4. Analysis

The coastal zones of the Channel-Southern North Sea region are of enormous variety and geomorphological interest on account of the wide range of geological exposures along its coastline. The geological history, including the impacts of mountain-building phases, have caused the rocks to be compressed, folded and faulted and, subsequently, they have then been subjected to the processes of weathering and erosion over millions of years. Later, the impacts of glaciation and changes in sea level have led to the evolution and shaping of the coastline as we know it today. Over the last two centuries geologists, geographers and archaeologists have provided evidence of coastal change, this includes records of lost villages, coastal structures such as lighthouses, fortifications and churches, as well as other important archaeological sites that may have been constructed thousands of years before. Some important historical assets have been lost or obscured through sea level rise or coastal erosion whilst, elsewhere, sea ports have been stranded from the coast following the accretion of extensive mudflats and saltmarshes. The Arch-Manche project has sought to advance our understanding of the scale and rate of long-term coastal change by maximising the use of currently under-used historical resources, including archaeology, palaeoenvironmental data, works of art, maps, photographs, as well as historical literature accounts. Information about the various data sources and the methodology can be found in Section 2 of this report.

This section presents the results of the analysis, demonstrating how information extracted from each of the datasets has been used to maximise the potential for understanding coastal change. Analysis has included work within each data source, such as direct comparison between paintings and modern coastal conditions, the use of sequences of maps and charts to determine change over time, the analysis of monitoring data gathered from archaeological sites, and the comparison of results from the programs of geophysical survey and coring to investigate submerged landscapes. These results were then used in combination to provide a multi-source detailed analysis of change in a range of locations across the Channel-Southern North Sea region.

4.1. Results

This section presents the initial ranking results for each of the data types across the whole project study area. This is followed by the analysis of the ranked data to demonstrate how it can provide information on coastal change. A ranking approach was used across the data sources in order to extract information on sites of highest potential to inform on coastal change, this helped target sites for more detailed investigation. It also demonstrated where sites or areas of the coast were represented within several of the available data sources. Detailed results of each case study area can be found in Section 3.

4.1.1. Archaeology, Heritage and Palaeoenvironmental Data

A total of 3150 archaeological and palaeoenvironmental sites were assessed across the partner case study areas. It should be noted that the distribution and number of sites depicted on the map does not mean there are more sites in any one partner country but reflects the size and number of case study areas and the amount of data available for the study. The table below lists the highest ranking sites, the locations are shown in Figure 4.1.

UID	SITE NAME	COUN TRY	CASE STUDY AREA	PERIOD	SITE TYPE	TOTAL SCORE	BROAD E'MENT
27	CROOKLETS BEACH - Prehistoric Remains	UK	North Cornwall/Devon	Prehistoric	Submerged landsurface	100	Marine
361	SAINT-MICHEL-EN-GREVE - Croix de Mi-Lieu	France	Leguer Estuary	Medieval	Monument	100	Intertidal
700	SAINT-MICHEL-EN-	France	Leguer Estuary	Roman	Other	100	Intertidal

	GREVE - Roman road						
1297	HOEDIC - Douet alignement	France	Quiberon Peninsula	Neolithic	Monument	100	Coastal
1298	HOEDIC - Groah Denn alignement	France	Quiberon Peninsula	Neolithic	Monument	100	Coastal
600	PITTS DEEP - Submerged Peat Deposits	UK	Solent/Isle of Wight	Prehistoric	Submerged landsurface	100	Marine
708	BULVERHYTHE - Submerged Forest	UK	Hastings	Prehistoric	Submerged landsurface	100	Marine
707	BOULDNOR - Submerged Mesolithic landscape	UK	Solent/Isle of Wight	Mesolithic	Submerged landsurface	100	Marine
713	LITTLE GALLEY HILL - Submerged Forest	UK	Hastings	Bronze Age	Submerged landsurface	100	Marine
457	LANNION - Petit Taureau	France	Leguer Estuary	Early Medieval	Marine installation	100	Intertidal
1074	SAINT-PIERRE-QUIBERON - Ile Guernic	France	Quiberon Peninsula	Neolithic	Other	100	Coastal
1163	SAINT-PIERRE-QUIBERON - Kerbourgnec	France	Quiberon Peninsula	Neolithic	Monument	100	Intertidal
1166	SAINT-PIERRE-QUIBERON - Petit Rohu	France	Quiberon Peninsula	Neolithic	Other	100	Intertidal
324	RUSSELLS LAKE - Prehistoric Forest	UK	Langstone Harbour	Prehistoric	Submerged landsurface	100	Marine
1213	QUIBERON - Beg er Vil	France	Quiberon Peninsula	Mesolithic	Other	100	Coastal
313	DOELPOLDER NOORD – buried landsurface	Belgium	Scheldepolders	Prehistoric	Buried lansurface	100	Coastal
2446	WAASLAND POLDERS – buried landsurface	Belgium	Scheldepolders	Prehistoric	Buried lansurface	100	Coastal
339	BAKERS RITHE - Prehistoric Forest	UK	Langstone Harbour	Prehistoric	Submerged landsurface	100	Marine
604	HURST SPIT - Hurst Castle	UK	Solent/Isle of Wight	Medieval	Coasal defense	100	Coastal
1491	HOEDIC - Sterflant	France	Quiberon Peninsula	Iron Age	Other	88	Coastal
1494	RAVERSIJDE - peat excavation	Belgium	Raversijde	Roman	Submerged landsurface	88	Intertidal
1285	ILE D'HOUAT - Ile aux chevaux	France	Quiberon Peninsula	Mesolithic	Other	88	Coastal
711	HASTINGS - Submerged Forest	UK	Hastings	Unknown	Submerged landsurface	88	Marine
686	TREBEURDEN - Enclosure	France	Leguer Estuary	Medieval	Other	88	Coastal
687	PLESTIN LES GREVES - Railway	France	Leguer Estuary	Inter-war	Monument	88	Coastal
716	PENNINGTON MARSHES - Peat	UK	Solent/Isle of Wight	Unknown	Submerged landsurface	88	Marine
717	PYLEWELL LAKE - Peat	UK	Solent/Isle of Wight	Unknown	Submerged landsurface	88	Coastal
718	RIVER YAR - Peat	UK	Solent/Isle of Wight	Unknown	Submerged landsurface	88	Marine
712	HAWKERS LAKE - Submerged Peat	UK	Solent/Isle of Wight	Unknown	Submerged landsurface	88	Marine
714	OXEY MARSH - Submerged Forest	UK	Solent/Isle of Wight	Unknown	Submerged landsurface	88	Marine
715	PEGWELL BAY - Submerged Forest	UK	Solent/Isle of Wight	Unknown	Submerged landsurface	88	Marine
719	TANNERS HARD - Submerged Forest	UK	Solent/Isle of Wight	Unknown	Submerged landsurface	88	Marine
1083	SAINT-PIERRE-QUIBERON - Groh-CollÃ©	France	Quiberon Peninsula	Neolithic	Other	88	Coastal

1161	QUIBERON - Port Haliguen fishtraps	France	Quiberon Peninsula	Bronze Age	Marine installation	88	Intertidal
1162	QUIBERON - Saint Julien fishtraps	France	Quiberon Peninsula	Bronze Age	Marine installation	88	Intertidal
1581	PAKEFIELD - Submerged Forest	UK	East Anglia	Palaeolithic	Submerged landsurface	88	Intertidal
2460	HASTINGS – significant prehistoric finds	UK	Hastings	Prehistoric (multi)	Other	88	Coastal
705	HURST CASTLE SPIT - Core Samples	UK	Solent/Isle of Wight	Prehistoric	Other	88	Marine

Table 4.1. Highest scoring archaeological and palaeoenvironmental sites from all partner case study areas.

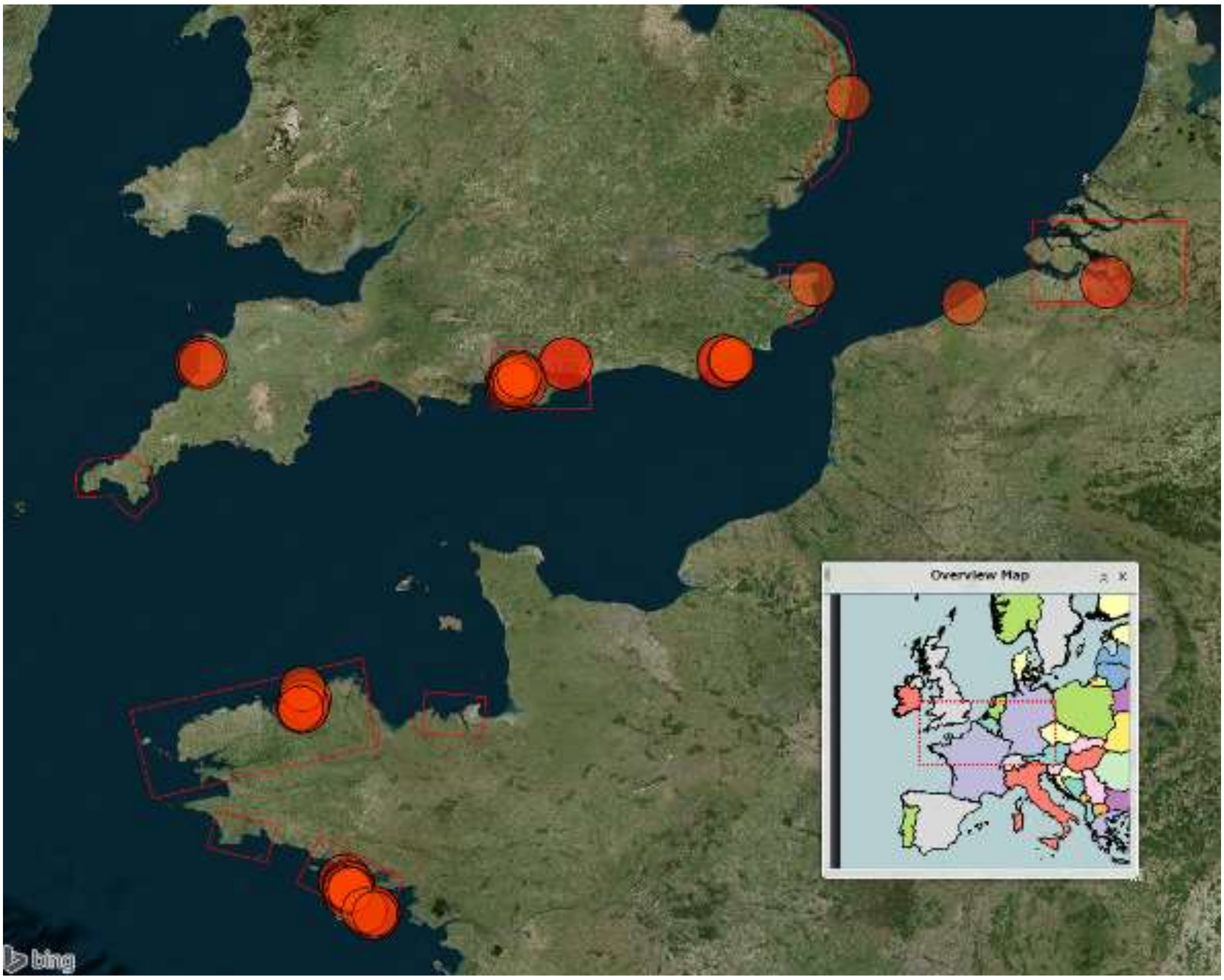


Figure 4.1. Map showing the location of the highest ranking archaeological/palaeoenvironmental sites assessed during the project.

The highest ranking sites range from the Mesolithic to modern times and are found both in the marine and intertidal zones as well as on the near shore coast. However, the majority of sites which ranked high are submerged landsurfaces. These are found in all partner countries and many contain long stratigraphical dated sequences that have been subject to detailed investigation. The ranking demonstrated that certain types of site and deposit can gain consistent positive scores for their potential to inform on coastal change. Five of the sites which ranked high: Bouldnor Cliff, Langstone Harbour, the Leguer Estuary, Raversijde and Scheldt polders, were all investigated further through detailed fieldwork, fieldwork techniques applied are outlined in Section 2 of this report.

4.1.2. Art Representations

The ranking system for the artworks has provided a shortlist of those artists who depicted the coastline in the most accurate way, and armed with this information we can examine these artist's works and make qualitative judgments about long-term coastal change. In some cases, where artists were known for their particular attention to detail, for example the works by the Pre-Raphaelite artists and their followers in England, it may be possible also to assess quantitative changes (e.g. the extent of cliff retreat or beach change), particularly where structures such as lighthouses, fortifications, coastal protections or other historical ruins are located close to the coastline. In addition, beach conditions can be assessed when the level of the beach is shown in historical images, for example, adjacent to structures such as piers, breakwaters and sea walls.

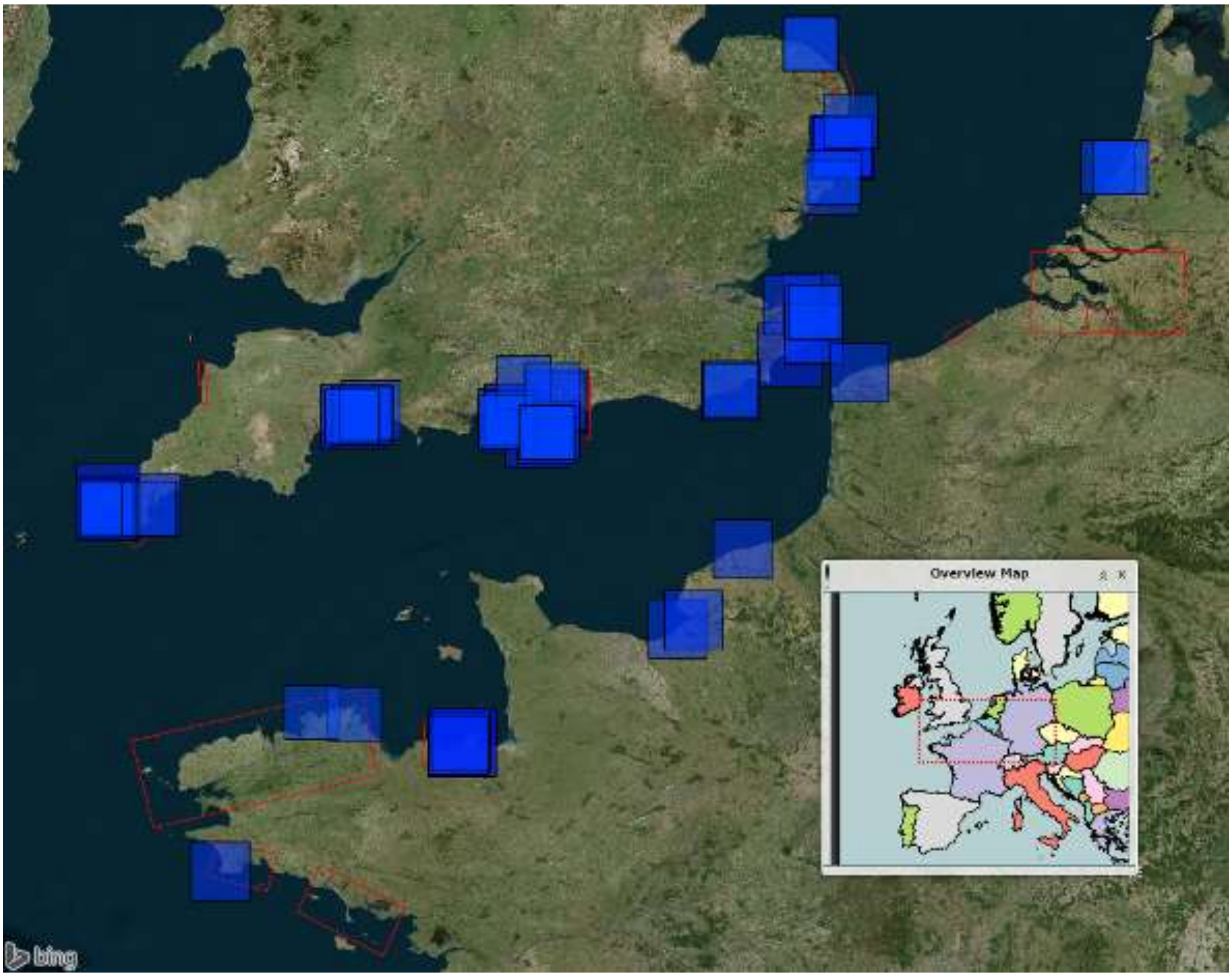


Figure 4.2. Map showing the location of the highest ranking artworks assessed during the project.

The table below provides a list of the highest ranking artists for each of the study areas, listing also the medium which the artist used most commonly and the typical scores that their works achieved. It should be noted that there were other artists who also painted these parts of the European coastline whose works lie outside the study areas.

East Anglia UK

Artist	Medium Used	Ranking Score
Alfred Robert Quinton	Watercolour	70
Walter Frederick Osborne	Oil Painting	70
John Moore of Ipswich	Oil Painting	66
Myles Birket Foster	Watercolour	62
Alfred Heaton Cooper	Watercolour	62
Edwin Hayes	Oil Painting	59
Thomas Smythe	Oil Painting	55
John Varley	Watercolour	55
William Daniell	Engraving	55

East Kent UK

Artist	Medium Used	Ranking Score
William Dyce	Oil Painting	62
Henry Pether	Oil Painting	55
William Daniell	Engraving	55

Hastings UK

Artist	Medium Used	Ranking Score
Alfred Robert Quinton	Watercolour	70
William H. Borrow	Oil Painting	59
Charles A. Graves	Oil Painting	59
Edwin Hayes	Oil Painting	51

Solent/Isle of Wight UK

Artist	Medium Used	Ranking Score
Charles Robertson	Watercolour	77
William Gray	Watercolour	44
William E. Atkins	Watercolour	70
Alfred Robert Quinton	Watercolour	70
William Westall	Engraving	62
Robert Brandard	Engraving	55
Clarkson Stanfield	Engraving	55
Henry Pether	Oil Painting	55
William Turner of Oxford	Watercolour	51

West Devon/East Dorset UK

Artist	Medium Used	Ranking Score
Arthur Perry	Watercolour	70
J. Baker	Engraving	66
W. Dawson	Engraving	66
Daniel Dunster	Engraving	66
Alfred Robert Quinton	Watercolour	62

West Cornwall UK

Artist	Medium Used	Ranking Score
Alfred Robert Quinton	Watercolour	70
John Brett	Oil Painting	62
John Mosford	Oil Painting	59
William Daniell	Engraving	55

Brittany France

Artist	Medium Used	Ranking Score
Eugène Isabey	O/WC/E	74
Paul Sébillot	WC/P/E	62
Theóphile Busnel	WC/P/E	62
Maxime Maufra	O	59
Duroy Bateau	WC/P/E	59
Alexandre Nozal	WC/P/E	59
Theodore Godin	O	55
Henry Riviere	WC/P/E	55
Emmanuel Lansyer	O	51
Gaston de Latiney	WC/P/E	51

Key

Watercolour	WC
Engraving/Etching	E
Oil Painting	O
Pencil	P

Table 4.2. Highest ranking artists from the case study areas.

4.1.3. Map Representations

A total of 101 maps from the partner counties were evaluated based on topographic, geometric and chronometric accuracy (Figure 4.3). These maps ranged from small to large scale and date from as early as the 16th Century. The ideal way to analyse coastal evolution through historical maps is by integration into a GIS (for instance ArcGIS or QuantumGIS) making it possible to georeference the maps and to make diachronical series' of coastal evolution based on the historical maps by digitizing the parts of interest in the form of points, lines or polygons. Hereafter, quantitative analysis on the observed changes is possible. Additional data, for instance physical data, artworks or historical photographs, can be integrated easily.

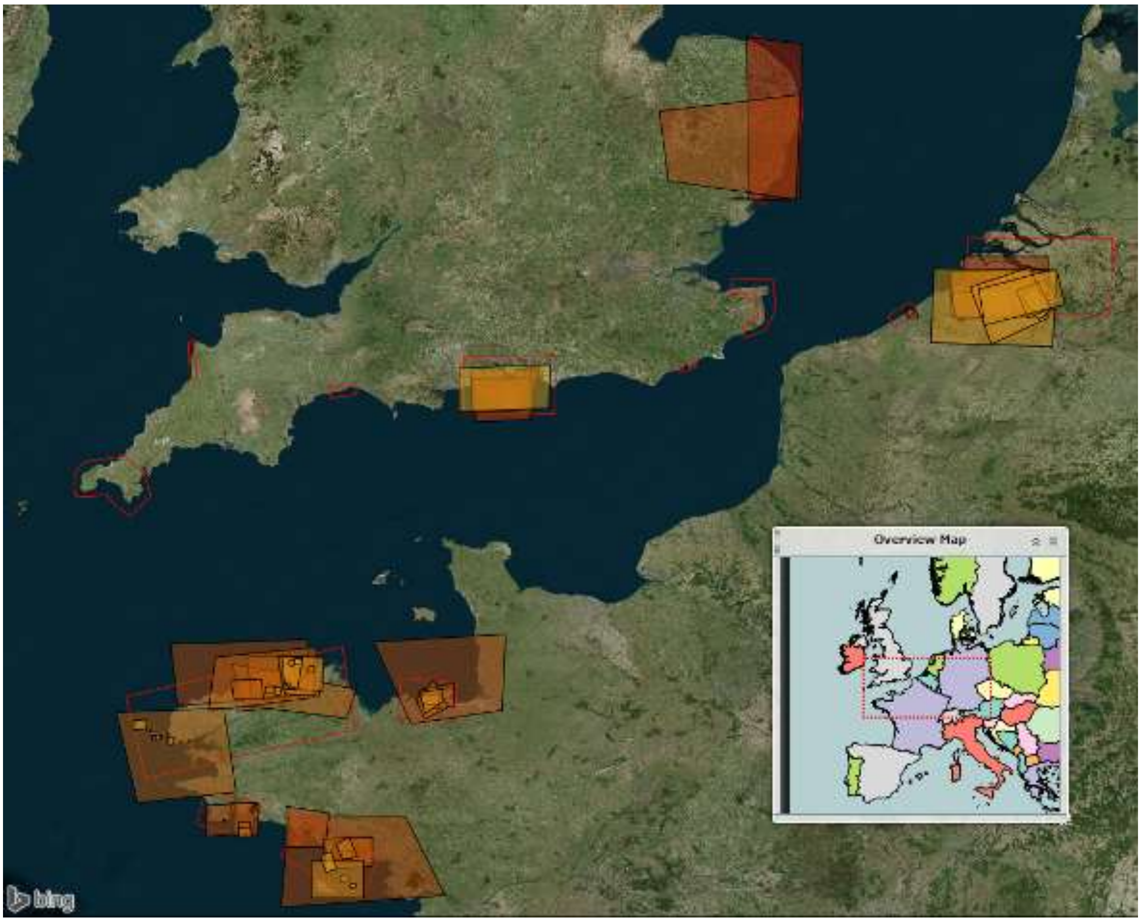


Figure 4.3. Location of historic maps assessed. The outline represents the area covered by the map, the colour reflects the ranking results – red is higher and yellow is lower.

In terms of topographical accuracy the maps varied widely, but many of them proved to be rich in detail. Key factors influencing the level of accuracy were the scale and purpose of the map. Key factors influencing the geometric accuracy were: the date of production with accuracy increasing through time, although some exeptions to this were found, the scale of the map with large scale maps being most useful for coastal research, and the reason the map/chart was produced impacting detail in particular areas. The chronometric accuracy varied largely due to the amount of detail available on the origin and date of the map or chart. While some included date of production, whether a copy or orignial or the measurements it was based on, others had little information on their origin or context.

MAP_uid	Title	Year	Case Study Area	Total Map Score
148	Hurst Spit to the Isle of Wight	1934	Solent/IOW	88.6
125	Kaart en meting van de schorren gelegen voor de polders van Nieuw-Arenberg en Kieldrecht	1816	Scheldt polders	87.5
89	Plan du terrain au dessus du moulin du Boschet	1756	Cote d'emeraude	87.5
144	A Plan of Hastings and St Leonards	1890	Hastings	85.83
146	England South Coast	1848	Langstone	83.3
141	OS map 1st edition	1880	East Anglia	81.6
123	Kaert Figuratif vande geprojecteerde Dyckague vanden Nieuwen Arenberg Polder	1783	Scheldt polders	80.8
107	Plan de Concarneau	1764	Cote d'emeraude	76.6
137	Hydrographical map of the river Scheldt	1892	Scheldt polders	75
98	Carte hydrographique, topographique et archaeologique du golfe du Morbihan et de son littoral	1869	Quiberon	75
124	Plan van de blicken ende schorren onder de jurisdictie van Kieldrecht	1783	Scheldt polders	75

Table 4.3. Highest ranking maps from across the partner countries.

Maps ranked highly across the case study areas, this highlights the potential of this resource, and the analysis of this for understanding coastal change is detailed below. The main focus has been on the Scheldt polders area, but the results of the ranking demonstrates the potential for further work on the other case study areas. The highest ranking maps are listed in Table 4.3 above. Although direct comparisons between the maps and the current situation can be made and are useful, the highest resolution data is available when a series of maps depicting the same area over several hundred years can be analysed, this has been achieved in the Scheldt polders study area, see Section 4.2.3 below.

4.1.4. Historic Photographs

A total of 1115 historic photographs and postcards were assessed as part of the project, the photos were ranked based on the potential they have to provide information on the changing coast. Photos were generally selected from areas along the coast where historic paintings and archaeological sites were also known. It should be noted that this study is not intended to be exhaustive, it simply aims to highlight the potential for historic photos to provide information on coastal change. Historic photos were mainly assessed in the UK and French case sudy areas, with some examples from the Dutch and Belgian coasts. Figure 4.4 shows the location of the highest ranking photographs.

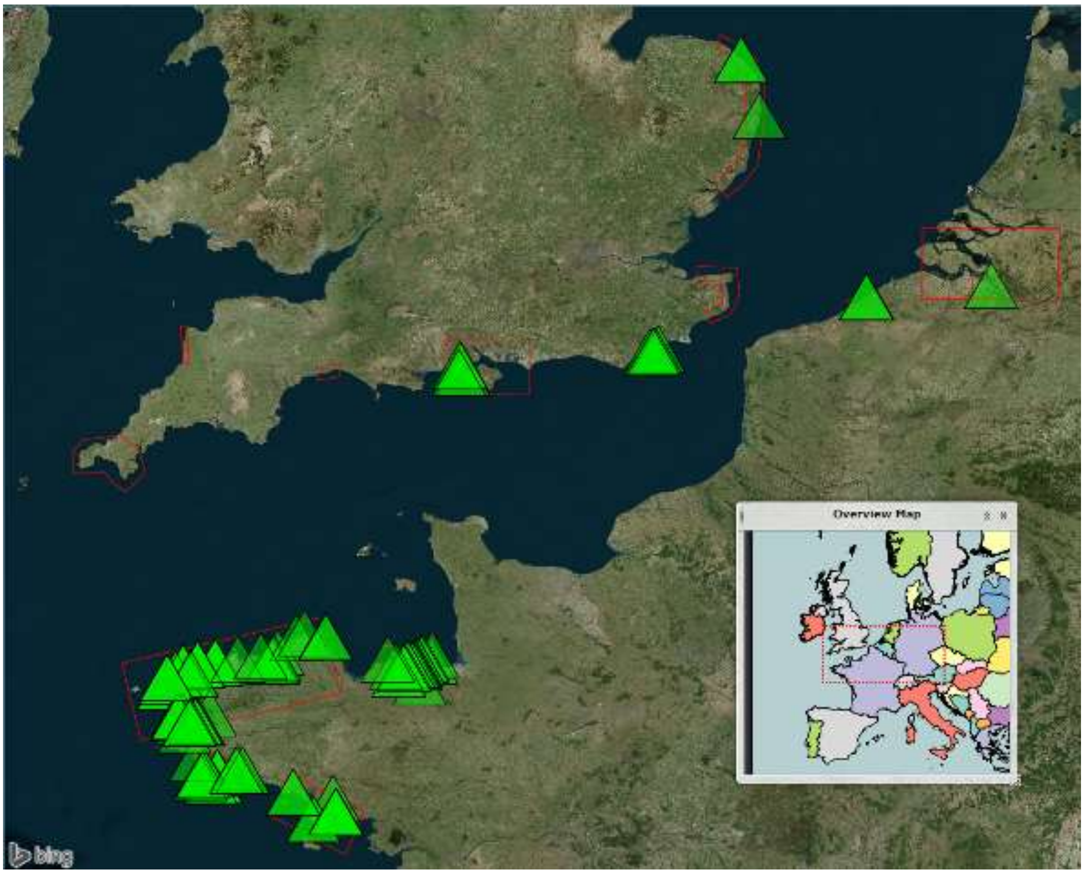


Figure 4.4. Location of the highest ranking historic photographs assessed.

Unlike the artworks, maps and charts, the historic photographs did not need to be assessed for their reliability. Photographic images capture detailed and objective views of the coast's composition, providing quantifiable representations that could be used for comparative analysis. The photographs were ranked based on their usefulness in supporting understanding of long term coastal change, this was primarily based on the subject matter.

Img_uid	Title	Year	Score Heritage View	Case Study Area	Physical Image State	Total Score
1200	Lymington River and the Solent	1952	High	Solent/IOW	Good	100
1201	Hurst Castle & Lighthouse	1953	High	Solent/IOW	Good	100
69	Yarmouth Harbour	1910	High	Solent/IOW	Good	100
998	Er Lannic	1920	High	Quiberon	Good	100
147	Men Ozac'h	1900	High	Northern Finistere/Tregor	Good	100
159	Allée couverte Kernic	1920	High	Northern Finistere/Tregor	Good	100
1198	Oostende - Kursaal	1899	High	Oostende/Raversijde	Good	100
1196	De molen van Doel	1900	High	Scheldt polder	Good	100

Table 4.4. Table of a selection of high ranking photographs from across the partner countries.

Many of the high ranking photographs in the French case study areas depict prehistoric monuments including passage graves and megaliths which are now partially or fully submerged. In the UK high ranking photographs include those that depict heritage features including castles and lighthouses. All of these can be compared to the present day situation, using the heritage feature to measure change against, they can also be compared to archaeological data where the environment in which the feature was constructed is known.

4.2. Measuring the Scale and Rate of Coastal Change

All those involved in coastal management have a requirement for high quality data and a thorough understanding of the physical processes at work around the Channel-Southern North Sea coastlines. An appreciation of the impacts of coastal evolution and processes is fundamental if we are to understand and manage our frontages in the most effective way. Long term coastal monitoring is increasingly recognised as an invaluable data source to support coastal risk management, as well as providing information to assist, for example, the design and construction of coastal defence measures, which can, as a result be commissioned with greater confidence in the efficiency of design.

Future requirements for coastal management can be established more accurately using monitoring data, which may change the risk management philosophy from a reactive to a more proactive one. However, for many parts of the coastline of the Channel-Southern North Sea, coastal monitoring is a relatively recent innovation with few stretches of the coastline having been monitored for longer than twenty years. The aim of Arch-Manche is, therefore, to raise awareness of the potential of these currently under-used tools (archaeology, palaeoenvironment, artworks, photography and cartography) to support our understanding, and to extend the time line of information back by hundreds and even thousands of years.

This section looks at how the data sources described above have been used to measure the scale and rate of coastal change and their relevance to coastal management. Detailed results and analysis can be found in the individual case study reports (Section 3).

4.2.1. Analysis of Archaeological and Palaeoenvironmental Data

As mentioned above over 3000 sites were assessed as part of the project and six sites were selected for detailed fieldwork and investigation. Information from these sites tells us about the scale and rate of coastal change in these areas across the Channel and Southern North Sea regions. Sites in the region from the Mesolithic period contain evidence of rapid sea level rise as thousands of kilometres of inhabited land were lost to the sea, current climate change models predict future increases in sea level, making inundated Mesolithic sites in particular, important case studies for coastal management. Archaeological research in such sites can also contribute new sea level index points, providing valuable information to improve existing climate change models.

Palaeoenvironmental data provides evidence of past landscapes from early prehistoric times through to the present. Analysis reveals evidence of the environment including plants, animals and insects, the types of soils, and whether it was dry, damp or wet, saline or brackish. Recording changes to these environments demonstrates the impact of rising or falling sea levels and relationships with coastal adaptations. Humans have used the coastal zone for thousands of years, the position of settlements shows the proximity to coastal areas, meanwhile specific features like trackways to cross marshy areas show adaptations to marine environments. Studying the archaeological record can demonstrate how humans adapted to change, and in more recent times, how they effected change. The sites targeted for detailed fieldwork are shown in Figure 4.5.

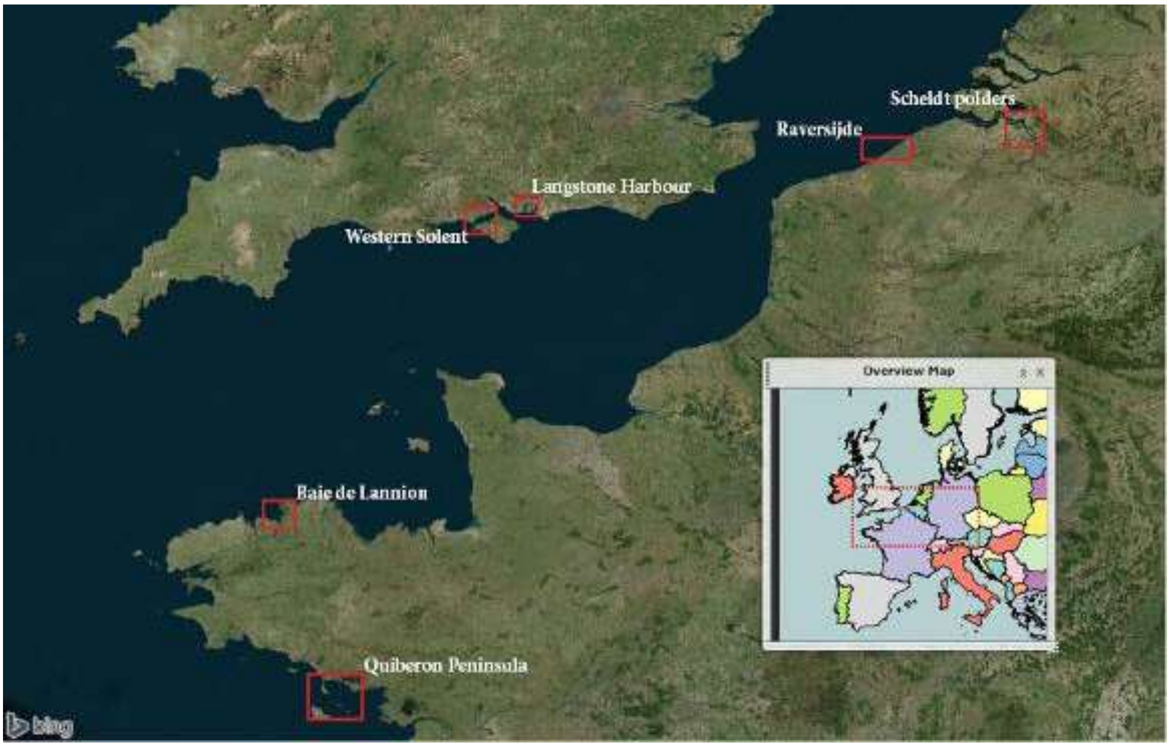


Figure 4.5. Location of fieldwork sites selected for detailed investigation.

The results of the analysis on a selection of these sites and what they can tell us about coastal change are detailed below. Full details can be found in the relevant case study reports.

Langstone Harbour

Langstone Harbour is a large, shallow marine inlet on the south coast of England that has a long archaeological record of occupation and use, stretching from the early Palaeolithic right through to the present day. The harbour is an eroded inland basin within which the islands at the northern end contain the remaining in-situ archaeological deposits, now threatened by coastal erosion. See case study report 3D for more detailed information. At the case study site of Langstone Harbour data from archaeological surveys has been used to model the evolution of the harbour from the Mesolithic to modern times.

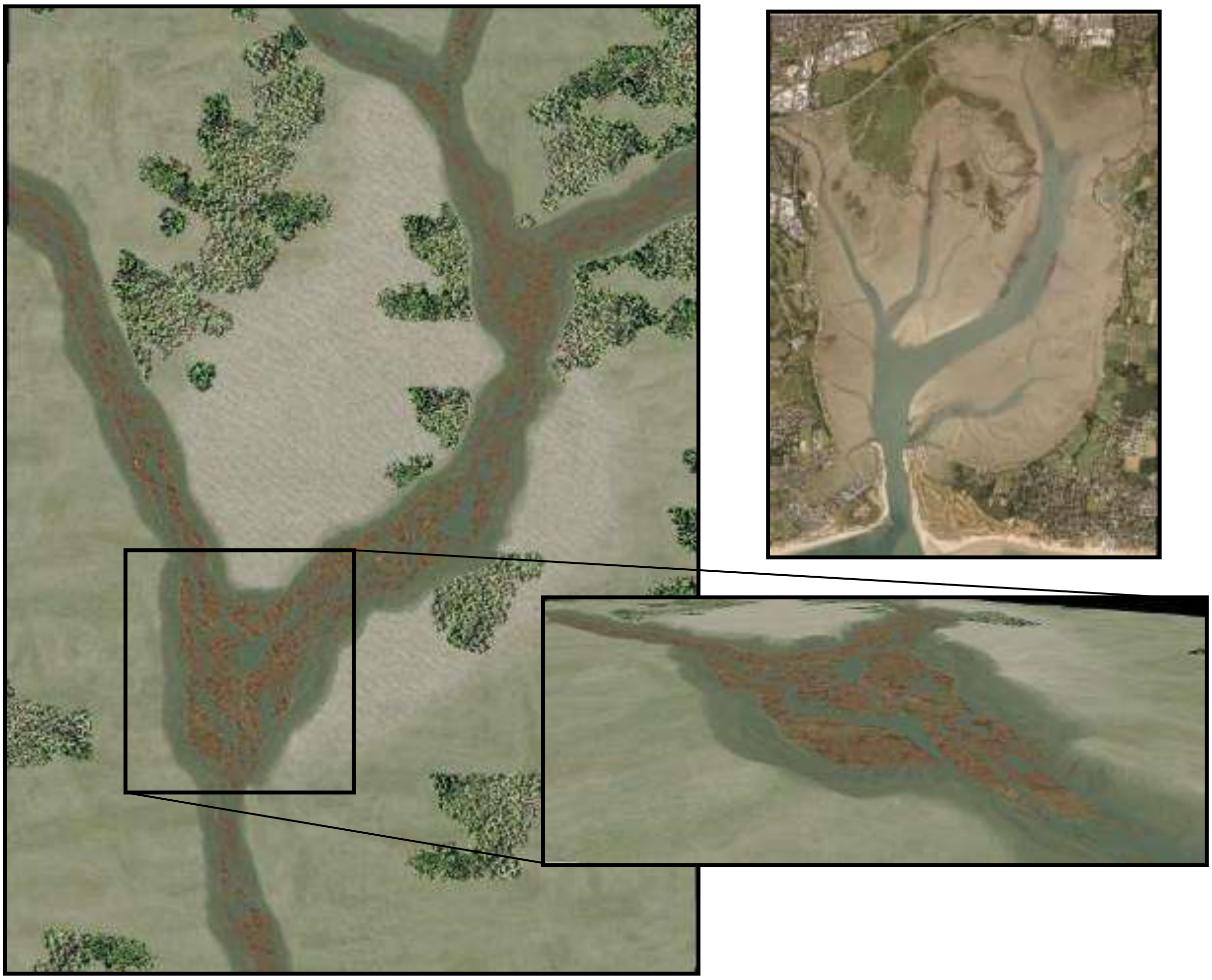


Figure 4.6. Reconstruction of Langstone Harbour during the Mesolithic period, above right: Langstone Harbour in 2013, aerial photography courtesy of the CCO. .

In the Mesolithic period Langstone Harbour was an inland site, the landscape was dominated by a valley with steep sides leading down to fresh water streams. The two deep ravines were up to 150m wide in places and the area now forming the harbour was some 14m above the ravine floors (Allen & Gardiner, 2000:203). Environmental data demonstrates that the land above the ravines was a rich and diverse landscape consisting of a mixed forest attractive to human populations, this is further reinforced through the array of flint tools found across the harbour. By the Neolithic the valley became in-filled with organic material giving it a more shallow gentle profile and by the Bronze Age the area developed towards a stronger marine environment made up of salt marsh and tidal rivers. A small rise in sea level during the Iron Age made the area much wetter and the now, almost non-existent valley was flooded.

The project has built on the work carried out in the 1990's as part of the Langstone Harbour Project (Allen & Gardiner, 2000). Fieldwork in 2012 and 2013 focussed on augering off the islands in the north of the harbour and a marine geophysical survey to track the buried palaeochannels. A seismic profile in the main Langstone Channel shows a large buried palaeochannel which may be evidence of the deep ravine from the Mesolithic period.

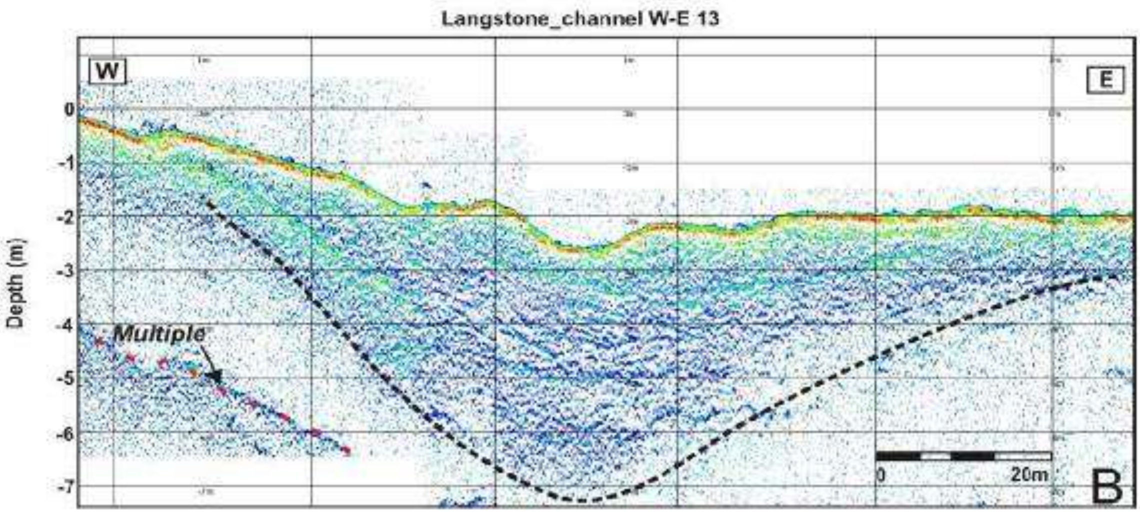


Figure 4.7. Seismic profile in Langstone Channel showing a large buried palaeochannel.

Shallow palaeochannels in the area of the Bakers Rithe and Russels Lake submerged forests were also tracked. Bakers Rithe submerged forest was dated to 2310-1950 Cal BC and Russels Lake dates from 3350-2910 Cal BC (Allen & Gardiner, 2000:89-90). By this time the earlier ravines had become infilled and were much shallower, this is demonstrated by the large palaeochannels found during the seismic survey, these had a shallower and more gentle profile.

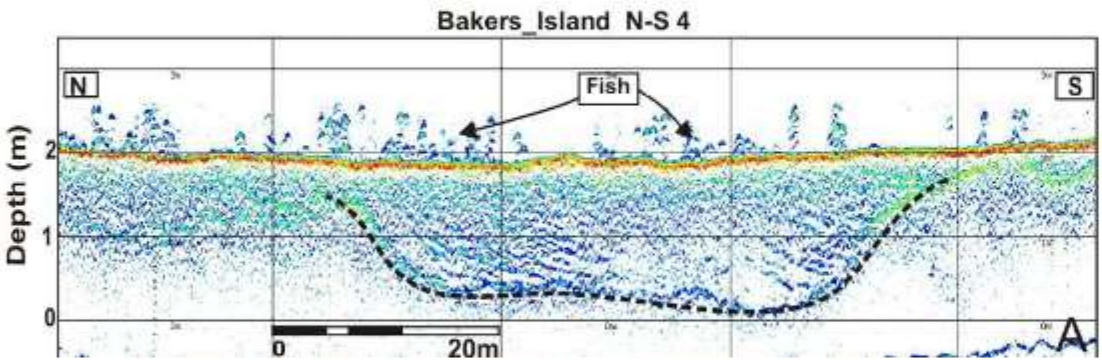


Figure 4.8. Seismic profile showing a large buried palaeochannel (black dashed line) in the area of the submerged forests.

Combining this data has facilitated the creation of a 3D reconstruction of the harbour from the Mesolithic to the current day. The timescale can be changed by the user so it is possible to see how the harbour evolved, adding a fourth dimension. The model can be viewed through the Arch-Manche portal www.archmanche-geoportal.eu

Lannion

Archaeological fieldwork was carried out on fish traps along the Léguer estuary in the Bay of Lannion (see case study report 3I for full details). The focus of the fieldwork was on the Petit Taureau fish trap which represents several phases of development. This area of the coast is subject to intensive erosion, accelerated by sudden climatic events such as storms. As well as this the area is at risk from human activities including marine aggregate and sand extraction.

The fish traps can provide important information on past coastal and sea level change, the level at which they are built provides precise indications of the local sea level as they are built at a very specific height in order to work, the fish trap dam stops being efficient when it is no longer accessible at low tide. Many older fish traps are now completely submerged in the mouth of the estuary, with time they were progressively built upstream. As well as rising sea levels affecting the efficiency of the traps, they are also impacted by changing sediment levels as they trap the sediment, raising the level of the seabed and again causing the trap to become less efficient.

Fieldwork on the Petit Taureau fish trap revealed four phases of construction, the earliest phase dates to the 7th Century AD and the latest stage dates to the 15th Century AD. The evidence demonstrates that the fish trap needed to be re-built several times, and it is thought this is due to the impact of the trap on sediment flow, as people had to continually modify the shape of the trap with the changing environment.

Fish traps can therefore not only be used as sea level indicators but can also provide information on how such structures impact the sediment regime, both of which are useful for coastal managers. Later work on this site has also been used to look at more recent changes in sediment levels, aerial photographs of the site from 1952 only show one of the construction phases, by 2000 all are visible (Figure 4.9).

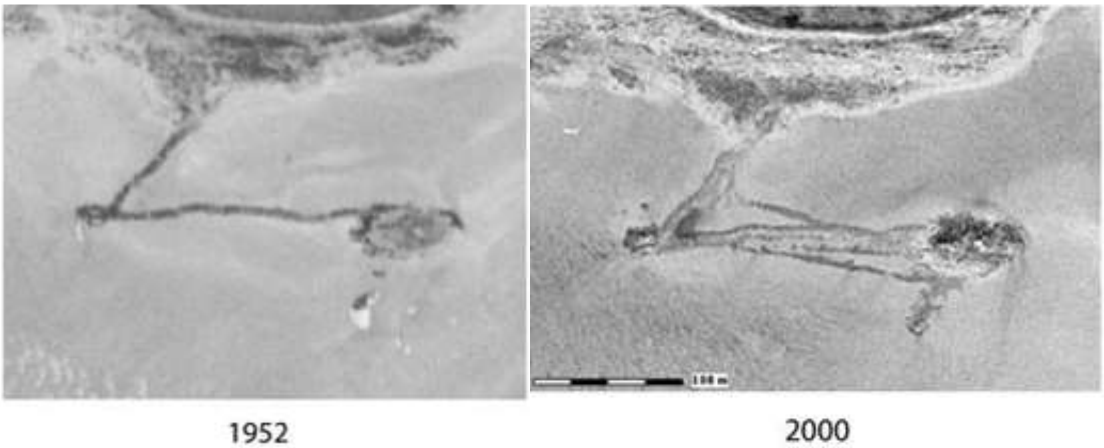


Figure 4.9. Comparison of 1952 and 2000 aerial photography demonstrating the changing sediment levels on the Petit Taureau fish trap (after IGN – Geoportail).

Studying and dating a large number of fish traps will provide further sea level index points and can be used to reconstruct the changing sea level and sediment dynamics along the coast. Many sites like this have been used to provide accurate data in the creation of local sea level curves and more recently they can provide information on the impact of sand extraction on the local environment, as shown in Figure 4.9.

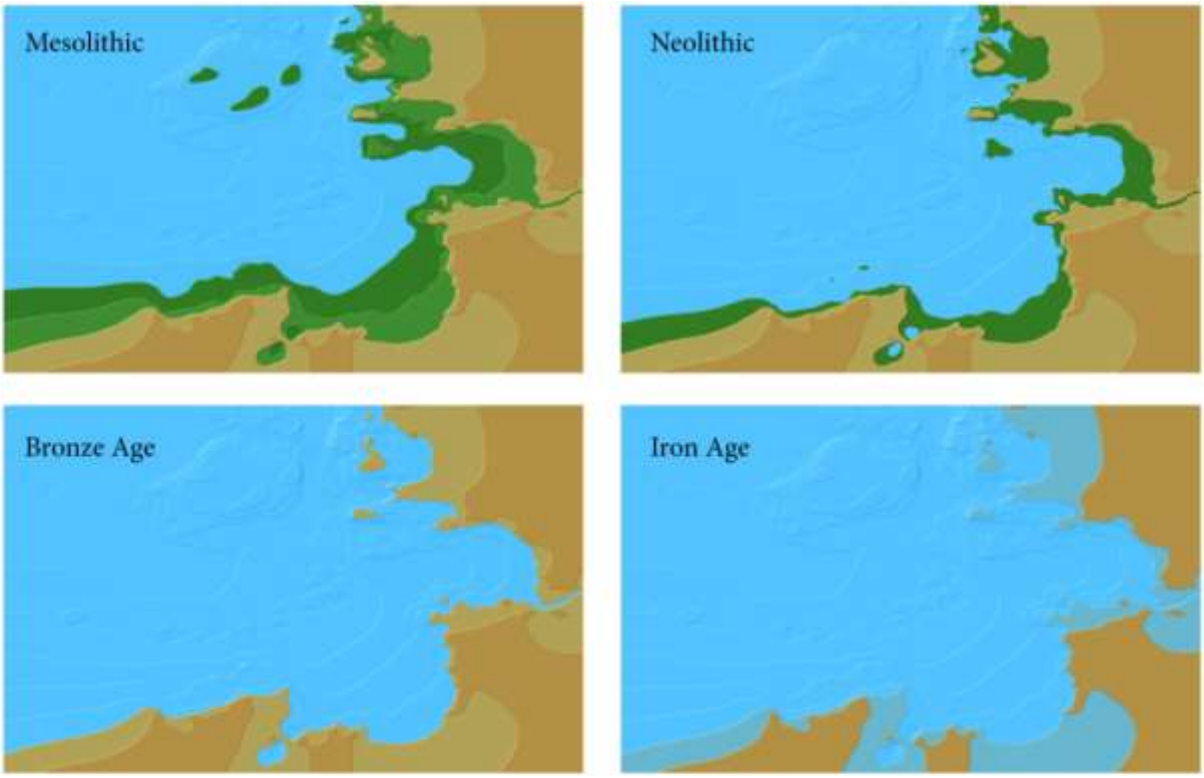


Figure 4.10. The changing coast of the Bay of Lannion from the Mesolithic to the Iron Age.

Data from this area has also been used to create a 3D model of the changing landscape from the Mesolithic to the Iron Age (Figure 4.10), the model is available through the Arch-Manche portal www.archmanche-geoportal.eu.

Scheldt Polders

The Scheldt polders case study was chosen due to its potential to provide data for palaeogeographical landscape reconstruction. It is an area where interactions between nature and humans are intensely intertwined and is a valuable example of how environmental change affects human life, but also the capability of humans to sculpt a landscape. Much of the area is under imminent threat from harbour extensions and de-embankment. See case study 3M for full details.

In the Scheldt polder samples extracted through coring have been used to gather data on past landscapes. Both existing and new samples were analysed to record changes in sediment types with depth. Sediments contain archaeological and climatic details of the surrounding environment at the time they were laid down. As the layers built up this created a sequential record of events. This data allowed the progressive development of archaeological landscapes to be reconstructed. The presence and absence of silt and peat layers showed the relationship between natural inundations and those instigated by humans.

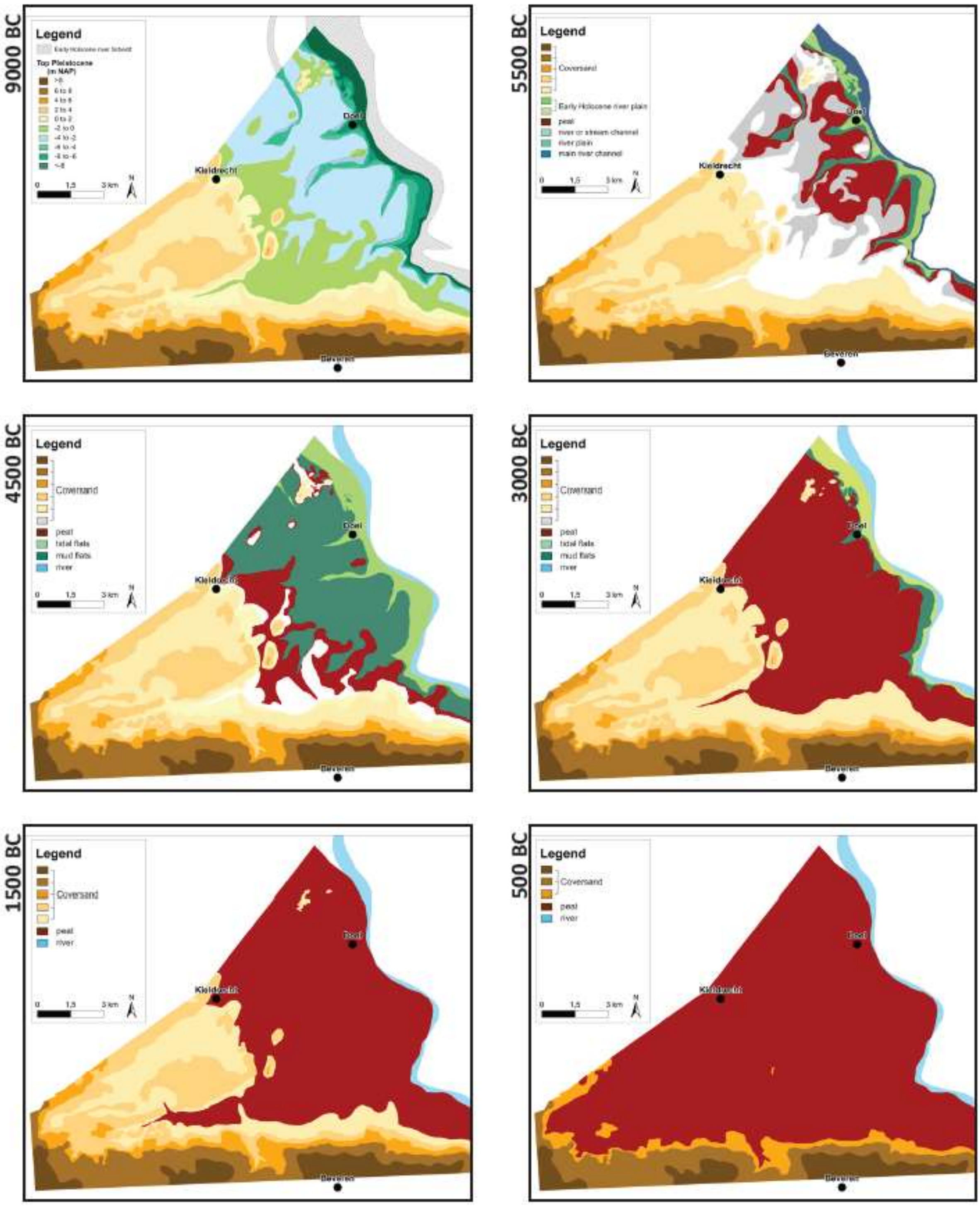


Figure 4.11. Series of palaeogeographical maps of the Waasland Scheldt poders from 9000BC to 500BC (courtesy K.Heirman, UGent).

This data allowed a series of palaeogeographical maps from 9000 BC to 500 BC to be created (Figure 4.11), these 2D reconstructions demonstrate how the landscape evolved over time, this is then complemented by later work reconstructing the landscape in the Post Medieval period based on historic maps, see below (section 4.2.3).

Southwestern Netherlands

Two sites were studied in detail in the Southwestern Netherlands. At the Verguide Hand West site data from large-scale archaeological excavations from the Middle Bronze Age to the Middle Ages is brought together with geological research in order to reconstruct past palaeoenvironments. The history of this landscape is intrinsically linked to human occupation and activity. Due to the extensive geological, palaeoenvironmental and archaeological research the landscape and occupation history can be reconstructed in detail. The landscape history has been visualised in a series of local palaeogeography maps from 1600 BC to 1050 AD and in profile reconstructions from 550 BC to 2000 AD. Full details are available in case study report 3N.

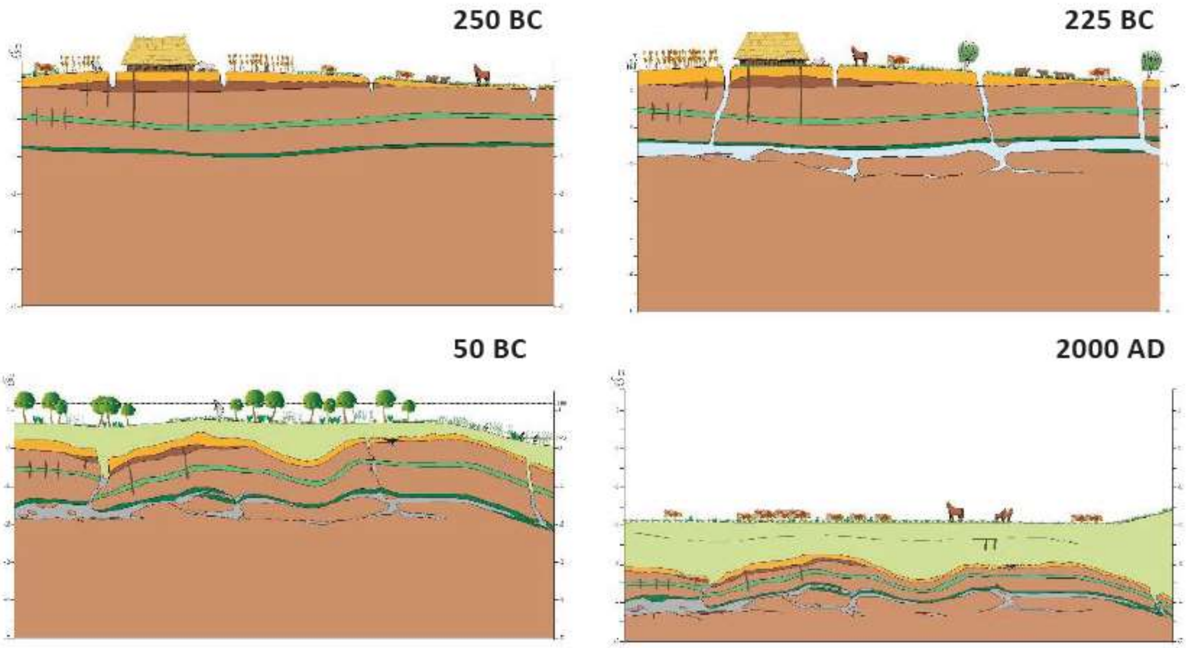


Figure 4.12. 2D profile reconstructions from the site of vergulde Hand West (courtesy Vos, P.C. & Y. Eijskoot, 2009. Geo- en archeologisch onderzoek bij de opgravingen van de Vergulde Hand West (VHW) in Vlaardingen. Deltares-rapport, 0912-0245, 160 pp.).

Data from the Yangtze Harbour site in the Netherlands has been used to develop models of the Mesolithic landscape which had been drowned and buried below current seabed levels. In addition to modelling the landscape form, data from palaeoenvironmental work and archaeological analysis was used to generate illustrative presentations of the past landscape. The area was mostly a dry river plain around 9000 BC, by 7250 BC large parts of the area became wetland and over time the habitable areas became much smaller, the landscape was then rapidly drowned around 6500 BC.

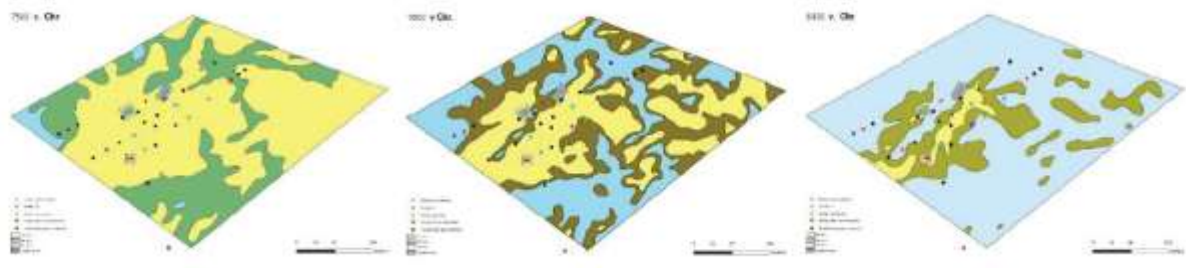


Figure 4.13.2D plan view reconstructions of Yangtze Harbour (courtesy P.Vos, 2013, Deltares).

The Southwestern Netherlands is also a valuable case study site in assessing the impact of human influence on coastal change, particularly during the Roman period. Tidal channels through coastal barriers were used to drain the high peat areas in the hinterland. The drained peat areas became habitable and the peat was also extracted on a large scale. However, because of the lowering of the surface major parts of the peat areas were flooded and the tidal channels increased in size eroding the peat near the tidal outlets. By about 270 AD a self-reinforcing process of peat erosion, lowering of the surface, increase in tidal storage capacity and expansion of tidal channels came into being causing the Roman peat excavation areas to be completely submerged by 350 AD such that habitation and peat excavation in those areas had become impossible. The process of drowning of peat areas continued there until about 800 AD when almost the whole of Zeeland was flooded.

4.2.2. Analysis of Artworks

The popularity of the seaside particularly during the nineteenth and early-twentieth centuries, has meant that there is excellent coverage of many parts of the Channel - Southern North Sea coastline. This includes both original paintings and watercolour drawings but also kinds of engravings, many of which were included in illustrated topographical and travel books and guides. The same artists would often return to the spot many times to re-paint or update a particular view as the coast changed and expanded over that time period. Where one is confident of the accuracy of the artist, it is, therefore, useful to examine a sequence of their work or to group artists' works together to help increase understanding of a particular location.

Desk studies and fieldwork at the case study sites have sought to use data from the historical images to illustrate those aspects of coastal change that are of particular importance to the wide range of scientists, managers and stakeholders with an interest in coastal risk management. The following section provides some examples of how such historical images can be examined and interpreted, explaining the information that they provide. These include examples of hard cliffs, coastal cliff instability, soft cliffs, beaches, low-lying coastlines and locations where art can illustrate understanding of environmental change. Furthermore, some artworks suggest no significant change since they were painted, when compared with the present day situation. This does not of course mean that there have not been fluctuations in, for example, beach levels over the intervening period, but the overall situation would suggest a status quo over the time period concerned.

The analysis of a selection of artworks is presented below, for more details see the case study reports in Section 3.

Hard Cliffs – Saint-Matthieu, France, *cap abbaye et phare*

The engraving by Félix Benoist (Figure 4.14) shows the ancient (Pre-Cambrian) hard rock coastline at the western tip of the Brittany peninsula near the port of Brest. The cliffs have been subjected to aggressive marine erosion and weathering over the last 150 years and some changes to the cliff can be observed today (see areas hatched in red). Such images may also depict development and environmental changes that have taken place over the intervening period. As might be expected such durable coastlines remain similar in appearance to that portrayed by the artist in the nineteenth century.

Figure 4.14. Engraving by Félix Benoist of the Brittany Peninsula, compared with a photograph from 2013 (after Motte, 2013).

Coastal Cliff Instability – Ventnor, Isle of Wight, UK

Artworks can also be used in areas of coastal cliff instability, this has been particularly useful at Ventnor on the Isle of Wight. Ventnor undercliff is a 12km long coastal cliff and landslide complex between Luccombe and Blackgang on the south coast of the Isle of Wight. The Undercliff is regarded as one of the most unstable developed geological settings in the UK; the complex cliffs are formed from weak rocks that are sensitive to the effects of toe erosion and groundwater. There is concern that increases in relative sea level and winter rainfall will result in accelerated ground movement rates and more frequent landslide events over the next 100 years.

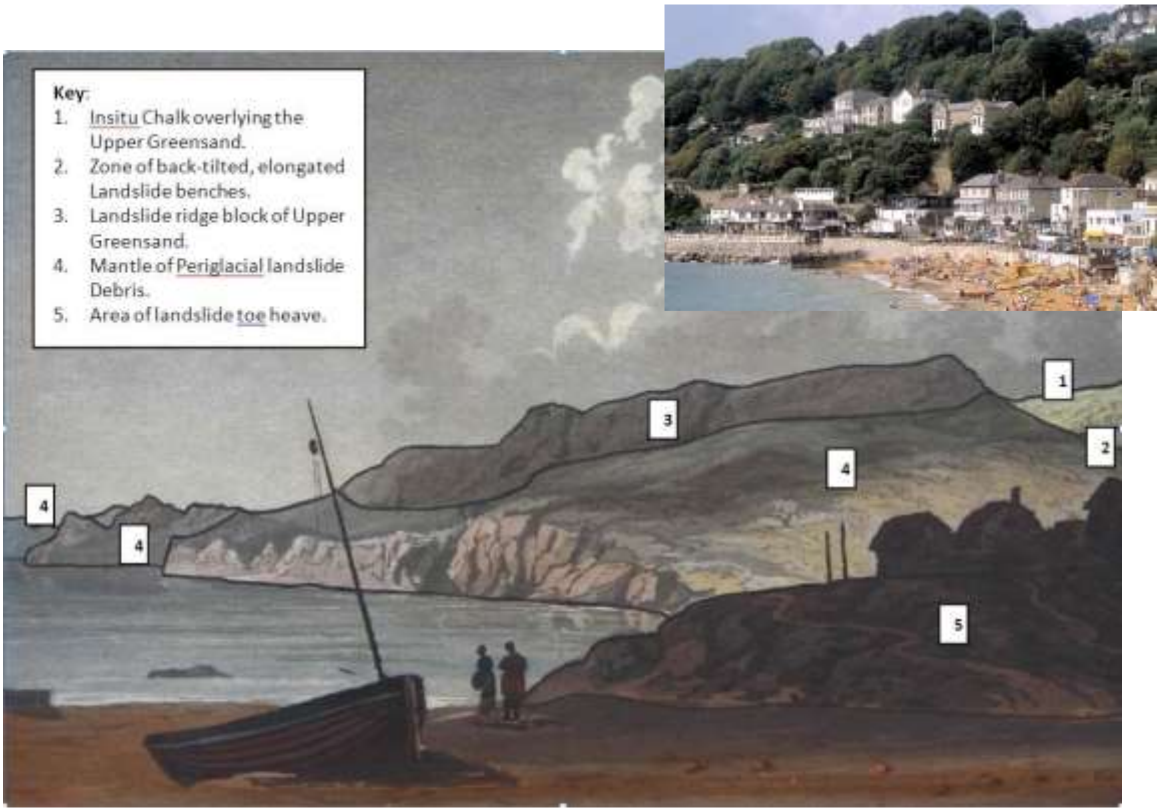


Figure 4.15. Ventnor Cove' by Charles Raye. 1825. The geomorphology of the seaward face of the Undercliff landslide complex is clearly visible compared with the present day view. Image courtesy R.McInnes.

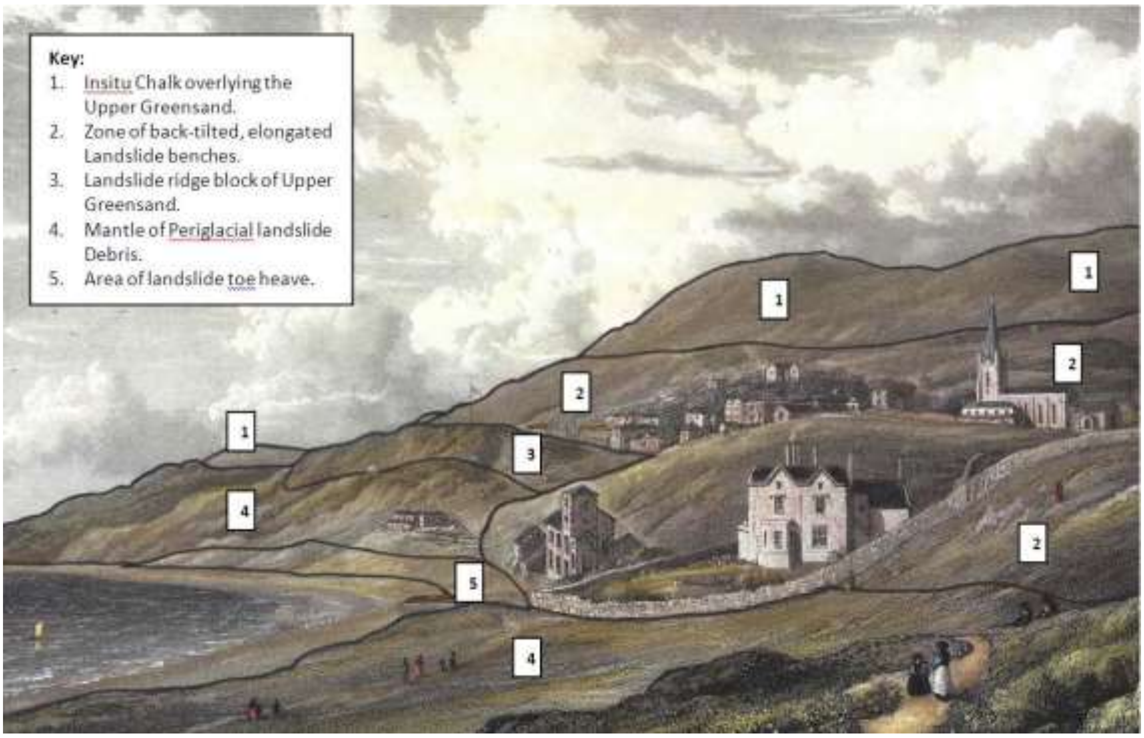


Figure 4.16. A view of the same location by William Westall is rather more extensive and even more detailed. Victorian and Edwardian development over the coastal slopes and planting and spread of the Holm Oak in the early 20th century now masks the geomorphology. Image courtesy R.McInnes.

Figure 4.17. 'Ventnor Beach' by Rock & Co. 1863. The view shows a rock formation seaward of the existing sea cliff. The rocks illustrated in this engraving, which have long since been lost to erosion, identified a former cliff line further seaward. Image courtesy R.McInnes.

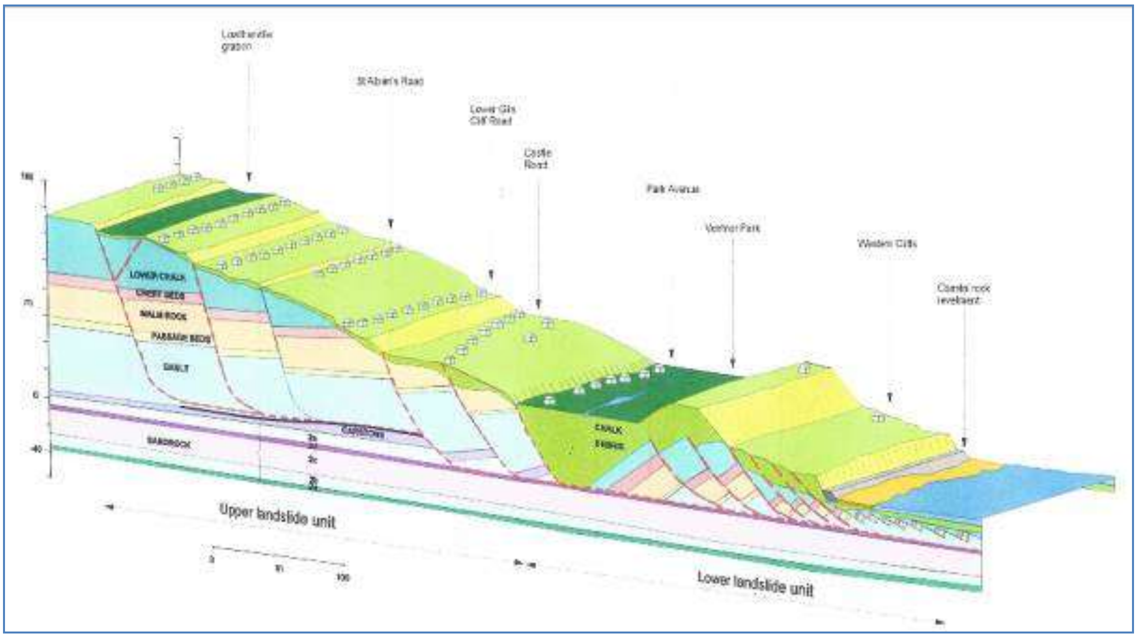


Figure 4.18. The rocks depicted in the engraving by Rock & Co have long since been lost through erosion, they identified a former cliffline further seaward and helped to develop this landslide model for the Undercliff (courtesy of Halcrow, 2006).

In recent years research has sought to understand more about the formation and development of the Undercliff landslide complex in order to support effective planning and risk management. A fundamental need was to understand how the landslide complex was formed and its extent seawards.

The paintings studied show the town of Ventnor before the coastal frontage was extensively developed from the 1830s onwards, allowing some of the main components of the landslide complex to be identified, as well as providing information on the former cliff line further seawards.

Beach Change – Saint-Malo, France, *Le grand Bé à mare basse*

Artworks have also been used to assess changes in beach levels, the example below is from Saint-Malo in France.

Figure 4.19. Painting of the Isalnd of Grand Bé at St Malo c1850, compared with a photograph from 2013 (after Motte, 2013).

Eugéne Isabey (1803-1886) produced numerous accurate paintings in oils along the Channel coasts of Brittany and Normandy. Her view, painted in about 1850, shows the Island of Grand Bé at St Malo at Low Tide. The present day view suggests that this beach has accreted significantly over time. Natural vegetation growth has also taken place on the island itself. The Bay of St Malo is exposed to significant storm surges with waves often overtopping the defences, so beach fluctuations can be expected. However, the painting of Isabey and the present day view confirm the healthy condition of the beach.

Low-Lying Coastlines – Brading, Isle of Wight, UK

William Daniell RA produced numerous aquatint engravings of the British coast between 1814 and 1825; he is regarded as one of the finest early topographical artists. His engraving of '*Brading, Isle of Wight'* (1823) is a good example of how artworks can be used for low-lying coastlines. The engraving was made before the harbour was reclaimed for agricultural use. A road and railway link was provided across the harbour together with a tidal embankment in the 1930s. The present day view is taken closer to the sea. The East Yar river has been channelised and development has taken place at Bembridge (on the right). Artworks of this kind can record not just physical changes but also human intervention, which may result also in environmental change (Image courtesy: Wight Light Gallery).

Figure 4.20. 'Brading, Isle of Wight' (1823) by William Daniell RA. Image courtesy Robin McInnes

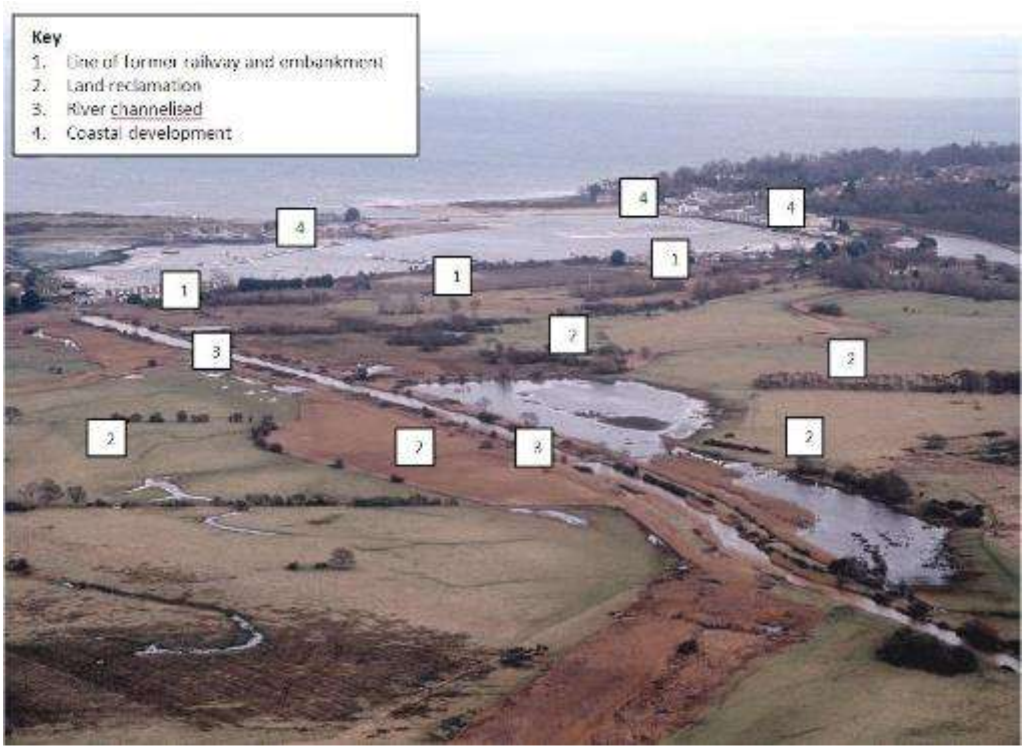


Figure 4.21. Present day view showing how the River Yar has been channelised and development has taken place at Bembridge (on the right). Image courtesy Wight Light Gallery.

4.2.2.1 Qualitative and Quantitative Assessments of Coastal Change

It has been demonstrated clearly through the case study examples how art can be used as a qualitative tool to support understanding of long-term coastal change. Also, however, where images are painted by high ranking artists, which include structures such as buildings or coast protection works (seawalls or groynes) it may be possible to measure or compare coastal change over time.

Figure 4.22. (above): Sidestrand Church Tower, Norfolk by Charles Frederick Rump shows the close proximity of the structure to the cliff edge (Image Courtesy: Sheringham Museum).

Figure 4.23. (above right): A photograph of the tower even closer to the cliff edge. If the height of the structure is known an assessment can be made from paintings and photographs of the distance to the cliff edge (photograph courtesy of N. Storey).

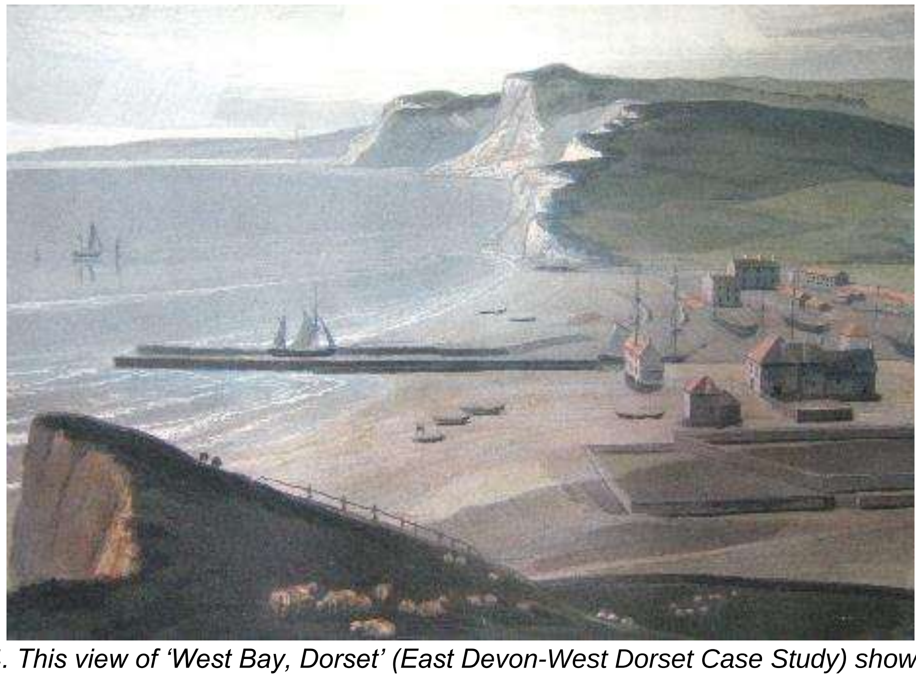
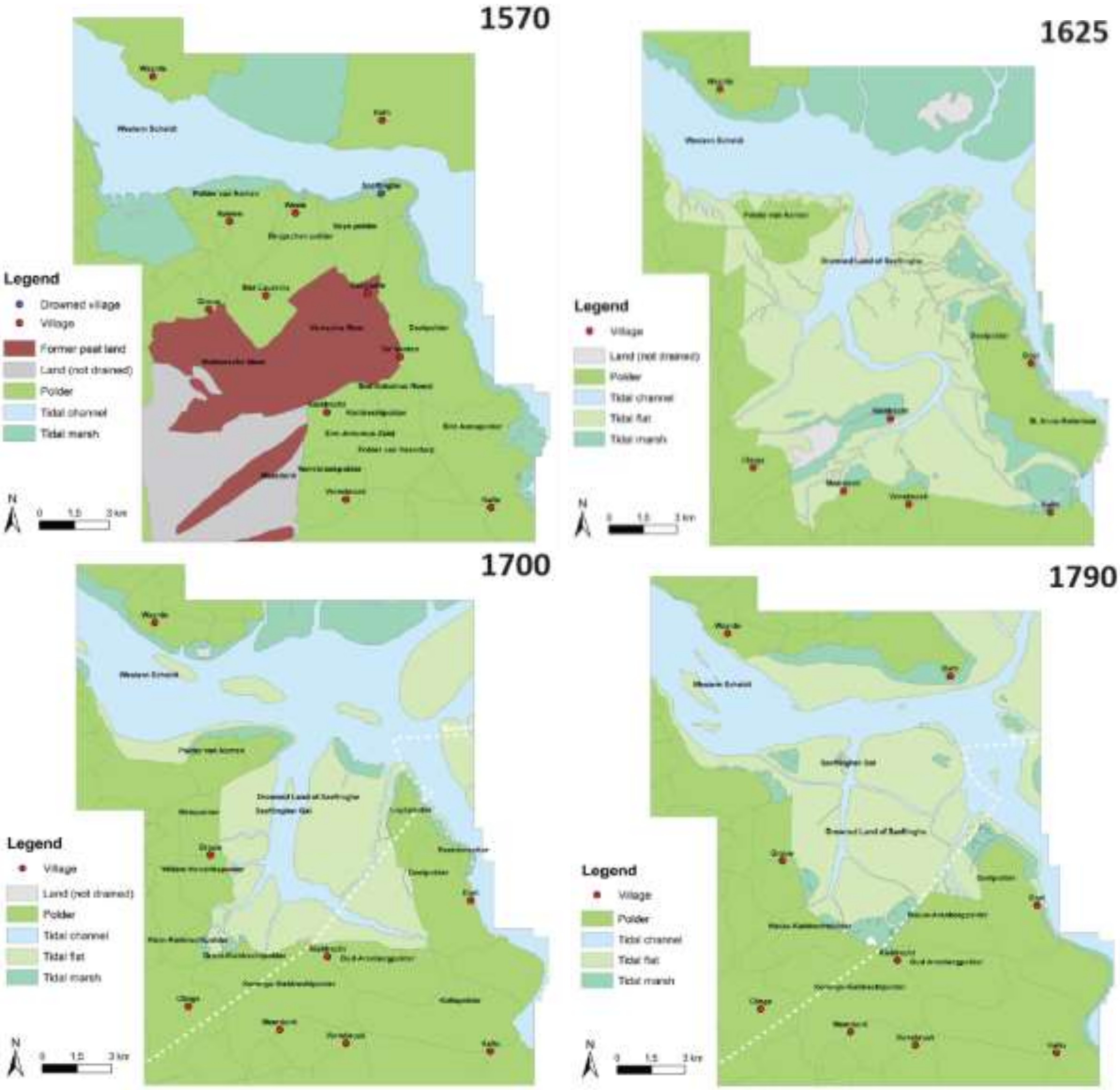


Figure 4.24. This view of 'West Bay, Dorset' (East Devon-West Dorset Case Study) shows the extent of the beach on either side of the harbour arms in 1824/25. By comparing the length of the arms with historic maps the position of the beach can be plotted. William Daniell produced 308 accurate aquatint views covering the whole of the British coast between 1814-25. Image courtesy R.McInnes.

4.2.3. Analysis of Maps and Charts

Maps and charts provide an important source of information from the Middle Ages onwards. Through time there is a rapid rise in the quantity of available maps and charts. However, the quality and detail varies widely between different maps, therefore it is important to analyse maps prior to interpretation. The most significnt study of maps and charts has been within Belgium and the Netherlands, the results are presented below along with some examples from the UK and France.

The Waasland polders Post Medieval landscape was reconstructed using historical maps. The highest ranking maps were selected for GIS-rectification and digitization. As a result, in five reconstruction maps the landscape evolution from 1570 (just prior to the inundations) to 1850 is shown.



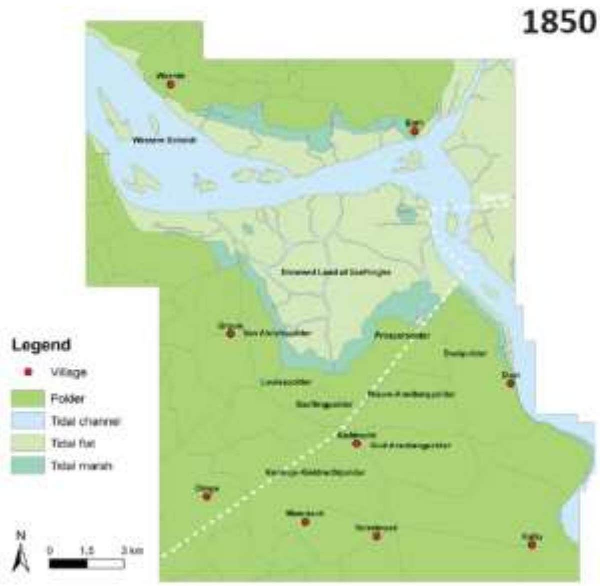


Figure 4.25. Reconstruction of the Waasland polders post-medieval landscape using historical maps from 1570 to 1850 (courtesy I.Jongepier, UGent).

The analysis of the maps has shown that almost the entire study area was embanked by 1570, by 1625 we see extensive tidal marsh formed after the inundations (from the Eight years' War) with a large tidal channel crossing the entire area. In 1700 the eastern course of the channel changed, this was probably of anthropic origin in order to facilitate future tactical inundations. By 1790 the area witnesses' new embankments converting the former higher tidal marsh to embankments, sedimentation has also allowed the tidal marsh to be heightened. The tidal marsh decreased further by 1850 as a result of further embankments. Full details are available in case study report 3M.

Similarly, in the UK, historic maps were used to assess the rate of saltmarsh and mudflat erosion in the north west Solent. The highest ranking maps from the area were georeferenced and the limit of the saltmarsh digitised. This allowed us to see the rate of change from 1781 to the present day.

This analysis has helped us to understand the rate of change in this area. Over a period of 153 years from the date of the first map (1781) to the second map (1934), the area witnesses around 500m regression of the saltmarsh. Over the next 57 years this is between 200-400m, then dramatically in just 22 years the saltmarsh erodes by up to 500m in places. The rate of erosion has dramatically increased in the last 100 years. The specific cause of saltmarsh regression is currently little understood and these maps cannot provide an answer, but they can provide high resolutuin detail on the rate and scale of change from the 18th century.

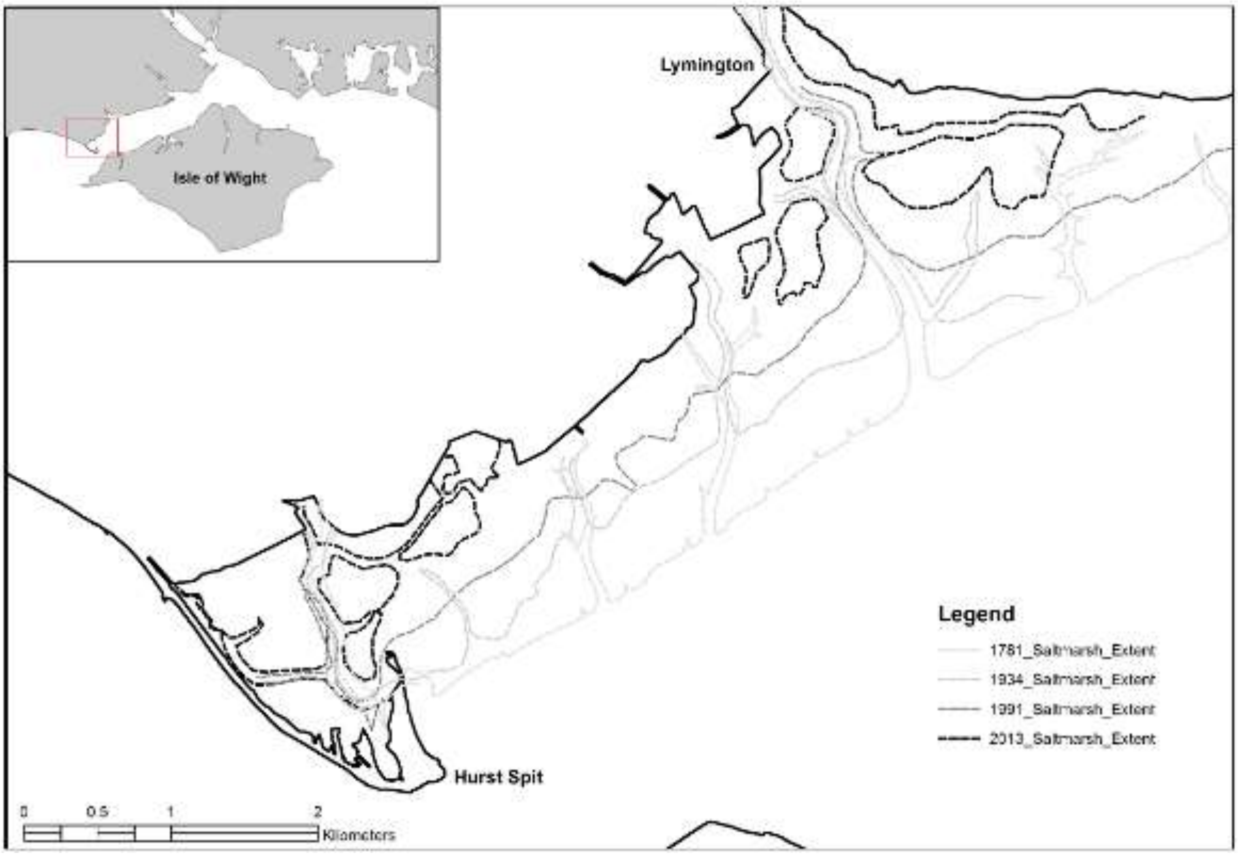


Figure 4.26. Saltmarsh and mudflat regression in the north west Solent from 1781, 1934, 1991 and 2013 based on the analysis of historic maps.

The examples above highlight the potential of historic maps for landscape reconstruction. Several maps were scored in the other case study areas and further work is required in order to georeference these and create corresponding evolution maps of all partner case study areas. This has been done at a smaller scale in some areas, see individual reports for details. Maps have also been combined with the other data sources in the Langstone Harbour case study area, this has resulted in the creation of a 3D evolution model of the harbour from the Mesolithic to present day. See section 4.2.5 below.

4.2.4. Analysis of Historic Photos

The introduction of photography as a means of depicting the coastline first commenced in the 1840s but only became more widely used in the late 1850s. Later, photographic postcards also became popular following the introduction of the first postcard in Austria in 1869. The use of photographs and photographic postcards, and their potential to assist the understanding of coastal change, has been explained through the French and UK case study examples. Below is a selection of sites where historic photographs have proved to be valuable tools in understanding past changes to the coast.

The Men Ozac’h monument is located in a large flat sandy bay, in the estuary of the “Aber Wrac’h” river, which is a geomorphologial feature typical of this area, called the “Aber Coast”. This coasts belongs to the “Low Shelf of Léon” formation (northern Finistère), comprising deep indentations and bordered by numerous island and islets; the rocky parts alternate with large sandy beaches. The tide range in this part of Brittany (c. 8 metres) exposes large areas of seabed to enlarge the territory during low tide. As shown within the photographs, the small islands can be reached on foot during low tide.

This area is subject to intensive coastal erosion, due to several factors:

- its geographical location, facing the west and exposed to the main storms;

- the effects of the tide and waves on the soft rock formations;
- the buildings (ports, quays) which can modify local sedimentation processes and retain sand.

Figure 4.27. Views of the tidal Men Ozac'h standing stone (menhir), Plouguerneau (Finistère) (photos by A; Devoir, early 20th century) © Labo Archéosciences UMR 6566 CReAAH.

Among the available pictures of the site, number one was selected for ranking as it appeared to be the most informative due to the view showing the landscape around the standing stone and because the person standing next to the 'menhir' provides a "scale" for the monument. The ranking score achieved was high at 77. Despite the very high quality of palaeoenvironmental indications, the ranking score is not maximum due to the fact that menhir (standing stones) monuments are difficult to date with precision, as they are known to have been constructed from the Neolithic to Bronze Age period.

Photograph number two shows the monument at high tide and number three details the presence of attached seaweed. Both images provide historic evidence for the position of the 'menhir' which is regularly (twice a day) submerged by sea water. The original view (glass photographic supports and positive papers) are part of the collection of the Laboratoire Archéosciences (Rennes University).

In the UK many historical photographs are now available through online collections. Images from the 'Britain from Above' have been used to look at changes in sediment levels and salt marsh erosion. The images below are from Hurst Spit and Lymington Harbour in the western Solent.

Figure 4.28. Hurst Spit in 1953 (left) and 2013 (right).

Hurst Spit is a cuspate shingle foreland dominating and protecting the entrance to the western Solent. This feature is best known to most for the presence of Hurst Castle. The castle is a national historic monument and tourism asset situated at the tip of the spit. Its survival depends on the future stability of the spit yet, by its very nature, the spit is an evolving coastal beach-form capable of dispersal or migration.

For observers of shoreline behaviour, the spit is of particular importance because of the natural protection it has long provided for the sheltered coasts and habitats of the western Solent seaway. The spit is an ephemeral coastal feature that is capable of changing its form and shifting its position. It is now known that its entire development must lie within the past 8,000 years. Some perceptible shifts in the configuration of the spit are evident in recent history and can be seen through historic photographs. Below is an aerial photograph from 1953 obtained through the Britain from Above Project. This is presented next to a current view of the area.

Comparison of these images shows the extent of the sediment erosion on the spit, the sea now reaches the walls of Hurst Castle. However, further north at the old jetty by the lighthouse the accretion of shingle around the jetty made this no longer usable by boats.

Loss of intertidal mudflats and saltmarsh at the entrance of Lymington Harbour can also be seen through historic photos. Below is an aerial view from 1952 compared to a view from 2013.

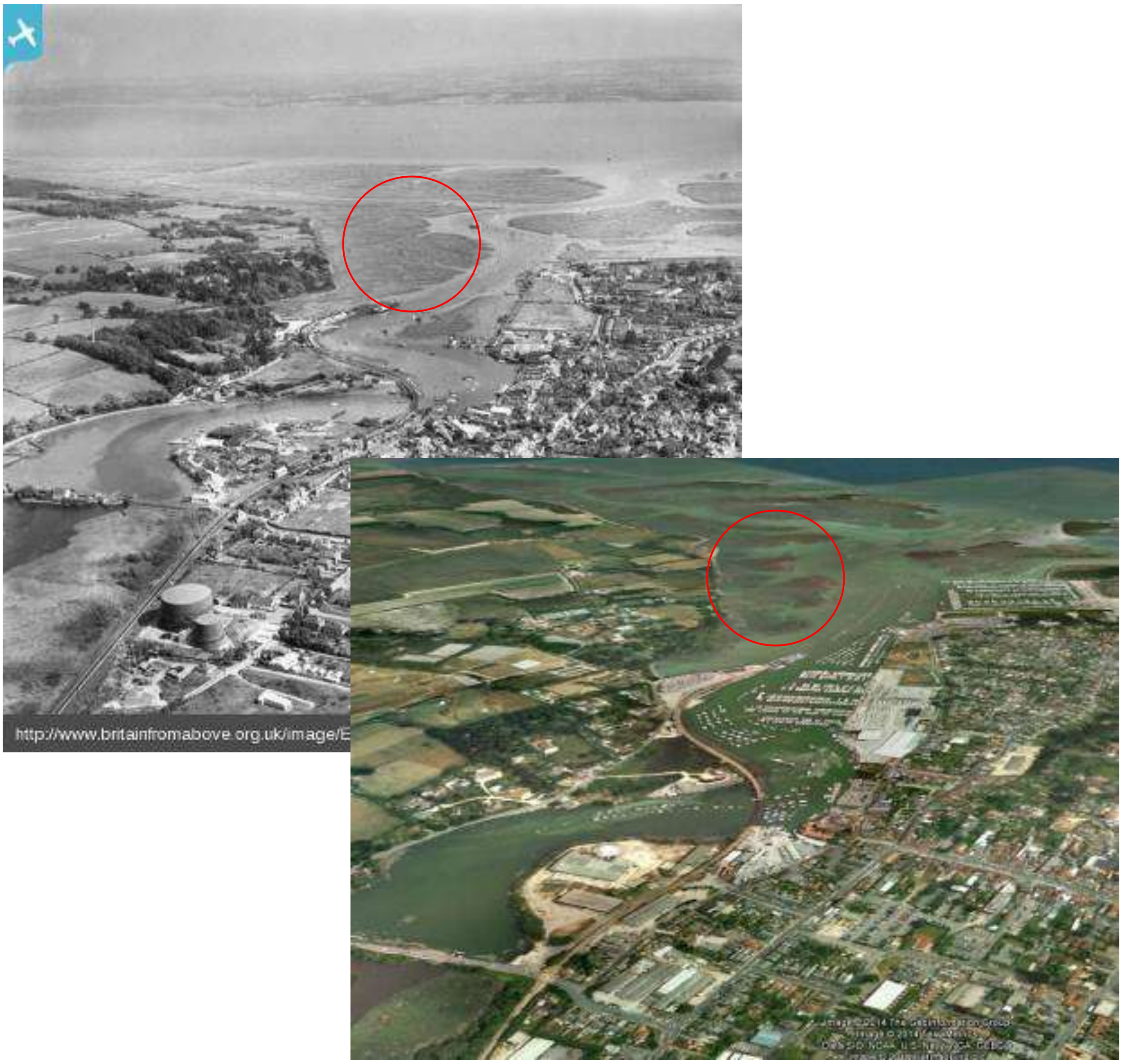


Figure 4.29. Lymington Harbour in 1952 (left) and 2013 (right). The red circle marks the most notable changes in the saltmarsh.

The specific cause of saltmarsh loss is little understood. A combination of factors including wave action, lack of sediment supply, dieback of vegetation, tidal currents and sea level rise are all thought to influence the erosion of the saltmarsh (NFDC, 2014). The use of historic resources such as these images may not provide the answer as to the specific causes of erosion, but can provide high resolution data on the rate and scale of erosion since at least the 1950's. Combining this with historical maps, charts and archaeological and palaeoenvironmental data will provide a long term perspective on the rate and scale of change to help with management in the future.

4.2.5. Combined Resources

The Arch-Manche project combined the various data sources outlined above to extract maximum amounts of information that provide details on long-term coastal change. This section presents a selection of sites that have been studied using a combination of the data sources and demonstrates how this can advance our understanding of the scale and rate of long term coastal change, realising the potential of these previously under-used data sources.

The 3D model of Langstone Harbour was primarily created using archaeological and palaeoenvironmental data as detailed above, this covered the Mesolithic to the Saxon period. However, in order to reconstruct the post-medieval landscape several high ranking historic maps and charts were used (Figure 4.30). This has allowed us to create a model covering a period of over 8,000 years, demonstrating how the harbour has changed. Similarly in Belgium, the Scheldt polders have been mapped using a combination of archaeological and palaeoenvironmental data for prehistoric periods and historic maps and charts for the post-medieval period.

Figure 4.30. Left: reconstruction of the post-medieval landscape prior to the reclamation of Farlington marshes in 1771. This has been based on high ranking historic maps such as the one presented above right by Milne and can be compared with the present day (bottom right), aerial image courtesy of the CCO.

Combined resources have also proved valuable for the Saint-Servan Promontory, France. The use of historic maps, heritage feature data and historic aerial photographs have enabled the analysis of change around the Saint-Servan (Alet) Promontory.

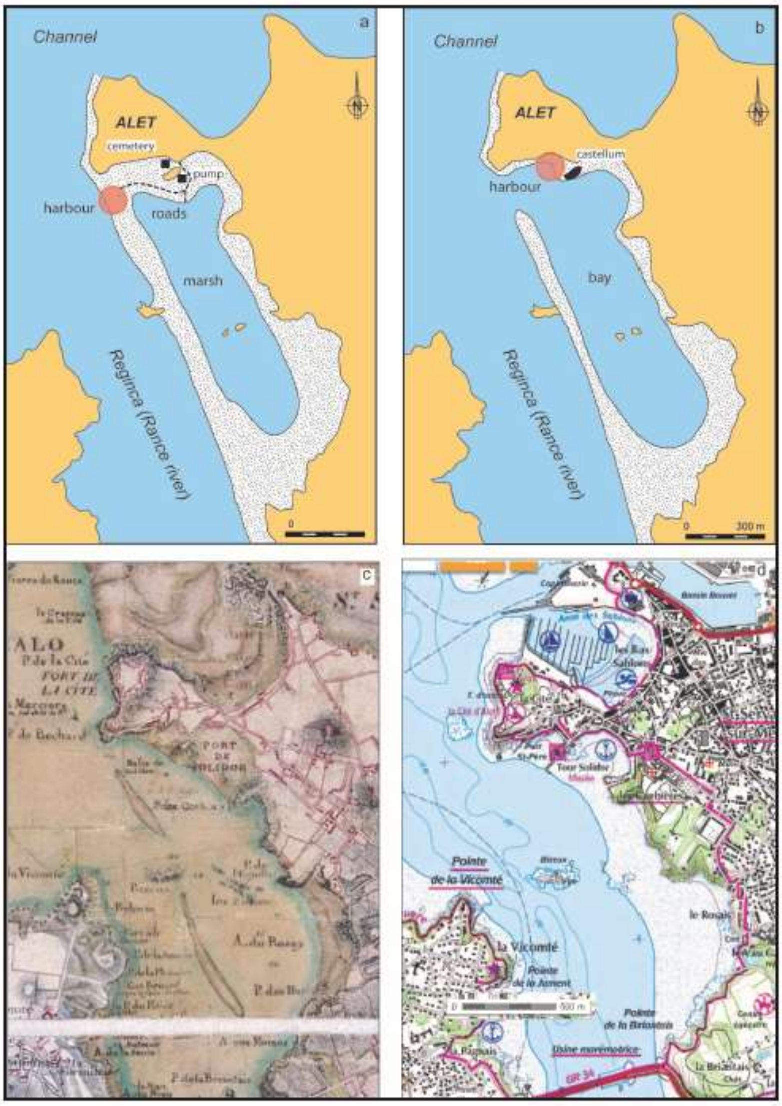


Figure 4.31. Above: Saint-Servan (Alet) promontory and coastal evolution of the harbour: evolution of the topography before (a) and after (b) the 4th century AD. The beak of the alluvial bar led to modification in the use and frequentation of the area. On the ancient map (18th century, Ministère de la Défense, Vincennes) (c) some remains of the alluvial bar still appear. (d) 20th century view (IGN map).

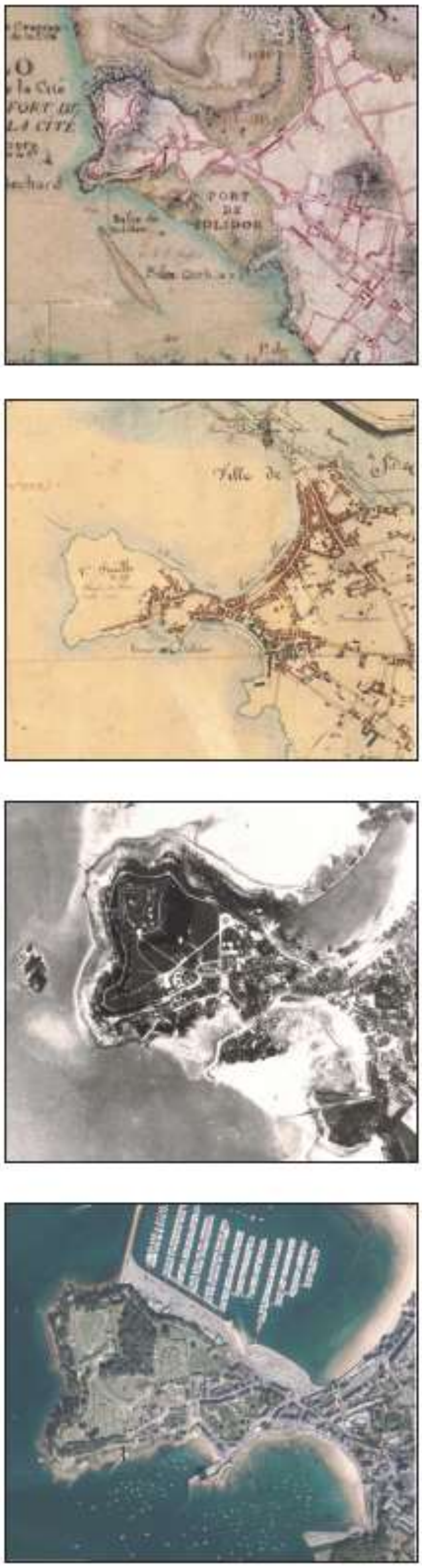


Figure 4.32. Right: Saint-Servan (Alet) promontory and coastal evolution of the harbour. From top to bottom: Carte des Ingénieurs Goégraphes du Roi (c. 1785) (Ministère de la Marine). Napoleonian cadastre (1835) (Archives du département d'Ille-et-Vilaine). Aerial views (1945 and c. 2012) (Geoportail, IGN source).

During the first millennium BC the bay was protected from the sea by an alluvial bar (Figure 4.31 – top left), evidence of this has been found through archaeological and palaeoenvironmental studies. It is unclear whether the breakthrough of the bar is due to natural causes or human action, but it is thought that this occurred around the 4th Century

AD. This led to the abandonment of a Roman pumping station (the fresh water pumping station was found at a location 4 meters below the current high water level) and necropolis, as well as this harbour activities appear to have been moved to the Saint-Père Bay (Langouët, 1996).

During the following centuries, the major modifications of this area are linked to religious and historic events with the building of churches, fortifications and ramparts (Middle Ages to 17th-18th centuries). During the modern period, the density of habitation and the development of modern sailing harbour installations are visible while comparing the maps and aerial photographs; more recently, the building of the Rance Tidal Power Station has had a great impact on the whole estuary and, more precisely, on the Saint-Servan/Alet area.

4.3. Implications for Coastal Management

Over the last thirty years, significant progress has been made towards achieving more sustainable management of coastal zones in the Southern North Sea - English Channel regional sea area. Initiatives promoted by the European Commission, governments and networks such as coastal fora and coastal defence groups have also encouraged a better understanding of physical processes in order to inform coastal policy making. The Channel - Southern North Sea coastline, which is composed largely of softer rocks with considerable lengths of unstable clifflines, as well as low-lying coastlines, are particularly prone to a range of natural hazards including coastal erosion, landslides and sea flooding. These hazards and the resulting risks to coastal property and assets, as well as infrastructure and the natural environment, have led to the development of risk management strategies such as shoreline management plans in some areas, which provide a framework for addressing risks looking ahead over the next century.

Whilst, in some locations, monitoring of coastal change has been undertaken in recent decades, for most of the coastline there is no long-term record of coastal evolution and, indeed, aerial photography only became available more widely after the Second World War. The importance of a strategic monitoring framework, particularly in the face of climate change, has become increasingly recognised and will provide a benchmark against which future changes can be measured. However, it has been recognised that a thorough understanding of coastal evolution and change can only be considered effectively if a long-term perspective of change can be obtained. In view of the absence of data from past decades, the Arch-Manche project has highlighted the benefit of making use of archaeological and palaeoenvironmental data, historical images, including landscape paintings, watercolour drawings, various kinds of prints (for example, engravings, aquatints and lithographs) together with photographs, photographic postcards and old maps and charts, to inform us on long-term coastal change. This research has highlighted that, in many locations, these resources have been under-used as a resource to support understanding of long-term coastal change.

The significant challenges to be faced around the Channel - Southern North Sea, as a result of coastal change exacerbated by climate change over the next century, can be addressed most effectively by taking advantage of the wisdom of hindsight, drawing in historical information from artworks, photography and cartography as well as archaeological and palaeoenvironmental data, to support the new technologies available to coastal scientists, engineers and coastal managers, who are facing such problems on a day-to-day basis. The recognition that sustainable coastal management should be based upon a thorough understanding of long-term coastal evolution, and the need to develop adaptation strategies through collaboration between coastal engineers and planning officers, highlights, all the more, the importance of taking advantage of those records that are available.

By looking back over time, and viewing the coastline before much of the human intervention, and having the ability to note progressive changes and alterations to the coast, allows us to assess impacts and support wise management. The use of such tools as archaeology, art, cartography and photography, which are familiar to many coastal residents who often have a long-standing knowledge and interest in the history of their coastline, therefore, provide a good way of engaging with these stakeholders when discussing issues relating to coastal change and its implications in practice.

The wealth of coastal landscape art and photographic images, as well as cartography, archaeology and palaeoenvironmental data, can be used most effectively when these resources are brought together and considered alongside one another. With these additional resources those responsible for coastal management will be much better prepared to address the challenges to be faced in the future.