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Historical Evolution of the Salso River Mouth with Respect to the Licata Harbour System (Southern Sicily, Italy)

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Abstract

The present Salso River mouth is an excellent example of a wave-dominated fine-grained deltaic system, where the marine processes predominate over the fluvial ones. Also if in the past it had a significant role in the sediment supply to the sandy beaches of the Gulf of Gela (Southern Sicily), actually, it has characterised by an unstable natural equilibrium, mainly regulated by a strong anthropic pressure. The purpose of this paper is to describe the temporal evolution of the Salso River mouth, linking it to recent flood events and to different interventions in the design of the Licata Harbour system, one of the most important for fishing boats of southern Sicily. Historical documents and ancient maps together with aerial photos (1952–1997) and direct measurements in field survey, help us to appreciate and recognise the evolution of the Salso River mouth in the last years.

1. INTRODUCTION

The coastline situation of Sicily is serious with many beaches in retreating, above all near the 105 coastal structures (ports, harbours, pears, banks, etc.) present along the whole perimeter (Zanghì & Randazzo 2000).

Generally, they have influenced negatively the evolution of the coastline inducing erosion, which has brought to the construction of breakwaters and parallel rigid structures of defence, which have moved downdrift the erosion problem.

On the other hand, the sediments carried from the longshore currents have infilled several port structures giving rise their unpracticability.

In Licata, in the last years, the presence of a renewed fishing-fleet and the increase of greenhouses along the coastal plain has increased local economy and the necessity for an efficient harbour structure.

As a result, the local administration has made different plans for the extension and improvement of the Licata harbour. It also performs the periodic dredging of the bottom, at the entrance and in the central area of the harbour, essential for the maintenance of a sufficient depth for the transit of large boats.

Starting from this evidence we carried out this study, as a part of a complete investigation of all Sicilian coastlines, focusing above all on the interaction between riverborne material reaching the sea and the adjacent harbour systems.

2. GEOLOGICAL AND SEDIMENTOLOGICAL BACKGROUND

2.1 Salso River catchment area

The Salso or Southern Imera River originates in the southern sector of the Madonie Mounts (1,500 m a.s.l.). It flows out, after 132 km, with only a distributary channel into the Mediterranean Sea, at the western end of the Gulf of Gela, in correspondence of Licata town, Figure 1.

The Salso River is a torrential stream with brief and violent floods during the rainy season from November to February and with long periods of drought during spring and summer: because of the land mainly impermeable or with low permeability.

The catchment area covers about 2,000 km^2, and the average annual sediment supply at its mouth has been computed to be about 350,000 m^3/year, with a specific discharge of 425 m^3/year/km^2 (Servizio Idrografico 1978).

From a morphological point of view, the basin is mountainous in the northern sector, hilly in the central sector and flat in the southern one, where there is a typical coastal plain largely anthropised and adapted for greenhouse crop-growing.

Moreover, in the last century, because of the land reclaiming for agricultural needs, the river channel, which is meandering with a low width/depth ratio, was rectified and banked in many points covering the marsh areas in the coastal plain.

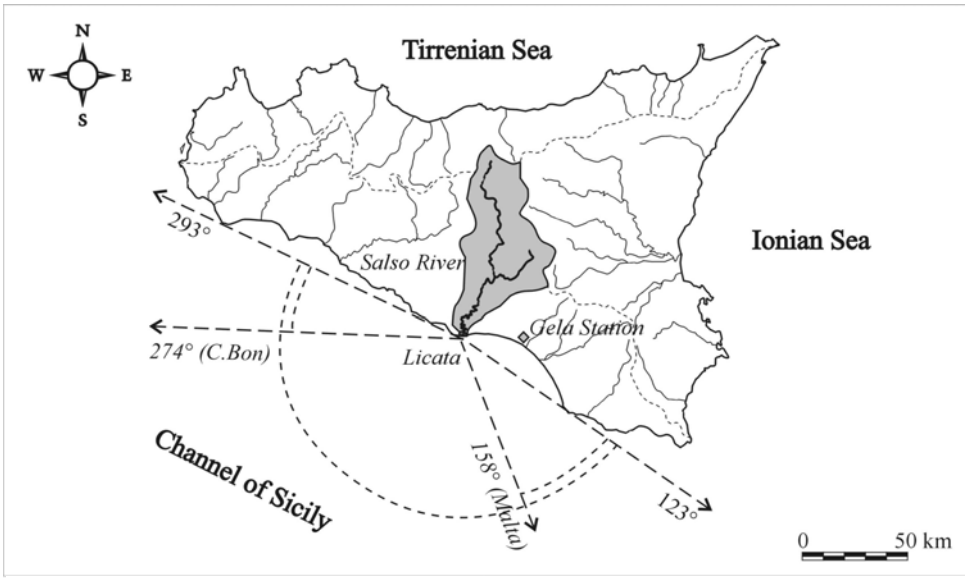

Figure 1: Site map of Salso River and Licata harbour system in the Gulf of Gela (Southern Sicily, Italy)

From a geological point of view, in the catchment area there are outcrops, that can be resumed in some principal lithological types: clays and marls with a frequency of about 59%, which give lutitic grain sizes to potential sediment load; limestones and evaporites (12%), which give arenitic-lutitic grain sizes; conglomerates and sandstones (29%) which give arenitic-ruditic grain sizes.

But according to direct measurements of riverborne material grain size at its mouth, it is possible to define the Salso River a suspended-load channel, because only 10% of the total sediment load is composed by fine sands, while 90% is muddy, exactly coarse-medium silts for about 15% and fine silts- clays for about 75% (Amore *et al.* 1995a).

The dispersion in the sea of these riverborne materials takes place, above all, during the floods in correspondence of intense rain storms, with the formation of both emerged and submerged bars; furthermore, the river was involved in some episodes of widespread flooding with abandon of meanders, like a wide leftwards meander, about 2 km far from the coastline.

2.2 Salso River mouth

Salso River mouth can be considered as a mouth apparatus in the sense of a discrete shoreline protuberance formed where an alluvial system supplies, at irregular intervals, sediment more rapidly than it can be redistributed by marine processes.

Its short term variability in sediment accumulation form and process can be partly explained by the relative strength of hydraulic parameters such as river discharge and wave energy flux, but the grain size is surely the variable most important (Orton & Reading 1993).

The Salso River was also characterised until the last century, by a diversion, 5 km far from the coastline, in two equally distributary channels: the first in correspondence of present mouth and the second towards the Mollarella Bay, 6 km to West.

At present, the river mouth area is profoundly degraded by the coastal structures and other installations, which extend as far as the river banks, and, above all, by the Eastern Dike of Licata Harbour (Figure 2).

Along the coastline, at West of the mouth, beyond to the harbour system, there is a series of pocket beaches for about 5 km, separated by relict and active wave-cut platforms and sea cliffs, high up to 40 m and subject to notching at the base and collapse and denudation of the entire cliff face by marine and atmospheric processes (Amore *et al.* 1995b).

At East of the mouth, the situation is worsened by intense urbanisation, leading to the disappearance of the coastal dune system, a sandy natural reserve which the beach usually draws upon in winter to replace its losses due to marine agents.

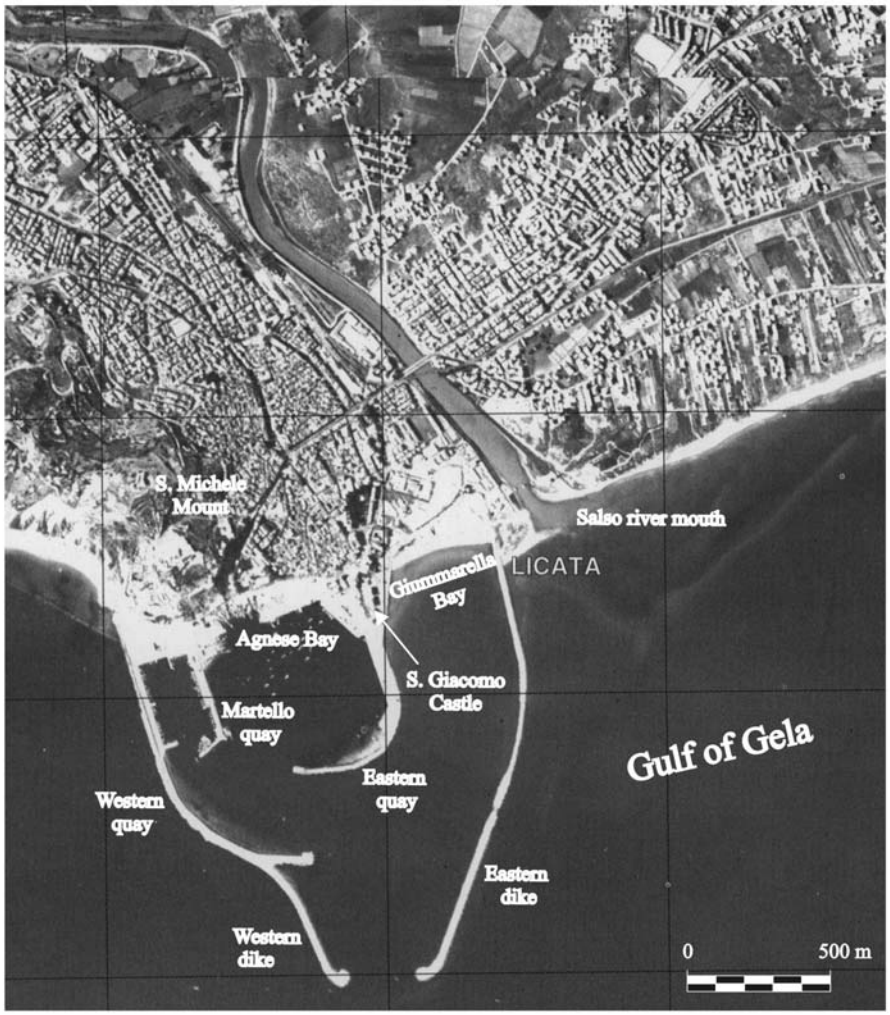

Figure 2: Topographic map of Licata harbour system and Salso river mouth.

3. OCEANOGRAPHIC AND METEOROLOGICAL REGIME

The study area presents a Mediterranean climate, warm temperate, with mean annual rainfall of 453 mm and mean annual temperature of 17.9 °C and only 60 rainy days in a year (Servizio Idrografico 1984).

For the Licata harbour system the sector with maximum traversia is of about 170°, included between 123°N and 293°N with a maximum geographic fetch of about 1,224 km, between 274°N and 293°N, and of about 850 km between 123°N and 158°N.

In this coastal zone of Southern Sicily, the main driving force for the nearshore sediment transport is the wind; it blows in all seasons, principally directed towards the East and Northeast, so also both the dominant littoral currents and waves.

Therefore, the waves responsible for the most damaging effects come from the West, but due to the interference determined by the dikes of Licata Harbour, the wave fronts usually reach the mouth from the Southeast.

According to the "Atlas of the littoral currents in the Italian Seas", in the Southern Sicily the littoral currents are weak and generally direct to East with mean rate of about 0.5 ÷ 1.2 knots (Istituto Idrografico della Marina 1982).

The tides have little relevance with tide range inferior to 0.2 m, also if the baric variations can generate swift sea-level variations with waves heights of 0.9 m.

In 1960 the hydrometric station of Ponte Drasi came into use, situated about 14 km inland from the coastal plain of Licata, where till 1971, when a maximum flood of 1,121 m^3/sec was measured, the recordings are all between 115 and 645 m^3/sec (Servizio Idrografico 1978).

Significant events were recorded on 1st January 1973 and 25th October 1976, when the river overflowed its banks flooding the valley and the lower part of Licata, as a result of two full floods, of 2,281 and 3,170 m^3/sec respectively, caused by continual meteorological events in the area with rainfall varying from 150 to 200 mm in just 24 hours.

4. VARIATIONS IN THE MOUTH AND HARBOUR SYSTEM OF LICATA

4.1 Transformations from Licata foundation to the 19th century

The city of Licata was founded in 282 b.C., between San Michele Mount and the right bank of the Salso River, by *Phintia*, an ancient tyrant of Agrigento.

The choice of this position was influenced by the possibility to use, as a harbour, the small natural bay, wide about 80 m, below the San Michele Mount. Actually, it corresponds to a natural depression along the coast, by now filled and surrounded by ancient buildings of boundary-wall, Figure 3.

The ancient small harbour appears well protected by marine agents, at West, with natural defence of San Michele Mount and thanks also to the dike in natural stones, about 130 m long, which extended in direction to the East.

It is important to add that this old harbour was also enough protected from solid fluvial load of Salso River by a carbonatic rocky spike, at about 40 m from the shoreline, situated exactly between the old ancient harbour and the Salso River mouth, further back in comparison with its present position.

In fact, the first testimonies of the position of the river mouth, linked to surveys carried out by Spannocchi in 1578 and Merelli in 1677 (Dufour 1992), place it in an area further landward than its present position with a single navigable channel and a typically "wave-dominated" delta model.

We do not have information about the reasons of the abandonment of the ancient small harbour of Licata and the silting up of strait between the shoreline and the rocky spike, where the San Giacomo Castle was built, but it is possible that these events are to connect to advancement of the Salso River mouth as a direct consequence of important flood events.

Afterwards, the local authority decided to create a new and wider port in correspondence of Agnese Bay protected, at West, by the extension of the old stones dike, and at East, by the natural protection of the rocky spike, where the ruins of the ancient San Giacomo castle are still visible at basis of the contemporary Licata lighthouse.

Although the quality of ancient illustrations is not good enough to permit an estimation of the advancing rate, it is clear that, until the 19th century, the river mouth undergoes a continuous transformation with significant lateral migrations.

All that can probably be linked to climatic modifications recorded between the 17th and 19th centuries and to the deforestation of the hinterland deriving from the expansion of cultivated land or land given over to grazing.

4.2 Transformations from 19th century to 1960

In 1823 Schauroth's survey (Dufour 1992) the river channel is meandering with subaerial levees and swash bars on both banks and it flows out in a position more retreated of about 460 - 480 m in comparison with the present coastline, and more at East of about 140 m in respect to actual mouth.

Instead, in 1886 the left bank of the river mouth seems advancing of about 200 m in comparison with its position in 1823, with a lateral migration towards the West of about 460 m, Figure 4.

Between the end of the 19th century and the beginning of the 20th century, the economic development of the Southern Sicily was linked to the mining and refinement of the sulphur, salt and gypsum.

It led to realisation of a big harbour, accessible for larger and larger ships and with railway line, between Agnese Bay and the ruins of the ancient San Giacomo Castle; so the city of Licata became the biggest industrial centre in Europe for the refinement of sulphur.

Afterwards, the natural protection of San Giacomo rocky spike comes artificially lengthened towards the South with the East quay. It served as a mooring quay and as a protective barrier to avoid up the silting up by riverborne material of Salso River; successively, at West of the old western dike, the smaller Martello quay was built.

In respect of 1886, in 1940 the coastline is stationary at West of Licata harbour system and in advancing in correspondence of river mouth with an important accretion at Giummarella bay of about 220 m and a maximum advancement of about 520 m near at East of present mouth.

Furthermore, in this period the river mouth migrates in parallel to the coastline towards the East for about 420 m with an advancement seaward of about 270 m and causing the formation of a right focial bar of about 70 m.

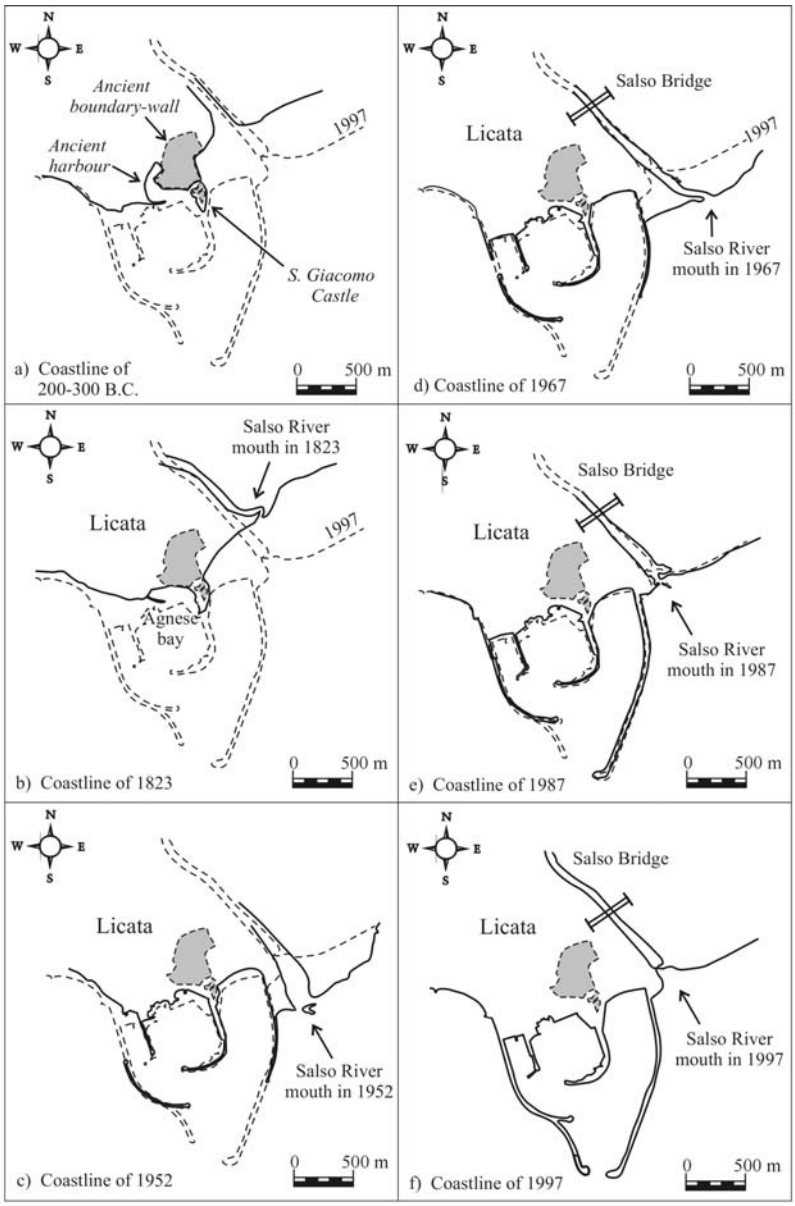

Figure 3: Evolution of Licata harbour system: a) II-III sec b.C.; b) 1823; c) 1952; d) 1967; e) 1987; f) 1997

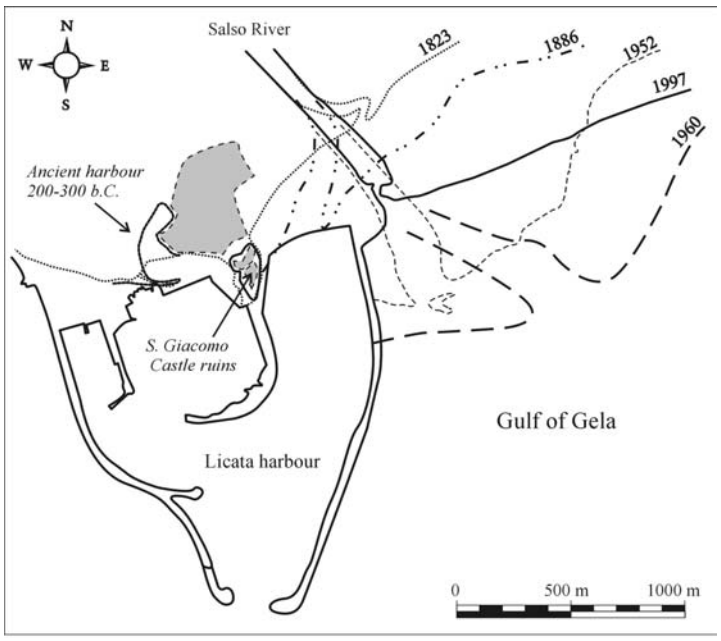

Figure 4: temporal evolution of Salso River mouth from 1823 to 1997.

It is evident that this kind of evolution is also due at the "natural" state of the area which has "reacted" to the inputs coming from inland.

This trend is probably related, above all, to two exceptional meteorological events: the first on November 1915, when the irony bridge connecting the two banks near the mouth collapsed and 109 people were killed, swept away by flood; and the second on December 1933, when the river flooded as a result of precipitation event of about 120 mm.

Between 1940 and 1952, the Licata harbour system was modified with the construction of two important coastal structures: the Western Quay, a breakwater stretching in direction Northwestern – Southeastern to prevent the sediment longshore transport towards the East, and the new Eastern dike at Giummarella bay, between the river mouth and the ruins of the old Castle.

In 1952, because of the enlargement of the Harbour structure, the distance between the river mouth and the harbour itself was reduced and the coastline assumed a South cuspidate shape with a wide distributary mouth bar in the middle; in this last period, both banks advanced of about 144 and 324 m in respect of 1940.

In 1960 the river mouth, following the previous trend, reaches its maximum accretion of about 770 m with a lateral migration of about 400 m towards Southwestern; in the same year we have also a strong accretion along the eastern beach of Licata with maximum of about 440 m in comparison with 1952 and with formation of little marshes in front of a big coastal dune belt, of which few traces only remain, Figure 4.

The causes of advancement, between 1950 and 1960, are connected mainly to the abandonment of the river channel flowing out in the Mollarella Bay, occurred in the late 1950s, and to the consequent concentration of fluvial load only in the river channel, while the enlargement of the harbour system hadn't negative effects on the shoreline, which continued to advance until it reached its maximum in 1960.

4.3 Transformations from 1960 to present time

From 1960 it is possible to note a considerable retreat all along the Licata shoreline, above all till 1970 with the loss of beach area to the extent of 15 – 30 m/year with maximum points of 60 m corresponding to the left-hand bar of the river mouth; some exceptions are: Giummarella bay, now enclosed between the East Quay and Eastern Dike; and the pocket beach at West of Licata harbour, where a new dike has now been built to enlarge the harbour structure towards the West.

Exactly, in 1967 the river mouth retreated to a position similar to that recorded in 1952 but facing south-east, with a right-hand river bed bar about 40 m wide and stretching for almost 200 m.

The river mouth continued to recede until 1977 when with a system of emerged and submerged bars it assumes a position, which appears only about 110 m to the west of its present one.

The causes of this coastal erosion, between 1960s and 1980s, are connected to the enlargement of the Licata harbour system with the construction of the Eastern dike, jutting out 3 km, blocking sediment transport parallel to the coast.

But there are also other causes of the local disappearance of the local beach, as the rising anthropic pressure along the coast and the realisation of some dikes in the hydrographic basin of Salso River with consequent reduction of sandy component of the solid load to about 10% of the previous quantity.

The structure of Licata harbour was thus completed between 1977 and 1987 with the linking of the western quay to old western breakwater, as a further protection against the littoral currents from the West.

Between 1987 and 1997 further interventions were made to extend the external westward and eastward dikes, as far as was necessary to avoid the deposition of fine materials inside the harbour area.

From 1980s to today, the final stretch of the Salso River has become totally stabilised and only small alterations may be noted at the river mouth, connected to a lengthening of the right-hand bar, of less than the 40 m, recorded in 1987, and of the left-hand one, of about 50 - 125 m, while the central bar emerged only in 1987.

After a sharp and continue recession, no great alterations are noted between 1983 and 1997, although a number of flood events of considerable significance, such as those which occurred on 17th January 1985 and 12th October 1991, led to the Salso overflowing its banks and reaching as far as the old abandoned channel until the Mollarella Bay with a water-level of about 1 m.

A few specific situations create an exception, such as the retreat of about 110 m along the beach at East of river mouth, between 1983 and 1987, and of about 25 m, between 1988 and 1989.

For the rest, from 1980s, the advances and retreats recorded are of small entity, so that the present situation of the coastline may be defined as stable, mainly, in the pocket beach at West of Licata harbour no variation has occurred, also on account of the presence of a breakwater in natural rock built adjacent to the external western quay.

5. CONCLUSIONS

The Salso River is a torrential stream, seasonally intermittent, with a small developed deltaic system at its mouth, because the sediment input is dispersed by strong marine agents along the coast.

Surely, it is the most important sediment source in the Gulf of Gela and a typical deltaic facies distribution is possible only in correspondence of large flood events.

The reconstruction over time of the interaction between the Salso River mouth and the Licata harbour has carried out using either geographic and topographic maps, aerial photos and historical illustrations on the Licata town, mainly, of its ancient boundary-wall and the ruins of San Giacomo castle.

The coastline is characterised by depositional phases up until the 1960s, and subsequently by erosive processes which have noticeably influenced the littoral dynamics of a system, rendered rigid by an intense anthropization, with notable damage caused both in naturalistic and economic terms.

Looking at the evolution of the port and of the river mouth, there is no a correct level of sustainability and the need is to individuate before the problems come out.

Licata littoral beach, thanks to its sandy beaches, could become a very attractive tourist centre, but the whole Salso river mouth has been so heavily urbanised that it has now lost nearly all the environmental features which were so evident until the 1960s.

The anthropic pressure on the Licata littoral since the 1960s has undergone too many transformations rendering it immovable, and just in consequence of some most severe floods, as in 1980, in 1985 and in 1991, there were few important modifications.

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