

## ANTHROPOGENIC IMPACTS ON ESTUARIES

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### Contents

1. Introduction
  2. Physical impacts
    - 2.1 Direct impacts on the physical environment(geomorphology and hydrology)
      - 2.1.1 Embankments/Quays/Jetties
      - 2.1.2 Training walls
      - 2.1.3 Dredging
      - 2.1.4 Reclamation
      - 2.1.5 Siltation and Dumping
      - 2.1.6 Barrage and weir construction
      - 2.1.7 Marine resource exploitation—kelp grids, fish traps
      - 2.1.8 Mouth manipulation
      - 2.1.9 Artificial salt marsh
      - 2.1.10 Managed retreat
    - 2.2 Indirect physical impacts
      - 2.2.1 Stream impoundment and water abstraction
      - 2.2.2 Boat movements
      - 2.2.3 Growth of cultural resource
  3. Chemical impacts
    - 3.1 Water Column Impacts
    - 3.2 Sediment impacts
    - 3.3 Animal and plant tissue
  4. Biological changes
    - 4.1 Fish farming
    - 4.2. Exploitation of natural stocks
    - 4.3. Ecosystem manipulation
  5. Aesthetic changes
  6. Discussion
- Glossary  
Bibliography  
Biographical Sketch

### Summary

Anthropogenic modification of the estuarine environment can take place through a number of varied activities that have changed with time and vary from one location to another. Modification of the physical, chemical, biological and aesthetic elements of estuaries is possible and the major impacts in each of these categories are described. Each of the impacts may produce additional impacts that relate to other elements of the

estuarine ecosystem and while this is often recognised qualitatively little research has been undertaken that quantitatively links various forms of modification. Temporal variation in the extent and nature of estuarine modification is shown to be largely dependent on changing socio-economic conditions and many estuaries contain a long record of human modification that is now part of the maritime archaeological resource. Trends toward increased leisure time and growing environmental awareness characterise current trends in modification of estuaries and the resulting growth in conservation initiatives and recreational activity place new anthropogenically-stimulated stresses on the estuarine ecosystem.

## 1. Introduction

Estuaries form where terrestrial drainage systems meet the sea and waters of terrestrial origin meet with those of marine origin. The resulting mixing of the two water types in a confined basin produces brackish water conditions and sets up circulation and depositional patterns that are distinctive of estuaries. The high variability of receiving basin morphologies coupled with variable marine and freshwater discharge characteristics means that estuaries vary greatly in form from one location to another. They range from large coastal plain systems to small, incised valley systems and from deep stratified systems to shallow well mixed water bodies.

Latitudinally estuaries show great variability and their morphology is often influenced by the type of vegetation that grows in them. Mangroves, which are typical of the tropics, are known to produce distinctive channel patterns and progradational shorelines whereas seasonal freezing in high latitudes gives rise to distinctive ice-push features at estuary margins. Temperate estuaries are frequently characterised by salt marsh vegetation and associated landforms. A number of classification schemes have been devised that seek to identify various types of estuary and account for the differences between them. These are based on many different parameters such as tidal range, relative sea level history, sedimentation rates, climatic setting, freshwater discharge characteristics and coastal morphology.

Estuaries also vary greatly with time and are constantly undergoing change in response to natural processes. Sedimentation or sea level fall tends to reduce the volume and tidal prism of an estuary whereas sea level rise, if not matched by equivalent sedimentation rates, tend to 'drown' or deepen estuaries. State-of-the-art reviews of the natural processes of estuarine evolution illustrate that estuarine evolution occurs at a variety of timescales from progressive changes that have occurred since estuarine genesis at the beginning of the Holocene through changes associated with climate change, and sea level variability over the past few centuries, to changes involving regular tidal cycle variability. Recently there has been an increased recognition of the role of episodic events in estuarine behaviour as extreme storms or river floods may produce impacts that require several years or decades of recovery time.

The unusual characteristics of estuaries imparted to them by their transitional position between freshwater and the sea, provide a range of physical conditions in which distinctive estuarine ecosystems develop. Estuaries typically produce 10 to 25 grams of dry organic matter per m<sup>2</sup> per day compared with 1 in the open sea and 0.5 to 3 in coastal waters. Organisms that inhabit these ecosystems rely on the rich food resources

and rapidly changing and therefore stressful environmental conditions in estuaries to out-compete other organisms, and many marine and freshwater organisms consequently spend the juvenile phase of their development in estuaries where a good food supply and low abundance of predators favours survival.

The same characteristics that lead to development of rich estuarine ecosystems, caused humans to make use of estuaries as early as the Mesolithic (and probably beforehand) for their food resources and the history of human use (and alteration) of the estuarine environment has continued since then. Perhaps the major influence on estuarine morphology has been associated with their use as ports whereby they provided sheltered locations for loading and unloading boats and providing access between terrestrial drainage systems and the sea. The history of associated urban development has modified many estuaries and the fact that many major cities are located on estuaries bears testimony to the extent of human modification since early times.

Estuaries, by virtue of their transitional nature between river catchments and the marine environment, are susceptible to anthropogenic impacts from geographically diverse sources that range from the limits of river catchments to distant marine sources. They are also historically, sites at which human activity has been focussed, albeit at different levels of intensity and involving temporally differing activities.

It is important to note, however, that given the diversity of estuary forms and processes that the potential for anthropogenic alteration may vary in extent and nature between estuaries. For example, large, macrotidal estuaries present a much greater potential for reclamation of intertidal flats than do small microtidal systems; small barred estuaries are more susceptible to interference in their fluvial hydrology than are large, tidally-dominated systems. This variability should be borne in mind when considering the extent of human alteration.

Humans can alter the estuarine environment in many different ways and with effects that require many different scientific disciplines in their assessment. The nature and impact of the main anthropogenic-related changes in estuaries is addressed below in terms of the primary nature of impacts on the environment. The impacts are considered initially in terms of their origin and are subdivided into physical, biological, chemical, and aesthetic categories.

## **2. Physical impacts**

Physical changes in estuaries as a result of human activities may be divided into two categories: direct impacts and indirect impacts. Direct impacts are those that are undertaken within the estuary area and which produce physical changes in the system. Indirect impacts are those that occur on the physical environment as a result of activities elsewhere in the marine, or riverine system or through other activities. Most of these impacts result from the incompatibility between most types of human activity and a physically changing environment.

### **2.1 Direct impacts on the physical environment(geomorphology and hydrology)**

#### **2.1.1 Embankments/Quays/Jetties**

Estuaries have been of use to humans through the fact that they provide ready access to the sea via ports and deepwater channels. This access in macrotidal estuaries in particular may be impeded by the presence of intertidal flats and thus many tidal flats have been reclaimed behind embankments built on the margins of the deep water channels. As ports develop, these embankments may become more and more complex and may assume a variety of forms from quays at which ships may tie up to various docks and jetties to facilitate ship handling and repair. Ship building activities have frequently been the catalyst for major engineering works that modify estuarine shores.

Alternative motivations for construction of embankments relate to processes of coastal erosion or periodic flooding on the margins of estuaries that may begin to threaten infrastructure associated with human activities. In either instance, the construction of embankments has been undertaken to stabilise the estuary margins and/or to prevent overtopping of the estuary bank during high water levels associated with storms or river floods. Many such embankments are of considerable antiquity and in some estuaries such as the Severn (Great Britain) a distinctive sequence of embankments records several phases of new defences that date from the Roman period up to the present and which were constructed in response to changes in sea level.

The impacts of such embankments are to introduce a fixed boundary where previously the shoreline was free to migrate and to impound water that previously could expand laterally. Such constraining of the natural processes of estuarine geomorphological and hydrological behaviour may induce secondary impacts in the estuary. Wave action which may formerly have been reduced through breaking and accomplishing erosion is now contained within the estuary leading to a more energetic environment (with potential knock-on effects elsewhere) and water too is contained within the basin so that overbank sedimentation is now confined to the margins of the estuary, thus potentially accelerating sedimentation rates and even changing patterns of sedimentation.

While much embankment construction relates to previous phases of estuarine modification, a recent growth in the number of recreational marinas in estuaries has provided the impetus for further modification of the estuarine shoreline.

### **2.1.2 Training walls**

The mouths of estuaries with their associated sand bodies have frequently been regarded as hazardous for navigation as the positions of submerged shoals changed with time and the position of estuary mouths has varied with time.

As a consequence, the mouths of many estuaries have been stabilised through the construction of training walls (jetties) designed to fix the mouth position.

These training walls often have the desired effect of stabilising the mouth position but they seldom produce a more navigable channel as sedimentation still occurs around the fixed inlet, and this has to be addressed by dredging (see below). Training walls may have further undesirable effects as they interrupt potential longshore sediment transport and may result in sediment accumulation on the updrift margin and concomitant erosion

on the downdrift side of the inlet. Numerous examples from the barrier island coast of Florida (USA) illustrate the difficulties associated with stabilisation of tidal inlets.

### 2.1.3 Dredging

Utilisation of estuaries as ports necessarily requires that the main shipping channels be sufficiently deep to cope with the draft of vessels using that port. As vessels change in size over time, there may be a temporally variable requirement for deeper channels and most major harbours are periodically dredged. The widespread use of dredging is evidenced by the fact that the US Army maintains a dredging operations technical support program with its own newsbrief.

The impacts of dredging are numerous because not only does this activity physically disturb the bottom sediments and the organisms that live within or on it, but the deepening of the channel will produce changes in hydrology that influence for example water velocity, stratification and turbidity. Disposal of the dredge spoil poses further problems as the dredged material may be contaminated (dredging may also release previously bound compounds) or be fine grained and difficult to dispose of without adverse effects at the dumping site (smothering existing benthic environments, introducing contaminants, altering sediment budget).

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### Biographical Sketch

**Dr Andrew Cooper** is a coastal geologist who has worked on the coast and estuaries of southern Africa, western Europe and North America. His main research has been on the evolution of the coastal zone under natural and human forcing mechanisms, in which field he has published more than 100 articles. He is currently head of the coastal research group at the University of Ulster and course director of the virtual (e-learning) MSc programme in Coastal Zone Management.