Journal of Coastal Conservation 7: 163-170, 2001

Rapid shoreline retreat along the Esmeraldas coast, Ecuador: natural and man-induced processes

Federici, Paolo Roberto[1] **& Rodolfi, Giuliano**[2]

[1]*Dipartimento di Scienze della Terra, Università di Pisa, Via Santa Maria 53, I-56100 Pisa, Italy; Fax +3950500932; E-mail federici@dst.unipi.it;* [2]*Dipartimento di Scienza del Suolo, Università di Firenze, Piazzale delle Cascine 15, I-50144 Firenze, Italy; Fax +3955333273; E-mail rodolfi@iges.fi.cnr.it*

Abstract. Along the coast facing the Pacific Ocean in the province of Esmeraldas (Ecuador) one can observe some stretches where a process of rapid erosion is currently in progress. If it is not prevented, it seriously risks compromising the development of any form of utilization. In this paper, which summarizes the observations carried out in three different periods (1989, 1992 and 1999), we express the opinion that this process is the product of two distinct main causes. Along the Atacames bay, which may be considered as the main seaside resort of Quito, the capital of Ecuador, progressive cliff retreat is not only very dangerous for the existing tourist settlements, but also hinders their further development. The shoreline dynamics that seems to be due only to 'natural' causes (sea level rising, or the last *El Niño* event) are so active that defence works are not recommended. At Camarones the erosion of the coast is clearly due to the systematic destruction of mangroves by man. Also as a result of the last *El Niño* event, the situation has become alarming and it could rapidly get worse. By means of the present contribution, the Authors intend to attract the attention of the international scientific community upon the processes, not surveyed so far, affecting the 'weakest' stretches of the Ecuadorian coast.

Keywords: Cliff erosion; Coastal erosion; *El Niño*; Mangal; Mangrove; Seaside resort.

Introduction

A very severe process of rapid erosion is affecting some stretches along the northern sector of the Ecuadorian coast, which represents the main seaside resort of the capital, Quito. It has already provoked considerable damage to the road network, to agriculture, industry, human settlements and tourist resorts. After some surveys carried out in different periods in the Muisne-Rio Verde area (*Provincia de Esmeraldas*), the Authors are now able to state what they observed on previous occasions (Federici & Rodolfi 1993, 1994). Such an erosive process is very interesting both because it is undoubtedly due to natural events (*El Niño*, in particular) and because it seems, in some cases, to be induced or in some way favoured by human intervention in the coastal area.

In our opinion, the understanding of the causes which trigger these destructive events constitutes the necessary starting point for any reclamation and development plan. With regard to this, we must point out the bad economic and social situation of this part of Ecuador, in addition to an actual lack of knowledge. In fact, the two main attempts in order to improve the local economy are the expansion of the touristic settlements (as in Atacames) and, the expansion of shrimp raising (as in Camarones). Since both activities need more and more room close to the shoreline, a heavy conflict in terms of both policy and management is developing.

General features of the Muisne-Esmeraldas-Santiago basin

Our surveys were carried out in the Muisne-Punta Galera-Sua-Atacames-Esmeraldas-Camarones-Rio Verde reach, which constitutes the coastal fringe of the Esmeraldas-Santiago sedimentary basin (Ayon 1989). It is located northwards and westwards of the Viche hills, and it is drained by the fluvial network of the Rivers Verde, Esmeraldas, Atacames, and Repartidero-Muisne (Fig. 1).

Between Muisne and Esmeraldas the relief is formed by hills of 10 to 130 m height. They result from the deposition of sandstones, conglomerates, sands and clays, during the Neogene sedimentary cycles of the Daule Group: Onzole formation, Upper Miocene, and Borbón formation, Mio-Pliocene (Baldock 1982). The slopes show convex to concave profiles, with an inclination of ca. 40% on average. North of Esmeraldas, we find hilly reliefs progressively lowering from the 800 m a.s.l. of the Andes piedmont to the Pacific coast. The outcropping formations (Angostura, Viche, Pambil-Playa Rica) stratigraphically lying under the above-mentioned formations, are structured as monoclinals and alternate with

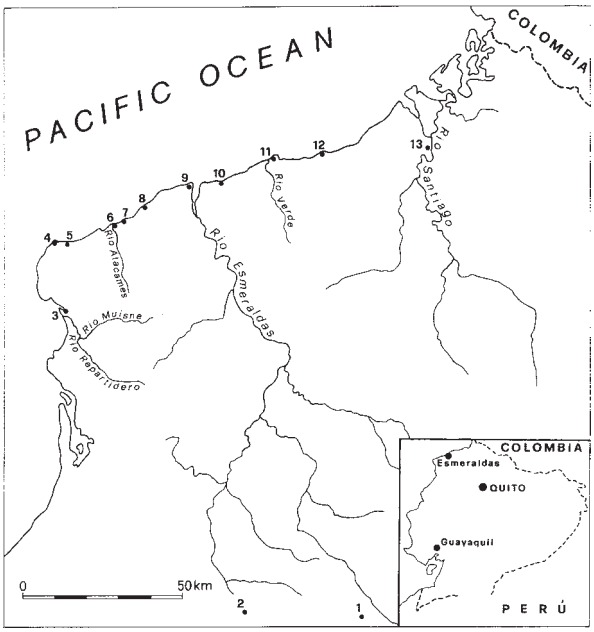

Fig. 1. Location map. 1. Santo Domingo de los Colorados; 2. El Carmen; 3. Muisne; 4. Punta Galera; 5. Sua; 6. Atacames; 7. Tonsupa - Puerto Gaviota; 8. Chevele; 9. Esmeraldas; 10. Camarones; 11. Rio Verde; 12. Las Peñas; 13. Borbòn.

depressions; West of Borbón they become tabular reliefs, with heights of 200 - 400 m a.s.l. Two almost flat surfaces, located at 25 and 10 m a.s.l., respectively, can be found without interruptions up to the latitude of Muisne.

The coast is characterized by beaches separated by rocky promontories > 90 m high in places (Las Palmas, Sua, Galera, Chevele). In the expansion areas of the river outlets, as well as in the low terrain of the coastal alluvial plains, and also in the lagoons and deltas, the typical mangrove landscape (*manglar*) develops. It enters fluvial environments, such as the wide Santiago low-lying plain, but also the terminal reaches of the Rio Verde, Rio Esmeraldas, Rio Atacames and Rio Muisne-Repartidero outlets. The *manglar* was also the typical vegetation of the lowlands far from the river outlets.

Table 1. Monthly rainfall (mm) during the last two *El Niño* events, related to the monthly averages of the last 15 yr (from Perrin et al. 1998, slightly modified).

Month	Monthly average	*El Niño* events 1982-1983	1997-1998
December	33.0	99.2	232.3
January	130.2	225.7	306.9
February	199.2	358.0	425.5
March	117.5	198.6	334.8

Where preserved, it covers the beaches, even when they are bordered by the close, often terraced, external wedge of the hill slopes.

The climate – according to the Köppen system – is *Am* – tropical monsoon (Blandín Landívar 1989), with a rainy winter and an arid summer (December to March). Rainfall is distributed irregularly even over longer time intervals, because of the periodic pulsations closely related to the consequences of the atmospheric circulations known as *El Niño* Southern Oscillations (ENSO).

During these exceptional events, rainfalls can reach very high intensities: up to 90 mm in 24 hours were recorded in March 1998 (Tables 1 and 2) at the Esmeraldas-Tachina rain gauge (Perrin et al. 1998). Exceptional tides, as well as heavy sea storms, with high waves, can occur at the same time.

Erosional processes along the coast between Esmeraldas and Rio Verde

Between the outlets of the Esmeraldas and Rio Verde rivers the coastal belt is 31 km long, low and straight or gently shaped with regularized scythe-like inlets connecting the small headlands (Cementerio, 98 m a.s.l.; Camarones, 45 m a.s.l.), offshoots of the Tertiary arenaceous-clayey hills reaching the sea. The entire coastal belt is very narrow, less than 1 km, and it is limited landwards by the slopes of the hills, which are usually terraced. According to Ayon (1989) the Esmeraldas-Rio Verde stretch is limited seawards by some sandy bars (*cordones litorales*). Due to the denudation of the hill slopes, large quantities of colluvial material are supplied to the beaches. The latter are also fed by the sediments carried by minor streams (*esteros*) as well as by the Rivers Colope, Rio Verde and Esmeraldas. However, the latter releases its suspended load on the open shore, so that some silty-sandy banks can outcrop at a remarkable distance from the shoreline during low tides, despite the considerable sediment dragging carried out by the Esmeraldas submarine canyon (De Miro et al. 1977).

However, the distribution of sediments is controlled by littoral streams, which drift prevalently towards the N-NE in summer, but southwards in winter and during

Table 2. 1997-1998 *El Niño* event. Daily (24h) rainfall (in mm) and percentage of the mean monthly rainfall (Pt) (from Perrin et al. 1998, slightly modified).

Date	Rainfall	% Pt
8 December, 1997	58.0	25
12 January, 1998	74.0	24
7 February, 1998	86.0	20
25 March, 1998	90.0	27

Fig. 2. A stretch of the Pacific shoreline near Camarones during low tide. Due to the low angle of inclination, a wide beach belt emerges. Here, it constitutes the only way for vehicles to reach the villages along the coast after the destruction caused by the last *El Niño* event.

the El Niño rainy season. The semi-diurnal tidal streams merge with them, leading to an amplitude which can reach 3 m (Ayon 1987). They alternately cover and uncover wide littoral areas, due to the low angle of inclination of the beaches.

Traces of a process of severe erosion have been observed along the coastal stretch north of the village of Camarones, where the hill slopes almost reach the narrow littoral belt; the only road to the North was built with difficulty at their base. Some stretches of that road were destroyed by marine erosion mainly during the winter of 1997-1998, which coincided exactly with an exceptional *El Niño* event. In these stretches, during low tides, it is easier to drive along the beach than on the road (Fig. 2). We believe that, besides the natural cause of the impact of the waves during the *El Niño*, another triggering factor of the failure may have been the environmental modification produced by man's activity in an area where, as we mentioned above, *manglar* is the typical vegetation.

Indeed, the mangrove littoral constitutes an impressive ecosystem in which sedimentation and tide-flow are the main environmental components. The mangrove trees, up to 10 - 20 m tall, mainly belonging to the genera *Avicennia* and *Rhizophora*, are typical of the salty-brackish environment. They are fundamental in stabilizing the soil, by means of a dense network of roots which anchor the suspended load that the littoral drift, as well as the inland streams, deposit in fluvial banks, estuaries and deltas. They represent the dominant element of the typical transitional landscape between the marine and the continental environment. This landscape varies throughout the day: the lower part of the trees can be submerged by the quick rise of the tide, so that the landscape takes on the appearance of a boundless hydroponic culture, or they can emerge and create a true swampy wood. The mangal animals are therefore forced to migrate periodically (Acosta Solis 1959). Some villages, basically built up by wooden houses on piles, rise among the mangroves, especially along riverine and lagoonal banks. Evidently, once this barrier is removed and its protective and sediment-filtering function has ceased, the waves can exert their strongest mechanical energy during high tides and become an effective destroyer during the *El Niño* events.

Some reaches of the mangrove littoral, i.e. at Camarones, have faced a radical transformation as a result of the installation of large tanks dug into the soil and bordered by levees. These tanks (*camaroneras*) are used as basins for raising a particular kind of shrimp (genus *Penaeus*), which Ecuador exports all over the world. The mangroves were destroyed and these basins, up to 100 m long and 30 - 40 m wide, took their place. In fact, the tanks must be dug where an easy salt water exchange is assured. This is the case with both the lowest areas entering inland and of the raised areas close to the shoreline where the circulation of salt water is supported by pumping.

The installations in Camarones were swept away by the strength of the sea, which in some reaches also demolished the coastal road. Only some remnants of these installations, such as fragments of concrete walls, emerge from the sandy banks during low tides. A comparison of the situation recorded by us in 1989, 1992 and 1999 (Figs. 3 and 4), clearly shows that the mangroves were first eradicate to allow for the installation of the

camaroneras, and that the place where they were installed has subsequently become a bare, muddy, stretch with only some remainsof the tanks.

As far as the coastal erosion is concerned, several authors, notably Ceron (1992) and Federici & Rodolfi (1994), have expressed their concern, mainly from an environmental point of view, about the expansion of the tanks to the detriment of the mangroves. It is indeed a delicate question. Any reclamation work, sometimes urgent in the zones affected by accelerated erosion, as in the case of Camarones, must take into account the fact that shrimp-raising is economically very important. In fact it is one of the main productive activities of the coastal zone and a major source of income for many people. The export of this product constitutes 17.5 % of Ecuador's foreign trade, making it the third important trade after oil and bananas. On the other hand, traditional agriculture is very poor.

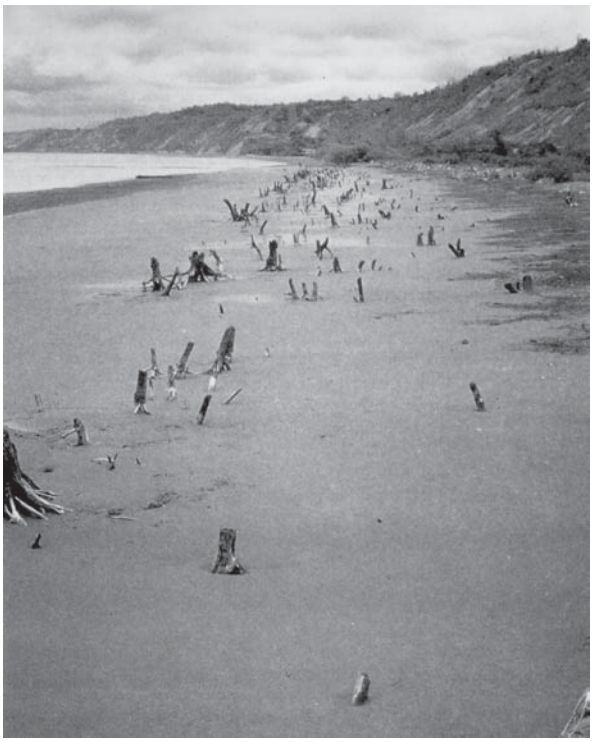

Fig. 3. The Pacific coast few kms north of Camarones, as it appeared in 1992: the *manglares* had been eradicated to install the *camaroneras*.

Erosional processes along the coast between Esmeraldas and Punta Galera

In this stretch of the shoreline, the hilly reliefs of the Cordillera Costanera, composed of the above-mentioned Tertiary formations, reach the seashore directly, forming high cliffs (Las Palmas, Chevele, Sua). The Esmeraldas-Tonsupa stretch, 20 km long, is a cliffed coast (*acantilados altos*, see Ayon 1989) up to 50 m high, whereas from Tonsupa to Punta Galera lower reaches, normally corresponding to the front of low terraces, alternate with those spurs. Moreover, low, sandy coasts, frequently covered by mangroves in areas little affected by men, develop in correspondence with the fluvial outlets.

In the Atacames area the most evident morphological element is a wide-terraced surface, which extends between 13 and 3 m a.s.l. The final stretch of the Rio Atacames, that leans out seawards with a long sandy bar, is carved into it. Traces of an ancient settlement, as testified by both pottery fragments and rubbish dumps (*basureros*), have been found on this surface. Archaeologists (Alcina Franch 1979; Guinea Bueno 1982) attribute them to a pre-Colombian civilization, in par-

Fig. 4. The same locality as it appears today, after being affected by strong waves during the 1997-1998 *El Niño* event. The *camaroneras* were completely destroyed (see some remnants in the background) and the undermined coastal road has remained interrupted at several points.

Fig. 5. The rapid retreat of the cliff bordering the Puerto Gaviota surface, due to undermining by waves during high tides, is affecting some cottages built too close to its edge at the time.

ticular to the 'Atacames phase' which developed between 770 and 880 A.D. The population has been estimated to exceed 2500 inhabitants, who lived in a village of at least 500 houses. This settlement still existed at the time of the arrival of the Spanish invaders in the 16th century, as the chronicles of that time show. The surface, which we will name 'Puerto Gaviota', ends with a long cliff on the seashore, clearly visible to the northeast and north of Chevele. The abundant remnants of the pre-Colombian settlement testify that the area was inhabited for a long time by people with a relatively high level of civilization. Since the retreating cliff is cutting these remnants, it could be inferred that the inhabited area was, at that time, much more extended seawards.

Because of its remarkable length of the cliff bordering the Puerto Gaviota surface, the height of which is generally ca. 3 m a.s.l., but 4 - 5 m at Puerto Gaviota, we have investigated its nature. It is undoubtedly composed of a sedimentary body deposited in a lagoon pond, certainly of continental or transitional environments (sediments contain pulmonate gastropods), the thickness of which is unknown, because its base is located under the present-day sea level. The texture of the sediments, very poorly cemented and rich in calcium carbonate, is prevalently silty.

The village of Atacames, located at 1-2 m a.s.l., was built on the flood-tidal flat of the same name. A wide area, extending towards the northeast up to Castel Nuevo and beyond, is directly affected by the interactions between the coastal- and the continental processes, connected with the evolution of the Rio Atacames outlet. Most of this surface, which disappears southwards in the Rio Atacames alluvial plain, is deeply embanked in the hilly reliefs of the *Cordillera Costanera*, and is covered by semi-permanent swamps with a typical hygrophilous vegetation, which probably replaced the old mangrove woods. The most dynamic stretch is undoubtedly the final one: the Rio, after some meanders, flows into the Ocean forming a very long mouth, clearly NNW-SSE oriented, as a result of the obstruction due to the NE littoral drift. The long projection seawards of the so-called *arena* testifies the progressive silting up of the outlet.

The coast of the Atacames area has already been subject to land use changes, with the transition from shrimp raising to tourism: Atacames has become the seaside resort of Quito. The *camaroneras* are being replaced by bathing establishments, shops, entertainment places, handicraft shops (black coral); these activities are all in an embryonic form now but it can be forecasted that this typical coastal landscape will undergo a violent transformation over the next few years.

The dominant morphogenetic process in the Atacames bay, in particular in the northern sector from Tonsupa to Chevele, is undoubtedly the rapid erosion of the shoreline, due to wave motion. Even during the ordinary high tide phase it undermines the cliff, the base of which, as mentioned above, is constituted by weak silty sediments, provoking its progressive fall and retreat. The failures which have affected the settlements built along the coast bear witness to the gravity of this process. The terraced surface of Puerto Gaviota-Tonsupa was probably much more extensive in the past than it is today, as one can infer from its imaginary continuation seawards, following the same inclination. Considerable, continuous erosive phenomena have progressively

Figs. 6 and 7. These pictures of the northern coastal stretch of the Puerto Gaviota surface (Chevele hilltop in the background) were taken in 1992 (Fig. 6) and in 1999 (Fig. 7). Taking the two palm trees as a reference, one can evaluate the rate of the cliff retreat.

reduced the extension of this surface to its present-day conditions.

The rapidity of the cliff edge retreat, ca. 1 m per year, was evaluated on the basis of some surveys carried out directly on the site in two different time-lapse periods (three years: 1989-1992; seven years: 1992-1999), using as a reference both the national topographic map, scale 1 : 25 000, and the aerial photographs taken in different periods by the Ecuadorian Military Geographical Institute in Quito. We should like to acknowledge the latter for the assistance provided. In fact, within the context of the Puerto Gaviota building plan (in 1977), the maps show a road running parallel to the cliff edge, as well as some cottages close to it. These had already disappeared at the time of the first survey (1989). Since 1992 the undermining of the cliff has provoked the edge retreat, affecting other houses (Fig. 5) and dangerously approaching the *camaroneras* of Puerto Gaviota, as well as demolishing the high cliffs of the Chevele hills. Up till 1999 the increases in retreat were spectacular. The seaward front of such a tank at Puerto Gaviota is now directly on the seashore and the water pipes have become obsolete; the fishermen's huts, once quite far from the cliff edge, now overhang the beach (Figs. 6 and 7) and other cottages, along the same line, are almost completely destroyed. In particular, there is a remarkable remnant of a water well, with its higher part overhanging the beach, while its base is undermined by swash (Fig. 8). The beautiful seafront terrace of one of the best hotels, with a double row of palms planted at the time of the Puerto Gaviota building plan, has been cut seawards. The staircase carved on the cliff has been destroyed, so that it is now difficult to get down to the beach.

Fig. 8. A water well, dug some tens of metres inland at the time, is now close to the cliff edge.

Final remarks

The question which emerges is how the erosional process, which seems unrestrained at present, could have been triggered. It is evident that the sedimentary balance of a beach depends both on the inputs and outputs of material, and it is also known that most of the Earth's coasts are now retreating. One must not forget, among other things, the progressive raising of the mean level of the Oceans. But here, in the Atacames bay, we have very strong and rapid erosional phenomena. The main impulse is probably due to the effects of the *El Niño* events on the meteo-marine balance. Even if the surveys on the consequences of the strong event which occurred in 1982-1983 are not available, we are able to document the 1997-1998 one. The entire Esmeraldas, Camarones, Rio Verde coast was strongly affected, and the shore road, as well as the adjacent *camaroneras* were partially destroyed. At Tonsupa, as we have already mentioned, the cliff retreat and the consequent damage were severe at some points: houses and bathing establishments were destroyed. The hinterland of the town of Esmeraldas is riddled with hundreds of slides, which have upset the road network (Perrin et al. 1998).

Despite the existence of substantially untouched and morphologically stable environments, the northern Ecuadorian coast shows worrying phenomena of shoreline retreat in some stretches, due to the increasing in erosion intensity. What is happening at this time can be regarded as the result of two different acting processes.

At Camarones and at the outlet of Rio Esmeraldas the coastal degradation is to be attributed, almost entirely, to man's systematic destruction of the *manglares*. At this time the risk situation is thought to be susceptible to a rapid increase. If this is the case, the first recommended step should be to put a stop to the cutting of the *manglar*, and indeed to restore them in the degraded coastal stretches.

In the bay of Atacames the rapid erosion process seems to be of natural origin. The progressive retreat of the cliff edge is not only affecting the existing touristic and recreational settlements, but is also endangering their future development, with consequent heavy economic damage. The shoreline dynamics are so rapid that the failure of any defence works (artificial wave-breaks, groynes), which are, in any case, very expensive and require an adequate technology, is a real risk.

In both cases the erosive process received a decisive impulse during the major *El Niño* events, particularly the last one in 1997-1998. Clearly, at the occurrence of such highly intense natural events, one also wonders whether man has not unintentionally exposed the environment to a higher risk, as a consequence of unplanned land transformations.

Under such conditions it is very difficult to speak in terms of coastal conservation and to suggest any solutions to solve the problem. We observe the simulataneous occurrence of both processes of strong erosion (wave motion and periodic storms from sea attacking 'weak' coasts) and an extremely critical social-economic situation. The reclamation of the coast, which is to be considered as a resource along the Atacames and Camarones stretches, would not only need on a more detailed knowledge of the erosion process itself – in order to prepare appropriate defence plans – but also, and first of all, the availability of a great amount of money. Both these issues are, at the moment, far from being reached.

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Received 7 August 2000;
Revision received 30 April 2001;
Accepted 1 October 2001.
Coordinating Editor: W. Ritchie.