COASTAL DUNES ALONG THE MARCHE LITTORAL (ADRIATIC SIDE OF CENTRAL ITALY)

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Abstract – An analysis of the main features of relict dunes and scarcely anthropized zones located along the littoral of the Marche Region is reported. The coast is strongly affected by man-made transformations mostly implemented from the '60s of the previous century to face beach erosion triggered by a reduction of river solid load derived from man-made interventions in the hydrographic basins. Presently, no real beach-dune still exists, but, locally, some eroded remnants can be found. The typical vegetation of dunes is very fragmented, depleted and strongly altered. Standing their extremely relevant ecologic function, it is instrumental to carry out actions aiming at preserving these relict dunal areas.

Introduction

The coastline of Marche Region (Adriatic side of Central Italy) [1, 2, 3] is mainly represented by sandy and/or gravelly beaches (about 150 km of 172 km).

After irregular alternances of progradation and retreat phases directly driven by climate up to about 2 millennia ago and then by agricultural activity (in turn, strongly influenced by climate conditions), the studied sector has been strongly affected by man-made transformations and presently shows an almost continuous series of coastal protection works: emerged and submerged breakwaters, seawalls, groynes and revetments. Moreover, harbor structures and channelized outlets locally interrupts the lateral continuity of the shoreline.

Such interventions were mostly implemented starting from the '60s of the last century to face beach erosion phenomena triggered by a dramatic reduction of river solid load. The latter, in turn, derived from man-made interventions in the hydrographic basins, such as construction of dams and check dams, gravel quarrying from the thalwegs, crops abandonment etc. Unfortunately, the lack of territorial planning for coastal intervention projects instead of solving the problem of shore retreat mostly brought to downdrift migration of erosional phenomena, thus requiring further interventions: in this way, almost all the regional shoreline was progressively artificially stiffened.

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In particular, in the 19th century, all along the Marche coastal belt several beach-dune systems were present, mostly close to the main river mouths. Many of these peculiar landforms were destroyed during the construction of the Adriatic railway (1862-63), while others survived up to the second half of the last century. Presently in the Marche Region, because of coastal erosion and construction of touristic facilities along the beaches, no real beach-dune still exists, even though locally some strongly eroded remnants can be still found, where natural habitats are severely degraded, and the typical vegetation of dunes is very fragmented, depleted and strongly altered.

Standing the extremely relevant geological, environmental and ecologic function of coastal dunes, mostly for protection from coastal erosion and habitat conservation, an accurate monitoring of their present remnants as well as of scarcely anthropized coastal areas has been carried out. Therefore, the study aims to provide an instrumental tool for preserving the coastal dunes and restoring the psammophilous phytocoenoses, which is fundamental for their consolidation, also favoring a proper management of the coastal belt.

The study area

The shoreline of the Marche Region stretches for about 172 km on the western side of the Central Adriatic Sea.

Three main morphodynamical sectors can be individuated ([4] and references therein):

1) The prevalently low coasts with the exception of the Mt. San Bartolo area wave-cut cliffs, which is located north of Ancona facing to the NE, and about 97 km long;
2) The pocket beaches intercalating wave-cut cliffs on the Mt. Conero headland (about 19 km);
3) The beaches of the «Piceno» coast to the south, facing about ENE (about 56 km).

The «dominant sea» (direction of provenance of the most frequent storms) is from SE (Sirocco), while the «regnant sea» (the direction of provenance of the most intense storms) is from N – NNE (Tramontana and Bora) (Fig. 1). Only very seldom waves reach heights up to 5 m (0.02 %) [5].

Except for the Mt. Conero area, the natural nourishing of all the beaches, and therefore their evolutionary trend, derives only from the solid load brought by the rivers draining the region, all of them showing an almost torrential regime.

The prevalent longshore drift is from south to north: only during the quite rare sea storms from N – NNE it reverts.

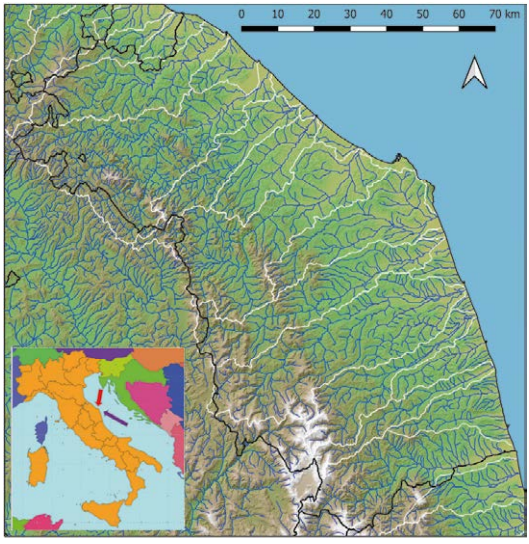

Figure 1 – Relief map of the Marche region.

All the main rivers of the region originate from the mainly calcareous reliefs of the Umbria-Marche Apennines and flow for most of their length over the more recent (Pliocene – Pleistocene) terrigenous deposits of the Outer Marche Basin (Fig. 2) ([4] and references therein).

The latter, generally being too fine grained, do not contribute efficiently to the natural nourishing of the littoral.

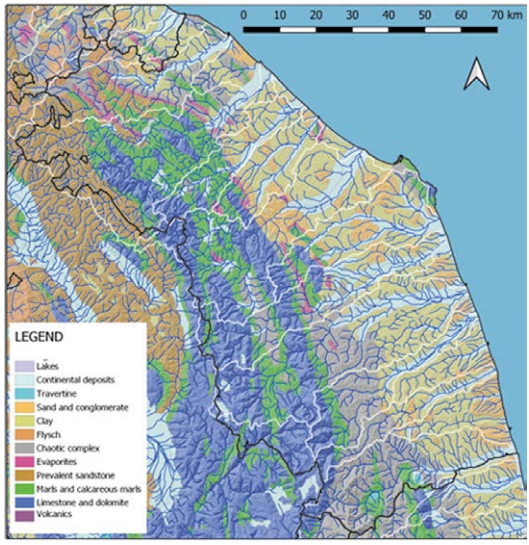

Figure 2 – Lithological sketch of the Marche Region.

Materials and methods

To reconstruct the historical evolution of the analyzed littoral we based upon geological, archeological and historical evidences, also considering the climatic records.

Starting from the second half of the 19th century the availability of reliable topographic maps allowed us to delineate more accurately the variations of the shoreline and of the emerged beaches. For the last decades large use of more accurate remote sensing imagery and digital vector maps has been done.

Present day environmental status and geometry of dunal remnants and scarcely anthropized coastal areas have been investigated by detailed field surveys.

All the above information has been used to implement a co-georeferenced geodatabase, used to carry out GIS based analyses and mapping.

Historical evolution of the littoral

After the emersion of the Umbria-Marche Apennines the coastline of this portion of Italy slowly advanced as a consequence of tectonic uplift. Anyhow, this progradation was not homogeneous, experiencing trend alternations as a consequence of intense climatic changes. Particularly, advancing, when the cold climate related to glacial ages lowered the sea level, and retreating, when better climatic conditions brought to massive ice melting.

During the last cold phase (Würm maximum, about 20 000 y. b.p.), the Adriatic Sea was some 120 m lower than nowadays and the emerged areas were mostly denudated, thus producing a huge amount of sediments that filled river valleys. All the rivers of the study area were right-hand tributaries of the Po River, whose low-stand delta was located a few kilometers to the SSE of the regional boundary [6, 7, 8, 9, 10, 11, 12].

During the Holocene, warm and humid climate (up to the so called "Holocene Climate Optimum") brought to a fast growth of the sea level (Flandrian transgression, 0.5 – 1.5 cm/y, up to about 6000 y b.p.).

At the same time, emerged areas were progressively colonized by vegetation and forests started to grow, thus strongly reducing the amount of sediments reaching streams; the latter, therefore, started to cut the previously accumulated thick alluvial deposits [1, 13, 14].

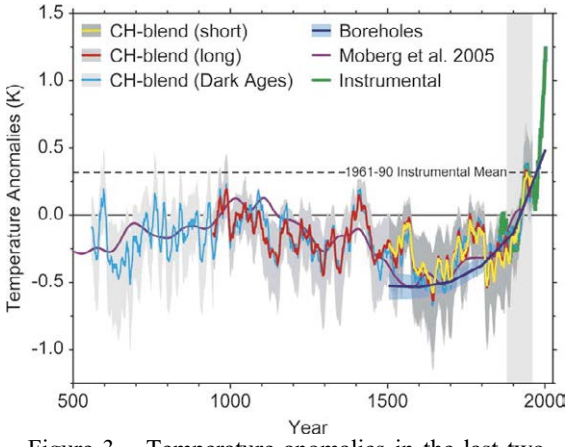

Figure 3 – Temperature anomalies in the last two millennia (after [36]).

The lower reaches of rivers were inundated by the sea to form *rias* [14, 15, 16, 17], having at their heads gravelly pocket beaches, alternating with long active wave cut cliffs [17, 18, 19, 20, 21].

The first historical progradation of the coastline happened during the Roman age: it was not driven by climate (still warm and humid, with biostasy conditions) being the consequence of widespread deforestation following increase of population and, therefore, of need for cultivated areas and wood, which took place during the late Bronze age and, most of all, during the Iron Age [22].

After having filled the *rias*, rivers started to advance toward the sea, forming beach-lagoon systems [16, 23], anyhow still located some hundred meters inland, as testified by many archaeological findings ([4] and references therein).

Between the beginning of the 5th century and the mid 8th century, climate worsening and somehow related socio-economic problems determined a significant reduction of the population, which in turn brought to the abandonment of many previously cultivated plots, thus reducing debris production and reverting the previous progradational trend of shorelines [24, 25].

Then, when climate become warmer and more humid (Medieval Climatic Optimum, around 1100 A.D.) population growth again with consequent intense deforestation [17, 26, 27, 28] for agricultural purposes: this resulted in relevant increase of streams solid load, allowing river mouths and, after some time, beaches to advance [14, 17, 25, 29].

This progradation ended when the colder climate (Little Ice Age, beginning in XIV century) [30] started to reduce the population; then, the Black Plague (1363) almost halved the European population. Consequently, many areas were abandoned and forests began to expand themselves again, thus reducing the solid load of streams and inducing a generalized retreat of the coastline [14, 25].

Later, population slowly started to grow again up to present days [31], with subsequent progressive deforestation, increase of agricultural pressure and production of debris along slopes which induced a new progradational phase, mostly close to river mouths [4].

Almost all the wave cut cliffs become inactive during the last centuries, being protected by generally not very large gravelly-sandy beaches.

Recent evolution of the littoral

Up to the mid 19th century, beaches continued to show a progradational trend and coastal dunes were very frequent all along the coast ([4] and references therein).

The first impact on those sedimentary bodies derived from the construction of the Adriatic Railway (1862 – 1863) (Fig. 4), mostly built very close to the shoreline, often above the coastal dunes, thus avoiding crossing the hilly, more unstable area located a few hundred meters inland. Moreover, to protect the railway from the erosion deriving from the most severe sea storms, hard coastal protections (mostly revetments) were locally built (Fig. 4). In this way the local natural littoral dynamics and the related longshore sediment drift were severely modified, inducing erosion down-drift.

Starting from the beginning of the 20th century dams and check dams (Fig. 5) were built along the upper-mid reaches of most rivers, thus dramatically reducing their solid load.

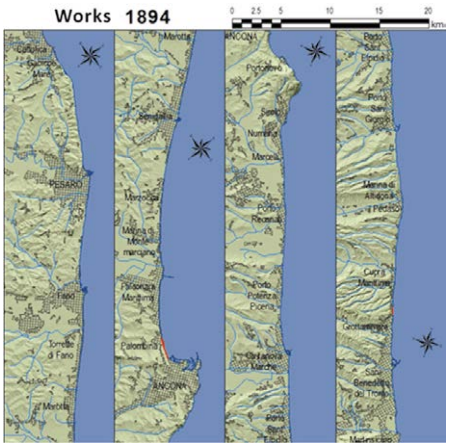

Figure 4 – Coastal protection works along the coastline realized before the 1894.

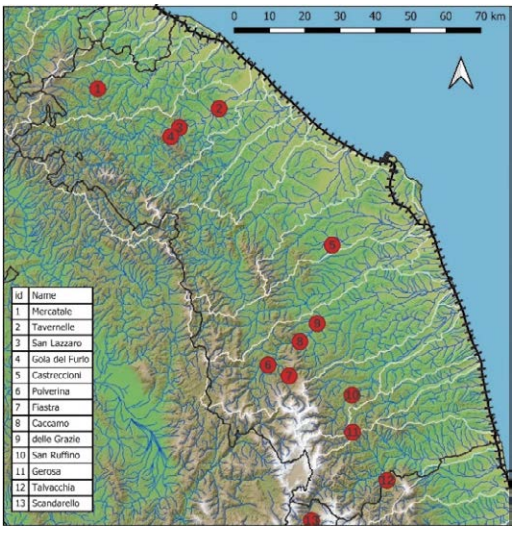

Figure 5 – The Adriatic railway (black line) and the main dams (numbered red dots) in the Marche Region.

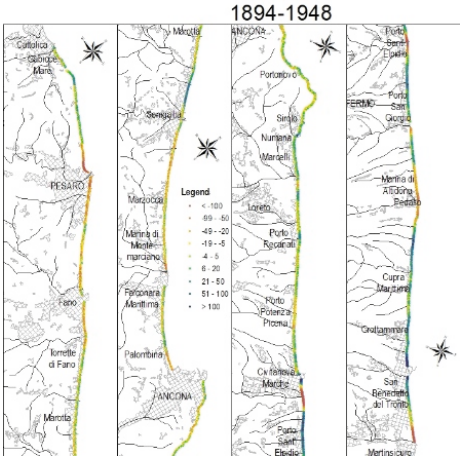

Figure 6 – Coastline changes from 1894 to 1948: orange to red tones indicate progressively stronger retreat, green to blue ones increasing advance. Bold black line highlights active cliff sectors.

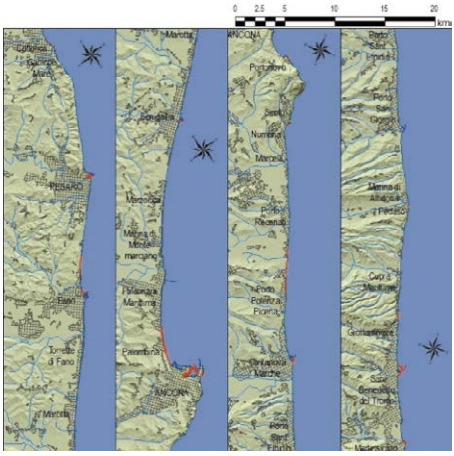

Figure 7 – Coastal protection works along the coastline realized from 1894 to 1948 (in red).

Moreover, piers and grayness built to protect the first harbors, locally stopped the natural longshore drift of sediments (Fig. 6).

As a consequence of all the above modifications of the natural equilibrium of the littoral, the progradational trend slowed down almost everywhere, even though in an inhomogeneous way, and some retreat phenomena locally started to take place (Fig. 7).

During the second half of the 20th century, the economic boom and the rapid growth of marine tourism induced a strong urbanization of the littoral stretches, and roads and facilities were built over many of the remaining dunes and emerged beaches.

Moreover, the industrialization brought both to field abandonment with subsequent reduction of erodibility of slopes and to very intense quarrying of gravel from riverbeds, thus inducing a sudden, very severe lack of adequate sediments reaching river mouths and, subsequently, widespread, locally severe, phenomena of coastal erosion (Fig. 8).

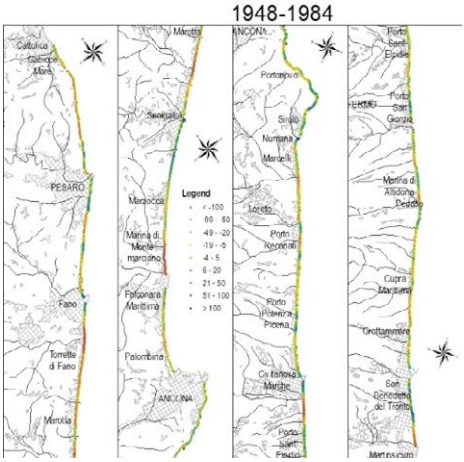

Figure 8 – Variations of the coastline between 1948 and 1984: orange to red tones indicate progressively stronger retreat, green to blue ones increasing advance. Bold black line highlights active cliff sectors.

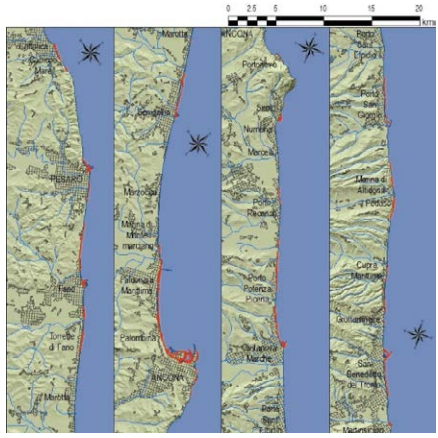

Figure 9 – Coastal protection works along the coastline realized from 1948 to 1984.

Shoreline retreat, having acquired a more relevant socio-economic relevance, was very often faced with many more "rigid" protection works (Fig. 9) of different types (emerged and submerged breakwaters, seawalls, groynes and revetments).

Unfortunately, most of these interventions were not supported by accurate investigations and therefore they often altered the natural longshore drift of sediments, thus causing downdrift migration of erosional phenomena. This almost continuously induced the stakeholders to build new and more extensive structures, thus altering even more the naturality of littorals.

Anyhow, these protection works, together with the prohibition to quarry gravel from rivers, allowed a significant mitigation of erosional phenomena toward the end of the last century (Fig. 10), but also brought to the beginning of creation of a mainly artificial, stiffened coastline (Fig. 11).

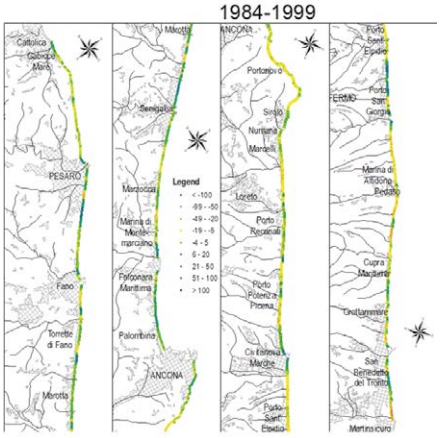

Figure 10 – Variations of the coastline between 1984 and 1999: orange to red tones indicate progressively stronger retreat, green to blue ones increasing advance. Bold black line highlights active cliff sectors.

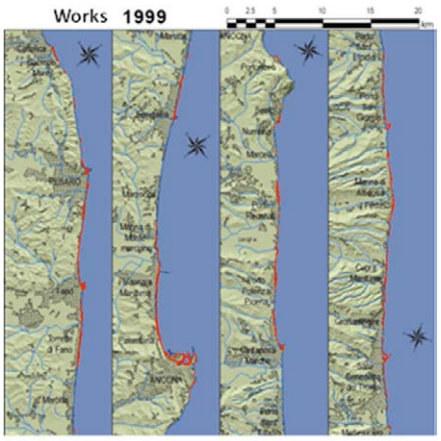

Figure 11 – Coastal protection works along the coastline realized from 1984 to 1999, in red.

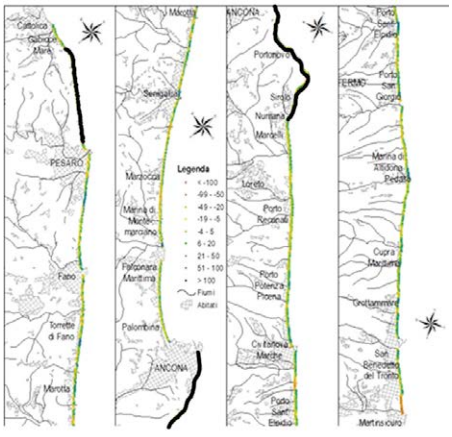

Figure 12 – Coastline changes from 1999 to 2020: orange to red tones indicate progressively stronger retreat, green to blue ones increasing advance. Bold black line highlights active cliff sectors.

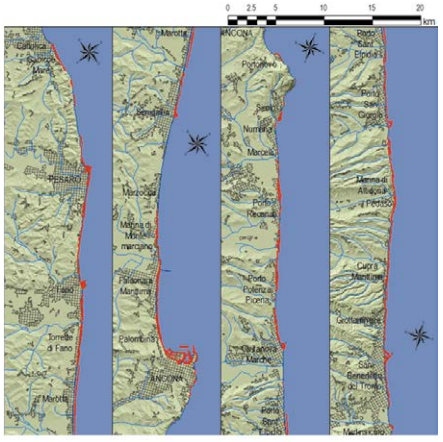

Figure 13 – Coastal protection works along the coastline realized from 1999 to 2020, in red.

During the last two decades, most of the coastline became stable or in slow progradation: unfortunately, this has been achieved only increasing the extension of protection works thus bringing most of the regional coastline to become artificial (Fig 12 and 13).

Anyhow, significant erosional phenomena locally still affect many beaches and further "rigid" protection works are supposed to be built in the next future.

Rare were the interventions adopting artificial nourishing: moreover, in some case they have been carried out with sediments whose grain size was too small to be stable for an acceptably long time or with amounts of debris too small to solve the problem.

Completely different has been the evolution of the pocket beaches of the Mt. Conero headland, where sedimentary supply mostly derives from mass movements (affecting the wave cut cliffs and the scarps bordering them inland) and it generally oscillates from one side to the other of the beach, without any interference among neighboring beaches.

Biodiversity of Dunes and coastal areas

Recently, a study has been carried out to survey all the relict dune deposits still present in the Region, as well as the scarcely anthropized coastal areas where dunes could start to develop, and to characterize them from morphological, sedimentological and botanical-vegetational points of view [32, 33]. At present, the coastal dunes bordering almost all the beaches of the Marche Region up to about 160 years ago, have been almost completely destroyed (Fig. 14).

Only less than 85 hectares of land still present dune sediments, mostly severely threated by sea storm erosion and, most of all, by wrong anthropic interventions. Among the others, still particularly interesting are the deposits located close to Fosso Sejore (between Fano and Pesaro, in the North of the Region) and those bordering the southernmost reach of the Marche coastline, in the Sentina Regional Natural Reserve (close to the mouth of the Tronto River).

Moreover, about 127 hectares not severely altered by human activities have been spotted that could be protected thus allowing dune growth.

As a rule, the investigated remnants of coastal dunes are small (as a maximum 2 m high and 20-25 m wide) and gentle reliefs located about 20-30 m at the back of the shoreline.

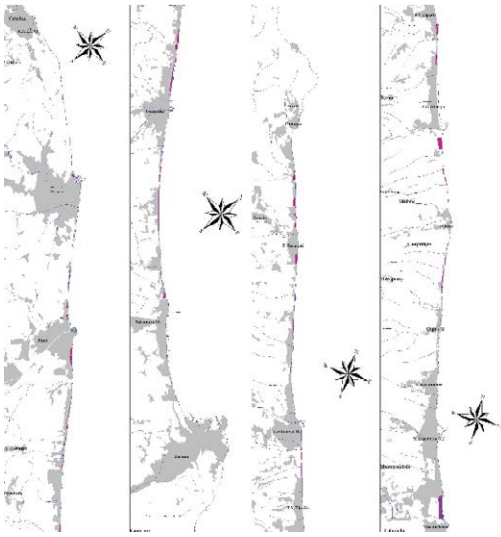

Figure 14 – Distribution of remnants of coastal dunes (in red and purple).

Locally, embryonal accumulations were individuated leaning against natural or artificial obstacles.

Sediments are represented by mostly siliceous fine sand showing rather homogeneous grain size.

From a botanical-vegetational point of view, the typical vegetation of dunes is very fragmented, depleted and strongly altered. The most common coenoses are those made up by annual species, such as *Cakile maritima* and *Salsola kali,* constituting the *Salsolo kali-Cakiletum maritimae* association (Fig. 15), often compenetrated by nithrophilous, sometime exotic, species. Perennial coenoses, such as the *Echinophoro spinosae-Agropyretum juncei* (Fig. 16), and the *Echinophoro spinosae-Ammophiletum arenariae* associations (Fig. 17), are much rarer: mostly the latter, still individuated only in a very few places along the studied coastal belt [34, 35, 36].

As it can be deduced from the above consideration on the recent evolution of the beaches of the Marche Region, coastal flora, vegetation and habitats have been profoundly modified and altered by human activities and are currently really poor and in an accentuated state of decay, thus making it difficult to imagine a significant improvement of their condition in a short while.

Figure 15 – *Salsolo kali-Cakiletum maritimae* association at the Sentina Beach (Southern Marche Region). a) The vegetated area; b) particular.

Figure 16 – *Echinophoro spinosae-Agropyretum juncei* association. a) the vegetated area; b) particular of the community in late summer.

Figure 17 – Remains of the association *Echinophoro spinosae-Ammophiletum arenariae*.

Anyhow, some small strips of dune vegetation have survived in a few places, where it is possible to find, although fragmented and impoverished, small nuclei of habitats 1210 [Annual vegetation of drift lines], 2110 [Embryonic shifting dunes] and 2120 [Shifting dunes along the shoreline with *Ammophila arenaria (white dunes*)]. These small remnants of habitat which importance is highlighted by the Directive 92/43/CEE of the European Unions, should make reflect on the need to preserve and, indeed, increase these habitats. Their preservation is of fundamental importance both for the good environmental status of the coastal belt, for effective and reliable contrast to the coastal erosion, and also for a differentiated recreational tourism and economic progress, in other words, for a modern Integrated Coastal Zone Management approach.

Conclusions

The study evidenced that the position of the shoreline of the Marche Region followed climatic variations up to about two thousand years ago, advancing when the climate was colder to retreat when it became warmer.

During the final part of the Bronze Age, anthropic interventions (namely deforestation to obtain wood and to gain cultivable land) became predominant, inducing the first progradation during a warm period. From then on, man made interventions within the river basins bringing sediments to the coast started to be the leading factors in determining the evolution of the littoral. Those interventions, anyhow, where strongly influenced by climatic variations, since the population increased during climatically more favorable periods to diminish when it was colder.

Starting from the second half of the 19th century, with the construction of the Adriatic Railway, the relevance of human interventions become even stronger, to further increase in time. Mostly with the economic boom of the ‘60s, river solid load (and therefore natural nourishment of beaches) was dramatically reduced by man-made interventions in the hydrographic basins, such as construction of dams and check dams, intense gravel quarrying from the thalwegs, crop abandonment, reforestation etc. At the same time, beaches started to

assume a very high socio-economic relevance because of the blooming of seaside tourism, and structures (mostly roads and touristic facilities) were densely built over the residual coastal dunes and on the emerged beach. The result of the above combination brought to "savage" construction of protection works of various type, very often built without an accurate and detailed knowledge of local littoral dynamics. This, most of the times resulted in downdrift transfer of the erosional phenomena, thus bringing to an almost continuous request of further interventions to follow the above migration.

Therefore, presently most of the regional coastline is artificially stiffened by protection works and the natural coastal environments have been almost everywhere destroyed.

The coastal dunes bordering inland almost all the beaches up to less than one century and half ago are presently almost completely destroyed: only a few remnants, generally badly preserved, are still present, further endangered by wave erosion and anthropic activities.

The presence of dune phytocenoses is extremely altered and rarefied; there are still a few well-preserved nuclei in which it is possible to recognize the psammophilous communities typical of the dune series. Urgent actions need therefore to be planned and realized to protect the few remains of coastal dunes from environmental and geological point of view. This will allow the growth of more of such ecologically very relevant sedimentary bodies where the anthropic pressure is not too much invasive.

Summarizing, to avoid repeating the severe errors of the recent past, also considering the effects of climate change and the strong anthropic pressure on the coast (and its touristic relevance), the present coastal dynamics of the area requires detailed, accurate and continuous monitoring to be carried out, in order to allow sustainable integrated coastal management.

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