

Coastal erosion and shore protection: A brief historical analysis

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Abstract Since the Neolithic, humans have gathered along coastal plains, where they had to face sea level rise and subsidence without the technology to oppose these processes. When sea level stabilized, approx. 6.000 yr. B.P., coastal colonization was allowed, but where mountain deforestation was carried out river sediment input increased tremendously: settlements were disconnected from the shore and harbour siltation occurred. Shore erosion was a limited process at the time and local solutions were adopted: clay dikes, wood piles, fascines and rock revetments. Along the Mediterranean, in China and Japan the construction of more complex structures has been documented since the Middle Ages. Further human development, with river bed quarrying, wetland reclamation, dam construction and mountain re-afforestation, favoured a coastal erosion that nowadays threatens most world coasts. From the Venetian “Murazzi” to the recent 114-km-long concrete element defence at the Yellow river delta, shore protection structures evolved following the different needs (protect coastal communication routes, urban and industrial settlements, tourist resorts). Beach nourishment, previously performed with inland quarried materials, is now intensively carried out with marine aggregates. The vernacular solution, left to undeveloped countries, has been recently revaluated by “green engineering”. However, with Sea Level Rise, the debate of whether to defend, accommodate or retreat is open.

Keywords Shore protection history · Coastal erosion · Shore protection · Vernacular structures · Beach nourishment · ICZM

Until prehistoric times, humans gathered along the coast, where food availability, climate conditions and transport possibilities were most favourable, even though they were accompanied by a higher risk for erosion, subsidence, tsunamis and floods from the sea and rivers (Nicholls 2002). Alluvial plains, and even more so river deltas, were preferred since the Neolithic, as a consequence of agriculture development (Neil 1989).

Unfortunately, at the same time, sea level was still rising after the Last Glacial Age low standing (approx. -120 m; 18,000 yr. B.P.) and the flooding of flat coastal plain was very rapid; in one generation the shoreline could retreat several kilometres (Turney and Brown 2007). No technology was available at that time to oppose this process and any feeble defence that could have been constructed would have been destroyed and submerged by the sea. The memory of a Great Flood is present in almost all ancient cultures; famous examples are in the Bible (Mediterranean), *Śatapatha Brāhmaṇa* (India), Gilgameš (Mesopotamia), Shūjīng (China), not to mention the orally handed down myths of the Pacific islands, Australia, North and South America.

Approximately 6000 yr. B.P. sea level arrived near its present position (even few meters higher in some areas; Möner 1996) and stable coastal settlements became possible.

However, an almost stable sea level did not grant coastal stability, especially where land was subsiding (for sediments compaction, tectonic activity or isostatic rebound); e.g. in The Netherlands, where dykes were built just at the end of the first Millennium, or at Delos, where an Hellenistic seawall could not prevent the settlement flooding, at least after town destruction (Mourtzas 2012).

In the meantime, human impact on natural processes was becoming more and more important. Forest clearance to expand pasture and agriculture increased soil erosion and thus, sediment input to the coast. Ancient authors, e.g. Pausanias,

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Strabo, Pliny, portrayed the Mediterranean basin as a barren area, where soil was washed away by run-off (Hughes and Thirgood 1982). Valley siltation, coastal expansion and harbour abandonment were also described. Similar processes, and for the same reasons, are documented in China (fourth century B.C.; Han and Dai 2002) and in Japan (9th - eleventh century A.D.; Koike 1988).

Demographic and socio-economic development is everywhere accompanied by deforestation (Burns et al. 1994), which triggers soil erosion and increased riverine sediment input to the coast. The geological instability of the Middle Ages and of the Renaissance in Europe provided generations with wide coastal plains, with several dune ridges (Pranzini 2007) and large beaches to support the present day tourist industry.

Things began to change at the end of the eighteenth century, when soil erosion, agriculture and pasture abandonment appeared (in Italy from 4 to 11 M hectares of forest from 1930s to the present), river bed quarrying (frequently for more than one order of magnitude of river yield) and coastal wetland reclamation triggered an erosion process starting at rivers mouths and gradually extending to side beaches (Pranzini 1989). Harbours constructed in sand coasts intercepted longshore sediment transport with subsequent downdrift erosion.

Increasingly soil erosion in developing countries, due to the forest industry and unregulated pasture, was no longer sufficient to provide the needed sediments to the coast: large reservoirs retained a significant part of them: up to 25% in Africa and 31% in Asia (Syvitski et al. 2005) and today approximately 70% of the world's coast is eroding (Bird 1996).

Although in past centuries coastal erosion was a minor problem, shore protection works were locally carried out. In 238 A.D., Romans performed the first known artificial nourishment of a beach before reconstructing a stretch of Via Severiana (from Ostia to Terracina, Latium), which was demolished by the sea; and earth dykes with fascines cores

were defending the Venice Lagoon at least in 537 A.D. (Grillo 1989).

Clay dykes have been present along the German coast since the eleventh century, built to oppose storm surge (Behre 2004), and the same material is used today by rural populations where rocks are too far from the coast (e.g. Suriname; Augustinus 1988).

However, wood piles, fascines and stones were the preferred material to build coastal defences, and they formed an almost continuous well-structured defense system in Venice at the end of the seventeenth century.

In the eighteenth century, the construction of *Murazzi* (seawalls) commenced with large rectangular stones cemented with *Pozzolana*, a binder invented by the Romans but never used in Venice before. Originally, 5 km of discontinuous structure were built that gradually extended to 20 km at the end of the nineteenth century (Zunica 1971).

In China, earth and stones were known to be used for a dike in 713 A.D. in the Quintang Estuary, and bamboo baskets filled with stones were used since 910 A.D.; in the middle of the fourteenth century the first rock seawalls with wooden piles foundations was constructed (Jiang and Tao 2002).

Wooden poles and twig mats were used in Belgium to build the first groin in 1502 (De Moor 1988), and an early eighteenth century map of Ostende clearly shows the design of the structures built along this coast (Fig. 1).

The presence of similar structures (Fig. 2) in many present low-technology cultures suggests their existence since the first stable human settlements along the coasts.

Limited to few and scattered coastal segments in historical times, shoreline retreat became a widespread problem at the end of the nineteenth century. The hyperbolic growth of coastal towns, industrial plant development close to the sea, road and railway construction along the coastline - once for morphological conditioning and now to connect new settlements - and the increasing dimension of 3S (Sea, Sand and Sun)



Fig. 1 Eighteen century groins structure description in the *Novissima Ichnographica Delineatio Munitissimae Urbis et Celeberrimi Emporii Ostendae*, in Comitatu Flandriae Austriacae Sitae, by Matthias Seutter, 1734 ca. (Author's collection)



Fig. 2 Wood and stone vernacular shore protection at Barù (Bolivar, Colombia)



Fig. 4 Rope network holding small stones in a revetment at Coco Beach (Goa, India)

tourism industry transformed a geomorphological process into a social and economic problem.

However, in the late '800 s and early '900 s local shore protection structures were still dominant, e.g. permeable wood pile groins along the Baltic and the North Sea, bulkheads in the US, rock groins and seawalls in the Mediterranean (Pranzini and Williams 2013).

Concrete complex profile seawalls, revetments with artificial blocks (Fig. 3), submerged detached breakwaters and groins, beach dewatering, multipurpose structures (defence plus entertainment) are now a globalized solution, leaving vernacular ones (wood piles, fascines, clay dike, small rock revetments) to the autonomous initiative of rural populations (Fig. 4), although some “green engineering” is rediscovering them (Nordstrom 2014).

What sediments rivers do not carry to their mouths, is now transported by humans: quarried at river mouths, river beds

and later alluvial plains. Aggregates are now mostly dredged on the continental shelf (Fig. 5). Estimates of inland quarried materials escape any investigations, being frequently performed as small projects at local scale, although examples of huge nourishments are documented, which in Italy at present, adds up to 10 million cubic meters. Continental shelf dredging for beach nourishment was calculated to be 50 M m³/yr. in the USA and 28 M m³/yr. in Europe (Hanson et al. 2002). A recent nearshore fill for 21,5 M m³ was performed in The Netherlands with the goal of creating a source area from which sediments will move to “naturally” feed the coast for many years (Stive et al. 2013).

Not all countries have these possibilities: village relocation due to coastal erosion dates back at least to 1954, when Amanzaguapos, a small village on the Colombian Pacific coast, had to be relocated after erosion of the spit protecting it from wave attack; in 1985 the “Pueblo Nuevo” was further moved landward (Correa and Gonzalez 2000).



Fig. 3 The 114-km-long shore protection structure defending Gudong oil field on the Yellow River delta



Fig. 5 Nearshore nourishment through “rainbowing” at Grottammare (Marche, Italy)

Under the forecasted Sea Level Rise (IPCC 2014) wide areas of coastal plains will be submerged and increased storminess (Berlin et al. 2013) will test humans' capability to oppose the sea. *Protect, accommodate, retreat* are the keywords of the issue that planners reiterate (Williams et al. 2017), together with technical, economic, social and political problems. But abandoning ancestral land will be the only solution for people living in low reef island or in flat sandy spits and barrier islands.

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