prism (Halcrow, 1999).

Table 4.3; Summary of sediment transport pattern in each bays

	Study area	Sediment transport
1	Arne Bay	stores large amount of fine sediment which derived from fluvial flow, marginal erosion and reworking of bed deposit
2	Middlebere Lake	
3	Wych Lake	
4	Ower Bay	sediment was derived from fluvial flow, marginal erosion and reworking of bed deposit
5	Newton Bay	
6	Brands Bay	sediment was controlled by wind direction
7	Holton Bay(South)	sediment was derived from fluvial flow
8	Holton Bay(North)	large amount of fine sediment is stored in frontage mudflats

After integrate above conditions the PHB 4 and 5 divided into five sub-units, which can be managed on a co-ordinated way. Figure 4.9 shows the refined sub-units boundary which is in red. Acoording to the first generation of SMP (Poole & Christchurch Bays Coastal Group, 1998), each sub-unit will be introduced briefly in the next section.

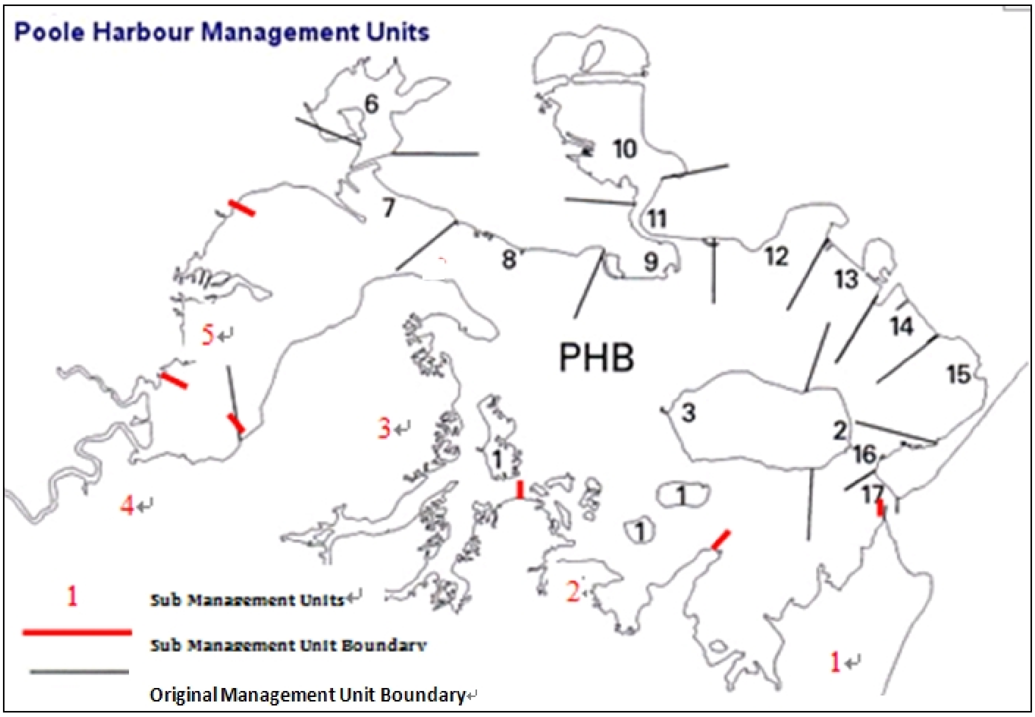


Figure 4.9; Refined Sub-Management Units Boundary (Source from HALCROW MARITIME. 1999)

Sub-Unit 1, South Haven Point to Goathorn Point: This unit is located at southern outer harbour including Bramble Bush Bay and Brands Bay. It is entirely undeveloped and undefended along its length. The sediment transport and deposition is controlled by wind direction. The shoreline is flanked with mudflats and marshland all of which have been designated SSSI due to the important wildfowl and associated wetland species they contain. The land rises up to form heath land and coniferous plantations (Poole & Christchurch Bays Coastal Group, 1998), the latter most dense along the Goathorn Peninsula and Rempstone Heath with mixed woodland along the western shores of Bands Bay.

Sub-Unit 2, From Goathorn Point to Fitzworth Point: This unit is located at southern part of middle harbour including Newton Bay and Ower Bay. The land use condition of this unit is similar to Unit 1. There are large area of farm land behind the shoreline and no any coastal defense. The relative tidal elevation is slightly lower than Unit 1 probably because this area is relative open and shallow. The frontage mudflats and saltmarshes store the fine sediment which derived from fluvial flow, marginal erosion and reworking the bed deposition. The shoreline is flanked with mudflats and marshland all of which have been also designated SSSI.

Sub-Unit 3, From Fitzworth Point to Gold Point: This unit is located at middle harbour including Wych Lake, Middlebere Lake Arne Bay and Crofe River. The land use and environmental condition is relatively complex. There are embankment lying along the River Corfe and some low lying area near Hartland Moor and Wytch Farm. The majority of land is farm land and heath. Important cliff exposures of the Poole Formation occur at Shipstal Point that have been designated GCR and RIGS status whilst the entire area has also been designated Heritage Coast and AONB for its outstanding landscape importance.

Sub-Unit 4, Gold Point to Keysworth: This Unit is located at South west said of the Harbour. This unit is characterised by river estuaries tidal and reclaimed marshland and wetland, with reclaimed pasture land further south at Keysworth and the Moors. A small eroding cliff line separates the edge of the marshes from seawall to the south of the unit near the mouth of the Wareham Channel. The wetlands which cover much of this area are an important area for wildfowl populations and therefore a proposed SPA whilst also qualifying under the Ramsar Convention. The whole area, including wetland heath land, marshland and meadows is designated SSSI and an area of considerable landscape importance thus afforded AONB status. (SMP1)

Sub-Unit 5, Keysworth to Holten Point: This unit is also characterised by tidal and reclaimed marshland and wetland, with woodlands to the north of the unit at Holton Heath. Flood earth embankments occur in the unit which are currently maintained by the EA. These include a small earth embankment protecting the railway line which runs close to the shoreline to the west of Lytchett Bay and an industrial estate at Holton Heath which backs onto an area of wetland (Poole & Christchurch Bays Coastal Group, 1998).

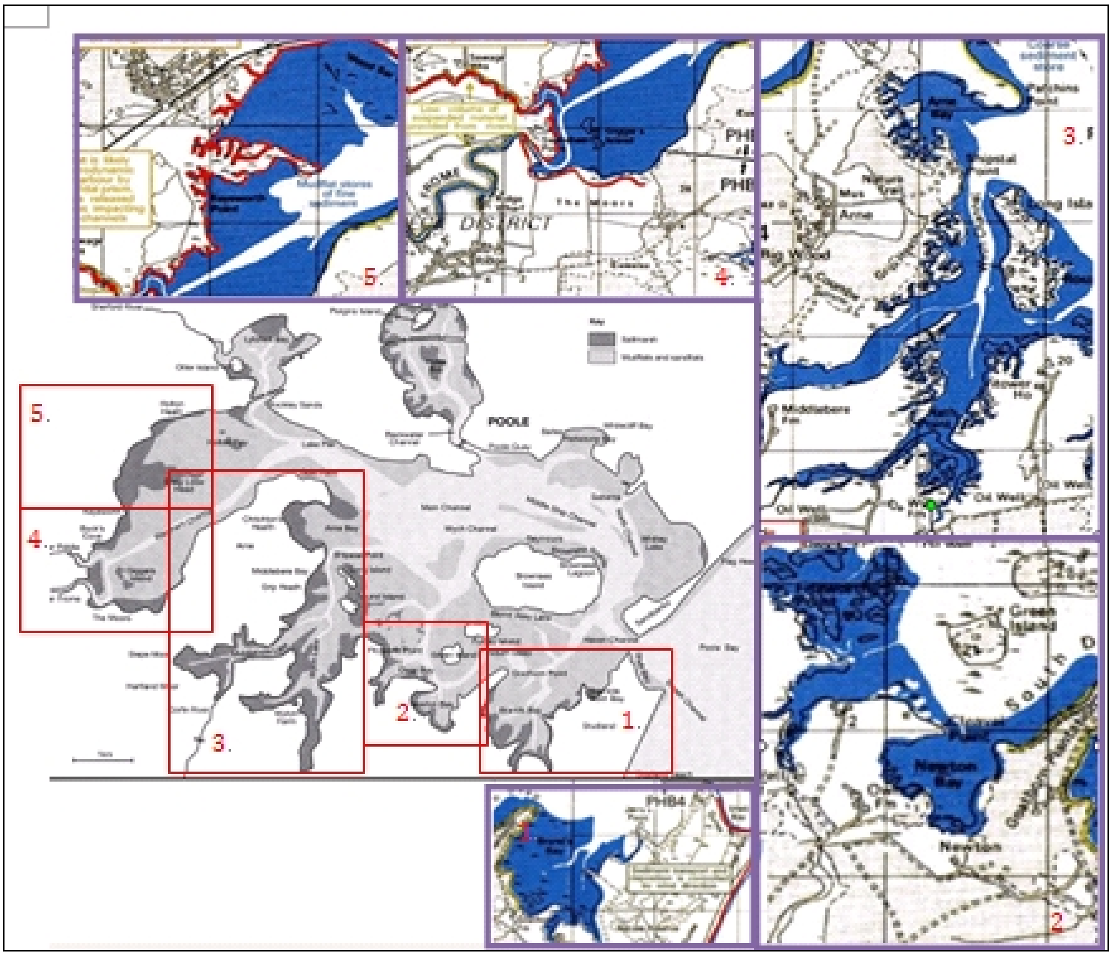


Figure 4.10; Refined Sub-Management Units

These sub-units were checked by histogram of intertidal habitats vertical distribution. From previous testing, Figure 4.11 shows the comparison of histograms from single bay (1) to multi-bays (2). In first one is the histogram of Arne bay and the second shows the histogram of sub-unit2 which includes Newton Bay and Ower Bay. It was found from histogram (1) that in the histogram, intertidal habitats vertically follow a normal distribution. In histogram (2) an approximate normal distribution was considered to that the tidal elevation related to intertidal habitats are with similar characteristic in these two bays. In this way every sub-unit was checked and the histograms are in Appendix. Due to histogram testing is also based on API result; its accuracy could directly influence the histogram results. The histogram result was only considered as a reference to check the feasibility of sub-units classification.

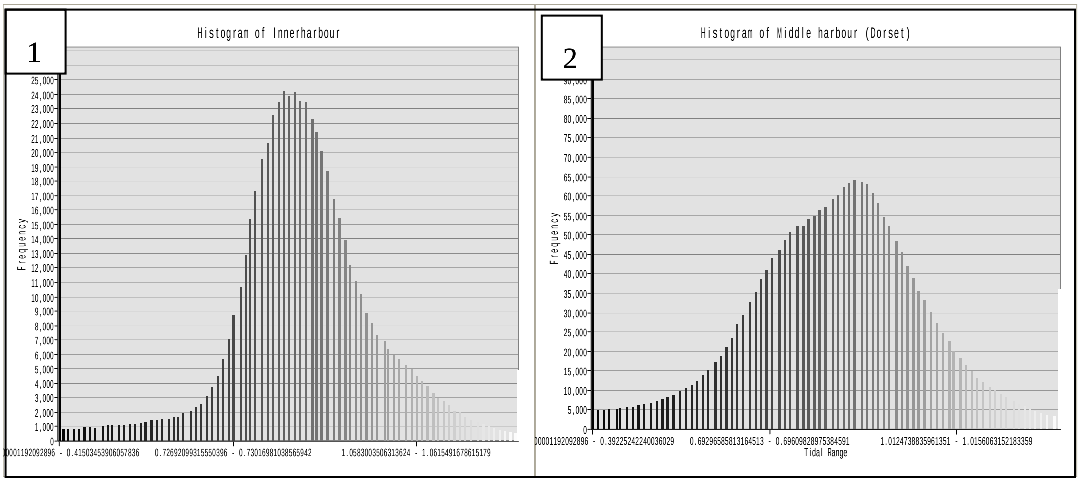


Figure 4.11; Histogram of intertidal habitats distribution in single bay and multi-bays

In this study, the options available for management of the inter-tidal habitats were examined in terms of four Strategic Coastal Defence Options (SCDOs), based on the options identified within the first generation Shoreline Management Plans (Poole & Christchurch Bays Coastal Group, 1998) for Poole & Christchurch Bays, known nationally as plan 5f. SMP provided four SCDO types are briefly outlined below after which their applicability to the area in question will be discussed.

Considering the land asset and coastal line risk in this area it is not necessarily to advance the current defence line. Thus, maintaining, treating current or doing nothing were the major concern in this study. The LTEI described in Section (3.1.1) was applied to three scenarios:

Maintenance of the current defence line

A managed realignment involving the total removal of the current defences

A selected realignment of appropriate areas

Maintenance of the current defence line

Current defence lines of South west the Harbour keep out the saltmarsh and mudflats from grazing marsh and saline lagoons. Although sedimentation happens in the intertidal habitat, rising of sea level and horizontal erosion have threatened the existence of this habitat in the future. Current (baseline 2007) inter-tidal habitat covers an area of 1930 ha of which 383 ha is saltmarsh. The modeling predicts that the area of saltmarsh is diminishing. By 2080s, more than 80% saltmarsh in front of the defence will be lost in the Poole Harbour under a DEFRA sea-level scenario with no accretion (Figure 4.12). The survived saltmarsh is scattered around the harbour without particular pattern to its distribution. Hence, wave attack on the seawall will increase due to the loss of the protective saltmarsh (Moller et al., 2001), necessitating significant and costly upgrades.

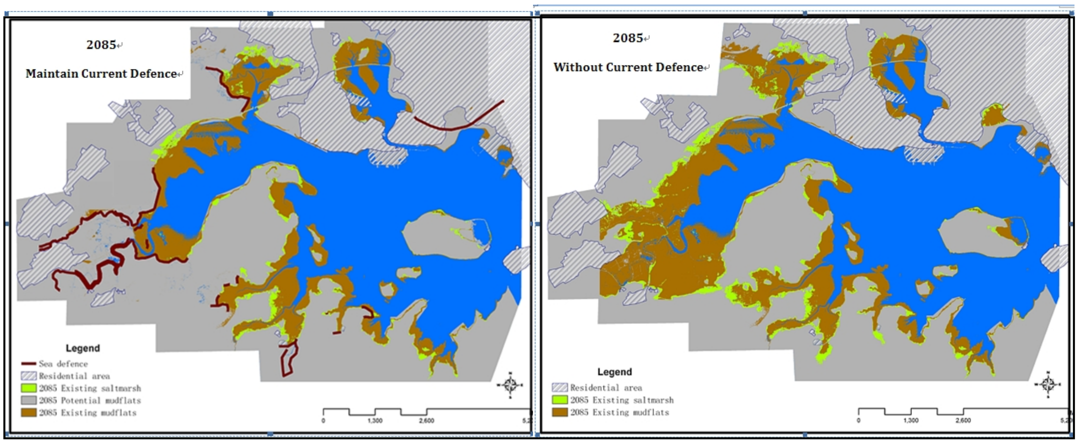


Figure 4.12; Comparison of maintaining and breaching defence in 2085

A managed realignment involving the total removal of the current defences

The erosion of intertidal habitat results on the exposure of the seawall to wave attack. Due to wave attack, reliability of current defence line will decrease so that it will be necessary to build a higher defence line. Building a higher seawall will be uneconomical because the construction of higher seawall will be required again and again. For this reason, managed realignment is suggested, offering more economical and sustainable solution, to overcome the erosion of current intertidal habitat in the future due to the rising of sea level. Figure 4.12 shows the effect of defence on saltmarsh distribution, the condition of maintaining current defence line is compared with the condition if current defence line is totally breached.

Table 4.4; Intertidal habitats distribution under DEFAR scenarios

2085 Intertidal Habitats (ha)	Maintaining Defence		Totally Breaching Defence	
	Mudflats	Saltmarsh	Mudflats	Saltmarsh
	994	80	1523.7	180

LTEI results give a number low laying areas behind the current defence. There are potential areas of coastal grazing marsh and saline lagoons behind the current defence line which can be employed as the new intertidal habitat in the implementation of managed realignment. With managed realignment, modelling suggests that mudflats will remain the dominant habitat, which is mainly because i) the elevation of new intertidal areas will be too low to replace lost saltmarsh and ii) potential areas of saltmarsh formation are restricted by different land use.

Possible managed sites in PHB4 and PHB5

Managed realignment is those that require the removal of defences depend on coast-benefit analysis, land ownership, compensatory (Mark 2006). In south west of the harbour there are potential areas of coastal grazing marsh and saline lagoons behind the current defence line which can be employed as the new intertidal habitat in the implementation of managed realignment. Those areas are Ower Bay, Slepe Moor, The Moor, Bestwall, and Keysworth marshes. Restricted by Oil wells and landfill, there are only around 327 ha of potential area behind the seawall that can be used in managed realignment. These areas are, Slepe Moor, The Moor, Best Wall, and Keysworth marshes marshes.

Table 4.5; Summary of intertidal habitats distribution in each realignment site

Location	Site area (ha)	Saltmarsh (ha)	Mudflats(ha)
Slepe Moor	50	20	30
The Moor	47	0.4	46.6
Best Wall	120	12.3	107.7
Keys Worth	110	18.5	91.5

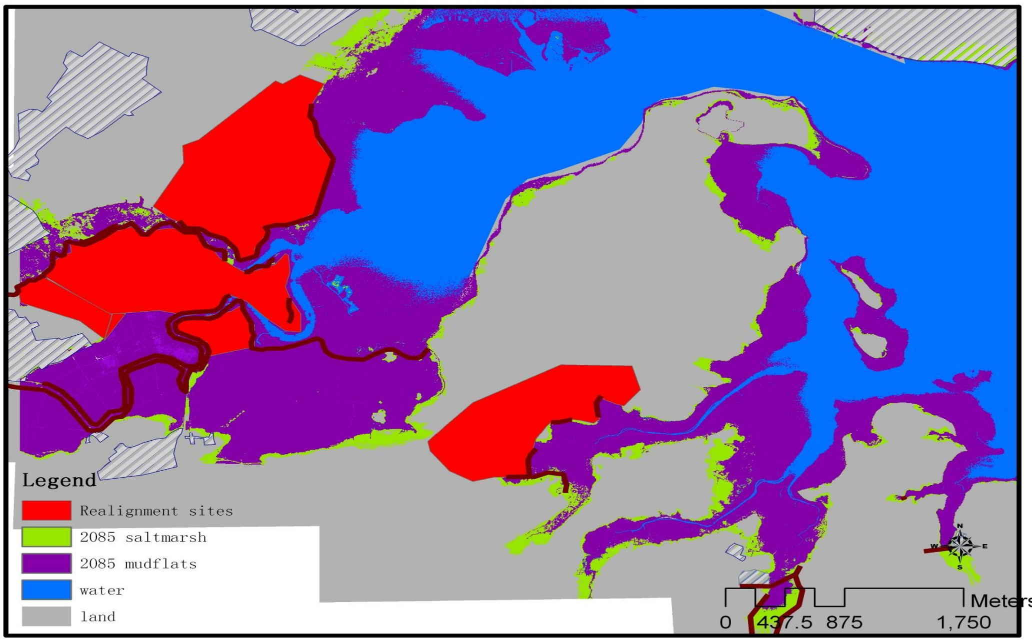


Figure 4.13; Possible Realignment Site in PHB4 and PHB5

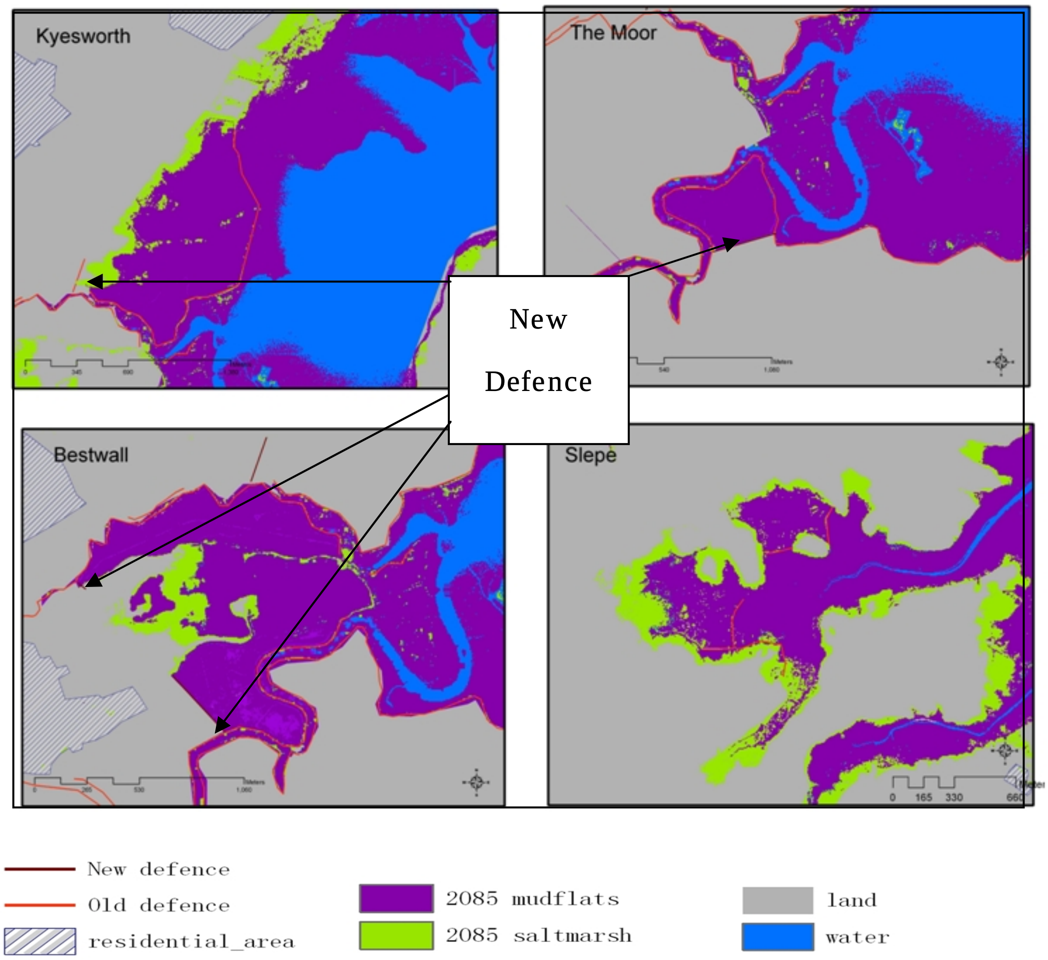


Figure 4.14; Realignment in each sites under DEFRA SLR scenarios and no accretion assumption

At the Slepe Moor site two sea walls will be breached. There are approximately 50 ha of potential realignment. Based on GIS analysis, managed realignment of this area will create intertidal habitat consist of 20 ha saltmarsh and 30 ha mudflats in 2085.

At The Moor site, the current defence will be setback and a new defence line will be created. There are approximately 47 ha of potential realignment. Probably because the elevation of new intertidal areas will be too low to replace lost saltmarsh, there will be only 0.4 ha saltmarsh in 2085 after realignment.

At the Bestwall site, the current defence will also be setback and two new seawalls will be built. There are approximately 120 ha of potential realignment. Based on GIS analysis, managed realignment of this area will create intertidal habitat consist of 12.3 ha saltmarsh and 107.7 ha mudflats in 2085

At the Keysworth site, managed realignment considers setback of the seawall which could offer approximately 110 ha of potential intertidal habitat. Projection of intertidal habitat under high sea level rise in 2085 indicates that there will be 18.5 ha area of saltmarsh and 91.5 ha area of mudflats.

5. Discussion

In above section, the SMUnits PHB4 and PHB5 were divided into 5 sub-units based on the consideration of coastal processes. In this section options available for management of the inter-tidal habitats within these 5 sub-units were examined in terms of four Strategic Coastal Defence Options (SCDOs), based on the options identified within the first generation Shoreline Management Plans for the Poole Harbour and Poole & Christchurch Bays. The land assets, flooding or erosion risks and cost-benefit were taken into account to evaluate the application in each sub-unit.

Table 5.1; Summary of Strategic Coastal Defence Options in each Sub-unit

Sub-Units	SCDOs			
	Hold	Retreat	Advance	Do Nothing
1	x	x	x	√
2	√ Selective	x	x	√
3	√ Selective	√ Selective(in)	x	√
4	√ (Short term)	√ Selective For Long term	x	√ Selective (Short term)
5	√ Selective (Short term)	√ Selective (Long term)	x	√ Selective (Short term)

While all the four coastal defence options may be applied in theory to the inter-tidal habitats of Poole harbour, some options seem more practically feasible and more in tune with the general policy followed in the UK and most of Europe and other parts of the world of preserving and if possible enhancing natural coastal habitats. Based on the results from the simulations carried out, the current land-use patterns in the area and current coastal policy in the UK, an analysis was carried out on the applicability and relevance of each of the four coastal defence options. In all the options, a decision would have to be taken as to which sea-level rise scenario to use as the baseline, though for the purpose of this analysis the DEFAR scenario was given greater preference.

Sub-unit 1 South Haven Point to Goathorn Point

This unit is located at southern outer harbour including Bramble Bush Bay and Brands Bay. It is entirely undeveloped and undefended along its length. Along the 30m inshore of South Haven Point there is a rubble revetment and masonry wall which protect the privately owned Shell Bay boatyard, café and the nearby road to the ferry. The shoreline is flanked with mudflats and marshland all of which have been designated SSSI due to the important wildfowl and associated wetland species they contain. The land rises up to form heathland and coniferous plantations (Poole & Christchurch Bays Coastal Group, 1998) the latter most dense along the Goathorn Peninsula and Rempstone Heath with mixed woodland along the western shores of Bands Bay. The sediment transport and deposition is controlled by wind direction.

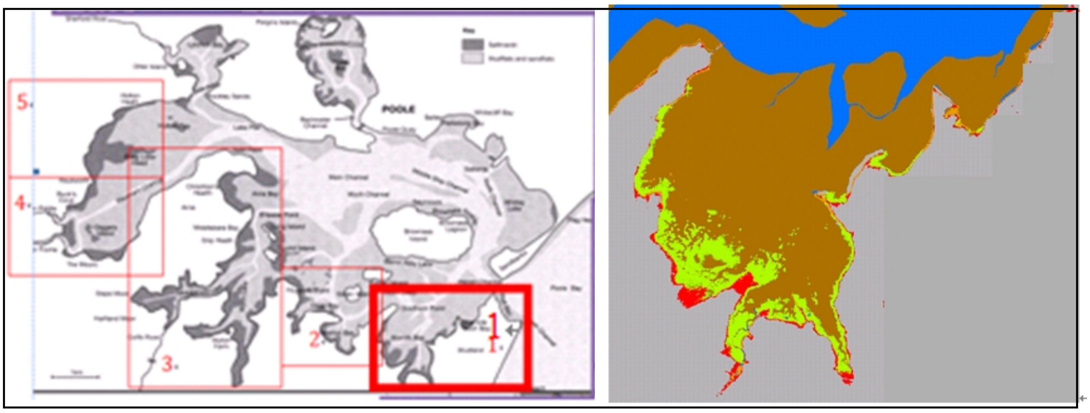


Figure 5.1; Sub-Unit 1 with simulated intertidal habitats distribution (Brownish: existing mudflats; Greenish: existing saltamarsh; reddish: potential saltmarsh)

Due to the cost-benefit consideration, both Advance and Hold line options are not appropriate for this Sub-unit and are not considered any further. Observed from LTEI result, Managed Retreat for this sub-unit is also not feasible due to topographic nature of backing land coupled with how it is currently used. Due to the land use value Managed retreat. Currently, the shoreline management option of this unit is doing nothing and it will continue to be the optimal option in the future. This method lets the situation remain as it is, in short term, with no steps taken that would either increase or decrease the inter-tidal habitats. However, the long term implication of it would cause an increasing trend of saltmarsh erosion. Depending on sea level rise predictions, only 20% of saltmarsh (reddish in figure 5.1) will remain at 2085. The Goathorn Peninsula with higher topographically elevations will not suffered from this kind of impact, but the cliff erosion may increase. Therefore, this strategic option should be accompanied by constant monitoring to ensure that habitats are not lost due to sea-level rise, human activity or by neglect.

Sub-Unit 2: From Goathorn Point to Fitzworth Point

This unit is located at southern part of middle harbour including Newtion Bay and Ower Bay.   The land use condition of this unit is similar to Unit 1. There are large area of farm land behind the shoreline and some oil field around Ower Bay. A sea wall protects the western side of Newton Bay. And in south east Ower Bay, there is an embankment to protect the farm land. The relative tidal elevation is slightly lower than Unit 1 probably because this area is relative winder. The frontage madflats and saltmarshes store the fine sediment which derived from fluvial flow, marginal erosion and reworking the bed deposition. The shoreline is flanked with mudflats and marshland all of which have been also designated SSSI.

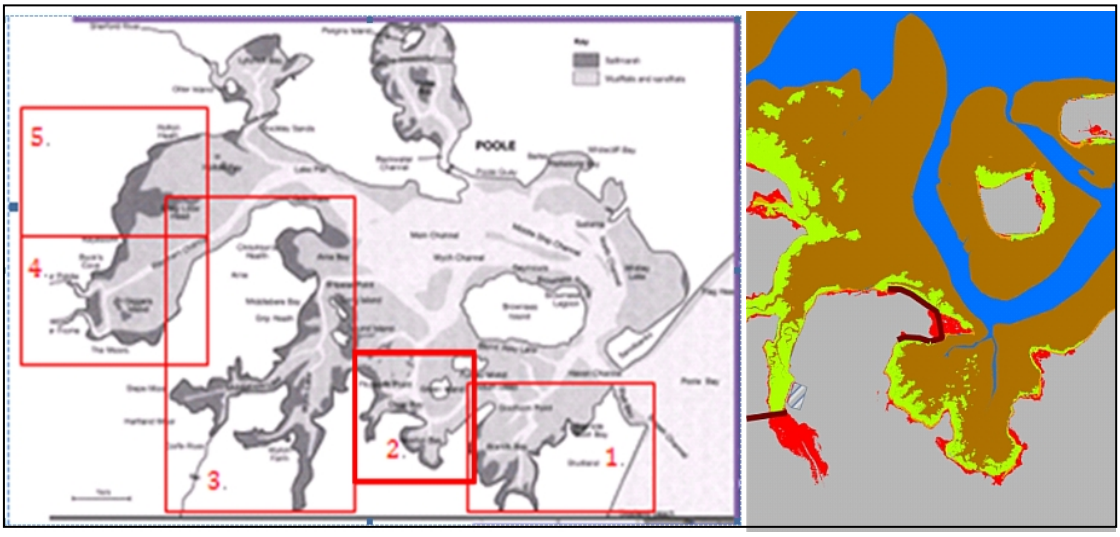


Figure 5.2; Sub-Unit 2 with simulated intertidal habitats distribution (Brownish: existing mudflats; Greenish: existing saltamarsh; reddish: potential saltmarsh)

Considering above description, the Advance or Retreat the line options are not appropriate for Sub-unit 2 and are not considered any further. Due to the oil field is behind existing defence in Ower Bay, Selective Hold the line is considered as an optimal option. It is including the Maintenance of existing defence and selective protection of assets. The long term implication of this strategic option would exacerbate the saltmarsh erosion.

Management Unit 3: From Fitzworth Point to Gold Point

This unit is located at middle harbour including Wych Lake, Middlebere Lake Arne Bay and Corfe River. The land use and environmental condition is relatively complex. The Wytch lake and Middlere Lake are relatively low laying area (< 2m) where will be influenced by increased sea level rise. There are embankment lying along the River Corfe and some low lying area near Hartland Moor and Wytch Farm. The majority of land is farm land and heath. There are two oil fields near Wych Lack. Important cliff exposures of the Poole Formation occur at Shipstal Point that have been designeated GCR and RIGS status whilst the entire area has also been designated Heritage Coast and AONB for its outstanding landscape importance.

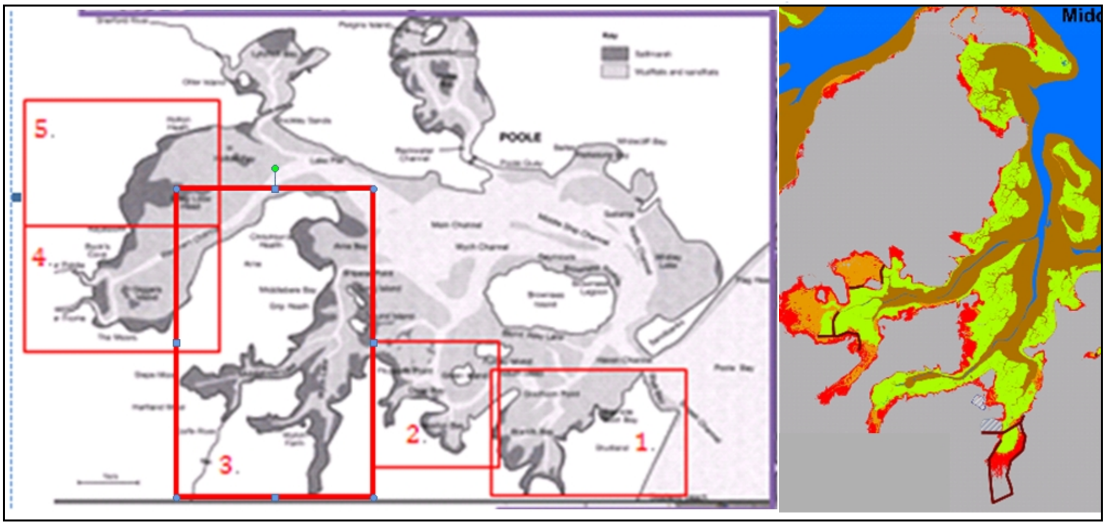


Figure 5.3; Sub-Unit 3 with simulated intertidal habitats distribution (Brownish: existing mudflats; Greenish: existing saltamarsh; Yellowish: potential mudflats; Reddish: potential saltmarsh)

Considering above description, the Advance line options is not appropriate for this Sub-unit and is not considered any further. A localised issue of consideration must be the protection of the oil field at Wych Bay. Selective Hold the line is considered as an optimal option. It is including the Maintenance of existing defence and selective protection of assets.

Selective Managed Retreat could be considered as an option for the length of the defence excluding the part in front of the landfills at Slepe Moor. However, the analysis that was performed without the defence indicated that most of the habitats in that region would become mudflats if the defence were removed. This therefore called into question the effectiveness of the option of managed realignment for this particular area.

Management Unit 4: Gold Point to Keysworth

This Unit is located at South west said of the Harbour. This unit is characterised by river estuaries tidal and reclaimed marshland and wetland, with reclaimed pasture land further south at Keysworth and the Moors. A small eroding cliff line separates the edge of the marshes from seawall to the south of the unit near the mouth of the Wareham Channel. The Rive Core Piddle and River Frome bring low volume of suspended materials to the southern Holten Bay. The rivers

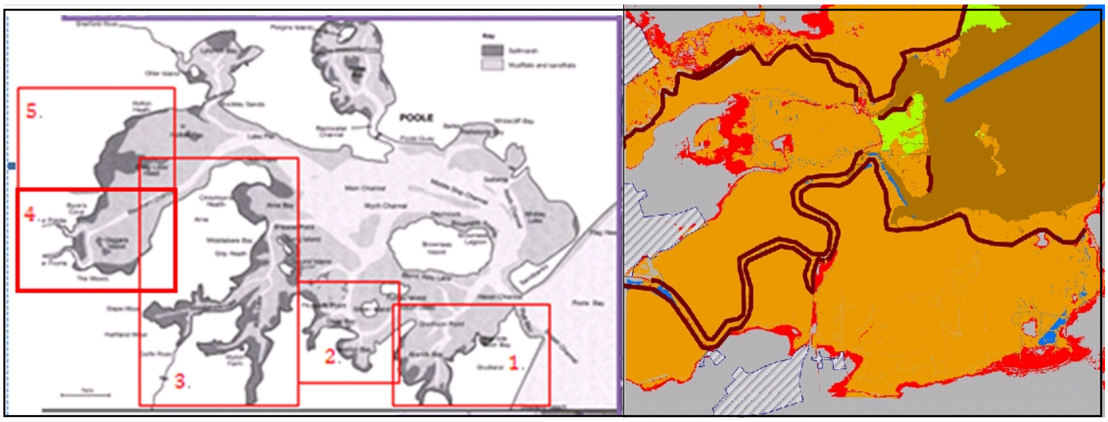


Figure 5.4; Sub-Unit 4 with simulated intertidal habitats distribution (Brownish: existing mudflats; Greenish: existing saltamarsh; Yellowish: potential mudflats; Reddish: potential saltmarsh)

defences are alone these two rivers till up stream to protect the large low lying area. The wetlands which cover much of this area are an important area for wildfowl populations and therefore a proposed SPA whilst also qualifying under the Ramsar Convention. The whole area, including wetland heathland, marshland and meadows is designated SSSI and an area of considerable landscape importance thus afforded AONB status (Poole & Christchurch Bays Coastal Group, 1998).

Considering above description, the Advance line options is not appropriate for this Sub-unit and is not considered any further.

The option of Do Nothing or Limited Intervention, though economically attractive in the short term did not seem effective in the long run. Replenishment of sediment would not be sufficient in order to maintain habitats seaward of the wall at their current state. From the simulation result, there is a clear danger of current mudflats (Brownish) and saltmarsh (Greenish) in front of defence being lost in the coming decades. As a consequence, there will be an impact upon backing wetlands where flood defences exist. For the defence of Rive Core Piddle and River Frome, this option will increase the risk of breaching or overtopping into the marsh grasses and floodplain. The Moor is the most likely areas to be inundated by higher sea levels in the future.

Selective Hold line applies only to those lengths of coast where EA maintain flood embankment. The difficulty with this policy would be the maintenance of inter-tidal habitats in front of the defence. The results from the modelling showed that with increasing sea-levels the current habitats, with the possible temporary exception of mudflats, would be either be inundated or would be squeezed between the sea and the defence, eventually being lost to the sea in either case. Further upstream, sluices do occur though are not maintained on a regular basis whereas the boast moorings that occur are regularly maintained.

Selective Managed Retreat could be considered as optimal option for the length of the defence. Because current the defence from the Moor to the right hand bank of the River Frome is obligated to maintain it up to 2005, which now is already expired. Moreover the dredged materials from regular maintenance of Wareham Channel previously has been used to fortify the defence, which can be deposited further inland to build up a new defence in the future (Poole & Christchurch Bays Coastal Group, 1998). It would make this option economically feasible. However, the analysis that was performed without the defence indicated that most of the habitats in that region would become mudflats if the defences were removed. This therefore called into question the effectiveness of the option of managed realignment for this particular area. Further this option would still need to address the issues examined in the previous option, of the maintenance of the structure against increased wave-attack and scour and prevention of incursion of sea-water into the ground. Also, the presence of the urban settlements in close proximity to the current shoreline would make any landward move even more difficult.

Management Unit 5: Keysworth to Holten Point

This unit is also characterised by tidal and reclaimed marshland and wetland, with woodlands to the north of the unit at Holtion Heath. Large amount of fine sediment is stored in frontage mudflats which also may be realised in suspension thus impacting on navigation channel. Managed retreat has likely altered the hydrodynamic prime of the Harbour by increasing the tidal prism. Flood earth embankments occur in the unit which are currently maintained by the EA. These include a small earth embankment protecting the railway line which runs close to the shoreline to the west of Lytchett Bay and an industrial estate at Holton Heath which backs onto an area of wetland (Poole & Christchurch Bays Coastal Group, 1998).

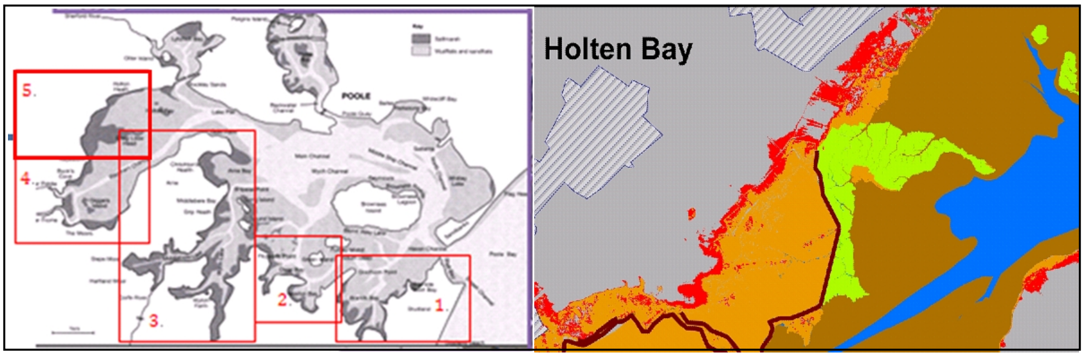


Figure 5.5; Sub-Unit 5 with simulated intertidal habitats distribution (Brownish: existing mudflats; Greenish: existing saltamarsh; Yellowish: potential mudflats; Reddish: potential saltmarsh)

Considering above description, the Advance line options is not appropriate for this Sub-unit and is not considered any further. In sub-unit 5 there are massive salt marsh and mudflats in from of current defence especially at Shag Looe Head. Behind the defence there is SSSI designated Grazing marsh area. Under Do Nothing option, would cause an increasing rate of marsh edge erosion in long term run. There will be an impact upon backing designate area.

The Hold Line Option would facilitate the continued protection of the coastal lagoons and grazing marshes that were currently designated SSSI sites. And at Holton Heath there are industrial waste tip and railway line which would also be protected. The difficulty with this policy would be the maintenance of inter-tidal habitats in front of the sea-wall. The results from the modelling showed that with increasing sea-levels there is a clear danger of current mudflats (Brownish) and saltmarsh (Greenish) in front of defence being lost in the coming decades. As a consequence, there will be an impact upon backing wetlands where flood defences exist.This policy would therefore need constant replenishment and maintenance of these habitats if they were to be protected in situ or the provision of compensatory habitats in an alternate location, since all these habitats are protected by a number of national and international laws.

Due to topographic, economic and political factors within this sub-unit, Managed Retreat Option could be considered as more suitable long term option, excluding the part of industrial waste tip and railway line at Holten Heath. However, Managed retreat will contain likely alter the hydrodynamic prime of the Harbour by increasing the tidal prism as a consequence of its implementation. Thus, it is important to undertake a detailed study and a constant monitoring.

Has to be mention, all designated coastal grazing marsh and saline lagoons in these 5 sub-units, which should be maintained to comply with the Habitat Directive, will be lost. Relocation is an option as these are largely artificially managed habitats but opportunities are restricted within the case study site due to competition from urban and industrial land use.

6. CONCLUSION

Under the idea of 'adopting a sustainable policy for the longer-term', at present the second generation of SMP is being producing to replace the SMP1 in Poole harbour. This study estimated the present and future behaviour of inter-tidal habitats (saltmarh and mudflats) in Poole harbour which was based on the up to date climate change and other environmental considerations. It was founded that in Poole Harbour there are some locations where the current SMP policy to defend is no longer practical, After investigating possible realignment options and other spatial planning issues related to the long term protection of these habitats an assessment was provided for the possible management options to the specific area. The following key findings were established in this study:

1. At present, the existing intertidal habitats were calculated as being approximately 1930 ha. Among which 80% is mudflats which is distributed all over the harbour. Saltmarsh currently covers approximately 383 ha and most of them located around the south and west of the harbour as well as the Lytchett bay, Holes bay.
2. LTEI results shows that a significant loss of saltmarsh happened by 2085. The survived saltmarsh is scattered around the harbour without particular pattern to its distribution. Potential saltmarsh is mainly located at south and west of the harbour around the mouths of rivers Piddle and Frome. This is the case of potential mudflats as well.
3. It was fund in SMP1 due to the low land-use value, shoreline management units (PHB4, PHB5) in the south and west of the harbour is too large. But these two units have high value of natural environment. Thus, based on the tidal regime and sediment transport, the PHB4 and PHB5 were divided into 5 sub-units.
4. From LTEI results, there are 4 sites, which are totally 327 ha of potential area behind the seawall in these 5 sub-units that could be used for managed realignment. The simulation results were then applied to within a coastal

management framework wherein four coastal zone management options were investigated.

5. Finally, various land-use restrictions on space in the area, such as the presence of urban settlements or the presence of landfill sites near the defence were also taken into account. It was found in conclusion, that the most feasible coastal defence option of each site in short term was a combination of the Strategic Coastal Defence Options of 'Do Nothing' and 'Selective Hold the Line'. For long term was a combination of 'Selective Hold the Line', and 'Selective Managed Realignment'.

Table 6.1; Summary of Strategic Coastal Defence Options in each Sub-unit

Sub-Units	SCDOs			
	Hold	Retreat	Advance	Do Nothing
1	x	x	x	√
2	√ Selective	x	x	√
3	√ Selective	√ Selective(in)	x	√
4	√ (Short term)	√ Selective For Long term	x	√ Selective (Short term)
5	√ Selective (Short term)	√ Selective (Long term)	x	√ Selective (Short term)

Due to the limited use of ArcGIS in this project, the result should be considered as a guide to possible future change. And there were a couple of drawbacks that could be rectified and improved upon in future. For instance, the coupling of the modelling of horizontal and vertical habitat movement trends- something that was not done in this study, would allow a much better understanding of how the habitats actually respond to changes in sea-level and to the process of coastal squeeze. Errors inherent in the use of the GIS software and in performing simple calculations, though they did not significantly affect the results of this study, could well become a problem in case of more detailed or refined studies and would therefore need to be paid closer attention to. Also, assumptions about the behaviour of habitats behind the sea-wall remaining static, though useful in this study may not be representative of the ground reality. A final recommendation for improvement would be a more detailed and up to date representation of local sea-level rise scenarios for a given time slice, which would facilitate, for engineers and planners alike, the decision-making process with regard to the direction in which to steer coastal development for a given region.

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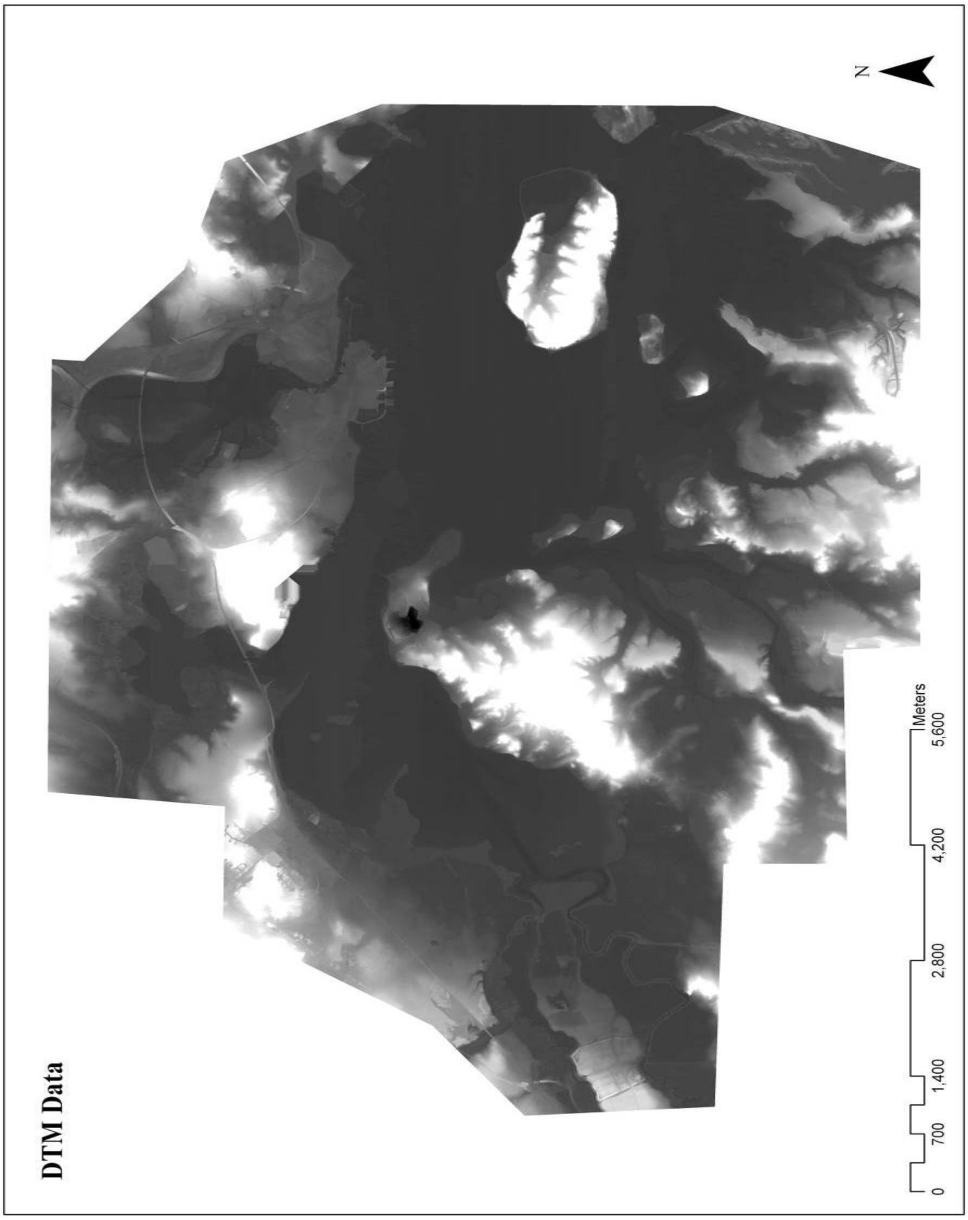
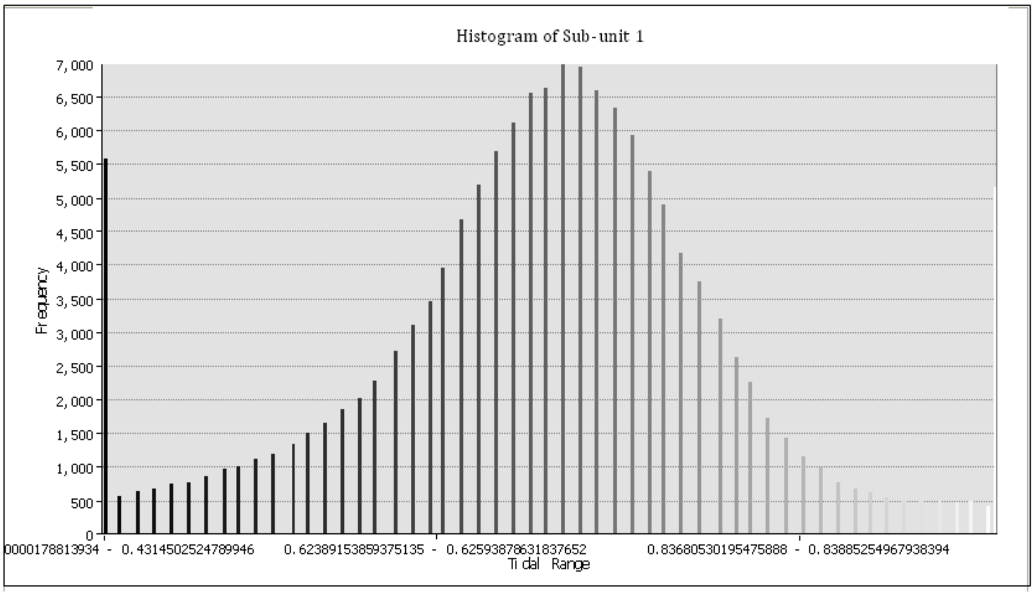
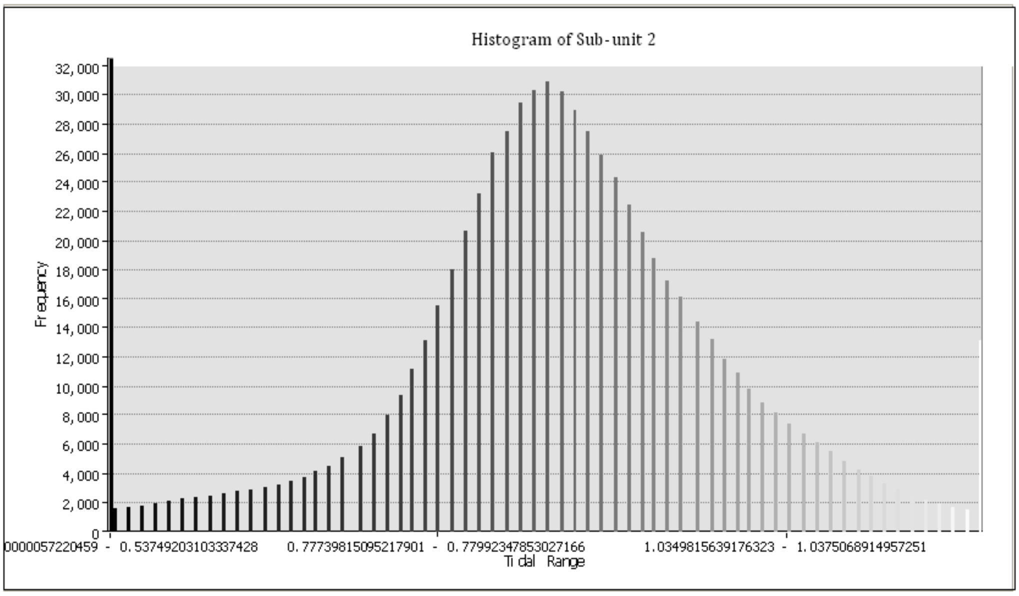
Sustainability, Coastal Erosion and Climate Change: An Environmental Justice Analysis

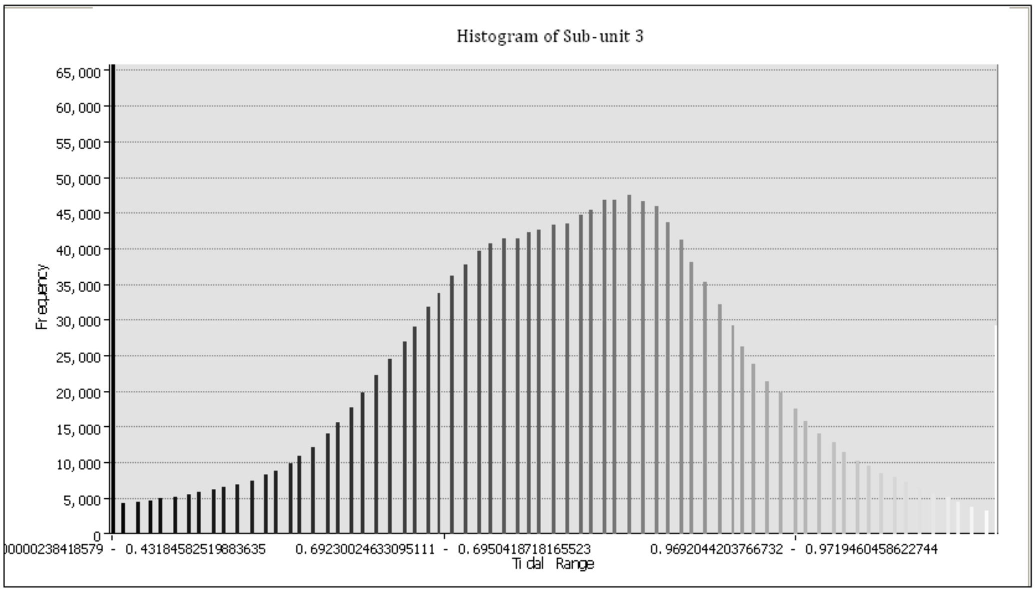
Appendix A1 Digital Terrain Model (DTM) obtained from LiDAR data



Appendix A2: Histogram of intertidal habitats distribution in each Sub-unit






Histogram of Sub-unit 3
Frequency
Tidal Range
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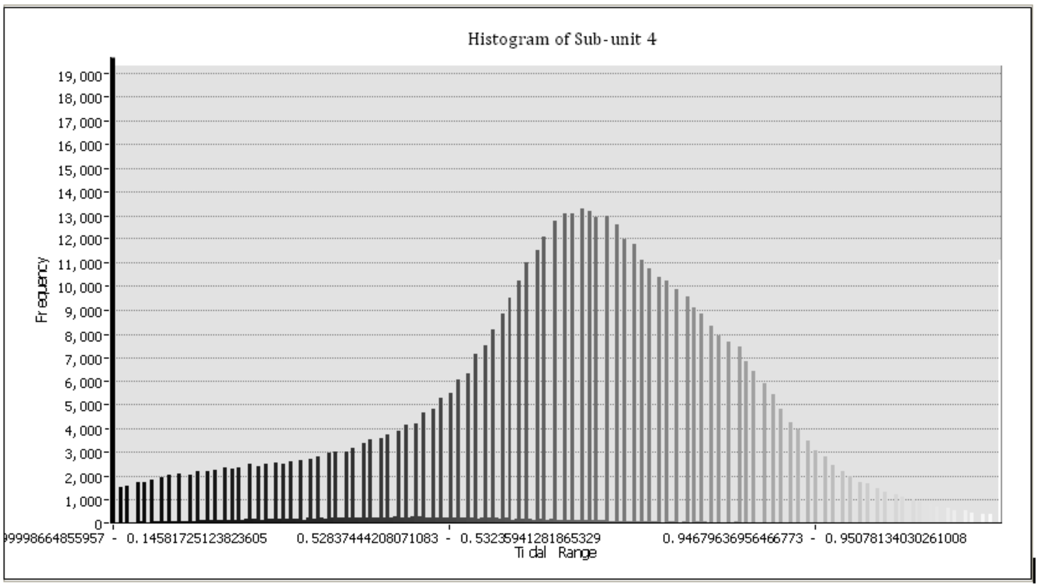
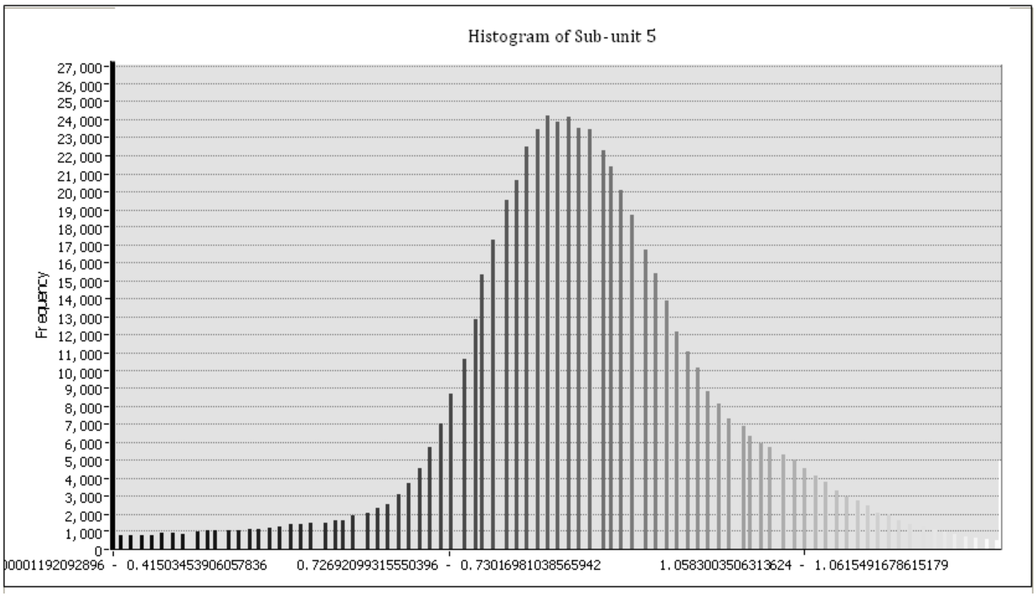
0.69230024633095111 - 0.6950418718165523
0.9692044203766732 - 0.9719460458622744


Histogram of Sub-unit 4
Frequency
Tidal Range
0.14581725123823605
0.52837444208071083 - 0.53235941281865329
0.94679636956466773 - 0.95078134030261008


Histogram of Sub-unit 5
Frequency
0.41503453906057836
0.72692099315550396 - 0.7301698103856594
1.0583003506313624 - 1.0615491678615179