

Beach Evolution on the Southern North Sea Coast.

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Abstract

A monitoring programme has been established for the 351km of the UK Southern North Sea Coast (between the Humber and Thames estuaries). This has produced over 3300 beach profiles captured to a clear specification at 1km intervals in summer and winter since 1991. The analysis of this data has been previously linked to specific flood defence and coastal protection engineering schemes. The first analysis on a region wide basis has now been undertaken to provide some strategic insight into how the coast is evolving on an Integrated Scale. The analysis provides quantification of the change at the coast, and demonstrates that simple analytical tools combined with geomorphological interpretation can provide meaningful information for coastal management.

1. Introduction

The increased awareness of natural processes in the management of the coast has led to renewed efforts in the monitoring of the UK coastline. Such monitoring has been carried out in an ad-hoc fashion over the last 50-100 years with local grids and datums being employed. The purpose of such monitoring is to provide information on long term (decade - century) changes in the coast and intelligence on what is happening with the highly complex and dynamic coastal processes in the short term (month - year). Monitoring considers both the forces affecting the coastline and the response of the coast to these forces, in many cases a symbiotic relationship.

One of the core data sets in monitoring is beach profiles (for the purpose of this paper beaches may be of any sediment type, including fine-grained silt and mud). Beach profiles provide indicators of coastal change in the most important area to coastal managers, the inter-tidal zone (Davis, 1971; Pethick, 1984). However the offshore bathymetry should also not be overlooked in their importance to the inter-tidal profile (Leggett, 1995). Beach profiles provide qualitative and quantitative information on how a coastline is reacting to the forces upon it. Over time the pattern of reaction enables trends, cycles, or the impact of distinct events to be identified.

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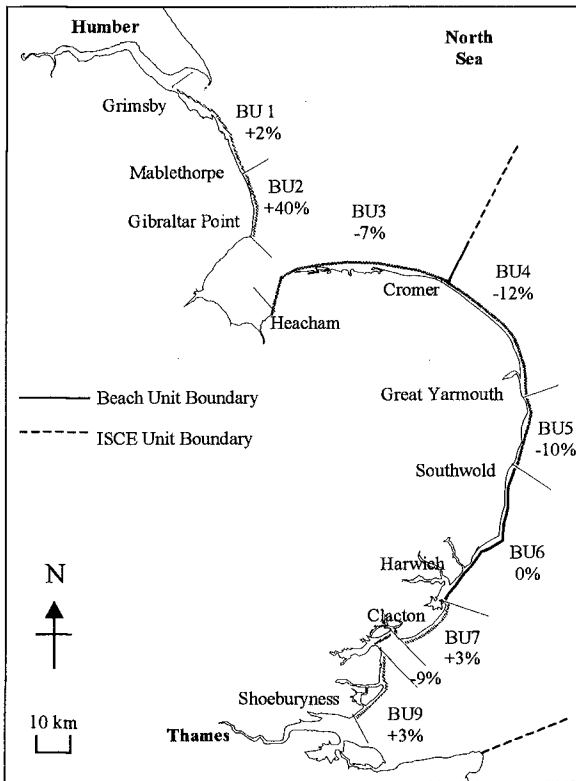


Figure 1. Location of the Southern North Sea Coast with Average Change in Profile Volume, 1991 to 1996

The Southern North Sea Coast of the United Kingdom (figure 1) has had a structured monitoring programme since 1991 (Child and Leggett, 1991). This paper reports on the first five years of this programme with particular reference to beach profiles.

2. Coastal Scale

The Southern North Sea Coast has 5,400km² of low lying land which alternates with soft rock cliffs (Leggett, 1993). This means it is vulnerable to flooding and coastal erosion. The management of this coast involves a number of approaches but almost all of the open coast has some form of man-made defence along it. Defence includes hard sea walls, clay embankments, groynes, nearshore reefs, and beach recharge. To be able to take effective management decisions a fundamental question is: What is the change of the beaches over medium to long time scales and how best can this be evaluated? To be able to answer such a question for over 351km of coastline there is a need to consider the philosophical approach to take.

The approach has been derived from the Coastal Evolution work in the Netherlands (Stive *et al.*, 1990). This approach considers the relationships that exist

between the spatial scale of the coastal feature and the temporal scale over which its behaviour is manifested. Changes on the temporal scale of a tidal cycle that link to profile shape and landforms over (say) a hundred meters are Small Scale Coastal Evolutions (SSCE). Changes over about a kilometre, that take a year to form, can be considered as Medium Scale Coastal Evolution (MSCE). Large Scale Coastal Evolution (LSCE) happens over tens of kilometres and form over decades. This approach has been further developed to create the Integrated Scale Coastal Evolution or ISCE (Pethick and Leggett, 1993).

The ISCE integrates the MSCE and LSCE as critical parts of coastal evolution. It also extends the temporal frame to include high magnitude - low frequency events such as 1:250 year return period storms. The approach also extends the longshore scale to hundred of kilometres and, importantly, integrates offshore processes to changes at the beach. The ISCE is an important philosophical approach to coastal management problems and has influenced the approach to monitoring the coast on a Regional scale.

3. Coastal Forcing Parameters

Beach surveys in themselves yield valuable information on changes at a particular site; this can be greatly enhanced if they form a carefully co-ordinated component of a broader monitoring programme. Wave, water level, wind and (estuary) tidal prism measurements all provide invaluable information to aid the interpretation of beach profile changes. The Southern North Sea Coast monitoring programme measures all these coastal forcing parameters (Townend and Leggett, 1992), however, this paper focuses on the use of beach profiles.

As analytical methods continue to become easier to apply, are better understood by managers, and become more sophisticated, it will be the paucity of data that will be a limiting factor. These long-term records are an invaluable benchmark for any future monitoring and analytical activities.

4. Strategic Beach Monitoring

The apparent ease of collecting beach profiles is very attractive in a subject area where field measurements may be highly specialised and costly. The ease of collection provides a source of valuable information that, with geomorphic interpretation, provides extremely good value for money. The ease of collection has, however, spawned a proliferation of approaches, which often means that modelling analysis cannot directly compare data sets together, limiting the value of time series information. Data capture in the past has varied from location to location meaning that spatial analysis of information is equally problematic.

To answer the main management questions it is suggested that a beach monitoring programme has, as its goal, the collection of beach survey and coastal forcing parameters in order to facilitate:

- The development of a holistic understanding of coastal processes along the coastline to guide the development of coastal defence and coastal zone management strategies.
- The provision of coastal engineering design data for the design of coastal defence.
- The monitoring of beaches to guide beach recharge and recycling programmes.

The focus of the Regional survey is not on the extreme event but on the envelopes of beach change from year to year.

5. Beach Profile Measurement Methods

There are a variety of techniques for monitoring beach profiles. These range from traditional survey techniques, to laser and active aircraft remote sensing (Cracknell and Hayes, 1991), to video imaging. These techniques all provide the same basic information, beach level. Some provide highly detailed (but less accurate) images of the beach surface whilst others provide an accurate cross section.

Collecting data and analysing it regularly requires rigorous and repeatable techniques. New techniques are always under investigation and when suitably developed may replace existing methods or provide a useful additional data set; they may in time also be able to provide suitably accurate profiles that would negate the need for direct land survey. Most remote methods provide accuracy in $\pm$ hundreds to thousands of millimetres. This accuracy would provide considerable error over the length of Southern North Sea Coast. Until methods are proven (such as kinematic global positioning) the risk of missing a time step in the data set is too critical to contemplate embracing new techniques.

There are merits and drawbacks in all approaches but certain issues are important for any long-term monitoring activity:

- Repeatability.
- Accuracy.
- Comparability.

These principles should affect the decision of monitoring approach, rather than just following the latest technology. Repeatability is vital if any meaningful analysis is to be achieved. This requires both spatial and measurement accuracy to be well defined. If this is the case then the best approach at present is considered to be measurement of beach profiles using land based survey techniques.

5.1 Cross Section Specification

The beach profile survey lines of the UK Southern North Sea Coast monitoring programme run from the landward toe of the defence line or 200m inland of a cliff edge to MLWS as a minimum. Spot heights are taken on section lines at all breaks of slope, at a maximum of 20m intervals, and at all changes in beach material. Changes in beach material (sediment and vegetation) are recorded qualitatively against each profile.

All levels are taken to Ordnance Datum Newlyn at $\pm$ 3mm accuracy for spot height. The corresponding plan position accuracy specification is $\pm$ 20mm. These values correspond fairly closely to the recommendations made from analysis of annual data captured over 30 years on the Lincolnshire coast (HR Wallingford, 1990).

5.2 Ground Control

Lack of ground control in beach survey has led to errors in the repeatability of some surveys and invalidated time-series data. At worst it may yield erroneous answers and false information on which to base decisions. A sound ground control and permanent marking is considered essential for any repetitive survey work.

Survey section lines, each with their own co-ordinated reference monuments have been established along the Southern North Sea Coast at 1km intervals to determine regional beach changes. All surveys are tied to OSGB 1936 as a common co-ordinate system; being the most commonly used in the UK (Pos, 1994). This enables re-location of profiles in the event of loss during defence works or through

erosion and also instant utilisation of data transferred between coastal authorities and passed to consultants. The monuments are established from the national grid network at 1:20,000 accuracy and their existence aids the identification of profile location by surveyors.

Each profile data point has a chainage calculated for it. Zero chainage represents the original profile marker position which is normally at the first line of sea defence, or inland from a cliffline (the current position could be landward, and in a few cases seaward, of this original position). This chainage system does not change if the marker is re-established, instead the marker has a positive or negative value. Chainage is positive to seaward and negative to landward of this original position.

5.3 Frequency and Timing of Surveys

Twice-yearly surveys are a recommended minimum requirement for beach surveys. However, additional site specific surveys should be carried out at particularly volatile locations to monitor the maximum negative (or positive) beach conditions. It may also be necessary to monitor more frequently for beach recharge purposes.

Whilst profiles after storms may show the most extreme condition of the beach it is difficult to capture *the* most extreme profile each year along the 351km of coastline. The volatility of beaches under storms leads to daily change in beach profile and high spatial variability. For specific defence schemes such detail may be feasible to collect, and indeed critical for structural design and stability. In order to represent more 'typical' beach conditions and to determine long term change in beaches it is more suitable to survey the coast at times of reduced beach volatility. The timing must, however, still capture the key beach change between the winter (storm) and summer (swell) beach profiles (Komar, 1998). For this reason survey is undertaken in January and July where perturbation in the beach is reduced but the gross pattern of change is still represented. This reduction in perturbation also provides a wider time window to measure profiles, for the Regional beach survey, and helps to provide consistency in information from one year to the next.

5.4 Integrating Land, Aerial, and Bathymetric Surveys

The Southern North Sea Coast monitoring programme has many sources of data including:

- Historic shoreline positions (high water mark, low water mark and coastline) have been taken from Ordnance Survey maps dating back to 1880.
- Over 9000 aerial photographs, using stereo-photography methods at a scale of 1:5000 with forward motion compensation have been taken between 1991 and 1996. They are suitable for photogrammetry, timed to coincide with beach profile measurement, and cover the whole coastline.
- 3399 beach profiles and 509 bathymetric profiles were measured between 1991 and 1996.

The costs of different survey approaches are comparable but aerial techniques allow the plan form of the coast to be mapped and the movement of important geomorphic indicators (such as spits, nesses, or bars) to be quantified. The aerial technique requires suitable ground control, which can be provided by the land based survey operations. It is suggested that for consistency (and maximum necessary accuracy) profiling is best delivered through the land based survey technique with plan form being delivered from aerial or video methods (rectified using the land based

survey data). Such an approach provides high quality data on a consistent basis across all coastal types and gives a three dimensional view of coastal changes. In inaccessible or dangerous locations (such as on wide mudflats) photogrammetry can be used to extend beach profiles across the inter-tidal area. However, the different errors generated in this need to be considered and accounted for in any analysis and interpretation.

Beach surveys are undertaken in conjunction with bathymetric survey (extending the profiles offshore). These surveys extend to at least 10km offshore, or to at least 20m depth of water, which is a nominal closure depth (Hallermeier, 1981; Birkemeier, 1985). The inclusion of bathymetric profiling is on a five year rolling programme due to expense and the initial consideration that change offshore was not as volatile, or as critical, as beach change. This view has been challenged by some of the results of this work.

5.5. Data Quality

The accuracy of the survey technique, accuracy of data capture, and accuracy of data recording all effect quality. To be confident of subsequent analysis, and to generate a credible data archive, it is essential to check the data. For the Southern North Sea Coast specification checks need to be undertaken by the surveyor to identify erroneous or spurious data and consider:

- Data outside the limits of the sensor(s).
- Rates of change between data points.
- Gaps in data.
- Timing of data points within a data set.

The editing of data is restricted to deletion of clearly spurious data points. The validity of the data is checked upon receipt from the field. In 1991 this was undertaken manually using hard copy output, but this is now done automatically by checking the digital data through computer programmes. These routines check the data files for errors or changes in key data elements, for example, beach profile marker positions and level, beach profile orientation, maximum and minimum beach levels. The routines compare the new data to the previous data, and to predefined tolerances (such as 4m change in beach elevation). In some instances large change may be real, but where there is an error this approach helps to ensure it is identified quickly (within 24 hours) and if necessary re-survey of a profile can be undertaken.

Spot checks are also employed to give an independent assesment of the quality and accuracy of data capture. Where possible any errors found are corrected. Where it is not possible to correct an error the data is not used for analysis.

5.6 Data Storage and Databases

For the Southern North Sea Coast storage of data is undertaken using a Geographic Information System (GIS). The GIS (Intergraph MGE) is used to update, manipulate and supply information and data to coastal managers. This provides a consistent dataset and rapid access to information (Leggett and Jones, 1996). The development of the GIS to handle the data more efficiently, and provide analysis of data, has been recognised as an ongoing need (Leggett and Dowie, 1993). This is essential where such large volumes of information are being handled.

The quality control, visualisation and analysis software has been developed separately by the Centre for Coastal Management, University of Newcastle to allow

easy access to this data for non-specialist users. Such management tools are essential if the monitoring process is not to become just a data capture exercise.

6. Analytical Methods

A considerable number and range of analytical techniques exist for the manipulation and interpretation of beach profile data. However, the type of analysis undertaken depends upon two important factors, namely: the questions that the monitoring programme is intending to answer, and the type, quality and format of the data that are available.

Temporal analysis techniques can be employed at a specific location to identify both short-term variations in beach profile (often storm related), and the longer-term trends at that site. This can be of use when identifying the standard of defence provided by a particular beach profile. Spatial analysis techniques can be employed to determine changes in beach profiles along the coastline and to identify areas of material gain and loss on the ISCE scale.

6.1 Beach Volume Comparison

The data from the 1991 to 1996 monitoring has been analysed to determine the volume of the beach and the position of a fixed contour level. This is an initial analysis and the limits of integration and choice of fixed contour level have been chosen to be as wide as possible. There are a large number of different limits that could be used, dependent upon the use of the results; further analysis with different limits and levels is part of the on-going work to be undertaken.

Each survey yields a different total profile length because of natural changes, the tidal state at the time of survey (although all are undertaken on spring low tides), and the safe working area for the surveyor. The method of analysis must allow for this variability whilst providing a consistent spatial area for consideration. The elevation of the defined shoreline position will vary from profile line to profile line. The method allows maximum use of the available data and takes account of the varying nature of the coastal morphology (Lowe, 1997).

The analysis provides a comparative measure of beach volume, not the total beach volume surveyed for each survey campaign. This comparison is vital for coastal managers to be able to objectively consider the state of beaches. The area of beach represents the width over which energy may be dissipated, the change in volume of material within fixed bounds, and a means of comparing different geomorphological features that may have different coastal dynamics. This means that mudflat areas can be compared to sand beaches or gravel ridges in terms of their relative percentage change, rather than absolute change. This approach helps to determine whether change is independent of the type of coastline or not.

6.2 Expert interpretation

A major part of the analysis of the profiles is qualitative rather than quantitative. The ability to easily view the profiles and to determine their relation with other profiles in both time and space (through the GIS and bespoke software) allows a much greater depth of understanding of beach behaviour. Using this data in combination with information on the coastal processes and sediments helps the interpretation of the changes and to develop management advice.

7. Results and Analysis

This study is a first overview of the beach profile behaviour for the Southern North Sea Coast. Characteristic closure depths, eigenvalues, and other more recent methods of analysis have not been applied to this data yet. The analytical techniques are relatively simple but yield interesting results for comparison of change on an Integrated Scale (ISCE).

7.1 Beach Volume Results

Representative beach volumes and shoreline positions for each profile are dependent upon the nature of the morphology. It is, therefore, unwise to compare the absolute figures of change (mean and standard deviation) for the whole coast. The focus for management information is therefore the relative changes in volume and position of beaches between 1991 and 1996.

The cumulative percentage change in profile volume and the calculated shoreline position between 1991 and 1996 demonstrate the trend of beach evolution over the five-year period (figure 2).

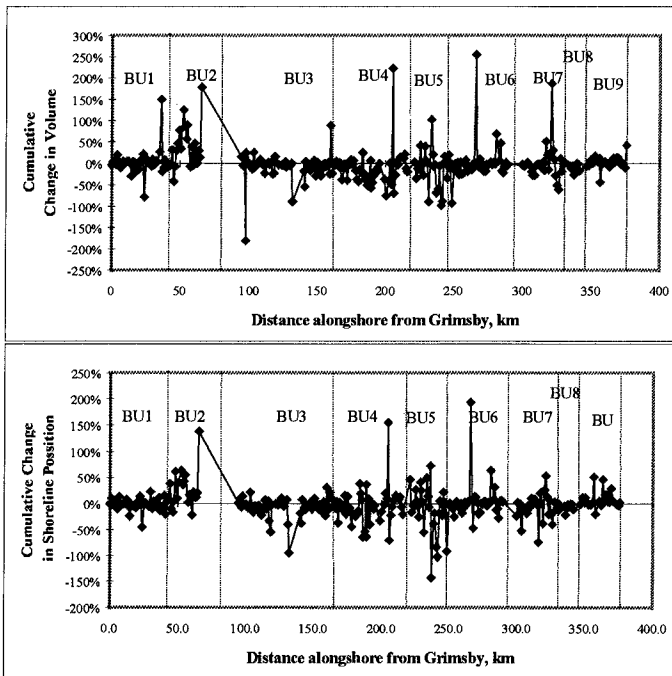


Figure 2. Cumulative Change in Profile Volume and Shoreline Position, 1991 to 1996

These have been plotted against the distance along the shore from Grimsby; the northern limit of the study area (this was calculated from the straight-line distance between the zero chainage of neighbouring profile lines; this is therefore slightly longer than the actual length of the coastline).

The results indicate that the Southern North Sea Coast can be split into a number of distinctive coastal evolution areas. The boundaries of these represent statistical divisions where profile evolution has a fundamental change along-shore. Change may be from gross erosion to accretion, a step in the magnitude of change, or the degree of intra-variability along the coast. The divisions have been indicated on figure 2 and can be considered as LSCE Beach Units. This analysis provides some indication of the broad behaviour of the whole coast, it also serves as an important starting point for any future analysis.

The average change within each LSCE Beach Unit is presented in figure 1. A total of nine units have been identified. The recent beach profile evolution in each of these areas can be explained by both natural and anthropogenic influences; each is briefly discussed below:

Beach Unit 1 – Unit 1 is at the northern end of the region from the Humber Estuary to Mablethorpe and appears to show overall stability. Here 2.4% accretion has been recorded over the study period. This area has a variety of profiles ranging from sand beaches in front of sea walls to wide sand flats and mud flats which are relatively stable. This gain in sediment links to protective offshore banks and a seaward extension of the profile. There is also a significant sediment supply from the Holderness coast via the Humber Estuary (NRA and SWHP, 1991).

Beach Unit 2 - This runs between Mablethorpe and Gibraltar Point. There is a consistent gain in beach volume within this Unit. The effect of large beach renourishment can be clearly seen along this 23km stretch of coast. The average beach volume has been increased by nearly 40% since 1991. The impact of the individual renourishments can be clearly seen in the temporal record. The on-going monitoring will be able to evaluate loss of sediment from this scheme but historic data shows a 15% loss over the five years prior to replenishment.

Beach Units 3 and 4 – These Units demonstrate that not all beach variation is due to anthropogenic impacts. The variation in the orientation of the shoreline along the Norfolk coast and the degree of protection afforded by the offshore banks can clearly be seen in the profile results. There is an increase in erosion of the beaches from Heacham eastwards to Cromer. The average loss of volume is about 10% over the past five years, although this can reach up to 50% in the southern half of this area. The gross pattern appears to be related to the continuing long-term reorientation of this coast since the last ice age.

Beach Units 5 and 6 – The reverse of the trend of Units 3 and 4 is found here, with erosion decreasing to the south from the critical LSCE divide at Cromer (Pethick and Leggett, 1993). Sea defence schemes designed to stabilise parts of this coast are starting to have an impact on this larger, longer-term pattern, with clear steps in the data from one scheme to another. This section also sees the linkage of the beach profile change to change offshore in the sandbanks. It is believed there is a large-scale sediment circulation spanning Units 3, 4, 5, and 6, this is subject to further investigation under the Southern North Sea Sediment Transport Study (ABP, 1996).

Beach Unit 7 – Unit 7 has a 3% increase in average volume since 1991. This masks a consistent spatial pattern of stability, accretion, then erosion as one moves southwards. The maintenance of high beach levels along the Clacton frontage, by the use of beach control structures, quite clearly starves the downdrift beaches. This starvation has led

to reduced beach levels (and standards of protection) and the requirement for beach nourishment, and re-design of the structures.

Beach Unit 8 – This Unit is on Mersea Island and is treated separately due to its geographical position. The profiles show an average loss of 9.1% since 1991. This is related to a lowering of the foreshore during this period which appears to be associated with a widening of the mouth of the adjacent estuary.

Beach Unit 9 – This shows stable areas that are accreting. Along the Essex coast, between Dengie and Shoeburyness, the average profile has gained about 3% in volume since 1991. This is an area of wide mud and sand flats that appears to be responding well to the high relative sea level rise. These are complicated profiles that show profiles evolving around an upper 'hinge'. Seaward variations of the profiles tend to be greater than the landward end of the profiles where vegetation helps stabilise the profile.

The nine Beach Units above support the two ISCE Units (figure 1) by demonstrating the critical evolutionary divide at Cromer and the general trends of change away from that point (Pethick and Leggett, 1993). The analysis has provided a more detailed view that allows the impact of defence schemes along the coast to be identified. The fact that the Beach Units are nested into the ISCE Units demonstrates that coastal management can have considerable affect upon the wider coastline.

7.2 Expert Interpretation

The analysis of the data has led to some fundamental understanding of the coast. The qualitative interpretation of the data sets has provided insight into a number of issues that merit more detailed and in-depth consideration. The following sections briefly describe some of the observations made when undertaking the analysis of individual profiles.

Orientation and Exposure - The role of beach orientation appears to have fundamental importance, particularly in Beach Units 3 to 6, which have a systematic change in profile bearing. This is illustrated where the profile bearing is plotted against the cumulative change in volume (figure 3).

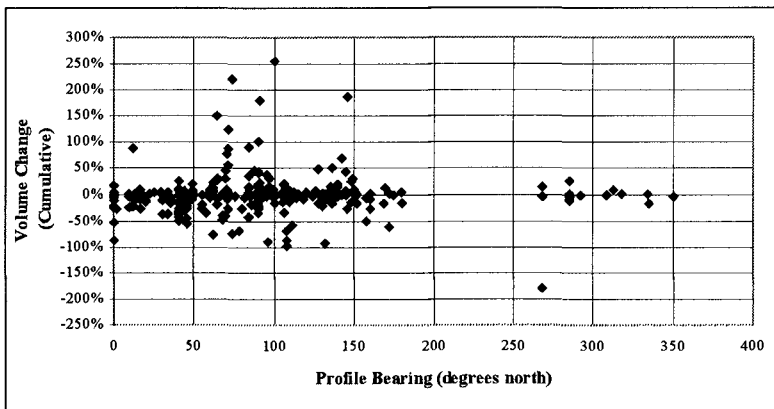


Figure 3. Profile Orientation vs. Cumulative Change in Beach Volume, 1991 to 1996

There are some indications that the volatility of the profiles is greatest between 60° and 100° N with another band around 120° and 150° N. These two groups, again, support the ISCE divisions. The degree of exposure to storm waves varies with orientation and the banding represent the northern ISCE beaches which are exposed to north-easterly and easterly storms, and the southerly ISCE beaches which are more exposed to the south-easterly storms (Pethick and Leggett, 1993).

Offshore Profile - Beach evolution is intimately related to the offshore bathymetry both in terms of the exchange of material and the dissipation of wave energy. The evolution of the offshore can be quite clearly seen in many of the longer profiles. Figure 4 is an example of the exchange of material between the offshore and the beach at Sea Palling (Beach Unit 4). Material appears to have been removed from the seaward side of the offshore bar and placed on the beach. Changes up to 1.2m in elevation are shown in 15m depth of water.

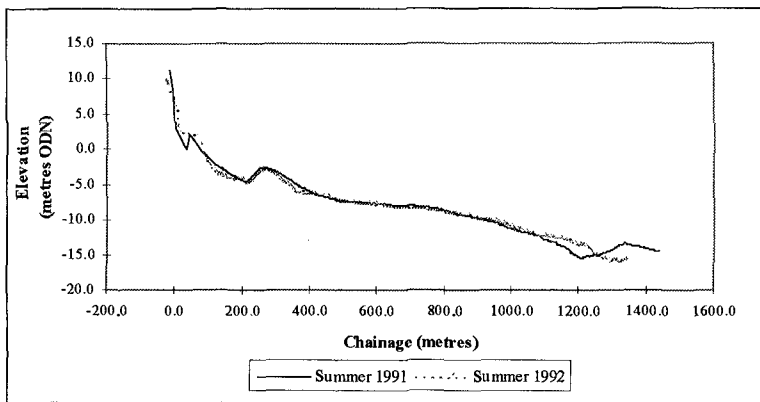


Figure 4. Evolution of Offshore Bathymetry, 1991 to 1996

The role of offshore bars (banks) in protecting the shoreline is illustrated at Orford Ness (Beach Unit 6) where profiles have distinctive bathymetric changes over a longshore distance of 4km. The northernmost profile has a large offshore bar that helps stabilise the beach profile (2% accretion 1991-1996). Further to the south the same orientation of the beach exists but no offshore bar, here 18% loss of volume occurred over the same period.

Trends of Profile Change - A number of different trends can be identified in the profile data (figure 5). Simple trends are shown in cliff profiles at Covehithe (figure 5a) where the cliff line can only retreat. The retreat of the cliff at Covehithe (Beach Unit 5) is a relatively simple process of parallel retreat - a constant form translates landwards.

Figure 5b shows nearshore bar movement at Cleethorpes (Beach Unit 1). The full time series shows the progressive movement onshore of this bar over the last five years. Clearly there are trends in the nearshore behaviour that will have an impact on shoreline management in the long term. These need to be identified before action is taken to stabilise the coastline.

A more complex response is shown at the Ray Sand at Dengie (Beach Unit 9). Here the saltmarsh has been accreting vertically since 1991 (figure 5c). The saltmarsh

cliff has, however, not moved. Seaward of the cliff the mudflat is also accreting but the rate increases offshore. The net result is a reduction of the slope of the mudflat, with the surface hinging around the toe of the cliff. This profile behaviour is characteristic along this stretch of the coast.

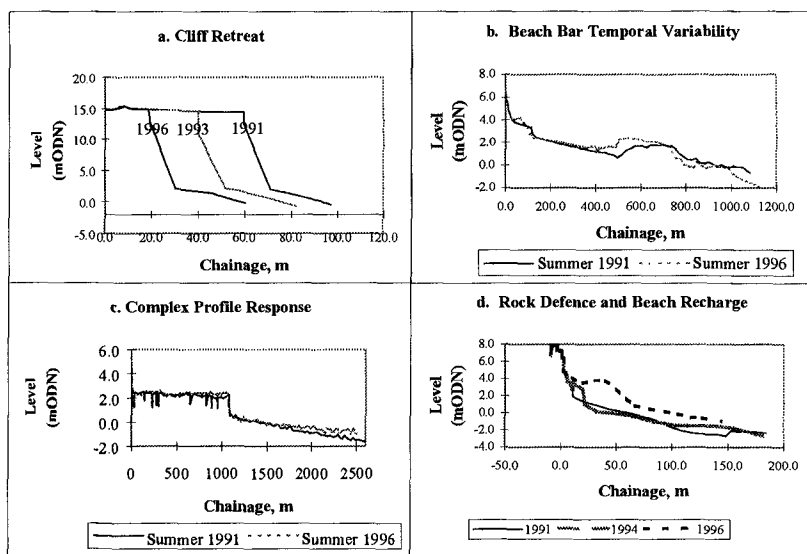


Figure 5. Examples of Profile Responses on the Southern North Sea Coast

Profile History - Knowledge of the history of each profile line (constructions, renourishments, etc) is increasingly important. This is illustrated at Chapel St Leonards in Beach Unit 1 (figure 5d). The low beach in 1991 caused sufficient problems to require the construction of a rock revetment which appears as 'accretion' of the upper profile. Beach levels at the toe of the rock revetment remained low so by the end of 1995 the beach was recharged, to completely cover the revetment. About 280m^3 of sand was placed per metre run of the beach of which 26% was lost in the following six months (73m^3 per metre). This history is based on the evidence in the profiles and the detailed local knowledge of relevant coastal engineers. Without that knowledge mis-interpretation of coastal change would be common place.

8. Conclusions and Recommendations

The analysis of 3399 beach profiles and 509 bathymetric profiles has provided a broad picture of beach evolution along the whole length of the Southern North Sea Coast. These results indicate some general trends and highlight specific challenges for some methods of sea defence. A re-analysis of the profiles following further survey work should be a relatively simple matter and provide more insight to coastal changes. The results presented, and those generated in the future will always be of an interim nature.

There is a definite need to integrate the profile data more closely with the forcing data (wind, wave and tides) which are also available. This integration will increase the value of the data that has already been collected and will help explain

some of the patterns and trends that have been observed. The ISCE approach has helped to define the data and information needs for the coast and helped in the conceptual approach to interpreting the analytical outputs. The critical divide for evolution of the Southern North Sea Coast at Cromer has been confirmed, this helps coastal managers to understand the evolution of the coast and to place individual schemes into context with the surrounding coastline, nearshore and offshore area.

The effect of large beach renourishment schemes undertaken for flood defence purposes can be clearly seen in Unit 2 (Lincolnshire) along a 23km stretch of coast. The average beach volume has been increased by nearly 40% since 1991. The impact of the individual renourishments can be clearly seen in the temporal record. It is too early to determine the long term stability of these schemes; however envelopes of expected change can be constructed.

Not all the variation in beach volume is due to anthropogenic impacts. The variation in the orientation of the shoreline from Units 3 to 6 (the Norfolk and Suffolk coast) and in the degree of protection afforded by the offshore banks can clearly be seen in the profile results. The gross pattern appears to be related to the long-term reorientation of this coast (certainly since 1880 and probably throughout the Holocene). Sea defence schemes designed to stabilise the coast are starting to have an impact on this larger, longer-term pattern.

Further to the south in Unit 7, (the Essex coast) at Clacton, the negative impacts of sea defence can be seen in the spatial distribution of erosion and accretion. Here the overall picture of relative change is fairly stable (a 3% increase in average volume since 1991) but this masks a spatial pattern of downdrift erosion. The maintenance of high beach levels along the Clacton frontage, by the use of beach control structures, quite clearly starves the downdrift beaches. This starvation has led to both reduced beach levels and reduced standards of coastal protection.

There are also stable areas that are showing accretion. Along the Unit 9 coast, between Dengie and Shoeburyness, the average profile has gained about 3% in volume since 1991. This is an area of wide mud and sand flats that appears to be responding well to the high relative sea level rise. A similar picture can also be found at the northern end of the region in Unit 1, from Humber to Mablethorpe. Here an average of 2% accretion has been recorded over a similar period.

These gross figures provide an overview and, combined with the analysis of individual profiles, better understanding of the evolutionary behaviour of the Southern North Sea Coast. The relationship of the beach behaviour to the offshore bathymetry, to the orientation of the coastline and to sediment pathways and their local interruption is very evident. For the first time coastal managers of the Southern North Sea Coast have an overview of the contemporary evolution of their coastline and the impact that their interventions have along a 351km shoreline. Monitoring continues on a twice-yearly basis and it is anticipated that the analysis will be repeated and refined at regular intervals. In the long term this will improve not only our understanding of how this coast behaves but also improve management decisions.

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