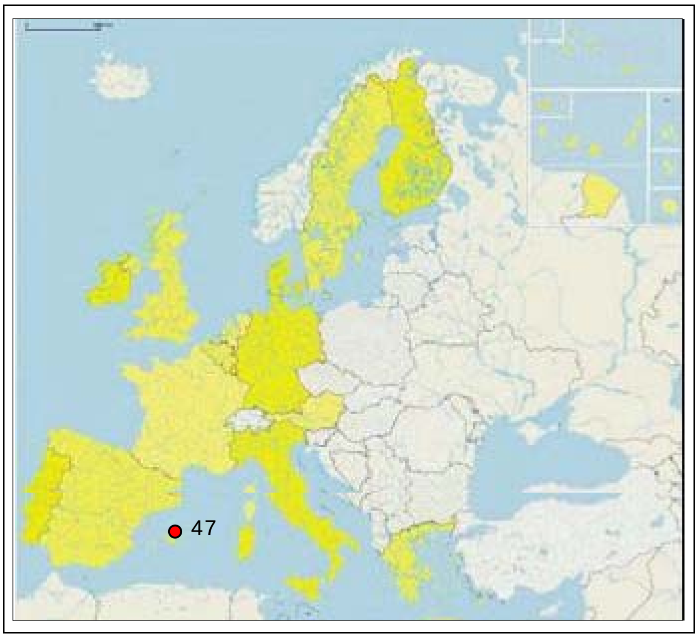
CAN PICAFORT
ISLE OF MALLORCA
(SPAIN)



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1. GENERAL DESCRIPTION OF THE AREA

Mallorca Island, located at the western Mediterranean Sea (Balearic Sea), is the greatest of the Balearic Islands. The area of interest is located at the northwestern sector of the Alcudia Bay (Can Picafort beach).

1.1 Physical process level

The studied zone is a classical Sandy Beach and Dune.

1.1.1 Classification

- Sedimentary microtidal (sandy beaches and dunes)

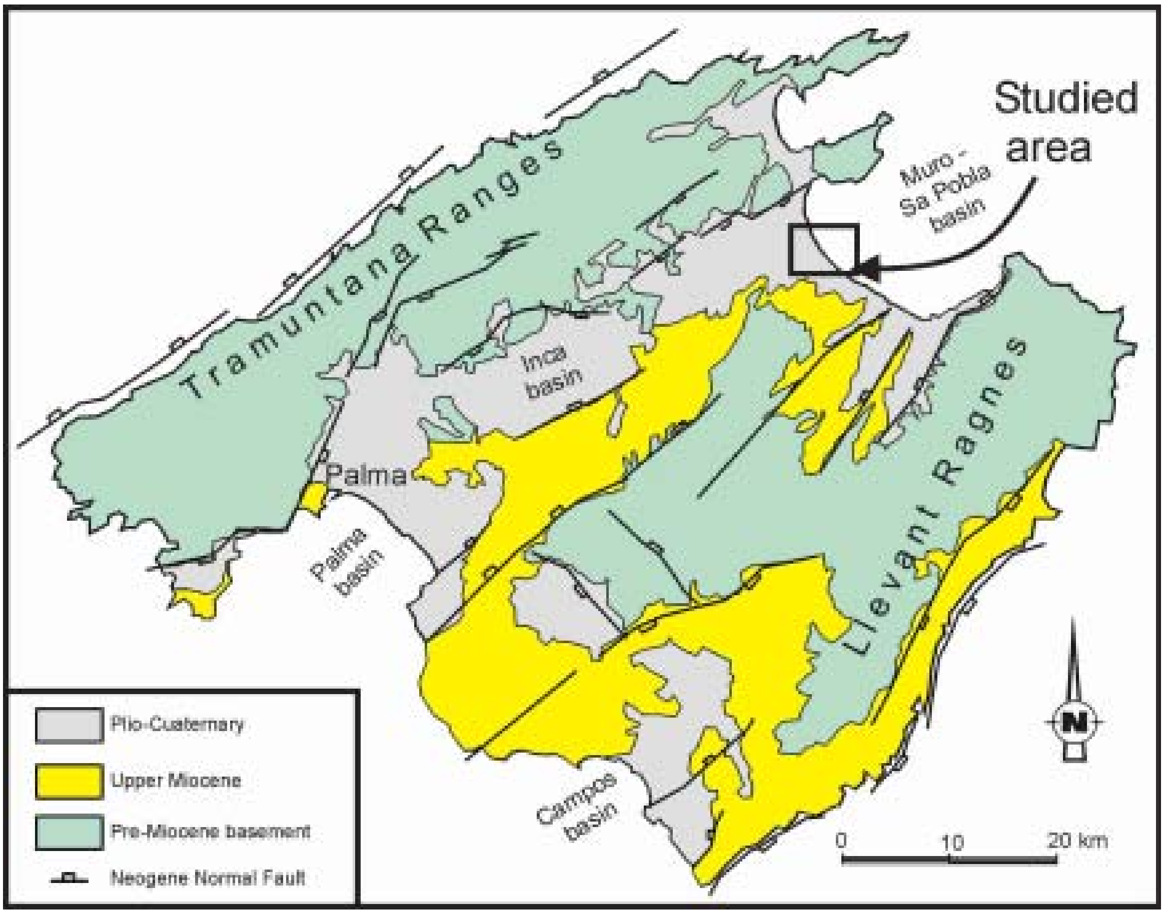

Fig. 1: Geologic sketch of Mallorca showing the area of interest.

1.1.2 Geology

Alcudia Bay has a structural origin, as it is limited by NE-SW Neogene normal faults at its margins, where Mesozoic materials outcrop (figure 1). Thus the bay is the undersea northeastern sector of the Muro – Sa Pobla Neogene basin. Two different zones have been differentiated within the bay: a subsiding sector (north) and a stable (or with a gently emersion) one (south) (Muntaner, 1980; Goy et al., 1997). At the subsiding sector a sand beach system with a wet zone onshore is present (Albufera d'Alcudia). On the other hand, at the stable sector sand beaches and gently rocky coast (Plio-Pleistocene eolianites) appear alternatively.

During early Holocene times along the subsiding zone a spit bar has grown from the south to the north. It is probable that during Roman times a connection between the present days wet zone (figure 2) and the open sea existed. Thus during the last 2000 years the spit bar has closed the estuary creating the present day morphology. On the other hand the southern sector has been subject to differential erosion and accretion processes.
The area of interest is located at the centre of the Alcudia Bay and corresponds to the limit between the subsiding zone and the stable one (figure 1). The northern limit is the "S'Oberta del Gran Canal", an anthropic channel created in the XIXth in order to dry the wet zone (Albufera). The southern one is the Can Picafort harbour, where the first consolidated Pleistocene eolianites outcrops. The subsurface sediments are mainly Pleistocene eolianites, nevertheless Upper Miocene materials also can be found.

The origin of the sediments is 89% bioclastic and 11%lithoclastic The Alcudia bay sand consists of 60 % medium sand (between 0.25 and 0.5 mm), 25 % of coarse sand (between 0.5 and 1 mm) and a 15 % of fine sand (between 0.125 and 0.25 mm) (table 1).
We present two different grain size analysis in order to show the great difference between the original sand of the area (Jaume & Fornós, 1992) and the grain size that it has been obtained after a beach nourishment in 2002 in Can Picafort area.

Table 1: Grain size characteristics of the Alcudia bay sand in 1992 (Jaume & Fornós, 1992) and in 2002.

	Fine sand (0.125–0.25 mm)	**Medium sand (0.25–0.5 mm)**	**Coarse sand (0.5–1 mm)**	**Very Coarse sand (1–2 mm)**	**Gravel (>2 mm)**
1992	15 %	60 %	25 %	-	-
2002	14 %	7 %	9 %	34 %	36 %

Thus the injected sand in 2002 has a much larger coarse fraction (more than 60% of > 1 mm size). This great difference is related to the fact that the used sand for the beach nourishment was extracted in front of the Tramuntana range (Western coast of Mallorca). In this area, the sand characteristics are different from those of the Alcudia bay. As we will discus, that grain size difference has been criticised by beach users and residents.

1.1.3 Morphology

The studied sector of coast consists of a 5 km long beach (from Can Picafort to S'Oberta) with a NW-SE orientation and facing the NE (figure 2). The topographic relief is very low and the higher zones correspond to sand dunes (up to 10 meters) that delimitates a wet zone (Parc Natural de s'Albufera) from the beach system. Tidal processes are almost imperceptible and max wave height is about 4 m at the open sea. The bathymetry of the Alcudia bay is also gentle. An inhabited zone and an uninhabited zone were selected in order to investigate the possible influence of human activity on the eroding processes.

1.1.4 Physical processes

Two independent sedimentary cells can be defined in the Alcudia Bay, a northern cell (studied area) and a southern one. Wave induced longshore transport can be considered as the most important process along the Alcudia Bay, which at the studied sector has a main SE-NW direction. Aeolian transport is also important but in this case the sand dunes move from North to South (Servera, 1997). Thus in the studied zone the longshore sea transport has a S-N direction and the eolian one has an N–S direction (figure 3).

1.1.5 Erosion

The studied shore shows erosion and accretion at different places. The distribution of the erosion and accretion sites is mainly controlled by human constructions (dikes and harbor) together with the longshore transport and storms. It can be considered that there is a continuous or gradual erosion process related to the longshore transport, and intermittent erosion related to storm episodes. These two processes cause redistribution of the sediment. As we will discuss the human activity has been determinant on the acceleration of the erosion processes.

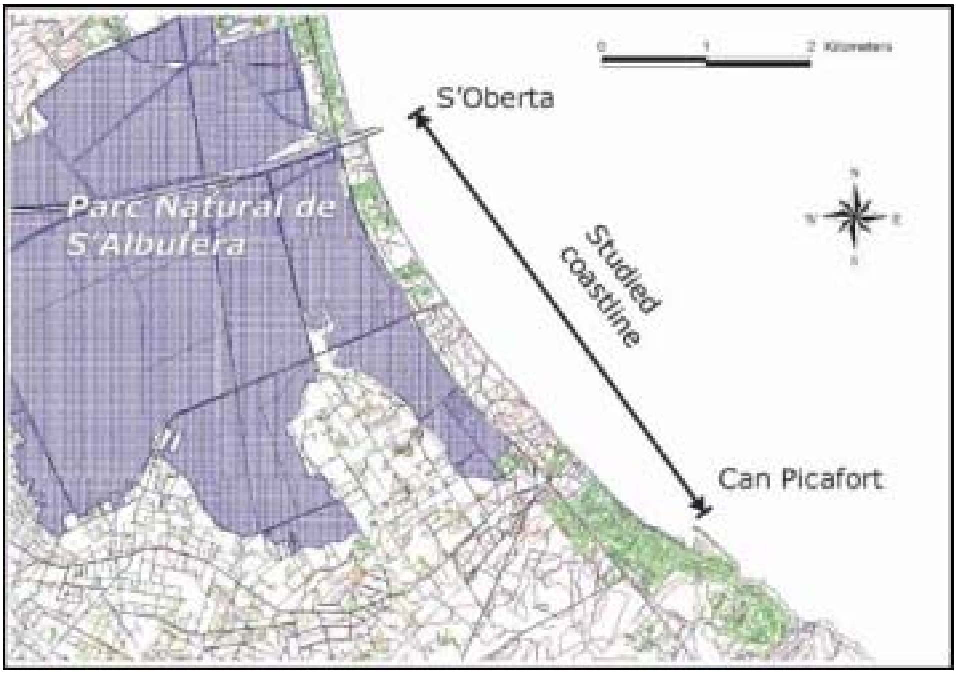

Fig. 2: Map of the studied sector of Alcudia bay (green, Houses; blue, wet lands; black, streets & roads; red, topography).

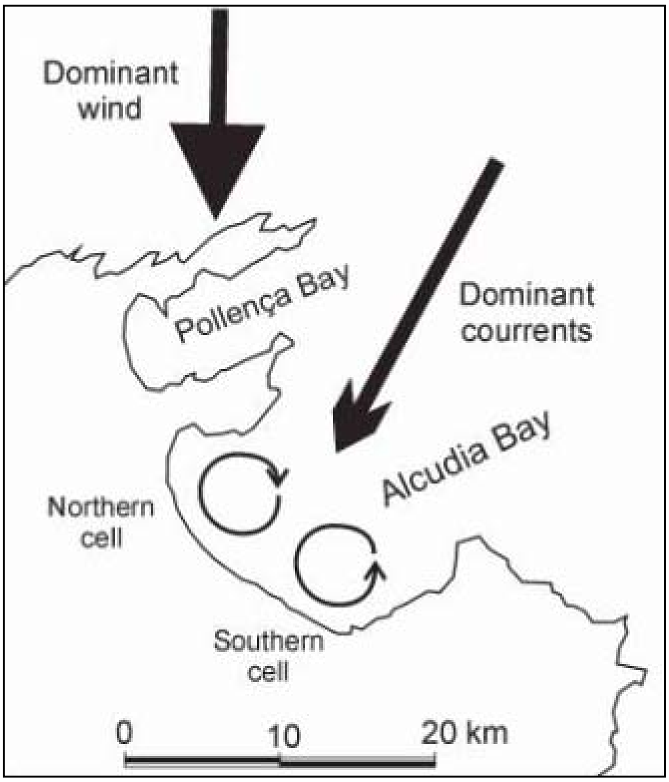

Fig. 3: System dynamic sketch showing the two independent cells related to the sea currents and operating in the Alcudia Bay and the most effective wind transport.

Erosion Type

The type of erosion observed at Alcudia Bay is a gradual sediment loss due to the S-N longshore transport. During storm events acute erosion is observed. Those processes produce a stretching of the beach at almost all the studied zone. In fact in some places of the studied zone the retreat has resulted in the destruction of the foredune, and at present waves are eroding the sand dune field. On the other hand, some places have undergone a sediment increase and the foredune is preserved.

The first human construction that has influenced the studied area was the dikes of the "S'Oberta" channel (end of the XIXth century) at the northernmost sector of the studied zone. Those dikes provoke a rupture of the longshore sediment transport that has induced a division of the northern sedimentary cell in two independent sedimentary cells (figure 4). As a result of this the coastline has been changing to a new equilibrium position during the XXth century. Two new beaches were developed: a northern beach (between Alcudia Harbour and "S'Oberta"), and a southern one (between "S'Oberta and Can Picafort) (figure 4). That southern beach (that corresponds to the sector where we are focusing this study) has had an enlargement at it northern extreme (S'Oberta) and a stretching at the central part. That stretching has been important, as the foredune has been destroyed in this sector (figure 4).

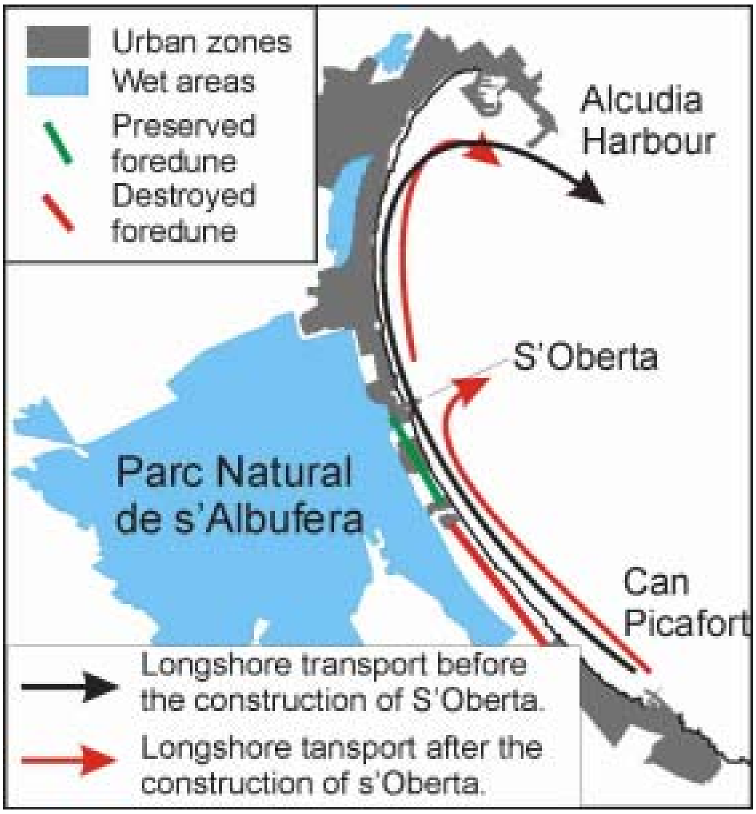

Fig. 4: Changes in the longshore transport sediment due to the construction of "S'Oberta" dike at the end of the XIX century.

Erosion Cause

Causes of erosion are mainly related to the human activities in combination with restricted sediment supply. Moreover, it must be noticed that the fact that the zone is located within a subsiding area (Muro - Sa Pobla Basin, figure 1) more intense erosion process associated with the relative sea level rise cannot be discarded. Nevertheless, taking into account the seismic activity of the area, we could not expect velocities higher than 0.1 mm/year of tectonic subsidence. Probably, the subsidence related to the sediment compaction must be greater than the tectonic one, but data on this aspect are not available.

Human activities can be divided in two main actions: **Housing near or on the foredune and dune field (anthropic pressure)** (figure 5), and **sea activities**.

Fig. 5: Construction of a Hotel over the sand dunes field near "S'Oberta".

Housing on the foredune implies that the de dune system is no longer part of the coastal zone. This makes the coastal zone (dune /beach and foreshore) more vulnerable for acute erosion. When there are no buildings in the dunes the foredune acts as a sand store which is eroded during severe storms and deposited under water. After the storm, given enough time, the deposited sand under water might gradually move landwards, building a new foredune. Hence, building in the dune area (fixing these dunes) leads to a more fragile beach system, in which the impact of coastal dynamics can have severe consequences.

Another important function of the foredune is to protect the sand dunes field and its vegetation from violent winds. In figure 6 we show an image of the effects of the wind on the stabilised sand dunes at the southern sector of the studied area (Cases des Capellans).

In summary the human pressure on the sand beach system can be seen as the main factor of influence determining the impacts of acute erosion.

On the other hand, the sea activities, especially in summer, cause a retreat of the *Posidonia Oceanica* prairie, which as we will explain is one of the most important organisms of the beach system. As noted above the sediment of the area has mainly a bioclastic origin (more than 80%). The longshore currents do not supply additional sediment to the Alcudia Bay zone. A unique sediment supply that is independent from the sea are sediments transported by the small creeks, which can be considered almost negligible, and those sediments coming from the erosion of the sea cliffs located at the extremes of the Alcudia Bay. The sedimentary cell of the Alcudia bay is nourished mainly by the biological activity that takes place in the sea.

Fig. 6: Effects of the November 2001 storm on the "Cases des Capellans" zone.

The biological activity is strongly related to the Posidonia Oceanica. Almost all the organisms that form the sediment of the beaches live around or depend on that plant. So, when we reduce the Posidonia Oceanica prairies we kill the sediment factory of the Mallorca beaches. As there is not any external supply when the Posidonia Oceanica prairies are destroyed we are inducing a beach retreat. In figure 7 we can observe the present day state of the Posidonia Oceanica prairies at the studied sector. It can be seen that the dark blue colours, which indicated a good state of the Posidonia oceanica prairies, are not well extended.

Fig. 7: Aerial view (2001) of the analysed zone. In this image we can observe the present day state of the submerged zone, where the Posidonia oceanica prairie is diminishing.

Another important aspect related to the Posidonia Oceanica is that during storms, dead parts are deposited on the beach. Those fragments form a little wall reducing the wave energy, diminishing the effects of the storms on the beach system. That is reducing the Posidonia oceanica we are reducing one of the natural protections of the system in front of strong events.

In summary, the presence of Posidonia Oceanica supports the natural protection of the beach system in front the acute erosion related to storms, and we also are assuring the sediment supply of the beach system in the future. Thus, that plant must be protected in order to fight the gradual lost of sediment from the coastal system.

1.2 Socio-economic aspects

1.2.1 Population density

The population density of the two communities of this area (Muro and Santa Margalida) can be obtained in different ways. First we can obtain a population density that takes into account the inhabitants of the two communities during all the year (real residents). Secondly a new population density can be obtained if we consider the maximum inhabitants that can be supported by the two communities in summer (real residents plus tourist places). In table 2 three different population densities are shown (inhabitants, tourist and maximum). Thus, in the year 2001 Muro community has a population of 6340 inhabitants and 15333 tourist places. Santa Margalida community, in the same year, has 7943 residents and 11564 tourists' places.

Table 2: Population, tourist and maximum densities obtained when we consider all area extent for each community.

Communities (Year 2001)	**Surface (km^2)**	**Population density (inhabitants/km^2)**	**Tourist density (tourist places/km^2)**	**Maximum density (inhabitants/km^2)**
Muro	58.6	108.2	261.7	369.9
Santa Margalida	86.4	91.9	133.8	225.8

Population densities in the studied sector could be much greater than the indicated in table 2. As most of the tourist places are located near the beach (studied area), the population density in summer in the studied zone (around the beach) can rise to 4000 inhabitants/km^2 (obtained considering an area of 5 km^2 for the tourist zone and 20000 tourist places).

Actually a project in Muro community examines the possibilities to increasing the population at Muro beach zone during the next years (Velasco, 1999). This study indicates that the number of inhabitants (residents plus tourists) at the Muro Beach zone can increase with 20000 inhabitants in next years. This indicates that the human pressure on the natural system will increase dramatically during the next years.

1.2.2 Major functions of the coastal zone

The major function of the coastal zone is tourism and recreation. The two communities of this area are manly dedicated to the tourism sector. The importance of the tourism in the economy of these two communities can be illustrated with the relation between number of resident inhabitants and number of tourist places. Thus for the Muro community we obtain 2.4 tourists per resident inhabitant and for the Santa Margalida community the relation is 1.5 tourists per resident inhabitant.

People from other communities also use the studied beaches for recreation. The increase of the human pressure related to the tourism on the studied area in the last 50 years has been shown in figure 8. In this figure we can observe an important increase of the tourist infrastructures. In 1951 the occupied area was les than 0.1 km^2, while in 2001 this area was bigger than 3 km^2.

Another important economic activity of the area is related to the wetland located close to the sand dunes field ("Parc Natural de S'Albufera de Mallorca") (figure 2). This natural conservation area has a special governmental protection, as it is one of the greatest wet areas of Mallorca. The area receives more than 100000 visitors a year.

Other economic activities as fishing or agriculture are also present but their importance to the economy of the area is very small, and can be neglected.

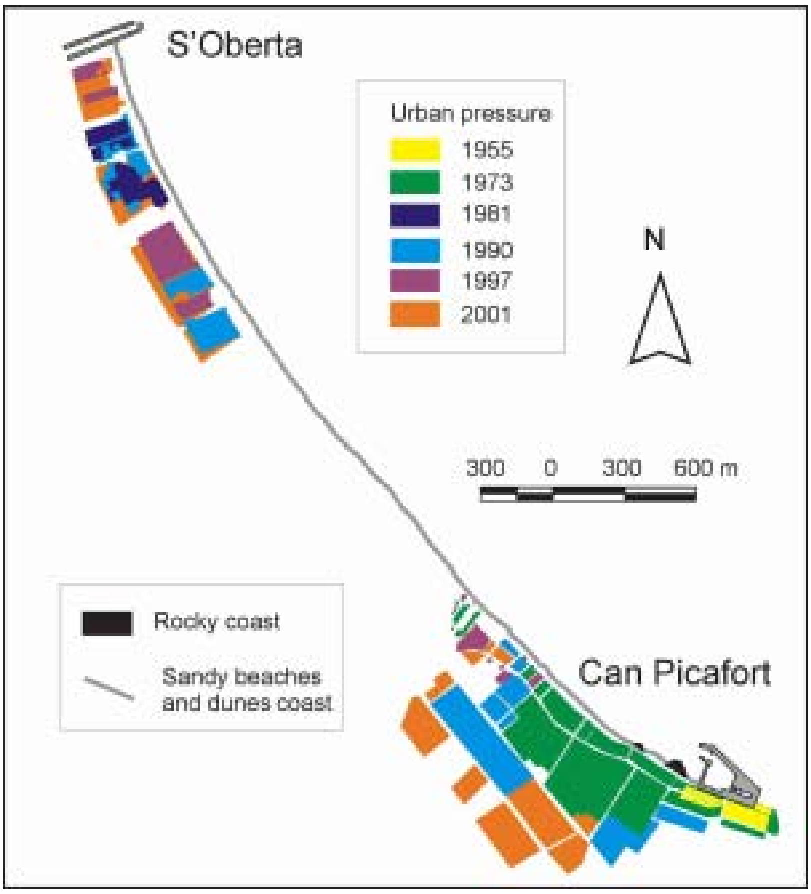

Fig. 8: Urban increase between 1955 and 2001. (Servera & Prieto, 2001).

2. PROBLEM DESCRIPTION

The main problem of this area is beach retreat due to the human impact.
The principal human actions that change the system dynamics can be resumed in five aspects:

- Construction of “S’Oberta” channel and Can Picafort Harbour
- Urban increase
- Tourist pressure
- Artificial beach nourishment

As noted above the first human impact was the construction of “S’Oberta” channel that induces a new equilibrium of the northern sedimentary cell, and the destruction of the foredune in the central sector. Maritime structures (harbours and dikes) act as sediment traps restraining and changing the longshore transport.

Housing increase, especially over the foredune and sand dune field (figures 5 and 8), put the proper role of the foredune area under severe pressure (sediment store).

Tourist pressure and recreation activities increase the destruction of the foredune (figure 9) and sand dunes field. Moreover maritime activities by the tourist cause the degeneration of the *Possidonia Oceanica* fields.

Fig. 9: Tourist activities as horse riding over the sand dunes increases the fragility of these sedimentary structures specially in front of the wind.

Artificial beach regeneration also has a bad effect on the *Posidonia oceanica* prairie, as the new injected sand strangles the plants. A recent study has corroborated that in some areas the Posidonia oceanica is retreating and that most of the prairies are covered with coarse sand coming from beach nourishment (Centre Balear de Biologia Aplicada & Pandion, 2002).

2.1 Eroding sites

The eroding sites are mainly located at the central and southern sectors of the studied area. The erosion is affecting the beach, the foredune and, in some places the sand dunes fields (figures 10 and 11).

Fig. 10: The absence of foredune in some sectors causes the erosion of the sand dune field. Here we observe two penetrated sand lobules on the sand dune field due to the generation of blow outs at the frontal section of the sand dune.

To analyse the evolution of the area in the recent years 5 aerial photographs', corresponding to 1973, 1981, 1990, 1997 and 2001, have been studied. Thus it has been possible to determine the changes that have taken place in the area during 30 years (figure 12). Three different sectors along the studied area can be defined taking into account their evolution during the studied period:

- A northern zone where the beach width has been increasing since the construction "s'Oberta".

Fig. 11: The sand dunes field is being eroded do to the fact that the foredune has disappeared. Here we observe eroding process that is affecting the frontal part of the sand dunes field, where a blowout has developed.

- A central zone, characterized by a low human impact, where a general retreat is observed.
- A southern zone, subjected to a more intense human pressure, where an important retreat has been taking place.

From the analysis of aerial photographs the next sequence has been obtained:

1973-1981 period
A great increase is observed in the northern zone during this period due to the sediment trapping effect of "S'Oberta" channel. On contrast, in the southern sector a general retreat is observed. The balance that we obtain is positive (+51162 m^2), having an area of 68018 m^2 of accretion and and an 13856 m^2 area of retreat (figure 12).

1981 – 1990 period
During this period a general retreat is observed in the whole area. The sedimentary balance indicates 1830 m^2 of accretion and 44095 m^2 of retreat (-42265 m^2). It must be noticed that in 1988 artificial beach nourishment was done in Can Picafort area (MOPTMA, 1995), which effects are almost imperceptible in 1990 aerial photograph. We must notice that during this period the urban pressure has had a great increase near the coastline, especially in the northern sector (figure 8).

1990 – 1997 period
Contrasting with the previous period, the general sedimentary balance of this period is positive (12815 m^2), having 15186 m^2 of accretion and 2371 m^2 of retreat. Thus a general accretion is observed in all the area (figure 12). Another artificial beach nourishment was done in Can Picafort zone in 1997 (previous to the aerial photograph) that injected 70000 m^3 (Córcoles, 1997). That sediment injection could explain the positive balance of that period.

1997 – 2001 period
The sedimentary balance of this period is negative (-1367 m^2). Thus we have measured 10690 m^2 of increase and 12057 m^2 of retreat. Most of the erosion is located at the central sector. At the northern area a general accretion is observed, and in the southern one the observed accretion can be explained with a new artificial beach nourishment done in 1999 (Ferrer, 1999).

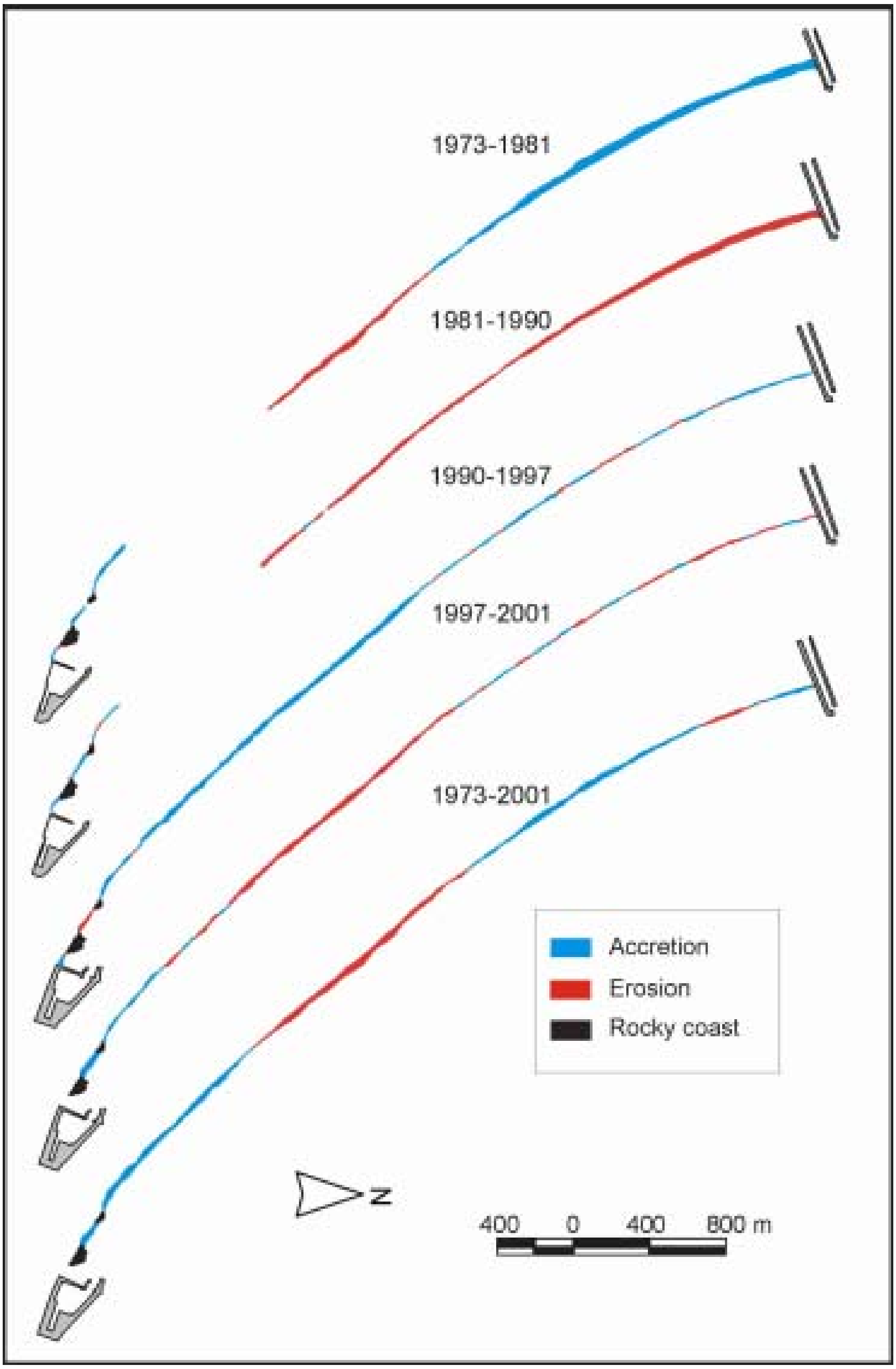

Fig. 12: Evolution of the studied sector between 1973 and 2001 (Servera & Prieto, 2001)

In summary a general retreat in the central sector and a general increase at the extremes can be deduced from the analysis of the aerial photographs (figure 12). The sedimentary balance obtained between 1973 and 2001 is positive (±18500 m^3), with ±43000 m^3 of accretion and ±24647 m^3 of retreat (figure 13). Between 1988 and 1997 three sand nourishments (1988, 1997, 1999) were realised by the government in the Can Picafort area. It is not possible to determine the exact sand volume injected in the area (±150000 $m^{3)}$. Without the sand nourishment an important coast retreat would have been expected at the central sector and an accretion at the northern one (related to the longshore transport). At the southern sector the retreat should be smaller than in the central one as the Can Picafort harbour protects the southernmost beach from the longshore transport.

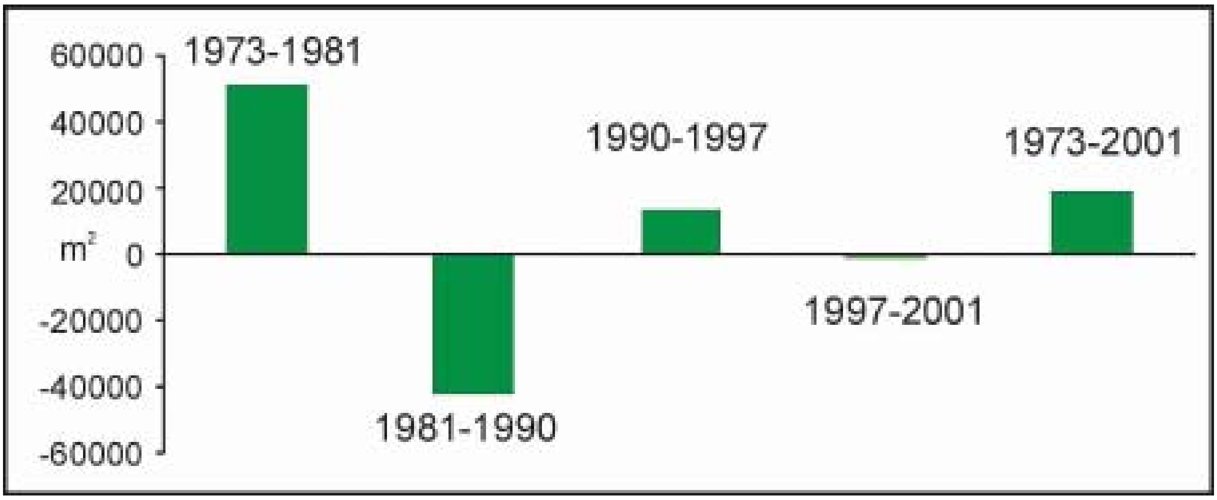

Fig. 13: Total sedimentary balance (m^2) of the studied zone according to the aerial photograph interpretation.

2.2 Impacts

As the major functions of the zone are tourist activities, the impact of the observed erosion is mainly related to the economy of the area. A large number of the inhabitants of the two communities work in the tourist sector. The attractiveness of the area depends largely on the beach and the sun. If the beach disappears the economic engine of the area will also disappear. For that reason the impact of beach retreat in this area will affect the inhabitants residing inland, not also those who live near the beach.

Another important impact is related to the increase in vulnerability of the coastal system for storms and winds. Especially when the foredune has been eroded the sand dune fields located inland can be destroyed easily in a single storm. The foredune morphology and its specific vegetation are able to reduce the strong winds coming from the sea. The absence of a foredune causes instability of the sand dune field, blowouts can be easily created in the sand dune field increasing the systems fragility. The absence of the foredune also implies a great risk of erosion done by the sea waves during storms.

3. SOLUTIONS / MEASURES

3.1 Policy options

The adopted policy option has been one of limited intervention. Intervention is restricted to nourishment of the beach using sand from other sectors of Mallorca. The nourishment's are only done when a significant retreat is observed and, generally, are done before summer time. Some hotels located just in front of the beach have done nourishments without any authorisation; in those cases nourishment's are small and concentrated in a very small area.

The authorised nourishment's that have been carried out in the zone have been concentrated in the southern zone (Can Picafort). In many cases the used sand has a very different grain size and mineralogy (table 1). This aspect has induced a lot of critics from the hotels owners and also from the users of the beach.

The critics are related to the bad quality of the used new sand, especially in the 2002 nourishment. In this official decision the sand was extracted from the southern sector of Serra de Tramuntana (Banyalbufar community). In that zone the grain size is bigger as the one of Alcudia Bay, and lots of shells have been extracted together with the sand. Trying to solve that problem the new sand has been triturated. But the new triturated sand was more dangerous than the original sand with big shells, because during the triturating process shells were broken. These broken shells have resulted in numerous problems for beach users.

3.2 Strategy

Unfortunately no strategy has been developed by the authorities in order to mitigate or stop the retreat of the beach. Sporadic beach nourishment's can be defined as the unique ad-hoc measure adopted by the government. As explained the nourishments have been realised when the beach retreat caused a problem for tourism or constructions.
Some specific studies supported by government agencies have been done to analyse the present-day situation of the area (beach and undersea) but to the present day any decision have been taken to solve causes of the erosion problems. It can be assured that most of the implied community governments do not accept the causes of the problem.

3.3 Technical measures

The only measure that the government has taken to fight against the retreat is the nourishment of the most affected beach (Can Picafort beach). It is very difficult to determine the number of m^3 sand used during single nourishment because the Can Picafort beach is not the only beach in Mallorca that experiences retreat.
In some cases it is possible to know the number of m^3 used in one governmental nourishment campaign done on several beaches of Mallorca littoral, but it is impossible to determine the quantities used for each beach. For example the 2002 nourishment used 70000 m^3 sand extracted from the western coast of Mallorca (southern Tramuntana zone), but the sand was injected in three specific areas, one was the Can Picafort zone and the rest located far away from Alcudia bay.
Also the costs of individual beach nourishments are unclear as government only indicates the total cost of all nourished beaches. For example, the nourishment of all the beaches from Mallorca affected by the November 2001 storm had a global cost of 1.200.000 Euros.

Other measures have been taken related to the use of the sand dunes zone. Part of the sand dunes zone has been incorporated to the protected zone of “Parc Natural de s’Albufera de Mallorca”. That measure will help to restrict the vehicle traffic within the sand dunes zone, which will help to protect the dunes from wind erosion.

4. EFFECTS AND LESSONS LEARNT

4.1 Effects related to erosion

Gradual erosion due to the human pressure on the beach system does not stop. The local nourishments done in the coastal zone have not solved the problem. As explained, the gradual longshore transport together with occasional storms redistributes the nourished sand, thus the adopted measures have no effect in a long term.
It can be said that the nourishment helps to maintain the beach amplitude some years (not more than 5) but with time another beach retreat is observed and new nourishment had to be done.

4.2 Effects related to socio-economic aspects

As explained the economic engine of the area is the tourism, and that tourism is directly related to the use of the beach. Thus the hotel owners and people who work in the tourist sector must take care of the beach system, otherwise their jobs will be in danger. It can be said that the adopted measures have been successful in a short time span, as the beaches has been proper to be used by the tourists each summer, so the tourist who use the beach has been happy. On the other hand, these measures are not the appropriated ones to solve the problem in the future.
One of the best measures that could be taken to solve the problem is a managed realignment. That measure will imply to destruct almost all the houses and hotels constructed near the sea (over the foredune or the sand dune field). But this measure will imply to transport the entire tourist zone some kilometres inland, imply huge costs and will not be accepted by the inhabitants. Exact financial implications (cost and benefits) and social acceptance of the local community needs further investigations.

4.3 Effects in neighbouring countries

The erosion problem described in the Alcudia Bay can also be observed in other beaches of Balearic Islands. In all the cases the main problem is the human pressure on the beach and on the Posidonia Oceanica prairies. Due to the fact that most of the beaches in Balearic Islands can be considered as single sedimentary cells, as the longshore transport is limited to each bay, the measures must be taken on each beach.
However, it must be said that the continuous nourishments in the Alcudia Bay had introduced a general increase at the northernmost sector of the bay (Servera & Prieto, 2001).

4.4 Relation with ICZM

At the moment we do not know the existence of any kind of project related to the general management of the area.

4.5 Conclusions

Effectiveness

Nourishments have shown to be effective for a short period of time, but they are not effective in a more extended time period. That is, nourishments can solve the problem of the acute erosion related to storms, but are not effective to solve the gradual lost of sediment.

Thus the longshore transport and the fact that the sedimentary factory of Balearic Islands is mainly limited to natural productivity gradually reduces the sediment volume availability of the beach system. Profound knowledge of the system, specially the role of the *Posidonia oceanica* prairies on the system, is necessary to adopt successful and long-term measures.

Possible undesirable effects

The nourishments could have some problems. The most important problem is that the used new sand must have the same grain size characteristics as the proper sand of the beach. Otherwise problems may arise: Bad quality of the beach for tourism, disequilibria of the beach system do to the new injected grain size and strangulation of the *Posidonia oceanica* prairies.

Gaps in information

To evaluate a proper model that explains how the system works implies new studies to be done to determine the exact longshore current. With those data it will be possible to determine the places where nourishment will have better results. At the moment the nourishments are applied in the areas where a retreat is observed, without taking into account any technical measure.

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