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Techniques for monitoring coastal change: a review and case study

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ABSTRACT

The coastal zone is increasingly being used for a diverse array of often conflicting uses. Recent approaches to coastal management have highlighted the need to base management practices on a detailed understanding of the processes at work within the coastal zone. This article discusses some of the methods available which coastal managers can use to examine the historical evolution and behaviour of areas of the coastline. It is suggested that an understanding of such changes can help the understanding of the effects of past management practices and help to plan future strategies. The use of cartographic and photogrammetric analysis is exemplified through a case study of East Head Spit, West Sussex, UK. © 1997 *Elsevier Science Ltd. All rights reserved.*

1. INTRODUCTION

Even without human intervention, coastal zones are dynamic and constantly changing environments. Human-induced pressures exacerbate rates of change and highlight the need for management and conservation of coastal areas. The predicted rise in global temperatures and the associated rise in sea level is one such environmental change and is of particular concern in Britain where 52% of agricultural land and many other areas of residential and industrial value lie below the Ordnance Survey five metre contour level.[1] The coastal zone is not only important from a sea defence perspective, however, and is an area with immense geological, geomorphological and ecological interest (see, for example Ref. 2). This

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article discusses a number of techniques with an important role in both monitoring and managing coastal change in Britain and elsewhere.

2. COASTAL MANAGEMENT

The natural and economic values associated with coastal zones mean that successful management of the areas is extremely important. In the past, management of many coastal areas has often ignored, or even worked against, natural forces and processes acting within the coastal zone. British coastlines, for example, have often been managed according to administrative boundaries rather than any understanding of the natural processes at work within the coastal zone. As a result, a disjointed system of management has emerged, partly due to the post-war planning system which segregates management of the terrestrial and marine environments. Recent research has repeatedly emphasised the need to understand the dynamic nature of coastal systems if we are to prevent the mistakes of the past being repeated (see, for example, Ref. 3). These studies argue that there is an urgent need to improve our comprehension of coastal processes and of the way coastal forms evolve and adjust to prevailing environmental conditions.

One method of investigation available to those concerned with coastal management is to examine how an area of the coastline has developed over a period of time. This allows the manager to examine past development of the coast as well as giving an insight into the effects of previous management activities. A knowledge of how a coastal area has developed may also be seen as a prerequisite for future planning and management. As technology advances, there is increasing range of options available with which to observe and understand the development of coastal areas. However, some of these tools, such as satellite imagery, are relatively recent developments and often financially unacceptable. For those wanting to examine the longer term development of the coast, there are a number of sources of information including aerial photographs, cartographic evidence, historical and archaeological records. This article focuses on cartographic and aerial photographic evidence and discusses a case study in which the techniques have led to a more complete understanding of the nature and extent of coastal change.

3. CARTOGRAPHIC EVIDENCE

The use of cartographic evidence for assessing coastal change is a practice that may be fraught with risk depending on the source used. The problems of using coastal maps and charts have been discussed by a number of

authors including Carr,[4,5] Diver,[6] Carr and de Boer[7] and Thieler and Danforth.[8] Until around 1750, many maps and charts were highly inaccurate with decoration often more important than accuracy.[5] Most early maps and charts were produced either for military purposes or for the establishment of land ownership rights and many were simply reproductions of earlier maps. There exists, therefore, a danger in coastal research of placing too much faith in early mapping and surveying of coastal areas. Perhaps one of the main uses of early maps and charts is in proving the existence of certain features along the coast. It is possible that coastal features may have been more accurately recorded on coastal charts to aid navigation although as Carr (1980) notes, the state of navigational aids still resulted in frequent complaints during the eighteenth century. Thieler and Danforth[8] discuss techniques for reducing and quantifying possible errors in historic maps and charts, though they note that any investigation involving the use of coastal maps and charts will involve a considerable amount of error. With the founding of the Ordnance Survey in 1791, the accuracy of mapping began to increase and has continued to improve as instrumental techniques and methodology have improved. Ordnance Survey maps, however, only cover the area from the landward side of the high water mark while the Admiralty's Hydrographic Office only surveys in detail below the low water mark. Tickell[9] examines the mapping of the intertidal zone which he describes as the missing link in Britain's maps. The debate over the need for a new system for coastal zone mapping in Britain was given added impetus by a House of Commons Environment Committee[10] report which unequivocally recommended that further resources be made available for coastal mapping and that the various sources of data be brought together in geographical information systems.

Despite its obvious difficulties, cartographic evidence has been used in a wide range of coastal studies.[5,11] This information often represents the only form of objective, quantifiable material available and it would appear necessary, therefore, to use cartographic evidence as long as the shortcomings are realised.

4. AERIAL PHOTOGRAPHY

Another method available to investigate coastal evolution is aerial photography. Collier *et al.*[12] note that aerial photography has several advantages over cartographical evidence since maps may be a composite of data collected over a significant period of time, whereas aerial photographs represent a snapshot image of one particular moment.

Collier *et al.*[12] also suggest that aerial photographs represent uncontaminated data where no attempt has been made to order or categorize the data within the image. It should also be recognised, however, that aerial photography has several potentially important shortcomings. In particular, the fact that aerial photographs represent a snapshot image means that the data extracted are, in effect, relevant only to that precise time and location, and may not represent the mean condition. This can be seen to be important in dynamic environments such as sand dune systems. Searle[13] notes that dune levels are higher in summer than in winter and therefore those using aerial photographs will need a detailed understanding of the processes at work. Also, the range, volume and quality of photographic material available will vary from area to area. Similarly, the accuracy of the information extracted from aerial photographs is, in part, related to the analytical equipment available to the researcher.

Despite the potential drawbacks, however, photogrammetric techniques have been increasingly utilised within the coastal zone in a variety of different areas of study. Use of aerial photography in the coastal zone has a long history, including the study of coral reefs in the East Indies in the early part of the twentieth century. During the same period in Germany, aerial photographs were being used to map coastlines. There are a number of sources which discuss the value of aerial photography in coastal research. As early as 1971, Stafford[14] pointed out that aerial photography can have significant advantages over other data forms such as maps in that they record infinitely more data which can be analysed with ever greater accuracy as technological advancement continues. Stafford also suggests that aerial photographs may have economic advantages for interested authorities, an opinion shared by Dolan[15] who suggests that aerial photography offers a unique opportunity to study large areas of coastal forms and identify associated processes.

Photogrammetric analysis can be a useful tool in a variety of coastal management areas including sea defence, pollution studies and habitat conservation. The technique has been more commonly used in recording vegetation on dune systems and identifying successional change (see, for example, Refs 16 and 17). It should, however, be recognised that there are a number of other techniques which may be available to study coastal change. These include the use of beach profile data as held by the Environment Agency in England and Wales and the use of historical and archaeological records. Morton *et al.*[18] suggest that beach monitoring using GPS surveying techniques allows the coast to be studied as a three dimensional phenomenon and enables the monitoring of change and identification of short-term trends. Wagner[19] discusses the increasing techniques available for satellite image mapping which it is suggested is

especially useful for monitoring inaccessible areas. According to de Vel and Bour,[20] the main advantage of satellite remote sensing over aerial photographs, ground surveys and nautical charts is that information can be collected uniformly in both time and space. Overall, satellite remote sensing is considered to be a cost-effective, non-intrusive means of mapping the coastal zone.[21]

Hortsmann[22] discusses how satellite remote sensing can be used to monitor offshore sediment transport. Microwave imagery is another option available as reviewed by Allan[23] who discusses the use of Seasat. There is also a growing interest in the use of aerial videography which may be valuable in coastal conservation and management. Raper *et al.*[24] examine the use of the technique in a GIS for coastal management and discuss the use of high resolution camcorders which allow the capturing of terrain imagery of high quality at a relatively low cost. Another increasingly accessible area for investigating coastal change and process is the use of GIS and computer mapping. Several articles have examined the developing use of GIS as technology advances and associated costs are reduced allowing the creation of GIS as information systems for the coastal zone (see, for example, Refs 25 and 26). Mumby *et al.*[21] examine the use of GIS as an integrated management tool for coastal zone management in Belize, whilst Jones[27] also reviews the progress of GIS use in coastal management and notes its increasingly significant role. Damoiseaux[28] discusses the use of GIS off the Dutch coast and suggests that GIS is indispensable for providing actual information on many themes of coastal zone management. Damoiseaux[28] also contends that as access to GIS is made more convenient by new systems such as Arcview 2, there will be fewer paper maps of coastal areas. Collier *et al.*[12] discuss the development of a GIS which is able to hold and display archaeological and environmental data for the analysis of the inter-tidal zone of Langstone Harbour on the south coast of England and argue that the ability of GIS to integrate different data sets is of considerable importance to many areas of coastal research.

5. COASTAL EVOLUTION: A CASE STUDY OF COASTAL CHANGE, EAST HEAD SPIT, WEST SUSSEX

East Head is a sand dune and shingle feature typical of the type of geomorphological feature found at the entrance of estuaries throughout Britain. East Head is a dynamic landform, constantly changing due to natural processes and the intentional and unintentional effects of human actions. It is important, therefore for local managers to understand both

how the spit has evolved and altered in the past and the effects of past management practices. From the 1950s onwards, East Head has been increasingly affected by sea defence works to the east which have restricted the sediment supply reaching the spit. As a result, dune levels have decreased and the spit was overtopped by the sea in 1963. Since its acquisition by the National Trust, intensive management has taken place in an attempt to address concerns about the stability of the spit area, to increase the overall area of the spit and raise dune levels.[13,29]

A detailed investigation was performed to identify cartographic and photogrammetric evidence regarding the development of the spit. The earliest evidence showing the existence and relative position of a coastal form at East Head can be found on early map representations of the area. These maps may be used to establish the existence of the spit but it is dubious to what extent these maps can be relied upon to give any accurate detail on the spit's orientation or size. One of the oldest known examples of this kind of map for the East Head area is the Armada map from around 1587. This map shows a coastal feature which follows the orientation of the coastline of the Manhood Peninsula, before turning northwards into Chichester Harbour. This evidence, however, can only be used to demonstrate the existence and approximate shape and orientation of the spit, and it is unlikely that any great attention was given to the accurate mapping of East Head during this early period. The problems with early cartographic evidence can be seen when comparing the Armada map with the with the slightly earlier map of the area by Saxton in 1575 in which no record of the spit is shown. The map evidence suggests that the orientation and form of the spit has changed considerably from 1870 onwards before stabilising in the 1930s.[29] Cartographic evidence of the East Head area exists up until the time when the earliest photogrammetric material was available and therefore it is possible to trace the development of the spit from 1587 onwards. Overall, the map evidence demonstrates that the spit is a dynamic feature which has changed orientation and form considerably, with such change being integral to the survival of the landform and its flora and fauna.

A search of various sources revealed that aerial photographs for the area were found to be available from 1945. From these photographs, it has been possible to produce several detailed maps of East Head which demonstrate how sediment volumes and the shape of the spit has altered. Figure 1 illustrates the condition of the spit in 1946 whilst Fig. 2 shows the situation in 1994. These maps indicate a considerable accretion of sediment at the distal end of the spit between the late 1940s and early 1990s. Analysis of the available photographs suggests that this occurred after the late 1960s and is related to a subsequent increase in positive

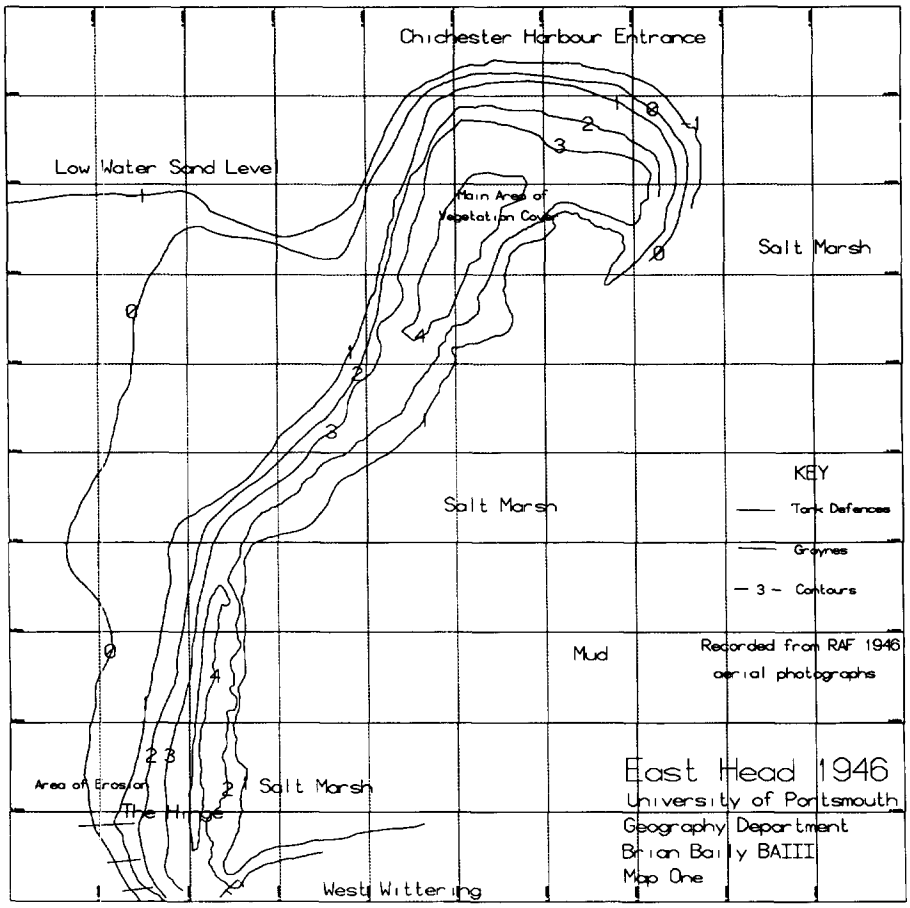

Fig. 1. East Head Spit in 1946.

management measures. In particular, the successful measure of installing numerous fences and wave screens to entrap sediment can be seen to have played a significant role in this process. The photogrammetric analysis was able to show the extent to which the management of the spit had achieved its objectives, while the cartographic investigations demonstrated the dynamic nature of the spit. According to the photogrammetric analysis, East Head now covers a substantially larger area than at any time during the last fifty years. This accretion appears to coincide with the period when active management of the dunes system increased and therefore it would seem likely that the build up of sediment can be related directly to the management techniques employed.

When using coastal aerial photography it should be recognised that there are a number of problems or restrictions which are encountered in

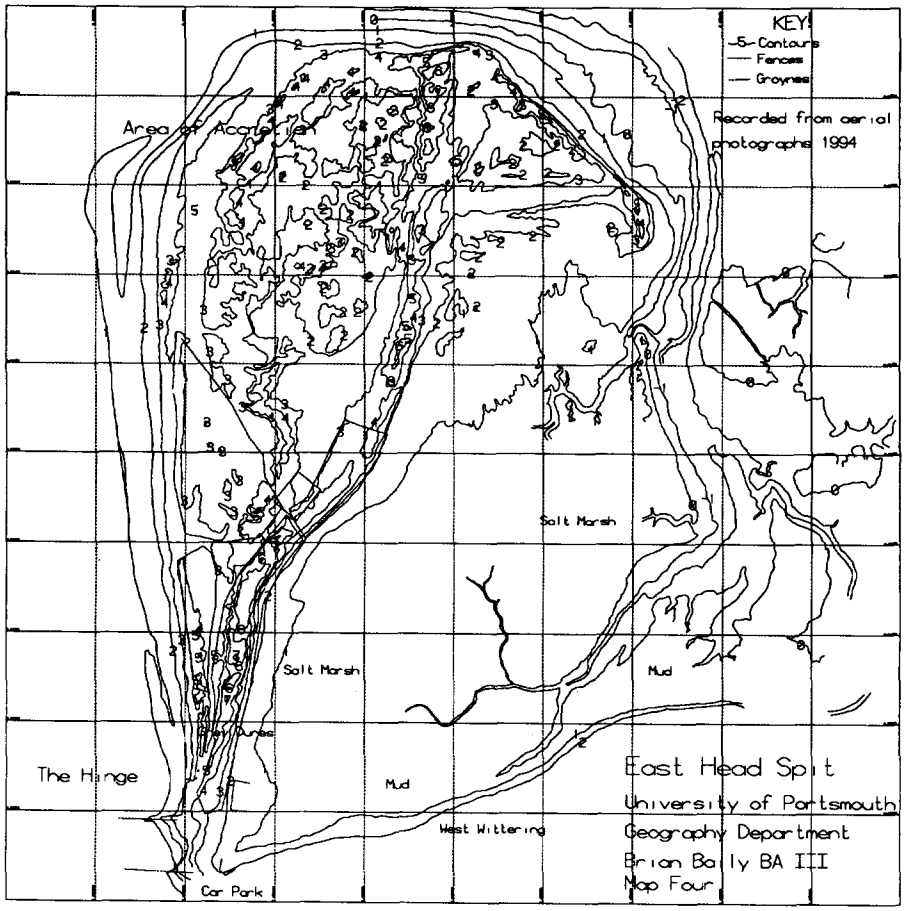

Fig. 2. East Head Spit in 1994.

the photogrammetric investigation of coastal areas. One of the main problems involves the range of material available and the restrictions that this may have imposed. In particular, it is often only possible to use the material available for particular years and for distinct periods during those years. It also needs to be recognised that tidal heights within different pairs of photographs may differ causing difficulties in ascertaining exact changes in shape or in sediment volume. Ideally, photographs would have been taken when tide levels were approximately the same. Another possible problem with photogrammetric analysis is that photographs may have been taken at different periods of the year. Searle[13] points out sediment levels on the spit may fluctuate depending on the time of the year analysis occurs, with higher dune levels in the summer than in the

winter months. Another possible drawback which applies to this and all other photogrammetric studies, is that aerial photographs only record conditions at a precise moment in time and therefore may present an unrepresentative image of an area. This factor is especially relevant in a study of such a sand dune system where change can occur dramatically. It also needs to be recognised that in sequential studies, there is the possibility that important changes may have occurred between the time periods selected for analysis or before the first image selected for analysis.

6. CONCLUSION

A detailed knowledge of the processes at work in an area and the history of an area would seem a necessary prerequisite for any form of coastal management. Although this article has discussed just two of the techniques available to examine change on the coast, there exists a wide range of technologically advanced systems with which to monitor environmental change. In the absence of detailed ground survey data, the use of early maps and aerial photography appears the primary way in which analysis of the historical development of coastal forms can be carried out. While it must be accepted that the use cartographic evidence is fraught with difficulties, there is often no alternative when attempting to examine long-term coastal changes. Likewise, photogrammetric analysis has a range of disadvantages and advantages which means that this method should be seen as one of an increasing range of tools available to the coastal manager rather than a technique which will provide definitive answers. Nevertheless, such tools offer managers useful insights into the nature of coastal changes and can provide a crucial input into decision making processes.

REFERENCES

1. Ministry of Fisheries Agriculture and Food, *Coastal Defence and the Environment*. MAFF, London, 1994.
2. Viles, H. and Spencer, T., *Coastal Problems*. Edward Arnold, London, 1995.
3. Barrett, M. G., *Coastal Zone Planning and Management*. Thomas Telford, London, 1992.
4. Carr, A. P., The significance of cartographic sources in determining coastal change. In *Timescales in Geomorphology*, ed. F. Culling, Wiley, Chichester, 1980.
5. Carr, A. P., Cartographic record and historical accuracy. *Geography*, **47** (1962) 135–144.
6. Diver, C. The physiography of the South Haven Peninsula, Studland Heath, Dorset. *Geographical Journal*, **81** (1933) 404–427.

7. de Boer, G. & Carr, A. P., Early maps as historical evidence for coastal change. *Geographical Journal*, **135** (1969) 17–39.
8. Thieler, E. R. & Danforth, W., Historical shoreline mapping: Improving techniques and reducing positioning errors. *Journal of Coastal Research*, **10** (1995) 547–563.
9. Tickell, O., Coastal zones: The missing link. *Geographical*, **66** (1994) 22.
10. House of Commons Environment Committee. *Coastal Zone Protection and Planning*. HMSO, London, 1992.
11. Fox, W. T., Haney, R. L. & Curran, H. A., Penouille spit, evolution of a

(1995) 478–493.
12. Collier, P. Fontana, D. and Pearson, A. GIS mapping of Langstone Harbour for an integrated ecological and archaeological study. In *Proceedings of International Symposium on GIS and Computer Mapping for Coastal Zone Management*, ed. R. Furness, 1995, pp. 315–327.
13. Searle, S. A., *The Tidal Threat*. The Dunes Group, Chichester, 1975.
14. Stafford, D. B., Air photo survey of coastal erosion. *Photogrammetric Engineering*, **3** (1971) 562–575.
15. Dolan, R., Coastal processes high aerial photographs aid in investigations. *Photogrammetric Engineering*, **39** (1973) 255–260.
16. Pizzey, J. M., The assessment of dune stabilisation at Camber, West Sussex using air photographs. *Biological Conservation*, **7** (1975) 275–289.
17. Budd, J. T. C., An investigation into the utility of remote sensing in the study of the ecology of some south coast harbours. Unpublished Ph.D Thesis, Portsmouth Polytechnic, Department of Geography, 1985.
18. Morton, R. A., Leach, M. P., Paine, J. G. & Cardoza, M. A., Monitoring beach changes using GPS surveying techniques. *Journal of Coastal Research*, **9** (1993) 703–720.