Effects of artificial structures on coastal lagoon processes and forms

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ABSTRACT
For thousands of years man has settled adjacent to lagoons, used their resources, disposed wastes in them, sheltered boats in them, constructed transportation networks through and across them, and even converted them into agricultural fields and industrial sites. One of the ways man modifies lagoons is by placing artificial structures along their shorelines, along the barriers that separate them from the open ocean, and upstream in the rivers that drain into them. Structures built adjacent to or on barrier islands including groins, seawalls, dikes, and breakwaters change normal washover processes; jetties and tidal gates interfere with currents and sedimentation at tidal inlets; and structures on the mainland alter sediment supply, currents, biota, salinity, and water quality. Projects within the lagoon itself, including reclamation and maintenance of canals and dock and harbor facilities modify lagoon form and consequently sedimentation and circulation.


RÉSUMÉ
Les effets des structures artificielles sur les processus et la morphologie lagunaires.
Pendant des milliers d'années, l'homme s'est installé près des lagunes; il a utilisé leurs ressources, y a rejeté ses déchets, il a abrité ses bateaux, construit des réseaux de transport et il les a même converties en zones agricoles ou industrielles. Une des façons par lesquelles l'homme transforme les lagunes est de placer des structures artificielles le long de leurs lignes de rivage, le long de barrières dunaire qui les séparent de l'océan, et au niveau des rivières qui les drainent. Les structures construites à proximité ou sur les îles barrières comprennent des arêtes, des digues, des levées de terre; elles modifient les processus normaux de chasse; les jetées, les écluses de marée interfèrent avec les courants et la sédimentation au niveau des passes; et les structures bâties à terre modifient les apports sédimentaires et biotiques, les courants, la salinité et la qualité de l'eau. Les aménagements dans la lagune proprement dite comprennent l'approvisionnement de terres et l'entretien de canaux et de facilités portuaires modifient la morphologie de la lagune et, par conséquent, la sédimentation et la circulation.


INTRODUCTION
Although the importance of man as an agent in modifying the surface of the earth has been recognized for well over a century, we are still reluctant to consider him as a geomorphic agent in the same way we do water, wind, and glaciers. Because of this reluctance, there has been general neglect in the study of what today may be the most important modifier on earth, at least over a short time span. In 1979, Ota and Nogami wrote that they consider man to be the predominant geomorphic agent in Japan, a country that is changed morphologically by natural causes to a greater extent than almost any other country. There is no better place to see the evidence of such a change than along the world's shorelines and especially along the shoreline of Japan (Walker, 1981 a). For example, a six
square kilometer man-made island has just been occupied in Osaka Bay. Built of rock transported from the top of a mountain behind Kobe, it now supports the largest container port in the world and will soon house 20,000 people. On the drawing board is an even larger island, also in Osaka Bay. To serve as a regional airport, it will be made by transferring by conveyor belt and barge from mainland nearly half as much material as ejected during the 1981 eruption of Mt. St. Helens, USA.

These two examples suggest the extent of the efforts of man in creating new land in the sea. At the same time, of course, new shorelines are developed. Although island building is a relatively new endeavor, at least on a large scale, human modification of natural shorelines has been underway for millennia. Modification has been carried to such an extent that there is little natural shoreline left along some coasts. Nearly all coastal types (with the exception of those shorelines composed of glacial ice) have suffered some modification. Most efforts have been attempted along shorelines in populous countries, especially those in the mid-latitudes. Among the shorelines most frequently modified are those that border semi-enclosed bodies of water such as bays, estuaries, and lagoons.

The objective of this paper is to consider artificial structures in relation to this type shoreline (in contrast to that of the open coast) with most emphasis on mid-latitude lagoons. We concentrate on the effect of artificial structures on shoreline forms, shoreline materials, and shoreline processes.

**LAGOONS**

The term "lagoon" has been defined in a number of ways, including:

1) "... a shallow sound, channel, pond, or lake near or communicating with the sea <-s of Venice > < the - of a coral island > ... " (Webster's Third New International Dictionary, 1961, p. 1264).

2) "... an elongated body of water lying parallel to the coastline separated from the open sea by barrier islands" (Stevenson, 1968, p. 590).

3) "A shallow body of water, as a pond or lake, usually connected to the sea."

4) "... a tidally inundated depression, located in the shore zone, which is protected from the sea by some type of barrier, but which is in either permanent or ephemeral communication with the sea" (Lankford, 1978, p. 246).

5) "... a semi-enclosed body of water connected with the open sea by inlets through a system of barriers (physical, chemical, hydrodynamical)" (SCOR/UNESCO, 1980, p. 7).

Such definitions appear to be somewhat restrictive. However, most of the qualifying terms are relative, e.g. "elongated", "shallow", "usually", "semi-enclosed", "narrow", and even "barrier". Therefore, it is not surprising to note that the term has been used for bodies of water that
range from enclosed freshwater coastal lakes on one end of
the spectrum to open bays on the other.
It is of interest to note that the authors of the « Aims of the
symposium » portion of the program for the 1981 Interna-
tional Symposium on Coastal Lagoons avoided providing a
definition of the term « coastal lagoon ». They did, howe-
er, note that « Coastal lagoons and their enclosing barriers
comprise 13 % of the world’s coastline ..., » (UNESCO,
1981 b, p. 2), a value used many times since published by
Leontiev in 1961 (see Kaplin, in press) and Cromwell in
1971 (see Barnes, 1980).
The definitions above state or at least imply that characteris-
tics vary from lagoon to lagoon. Equally as important, most
characteristics also vary spatially and temporally within each
lagoon. Such variability should not be surprising when one
considers the complex relationships that exist between a
lagoon and its surroundings: the sea, the land, the atmos-
phere, and the biosphere.

LAGOONAL SHORELINES
As in the case of shorelines on the open coast, lagoonal
shorelines show close linkages among form, material, and
process. Altering one usually has an important bearing on
what happens to the other two. Thus, the effects of either
natural or artificial changes are seldom simple. The most
important difference between lagoon shorelines and those
facing the open sea is in the nature of the waves reaching
them. The fetch of lagoons is normally limited. Even in the
case of those lagoons that are long (over 200 km in some
cases), widths are often limited (Mozambique, Fig. 1 and
Fig. 2). Thus, fetch is seldom more than a few kilometers
except when wind direction is parallel to the long axis of the
lagoon.
Most lagoons, especially those elongated parallel to the bordering ocean, have one shoreline that interfaces with the mainland and one that is part of the barrier that separates lagoon from sea (Fig. 2). Their shorelines vary in form from straight to curved and from smooth to irregular. Although the shoreline of many lagoons is relatively uniform in construction and form, others are more complex (Fig. 3). Complexity is usually associated with method of formation. For example, Bolinas Lagoon, Tomales Bay, and Bodega Harbor occur along the San Andreas fault north of San Francisco Bay in California. In each, the non-barrier bar portion of the shoreline is much longer than the barrier bar itself (Karp, 1976).

Although these California examples generally parallel the oceanic coast, similar lagoons (i.e. those with short barrier bar systems) are found where the lagoonal axis is more or less perpendicular to the shoreline. Most examples of this type of lagoon are drowned estuarine of river mouth systems. Mobile Bay (Fig. 4) along the Gulf Coast of the United States is an excellent example in that it is a lagoonal system that has been gradually filling by the oceanward migration of a bay-head delta. Filling, although it has been proceeding since stillstand was reached circa 5000 years ago, is only about three-fourths complete.

**Figure 4**

Lagoons along the Alabama and Florida coast illustrating variation in orientation and shape.

The drowned estuarine-type lagoon usually has a very irregular shore (Georgica, Fig. 3) because sea-level rise also drowned portions of the tributaries flowing into the main stream. Most of the shoreline of such lagoons is thus of terrestrial origin.

Cross-sectional profiles of lagoon shorelines are equally as variable as their origin. In those lagoons with relatively little sedimentation the terrestrial shoreline may be little modified from its original form. However, because lagoons are generally sediment traps, most lagoon shore zones are gently sloping and characterized by fine grained sediment and by either mangroves or salt (or even brackish or fresh) marsh grasses (Fig. 5).

Lagoon shorelines are usually crossed by streams entering from the interior and by relatively narrow inlets from the sea. Either or both may be permanent, ephemeral, intermittent, or, in rare cases, absent. Sheetwash across the shore is another major type of input. The relative importance of these connections is reflected in the chemical characteristics of the lagoon's water and the sedimentological characteristics of the lagoon's bottom and shores.

Lagoons, especially those along low-lying coasts, are composed mostly of fine grained sediments. Textural variation within the lagoon is closely associated with sediment source. Those zones near tidal inlets, tidal channels, and adjacent to the barrier have coarser sediment than the inner lagoon and the landward shore areas (Fig. 4). The texture of the bar may be quite coarse if it is adjacent to a rocky source. A major factor in deposition within lagoons is flocculation, which depends partly on the amount of electrolytic clay contributed to the system and the salinity within the lagoon.

The relative volume and timing of input from land, sea, and atmosphere and of outflow to sea and atmosphere determine to a great extent the lagoon's circulation patterns and salinity characteristics. Circulation in lagoons is normally controlled by the tides although the tidal influence varies within the lagoon itself. Tidal channels often develop levees, thereby adding to the local relief in the lagoon bottom. Outflow through tidal inlets is continuous if surface runoff into the lagoon is sufficiently great, whereas if evaporation of lagoon waters is large there may be continuous inflow from the sea.

Salinity and temperature vary from lagoon to lagoon, within each lagoon, and with time. Salinity ranges from nearly 0 to over 100%. Precipitated salts are not an uncommon type deposit in some lagoons. Because of the shallowness of lagoons, water temperature ranges approach those of the air above. The range normally decreases between the lagoon proper and tidal inlet and river mouth.

The above characterizations represent only a few of those found in lagoons. They, and others, are easily modified by man and especially by his addition of artificial structures to the lagoon system.

**LAGOOON UTILIZATION**

The importance of lagoons to early man in his quest for food and as shelter from storms has been well documented (Walker, 1981b). Although the earliest users did not modify lagoons to any great extent, the development of sea transport led to the construction of piers, docks, and breakwaters along lagoon shores. Such structures date back to at least the times of the Minoans in the Mediterranean (Inman, 1974). Equally as early, the Chinese were reclaiming coastal waters for the purposes of solar salt production and agriculture. Reclamation, whether ancient or modern, must be considered the ultimate in modification because the lagoon, marsh, bay, or estuary that is reclaimed is completely transformed, transformed from water to land.

Today, the use of lagoons, like that of most other coastal types, is complicated and diverse (Joliffe, 1976). There are not many of man's activities that do not impinge upon lagoons in one way or another (Lankford, 1978).

In addition to those used discussed briefly above — namely, use for fish and shellfish, for non-biotic resources such as solar salt, in the construction of harbors, and in reclamation — are several others (Table). These include energy related activities such as the use of lagoon water as a coolant in industrial plants and the siting of oil wells. Fluid withdrawal...
ARTIFICIAL STRUCTURES AND LAGOON PROCESSES

Table
Lagoon uses.

A) Living resources:
   1) Harvesting (birds, fish, invertebrates, mammals, plans, etc).
   2) Aquaculture (as in (1)).

B) Non-living resources:
   3) Raw materials (coral, nitrate, phosphate, salt, sand, shell, water, etc).

C) Services:
   4) Recreation and aesthetics.
   5) Transportation.
   6) Conservation and buffering zones.
   7) Dumping.
   8) Energy generation.

D) 9) Reclamation.
(modified from Unesco, 1981 a, p. 82).

(yoil, gas, or water) from sub-lagoon aquifers often leads to subsidence, which can alter greatly a lagoon's characteristics. In some locations, as at Baytown, Texas, USA, subsidence has been responsible for the creation of a lagoon.

Lagoons, bays, and estuaries play major roles in urbanization, industrialization, commercialization, communication, and recreation. Recreation, one of today's most rapidly developing uses, is evidenced especially in the numerous marinas that have been constructed along many coasts (Fig. 6). Boats by the hundreds may be berthed in them, a modern version of one of man's earliest uses.

Figur e 6

Lastly, man has always used lagoons as a dump. The kitchen midden along lagoonal shores is one of the archaeologist's most important data sources (Hedgepeth, 1975). The results of dumping, at least of modern day dumping, can be drastic and only now is this use (or, as most would say, « misuse ») beginning to receive serious attention on a broad scale.

At the present time, lagoons, especially in areas of dense population, are highly prized by many interest groups. Zunica (1976) states this well when he wrote that the area near Venice « ... is a coastal sector where, in the last few decades, what was left of the natural system has been completely broken down. In the ambit of the Venetian Conurbation where the interests of industries, ports, tourism-without forgetting those of agriculture—are in open contrast, conflict has developed » (p. 277). Because of such conflict, some kind of management is being actively pursued in many countries.

TYPES OF ARTIFICIAL STRUCTURES
Man modifies lagoons in many ways; drilling platforms, dredge spoil, and bridge pilings are present in many lagoons today and all cause some kind of modification to their surrounding areas (Fig. 7). However, when one considers artificial structures, it is more common to think in terms of those structures designed specifically for shore modification. The term « modification », used in this sense, usually means « protection ».

Such structures can be divided into four types; namely:
1) Dams, barrages, and watergates; 2) seawalls and other lagoon/land interface structures; 3) groins and jetties or as one author (Carter, 1976) has called them « stick-out structures »; and 4) breakwaters.

Figur e 7
Lagoon Utilization, South Louisiana, USA (photo by H. J. Walker, 1980).

Dams, barrages, and watergates may be built upstream from the lagoon, at the mouth of an entering stream, or at the inlet that connects lagoon to sea. The Bonnet Carre Spillway near New Orleans, Louisiana, USA, connects the Mississippi River and Lake Pontchartrain. It is used as a relief conduit only during an extreme flood. When such an occasion arises, the sudden influx of freshwater and river sediment provides a great shock to the lagoonal system.

The second type includes those forms that can be called interface structures, the most common of which is the seawall. Their main function is to separate land from water; reasons for such separation include harbor development, reclamation, and shore and property protection. There are several types of such interface structures-dikes, embankments, revetments and the like. Because of the low wave energy normally found within lagoons, these structures need not be so large or sturdy as those built along the open shore.

Whereas interface structures are constructed parallel to the shoreline, the third type, which includes groins and jetties, are placed at some angle to it, frequently perpendicular. Groins are designed to trap drift and retard erosion; jetties serve mainly to protect inlets and direct flow.

Figur e 8
Breakwaters, the fourth group, are used to reduce the energy reaching the area to be protected. In a detached or offshore form they may also serve to trap long-shore drift. The materials of which these structures are made vary greatly. They include spoil, scrap materials such as tires, riprap, concrete, and specially designed armor blocks. Armor blocks, although often referred to as tetrapods, come in many shapes and sizes. A few examples include the tetrapod itself, hollow triangles, and skimmers (Walker, 1981a). In Japan there are more than 25 types now in use (Fig. 8).

In the United States, low cost materials are being tested in shoreline protection schemes (Fig. 9). It is believed by the US Army Corps of Engineers that such structures will prove especially valuable along low energy shorelines such as those found in most lagoons. Along one shoreline in Florida a number of types such as sandbags, surgebreakers, and sandbags, have been tested (see Gifford et al., 1977).

**Figure 9**

Detached breakwater of tires along the north shore of Lake Pontchartrain, Louisiana, USA. (Photo courtesy US Corps of Engineers, Coastal Engineering Section, New Orleans.)

**EFFECTS OF ARTIFICIAL STRUCTURES**

Artificial structures affect lagoons in many ways. For example, they often: 1) change the input into a lagoon system; 2) affect biotic productivity; 3) alter shape, depth, area, and volume; 4) serve as a substitute for natural materials along a lagoon's shoreline and bottom; and 5) alter the dynamic processes within the lagoon. Such modifications occur as the result of structures that may be placed: 1) landward of the lagoon; 2) seaward of the lagoon, especially in association with the barrier bar; and 3) within the lagoon itself. The most important landward structure affecting lagoons is the upstream dam. It modifies the amount and timing of river water and river sediment entering the lagoon. In many areas of the world stream damming has led to beach starvation, shoreline erosion, barrier-bar breaching, and lagoon modification (Walker, 1978). Reduction of freshwater input often leads to an increase in the effect of tidal water which, in turn, affects lagoonal circulation and salinity. The opposite, i.e., the increase of freshwater into a lagoon system, can cause an impoverishment of the lagoon's biota as occurred in the Etang de Berre, France (Bellan, 1972). Elimination or reduction of the suspended load, most of which is fine grained, and of bedload will alter depositional patterns in the lagoon.

Other land-oriented activities within the drainage basin of streams entering lagoons include deforestation, agriculture, stream-bed mining, and industrial waste disposal. Such activities, unlike damming, usually result in increasing the sediment input into the lagoon. For example, new housing developments near Mobile Bay, USA, led to the formation of sediment plumes in the Bay of sufficient size to be observable on Landsat images.

Man-made changes of a lagoon's barrier bar are equally significant in lagoon modification. The inner shore of the bar is here considered as belonging to the lagoon and will be discussed later. This section is limited to a discussion of modifications caused by artificial structures placed on the bar itself, along its seaward shore, and in the tidal inlet. Several types of structures and activities are important and include seawalls, jetties, dune stabilization, and artificial nourishment. Seawalls are usually constructed along the seaward shore of a barrier bar in order to prevent shoreline erosion. They often have a profound effect on the lagoon behind the bar because they reduce or eliminate the input of sand that might otherwise cross the bar because of wind or ocean overflows. The reduction in the contribution of this relatively coarse grained sediment across the bar into the lagoon changes the composition of the near barrier shore and bottom of the lagoon. It also leads to a stabilization of the bar's inner shoreline (Godfrey, Godfrey, 1973).

Dune stabilization by fencing or by planting grasses or trees will have a similar effect, as will the construction of resort facilities, parking lots, and industrial plants. Groins on the outer shore, if successful, will widen the beach and reduce the amount of sand contributed across the bar. They alter flow characteristics near tidal inlets and, by trapping sand, change the amount of sand contributed through the inlet by the sea. One of the major results of groinning is the starvation of the beach downdrift from the groin. In the barrier bar-lagoon complex such starvation can lead to serious erosion of the barrier and eventually to breaching into the lagoon.

Some lagoons have been converted into freshwater lakes by placing barracks or water gates across their inlet. Murray Lakes in Australia is an example (Bird, this volume). Japan, China, and The Netherlands are three countries that have made extensive use of such barriers. However, one of the most recent of such developments is in Hong Kong where a large bay and a narrow strait have been converted into seawall freshwater reservoirs (Walker, 1980). The most common and possibly the most important structure affecting lagoons is the jetty. In the developed nations most major lagoon inlets are jettted. Drucy and Nielsen (1980) note that there are over 30 jettted entrances along the coast of New South Wales, Australia; Fisher (1981) reports that all of the Rhode Island, USA, inlets have jettties; and Morton (1977) illustrates a similar situation for the Texas, USA, coast (Fig. 2).

Jetties act as sand traps; indeed, one of the major objectives of the jetty is to keep sand from entering the inlet they protect. By serving to maintain a navigation channel, the jetty (or jettties), often aided by dredging, not only influences the composition of water and sediment between the lagoon and ocean but also alter the tidal characteristics of the lagoon.

The complicated effects inlet modification may have on lagoons can be illustrated by noting the changes that have occurred at Morro Bay, California, USA. Morro Bay, located about halfway between San Francisco and Los Angeles, is a long (11 km) lagoon with a narrow constricted, jettted inlet (Fig. 10). Originally the inlet was on both ends of Morro Rock. However, during the mid-1930s the WPA (Works Progress Administration of the US government) placed a barrier across the northern inlet creating a man-made tombolo. Although constructed for the purpose of aiding in reducing the filling of the Bay, this structure apparently increased deposition rates. Subsequently, jetty construction has been coupled with dredging in attempts at controlling bay fill. In the process the bay's depth and volume and the bar's position and shape have changed drastically (Fig. 10).

Although the shorelines within lagoons are relatively protected naturally, they nonetheless are frequently altered through or because of the addition of artificial structures. Included are lagoon-shore interface structures, groins, and
breakwaters. As mentioned, these structures usually do not have to withstand the wave energy that impacts on structures on the open coast. There are exceptions; some lagoons, such as those along the Texas and Louisiana coast, are often subjected to strong wind waves either because of hurricanes or other storm systems. The seawall along the south shore of Lake Pontchartrain north of New Orleans, Louisiana, USA, has become the focus of criticism because of its potential failure in the event of direct hurricane passage. The danger partly lies in the fact that much of New Orleans lies below sea level.

The construction cost of artificial structures in lagoons is usually relatively low, however, there are situations when such is not the case. Colombo (1977) notes that «it is rather difficult... to build dikes in lagoons unless large quantities of stone or concrete are used» because of the adverse mechanical and mobile properties of lagoon sediments. Linton, even earlier (1969) wrote: «Dikes constructed on high marsh sediments were capable of withstanding the forces of the highest spring tides [in Georgia, USA]. Dikes of similar construction upon low marsh sediments were undermined by high tides and eventually washed away» (p. 452).

Nonetheless, reclamation has been one of man's major endeavors in lagoons. Reclamation as mentioned above alters the lagoon almost completely. It substitutes agriculture, aquaculture, industry, housing, and parks for lagoon. Most reclamation results in dry land, but not always. In China, Japan, the Philippines, and France among other countries, fish ponds frequently occupy former lagoon areas. Some may be completely isolated from the sea, whereas others may still be connected to the sea and are in essence man-made lagoons (Fig. 11).

In addition to reducing the size of the lagoon, reclamation also changes its shape. After reclamation the artificial shoreline lies in deeper water than the shoreline it replaces. Often it is the substitution of a low but steep cliff for what was probably a gently sloping mudflat or fine-textured grass covered shore.

Because lagoon shorelines are subjected to lesser amounts of erosion than open coasts, groins and detached breakwaters are relatively uncommon. When they are used the results are similar to those occurring along open coasts, e.g., updrift deposition and downdrift scouring may occur with groins and tombolo formation may occur as the result of detached breakwater construction.

ARTIFICIAL STRUCTURES AND THE FUTURE OF LAGOONS

Although lagoons have long been used by man, only recently, with few exceptions, have they been directly modified to any great extent. Because such modification has normally been at the hands of the developed nations, most of the world's lagoons are still in a relatively unaltered state (Barnes 1980). Their natural shallowness and alternating linear arrangement, i.e. water, land, water, land, often with much marsh or swamp involved, delayed modification. Lagoons lent themselves best to elementary uses (such as fishing) until population pressure, recreational demand, and technological development made it economically feasible to alter them in modern ways.

In some coastal sectors lagoon alteration has been pursued intensively; although no precise data appear to be available, one can safely say that in the USA outside of Alaska over 25 % of all natural lagoons have been developed (see Gosselink, Baumann, 1980 for a discussion about wetland losses in the USA). In recent years the rate of change has been increasing; fortunately, however, this increase is being accompanied by an equally rapid increase in the awareness of the biological value (Fig. 12) and finiteness of lagoons. The major impact that present-day biological and ecological research can have on lagoon modification will probably be in the reduction in the rate of their reclamation for agricultural, industrial, and residential purposes. This research will also probably lead to an increase in attempts at maintaining most lagoons and their surrounding wetlands in a more or less natural state and in altering many for aquacultural purposes.

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Deuxième partie :
VIE ET AMÉNAGEMENT DES ÉCOSYSTÈMES LAGUNAIRES

Second part :
LIFE AND MANAGEMENT OF LAGOON ECOSYSTEMS