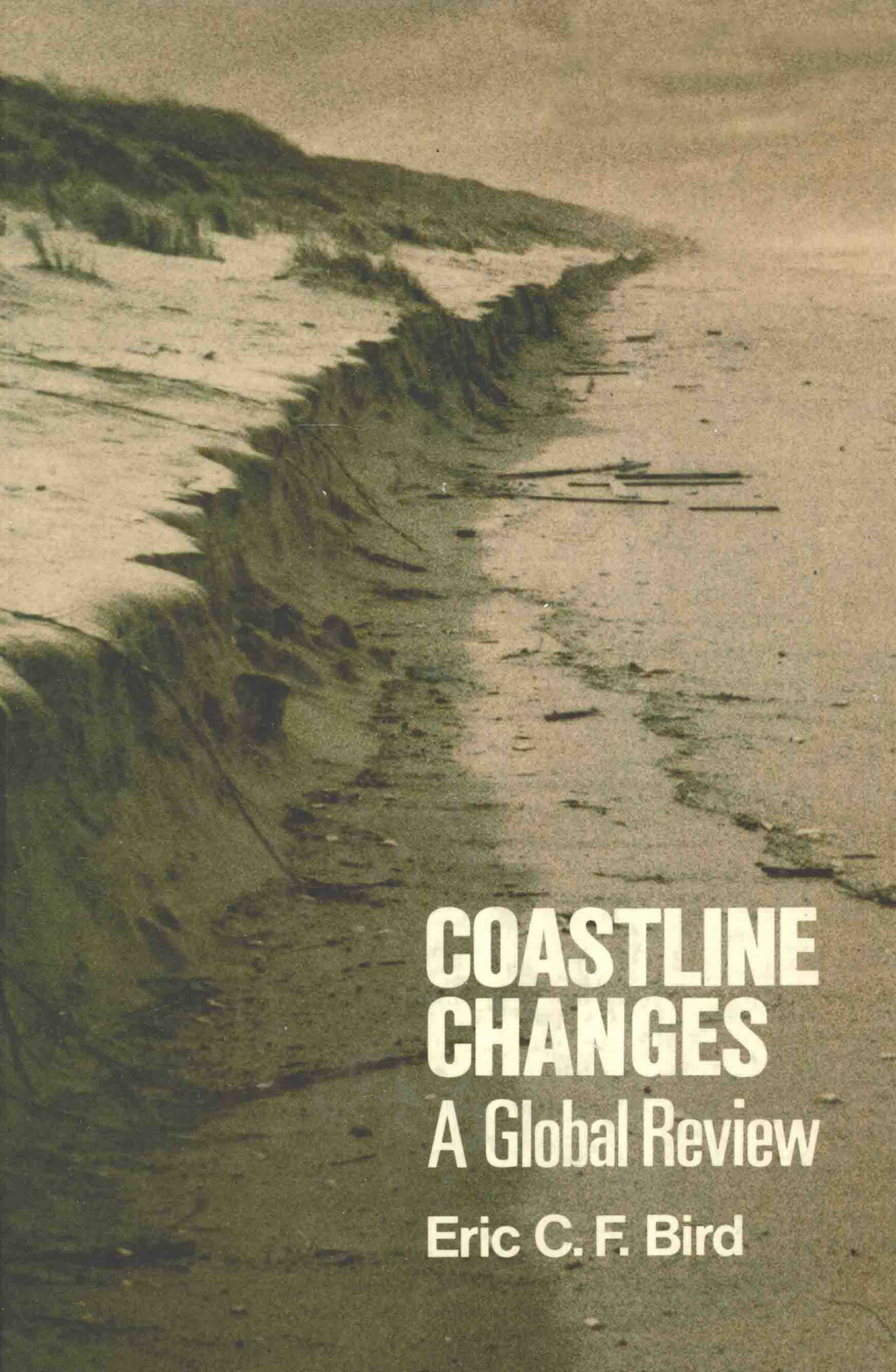

COASTLINE CHANGES

A Global Review

Eric C. F. Bird

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Preface

This book is based on the results of a project carried out by the International Geographical Union's Working Group on the Dynamics of Coastline Erosion (1972–76) and its succeeding Commission on the Coastal Environment (1976–84). As Chairman of the Working Group, and subsequently of the Commission, the author acted as Convenor for world-wide studies of coastline changes during the past century, and for longer periods where suitable information could be obtained. The outcome was the collection of a large amount of data on the nature, extent, and history of coastline changes, supplied by over 200 correspondents representing 127 coastal countries. In the course of this work it became clear that erosion has been more extensive than deposition around the world's coastline in recent decades, especially on low-lying sandy coasts. The explanation for this is not simple: a number of factors have contributed to the modern prevalence of erosion, their relative significance having varied from one section of coastline to another. It also became clear that, in our present state of knowledge of the world's coastline (some parts of which have been intensively studied, while others are known only at reconnaissance level), any attempt to derive globally valid generalizations from research on any one section of coastline is hazardous. Our understanding of coastal processes is still based on selective studies of very limited parts of the world's coastline: the opportunities for geomorphological research on the less well known sectors are extensive.

It is hoped that this book will stimulate interest in the study of coastal geomorphology, starting from the recognition, mapping, measurement and analysis of changes in progress on coastlines. It is impossible to report all the evidence of historical changes on the world's coastlines in such a book as this. Instead, the aim is to illustrate the kinds of change that have been documented around the world's coastline, with selected examples, and references to more detailed work. The first chapter reviews the origins of the International Geographical Union's project, examining the problems and methods of documenting geomorphological changes on particular coastlines over selected periods. There follows a round-the-world selective summary of the record of coastline changes, based on published references and unpublished reports by individual members of the Commission on the Coastal Environment, whose names are given in the text, with affiliations listed in the Appendix on page 193. This is illustrated by selected maps and photographs, but readers will need to use a good atlas, or consult national maps of coastal areas to locate places mentioned in this review. Reference can also be made to the illustrated descriptions of coastal geomorphology assembled in the same sequence in *The World's Coastline* (Bird and Schwartz, 1985), as a background to the study of changing coastlines. The third chapter then reviews the categories of coastline change that were identified in the course of the global project, outlining the geomorphological explanations. Only a few of the sectors where coastline changes have occurred during the past century have so far been investigated in detail, and the task for future research is to determine which of these geomorphological explanations are relevant to particular coastlines, and to assess the relative significance of the various geomorphological processes that have resulted in gains or losses of coastal land.

It is thus hoped that this book will stimulate more intensive local research, using historical sources as well as geomorphological methods, to analyse the changes that have occurred on particular coastlines. As well as people working from universities, colleges, research institutes and field studies centres in coastal regions, school teachers and other interested people living on or near the coast can assemble valuable information. The IGU Commission on the Coastal Environment was able to use a few local studies of this kind. For example, the evidence of stages in the growth of the Pantai Laut spit on the shores of the Kelantan delta, north-east Malaysia (shown in Fig. 59) came partly from studies carried out by a local school teacher.

It is also important to record existing coastal features by means of field surveys as well as ground and air photography, as a basis for measuring subsequent changes. Retrievable historical information on coastlines is patchy and of varying reliability, and more accurate contemporary surveys will benefit future studies. Monitoring of coastline changes is necessary for scientific understanding, as a background for assessing human impacts, and as a means of devising management strategies in the future. The remarkable spread of coastal engineering works in recent decades has already made long sectors of coastline artificial. The debate on whether such works are really necessary, and if they are, which of the possible alternatives (such as artificial beach renourishment) are most desirable, is best founded upon a broad understanding of the geomorphology of coastlines, and their recent evolutionary history. This book is intended to provide a global perspective for such discussion.

I would like to acknowledge the support of the members of the Commission on the Coastal Environment, especially those whose contributions are included in the text. In addition, I would like to thank Jock Murphy, Map Curator of the Baillieu Library, University of Melbourne, for much patient help with maps and charts from various parts of the world. Robert Bartlett and Wendy Nicol, of the Department of Geography, University of Melbourne, assisted by drawing the line illustrations and preparing the photographs respectively, and I am grateful to Neville Rosengren, of the same Department, for critically reviewing the text. In selecting material from the vast amount of information assembled by the Commission on the Coastal Environment I had incidental help from Catherine, Philippa and Jennifer Bird.

Lyme Regis, August 1984 ERIC C. F. BIRD

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CHAPTER ONE

Introduction

In July 1972 a group of coastal geomorphologists met in Halifax, Nova Scotia, to discuss the progress of research in their subject. They came to the conclusion that, although there had been a great deal of work on changes of sea level, and on upward and downward movements of the land, around the world's coasts relatively little attention had been given to the advance and retreat of coastlines, the gains and losses of land that result either from changes of sea level relative to the land or to erosion and deposition. Dr Hartmut Valentin, who was present at this meeting, had dealt with coastline changes in general and theoretical terms in his treatise, *Die Küsten der Erde*, and had devised the well-known analytical diagram reproduced here (Fig. 1); there had been many detailed studies of coastline changes at particular localities around the world, but no attempt had been made to document, measure, and analyse such changes on a global scale or over a particular interval of time. Accordingly, the Halifax group recommended a project on changes around the world's coastline during the past century, and the ensuing 22nd International Geographical Congress, held in Montreal, set up a Working Group to compile this information. Four years later a preliminary report was prepared (Bird, 1976) and widely circulated at the 23rd International Geographical Congress, in Moscow. As a sequel, the Working Group became the Commission on the Coastal Environment, which has carried out a number of projects, including further documentation of coastline changes. The results of this work have been presented in further reports (Bird, 1980), and are reviewed in this book.

The time scale of a century was originally selected because it was known that maps and charts dating from the period 1870–1900 were available in

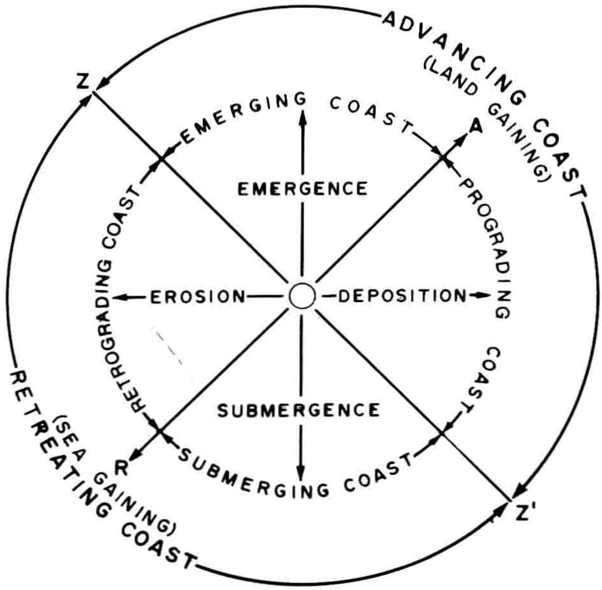

Fig. 1 Analysis of coastline change (after Valentin, 1952). Z–Z′ indicates a stable coastline, where erosion has been offset by emergence, or deposition by submergence, or where no changes have taken place (O). It is necessary to specify a time scale over which changes have taken place before using this scheme, for many coastlines have shown alternations of advance and retreat during the past century

many parts of the world, and that coastline changes could be detected and measured by comparing these with later surveys and modern air photographs. In some countries, such as Britain and Denmark, where earlier maps and charts are available, it was possible to determine changes over a longer period. In the Mediterranean region, and locally elsewhere, there is sporadic evidence of coastline changes over periods of at least 2000 years from historical descriptions and datable archaeological evidence. Some of these ancient sites, particularly in Greece and Turkey, were coastal settlements that are now found some distance inland, as the result of coastal deposition perhaps accompanied by emergence, due to land uplift or a fall in sea level, leading to a seaward advance of the coastline. Elsewhere, the foundations of ancient settlements are out on the sea floor, as the result of submergence, or the cutting back of the coastal margin by erosion. Still longer spans of coastline change can be determined where former shore deposits (beaches, corals, salt marsh) now found inland, perhaps above sea level, or offshore on the sea floor include material (such as shells, wood or peat) that can be dated by radiocarbon or other geochronological techniques. On some coasts it is possible to trace the extent of gains and losses of land since the sea attained approximately its present level (about 6000 years ago) as a sequel to the world-wide Holocene marine transgression, the sea level rise that began about 18,000 years ago, when the cold global climates of the Pleistocene ice age started to become warmer. It is important to realize that the existing world coastline has been shaped largely within this 6000-year period, with the sea at, or close to, its present level in relation to the land. Further details of this coastal evolution may be obtained from geomorphological textbooks (e.g. Bird, 1984).

Although information on coastline changes during the past century is widely available from historical maps, charts and photographs there are still many countries, especially in polar and tropical regions, where reliable surveys of coastlines exist only for the past few decades, usually the period for which air photography is available. In some cases the best available evidence of coastline change is purely geomorphological: beach-ridge plains, deltas and marshlands that have clearly prograded, or cliffs that have been cut back. Alternations of advance and retreat are indicated where coastal plains that had formerly been built forward by deposition now show eroding seaward margins (Fig. 2), or where earlier cliff recession has been brought to a halt by the accumulation of a wide beach, or beach ridges, in front of an abandoned bluff (Fig. 3). Such landform features may indicate the kind of changes that have taken place, but evidence of *rates* of coastline change require studies of maps or charts of various dates, successive ground or air

Fig. 2 Recession of a formerly prograded sandy coastline is indicated by a cliff cut into previously built beach ridges at Sandy Point, Victoria, Australia. Photo: Eric Bird (December 1979)

Fig. 3 Beach progradation has taken place in front of a formerly cliffed, receding coastline at Twilight Cove, Western Australia. Photo: J. N. Jennings (August 1963)

photographs, or even (making due allowance for artistic interpretation) dated drawings or paintings which show the former coastal configuration. In a few cases, written accounts of changing coastlines have proved useful: for example historical records of the lighthouse at Cap d'Ailly in northern France, which in 1775 was built 160 metres inland behind a retreating cliff. In 1845 it was only 60 metres inland, and in 1940, when it was destroyed by bombing, it stood on the cliff edge. From this, Ottmann (1965) deduced that cliff recession had averaged about a metre per year. In North Carolina the site of Sir Walter Raleigh's English colony (1585–7) on Roanoke Island is well documented, but failure to find it has been attributed to cliff recession, which measured 282 metres between 1851 and 1970, and could have attained 600 metres since Raleigh's time, thereby destroying this colonial site (Dolan and Bosserman, 1972).

In such studies it has been necessary to define the coastline on which changes have been measured. The term *coastline* is here taken as the seaward margin of the land, whereas the term *shoreline* denotes the water's edge, which moves to and fro as the tides rise and fall. The coastline, thus defined, is usually equivalent to the high spring tide shoreline, but where the tide range is large, as in the Bristol Channel or the Bay of Fundy, there is considerable variation in the positions reached by the sea at spring tides. Moreover, meteorological effects, including storm surges, and other unusual events such as tsunami waves generated by volcanic eruptions or earthquakes, result in temporary submergence of coastal land margins, and sometimes achieve considerable geomorphological change along the coastline. In practice, measurements of change have usually been made with reference to the crest or base of a cliff, or the seaward limit of backshore vegetation on beaches and deltas. Where the shore is occupied by salt marshes or mangrove swamps the vegetation boundary is usually well-defined, especially where erosion has cut a small cliff along the seaward margin. Such features are found at various inter-tidal levels, and changes mapped along them are strictly shoreline rather than coastline changes. Within the inter-tidal zone it is possible for high-tide shorelines to advance at the same time as low-tide shorelines retreat, the shore profile becoming steeper, and *vice-versa* as the shore profile is flattened (Fig. 4). Given these complications, changes are best mapped and measured along *coastlines*, as defined here.

Coastline changes can be expressed in linear terms, as advance or retreat measured at right-angles to the coastline; in areal terms, as the extent of land gained or lost from a coastal sector; or in volumetric terms, as the quantity of material added to, or lost from, the coast. Most reports of coastline advance or retreat have been based on linear or areal measurements, but reference will be made to attempts to assess 'sediment budgets' in terms of volumes of material eroded, transported and deposited within a coastal environment: there have actually been very few of these (cf. Figs 39, 43). Volumetric studies are easy to advocate, but in practice the difficulty of mapping and measuring changes in the nearshore zone, and out on the sea floor, has hampered attempts to quantify sediment movement, and

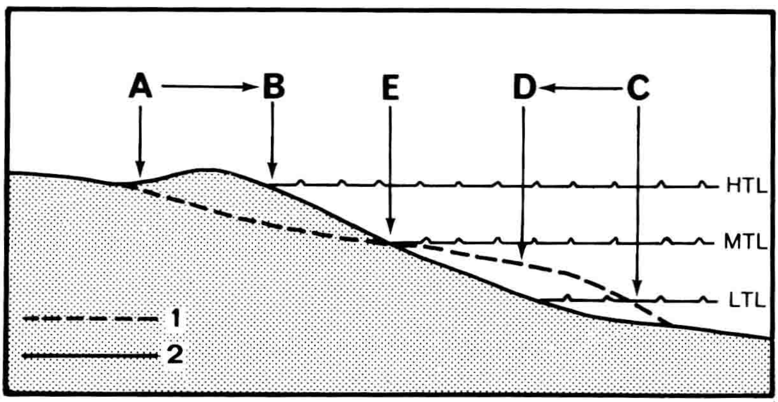

Fig. 4 Shorelines can be defined as the water's edge at various stages of the tide (e.g. high tide level, mid-tide level, and low tide level, as shown here). They may all advance seaward on a prograding coast, or retreat landward on a retrograding coast, but independent migrations can occur. Thus an advance of the coastline (high tide shoreline) from A to B may be accompanied by a retreat of the low tide shoreline from C to D, with no change at mid-tide level. In order to avoid such difficulties, coastline changes are measured as advance or retreat of the high tide shoreline, unless changes within the inter-tidal zone (e.g. on salt marshes) are specifically considered

assessments which treat offshore changes as a 'balancing item' achieve only a partial understanding of the coastal system. In general, coastline changes have been expressed in terms of linear or areal measurements, usually given over specified periods (e.g. 1925–78) determined by the dates of the maps, charts or photographs used, and sometimes expressed as annual averages (e.g. 2.5 metres per year). Annual averages can indicate only the mean trend, for rates of coastline change are often highly variable, with most variation occurring in stormy periods or episodes of coastal flooding by rivers or by the sea. Repeated surveys of low-lying coasts have often shown alternations of advance and retreat, with a resulting gain or loss, or perhaps no net change, over periods of a decade or more.

The problems encountered in using historical maps and charts as evidence of past coastline configuration have been summarized by Johnson (1925) and Carr (1962). Firstly, there is the question of technical accuracy at the time of the original survey, depending on the methods and instruments employed. Maps made before 1750 are generally unreliable, variable in scale and incorrect in detail, but after the introduction of triangulation by theodolite in the late eighteenth century accuracy improved. Nevertheless, errors persisted. Carr quoted an example from the first edition of the British Ordnance Survey map (1809) of part of North Devon which showed a rocky cliff a quarter of a mile *landward* of its 1960 position, commenting that a change of this kind would possibly have been accepted as evidence of progradation in the intervening period had this been on a low-lying sandy coastline. There are also mistakes made by cartographers when the map was being drafted, especially where accurate portrayal of the coastline was not essential for the purposes of the original map.

Secondly there is the problem of partial revision, when a new edition of a map retains some unrevised outlines from its predecessor. Coastal configuration may thus be shown as unaltered when in fact a change had occurred by the time the new edition was produced. In some cases the date on a map is the date of drafting or publication, rather than the survey on which the map was based.

Hydrographic charts are intended to show the pattern of navigable waters and the locations of hazards to shipping, and they are often inaccurate or out of date in portraying the coastline, especially where it is low-lying and the nearshore zone broad and shallow. Coastlines are usually more accurate on land maps, but these may be unreliable in showing inter-tidal features, especially low-tide shorelines, which are generally submerged and less easily surveyed and revised than features on land. The inter-tidal zone is still in many respects a no-man's-land where there is scope for the improvement of techniques of field surveying, remote sensing, and cartographic representation: the evidence for past positions of inter-tidal shorelines is much less reliable than the relatively easily mapped land margin, the coastline.

Finally there are the changes that occur after the publication of a map or chart, notably the stretching, shrinkage or distortion of the paper on which it is printed or on to which it has been copied by photographic or other methods. These effects can be minimized by the use of more stable materials, and by storage in dry, constant-temperature environments, but while this may provide more accurate data in the future it cannot make good the depredations of the past. In some cases it may be possible to retrieve the accuracy of a distorted historical map, if the original survey data can be found and used in re-drafting.

In recent decades, mapping has been based increasingly on air photography, using photogrammetric methods (with field checking of the nature, location, altitude and spacing of ground features) to produce original maps and charts, or to revise earlier surveys. Modern maps are usually more accurate than their predecessors, produced entirely by field surveys, and when they are used in the study of coastline changes it should be possible to refer back to the original air photography to check details and verify measurements (Stafford, 1972; El Ashry, 1977).

Measurements made from air photographs must also take account of internal scale variations due to (1) radial distortion towards the margins of the photograph, so that measurements should preferably be made from photographs where the features concerned are centrally placed; (2) relief distortion due to the portrayal of a variable surface topography on a flat plane, which is more of a problem on steep or cliffed coasts than on low-lying beach-fringed, swampy or deltaic coasts; and (3) tilt distortion where the airborne camera was not strictly vertical when the photography was taken, or where scale variations in a run of air photographs result from an ascent or descent of the aircraft. As with maps, there are errors introduced by stretching, shrinkage or buckling of the film or the printed photography.

In some cases it has been possible to make corrections for these various errors by using stereographic plotting instruments that can readjust distorted imagery with reference to the spatial distribution of ground control points. One must be sure that these points remained unchanged over the period of study: variations due to road widening, fence realignment, modifications of buildings and growth of tree canopies can lead to error when coastline changes are measured with reference to them (Fisher and Regan, 1978).

Despite enthusiastic advocacy of the value of satellite imagery in coastal studies on the part of agencies producing this material, it has so far proved to be of limited use in measuring coastline changes. The dimensions of pixels, unit areas of remote sensing, determine the precision with which a coastline can be located, for irrespective of the position of the coastline a pixel records land if 50% or more of its area of land. On the one hand a slight advance of a coastline may increase the land area within a pixel from 49% (recorded as sea) to 51% (recorded as land), the satellite imagery registering an apparent advance by the width or breadth of a pixel. On the other hand a substantial advance of a coastline, from halfway across one pixel to almost halfway across the next, will fail to register on satellite imagery. As Landsat imagery used pixels of approximately 60 metres by 80 metres, successive imagery cannot demonstrate changes within ±30 metres to ±40 metres, so that only the most rapid and extensive changes can be detected. Satellite photography has proved useful in estimating *areas* of land gained or lost, for example on the deltaic islands of the Bangladesh coast (Polcyn, 1981), and changes in the area covered by glaciers in Alaska and on the margins of Antarctica, but it is necessary to use conventional air photography to map the actual advance or retreat of coastlines accompanying such gains or losses. Undoubtedly techniques of mapping linear features from satellite imagery will improve, but in the meantime conventional air photography has been of much more value in detecting and measuring coastline changes than remote sensing from satellites.

DOCUMENTED COASTLINE CHANGES

A great deal of information on the advance and retreat of the world's coastline exists in the form of widely scattered published and unpublished material, much of the latter being held in the archives of national, provincial and local government departments, particularly land survey, port authority and coastal engineering divisions. Geologists, geomorphologists and engineers have long been aware of coastal changes in progress, but systematic studies have been sporadic. In the classic works of Gulliver (1899) and Johnson (1919) there are few references to actual measurements of coastline advance or retreat, and most subsequent textbooks of coastal geomorphology have given greater emphasis to general and theoretical modes of coastal evolution than to the documentation and analysis of actual changes.

One of the most comprehensive accounts of coastline changes was that assembled by the Royal Commission on Coast Erosion in Britain, which drew upon the numerous local reports of the extent and rate of erosion and accretion on the British coastline in the nineteenth century to produce two volumes of evidence (1907, 1909) and a report presenting conclusions (1911). The Royal Commission had set out 'to reach some conclusions with regard to the amount of land which has been lost in recent years by the encroachment of the sea on the coasts of the United Kingdom* and to the amount which had been gained by reclamation or accretion from the sea'. Evidence of changes during the previous century was sought from comparisons of Ordnance Survey maps of various dates, chiefly on the scale of 6 inches to the mile (1 : 10,560) and 25 inches to the mile (1 : 2534), and from information provided by local authorities and private individuals, notably coastal landowners. This was an unprecedented attempt to measure coastline changes on a national scale, and it still remains the most comprehensive study on such a scale in the coastal literature.

The Ordnance Survey provided data on areas of land gained or lost, based on measurements of changes in the position of the high tide line shown on early nineteenth-century surveys and on the most recent revisions then

* The United Kingdom then included all of England, Wales, Scotland and Ireland.

available, dating from the 1890s and the early 1900s. One difficulty was that until 1868 in England, and 1889 in Ireland, the surveyors had mapped the upper and lower limits of ordinary spring tides, but subsequently they used high and low mean tide lines in coastal survey work. Comparisons of maps showing the high spring tide shoreline with those showing the mean high tide shoreline led to over-estimates of land gains and under-estimates of land losses, and in places minor gains were recorded where in fact there had been no change, or even a slight land loss.

Despite these problems the results were considered worth tabulating on a county basis. They showed that Yorkshire, for example, lost 774 acres (313 hectares) between 1848 and 1893, much of it from the cliffed coastline between Bridlington and Spurn Head (identified as one of the more rapidly eroding sectors in Britain), but in the same period gained 2178 acres (881 hectares) by accretion and reclamation, mostly around the Humber estuary. Suffolk lost 518 acres (209 hectares) by erosion and gained only 151 acres (61 hectares) by accretion and reclamation during the period 1879 to 1904, but in general the land that had been gained in estuarine areas exceeded that lost, mainly from coastlines exposed to the open sea. Totalled by countries, the results are shown in Table 1, and showed a substantial excess of land gained by accretion and reclamation over losses of erosion, but if attention had been confined to 'outer coastlines', directly exposed to wave attack from the Atlantic Ocean, the North and Irish Seas, and the English Channel, land lost by erosion greatly exceeded land gained by deposition and reclamation, despite the extensive construction of sea walls and groynes to counter erosion (Sherlock, 1922). The discrepancy is because there had been such extensive land gains by siltation and reclamation within inlets and estuaries, especially around the Wash.

	Land gained (ha)	Land lost (ha)	Net change (ha)
England and Wales	14,344	1,899	+12,445
Scotland	1,904	330	+1,576
Ireland	3,178	458	+2,719
Totals:	19,426	2,687	+16,738

Source: Data compiled by the Royal Commission on Coastal Erosion (1911) for a period averaging 35 years in the nineteenth century.

The Royal Commission also received from the Ordnance Survey measurements of changes in the width of the shore, based on variations in the position of high and low tide lines between early and late nineteenth century surveys. These indicated a reduction in shore area around Britain during that period, implying that the transverse gradient of the inter-tidal zone had steepened. However, changes in the definition of tidal limits used by surveyors, mentioned above, and limitations in the accuracy of field surveys, especially of low tide alignments, make this conclusion doubtful.