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Introduction

The *Oxford English Dictionary* allows two meanings of the word ‘lagoon’: an area of salt or brackish water separated from the adjacent sea by a low-lying sand or shingle barrier; and a lake-like stretch of water enclosed in a coral atoll. The term coastal lagoon refers to the first of these two situations.

That a volume written and published in England should be devoted to coastal lagoons may at first occasion some surprise as there are relatively few examples of this type of habitat in the British Isles. It has been estimated by Cromwell (1971), however, that ‘features less than 10 m above sea level . . . which are impounding, or have at one time impounded, bodies of water between themselves and the mainland’ occupy 13% of the world’s coastline. Of this total, 34% is contributed by North America; Europe only has 5.3% of its coastline assignable to this category and is the continent with the lowest proportion of lagoonal coast (Table 1.1.).

Table 1.1. *Extent of the world’s barrier/lagoonal coastline.*
From Cromwell, 1971

<table>
<thead>
<tr>
<th>Continent</th>
<th>Length (km) of barrier/lagoonal coastline</th>
<th>% of continent’s coastline so formed</th>
<th>% of world’s lagoonal coast</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>10765</td>
<td>17.6</td>
<td>33.6</td>
</tr>
<tr>
<td>Asia</td>
<td>7126</td>
<td>13.8</td>
<td>22.2</td>
</tr>
<tr>
<td>Africa</td>
<td>5984</td>
<td>17.9</td>
<td>18.7</td>
</tr>
<tr>
<td>South America</td>
<td>3302</td>
<td>12.2</td>
<td>10.3</td>
</tr>
<tr>
<td>Europe</td>
<td>2693</td>
<td>5.3</td>
<td>8.4</td>
</tr>
<tr>
<td>Australia</td>
<td>2168</td>
<td>11.4</td>
<td>6.8</td>
</tr>
<tr>
<td>Total</td>
<td>32038</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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There are particularly extensive series of lagoons along the eastern and Gulf-of-Mexico coasts of the USA, in Mexico itself, in Brazil, West Africa, Natal, the southern and eastern shores of the Indian peninsula, south-west and south-east Australia, Alaska, Siberia, in the Landes region of France, around the Mediterranean (e.g. near Venice, in the Gulf of Lions and around the Nile Delta), and around the southern Baltic, Black and Caspian Seas (Fig. 1.1). All regions, it may be noted, with a low tidal range. In Britain, small lagoons are relatively common in East Anglia and in the south and south-west.

Comparatively easy as it may be to identify exceptional areas of lagoonal coastline, it is undoubtedly more difficult to decide which natural features may properly be considered lagoons. This results from the leeway permitted by the words 'separated' and 'impounded' in the definitions above. Because of the requirement for their water to be marine, or at least brackish, lagoons are rarely completely isolated from the sea. Characteristically, they have a channel (or series of channels) through which water is exchanged with the larger adjacent water body, although in some small lagoons exchange may be effected only by percolation through the confining barrier. On complete isolation, the contained water usually becomes fresh (e.g.

Fig. 1.1. World distribution of barrier/lagoonal coastlines. After Leont'ev & Leont'ev, 1957 and Gierloff-Emden, 1961.
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Slapton Ley in Devon and several of the Landes lagoons) and the lagoon evolves into a freshwater coastal lake or pond (see p. 14).

Therefore lagoons are only semi-isolated systems, permitting differences of opinion on the extent of separation required for the granting of lagoonal status. Some authors, for example, describe the wadden areas delimited by the Frisian Island chain which extends along the south-eastern shore of the North Sea (Fig. 1.2a) as being lagoons, although effectively the waddens are only very sheltered, shallow regions of the North Sea and they are more reasonably regarded as part of the marine environment. The many, relatively large gaps between the barrier islands suffice to prevent the establishment of a separate system. The typical lagoon has an entrance channel which is very small in relation both to the size of the lagoon itself and to the length of the barrier (Fig. 1.2b), down to the limiting state of no discrete channel at all (Fig. 1.2c).

Essentially similar to the latter, although with no permanent connection with the sea, are the small lagoons entrapped by movements of sedimentary material in growing spits, deltas (Fig. 1.2d) or similar geomorphological features. These are relict systems which, whilst they persist, show resemblances both to lagoons and to pans on salt-marshes and lakes in dune systems which may only communicate with the sea on an irregular temporal basis. Man has created equivalent lagoons during the reclamation of coastal marshes (Hunt, 1971; Barnes & Jones, 1975).

Lagoons, therefore, as one might expect, grade into other coastal habitat types: into semi-enclosed marine bays, into freshwater lakes, and into estuaries; and some of these intergradations may represent stages in an evolutionary sequence (pp. 7–19). Any attempt at rigid compartmentalisation will therefore be to a large degree artificial and arbitrary. Although the typical estuary and the typical lagoon are very different, the boundary between various habitat types is here at its most insubstantial and the two environments share many ecological features. Several differences are characterised on pp. 20–53, but from a gross geographical viewpoint, the matter, once again, ultimately comes down to the relative width of the entrance/exit channel (and the volume of freshwater or tidal input, which of course are inter-related). Estuaries, although often partially enclosed by a shingle spit, have relatively wide mouths and a large exchange or through-put of
Fig. 1.2. a. The Dutch/German Waddenzee (as it was before enclosure of the Zuiderzee) partially isolated from the North Sea by the Frisian Island chain. b. A lagoon with a single, narrow entrance channel: a composite diagram of the lagoons occurring on the shores of the Chukchi Sea, Eastern Siberia. Length may be 2–30 km. c. Isolated lagoons near Novorossiysk on the Black Sea; in general shape they are typical of the lagoons around the Eurasian Inland Seas. d. Isolated ephemeral lagoons in the Ebro Delta, eastern Spain, after Ferrer & Comin, 1979.
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Fig. 1.3 a–c. Lagoon systems enclosed by offshore barrier-island chains in the USA: a, Long Island, New York; b, Pamlico and Albemarle Sounds, N. Carolina; c, the Laguna Madre and associated lagoons, Texas. d. A lagoon enclosed within the land: the Lagoa dos Patos between Porto Alegre and Rio Grande, Brazil.
water in relation to their volume, whilst lagoons have relatively small mouths and little exchange or through-put. A number of geographers have distinguished between ‘estuarine lagoons’ into which rivers discharge and ‘marine lagoons’ without a major, running freshwater input, but biologically this distinction does not really seem to be warranted. A further characteristic of lagoons is their frequent alignment with their long axis parallel to the shore (Figs. 1.2b, 1.3a, c, d), a feature rarely shown by estuaries, although where drowned river valleys or small estuaries have been blocked by shingle ridges, lagoons may extend perpendicularly to the shoreline (p. 13).

Lagoons can indeed be classified on the basis of their salinity, or on substratum type, mode of formation (pp. 7–14), etc., but in many ways the most useful distinction relates to their degree of isolation, to the diversity of sub-habitats which they contain, and often to their size. This classification separates those lagoons impounded by an offshore barrier-island chain (Figs. 1.3a–c) from those enclosed by alongshore bars and spits (Figs. 1.2b, c, 1.3d). In nature, the former are nearer to enclosed bays, and the distinction between the North-Sea waddens (Fig. 1.2a) and the Gulf-of-Mexico lagoons (Fig. 1.3c), for example, is clearly only a matter of degree, whilst the more inland systems isolated by longshore barriers approximate the lakes and ponds into which they may ultimately evolve.

Within this framework of bay- or lake-like systems, semi-isolated by a barrier of sand or shingle, lagoons range in size from small pools only some tens of metres in length to huge inland ‘seas’ like the Lagoa dos Patos (Fig. 1.3d) in southern Brazil, which is 265 km long, and to extensive lagoon-systems exemplified by those along the eastern and southern shores of the USA which permit 4500 km and 1000 km, respectively, of uninterrupted navigation in quiet sheltered lagoonal waters. In contrast, the largest lagoon in Britain, the Fleet, Dorset, is only some 14 km long.

Their size and abundance, and their fisheries interest (pp. 69–70), make lagoons a very important habitat to man, and, even in Britain, a considerable amount of research has been devoted to them, although, sadly, only a small fraction of this has been biologically oriented.
Formation and fate of lagoons

Lagoons, especially the smaller ones, are rapidly changing, highly dynamic systems and their biology cannot be understood except within the framework of their formation, evolution and subsequent decline. Accordingly, this chapter will investigate their geographical and geological history. It will be evident from the previous chapter that the story of a lagoon is intimately connected with the barrier enclosing it – one cannot have one without the other – and hence we must start by looking at the barriers themselves.

2.1 Enclosure of lagoons by offshore barriers

Although many barriers have had a composite origin, it is convenient to consider the formation of offshore and longshore barriers separately. Offshore bars and barriers are produced by wave action on shallow, gently shelving sand coasts (or those comprising mixed sands and pebbles). Wave action may be of two types, constructive and destructive. Constructive waves plunge obliquely up a beach, generating a powerful swash but a relatively small backwash; destructive waves, on the other hand, plunge more vertically downward, creating a small swash but a powerful backwash. Constructive waves therefore tend to move sediment up an incline, whilst destructive waves move material down slope (see, e.g., King, 1972, for further details). When constructive waves enter shallow water they begin to break and their shoreward motion and swash move particles of sediment towards the coast, and when waves begin to break some distance offshore, a bar is formed there by this deposited sediment. Sand is, as it were, swept from offshore deposits in lines parallel to the coast which accumulate and merge in the breaking zone.

During the last 15000 years or so, sea level has risen some 100 m (although changes in the last 5000 yr have been minor). This has had
Formation and fate of lagoons

the effect not only of drowning low-lying areas, but also of permitting the sweeping action of constructive waves gradually to roll large quantities of material up the gentle slopes so that the barriers contain more material than they would have done had sea level been constant during this period. It is also possible that some barriers have received sand blown landward by wind during times of falling sea level (i.e. some 60,000 yr ago). Once the collected material is sufficient to extend above the water level, it can also, e.g., during low tide in relatively tidal areas, receive additional quantities of sand wind-blown from the intertidal zone so that sand-dunes may develop on the crest.

The length of the barriers will depend on shoreline and subtidal topography, but very long barriers may be formed – Padre Island, enclosing the Laguna Madre in Texas, is 200 km long, and a 600 km barrier, admittedly with some gaps in it, extends along the western coast of Kamchatka. Sand is the most common barrier material, though shingle, which because of its weight is less easily moved, does participate in some offshore barriers (especially those formed by storm waves). It is more abundant, however, in the longshore barriers considered below.

If offshore barriers are long enough to seal or effectively seal shallow coastal bays, lagoons are thereby formed from the erstwhile intertidal and shallow subtidal regions. A good example of the incipient enclosure of a lagoon by such a barrier may be seen off the North Norfolk coast between Holkham and Wells.

2.2 Enclosure of lagoons by longshore barriers

If the coast is steeply sloping, waves will break on the beach and not offshore. Waves also do not always approach parallel to a beach, and the effect of striking a beach at an angle is to move material along it. The swash of constructive waves approaching at an angle will move water and sand up the shore at the angle of attack, but the backwash will be directed, by gravity, perpendicularly to the shoreline, creating a longshore drift of sand (or shingle) (Fig. 2.1).

Particularly importantly for the cases under consideration here, material moved along a coast tends to maintain the alignment of that stretch of coast, even though the shoreline itself may change orientation. Thus spits form out across inlets or bays of the sea (Fig. 2.2a) and these spits, like offshore barriers, may be very long (spits
2.2 Enclosure by longshore barriers

in the Black and Caspian Seas achieve lengths of 70–100 km) and may seal off bays to form lagoons (Fig. 2.2b). Of course, material may move along offshore barriers, thereby joining together barrier islands formed separately, in exactly the same way and offshore barriers may

Fig. 2.1. Diagram to illustrate the process of longshore drift.

Fig. 2.2. a. Semi-diagrammatic representation of the northern spit partially enclosing Poole Harbour, Dorset, showing the alignment of the spit in relation to that of the coastline along which material is drifting. b. Spits enclosing lagoons on the Baltic-Sea coasts of Poland, the Russian SFSR and the Lithuanian SSR.
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become attached to the coast at headlands, etc. So compositely formed barriers are common.

It is here that the importance of tidal range, mentioned on p. 2, can be appreciated. Barriers, being constructed by wind-driven waves and currents, do not require tidal forces for their generation: indeed the opposite is often the case. Large tidal forces resulting from large tidal ranges can create breaches in sedimentary barriers and any breach formed will immediately be broadened by tidal currents rushing through the gap. The entrances between the barrier-island chain along the southern North-Sea coast (Fig. 1.2a) are maintained open by such tidal currents. The most perfect spits, therefore, are formed in tideless seas where water level is relatively constant.

Shingle is a more common constituent of spits, the material deriving from the erosion of cliffs updrift of the spit (Fig. 2.2a), from river discharges, and/or from material eroded from the land and deposited in the sea during glacial phases of the Pleistocene, subsequently to be moved ashore again by wave action.

2.3 Other processes of lagoon formation

Although most lagoons have probably originated by the processes outlined above, other evolutionary sequences may be locally important. Along coasts where the land is subsiding, for example, the sea may breach pre-existing barriers and flood low-lying ground. This may include volcanic craters, as in New Zealand. Secondly, some lagoons (e.g. along the eastern coast of Saudi Arabia) are considered to have originated as wave-cut terraces at times during the Pleistocene when sea levels were slightly lower than today; rising water levels and barrier development then formed shallow, flat-bottomed lagoons. Storms may also move masses of shingle from the ends of spits and deposit them on the mainland shore in such a manner as to enclose small lagoons (e.g. some of those at Shingle Street, Suffolk); and a combination of land subsidence, sediment redeposition and river channel changes may form equivalent lagoons in deltaic environments.

One of the more intriguing means by which small lagoons may be formed is illustrated in Fig. 2.3a. Here a spit developed (1) which was intersected subsequently by a second one formed by waves arriving from the opposite direction (2). After the enclosure of one lagoon,