LABRADOR CURRENT

See **FLORIDA CURRENT, GULF STREAM AND LABRADOR CURRENT**

LAGOONS

R. S. K. Barnes, University of Cambridge, Cambridge, UK

doi:10.1006/rwos.2001.0091

Introduction

A 'lagoon' is any shallow body of water that is semi-isolated from a larger one by some form of natural linear barrier. In ocean science, it is used to denote two rather different types of environment: 'coastal lagoons' (the main subject of this article) and lagoons impounded by coral reefs. Coastal lagoons are a product of rising sea levels and hence are geologically transient. Whilst they exist, they are highly productive environments that support abundant crustaceans and mollusks, and their fish and bird predators. Harvests from lagoonal aquaculture of up to $2500\,\mathrm{kg\,ha^{-1}\,y^{-1}}$ of penaeid shrimp, of 400 $\mathrm{tonnes\,ha^{-1}\,y^{-1}}$ of bivalve molluscs, and in several cases of $>200\,\mathrm{kg\,ha^{-1}\,y^{-1}}$ of fish are taken.

What is a Lagoon?

Coastal lagoons are bodies of water that are partially isolated from an adjacent sea by a sedimentary barrier, but which nevertheless receive an influx of water from that sea. Some 13% of the world's coastline is faced by sedimentary barriers, with only Canada, the western coast of South America, the China Sea coast from Korea to south-east Asia, and the Scandinavian peninsula lacking them and therefore also being without significant lagoons (**Table 1**, **Figure 1**). The lagoons behind such barrier coastlines range in size from small ponds of <1 ha through to large bays exceeding $10\,000\,\mathrm{km}^2$. The median size has been suggested to be about 8000 ha. Although several do bear the word 'lagoon' in their name, many do not. Usage of the same titles as for freshwater habitats is widespread (e.g. *Étang* de Vaccarès, France; Swan *Pool*, UK; Oyster *Pond*, USA; *Lake* Menzalah, Egypt; Benacre *Broad*, UK; *Ozero* Sasyk, Ukraine; Kiziltashskiy *Liman*, Russia, etc.), as is those for coastal marine regions (Peel-Harvey *Estuary*, Australia; Great South *Bay*, USA; Ringkøbing *Fjord*, Denmark; *Zaliv* Chayvo, Russia; Pamlico *Sound*, USA; Charlotte *Harbor*, USA; and even Gniloye *More*, Ukraine; *Mer* des Bibans, Tunisia; *Mar* Menor, Spain, etc.), whilst lagoons liable to hypersalinity are often termed Sebkhas in the Arabic-speaking world (e.g. Sebkha el Melah, Tunisia). Conversely, a few systems with 'lagoon' in their name fall outwith the definition; the Knysna Lagoon in South Africa, for example, is an estuarine mouth dilated behind rocky headlands between which only a narrow channel occurs.

Coastal lagoons are most characteristic of regions with a tidal range of <2 m, since large tidal ranges (those >4 m) generate powerful water movements usually capable of breaching if not destroying incipient sedimentary barriers. Furthermore, the usual meaning of 'lagoon' requires the permanent presence of at least some water and large tidal ranges are likely to result in ebb of water from open systems during periods of low tide in the adjacent sea. Thus in Europe, for example, lagoons are abundant only around the shores of the microtidal Baltic, Mediterranean, and Black Seas. However, they are also present along some macrotidal coasts – such as the Atlantic north of about 47°N (in the east) and 40°N (in the west) (**Figure 2**) – where offshore deposits of pebbles or cobbles ('shingle') are to be found as a result of past glacial action. Here, shingle can replace the more characteristic sand of microtidal seas as the barrier material, as indeed it partially does in the lagoon-rich microtidal East Siberian, Chukchi, and Beaufort Seas in the Arctic, because it is less easily redistributed by tidal water movements. Nevertheless, sandy sedimentary barriers have developed (and persisted) in a few relatively macrotidal areas (e.g. in southern Iceland and Portugal), although the regions impounded to landwards retain water only during high tide for the reasons outlined above. Those environments that are true lagoons only during high tide are often

Table 1 The contribution of different continents to the world total barrier/lagoonal coastline of 3200 km[a]

Continent	*Percent of coastline barrier/lagoonal*	*Percent of world's lagoonal resource*
N. America	17.6	33.6
Asia	13.8	22.2
Africa	17.9	18.7
S. America	12.2	10.3
Europe	5.3	8.4
Australia	11.4	6.8

[a](Reproduced with permission from estimates by Cromwell JE (1971) *Barrier Coast Distribution: A World-wide Survey,* p. 50. Abstracts Volume, 2nd National Coastal Shallow Water Research Conference, Baton Rouge, Louisiana.)

referred to as 'tidal-flat lagoons'. They are therefore the relatively rare macrotidal coast equivalent of the typical lagoons of microtidal seas.

In many cases, the salinity of a lagoonal water mass is exactly the same as that of the adjacent sea, although where fresh water discharges into a lagoon its water may be brackish and a (usually relatively stable) salinity gradient can occur between river mouth and lagoonal entrance channel. In regions where evaporation exceeds precipitation for all or part of a year, lagoons are often hypersaline.

The second environment to which the word lagoon is applied is associated with coral reefs; coral here replaces the unconsolidated sedimentary barrier of the coastal lagoon. Circular atoll reefs enclose the 'lagoon' within their perimeter, whilst barrier reefs are separated from the mainland by an equivalent although less isolated body of water. Indeed barrier reef lagoons are virtually sheltered stretches of coastal sea. Atoll lagoons, however, are distinctive in being floored by coral sand which supports submerged beds of seagrasses and fringing mangrove swamps just as do the coastal lagoons of similar latitudes. The similarity between the two types of lagoon is nevertheless purely physiographic since the atoll lagoon fauna is that typical of coral reefs in general and not related in any way to those of coastal lagoons. Coral lagoons are covered in greater detail in the article **Coral Reefs.**

The Formation of Lagoons

Lagoons have existence only by virtue of the barriers that enclose them. They are therefore characteristic only of periods of rising sea level, when wave action can move sediment on and along shore, and – for a limited period of time – of constant sea level. At times of marine regression, they either drain or their basins may fill with fresh water. Many

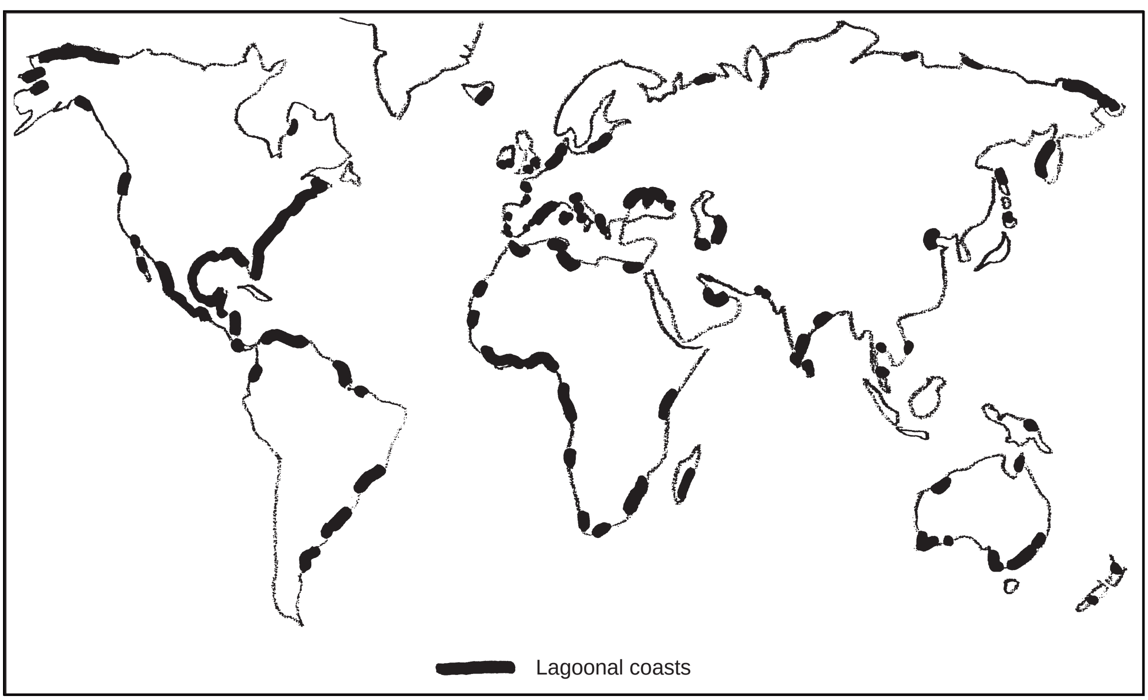

Figure 1 Major barrier/lagoonal coastlines.

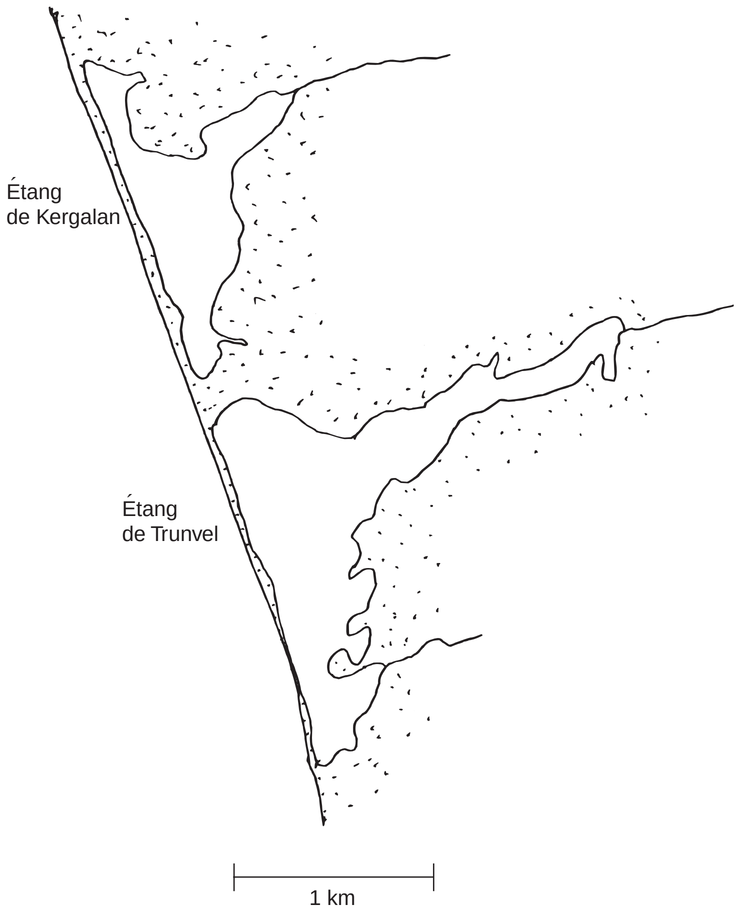

Figure 2 Shallow lagoons along the coast of the Baie d'Audierne (Brittany, France) formed behind a shingle barrier beach. Sea water enters these systems only via overtopping of the barrier; lagoonal water leaves by percolation through the barrier.

of the enclosing barriers have today been greatly augmented by wind-blown sand; for example, most of the larger systems along the South African coast (Wilderness, St Lucia, Kosi, etc.), and such enclosed lagoons have a particularly lake-like appearance (**Figure 3**).

The precise physiographic nature of a lagoon then depends on the relationship of the barrier to the adjacent coastline. Starting at a point at which the barriers are some distance offshore, we can erect a sequence of situations in which the barriers are moved ever shorewards. This starting point can be exemplified by Pamlico and Albemarle Sounds in North Carolina, USA (**Figure 4**). There a chain of long narrow barrier islands located some 30 km off the coast encloses an area of shallow bay of around 5000 km^2.

Further landwards movement of the barriers, often to such an extent that some of the larger barriers become attached to the mainland at one end to produce spits, leads to the situation currently characterizing most lagoonal coastlines and to the typical coastal lagoon. Sea water then enters and leaves these lagoons through the channels between the islands or around the end of the spit. More rarely, the lagoons are enclosed by multiple tombolos connecting an offshore island to the mainland, or even tombolos joining a number of islands (as, for example, in Te Whanga, New Zealand). With the exception of tombolo lagoons, the long axis of typical lagoons – and many are extremely elongate – lies parallel to the coastline. Typical coastal lagoons are especially characteristic of microtidal seas. They range in size up to the 10 000 km^2 Lagoa dos Patos, Brazil.

The abundant lagoons that occur within river deltas form a special case of this category. Several deltas (e.g. those of the Danube and Nile) have developed within – and have now largely or completely obliterated – former lagoons enclosed by spits and intervening barrier island chains. The filling of lagoons with sediment when they receive river discharge is an inevitable process and many surviving examples are but small remnants of their past extents (**Figure 5**) – islands of water in a sea of marshland. Some 5000 years BP, the Lake St Lucia lagoon in South Africa, for example, had a length in excess of 110 km and a surface area of nearly 1200 km^2; infilling with sediment has reduced the body of free water to a length of 40 km and an area of 310 km^2 (see **Figure 3**). Allowing for the shallowing that has also taken place, this is equivalent to an average input of 623 000 m^3 of sediment per year. Infill, coupled with barrier transgression via washover fans, is probably the ultimate fate of virtually all of the world's lagoons.

The next stage in the hypothetical sequence sees the barrier very close to the mainland, if not plastered onto it. This has several consequences, of which the first is impingement on emerging river systems. 'Estuarine lagoons', which as their name implies merge into estuaries, have formed where barriers have partially blocked existing drowned river valleys. For this reason they usually have their long axis perpendicular to the coastline. Even if blockage of the river is complete, lagoonal status may remain if sea water can enter by overtopping of the barrier during high water of spring tides. Nevertheless, many former estuarine lagoons are now completely freshwater habitats with seawater entry being prevented by the barrier. In many tropical and subtropical regions, closure of the estuarine lagoons is seasonal. During the wet season, river flow is sufficient to maintain breaches through the barriers. In the dry season, however, flow is reduced and drift can seal the barrier. If fresh water still flows, the

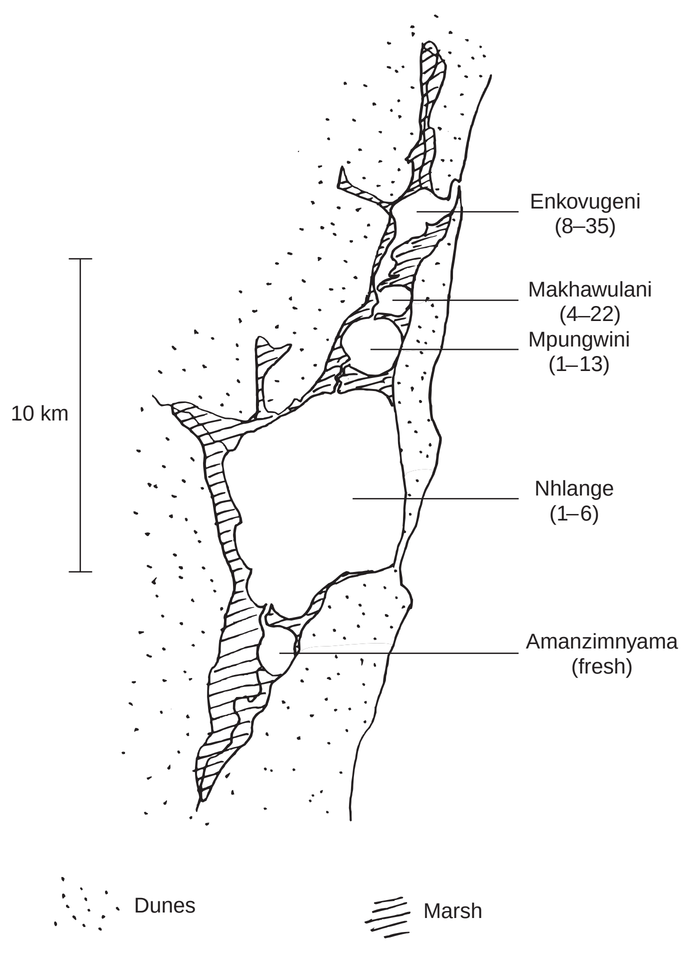

Figure 3 The Kosi Lakes (KwaZulu/Natal, South Africa), with approximate salinity ranges (in practical salinity units) in parentheses. They are enclosed within Pleistocene sand dune fields, and form a classic case of 'segmentation' of an original linear lagoon into a series of rounded basins. (Salinity data reproduced with permission from Begg G (1978) *The Estuaries of Natal*. Natal Town and Regional Planning Report.).

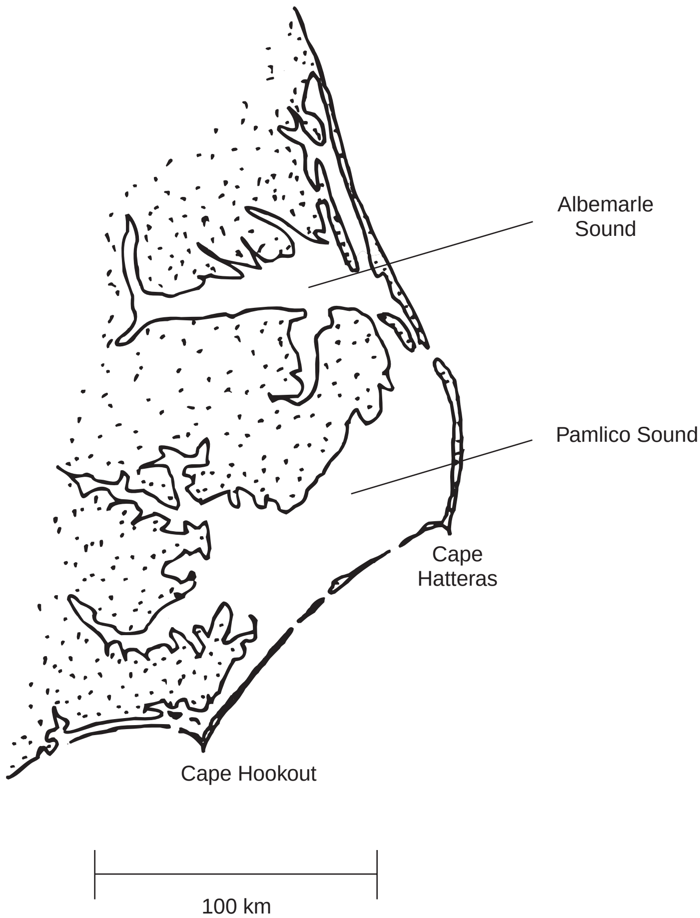

Figure 4 Pamlico and Albemarle Sounds (North Carolina, USA).

whole isolated basin then becomes fresh for several months. The mouths of many natural lagoonal barriers are periodically breached by man for a variety of reasons ranging from ensuring the entry of juveniles of commercially important mollusks, crustaceans, and fish to temporarily lowering water levels to avoid damage to property.

Longshore movement of barrier sediment may also divert the mouths of discharging estuaries several kilometers along the coast, as for example the 30 km deflection of that of the Senegal River by the Langue de Barbarie in West Africa, and the creation of the Indian River Lagoon in Florida, USA. Not infrequently a new mouth is broken through the barrier, naturally or more usually as a result of human intervention, and the diverted stretch can become a dead-end backwater lagoon fed by backflow.

Other consequences of onshore barrier migration also involve human intervention. Many small scale lagoons have (unwittingly) been created by land reclamation schemes. Regions to landwards of longshore ridges that were once, for example, low-lying salt marsh but which are now reclaimed usually receive an influx of water from out of the barrier water-table and this collects in depressions that were once part of the creeks draining the marshes. Equivalently, gravel pits or borrow pits in coastal shingle masses, from which building materials have been extracted, similarly receive an influx of water from out of the shingle. In both cases, the shingle water-table is derived from sea water soaking into the barrier during high tide in the adjacent sea together with such rainfall as has also soaked in. Some of the natural limans of the Black Sea coast also receive their salt input via equivalent seepage.

Finally in this category, barriers may come onshore in such a fashion as to straddle the mouth of a pre-existing bay. 'Bahira lagoons' (from the Arabic for 'little sea') are pre-existing partially land-locked coastal embayments, drowned by the postglacial rise in sea level, that have later had their mouths almost completely blocked by the develop-

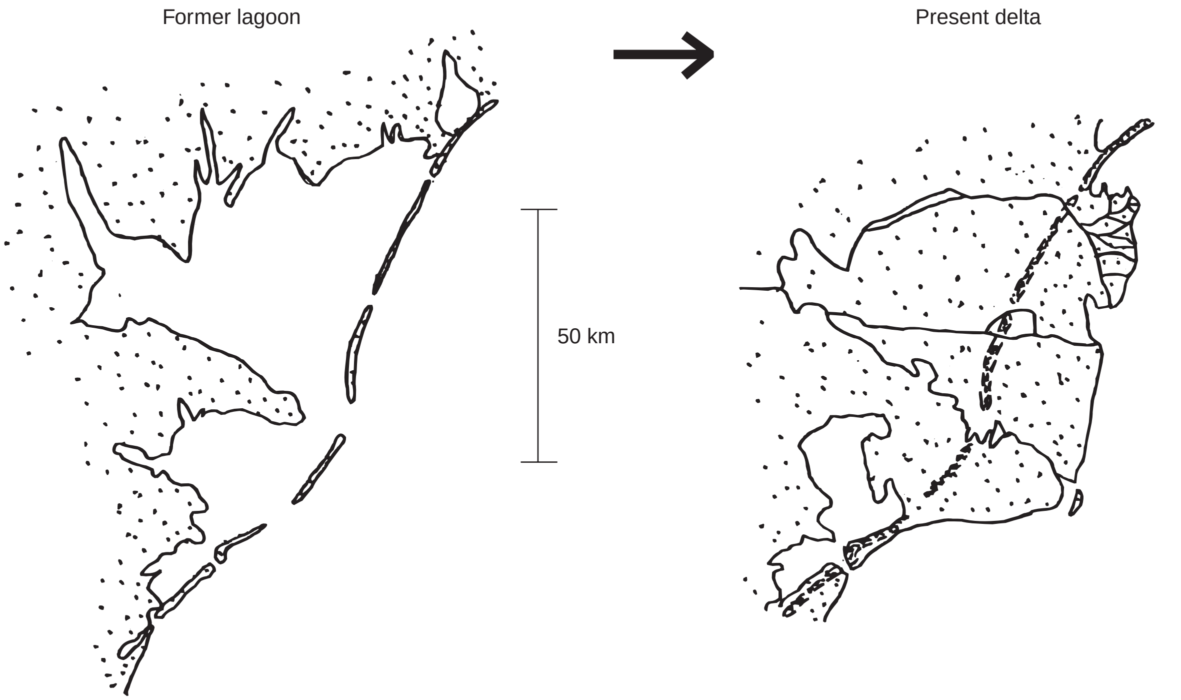

Figure 5 Infill of a former lagoon (established around 6000 years ago) on the Romanian/Ukrainian coast of the Black Sea with sediment carried by the River Danube. The current Danube delta occupies virtually all the former lagoon.

ment of sedimentary barriers. Also included here are systems in which the sea has broken through a pre-existing sedimentary barrier to flood part of the hinterland, but in which the entrance/exit channel remains narrow. Bahira lagoons clearly merge into semi-isolated marine bays.

Although lagoons may come and go during geological time, some of the larger lagoon systems are not solely features of the present interglacial period. Some, including the Lagoa dos Patos, the Gippsland Lakes of Victoria, Australia, and the Lake St Lucia lagoon, may incorporate elements of barriers and basins formed during previous marine transgressions. The history of the Gippsland lakes over the last 70 000 years has been reconstructed in some detail (**Figure 6**). Fossil assemblages of foraminiferans suggest that lagoons may have been a feature of the Gulf Coast of the USA and Mexico at intervals ever since the Jurassic.

Lagoonal Environments

It can be argued that the main force structuring lagoons is the extent to which they are connected to the adjacent sea, and they have been divided into three or four types on this basis (**Figure 7**) which largely reflect points along the hypothetical evolutionary sequence described above.

'Leaky lagoons' function virtually as sheltered marine bays (see also **Figure 4**). As a result of large tidal ranges in the adjacent sea or the existence of many and/or wide connecting channels, interactions with the ocean are dominant and the lagoons have tidally fluctuating water levels, short flushing times and a salinity equal to that of the local sea water.

'Restricted lagoons' have a small number of narrow entrance channels through elements of a barrier island chain or enclosing spits and are therefore more isolated from the ocean (see also **Figure 7**). Characteristics include: longer flushing times, a vertically well-mixed water column, both wind and tidal water movements as forcing agents, and brackish to oceanic salinity.

'Choked lagoons' are connected to the ocean by a single, often long and narrow, entrance channel that serves as a filter largely eliminating tidal currents and fluctuations in water level (see also **Figure 4**). The 1000 km^2 Chilka Lake lagoon, for example, communicates with the Bay of Bengal via a channel 8 km long and 130 m across at its widest. Choked lagoons are typical of coasts with high wave energy and significant longshore drift. Characteristics include: very long flushing times, inter-

Figure 6 Evolution of the Gippsland Lagoon system (Victoria, Australia). (Reproduced with permission from Barnes 1980; after Bird ECF (1966) The evolution of sandy barrier formations on the East Gippsland coast. *Proceedings of the Royal Society of Victoria* 79: 75–88.) The prior barrier (A) can be dated to about 70 000 years BP; the inner barrier (B) was formed during the late Pleistocene; the situation in (C) represents a low sea level phase of the late glacial, and (D) and (E) further evolution during the current marine transgression.

mittent stratification of the water column by thermoclines and/or haloclines, wind action as the dominant forcing agent, purely freshwater zones near inflowing rivers, and otherwise brackish, and in some climatic zones periodic hypersaline, waters. Wet season rainfall in the 44 km^2 Laguna Unare, Venezuela (at the end of the dry season), for example, can change the salinity from 60–92 to 18–25, at the same time increasing lagoonal depth by 1 m, area by 20 km^2 and volume by $76 \times 10^6 m^3$.

The 'closed lagoons' shown in **Figure 2** form the limiting condition of effective isolation from direct inputs from the ocean except via occasional over-topping or after percolation through the barrier system. Most are not only 'former lagoons', but also current coastal freshwater lakes; for example, the much studied Slapton Ley in England.

Characteristically restricted and choked lagoons are very shallow (usually about 1 m and almost always < 5 m deep), floored by soft sediments, fringed by reedbeds (*Phragmites* and/or *Scirpus*), mangroves (especially *Rhizophora*) or salt marsh vegetation, and support dense beds of submerged macrophytes such as seagrasses (e.g. *Zostera*), pond-weeds (*Potamogeton*) or *Ruppia*, together with green algae such as *Chaetomorpha*. The action of the dense beds of submerged vegetation may be to

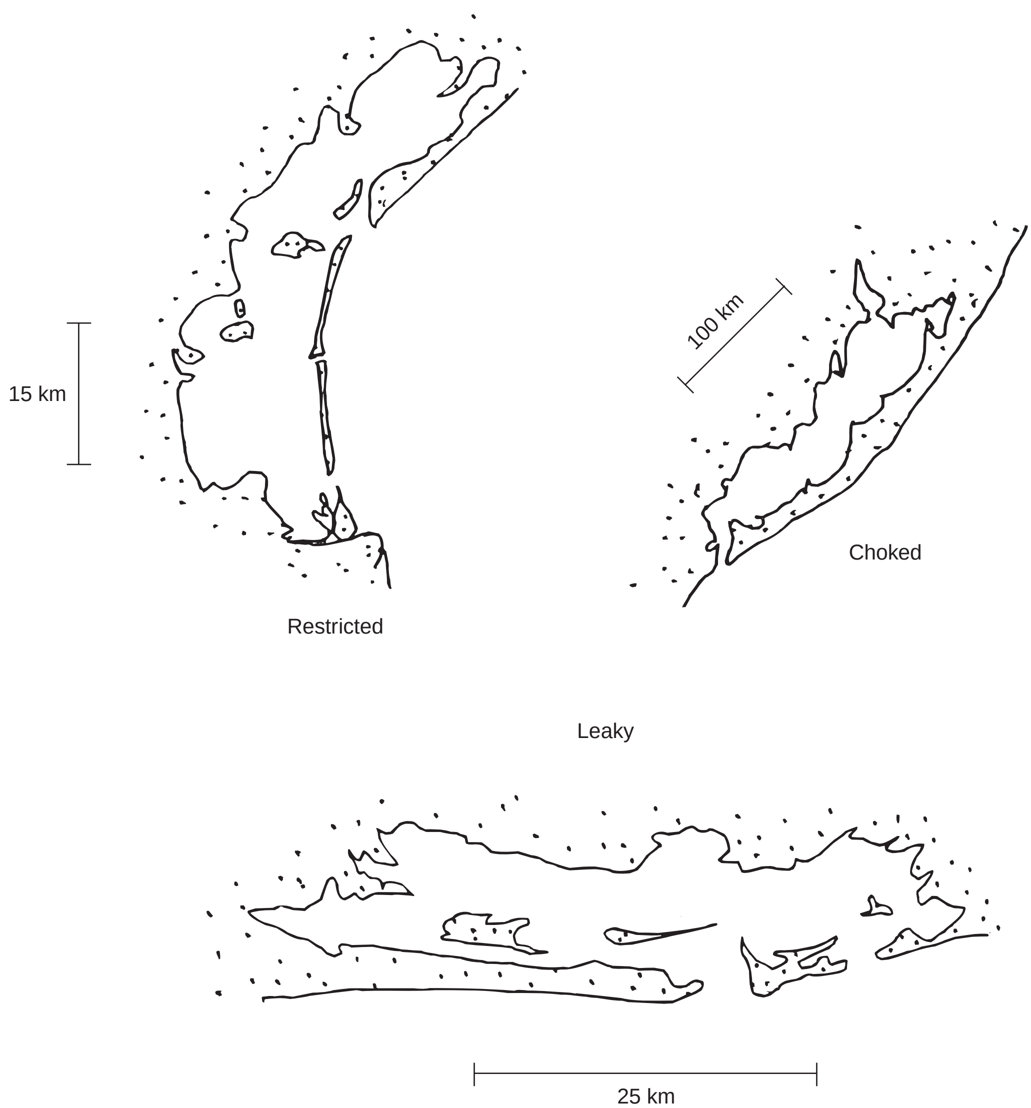

Figure 7 'Choked' (Lagoa dos Patos, Brazil), 'restricted' (Laguna di Venezia, Italy) and 'leaky' (Laguna Jiquilisco, El Salvador) lagoons.

raise levels of pH and to contribute considerable quantities of organic matter. In stratified choked lagoons, decomposition of this organic load below the thermocline or halocline can then lead to anoxic conditions, notwithstanding surface waters super-saturated with oxygen (**Figure 8**).

Lagoonal Biotas and Ecology

Insofar as is known, although the species may be different, the ecology of coastal lagoons shows the same general pattern as seen in estuaries and other regions of coastal soft sediment, although the relative importance of submerged macrophytes may be greater in lagoons (**Figure 9**). The action of predators as important forces structuring the communities in lagoons as in similar areas, for example, is reflected by the young stages of many species occurring within the dense beds of submerged macrophytes, as the hunting success of predatory species is lower there.

The primary productivities of lagoons appear to vary with their general nature, their latitude, and their depth. Choked lagoons tend to be the most productive, with recorded maxima approaching $2000\,g\,C\,m^{-2}\,y^{-1}$, and with productivities (allowing for the effect of latitude) some 50% more than in restricted lagoons. Temperate zone lagoons achieve only about 50–70% of the productivity of low latitude lagoons of comparable nature; and whilst shallow phytoplankton-dominated lagoons are more productive than deeper ones (depth $>2\,m$), the converse may be true of macrophyte-dominated systems. An order of magnitude calculation (assuming that the total area of the world's lagoons is around $320\,000\,km^2$ and that average lagoonal productivity is $300\,g\,C\,m^{-2}\,y^{-1}$) yields a total annual lagoonal production of $10^{11}\,kg$ fixed C. The contribution of lagoons to total oceanic carbon fixation is therefore minor, although they are as productive per unit area as are estuaries, and are only less productive than some regions of upwelling, coral reefs, and kelp forests.

What happens to this primary production? Data are still scarce. There has been much argument as to whether estuaries are sources or sinks for fixed carbon. Insofar as information is available it appears that lagoons are more nearly in balance, as is appropriate for their more isolated nature, although all those so far studied do function as slight sinks. Even though relatively isolated, however, no lagoon is self-contained, not least in that many elements in the faunas migrate between lagoons and other habitats.

Coastal lagoons are heavily used by wetland and shore birds as feeding areas, most noticeably by grebes, pelicans, ibis, egrets, herons, spoonbills, avocets, stilts, storks, flamingoes, cormorants, kingfishers, and fish eagles. Such birds prey on the abundant lagoonal invertebrate and fish faunas. These comprise mixtures of three different elements: both (a) essentially freshwater and (b) essentially marine and/or estuarine species capable of withstanding a degree of brackishness, as well as (c) specialist lagoonal or 'paralic' species that are not in fact

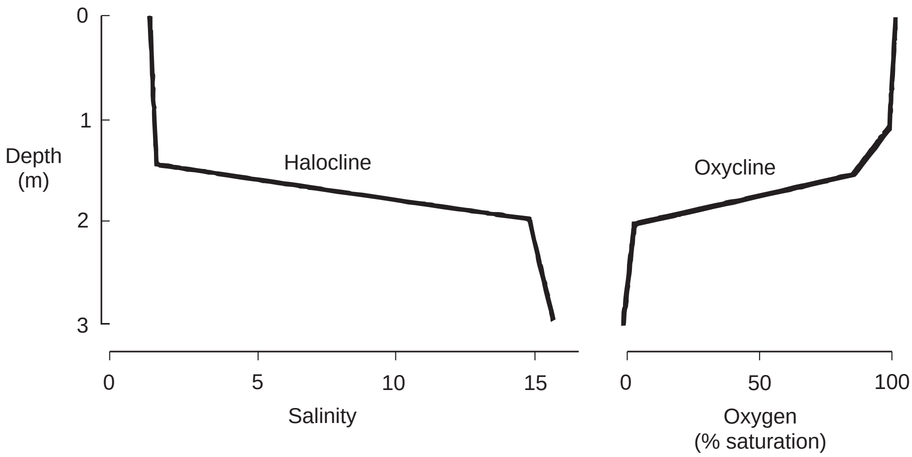

Figure 8 A halocline and consequent oxycline in the choked Swanpool Lagoon, England, after a prolonged period of high freshwater input (salinity in practical salinity units). (Reproduced with permission from data in Dorey AE *et al.* (1973) An ecological study of the Swanpool, Falmouth II. Hydrography and its relation to animal distributions. *Estuarine Coastal and Marine Science* 1: 153–176.)

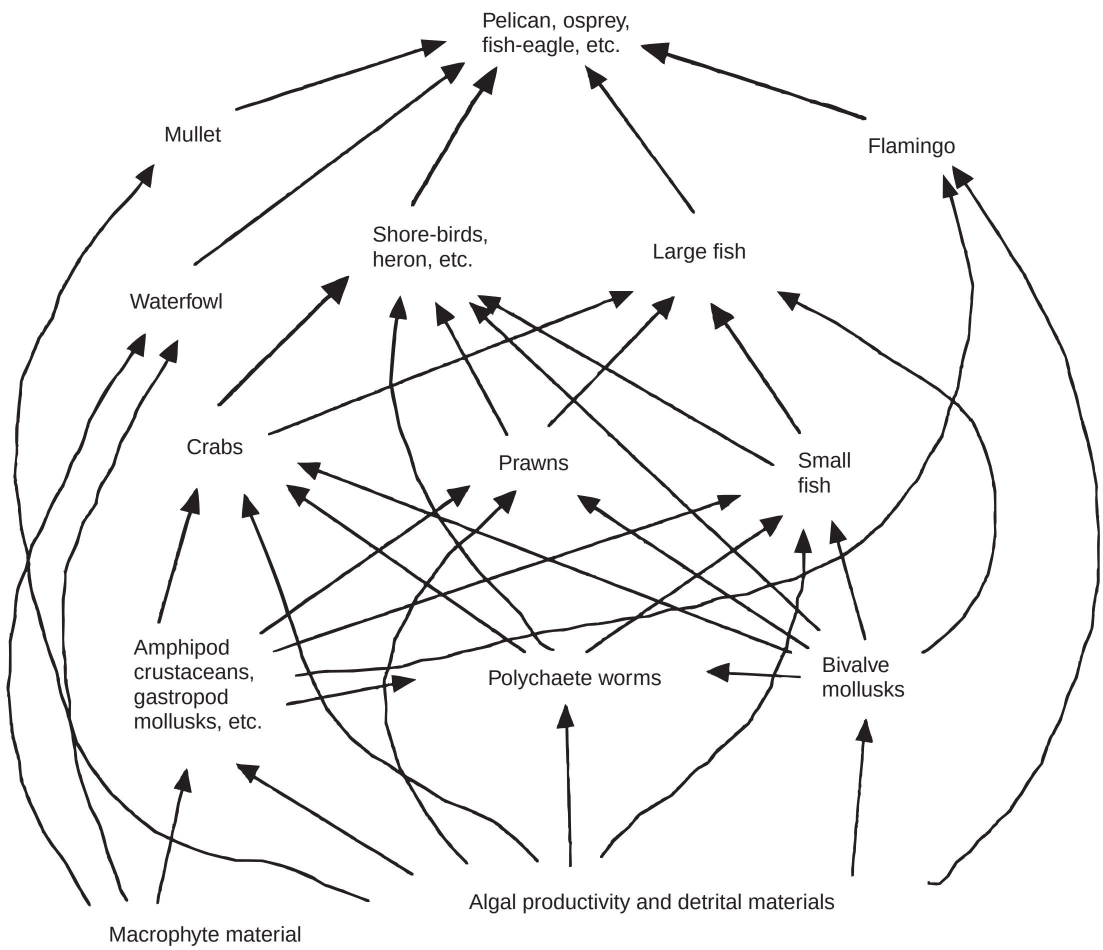

Figure 9 Simplified lagoonal food web.

restricted to lagoons but also (or closely related species) occur in habitats like the Eurasian inland seas (e.g. the Caspian and Aral), as well as in (the usually man-made) tideless brackish ponds and drainage ditches that are abundant in reclaimed coastal regions. The main feature of the lagoonal species category is that they are species of marine ancestry that seem to be restricted to shallow, relatively tideless maritime habitats; over their ranges as a whole they are also clearly capable of inhabiting a wide range of salinity, including full-strength and concentrated sea water, but not fresh water. Their relatedness to marine species is evidenced by the fact that they often form species-pairs with marine or estuarine species. The freshwater component of lagoonal faunas is often greater than would be expected in comparable salinities in estuaries, with the common occurrence of adult water beetles and hemipteran bugs besides the omnipresent dipteran larvae. The reasons for this are not understood, but may relate to decreased water movements.

Because oceanic and freshwater inputs into a lagoon occur at different points around its perimeter, these three elements of the fauna tend to be broadly zoned in relation to these inputs. Indeed, an influential French school, the 'Group d'Etude du Domaine Paralique', identifies six characteristic biotic zones in lagoons based not upon salinity but upon 'a complex and abstract value which cannot be measured in the present state of knowledge' which the group terms 'confinement'. This is a function, at least, of the extent to which the water mass at any given point is isolated from oceanic influence. Beginning with the Mediterranean Sea coast, disciples of this school have now published maps of the location of the 'six degrees of confinement' in many lagoons throughout the world.

Lagoons also form the nursery grounds and adult feeding areas for a large number of commercially important fish and crustaceans that migrate between this habitat and the sea, most of which spawn outside the lagoons and only later move in actively or

Table 2 Mean fisheries yield from coastal lagoons in relation to those from other aquatic habitats[a]

Habitat	*Fish yield ($kg\,ha^{-1}\,y^{-1}$)*	*Percent of sites exceeding yield of $200\,kg\,ha^{-1}\,y^{-1}$*
Coastal lagoons	113	13
Continental shelf	59	5
Coral reef	49	0
Fresh waters	34	2

[a](Data reproduced with permission from Chauvet, 1988.)

in some cases probably passively. In respect of the fish, temperate regions are amongst others used by eels (Anguillidae), sea bass (Moronidae), drum (Sciaenidae), sea bream (Sparidae), grey mullet (Mugilidae), flounder (Pleuronectidae), and various clupeids, and in warmer waters these are joined by many others, including cichlids, milkfish (Chanidae), silver gars (Belonidae), grouper (Serranidae), puffer fish (Tetraodontidae), grunts (Pomadasyidae), rabbit fish (Siganidae), various flatfish (Soleidae, Cynoglossidae), and rays (Dasyatidae).

Therefore, throughout the world lagoons support (often artisanal) fisheries, as well as being the location of bivalve shellfish culture (mussels, oysters, and clams). For obvious reasons, most data on secondary productivity have been collected in relation to these fisheries. The fish yield from lagoons is greater than from all other similar aquatic systems, averaging ($n = 107$) $113\,kg\,ha^{-1}\,y^{-1}$ and with a median value of 51 kg (**Table 2**) and with 13% exceeding $200\,kg\,ha^{-1}\,y^{-1}$. Yields vary with the intensity of human involvement in the catching and stocking processes. In the Mediterranean Sea, the region for which most data are available, the yield without intensive intervention is some $82\,kg\,ha^{-1}\,y^{-1}$; with the installation of permanent fish traps this increases to 185 kg; and with the addition of artificial stocking with juvenile fish it increases to 377 kg. For a 10 year period, the fishermen's cooperative based on the Stagno di Santa Giusta in Sardinia harvested nearly $700\,kg\,ha^{-1}\,y^{-1}$. West African lagoons with 'fish parks' – areas that attract fish because of the provision of artificial refuges – are considerably more productive, with average fish yields of $775\,kg\,ha^{-1}\,y^{-1}$.

Amongst the invertebrates, penaeid shrimp, mudcrabs (*Scylla*), oysters, mussels, and the arcid 'cockle' *Anadara* are the major harvested organisms. Yields of *Penaeus* may attain $2500\,kg\,ha^{-1}\,y^{-1}$ in lagoonal systems of aquaculture, whilst those of the oyster *Crassostrea* and the mussel *Perna* can both be $400\,tonnes\,ha^{-1}\,y^{-1}$. In the Indian subcontinent whole communities can be economically entirely dependent on these shrimp, crab, and fish harvests; for example, the 60 000 people living around Chilka Lake, India.

However, many of the world's lagoons are threatened habitats, suffering deterioration as a result of pollution and destruction, through reclamation and from the natural losses resulting from succession to freshwater and swamp habitats and from landwards barrier migration. The discharge of materials into lagoons and its consequences are essentially similar to those in any other semi-enclosed coastal embay-

Table 3 Discharges in the early 1990s into two lagoons on the southern (Polish/Russian/Lithuanian) coast of the Baltic Sea (inputs in tonnes yr^{-1})[a]

Parameter	*Curonian Lagoon*	*Vistula Lagoon*
Surface area	$1584\,km^2$	$838\,km^2$
Mean depth	3.8 m	2.6 m
Maximum depth	5.8 m	5.2 m
Volume	$6.0\,km^3$	$2.3\,km^3$
Annual water exchange	$27.3\,km^3$	?
BOD input	150 000	47 000
Inorganic N	20 000	25 000
Inorganic P	5000	2100
Chlorinated substances	1	'High concentrations'
Cu	30	?
Zn	50	?
Pb	600	?

[a](Reproduced with permission from data in *Coastal Lagoons and Wetlands in the Baltic*. WWF Baltic Bulletin 1994, no 1.)

ment, but there is one specifically lagoonal feature. As they are often used for aquaculture and yields are generally related to primary productivity, lagoonal waters are frequently deliberately enriched to boost catches. Such enrichment varies from domestic organic wastes from the surrounding communities to commercial processed fish foods. Probably in the majority of such cases, however, the result of this nutrient injection has been eutrophication, loss of macrophytes, deoxygenation, and in several areas a change in the primary producers in the direction of a bacteria-dominated plankton and, across wide areas, benthos as well. In Mediterranean France, this all too frequent state of affairs is known as 'malaïgue'. Culture of mussels in the Thau Lagoon in France produces an input to the benthos of some 45 000 tonnes (dry weight) of pseudofecal material. Not surprisingly, at times of minimum throughput of water, malaïgues can cause mass mortality of the cultured animals and degradation of the whole habitat. Thus in Europe, malaïgues in the south, pollution in the Baltic lagoons (**Table 3**), and reclamation of those on the Atlantic seaboard have rendered the habitat especially threatened even at a continental level. For this reason they are now a 'priority habitat' under the European Union's Habitats Directive. Intensive lagoonal aquaculture also injects not only nutrients, but antibiotics, hormones, vitamins, and a variety of other compounds, and the wider effects of these are giving cause for concern.

See also

Crustacean Fisheries. Demersal Fishes. Eels. Eutrophication. Geomorphology. Macrobenthos. Mangroves. Molluskan Fisheries. Pelecaniformes. Phytobenthos. Primary Production Distribution. Salt Marshes and Mud Flats.

Further Reading

Ayala Castañares A and Phleger FB (eds) (1969) *Lagunas Costeras. Un Simposio*. Universidad Nacional Autónoma de México.

Barnes RSK (1980) *Coastal Lagoons*. Cambridge: Cambridge University Press.

Bird ECF (1984) *Coasts*, 3rd edn. London: Blackwell.

Chauvet C (1988) *Manuel sur l'Aménagement des Pêches dans les Lagunes Côtières: La Bordigue Méditerranéenne*. FAO Document Technique sur les Pêches No. 290. FAO:

Cooper JAG (1994) Lagoons and microtidal coasts. In: Carter RWG and Woodroffe CD (eds) *Coastal Evolution*, pp. 219–265. Cambridge: Cambridge University Press.

Emery KO (1969) *A Coastal Pond Studied by Oceanographic Methods*. Elsevier.

Guélorget O, Frisoni GF and Perthuisot J-P (1983) La zonation biologique des milieux lagunaires: définition d'une échelle de confinement dans le domaine paralique mediterranéen. *Journal de Recherche Océanographique, Paris* 8: 15–36.

Kapetsky JM and Lasserre G (eds) (1984) *Management of Coastal Lagoon Fisheries*, 2 vols. Rome: FAO.

Kjerfve B (ed.) (1994) *Coastal Lagoon Processes*. Elsevier.

Lasserre P and Postma H (eds) (1982) Les Lagunes Côtières. *Oceanologica Acta* (Volume Spécial.)

Rosecchi E and Charpentier B (1995) *Aquaculture in Lagoon and Marine Environments*. Tour du Valat.

Sorensen J, Gable F and Bandarin F (1993) *The Management of Coastal Lagoons and Enclosed Bays*. American Society of Civil Engineers.

Special issue (1992) *Vie et Milieu* 42(2): 59–251.

Yáñez-Arancibia A (ed.) (1985) *Fish Community Ecology in Estuaries and Coastal Lagoons*. Universidad Nacional Autónoma de México.

LAGRANGIAN BIOLOGICAL MODELS

D. B. Olson, C. Paris and R. Cowen, University of Miami, Miami, FL, USA

doi:10.1006/rwos.2001.0406

Introduction

The Swiss mathematician Leonhard Euler (1707–1783) derived the formulations for describing fluid motion by either measuring the properties of the fluid at a fixed point over time or alternatively following the trajectory of a parcel of fluid as it is carried with the flow. The first of these is known as the Eulerian description of the flow, while the method following a material parcel or particle is known as the Lagrangian description after the French mathematician Joseph Lagrange (1736–1813). Most of the theory used to model ocean