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Beach Behavior and Defences Along the Lido di Jesolo, Gulf of Venice, Italy

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ABSTRACT

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The arched coastline enclosing the Gulf of Venice is extremely complex because the terminal stretches and mouths of its rivers and beaches have been considerably affected by human intervention. The Lido di Jesolo has been heavily exploited for tourist purposes since World War II with no account being taken of critical beach behavior which is closely connected to the extreme variability, both natural and artificial, of the Piave River mouth. High tides in the 1960's caused such serious damage that the entire coastline is now protected by a range of defences. In this paper, the evolution of the Piave River mouth and beach behavior are analyzed and the effects of protective structures are assessed. Although use of the Lido di Jesolo has been severely criticized, many doubts still exist regarding the impacts of the coastal defences.

ADDITIONAL INDEX WORDS: *Beach line, beach erosion, beach enrichment, coastal defence, Adriatic Sea.*

INTRODUCTION

The intensive occupation of Italian coasts has almost always failed to consider beach behavior, giving rise to the need in recent decades to limit the sea's destructive action (ZUNICA, 1987). The Lido di Jesolo is a particularly significant example of careless, hasty and questionable interpretation of this situation. For centuries, the area has been involved in events affecting the complex physiography of the Gulf of Venice within the northern Adriatic (Figure 1a). This unit was later fragmented by defences built at the mouths of the Lagoon of Venice and of the rivers flowing into the high Adriatic.

Today, the Lido of Jesolo, 12.5 km long (Figure 1b), lies in the central part of a 39 km-long physiographic unit between the mouth of the Livenza (Porto di S. Margherita, protected in 1960) and the Porto di Lido (protected after 1885) (Figure 1c).

This stretch of low-lying sandy coast was almost completely uninhabited until the 1950's. With impressive speed, all the available space was occupied, in the total absence of any urban planning, by an extensive seaside resort (VANTINI, 1985). The growth of this resort complex led to the destruction of the entire dune system. Reduced solid transport by the Piave River and the disordered construction of beach defences mean that the Lido di Jesolo must now be considered one of the worst examples of resort exploitation along the entire Italian coastline (C.N.R., 1976; BRAMBATI *et al.*, 1978; MATTEOTTI and RAUL, 1986).

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STUDY AREA

The study area is bounded on the east by the Piave River and by the Sile River on the west. Until a few decades ago the Lido di Jesolo was a wide sandy beach running ENE-WSW; it was confined by dune belts sometimes as high as 6–7 m. Before 1920 these dunes separated the sea from bodies of water and marshes and, later, reclaimed areas.

Depth profiles off the beach, characterized by several bars, show gradients between 0.5% and 0.6%. The 10-m isobath runs at a distance of 2 km or slightly less from the coast. The sediment grain-size of the submarine beach ranges between 0.18 and 0.062 mm; although the whole range of values occurs at the mouth of the Piave River (some samples are even smaller

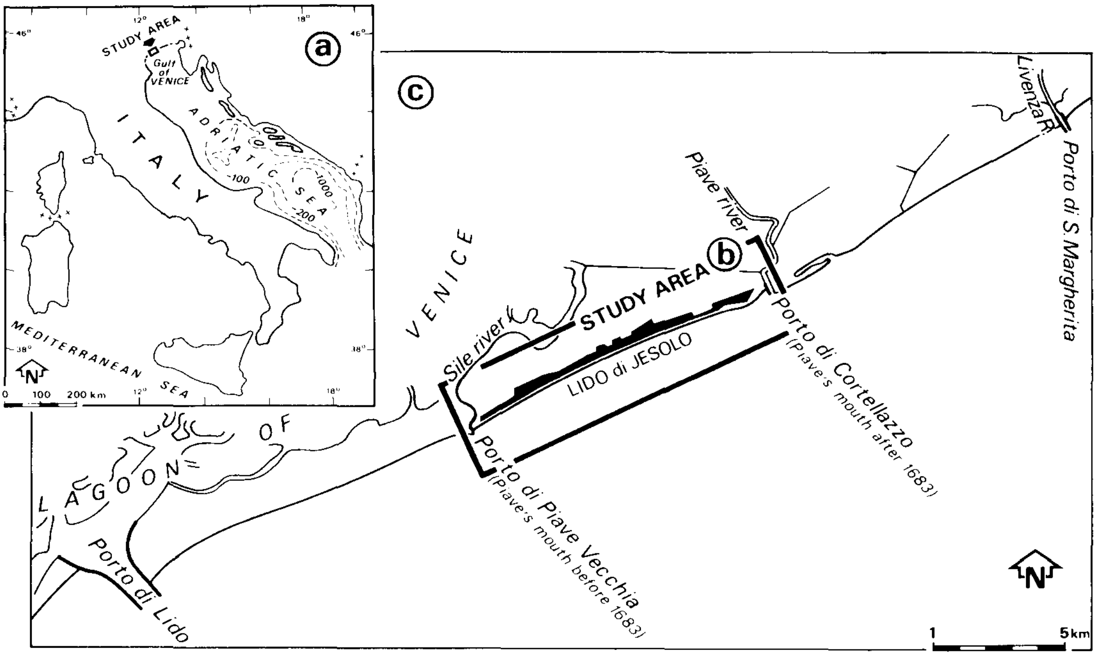

Figure 1. Study area and localities mentioned.

than the above minimum), only medium-high values are found off the mouth of the Sile River (BRAMBATI *et al.*, 1977; C.N.R., 1985) (Figure 2).

Tides are characterized by anti-clockwise movement and the maximum syzygial range does not exceed 100 cm. However, it is mainly the field produced by wave motion which affects a belt between +1 and −3 m. The strong side wind mainly fills the second quadrant and partly the first and third, but local sea behavior is principally influenced by first- and second-quadrant winds because those of the third are not significant. Wind directions causing the most significant wave motion fields are from NE, ENE (*bora*) and SE (*sirocco*). Although

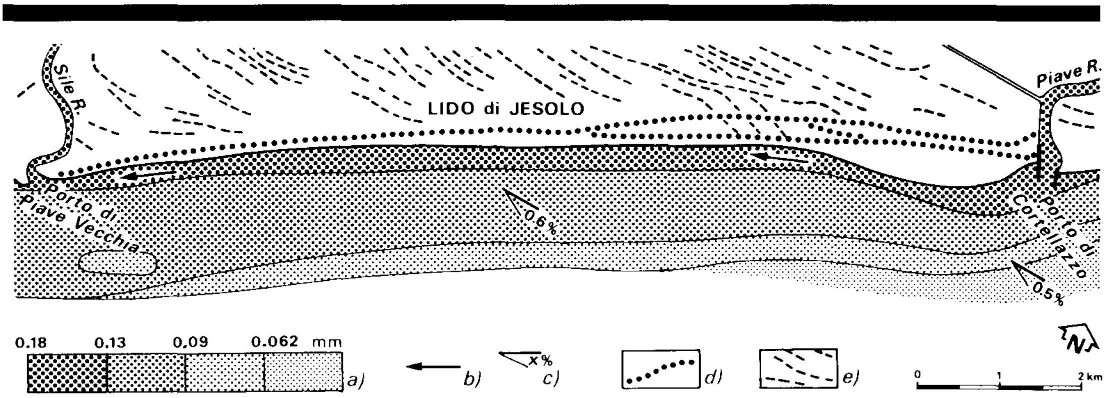

Figure 2. Lido di Jesolo: (a) grain-size of submarine sediments; (b) direction of beach net transport; (c) sea bottom slopes; (d) dune bars before urbanization; (e) traces of ancient shorelines (reconstructed by Castiglioni and Favero, 1987).

heavy south-easterly storms influence beach stability, beach transport is oriented westward according to the energy flow prevailing over the year.

As a consequence of the building, around 1885, of the northern jetty of Porto di Lido west of Jesolo, the beach has advanced more than 2,500 m in one century. Even as little as 25 years after the construction of Porto di S. Margherita in the early 1960's on the mouth of the Livenza River, which has negligible solid supply, the beach next to the eastern jetty advanced so far that the jetty had to be extended (ZUNICA, 1971).

It should be recalled that sea erosion now prevails over solid transport by rivers. In this context, the liquid and solid regimes of the Piave River play a very important role because the river reaches its maximum flow in spring and autumn, although its behavior has been altered by recent use. The quantity of bottom solid transport is unknown, although there are many reasons to believe that it has been greatly reduced.

In the watercourses of the Veneto area, the surface area affected by artificial reservoirs covers 42% of the usable surface. In particular, the Piave River has been fully utilized. It has been estimated that before its exploitation its turbid transport was 126 tons/km^2. Since most of its waters now flow into artificial reservoirs or are diverted into other water-sheds, the solid transport of the Piave has decreased considerably (S.A.D.E., 1952). Recent control and reclamation structures on slopes aimed at reducing the consequences of hydrogeological faults are other factors which can no longer be neglected. Moreover, most of the river waters are used for irrigation, while sand and gravel quarrying from the riverbed was intense until recently.

Better interpretation of problems related to the evolution of the high Adriatic beaches is helped by recalling the phenomenon of "high water," already well-known in the times of the Venetian Republic.

Due to astronomical, meteoric and hydrodynamic factors, high waters are also favored by the morphological features of the Adriatic Sea which, extending NW-SE for about 800 km, is closed to the north. It is a sea with a very extensive continental base, while the sea bottom, very shallow in the north, deepens only in the south (Figure 1a).

The phenomenon of high water has recently taken on more importance than in the past. Although the factors causing it are well-known, the reasons for its increased frequency are not. Syzygial tides, sirocco winds and seiches, each of which may lead to a rise of 50 cm in sea level, are three factors, while the formation of areas of low pressure and the onset of autumn are two more. If all these causes converge at any given moment, the sea level may rise by more than 2 m, and storm surges are clearly very dangerous in such situations. The violent storm of 4 November 1966 along the entire high Adriatic coast is still vividly recalled, and on that occasion the Lido of Jesolo also suffered severe damage (ZUNICA, 1970).

OBSERVATIONS

The Mouth of the Piave River

Recent studies have discovered traces of flattened mouth structures and beach belts oriented differently from those now existing. Their arrangement and number indicate various construction stages. However, a large delta may have coincided with the present-day position of the mouth of the Piave River, although many doubts remain about these reconstructions and little may be said about the ancient diversions of the end-stretch of the Piave River that was buried by Holocene alluvia or destroyed by reclamation of the low plain (CASTIGLIONI and FAVERO, 1987).

However, as far as this study is concerned, because the Piave River is now the only source of beach renourishment of this stretch of coast and the prevailing direction of solid transport is westward, the most recent events of this river and the coastline affected by it are of paramount importance for the following observations (VOLLO, 1942).

The mouth of the Piave adopted its present-day position (Porto di Cortellazzo) in 1683 when the Venetian Republic diverted it east of the lagoon (ZUNICA, 1968) because its solid transport, which at that time was considerable, tended to silt up the Porto di Lido. In the same year, the waters of the Sile River, which made the lagoon swampy, were diverted into the former bed of the Piave (Porto di Piave Vecchia) (Figure 1c).

A brief review of these historical events shows how the mechanisms regulating this stretch of coast have changed since 1683. As the Venetians were fully aware of the extreme dynamicity of the mouth of the Piave, immediately after diverting the river, they conducted careful measurements in order to understand its behavior (MONTANARI, 1822). Their documents are an exceptional example of how beach changes were studied and how situations occurring at short intervals from each other (1685–1688) were compared (Figure 3).

From 1683 until today, the mouth of the Piave River has changed directions many times, as indicated in Figure 4. Planimetries for the last 150 years are also available (Figure 5).

Four distinct stages of the displacement of the end-stretch of the Piave River may be recognized:

(1) From 1685 to 1935, discharge underwent slow anti-clockwise rotation (173°, or 0.7°/year), with generally small regular trends;
(2) From 1935 to 1957, very fast clockwise rotation occurred (170°, 8°/year), following a breach on October 6, 1935. In 1957, the mouth of the Piave showed a very complex situation due to the subdivision of its flow into two branches, one substantially following the coastline and the other perpendicular to it;
(3) From 1957 to 1972, discharge again tended to rotate anti-clockwise (80°, 5°/year). A halt was recorded between 1958 and 1969, due to preliminary stabilizing works on the mouth; and
(4) From 1972 to 1987, discharge began to oscillate by about 5° more or less than the 1972 direction, following mouth reinforcements. Today discharge is oriented SSE. However, many questions have been asked about the usefulness of this type of intervention.

The fact is that the mouth of the Piave naturally tends to form a triangular delta, as a result of the formation of sandbanks which, emerging, tend to approach and join the beach. As they are extremely mobile, changes in their shape and position affect the direction and volume of liquid and solid discharge from the river (Figure 6).

Recent bathymetric surveys show a submerged delta crossed by a SW-trending cut at about 800 m from the mouth.

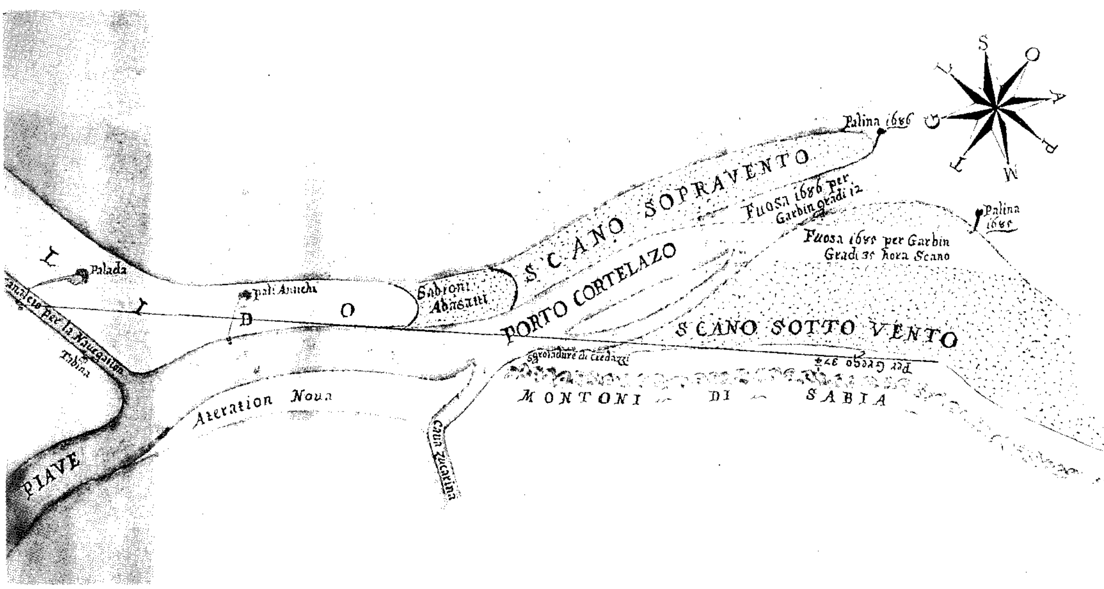

Figure 3. Detail from a hand-drawn map of 1686, from Republic of Venice Archives, with changes made to new mouth of Piave after breach of 1683.

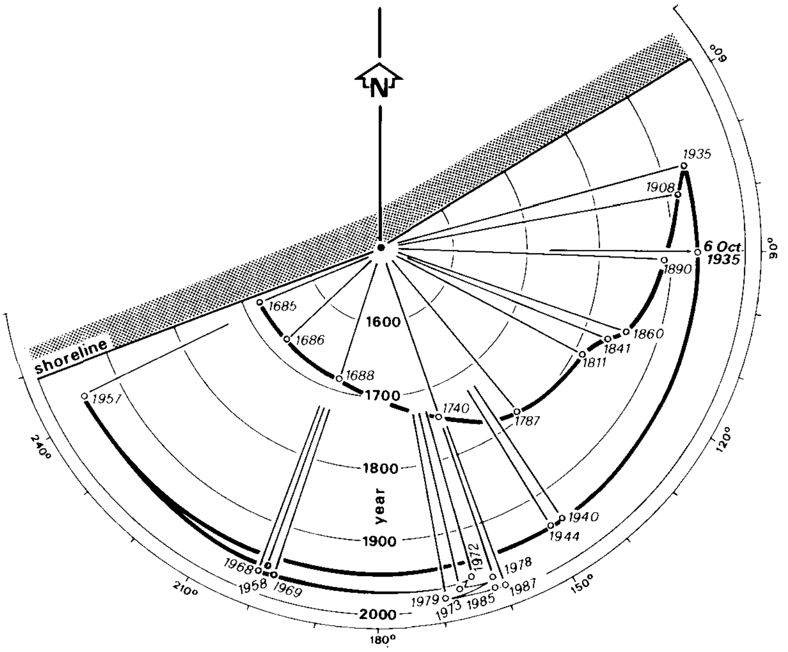

Figure 4. Later directions of discharge from mouth of the Piave River, from 1685 to 1987.

Beach Changes

Mention has just been made of the extremely critical situation of this stretch of beach, so deeply affected by the evolution of the Piave River. The Lido di Jesolo is today reinforced by defences constructed in the last 25–30 years.

Figure 7a shows overall dynamics from 1860 to 1978 when the whole beach was already protected. The picture is one of alternating behavior near the mouth, recession of the western sector and substantial advance in the centre. The data of Figure 7b compare these variations between 1892 and 1961 on maps (scale: 1:25,000) compiled by the Italian Instituto Geografico Militare. These maps are very homogeneous and systematically drawn up, and refer to the same reference plane. The centuries-old sequence of events mentioned above is clearly and substantially confirmed.

Although these variations show the extreme variability and evolutionary trend of this beach, they have taken on very different significance since the beach has been exploited by the construction industry.

The exceptional storm of November 1966 seriously damaged the whole built-up area along the shore, partly because previous defences, although on a much smaller scale, had led to an improvised, discontinuous and irrational system of protection. Each building had in fact its own defence, as expensive as it was ineffectual.

Defences of the Lido di Jesolo

Coastal defences begun in the 1950's continued for the whole decade and were essentially aimed at checking locally destructive storms by protecting the first buildings and the end-stretches of the Sile River and, in particular, those of the Piave River.

Extensions were made in the early 1960's, but only after the November 1966 storm were defence works extended along the entire shoreline (Figure 8).

Today, the type and position of these defences may be listed as follows (Figure 7c):

(1) Protective embankment of the end-stretch of the Sile (*c1*);

(2) Open groins in concrete piles cut into an impermeable coffer-dam driven to a depth of 2 m into the beach, for a distance of 5,900 m (*c2*);

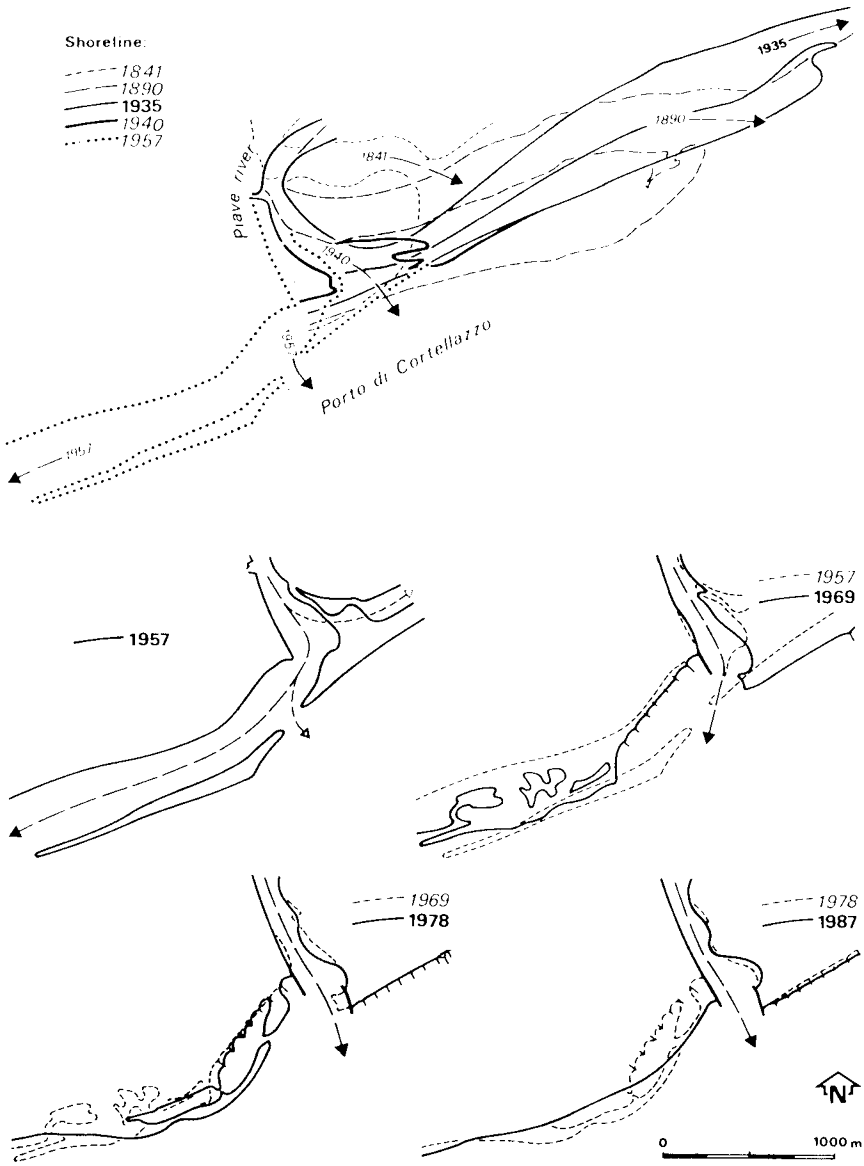

Figure 5. Changes in mouth of the Piave River between 1841 and 1957, with comparisons between 1957–69, 1969–78 and 1978–87.

(3) Rubble groins cut into a parallel reef for 550 m (*c3*);
(4) Breakwaters (originally about 50 m from the shore) for 800 m (*c4*);
(5) One structure on the shoreline with a reinforced concrete top wall along most of which reeflike groins are cut, while reinforced concrete groins are slanting and impermeable along the head stretch over 2,100 m (*c5*);
(6) A series of rubble groins for about 450 m (*c6*), followed by a 1,900-m stretch of unprotected beach (*c7*);
(7) A series of rubble groins for about 800 m along the eastern end-stretch, now com-

Figure 6. Eastern stretch of Lido di Jesolo and Piave delta in 1962, showing old mouths of 1935 and 1957.

pletely filled with sand (*c8*); and

(8) Two rubble dams reinforcing the mouth of the Piave River (*c9*).

RESULTS

As the dune belts were gradually destroyed by new building, sand supplies from the Piave River were reduced and longshore drift from Porto di S. Margherita was interrupted, supplies of sand to replace those removed for various purposes along the Lido di Jesolo decreased drastically.

On the whole, it may be said that no preliminary studies were made on homogeneous and effective planning of defences aimed at stabilizing the Lido. Moreover, as works were carried out at various times and with various aims, their results have not come up to expectations.

The stretch of beach from the Piave River to the breakwaters (Figure 9) tends to be subject to renourishment. Along the remaining stretch, the most homogeneous, defences do not tend to produce the desired effects, although this situation may be masked by frequent artificial replenishments carried out before the tourist season (Figure 10).

As already mentioned, the central stretch affected by the breakwaters is undoubtedly the most subject to sandfill. Although this may

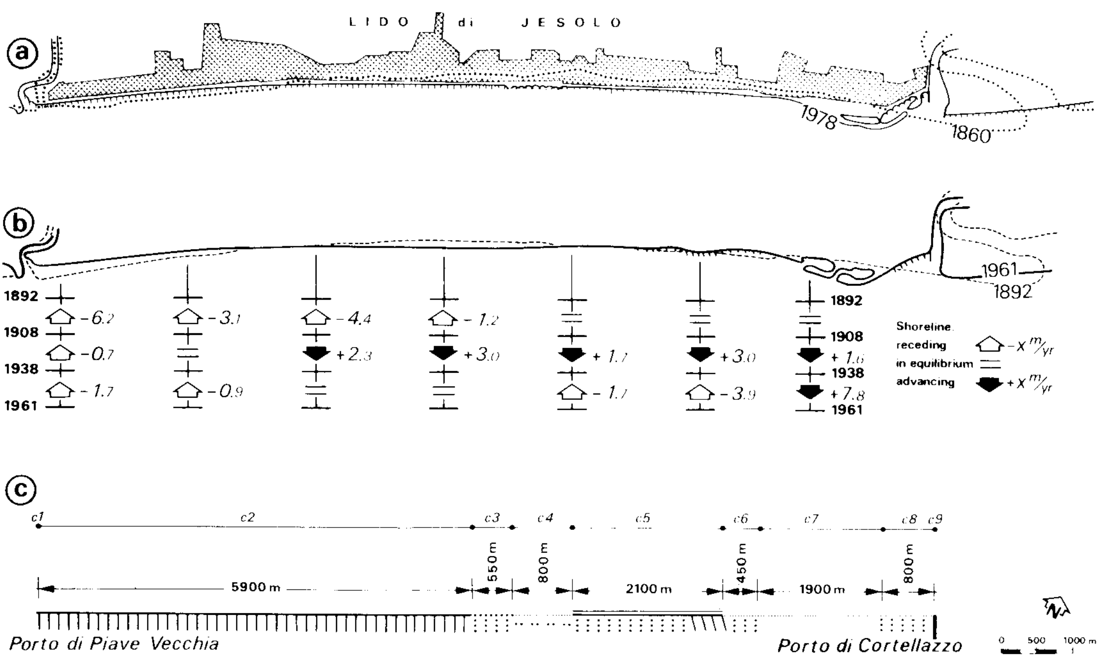

Figure 7. Lido di Jesolo: (a) in 1860 and 1978; (b) changes recorded between 1892 and 1961; (c) present-day type and distribution of defences.

seem positive, from the viewpoint of beach dynamics this type of defence gives the littoral current a subflow erosion capacity. Moreover, in more objective appraisal, it must be remembered that the entrapped sediment is quite fine, that the breakwaters increase the bottom slope, and that tourist bathing is negatively affected.

Reinforcements at the mouth of the Piave River have definitely created many problems. Although freshwater discharge parallel to the beach had to be eliminated because of its negative effect on tourism, solid transport was essential for renourishment of the eroding sectors. Together with the construction of groins to reduce liquid flow westward, sand was moved with the aim of reducing the swampy area between the sandbank and the beach and of gradually moving the sand towards critical sectors.

Increased discharge velocity at the mouth by means of carefully planned lengthening of the right jetty would probably favor longshore drift towards the western sectors, benefitting the more distant stretches and leading to further straightening of the beach on the right of the Piave River. The sandbanks hold reserves sufficient to ensure sandfill in the depressed swampy areas characterizing the inner part of this stretch of beach.

The situation is certainly extremely critical and any intervention must be carried out under continuous surveillance, due to the scarcity of solids coming from the river.

DISCUSSION AND CONCLUSIONS

It does not seem necessary at this point to stress man's lack of foresight as regards the present crisis, apart from the undoubted fact that the coastline in question has never behaved in accordance with theory or practices applied to it.

In this context, natural factors, in themselves difficult to identify and quantify, overlap important artificial causes.

Natural factors include subsidence, increased sea level, bottom deepening offshore, tidal current changes, and wind direction and intensity. Hypothetical climatic changes, with conse-

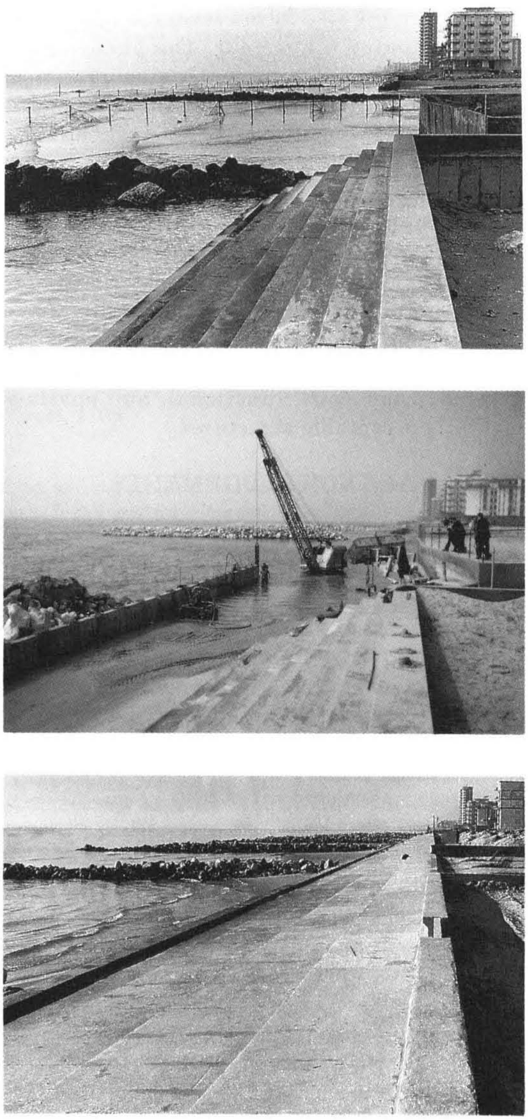

Figure 8. Chaotic situation along western stretch of Lido di Jesolo in December 1966 (above), during construction of defences (centre), and when nearly completed in 1970 (below).

Figure 9. Eastern beach near mouth of the Piave River and effects due to presence of groins, from 1977 (below) to 1987 (top).

quent eustatic changes, aggravated by subsidence in this particular sector, are further causes for concern.

Artificial factors include hydraulic reclamation and re-forestation, construction of reservoirs, sand and gravel quarrying from river beds, stream diversion, and flattening of the dunes which have drastically altered beach behavior. It should also be noted that inappropriate fishing techniques (*e.g.*, bottom trawling) may remobilize bottom sediments near the shore. Although the amount of material which may be lost is unknown, this activity certainly alters geotechnical characteristics, leading to loss of resistance to storms.

It has been repeatedly stated that the progressive emplacement of inhomogeneous defences indicates a total lack of method and knowledge which, combined with financial or aesthetic problems, has often been far from all functional principles. It may also be said that, while some interventions have produced satisfactory results, others have had the opposite effect.

The fact remains that, in spite of the considerable quantity of data collected in recent years, we still cannot identify the dimension of the problem or understand the reciprocal influences of single interventions proposed at such

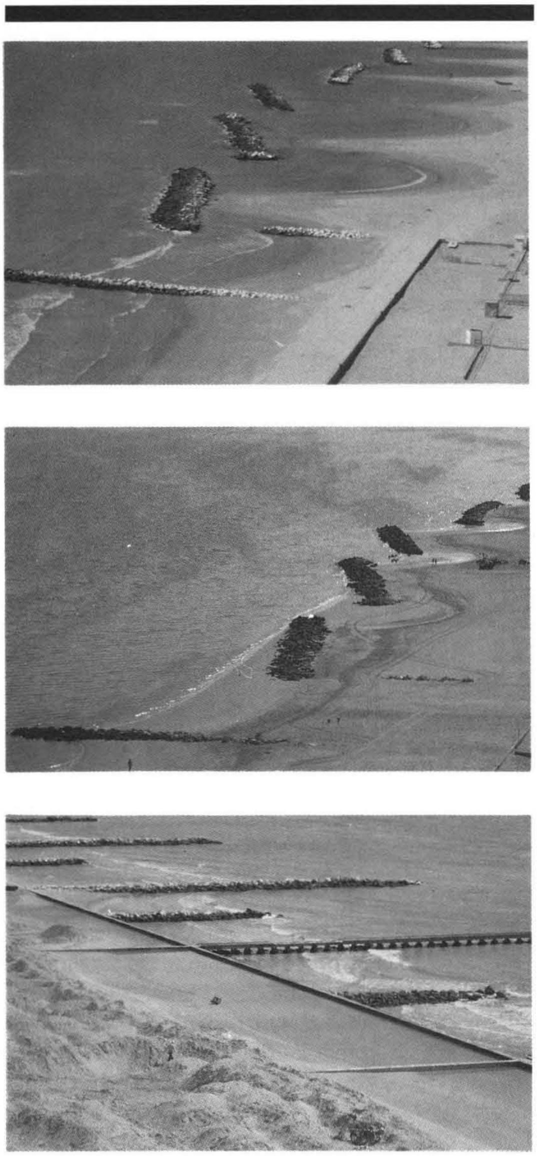

Figure 10. Effects of breakwater reefs: beach in 1977 (top) and 1987 (centre). Defences perpendicular to shoreline (bottom) are ineffectual and frequent artificial renourishment is necessary.

short intervals, because they overlap and do not allow clear evaluation of their effects. Yet the capital value of the high Adriatic beaches has recently been estimated at 3,000,000 lire/sq.m. (US $ 25,000).

In this context, the influence of climate should not be underrated. Eustacy connected to climate could lead to invasion by the sea of some dozen or hundred metres every ten years, even where the rise in sea level did not exceed the anticipated 6 mm/year. The phenomenon would occur over a very gently sloping coastal plain, where subsidence is considerable and is one of the factors causing recession of the shoreline.

The only way of preserving the maximum capital value of this coastal area lies in having the courage to remedy past errors. Solid supply must be more effective, and a greater degree of freedom must be restored to the mouth of the Piave River, resorting to artificial renourishment with carefully classified sands, and creating homogeneous, functional, and environmentally acceptable structures.

ACKNOWLEDGEMENTS

Concern about the Italian beaches goes back to the systematic studies initiated by Prof. A. Toniolo who, in the early 1930's, promoted research within the Italian National Research Council (C.N.R.—Committee for Geography and Engineering). In the Veneto region, the then Director of the Institute of Geography of the University of Padova, Prof. G. Morandini, requested the present author to start such studies. Later, the Operational Unit of the Department of Geography of the University of Padova, directed by the author, joined the "Special Program for Soil Preservation" (1972) and then the "Soil Preservation Project" (1977) ("Coastal Dynamics Subprojects"), again within the C.N.R. Research continues within the program "Coastal Dynamics and Protection," financially supported by the Italian Ministry of Public Education (MPI 40%).

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□ RÉSUMÉ □

L'action anthropique a considérablement affecté la côte associée à la lagune de Venise où débouchent les rivières, et ses plages. Le Lido di Jesolo a été lourdement exploité pour le tourisme depuis la seconde guerre mondiale, sans qu'une attitude critique ait été prise par rapport au comportement de la plage. Celui-ci est fortement lié à l'extrême variabilité, tant naturelle qu'artificielle de l'embouchure du Piave. Les fortes marées des années 60 ont sérieusement ruiné cette partie, et maintenant toute la côte est protégée par divers ouvrages de défense. L'évolution de l'embouchure du Piave et le comportement de la plage, l'évaluation des effets des ouvrages de protection sont estimés. Bien que l'utilisation du Lido di Jesolo ait été sérieusement critiquée, on peut encore se poser beaucoup de questions sur l'impact des ouvrages de défense.—*Catherine Bressolier (Géomorphologie EPHE, Montrouge, France).*

□ RESUMEN □

La línea de costa arqueada que encierra el Golfo de Venecia es extremadamente compleja. Los tramos terminales y las bocas de sus ríos y playas han sido considerablemente afectados por la intervención humana. El Lido di Jesolo ha sido explotado fuertemente con propósitos turísticos desde la Segunda Guerra Mundial, no habiéndose tenido en cuenta el comportamiento crítico de la playa, estrechamente conectado con la variabilidad extrema, tanto natural como artificial, de la boca del río Piave. En la década de 1960, fuertes pleamares produjeron tales daños que en la actualidad toda la línea de costa tiene algún tipo de protección. En este artículo se estudia la evolución de la boca del río Piave, el comportamiento de las playas y el efecto de las estructuras de protección sobre ellas. Aunque su uso en el Lido di Jesolo ha levantado fuertes críticas, existen grandes dudas en cuanto al impacto producido por dichas defensas.—*Department of Water Sciences, University of Cantabria, Santander, Spain.*

□ ZUSAMMENFASSUNG □

Der Aufbau der gebogenen Küstenlinie, die den Golf von Venedig umschlieldst, ist äußerst komplex. Dies liegt hauptsächlich in der anthropogenen Überformung der Flußunterläufe, der Flußmündungen und der Strände. Das Untersuchungsgebiet am Lido di Jesolo unterlag einer beträchtlichen Ausbeutung durch den Fremdenverkehr, insbesondere seit dem 2. Weltkrieg. Die Aktivitäten der Tourismusindustrie geschahen unter Nichtberücksichtigung der hohen natürlichen wie auch der durch menschliche Baumaßnahmen ausgelösten Variabilität der Mündung des Flusses Piave. Hohe Tidenstände in den 60er Jahren verursachten so beträchtliche Schäden, daß die gesamte Küstenlinie durch verschiedene Schutzmaßnahmen gesichert wurde. In diesem Aufsatz werden die Entwicklung der Piavemündung und die Auswirkungen der Schutzmaßnahmen analysiert bzw. bewertet. Zur Zeit wird nicht nur die aktuelle Nutzung des Lido kritisiert, auch bestehen starke Zweifel an der Wirksamkeit und den Auswirkungen der bestehenden Schutzmaßnahmen.—*Ulrich Radtke, Geographisches Institut, Universität Düsseldorf, F.R.G.*