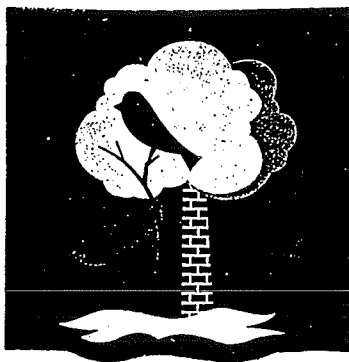


***MEDDELT***

**MEDDELT  
IMPACT OF CLIMATIC CHANGE  
ON  
NORTHWESTERN MEDITERRANEAN DELTAS**

**A FINAL SUMMARY REPORT**

**JANUARY, 1997**



**Climatology and Natural  
Hazards Unit**

***sponsored by***  
**Commission of the  
European Communities  
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(1994-1996)**

**MEDDELT**

**Impact of Climatic Change on NW Mediterranean Deltas.**

**A Final Summary Report**

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## 1. INTRODUCTION

### □ *SOME DELTAIC DEFINITIONS*

○ *Deltas* are accumulations of river-supplied sediments in the land-ocean border. The dynamic behaviour of subaqueous and subaerial zones is governed by natural (marine, riverine and atmospheric) and anthropogenic factors.

○ *NW Mediterranean Deltas* (see *e.g.* Jelgersma, 1996)

- Moderate wave and tidal climates:
  - significant wave-height in deep water, yearly average = 0.5 m to 1.0 m
  - spring tidal range = 0.1 m to 0.5 m
  - storm surge yearly average maximum = 0.25 m to 0.75 m
- Significant decrease in river solid discharges during the last (*e.g.* 5) decades due to extensive damming in the catchment area and river flow regulation policies:
  - % reduction: 50% to 95% (higher for the sand fraction).
- Subsidence rates of average magnitude.
  - Due mainly to compaction (0 to 3 mm/year during the last decades).
  - Limited effect of tectonic movements.
- Precipitation rates (local) of limited magnitude (less than 600 mm/year on average).
- Salt-wedge estuaries.
- Pressure of use and natural/anthropogenic values relatively high.
  - Ecologically rich areas in comparatively "poorer" environments.
  - Actively "exploited" (agriculture, fisheries, aquaculture, oil and gas, tourism, etc.) with clear conflicts between uses.
  - With relatively low population densities (with respect to nearby big urban areas outside the deltas).

These deltas are illustrated here by the Ebro, Po and Rhône (figures 1, 2 and 3).

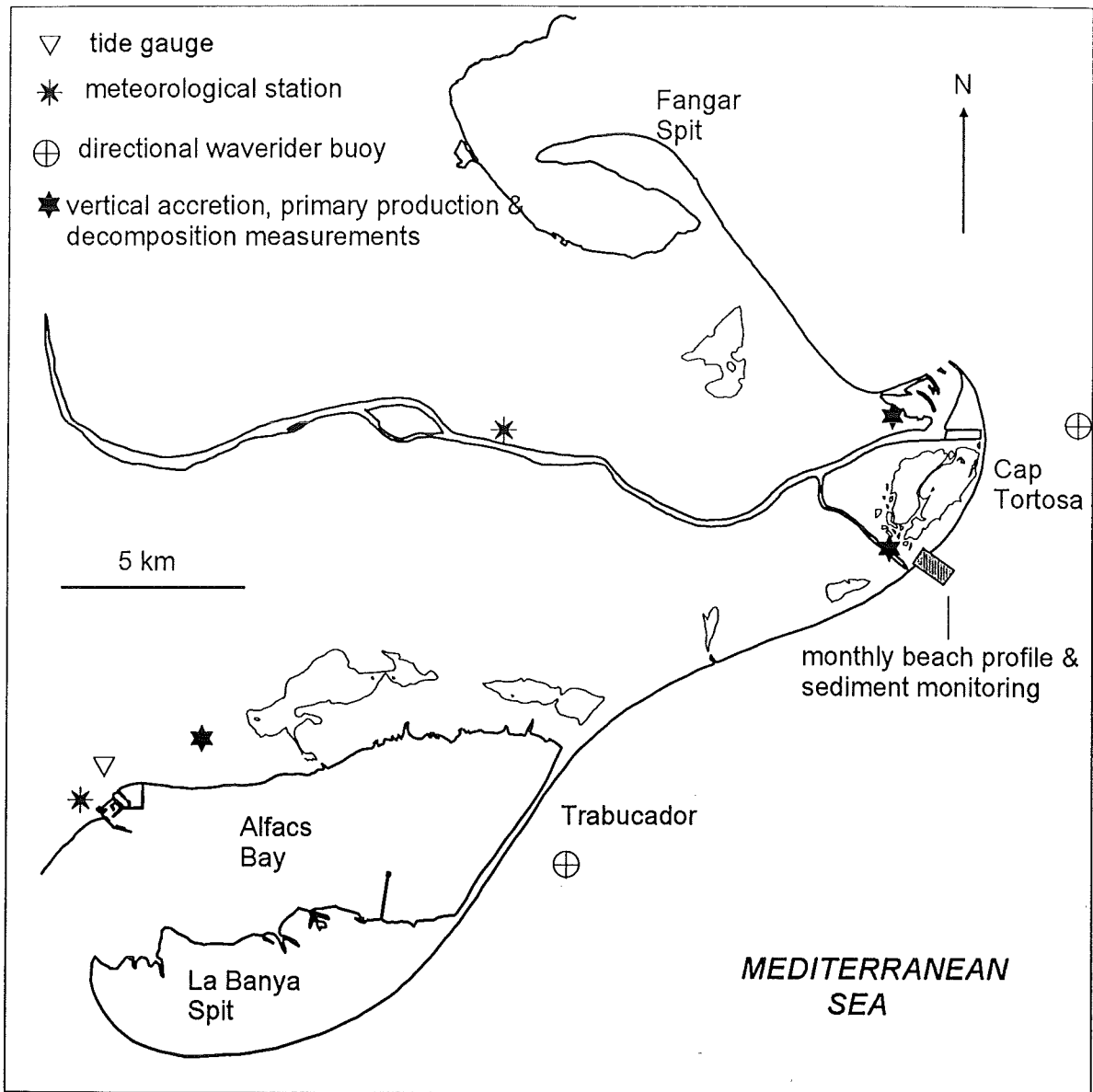


Figure 1. The Ebro delta (Spain).

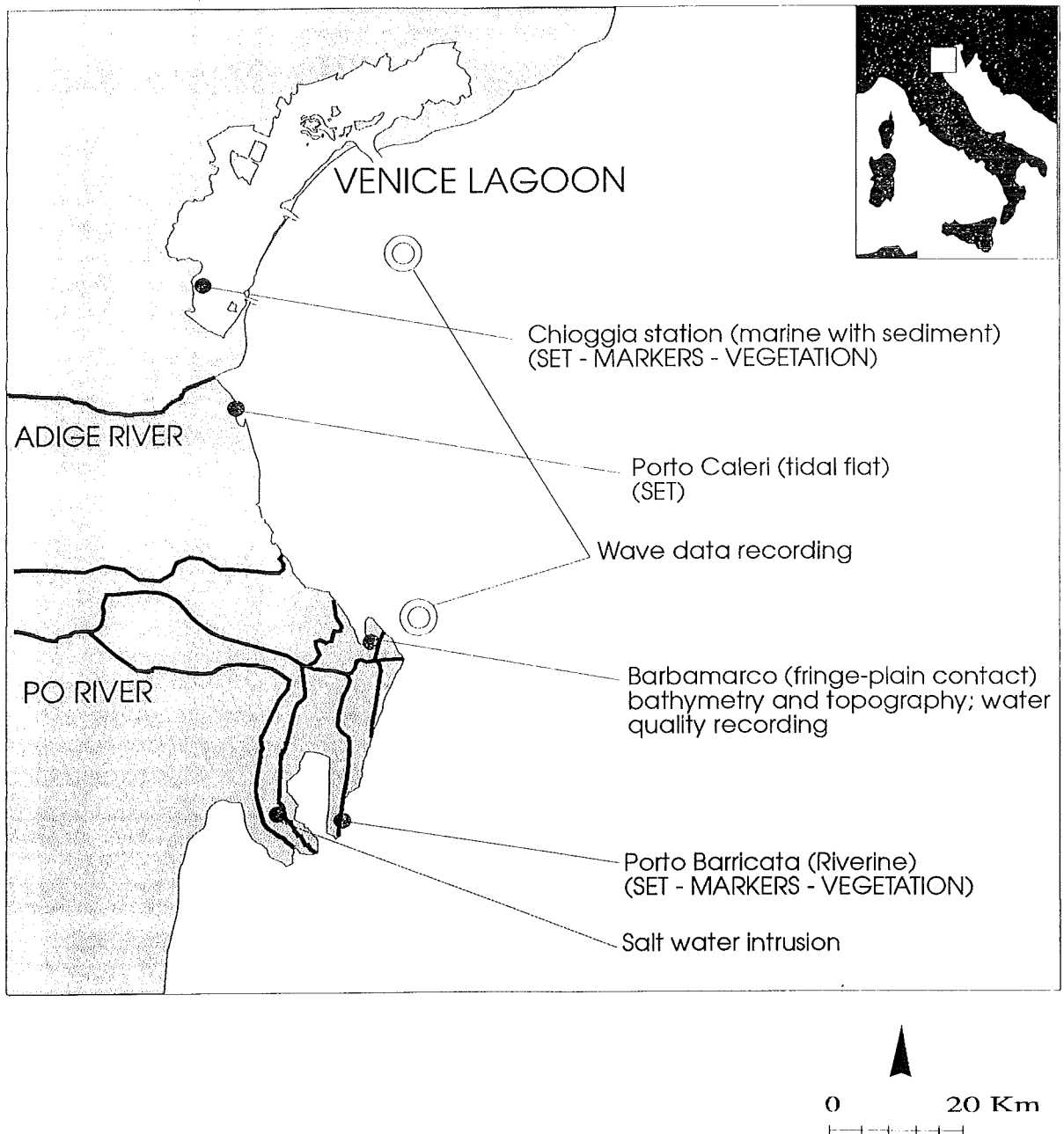


Figure 2. The Po delta (Italy).

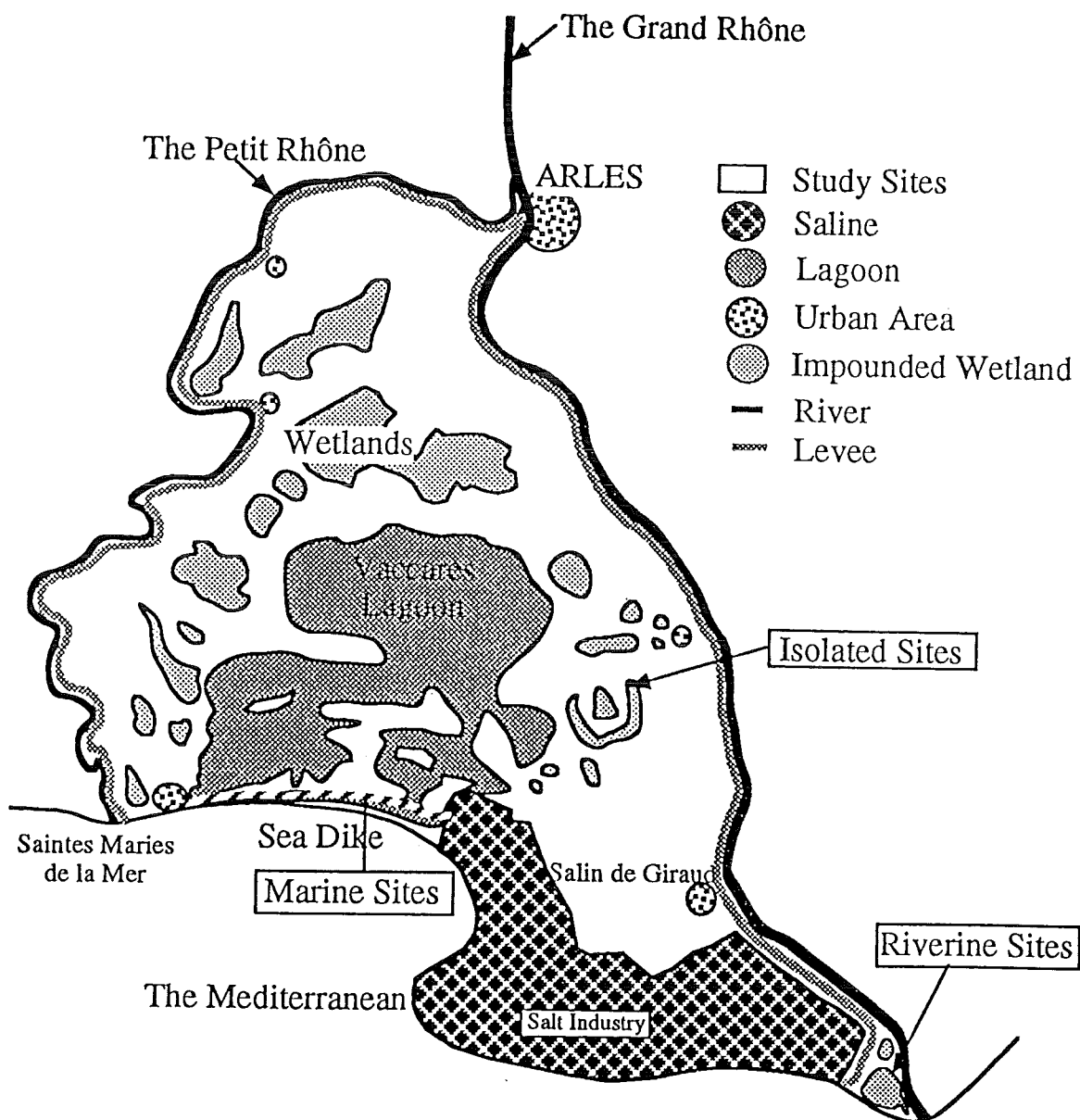


Figure 3. The Rhône delta (France).

○ *Deltaic impacts*

- Intrinsic "dynamic character" of deltaic systems (which means that periodic river floodings, coastline variations, etc., are "normal" events in deltaic evolution, see table 1 and figure 4 for illustration).
- Significantly different deltaic behaviour depending on the time-scale (*e.g.* Ebro delta evolution during the last centuries, with deltaic plain variations comparable or in excess to what would be associated to the present damming system, *e.g.* figure 5).
- Assessing the "impact" on such a dynamic system therefore depends on "a priori" definitions (*e.g.* time-scale, reference state, etc.) and social perception.

Event	Time Scale	Impact
River switching	1,000 yr	Deltaic lobe formation Net advance of deltaic land masses
Major river floods	50-100 yr	Channel switching Major deposition
Major storms	10-20 yr	Major deposition Enhanced production
Average river floods	Annual	Deposition Freshening (lower salinity) Nutrient input Enhanced primary and secondary production
Normal storm events (frontal passage)	Weeks	Enhanced deposition Organism transport Net transport
Tides	Daily	Drainage and/or marsh production Low net transport

Table 1. Spatial and temporal scales of forcing events (Day *et al.* 1995).

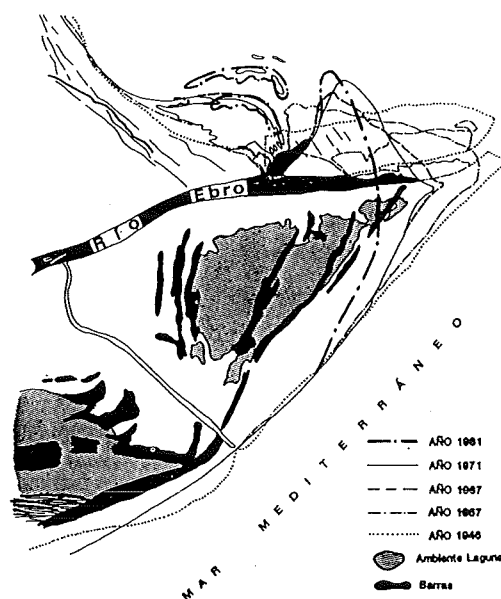


Figure 4. Switching of the Ebro river mouth (Maldonado, 1972).





Figure 5. Ebro delta evolution during the last centuries (Maldonado, 1986).

□ THE CLIMATIC CHANGE PERSPECTIVE

○ Climatic change "definition"

- Mainly considered in terms of sea-level-rise increases which clearly affect low-lying areas in delicate equilibrium such as deltas.
- Marginally considered in terms of precipitation and storminess changes.
- The reason being that the uncertainties associated to the "downscaling" of Global Circulation Models' results (e.g. for precipitation, storminess, etc.) are comparable in

magnitude to the predicted changes in these variables (at the regional scale required by deltas). Moreover, the effect of any changes in precipitation rates will be largely damped by the system of dams and the river flow regulation policy.

○ Additionally, any climatic change may have multiple and opposite effects on a system as complex (climatically and geomorphologically) as any of the three considered catchment areas. As an illustration, any rise in temperature, which would increase evapo-transpiration losses, may also affect plant production and cover and, thus, change the runoff pattern in an unpredictable manner.

□ *THE MEDDELT PROJECT*

○ The *conceptual approach* is schematised in figure 6.

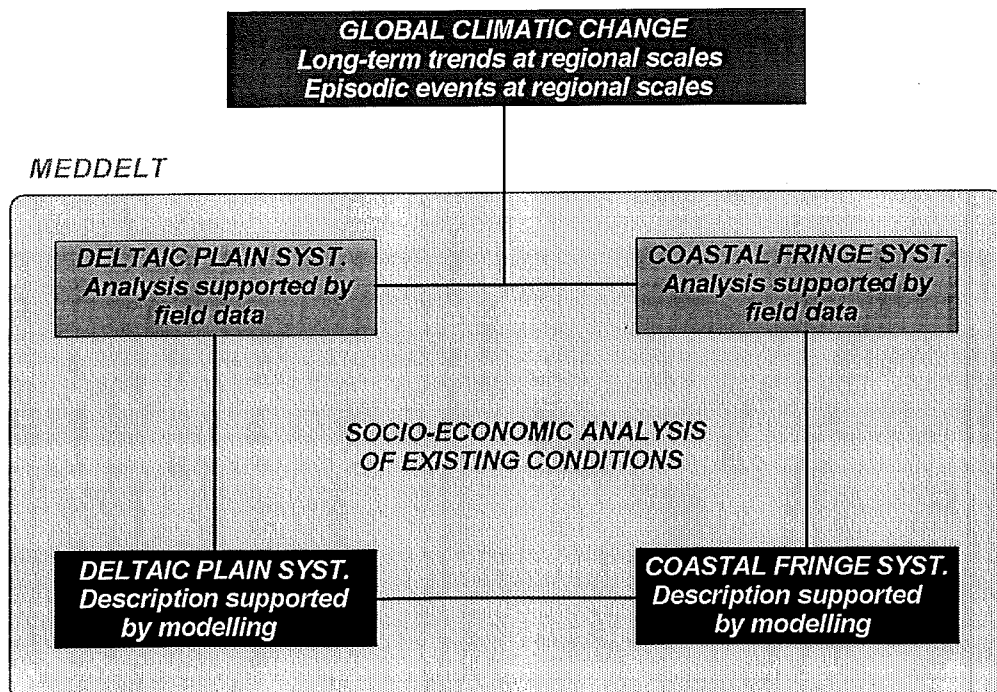


Figure 6. The MEDDELT conceptual approach.

○ *Strategy:*

- Characterise the deltaic system in terms of three elements.
  - *Deltaic plain and fringe* (two distinct geographic units with significantly different processes, time-scales and energy levels).
  - *The socio-economic system*, established upon the deltaic plain and fringe and linking them between themselves and to the rest of the territory (via management policies and land-uses).
- Define a reference situation for the deltaic system based on the "present" deltaic behaviour. This implies the development of a conceptual model for deltaic evolution under present conditions and defining these conditions and their time-scales.
- Analyse the effects of climatic change (basically through a "given" eustatic accelerated SLR) on the deltaic system by comparing its decadal evolution for two scenarios: a no-intervention one (*i.e.* steady trends for on-going activities) and another one in which some (one at least) management option to cope with SLR effects is included.

○ *Geographical perspective:*

- This approach is being followed for the three NW Mediterranean deltas studied in MEDDELT: Ebro, Rhône and Po.
- Using the same conceptual approach and climatic change boundary conditions.
- Allowing for the natural differences between the three deltas (*e.g.* different subsidence rates, abundance of inlets and lagoons in the Po coastal fringe, etc.).

## 2. SYSTEM ANALYSIS: DELTAIC BEHAVIOUR UNDER PRESENT CONDITIONS

### □ SOME DEFINITIONS

○ *Aim of the analysis stage:* To understand the deltaic behaviour (physical and ecological subsystems, leaving for the last sections the socio-economic component) for three time-scales (medium, long and episodic) and with three aims:

- Develop a conceptual model linking the main elements of the deltaic system (see figure 7 for a sample illustration).
- Establish quantitative links for this conceptual model at least for the "present" conditions.
- Define the "present" or "reference" situation/status of the deltaic system (see figure 8 and table 2).

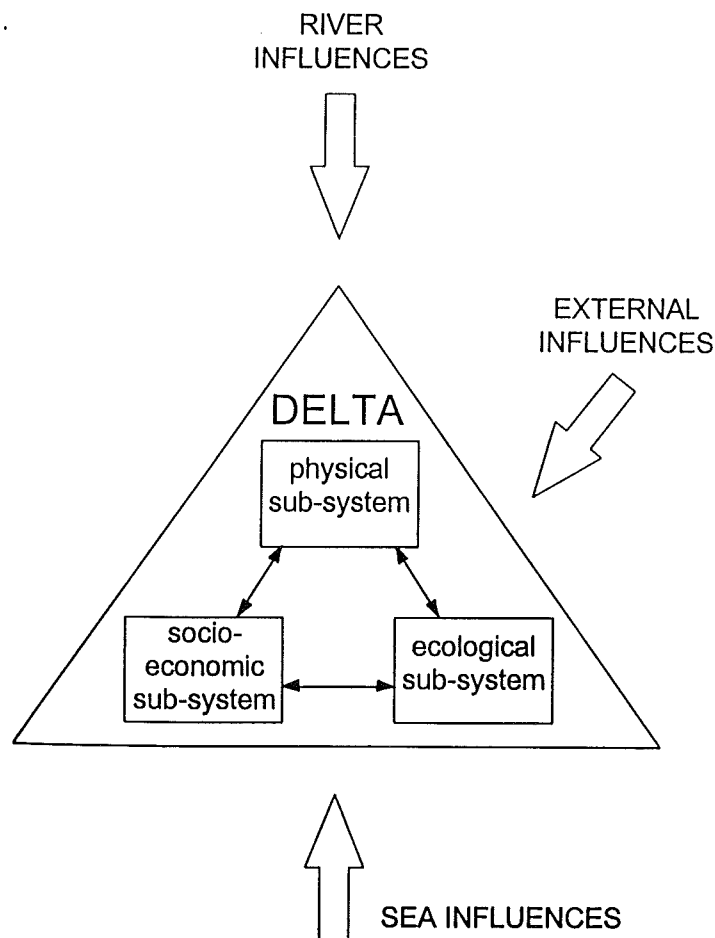


Figure 7. A conceptual model linking physical, ecological and socio-economic components for a deltaic system (Otter *et al.*, 1996a).

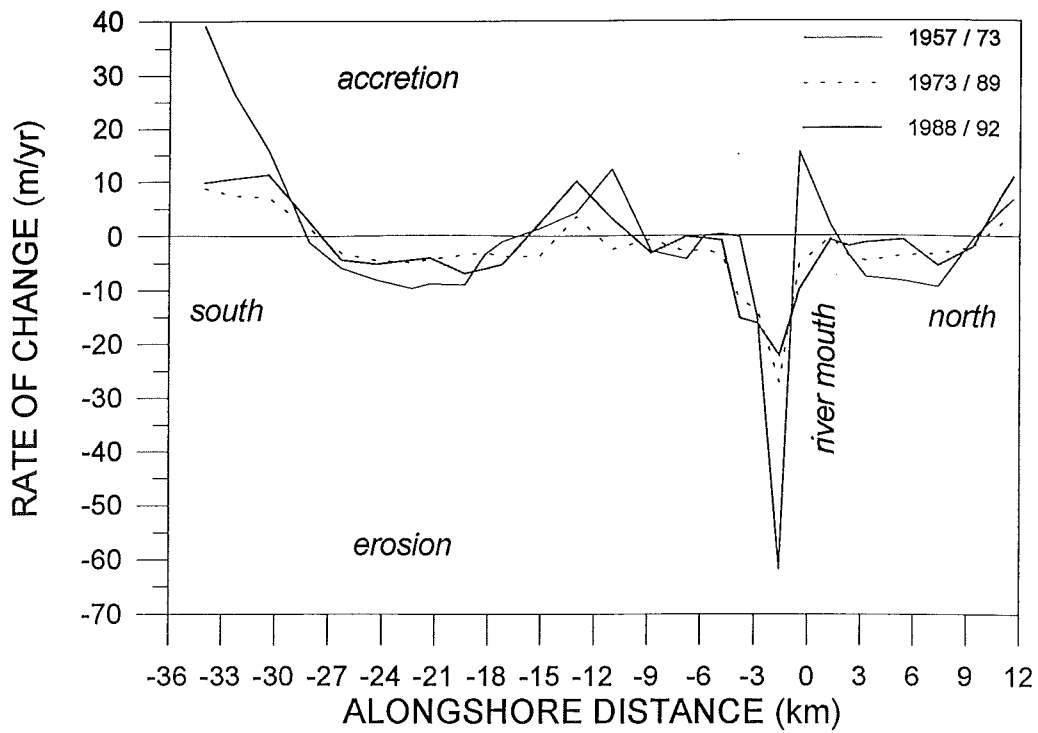


Figure 8. Reference (present) status of shoreline erosion/accretion rates for the Ebro delta (Jiménez, 1996).

classes	Ebro	Rhône	Po
5-4	0.49 (0.14)	6.50 (0.89)	(-)
4-3	7.68 (2.32)	21.61 (2.97)	(-)
3-2	27.22 (8.24)	58.55 (8.06)	1.87 (0.30)
2-1	68.90 (20.87)	106.35 (14.64)	8.52 (1.40)
1-0	171.08 (51.84)	252.74 (34.79)	75.17 (12.41)
below MSL	(-)	(-)	332.77 (54.95)
lagoons&marshes	13.96 (4.28)	280.39 (38.61)	167.77 (15.35)

surface in km<sup>2</sup> (percentage)

Table 2. Reference (present) distribution of deltaic plain elevation classes for the three considered deltas (Canicio *et al.* 1996).

○ The three considered *time-scales* are (for more details see Sánchez-Arcilla and Jiménez, 1997)

- *Long-term*: decadal or longer, affecting the whole deltaic body (e.g. global shape changes illustrated by the coastal evolution of the Rhône delta for the last five decades (see figure 9), barrier islands evolution along the Po delta coast (figure 10) and by the changes in relative land elevation for different sites of the Rhone delta 30 years from now (see figure 11)).
- *Medium-term*: several years and several kilometres in space (e.g. volume changes along the Ebro delta coast at the yearly scale (see figure 12)).

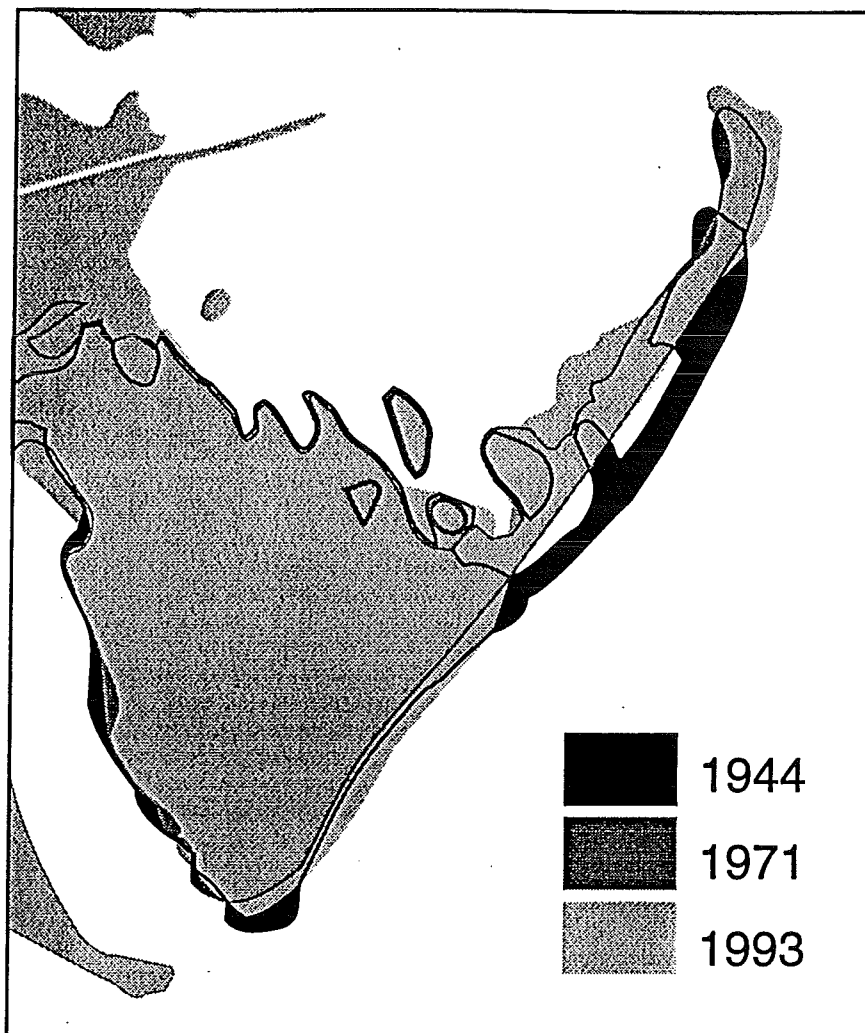


Figure 9. Shoreline evolution of the eastern part of the Rhône delta (Suarez and Provansal, 1996a).

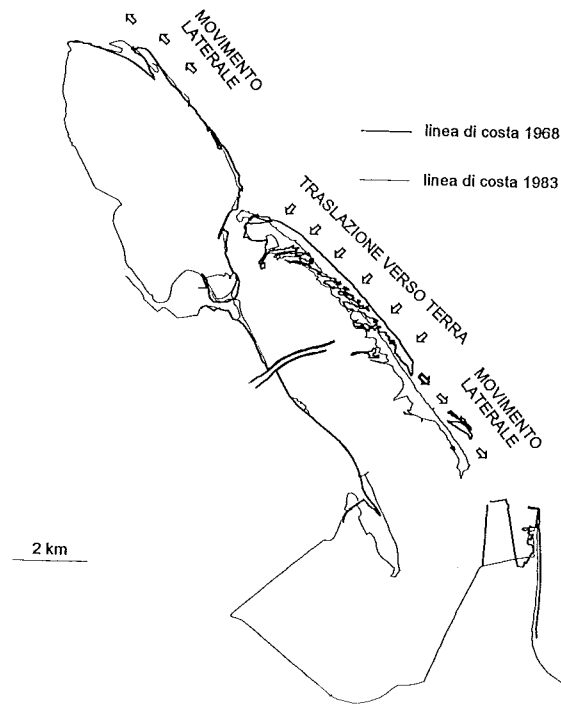


Figure 10. Barrier island evolution along the Po delta coast -Laguna Caleri and Laguna Valona- (Arcelli, 1996).

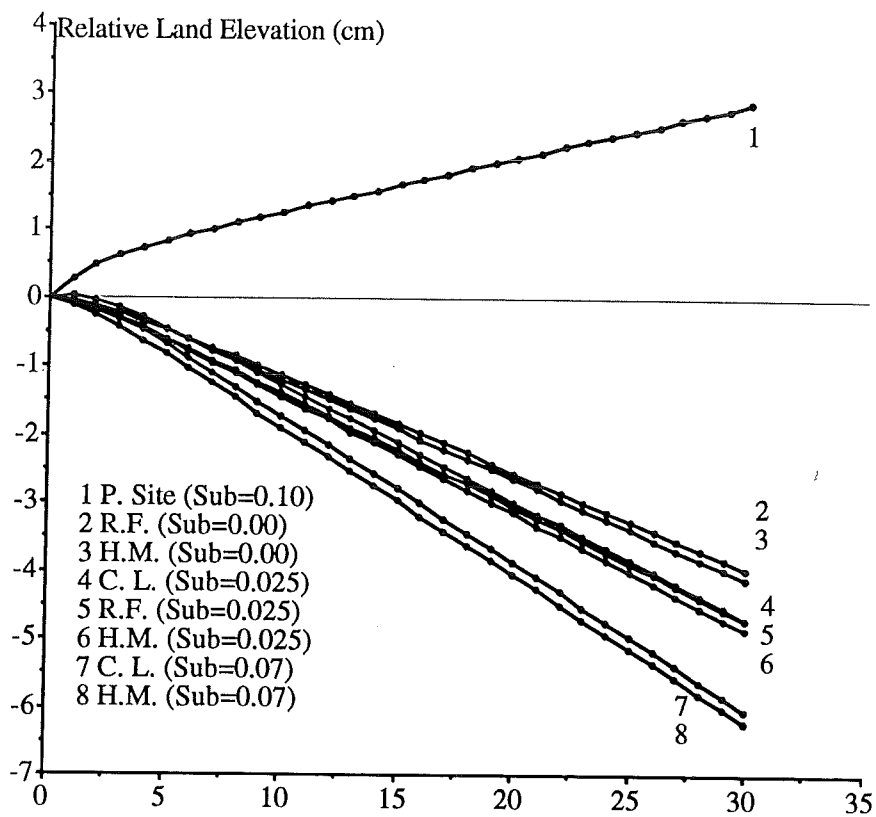


Figure 11. Changes in relative land elevation in Rhône delta plain 30 years from now (Sub: subsidence, P.site: riverine, RF: rice fields, HM: hunting marshes, CL: central lagoons) (Pont, 1996).

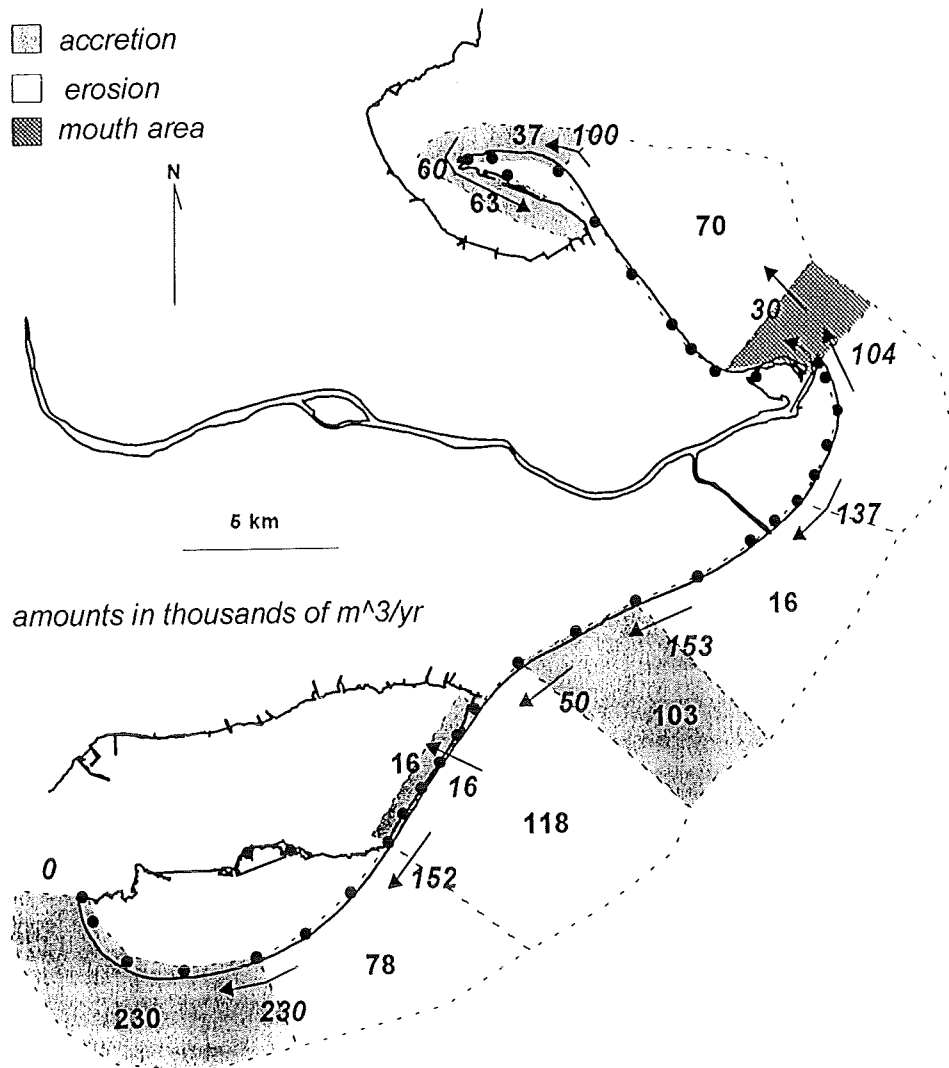


Figure 12. Volume changes along the Ebro delta coast at the yearly scale (after Jiménez and Sánchez-Arcilla, 1993).

- Episodic scale:* time and space scales defined by the impact of an "extreme" driving agent (sea-storm, river-flood, etc.) with a return period of at least several years. This scale can be illustrated by the breaching which took place in the Trabucador bar (Ebro delta) in 1990, corresponding to a wave storm and surge events with return periods of 10 and 1.2 years, respectively (see figure 13). This episodic scale can also be illustrated by the floods in the Rhone river during 1993 and 1994. These floods, with return periods greater than 30 years, significantly distort the mean Rhone annual solid discharge (which was estimated by Pont and Bardin (1996) as  $7.4 \times 10^6$  tons for the suspended load during the 1975-1994 period, but with a mean value of  $5.96 \times 10^6$  tons for the same period when the two exceptional years (93 and 94) are excluded).



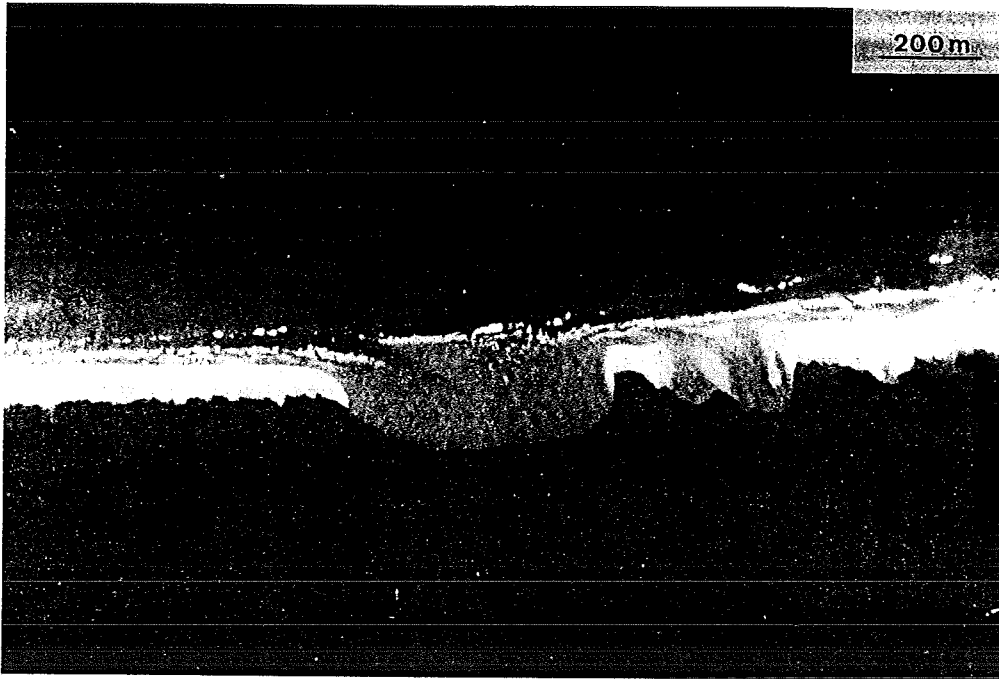


Figure 13. Breaching in the Trabucador Bar (Sánchez-Arcilla and Jiménez, 1994)

○ *Means* to achieve these objectives:

- Field data (already existing ones and newly measured to fill up gaps in information).
- Subsequent analysis for each delta.
- Comparative analyses between deltas.

□ *FIELD DATA*

○ For each deltaic system the following *data* have been compiled or reanalysed (to better characterise the medium/long-term components)

- Driving terms:
  - River liquid and solid discharges.
  - Wind-waves.
  - Mean-water levels.
  - Wind and atmospheric pressure.
- Deltaic "responses":
  - Deltaic levels (topography of the emerged delta and bathymetry of the submerged delta).
  - Deltaic shoreline positions.

- Sedimentological characteristics.

In addition, the following measurements have been obtained during the last years (basically in the frame of the MEDDELT project) (see figures 1, 2, 3):

- Driving terms: as before.
- Deltaic "responses":
  - Horizontal fluxes
    - of water along and across some representative coastal stretches
    - of sediment along and across some representative coastal stretches
  - Vertical fluxes (in terms of vertical accretion rates)
    - of organic production/decomposition
    - of vertical soil elevations (inorganic and organic contributions)

○ The field data collection program has been focused on three *key types of environment*:

- *Deltaic fringe*:
  - Inlet sites (in which emerged/submerged beach processes coexist and interact with river-mouth like processes).
  - Barrier beach sites (in which the conventional emerged/submerged beach processes coexist and interact with overwash and aeolian processes).
  - Beach/dune sites (in which the conventional sub-aerial and sub-aqueous beach processes can be observed and studied in detail).
- *Deltaic plain*:
  - Riverine sites (in which the river is still able to contribute to the deltaic plain vertical dynamics).
  - Isolated sites (in which the river is no longer able to contribute, so that deltaic plain dynamics are limited to the organic contributions).
  - Marine sites (in which deltaic plain dynamics are controlled by marine factors, and constitute an interactive border between deltaic plain and fringe).

Other important variables such as salinity levels, water quality, etc. are being considered only in a limited manner and will not be further discussed here.

## □ SUBSEQUENT ANALYSES

○ One of the main aims of deltaic system analyses is to better understand (*viz.* quantify) the vertical and horizontal sediment fluxes and resulting deltaic body evolution for the present climatic scenario. The reason is that this deltaic body acts as “substrate” -and thus strongly conditions- for the ecological and socio-economic deltaic subsystems.

○ The deltaic plain behaviour is assumed to be mainly controlled by vertical processes. This means that vertical accretion rates and wetland elevation changes can be compared with relative sea-level rise rates (the addition of local subsidence plus eustatic rise in the area). The relative land elevation (RLE) can be estimated as the difference between soil elevation (SEL) and subsidence (SUB) plus sea-level rise (SLR). This very simplified model allows to assess the flooding/salinization risks for different deltaic habitats. This approach can be illustrated by figure 14 (Pont, 1996) in which the Rhone delta areas at risk are those whose current RLE is less than 40 cm (in the sense that, depending on the scenarios adopted, this RLE could be wiped out in less than 60 years). Taking into account the distance to the shoreline and to the river course plus the corresponding infrastructure (protection, etc.) it is possible to assign risk levels (see figure 15), albeit with a certain degree of expert judgement (considering the present limitations of knowledge on the interactions between different elements/ variables of the deltaic system). These results show clearly that RLE and risk levels in the deltaic plain are not uniform, being the part of the plain directly influenced by the river -*i.e.* able to receive riverine supplies- the only one experiencing significant vertical accretion (comparable to the assumed SLR scenario). Impounded sites, without sediment input except during summer irrigation (if any) show very low accretion rates and even, in some cases, a *e.g.* the Beraches site in the Rhône delta, can show negative values (corresponding to erosion of the deltaic plain). This has important consequences, since it indicates that the larger the impoundment of the deltaic plain is, the shorter the vertical accretion will be. This is valid in general for all three studied deltas, being the general conclusion that under present-day conditions of SLR only the "open" riverine sites would have a positive RLE (2.9 cm after 30 years for the Rhone delta riverine site as shown in figure 11). Moreover, only the sites receiving inorganic input (by far the most important one on

terms of vertical accretion rates (Pont, 1996)) would be able to withstand a rise in eustatic level of 50 cm by the year 2100, even though some of these riverine sites have also higher subsidence rates. The "impulsive sedimentation" associated to large floods (provided that the sediment-laden water is able to flood the deltaic plain) can result in significant "instantaneous" accretion levels (up to 8 cm of fine sediments for the Rhone deltaic plain flooding of 1993/94 (Hensel *et al.* 1996)).

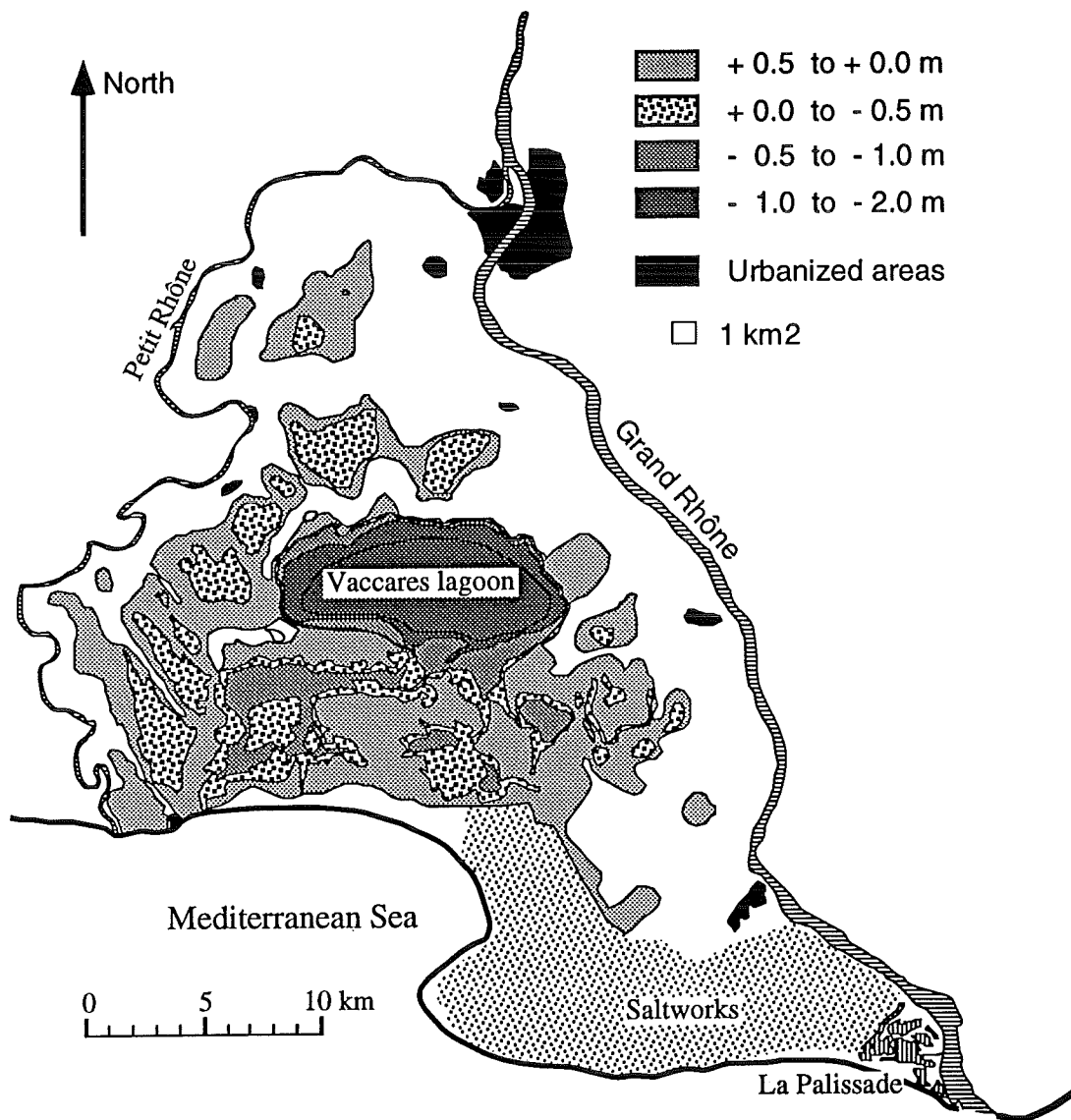


Figure 14. Distribution of zones with altitudes less than 0.50 m, corresponding to a RLE (see text for definition) less than 0.4 m (Pont, 1996).

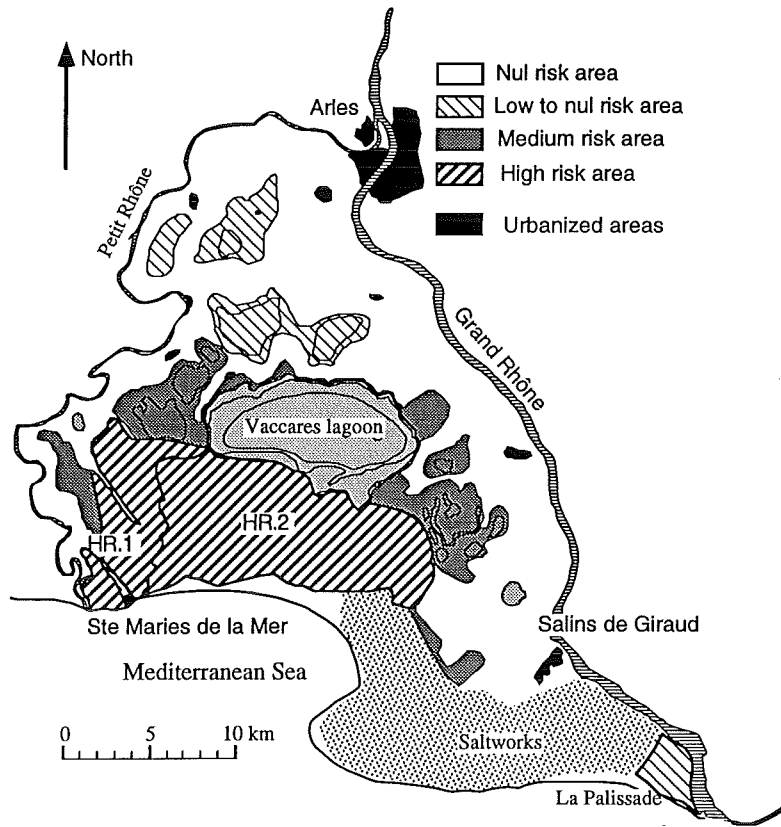


Figure 15. Map of risk zonation in relation to a rise in sea-level in the Île de Camargue, Rhône delta (Pont, 1996).

○ The short-term measurements of deltaic plain vertical accretion rates -using "sedimentation/erosion tables" and "marker horizons" (see Boomans and Day, 1993; Cahoon and Reed, 1995)- have been supplemented by longer-term estimates of land/sea levels. These longer term estimates are based on long-term series of tide-gauge data, long-term analyses of levees elevations and indirect estimations. As an illustration, figure 16 shows the estimated rates of relative SLR inside and just outside the Rhône delta (Suarez and Provansal, 1996b). The average rate of RSLR in the Rhône delta - about 2 mm/year- is about twice the corresponding rate in Marseille, just outside the delta, and compares well with the rates estimated for the Ebro delta from differences in levees elevations (Ibañez *et al.*, 1995) and from indirect calculations based on sediment budget considerations (Sánchez-Arcilla *et al.*, 1995). A summary of the various ways to assess RSLR rates appears in table 3.

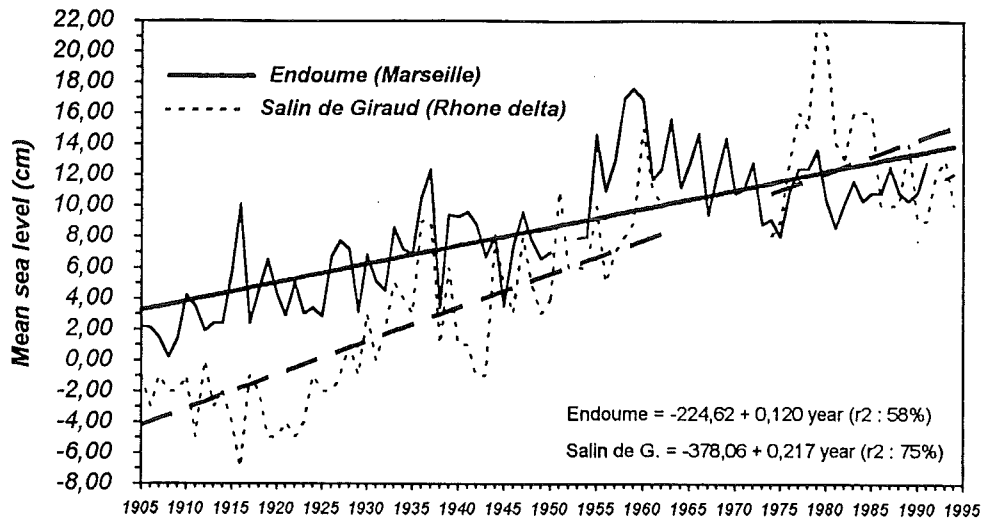


Figure 16. RSLR in the Rhône delta (Suarez and Provansal, 1996b).

Approach	Main time-scale	RSLR estimate	Remarks
Tide-gauge records	Decadal	2 mm/yr Rhône	Time-scale depends on available record series variable in time (Po)
		(n.a.) Ebro	
		5 mm/yr Po	
Topographic measurements	Decadal	5 mm/yr Ebro	Accuracy of RSLR estimate depends on quantity and quality of land-elevation data (only as an order of magnitude)
		(n.a.) Rhône	
		(n.a.) Po	
Sediment budget indirect estimates	Decadal	2-5 mm/yr Ebro	Accuracy limited by sediment budget uncertainties ( <i>i.e.</i> can be used only as an order-of-magnitude approximation)
		(n.a.) Rhône	
		(n.a.) Po	

Table 3. Summary of approaches to assess RSLR rates (n.a.: not available).

○ The analysis of long-term time series of field data can be used in a straight forward manner to assess the effects of a given climatic change scenario. As an illustration, figure 17 shows the storm surge climate for the Ebro, Rhône and Po coasts, derived from local tide-gauge records. The thin lines represent surge levels induced by a RSLR of 0.25m (which would be the corresponding RSLR for a no-subsidence assumption and an eustatic rise of 25 cm for the year 2050 as recommended by IPCC'95 medium estimation). The largest decrease in return periods corresponds to the Po delta, being the Ebro delta the less affected.

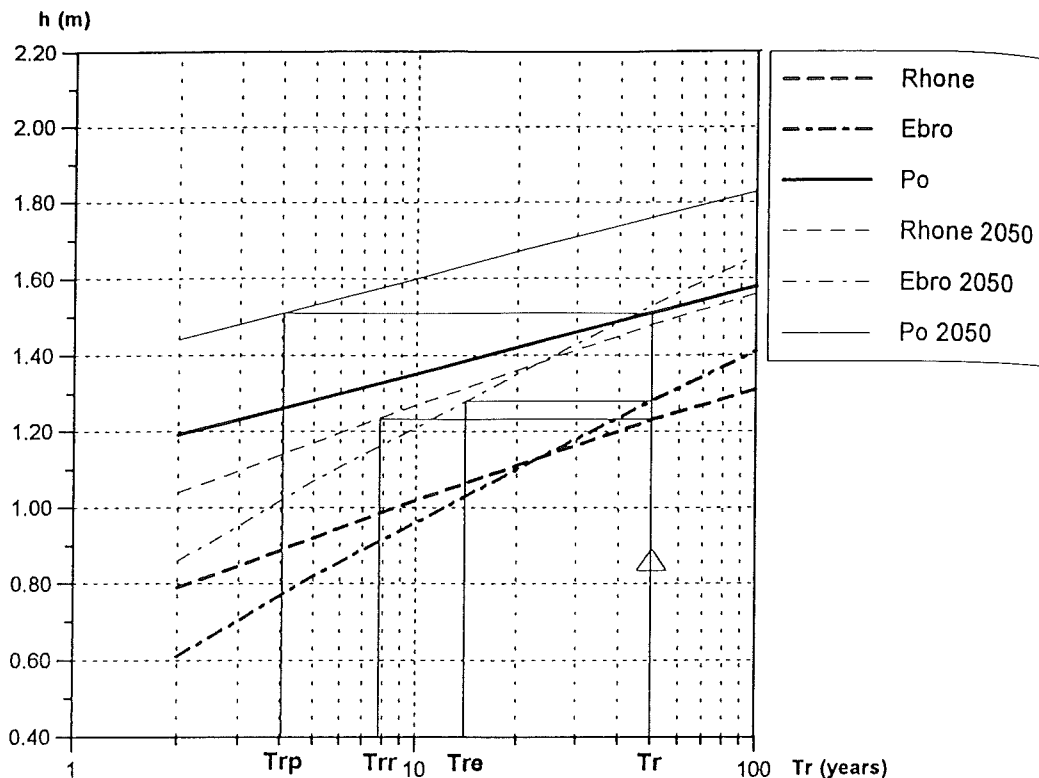


Figure 17. Storm surge climates in the Ebro, Rhône and Po deltas with and without SLR (Ruol and Tondello, 1996a)

○ Several other types of field measurements have been obtained and analysed to supplement the basic understanding derived from the previously mentioned measurements. Among these complementary observations there are:

- River mouth oceanographic studies to assess the interactions between river discharges and coastal dynamics, which control *e.g.* the dispersion of fine riverine discharges (Arnoux *et al.*, 1995). As an illustration figure 18 shows the distribution of fine suspended sediments at the mouth of the Rhone river for the following meteoro-oceanographic conditions: river flow of 2000 m<sup>3</sup>/s and a northerly wind of 8m/s.
- Subsidence studies -using cores and other geophysical means- to assess the local land elevations variations due to natural compaction (*e.g.* Barnolas, 1995) and man-induced ground-water extraction (*e.g.* Sestini, 1992).
- Circulation studies to assess the current patterns and associated nutrient fluxes around the deltas and in the adjacent coasts (*e.g.* Espino *et al.* 1994).
- Evaluation of primary production and decomposition in different deltaic plain environments (*e.g.* Curcó *et al.* 1996; Scarton and Rismondo, 1996, Rioual *et al.* 1996). The response of the different existing species to “stress” (to SLR in this context) have been assessed, showing a potential strong regression of *Arthrocnemum*

*fruticosum* in the Rhône delta due to SLR (Rioual *et al.* 1996). On the other hand, these data with the corresponding vertical accretion rates (*e.g.* Ibañez *et al.* 1996) have been used as an input to model soil formation in the deltaic plain (*e.g.* Torre *et al.* 1996).

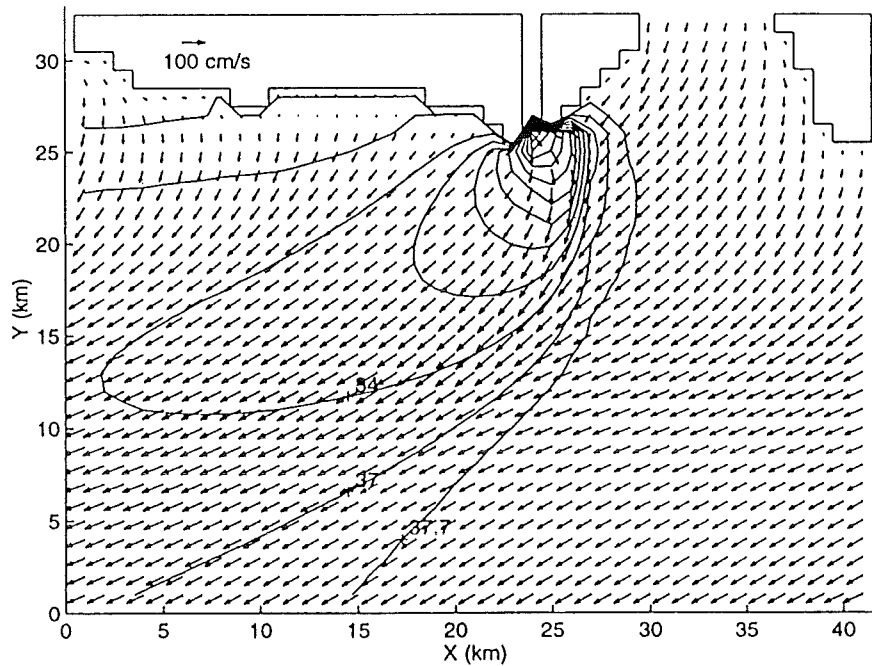
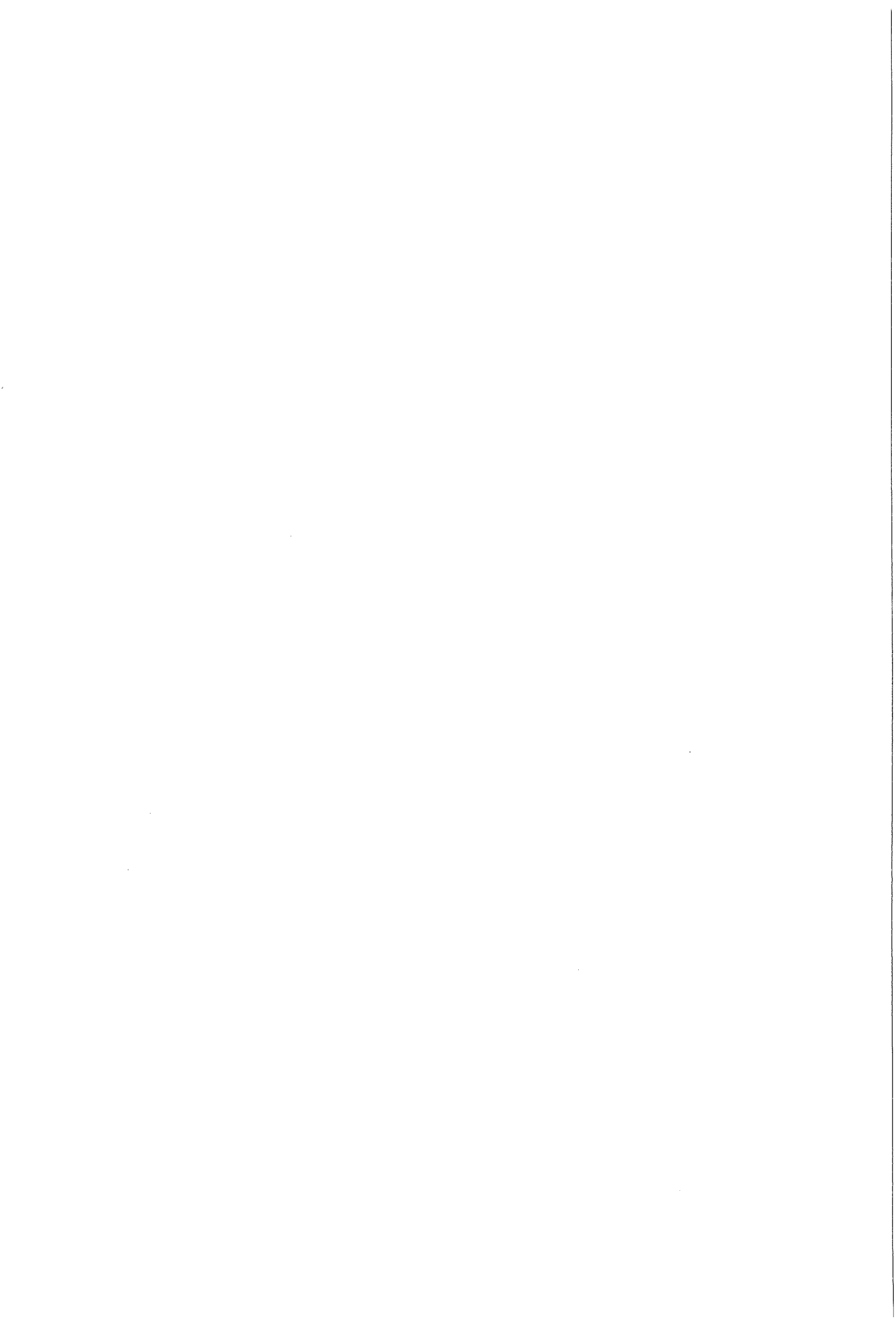


Figure 18. Suspended sediment distribution in the Rhône plume (Arnoux *et al.*, 1995).

- Bathymetric changes in inlets in order to estimate their contribution to the coastal sediment budget. This has been completed with physical models in a wave basin to simulate coastal changes close to the inlet entrance (*e.g.* Ruol and Tondello, 1996).
- Topographic measurements of beach profiles from the dune row to the shoreline, in order to estimate the cross-shore exchange of sediment between the coastal fringe and the deltaic plain as well as to estimate the aeolian and storm contribution to these processes (*e.g.* Suanez and Provansal, 1996c; LIM/UPC 1996).





### 3. SYSTEM DESCRIPTION: DELTAIC MODELLING AND IMPACT ASSESSMENT

#### □ *SOME DEFINITIONS*

○ The *main aim* in here is to

- Build-up a conceptual model of deltaic dynamics (from physical and ecological standpoints) for the plain and fringe units and long-time scales.
- Quantify the main links between the different units of the developed deltaic model. This allows a dynamic description of the "present" or "reference" situation for each delta (essential to assess any natural or man-induced impact).
- Build a series of quantitative models able to predict deltaic behaviour under "given conditions".

○ The variety of physical and ecological conditions and the presence of multiple human-related boundaries suggested the adoption of a physiographic unit based modelling approach.

- Physiographic units are defined for deltaic plain and fringe sub-domains in terms of controlling processes and "physical" boundaries.
- This implies that the dynamics within each unit can be described by suitable conservation laws and -in their absence- empirical relationships.
- These links between units depend on the particular type of model to be developed. For instance figure 19 shows the physiographic units defined for a generic deltaic coastal fringe. In the case of the Ebro delta, it was used to develop a decadal-scale shore-line evolution model. The links between units are, in this case, the yearly averaged along and across shore sediment transport rates. The corresponding model for the Rhône delta has required developing a detailed dune/dry beach response model. The corresponding model for the Po delta has required a detailed barrier-island and lagoon behaviour model (figure 20). This illustrates the particularities of the three studied deltas, within the common methodological approach and conceptual model framework.

□ DELTAIC FRINGE MODELLING

○ The developed *conceptual model for deltaic coastal fringes* is described in some papers from the final MEDDELT book of abstracts (Capobianco and Stive, 1996; Jiménez *et al.* 1996a, Capobianco *et al.* 1996) so that only a brief summary will be sketched in here. It is based on:

- Process-based defined physiographic units, illustrated by: shoreface, surf-zone, “sub-aerial beach” (of different types such as dune/beach, barrier coast, spit, deposition "mouth" area), lagoon, etc.
- The main driving terms considered are the river, the waves and corresponding wave-induced currents and the mean-water-level variations (in the external coast and through-out the delta).
- The coastal response is basically simulated by a combination of process-based models (*e.g.* for the coastline evolution associated with gradients in the net alongshore sand transport) and behaviour-based formulations (*e.g.* for the active profile response to SLR). An illustration of the simulated coastal response for the southern Ebro delta spit appears in figures 21 and 22, for various combinations of driving terms.

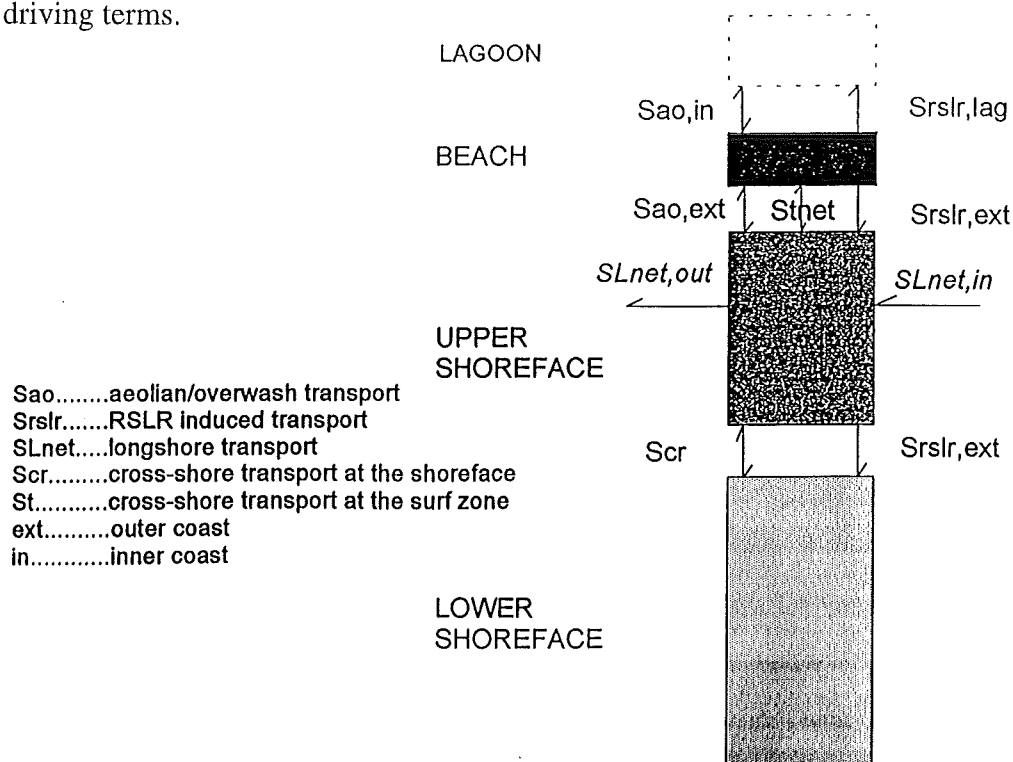


Figure 19. Physiographic-unit based coastal model.

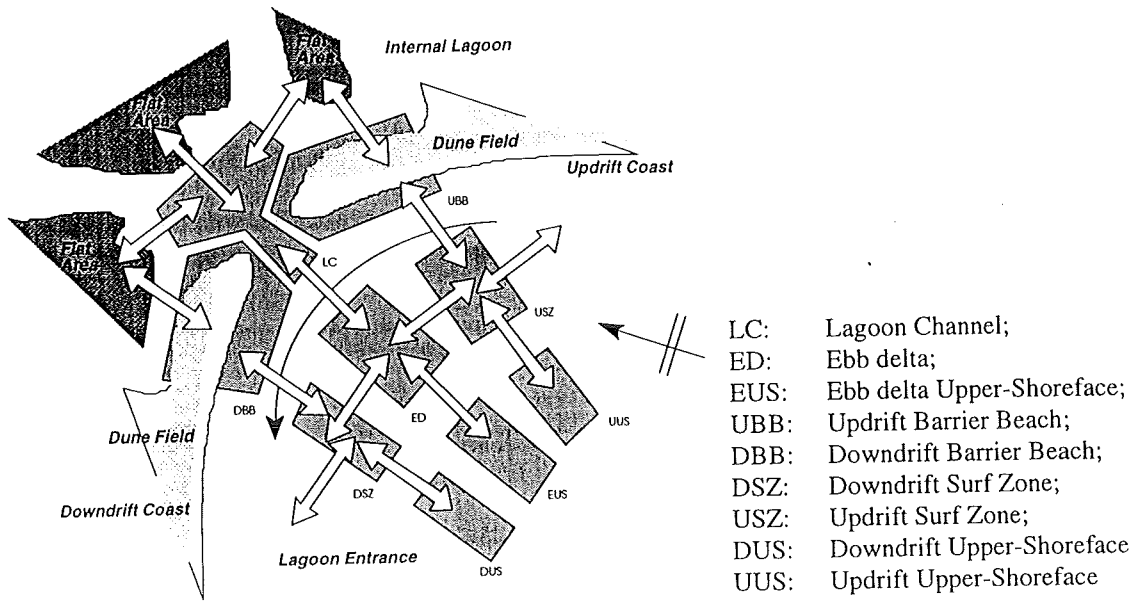


Figure 20. Simplified conceptual model for a generic lagoon inlet (Capobianco and Stive, 1996).

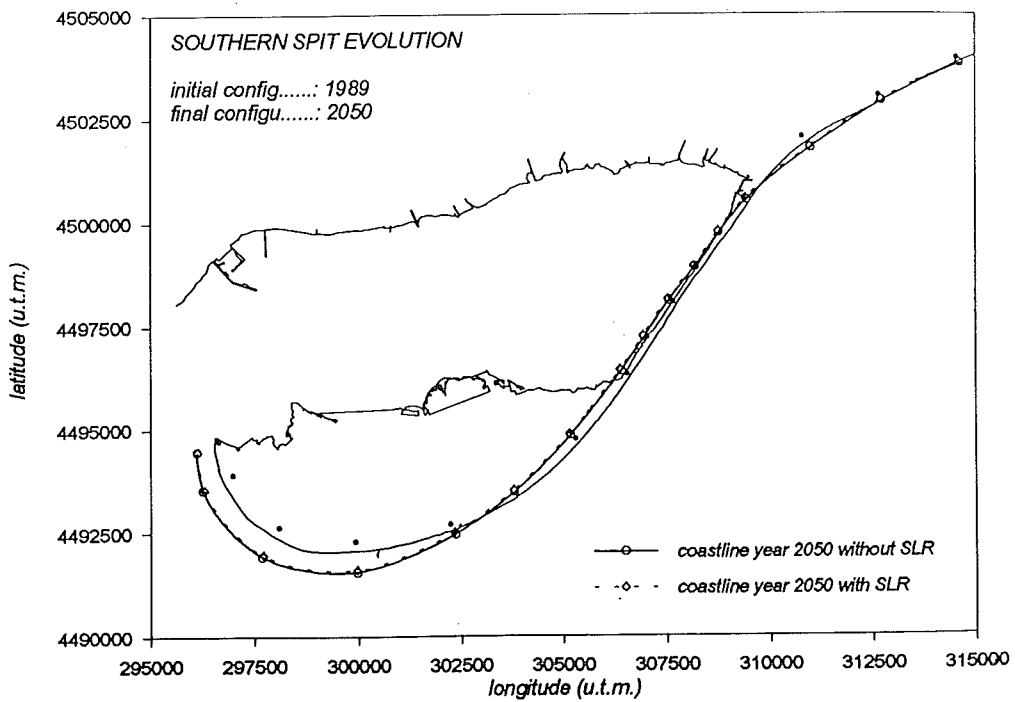


Figure 21. La Banya spit shoreline evolution with and without RSLR (Sánchez-Arcilla *et al.* 1996).

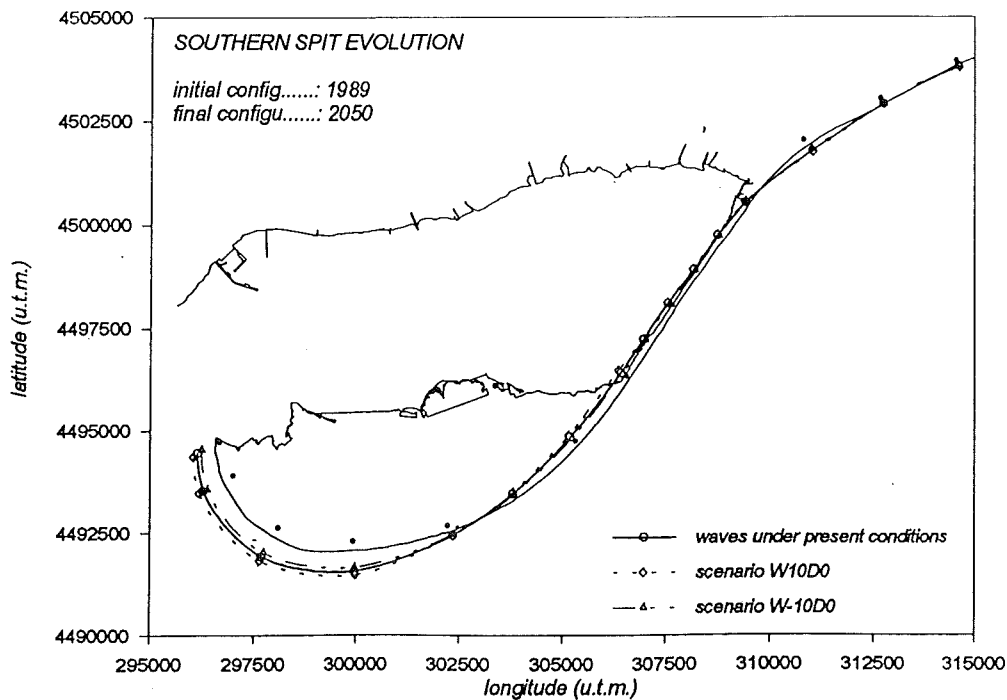


Figure 22. La Banya spit shoreline evolution considering a variation in the incident wave height (Sánchez-Arcilla *et al.* 1996).

□ DELTAIC PLAIN MODELLING

○ The developed *conceptual model for deltaic plains* is described in Day *et al.* (1995) so that only a brief summary will be sketched in here (see figure 23). It is based on:

- The vertical accretion rates for various deltaic plain sites, determined considering inorganic (marine and riverine contributions) and organic (above and below ground production and decomposition) material inputs. As was clearly shown in the model's sensitivity analysis, plant production only plays a minor role in soil formation both in terms of root production and inputs from the litter. The variation in land elevation is mainly a function of the input of allocthonous inorganic matter, and also of the sediment compaction at the surface and in deeper layers. Only the variables related to soil structure (pore density, maximum pore space and minimum pore space) were measured in the various types of wetlands (see for illustration table 4). The soil surface altitude compared to its initial value after  $t$  years of simulation, is denoted as "soil elevation" ( $SEL_t$ ). This "soil elevation" variable does not take into account the processes of subsidence in the deeper layers (SUBS), which includes not only compression of the entire Holocene sediment layers, but also possible tectonic movements in the underlying rocks. The Relative Land Elevation after 30 years

( $RLE_{30}$ ) is therefore equal to the difference between soil elevation and subsidence plus sea-level rise.

- The so determined "relative land elevation" is then extrapolated to a surface area of similar characteristics, from which the whole deltaic plain vertical dynamics can be assessed.
- The vertical accretion rate modelling includes a soil formulation which takes into account the changes in composition of mineral and organic matters as well as the resulting porosity.

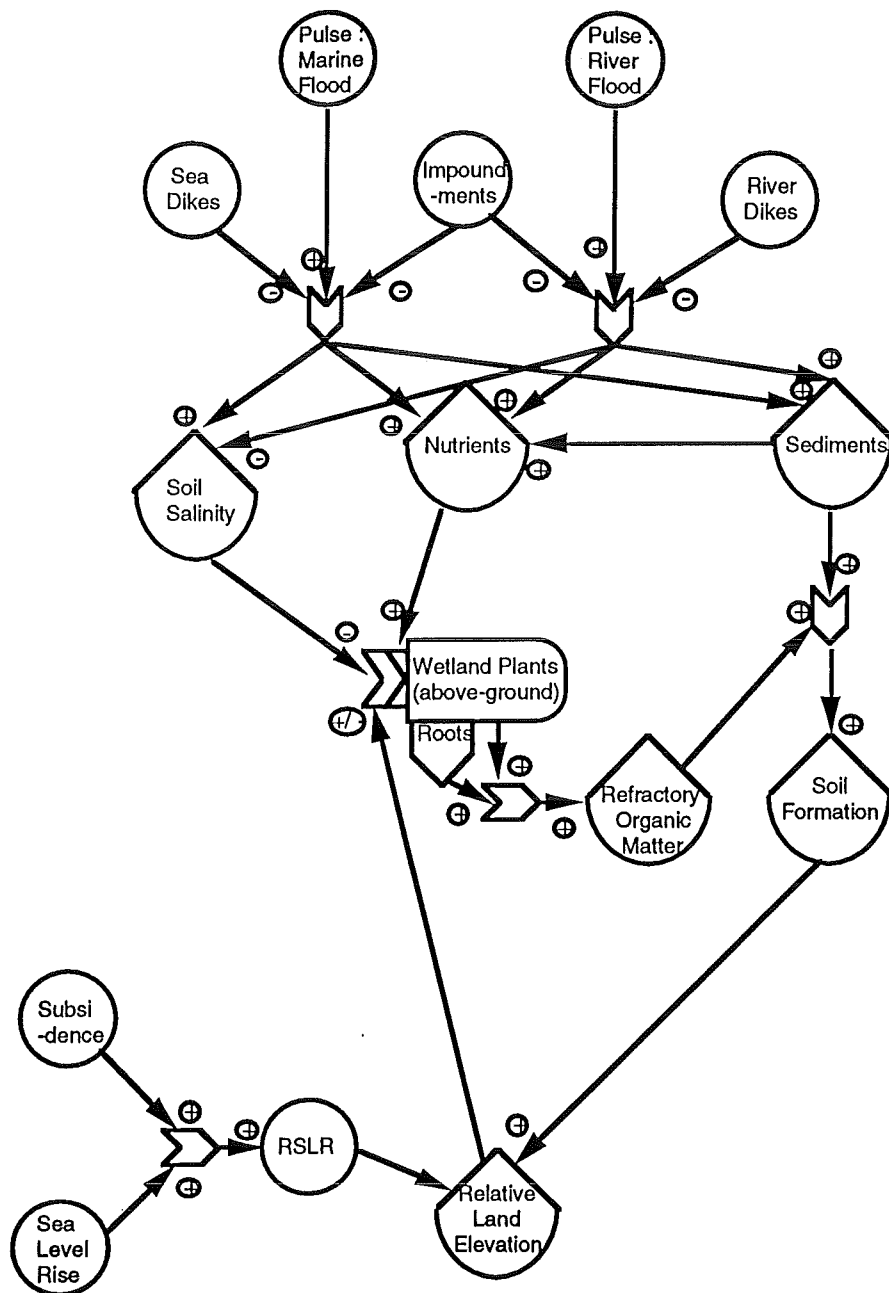


Figure 23. Conceptual model for deltaic plain functioning and the impacts of SLR (Day *et al.* 1995)

	La Palissade	Digue	Bernacles
Pore density	0.96	0.94	0.41
Max pore space (%)	0.53	0.66	0.41
Min pore space (%)	0.42	0.42	0.32
Compaction constant	1	1	1
Dead leaves input (g/m <sup>2</sup> )	773	773	773
Dead leaves decomp (%)	0.53	0.53	0.53
Stem Fall rate (g/m <sup>2</sup> /year)	59	59	59
Dead stems decomp (%)	0.16	0.16	0.16
Surf living root (g/cm <sup>3</sup> )	0.125	0.125	0.125
Root decay (%)	0.09	0.09	0.09
Root productivity (g/g)	0.26	0.26	0.26
Dead root/living root (ratio)	0.24	0.24	0.24
Decomposition rate (%)	0.12	0.12	0.12

Table 4. Model parameter values used for "soil elevation" simulation in the Rhône delta (Pont, 1996).

#### □ IMAPCT ASSESSMENT

○ The summarised models for deltaic plain and fringe have been developed for the "generic Mediterranean delta" -denoted MEDDELTA- as well as for each of the three studied deltas -Ebro, Rhône and Po-. Some of the constituent sub-models have been quantitatively verified (see for illustration figure 24 for the deltaic coastal fringe and figure 25 for the deltaic plain) while for others only a qualitative verification - supplemented by quantitative idealised calibration- has been possible.

This means that using these models it is, in principle, possible to assess the "physical" impact of a given climate scenario or management option (see for illustration figures 14 and 15 for deltaic plain and 21 and 22 for deltaic fringe). However, any integrated vulnerability assessment requires a consistent introduction of the ecological and socio-economic components. The first one has been considered in MEDDELT only in terms of the "physical substratum" and will not be, thus, further considered in this paper. The socio-economic component will be dealt with in the next sections.

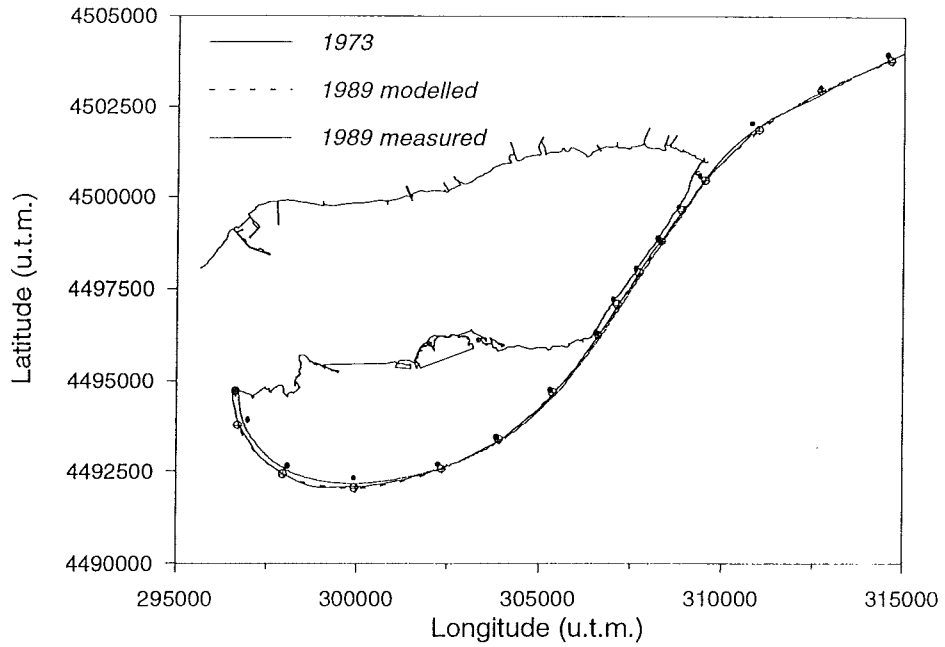


Figure 24. Hindcast validation of the long-term shoreline evolution model used to generate figures 20 and 21 (Sánchez-Arcilla and Jiménez, 1996).

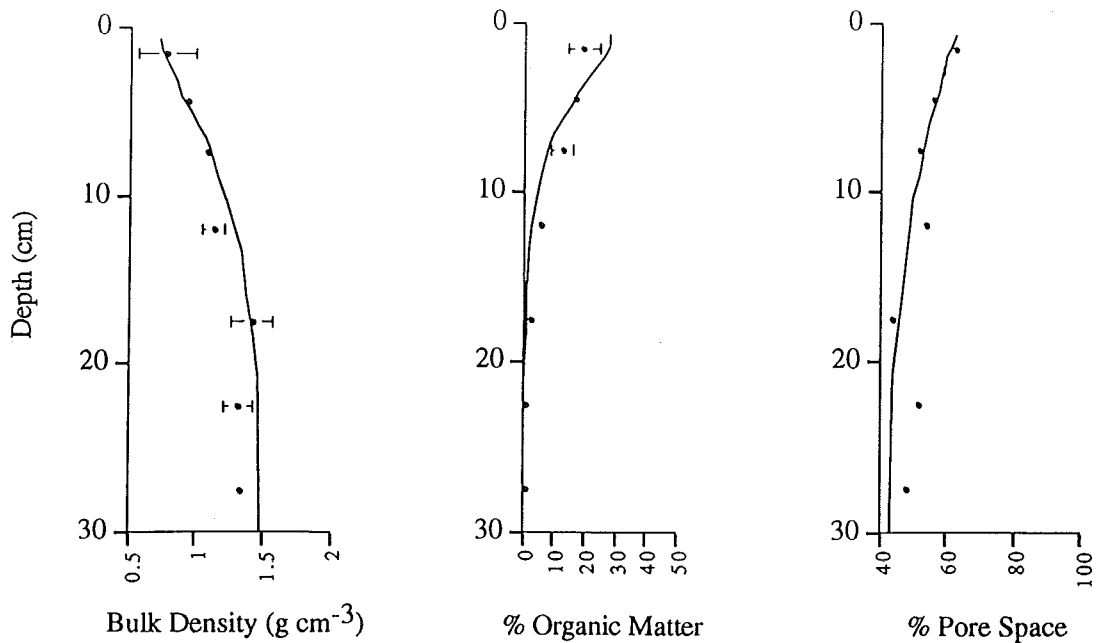
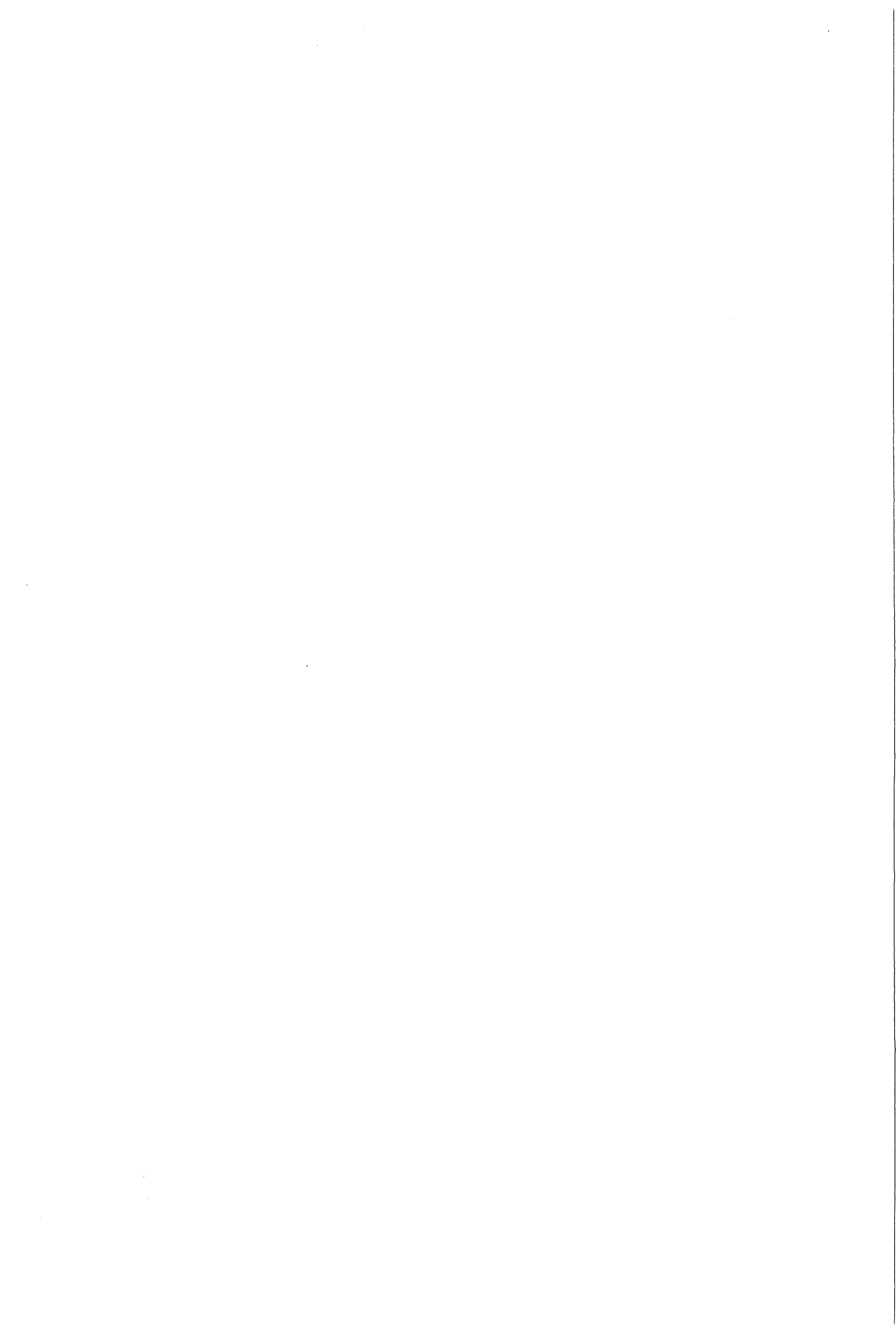


Figure 25. Calibration of the sediment dynamics sub-model in the Po delta plain -Barricata marsh- dots are field measurements and lines are model simulation (Rybczyk *et al.* 1996)





#### 4. THE LANDSCAPE INTEGRATED MODEL: CONCEPTUAL ISSUES

##### □ PROBLEM SETTING

○ The objective in here is to make a first approximation towards the development of an integrated landscape model by

- identifying the possible direct links between the socio-economic component and the physical (eventually ecological) components;
- assessing the socio-economic impact of the various scenarios considered;
- helping to develop enhancement and mitigation measures to cope with the predicted physical (eventually ecological) trends.

○ A complete landscape integrated model would require (see *e.g.* Capobianco, 1996):

- Full dynamical treatment of the horizontal and vertical dimensions involved in the deltaic surface evolution.
- Coupled dynamical simulation of the physical and ecological components.
- Efficient interactions between the socio-economic sub-system and the physico-ecological sub-systems, so as to be able to simulate the effects/impacts of natural and man-induced changes.

All these requirements are still very much under development, which justifies the limited presentation here included.

As an example of the requirements of this kind of models, figure 26 shows the difference between a static and a full dynamical approach to study the effects and impacts of climatic change on deltas.

##### □ METHODOLOGY DEVELOPMENT

○ A methodology for the analysis of socio-economic impacts of climatic change in deltaic areas has been developed. It is one of the building blocks of a landscape integrated conceptual model and is sketched in figures 27 and 28. It is a step by step

check list which should result in an overview of the socio-economic setting of each delta, the consequences of the selected "change" (e.g. sea-level-rise) and the possible measures to cope with these consequences. A more complete description can be seen in Otter *et al.* (1996a).

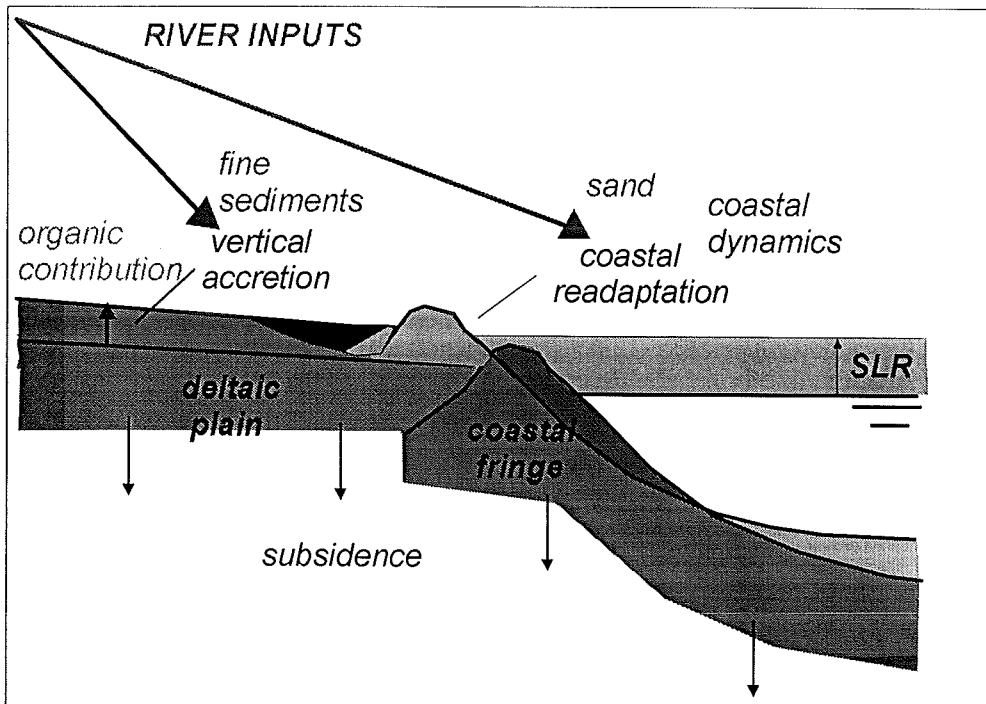
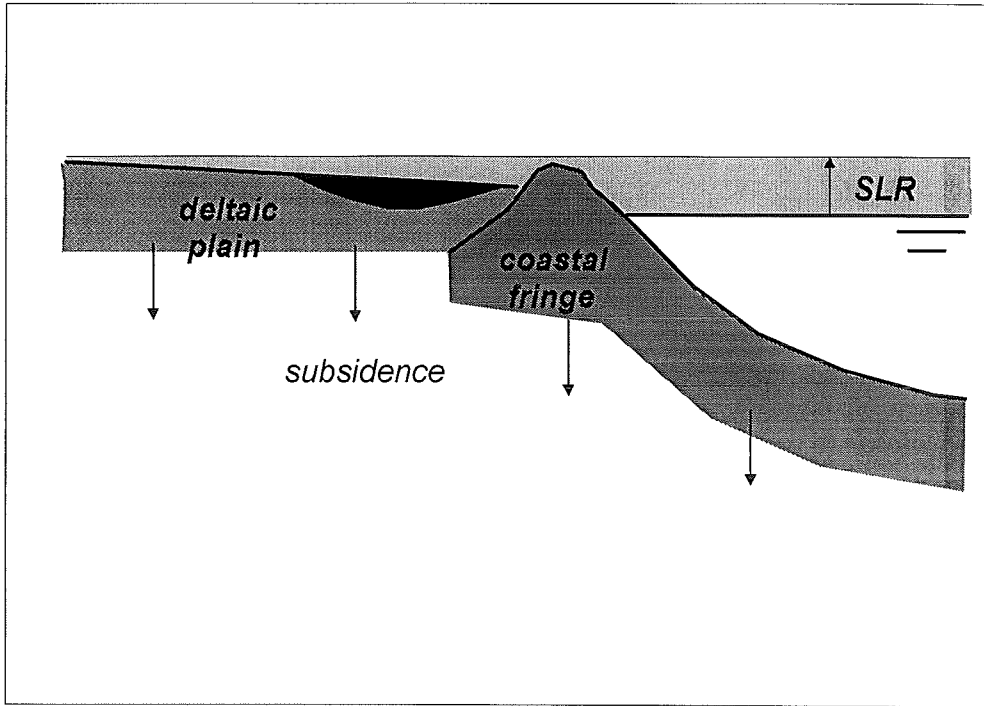


Figure 26. Static and dynamical approach to study effects and impacts of climatic change on deltas (Jiménez and Sánchez-Arcilla, 1997)

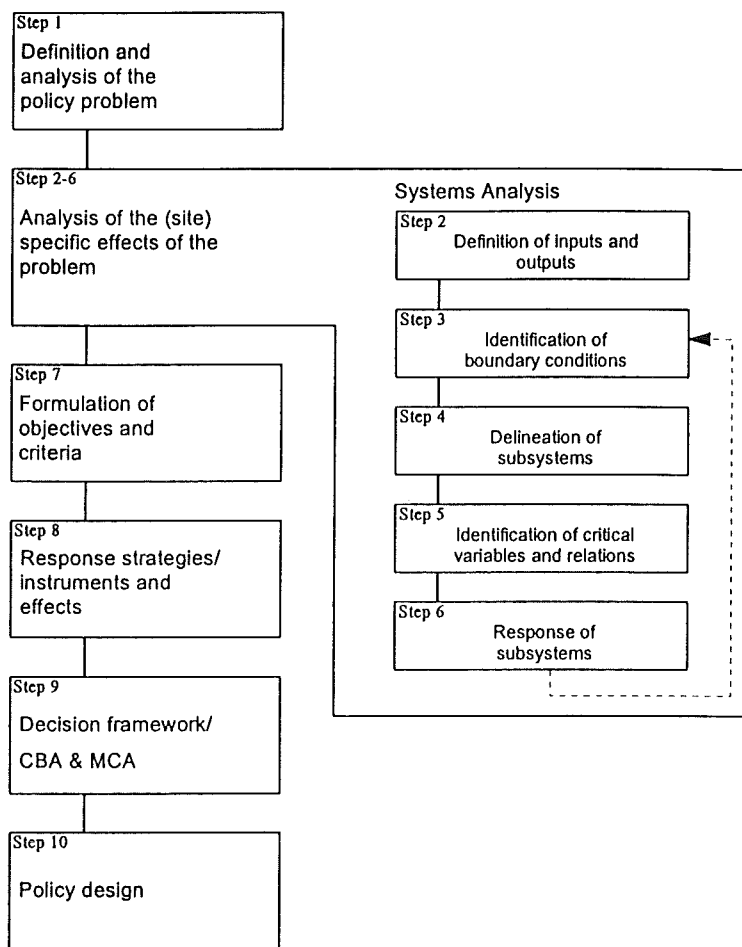


Figure 27. Methodology to analyse socio-economic effects and responses (Otter *et al.*, 1996a)

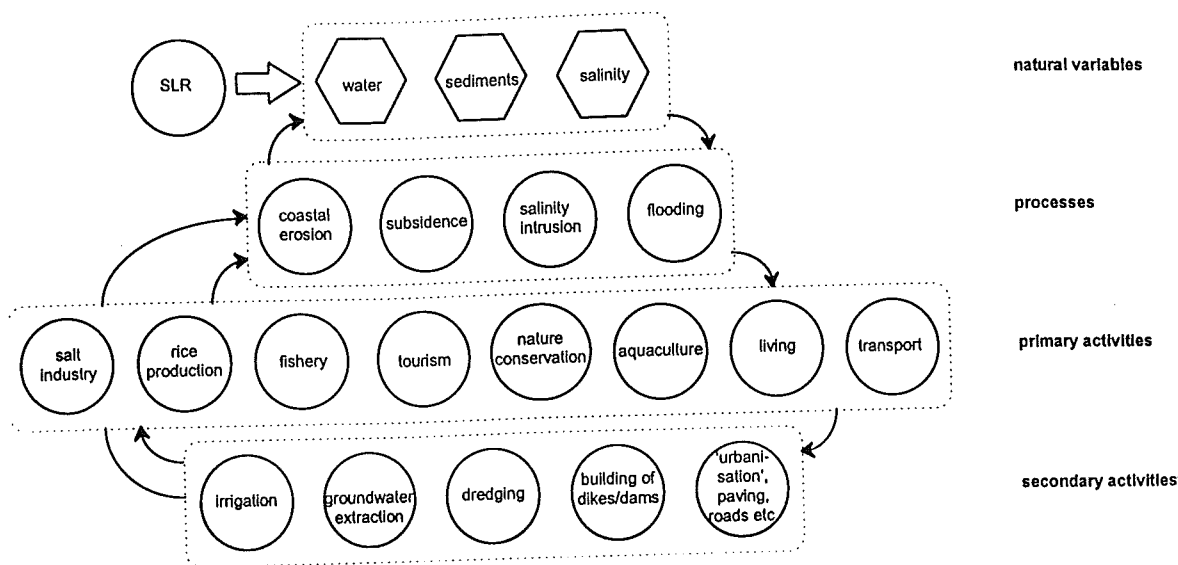


Figure 28. Schematization of the deltaic system (Otter *et al.*, 1996a)

○ The general methodology is made up of two sections. The first one is a policy analysis framework (steps 1 and 7-10). The second one is a system analysis framework (steps 2-6), which makes use of all the knowledge and modelling presented in previous sections.

○ In the policy framework, the "policy problem" is defined first. Depending on policy objectives and criteria, suitable "instruments" can be chosen. These "instruments" can be then "tested" in terms of their effects in the frame of a general deltaic vulnerability assessment (see next section). This approach must also include the weighting of pros and cons of each strategy, within a decision framework (be it cost-benefit analysis, multicriteria analysis or some other approach).

○ In the system analysis framework, the physiographic unit approach presented before must be supplemented with the socio-economic sub-system components. As already mentioned, specifying the existing (and expected) links between the full socio-economic, physical and ecological sub-systems is a far from trivial task very much under development, although some results are beginning to emerge (see *e.g.* Capobianco, 1996; Capobianco and Otter, 1996). It should be stressed that the socio-economic system description includes not only land-uses and population and activity distributions, but also administrative/legislative regulations (since they act as boundary or limiting conditions for management options and activity development), which further complicate the problem (*e.g.* Capobianco and Furlanetto, 1996).

#### □ THE LANDSCAPE MODEL

○ One of the characteristics of these kind of models is that they make use of *key variables, processes* and *activities*. These key parameters are selected as a function of the system characteristics to represent the deltaic system in an aggregated manner. The objective is to reduce the number of components to be considered in the analysis - retaining the main ones in term of deltaic functioning- without a significant loss of information about the deltaic integrated behaviour. This aggregation permits to reduce the links between components to be analysed. As an example, figure 29 shows the

conceptual model of links and interactions in the Ebro delta in terms of the above mentioned key parameters. The links are described in table 5.

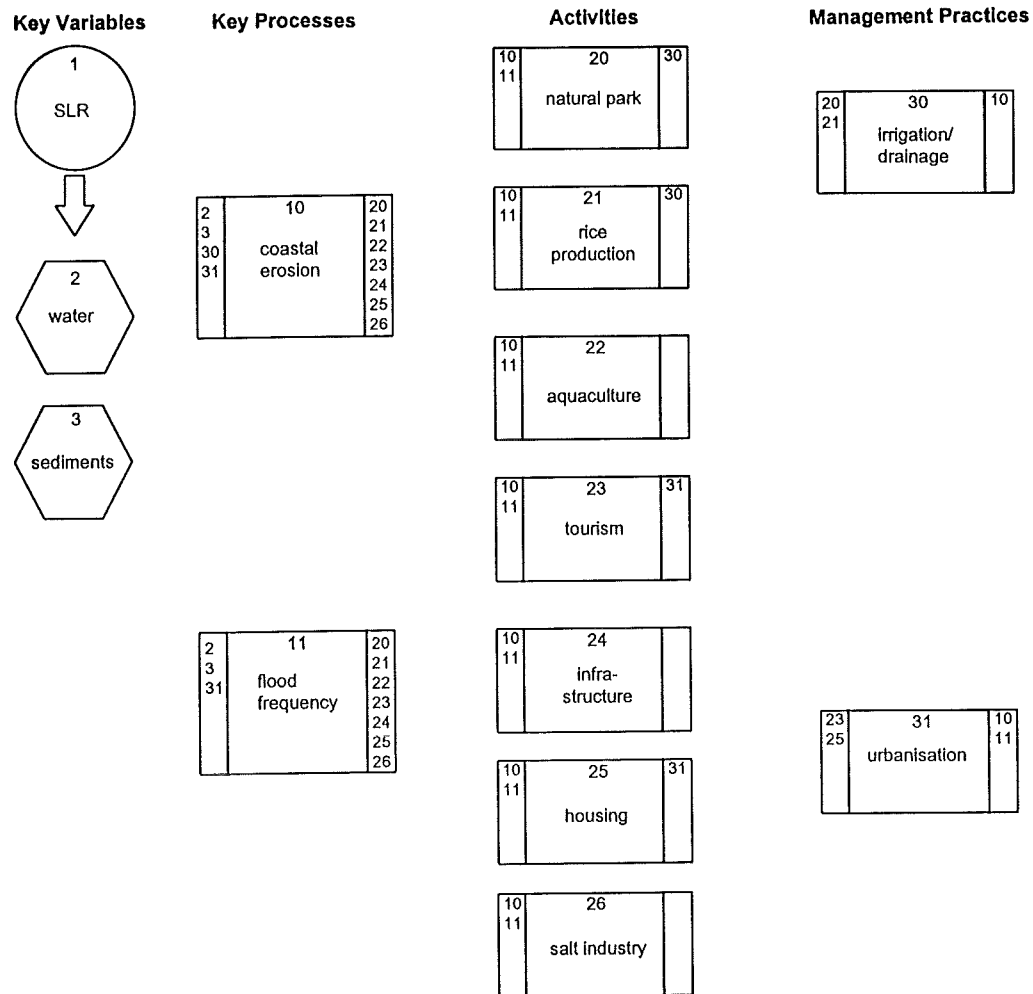


Figure 29. Conceptual model of links and interactions in the Ebro delta (Otter *et al.* 1996b)

○ In the practical application, these links have to be formulated in a quantitative manner by transforming them into (*e.g.* Capobianco, 1996):

- one mathematical formula describing the functional dependencies of the link;
- a series of possible values, *e.g.* height of embankments;
- a series of if-then conditions, *e.g.* describing management practices;
- the indication of a sub-model (as *e.g.* those used in soil formation in the deltaic plain (Torre *et al.* 1996) or those for coastal evolution (Sánchez-Arcilla and Jiménez, 1996));
- other.

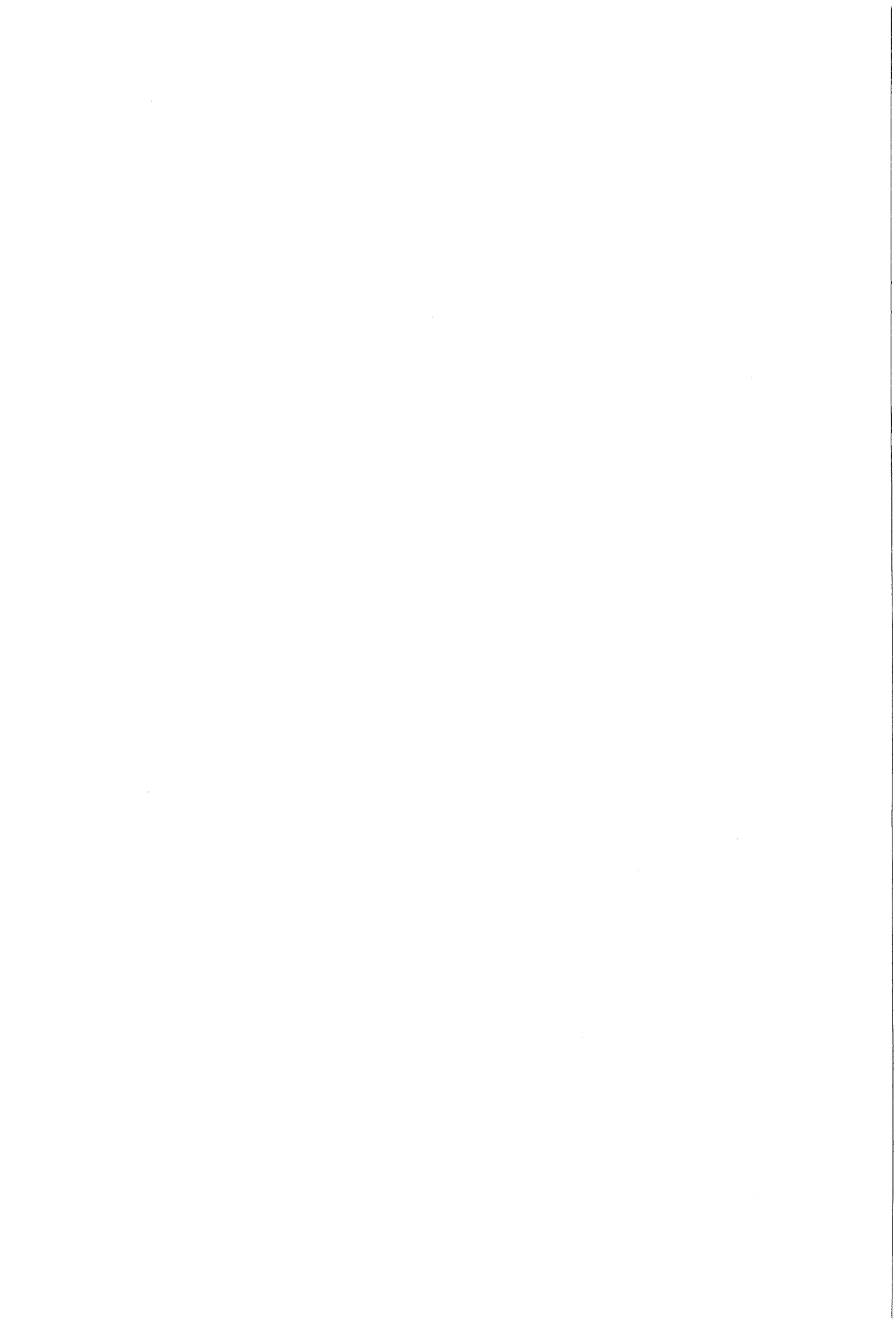
Link	Description
10-20	Most natural areas are located on or near the coast. Coastal erosion and accretion is therefore a relevant input to their evolution. Conversely natural areas have their effect on coastal evolution.
10-21	Rice production will be threatened by coastal erosion and the attending salt intrusion in so far as these activities are taking place near the coast.
10-22	Coastal erosion may put mussel production at risk. If the Trabucador isthmus erodes, the Alfaques bay and the southern parts of the delta will be exposed to the sea (Mariño, 1992) and the mussel habitat will be destroyed.
10-23	Tourism may be affected by coastal erosion by loss of tourist facilities or indirectly through the loss of attractions such as the natural area. There are presently two camping sites near the beach.
10-24	Coastal erosion may affect the port in Sant Carles de la Ràpita and the roads in the delta.
10-25	Houses may be affected by coastal erosion as long as they are located on or near the beach. However, there are just a few residential areas there.
10-26	Salt industry may be at risk from coastal erosion for the same reasons as mussel production.
11-20	The lagoons in the north and in the south of the delta will be regularly intruded by the sea, changing their fresh water characteristics and hence the habitat in and near the lagoons (Mariño, 1992).
11-21	The rice fields will be flooded in so far as they are located on the coast. Rice is a fresh water crop and salt water intrusion (which does not only occur as a result of flooding) will pose a great problem.
11-22	Aquaculture will be in jeopardy if the southern bay is exposed to wave action. Fisheries may decrease as a result of loss of breeding grounds in the bays (Mariño, 1992).
11-23	The tourist facilities which may be affected by flooding are two tourist resorts in the north and south of the delta. The flooding of the camp grounds may lead to extensive damages.
11-24	There is no large-scale infrastructure in the delta. The port in Sant Carles de la Ràpita is located just outside the delta and no structural problems are expected there as defences will surely adapt in time (Mariño, 1992). There are no main roads in the delta and those that cross it are rather inland, thus minimising the impact of sea level rise and erosion.
11-25	Houses may be affected as long as they are located on or near the beach. (there are just a few residential areas). Most of the houses are in the highest part of the delta which is about 3-4 m above sea level. The main effects of sea level rise will be felt by the tourist developments on the coast. These developments are, however, small compared to the rest of the developments on the Spanish Mediterranean coast and are of marginal value to the delta economy.
11-26	Salt works will experience major impacts of global climate change through a higher sea level and an expected increase in storms.

Table 5. Description of links of figure 28 (Otter *et al.* 1996b).

Link	Description
20-30	The drainage network has several pumping stations which discharge through the lagoons to the bays (Mariño, 1992)
21-30	The fresh water irrigation literally 'pushes down' the saline water.
23-31	The development of the tourist sector leads to urbanisation and an increased soil impermeability through the construction on roads, pavements, squares etc. leading to an increased run-off.
25-31	The development of the housing sector leads to an increased impermeability of the soils through the construction of roads, pavements, squares etc. leading to an increased run-off.
30-10	A change in irrigation and drainage practices may influence the coastal erosion process by affecting the (already minimal) flow of water and sediments.
31-10	The building of constructions on the coast may have negative effects on the coast itself and more specifically on the coastal wetlands through erosion. The constructions prevent the wetlands from moving landinwards under erosion conditions.
31-11	Urbanisation leads to an increased impermeability of the soils which increases the run-off and consequently actual floods may occur more frequently.

Table 5. Description of links of figure 28 (Otter *et al.* 1996b).





## 5. DELTAIC VULNERABILITY: ASSESSMENT AND APPLICATIONS

### □ VULNERABILITY DEFINITION AND ASSESSMENT

○ *Vulnerability* (worsening of the deltaic system status due to natural or man-induced factors) and the complementary concept of *resilience* (improvement or maintenance of the deltaic system status due to natural or man-induced factors) are difficult to define and evaluate for complex dynamical systems such as deltas, specially when their present situation is largely controlled or conditioned by the human influence.

○ Vulnerability/resilience is here defined in terms of three parameters:

- Variations in the "natural" rates of change (*e.g.* changes in the erosion rate rather than the appearance of erosion itself which may be a very natural process under present conditions). This can be illustrated by comparing the "natural" rates of erosion/accretion and lobe switching for the Ebro delta until 1960 *-i.e.* prior to the action of the present system of dams-, shown in figure 5, with the rates shown in figure 30 -which correspond to the period under the influence of dams and river flow regulation- (see also figure 31).
- Relative variations (*i.e.* gradient variations or sensitivity) in the same "natural" rates of change for a given increment in driving factors (*e.g.* relative variations in erosion rates for a unit increment of morphological wave-height or mean-water-level).
- Consumption of "resources" associated with the variations in rates of change (*e.g.* consumption of emerged barrier width associated with variations in erosion rates).

○ Each of these three classes of parameters contribute with a number of "vulnerability indexes" -which are simply the variations or consumptions above described after normalisation-. This means that vulnerability indexes range from -1.0 to 0.0 while resilience indexes range from 0.0 to 1.0. The so obtained vulnerability/resilience indexes can be then easily combined -in a linear manner to start with- including (optionally) a subjective weight for each of them to represent the political/subjective importance associated to each parameter (*e.g.* García, 1996).

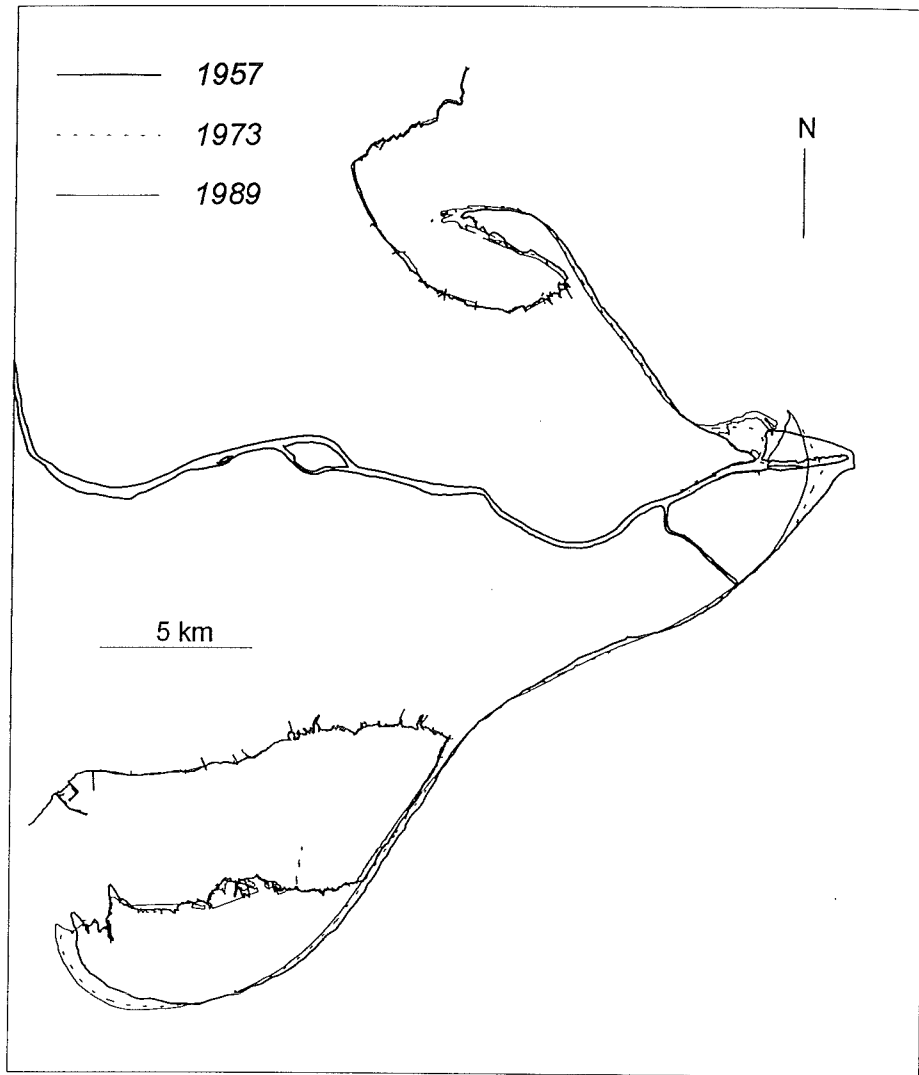


Figure 30. Shoreline rates of change in the Ebro delta from 1957 to 1989 (Jiménez and Sánchez-Arcilla, 1993).

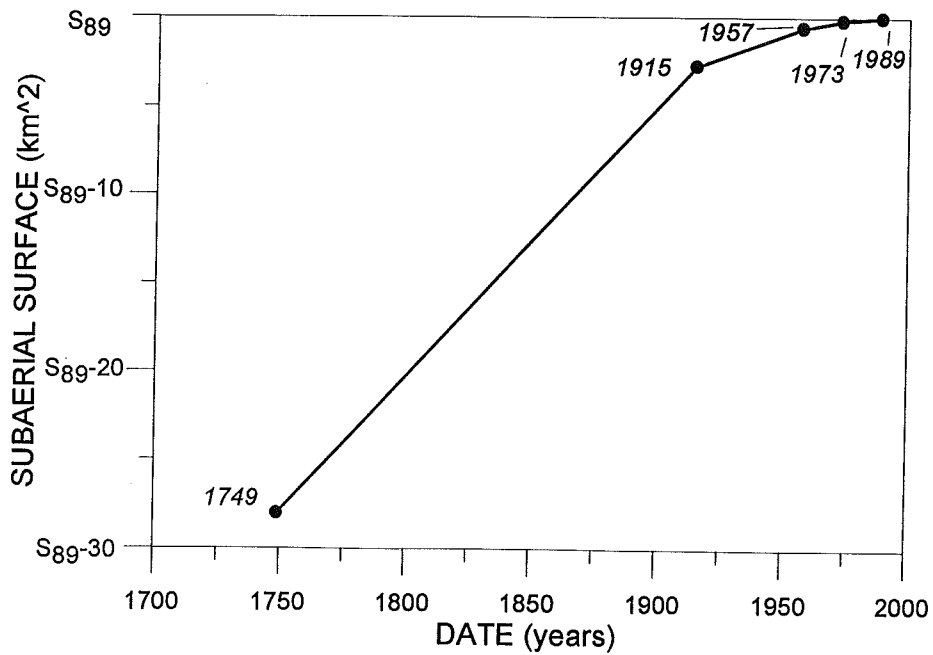


Figure 31. Ebro delta area changes during the last centuries (Jiménez, 1996; Jiménez *et al.* 1997).

## □ THE WAY TO APPLICATIONS

○ A complete application of the presented general approach is still very much under development. Some limited applications are being performed within the MEDDELT project and will be summarised in here. More information can be seen in Otter *et al.* (1996), Sánchez-Arcilla *et al.* (1996), Capobianco (1996), Pont (1996) and in the work to be subsequently done.

○ The vulnerability/resilience assessment to SLR effects is being done with three scenarios, defined assuming a Common Climate Boundary Condition which is the SLR given by the IPCC'95 best guess scenario:

1. *No-intervention scenario*, in which it is assumed that there are no new management "responses" to cope with SLR effects and represents the "natural" (*i.e.* present or reference) deltaic system behaviour under SLR. This scenario is analysed using a static approach (*e.g.* flooding the delta under the selected SLR and defining flooded areas as areas at risk, see figures 15 and 32 for an illustration of this approach in the Rhône and Ebro delta respectively) and a dynamic approach (based on the already presented physiographic-unit deltaic model, see *e.g.* figure 31 to assess the impact of SLR on the Ebro delta coast).
2. *Human-intervention scenario*, in which the effects of SLR on the deltaic system are analysed in a dynamic way which also includes "system management" options. This scenario obviously includes applying an evaluation technique to quantify monetary and non-monetary "costs" of the management options, with special attention on the values/weights of activities/uses difficult to evaluate in monetary terms.
3. *Sensitivity scenario*, in which the no-intervention scenario is re-evaluated using different initial conditions in order to assess the sensitivity of the conceptual model (of the deltaic system in more general terms) to different forcing conditions.

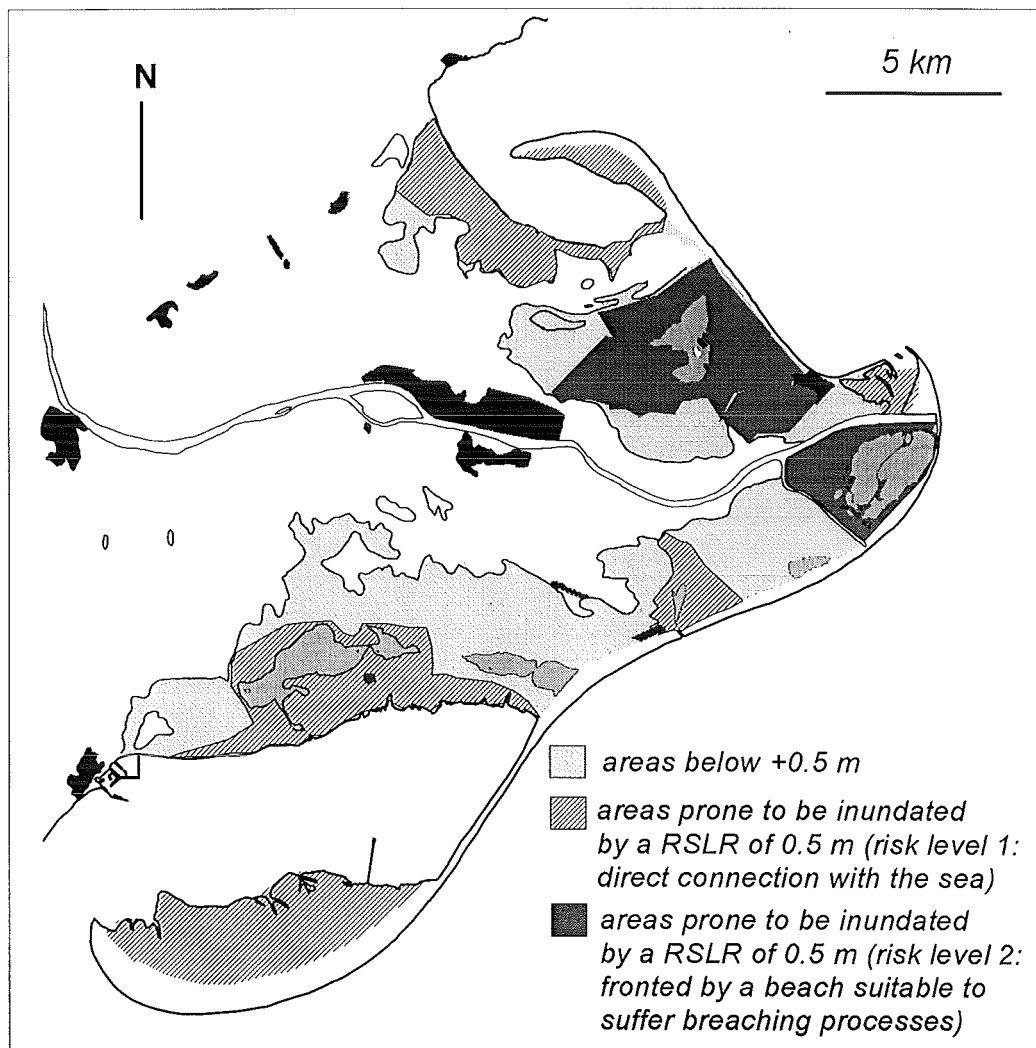


Figure 32. Risk areas in the Ebro delta (Sánchez-Arcilla *et al.* 1996a)

○ For each of these three scenarios a number of vulnerability/resilience indexes is determined so as to represent with the minimum possible level of information the deltaic system status and its response. The scenarios with a dynamic approach allow to quantify the system reaction to SLR so that the expected magnitude of the resulting changes can be quantified (rather than identifying only potential zones at risk as is done for the static approach or "flooding" models)

○ Eventhough the same approach is being followed for the three studied deltas, there are significant differences in initial conditions and resulting status. As an illustration, if the static and dynamic approaches are applied to the Ebro delta, the main difference is the quantification of flooding levels and affected areas. The same two approaches for the Po delta give significantly different results: the static approach predicts serious impacts on the coastal fringe and almost no impacts for the deltaic plain which is almost completely hydrologically controlled. The situation is nearly reversed with the dynamic approach which predicts an adapting coastal fringe (upwards and landwards migration of the active beach profile, etc.) and serious impacts on the plain, especially if the ecological system is considered under a scenario of no sediment supply (Capobianco *et al.*, 1996b).

○ When analysing vulnerability and resilience of the deltaic system it is necessary to study the system as a whole (*i.e.* all the components). However, in many cases it is useful to analyse the partial deltaic response to SLR by using some of the sub-models presented before. In this way, figure 33 shows a simulation of the response of wetland elevation in the Po delta (Chioggia) under a SLR given by the best estimate of IPCC'95 and for different mineral inputs. Obtained results predict that to keep in pace wetland elevation with the mean sea level (relative elevation) an input of 10,000 grams  $m^{-2} yr^{-1}$  would be necessary (Rybczyk *et al.* 1996). However, this amount is higher than the rates recorded for most salt marshes.

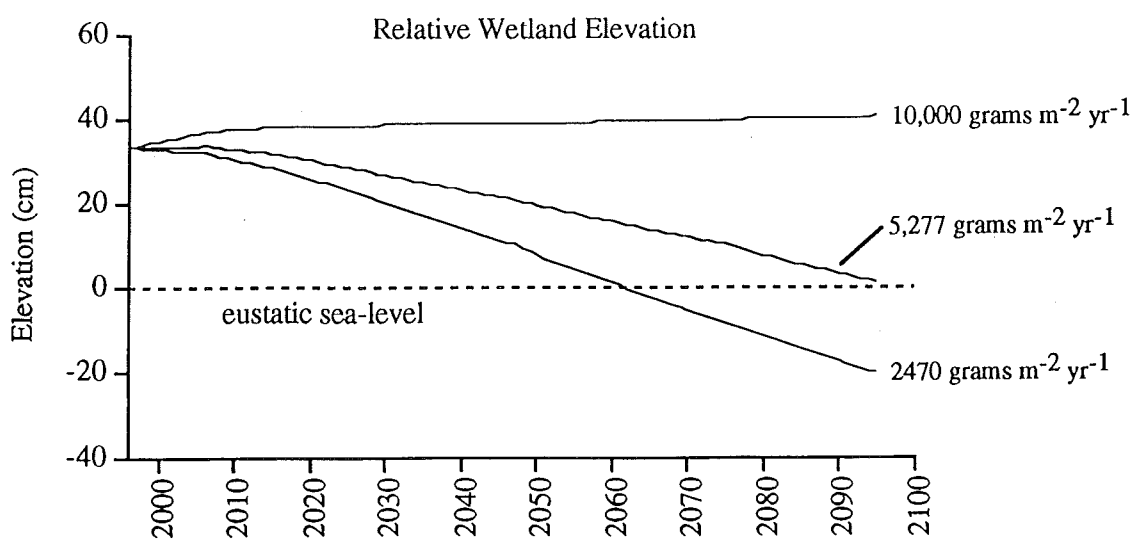


Figure 33. Simulated changes in wetland elevation for different mineral inputs under a SLR given by the best guess of IPCC'95 at the Chioggia wetland site -Po delta- (Rybczyk *et al.* 1996).

These results indicate that the Chioggia wetland is highly vulnerable -in terms of elevation- to SLR under present conditions (2,470 grams  $m^{-2} yr^{-1}$  is the current estimate of maximum mineral inputs, Rybczyk *et al.* 1996). Moreover, these results can also be used to assess the resilience capability of the system under different scenarios of sediment supply.

This “vulnerability” can also be measured in relative terms by comparing the expected wetland response under the present situation (current SLR conditions) with eustatic SLR, see figure 34. It can be seen that even under present conditions, the wetland is not able to maintain its relative elevation. This case therefore illustrates one of the types of vulnerability mentioned before, *i.e.* variation in the “natural” rates of change. Under both considered scenarios -current and accelerated SLR- the wetland evolutive trend is the same although with different rates.

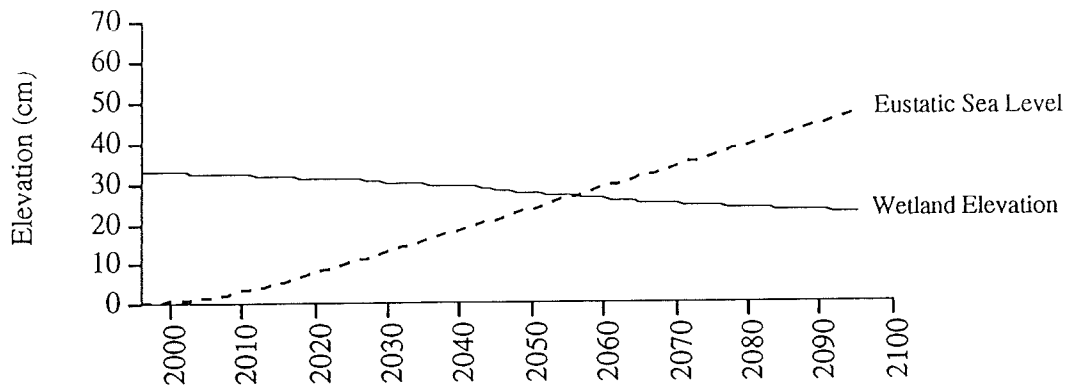


Figure 34. Simulated changes in wetland elevation for a mineral input of 2,470 grams  $m^{-2} yr^{-1}$  under current SLR (1.5 mm/yr) at the Chioggia wetland site -Po delta- (Rybczyk *et al.* 1996).

## 6. CONCLUSIONS: THE PAST AND THE FUTURE

### □ *GENERIC CONCLUSIONS*

○ The presented approach can be used to assess the impact of climatic change on NW Mediterranean type deltas, but is also a general methodology to

- Analyse deltaic systems using field data.
- Simulate deltaic systems using conceptual/numerical models.
- Assess vulnerability/resilience of deltaic systems using a landscape integrated model.

○ The "past" behaviour must be understood using available and newly collected data which allow to characterise the past and present system status and its underlying dynamics. The required amount of field data depends on the horizontal/temporal scale of the considered processes/responses. As an illustration, a stable assessment of the averaged yearly behaviour of the Ebro delta coastline, has required data series longer than 3 to 4 years. Measurements shorter than this are "polluted" by seasonal fluctuations (Jiménez and Sánchez-Arcilla, 1993) (see figure 35 for illustration).

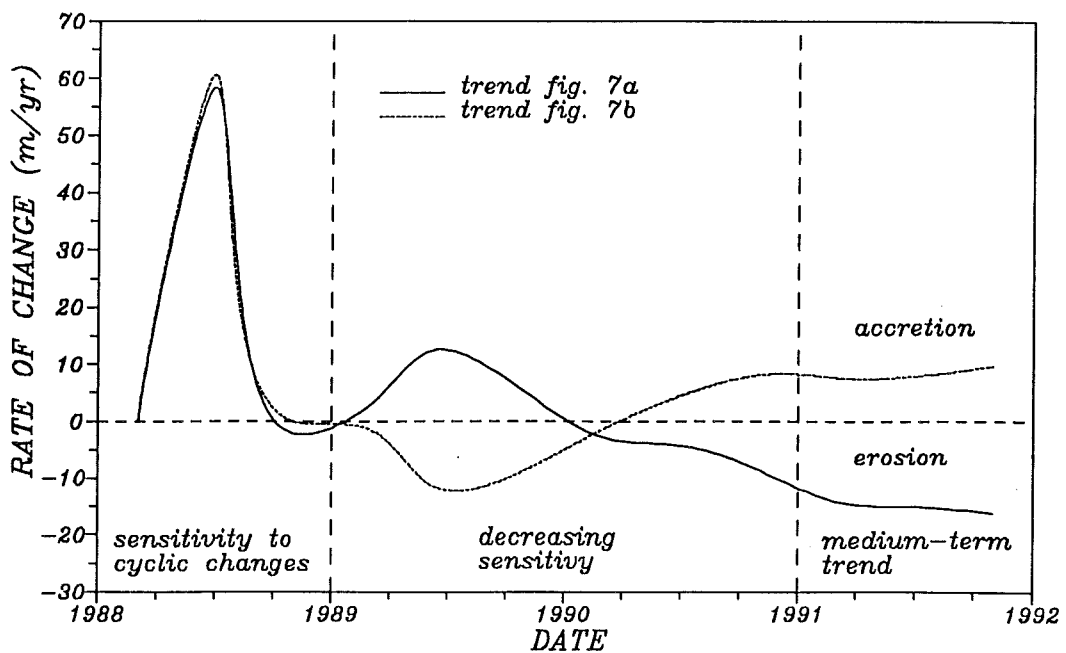


Figure 35. Effects of the length of the time serie of data for the determination of the shoreline medium-term evolution trend (Jiménez and Sánchez-Arcilla, 1993).



This "obvious" conclusion is not really a trivial matter since the only "long enough" time series normally available for climatic change studies pertain to atmospheric and terrestrial variables (temperature, precipitation, river liquid discharges, etc.). This leads to a situation where, although some of the driving terms are well characterised at the long time-scale, the associated deltaic response is seldom available.

In these cases (and the analysed deltas can be used as an example of this situation) numerical models have to be used to "reconstruct" the deltaic behaviour. One problem associated with the use of these models is that, in many cases, they have to be calibrated at the short-term scale (depending on the available data), even though they will be afterwards used in long-term simulations.

○ The "future" behaviour has been simulated using the conceptual model here presented, making use of the physiographic-unit concept and quantifying the links between units and physical/ecological/socio-economic sub-systems at the unit level. The use of this type of simulation models at decadal scale requires careful calibration of the component links and an overall model validation. This has been done, for instance, using coastline positions from the last 25 years in order to validate a shoreline evolution model able to forecast the Ebro delta coastal evolution at decadal scale (see figures 21 and 22). The same has been done to obtain the risk zonation in the Rhône deltaic plain presented in figure 15.

#### □ *SPECIFIC CONCLUSIONS*

○ The relatively low significance of "natural" climatic factors (river discharges, sea-level rise, wave climate, etc.) in determining changes in present deltaic behaviour. The conclusion is, thus, that management-related actions (river flow regulation, land uses, coastal zone defences, impoundment's, etc.) affect much more any possible change in deltaic behaviour.

In the analysed deltas, due to the existing extensive deltaic management/regulation policies, the climatic factor seems to accelerate the present evolutive trends (in terms of vertical elevation and coastal processes) instead of generating any clear change in

deltaic behaviour. This means that, under present conditions, these deltas are highly conditioned by the management practices which constrain the resilience capability of these environments to cope with SLR.

○ The importance of inorganic input (even if it is the wash-load fraction) to maintain relative land elevation. The same applies to sand input for all coastal fringes with a gradient in alongshore transport. In both cases the best way to make the most of the "remaining" natural input (*i.e.* what is left after the dams, etc. have taken their toll) is to allow the river to transport naturally the sediment and, at the same time, allow this sediment -fines for the deltaic plain and sand for the deltaic fringe- to be transported and deposited in the deltaic plain and fringe.

○ Only the areas with high sediment input (of riverine or marine origin) and without the negative effects of "limiting" structures (impoundment, groins, etc.) will be able to withstand naturally SLR.

As an example, Sánchez-Arcilla *et al.* (1996) have estimated that it is necessary that the Ebro river supplies at least four (4) times the present sand supply rate to counteract the coastal erosion induced by a SLR given by the IPCC'95 best estimate.

○ The same methodology has been applied to all 3 deltas, but a number of differences have illustrated the capabilities of the approach to other deltas in the world (variations in primary production related to soil elevation and salt content, variations in cross-shore transport and overwash related to beach profile and wave/surge climates, etc.). The numerical results obtained and presented partially in this report illustrate the feasibility of quantitative predictions for a better management.

○ As a final conclusion, it should be stressed that deltas depend on high-energy events to maintain themselves. The non-linear character of sediment transport formulations justify this strong dependence on the "peaks" of riverine and marine driving factors. Human management, so far, has been directed to reduce these high-energy episodic events. In the future, and if the final aim is to *enhance the natural survival of deltas*, there is a need to re-introduce these episodic events in the deltaic dynamics.



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## REFERENCES

- Arcelli, N. 1996. *Analisi dell'evoluzione recente dei litorali del delta del Po quale strumento di valutazione dell'impacto climatico*. Degree Thesis, Università di Padova, 177 p.
- Arnoux, S., Durand, N., Rey, V. and Fraunié, P. 1996. Three dimensional modelling of the Rhône deltaic fringe. In: E. Özhan (Ed.), *MEDCOAST'95*. Middle East Techn. University, Ankara, pp. 855-867.
- Barnolas, A. 1995. Evaluación de la tasa de subsidencia del delta del Ebro. *Jornadas sobre el delta del Ebro*, CEDEX, Madrid.
- Boumans, R.M.J. and Day, J.W. 1993. High precision measurements of sediment elevation in shallow coastal areas using a Sedimentation-Erosion table. *Estuaries*, 16, 2, 375-380.
- Cahoon, D.R. and Reed, D.J. 1995. Relationships among marsh surface topography hydroperiod and soil accretion in a deteriorating Louisiana salt marsh. *Journal of Coastal Research*, 11, 2, 357-369.
- Canicio, A., Pont, D. and Abrami, G. 1996. Topography and bathymetry of the Ebre, Po and Rhône deltas. *Impact of Climatic Change on NW Mediterranean Deltas. Vol. I*, 1.25-1.30.
- Capobianco, M. 1996. Impact of climatic change on Po delta. Integrated modelling as a

- support to integrated assessment. *Impact of Climatic Change on NW Mediterranean Deltas. Vol. II*, 5.1-5.28.
- Capobianco, M. and Furlanetto, L. 1996. Impact of climatic change on Po delta. The normative aspects regulating land use and socio-economic changes. *Impact of Climatic Change on NW Mediterranean Deltas. Vol. II*, 3.53-3.74.
- Capobianco, M. and Otter, H. 1996. Modelling land use and land cover changes for deltaic areas. *International Workshop on the State-of-the-Art of ICZM in the Mediterranean and the Black Sea*, (in press).
- Capobianco, M. and Stive, M.J.F. 1996. Climate change impacts on the deltas of Ebro, Po and Rhône: conceptual models for coastal fringes' response. *Impact of Climatic Change on NW Mediterranean Deltas. Vol. II*, 2.73-2.100.
- Capobianco, M., Rybczyk, J., Day, J.W., Rismondo, A., Scarton, F. and Area, D. 1996b. Impact of climatic change on Po delta deltaic plain modelling. *Impact of Climatic Change on NW Mediterranean Deltas. Vol. II*, 1.33-1.56.
- Capobianco, M., Stive, M.J.F. and Ruol, P. 1996. Impact of climatic change on the Po delta. Deltaic fringe modelling. *Impact of Climatic Change on NW Mediterranean Deltas. Vol. II*, 2.15-2.58.
- Curcó, A., Ibañez, C. and Canicio, A. 1996. Evaluation of primary production and decomposition. *Impact of Climatic Change on NW Mediterranean Deltas. Vol. I*, 6.1-6.35.
- Day, J.W., Pont, D., Hensel, P. and Ibañez, C. 1995. Impacts of sea level rise on deltas in the Gulf of Mexico and the Mediterranean: the importance of pulsing events to sustainability. *Estuaries*, 18, 636-647.
- Espino, M., García, M. and Sánchez-Arcilla, A. 1994. Rasgos de mesoescala de la circulación sobre la plataforma continental del Delta del Ebro. Análisis numérico. In: Valle, A. and Parés, C. (eds.), *Modelado de sistemas en oceanografía, climatología y ciencias medio-ambientales: aspectos matemáticos y numéricos*, 181-186.
- Hensel, P.F., Day, J.W. and Pont, D. 1996. Sediment dynamics in the Rhône river delta, France. *Impact of Climatic Change on NW Mediterranean Deltas. Vol. II*, 1.57-1.83.
- Ibañez, C., Day, J.W., Canicio, A., Prat, N. and Curcó, A., 1995. The Ebro Delta, Spain: Water and sediment management in the context of relative sea level rise. In: E. Özhan (Editor), *MEDCOAST'95*. Middle East Techn. University, Ankara, pp. 809-826.

- Ibañez, C., Canicio, A., Curcó, A., Day, J.W. and Prat, N. 1996. Evaluation of vertical accretion and subsidence rates. *Impact of Climatic Change on NW Mediterranean Deltas. Vol. I*, 5.1-5.24.
- Jelgersma, S. 1996. Geomorphological evolution of deltaic systems. *Impact of Climatic Change on NW Mediterranean Deltas. Vol. I*, 2.41-2.47.
- Jiménez, J.A. 1996. *Evolución costera en el delta del Ebro. Un proceso a diferentes escalas de tiempo y espacio*. Ph. D. Thesis, Universitat Politècnica de Catalunya, Barcelona, 274p.
- Jiménez, J.A. and Sánchez-Arcilla, A., 1993. Medium-term coastal response at the Ebro delta, Spain. *Marine Geology*, 114: 105-118.
- Jiménez, J.A. and Sánchez-Arcilla, A., 1997. Physical impacts of climatic change on deltaic coastal systems (III): coastal response. *Climatic Change* (submitted).
- Jiménez, J.A., Sánchez-Arcilla, A. and Maldonado, A. 1997. Long to short term coastal changes and sediment transport in the Ebro delta. A multi-scale approach. In: Maldonado, A. and Briand, F. (eds.), *Mediterranean coastal change and processes*, CIESM Science Series, No. 3, (in press).
- Jiménez, J.A., Valdemoro, H.I., Sánchez-Arcilla, A. and Stive, M.J.F., 1993. Erosion and accretion of the Ebro delta coast: a large scale reshaping process. *Large Scale Coastal Behavior' 93*, US Geological Survey, Open File Report 93-381: 88-91.
- Jiménez, J.A., Sánchez-Arcilla, A., Gracia, V., Valdemoro, H.I. and Nieto, F. 1996a. A conceptual model for the Ebro delta coast behaviour. *Impact of Climatic Change on NW Mediterranean Deltas. Vol. II*, 2.1-2.14.
- LIM/UPC. 1996. *Field campaign measurements at Buda Island (Ebro delta)*. MEDDELT Report, 35pp and annexes.
- Maldonado, A., 1972. El Delta del Ebro. Estudio Sedimentológico y Estratigráfico. *Boletín de Estratigrafía*, 1, Univ. de Barcelona, 450 pp.
- Maldonado, A., 1986. Dinámica sedimentaria y evolución litoral reciente del Delta del Ebro (Mediterráneo occidental). In: M. Mariño (Ed.), *El Sistema Integrado del Ebro: Cuenca, Delta y Medio Marino*, Hermes, Madrid, 33-60.
- Otter, H., van der Veen, A. and de Vriend, H.J. 1996a. A methodology for the analysis of the effects of sea level rise on the socio-economy of the MED-DELTAS. *Impact of Climatic Change on NW Mediterranean Deltas. Vol. II*, 3.1-3.17.

- Otter, H., van der Veen, A. and de Vriend, H.J. 1996b. Analysis of the effects of sea level rise on the socio-economy of the Ebro delta, Spain. *Impact of Climatic Change on NW Mediterranean Deltas. Vol. II*, 3.35-3.52.
- Pont, D. 1996. Response scenarios for the deltaic plain of the Rhône in the face of an acceleration in the rate of sea level rise. *Impact of Climatic Change on NW Mediterranean Deltas. Vol. II*, 4.51-4.72.
- Pont, D. and Bardin, O. 1996. Liquid and solid inputs from the Rhône into the Ile de Camargue and its hydrological functioning. *Impact of Climatic Change on NW Mediterranean Deltas. Vol. I*, 4.29-4.46.
- Rioual, P., Torre, F. and Pont, D. 1996. Primary production of Salicornia-type vegetation within the Rhône delta. *Impact of Climatic Change on NW Mediterranean Deltas. Vol. I*, 6.55-6.71.
- Rismondo, A. and Scarton, D. 1996. Primary production and decomposition in the Po delta. *Impact of Climatic Change on NW Mediterranean Deltas. Vol. I*, 5.25-5.34.
- Ruol, P. and Tondello, M. 1996a. Driving terms controlling coastal processes in three Mediterranean deltas. *Impact of Climatic Change on NW Mediterranean Deltas. Vol. I*, 7.61-7.73.
- Ruol, P. and Tondello, M. 1996b. Sediment transport and balance along the coastal fringe of the Po river delta. *Impact of Climatic Change on NW Mediterranean Deltas. Vol. I*, 8.17-8.32.
- Rybczyk, J.M., Day, J.W., Rismondo, A., Scarton, F. and Are, D. 1996. An integrated wetland elevation model for the Po delta. *Impact of Climatic Change on NW Mediterranean Deltas. Vol. II*, 1.17-1.31.
- Sánchez-Arcilla, A. and Jiménez, J.A., 1994. Breaching in a wave-dominated barrier spit: the Trabucador Bar (Northeastern Spanish coast). *Earth Surface Processes and Landforms*, 19: 483-498.
- Sánchez-Arcilla, A. and Jiménez, J.A., 1996. A morphological mixed-type model for the Ebro delta coast. *Proc. 25th Coastal Engineeringing Conf.*, ASCE, (in press).
- Sánchez-Arcilla, A. and Jiménez, J.A., 1997. Physical impacts of climatic change on deltaic coastal systems (I): an approach. *Climatic Change* (in press).
- Sánchez-Arcilla, A., Jiménez, J.A., Gracia, V. and Valdemoro, H.I., 1995. Sediment budget at the Ebro Delta coast: a multi-scale approach. In: E. Özhan (Ed.),

- MEDCOAST'95. Middle East Techn. University, Ankara, pp. 769-779.
- Sánchez-Arcilla, A., Jiménez, J.A., Gracia, V., Valdemoro, H.I. and Nieto, F. 1996. Physical impacts of climatic change on the Ebro delta coast. *Impact of Climatic Change on NW Mediterranean Deltas. Vol. II*, 4.7-4.28.
- Scarton, F. and Rismondo, A.. 1996. Primary production and decomposition in the Po delta. *Impact of Climatic Change on NW Mediterranean Deltas. Vol. I*, 6.37-6.35.
- Sestini, G. 1992. Implications of climatic change for the Po and Venice Lagoon. In: Jeftic, L., Milliman, J.D. and Sestini, G. (eds.), *Climatic Change and the Mediterranean*, London, Edward Arnold, 428-494.
- Suarez, S. and Provansal, M. 1996a. Large scale evolution of the littoral of the Rhône delta (Southeast France). *Journal of Coastal Research* (in review).
- Suarez, S. and Provansal, M. 1996b. Morphosedimentary behaviour of the deltaic fringe in comparison to the relative sea-level rise on the Rhône delta. *Quaternary Sciences Reviews* (in review).
- Suarez, S. and Provansal, M. 1996c. Dynamics of beach/dune systems: an example from the deltaic coast of the Rhône delta (Southeast France). *Journal of Coastal Conservation* (in review).
- Torre, F., Franquet, E., Rioual, P. and Pont, D. 1996. Modelling the soil formation and accretion within Salicornia-type environments of the Rhône delta. *Impact of Climatic Change on NW Mediterranean Deltas. Vol. I*, 5.35-5.51.





## LIST OF MEDDELT PUBLICATIONS

*Theses (Ph.D. and M.Sc.)**Ph.D.*

Jiménez, J.A. 1996. *Evolución costera en el delta del Ebro. Un proceso a diferentes escalas de tiempo y espacio*. Universitat Politècnica de Catalunya, 274 pp.

Suarez, S. 1997. *Dynamiques sédimentaires de la frange littorale orientale du delta du Rhone*. Université Aix-Marseille I, 279 pp.

(+3 in progress)

*M.Sc.*

Alfier, S. *Studio sperimentale in laboratorio sull'influenza di un oggetto in corrispondenza di un'imboccatura portuale*. Facoltà di Ingegneria, Università di Padova.

Ametller, S. 1995. *Evolución del delta del Ebro bajo las condiciones actuales y el efecto del cambio climático*. ETSECCPB, Universitat Politècnica de Catalunya, 119 p.

Arcelli, N. 1996. *Analisi dell'evoluzione recente dei litorali del delta del Po quale strumento di valutazione dell'impatto climatico*. Facoltà di Ingegneria, Istituto di Costruzioni Marittime e Geotecnica, Università degli Studi di Padova, 177 p.

Bixio, A.C. *Metodologie per l'analisi di stabilità delle imboccature a marea*. Facoltà di Ingegneria, Università di Padova.

Bony, P. and Buffet, R. *Dynamique éolienne et bilan sédimentaire sur le littoral du delta du Rhone*. M.M. Université de Provence, Aix-en-Provence, 180 p.

Bruzzi, C. 1995. *Impacts morphosédimentaires de quelques tempêtes sur les plages de Provence*. M.DEA. Université Aix-Marseille I, 120 p.

Caritey, C. 1995. *L'évolution de l'ambouchure du Rhone du milieu du XVIIIème siècle à la fin du XIXème siècle*, M.M. Université Aix-Marseille I, 100 p.

Conservan, P. and Longo, G. 1995. *Environmental restoration within a Po Delta fishery*. IUAV.

David, A. 1996. *Etude géomorphologique d'un paléochenal du Rhone en Basse Camargue au Petit Age Glaciaire: évolution sédimentaire des milieux fluviaux du Bras de Fer*. M.M. Université Aix-Marseille I, 128 p.

Ferro, M. 1995. *Delta Po Natural Park: Sustainability and compatibility among plans, programmes and projects*. IUAV.

García, A. 1996. *Planificación costera: usos, recursos y vulnerabilidad*. ETSECCPB, Universitat Politècnica de Catalunya, 174 p.

- Giorgetti, M. *Studio sperimentale in laboratorio sui fenomeni di trasporto solido litoraneo in prossimità di una imboccatura lagunare*. Facoltà di Ingegneria, Università di Padova.
- Henrot, E. 1996. *Caractérisation sédimentaire de quelques plages du delta du Rhone*. M.DEA. Université Aix-Marseille I, 81p.
- Novaco, A.R. 1995. *Po Delta Landscape Plan - Proposals*. IUAV.
- Pizzo, G.M. *Studio delle correnti costiere e del trasporto solido indotto dal moto ondoso lungo i litorali del Delta del Po*. Facoltà di Ingegneria, Università di Padova.
- Rossi R. 1995. *L'Economia Polesana, Realtà e Prospettive (Socio-Economy of the Po Delta)*. Univ. of Venice, Supervisor Prof. G. Zanetto, 115 p.

### *Journals*

- Arnaud-Fassetta, G. 1996. Les inondites rhodaniennes d'octobre 1993 et janvier 1994 en milieu fluvio-deltaïque, l'exemple du Petit Rhone. *Quaternaire*, (accepted for pub.)
- Arnaud-Fassetta, G. Transit et piégeage de la charge de fond du Petit Rhone (Delta du Rhone, France du sud) à l'échelle pluriannuelle: le contrôle événements hydrologiques exceptionnels. *Géomorphologie, relief, processus, environnements*, (submitted).
- Arnoux-Chiavassa, S., Rey, V. and Fraunié, Ph. Transport of suspended matter off the Rhone river plume. *Journal of Coastal Research*, (to be submitted).
- Broche, P., Devenon, J.L., De Maistre, J.C., Forget, P., Naudin, J.J. and Cauwet, G. Experimental study of the Rhone river plume. *Oceanologica Acta*, (submitted).
- Bruzzi, C. and Provansal, M. 1996. Impacts morphosédimentaires des tempêtes sur les côtes de Provence. *Quaternaire*, (accepted for pub.)
- Capobianco, M., DeVriend, H.J, Nicholls, R.J. and Stive, M.J.F. 1996. Coastal Area Impact and Vulnerability Assessment: A Morphodynamic Modeller's Point of View, *Journal of Coastal Research*, (submitted).
- Day, J.W., Pont, D., Hensel, P. and Ibañez, C. 1996. Impacts of sea-level rise on deltas in the Gulf of Mexico and the Mediterranean: the importance of pulsing events to sustainability. *Estuaries*, 18(4): 636-647.
- Forget, P. and Ouillon, S. Surface suspended matter quantification in the Rhone river mouth area from combined field radiometric measurements and satellite imagery. *Oceanologica Acta*, (submitted).
- Guan, C., Rey, V. and Forget, P. Improvement of the WAM wave model and its application to the Rhone river mouth area. *Journal of Coastal Research*, (to be submitted).
- Hensel, P., Day, J. and Pont, D. 1996. Wetland accretion and Elevation change in the Rhone River Delta, France. *Journal of Coastal Sciences*, (submitted).
- Hensel, P., Day, J., Pont, D. and Day, J.N. 1996. Short-term sedimentation in the Rhone River delta, France: the importance of riverine pulsing. *Estuaries*, (accepted for pub.)

- Ibañez, C., Canicio, A. and Day, J.W. Morphologic evolution, relative sea-level rise and sustainable management of water and sediment in the Ebro Delta. *Journal of Coastal Conservation*, (accepted for pub.)
- Ibañez, C., Day, J.W. and Pont, D. Primary production, decomposition and the effects of relative sea level rise and human management on the wetlands of the Rhone delta, France. (submitted).
- Ibañez, C., Pont, D. and Prat, N. 1996. Characterization of the Ebro and Rhone Estuaries: a basis for defining and classifying salt wedge estuaries. *Limnology and Oceanography*, (in press).
- Ibañez, C., Prat, N. and Canicio, A. 1996. Changes in the hidrology and sediment transport produced by large dams on the lower Ebro river and its estuary. *Regulated Rivers*, 12(1): 51-62.
- Ibañez, C., Saldaña, J. and Prat, N. 1996. A three-layer model to determine the advective fluxes in salt wedge estuaries: application to the Ebro Estuary. *Estuarine, Coastal and Shelf Sciences*, (submitted).
- Jiménez, J.A. and Sánchez-Arcilla, A. 1996. Physical impacts of climatic change on deltaic coastal systems (II): driving terms. *Climatic Change*, (in press).
- Jiménez, J.A. and Sánchez-Arcilla, A. 1997. Physical impacts of climatic change on deltaic coastal systems (III): coastal response. *Climatic Change*, (to be submitted).
- Jiménez, J.A., Maldonado, A. and Sánchez-Arcilla, A. 1997. Long to short term coastal changes and sediment transport in the Ebro delta. In, Maldonado, A. and Briand, F. (eds.), *Mediterranean Coastal Changes and Processes*, CIESM Science Series No. 3, (accepted for pub., in press).
- Jiménez, J.A.; Sánchez-Arcilla, A.; Bou, J. and Ortiz, M.A. 1996. Analysing short-term shoreline changes along the Ebro delta using aerial photographs. *Journal of Coastal Research*, (in press).
- Jiménez, J.A.; Sánchez-Arcilla, A.; Valdemoro, H.I.; Gracia, V. and Nieto, F. 1996. Agents forcing reshaping processes in the Ebro delta coast. *Marine Geology*, (in review).
- Pichard, G. 1995. Les crues sur le bas Rhone de 1500 à nos jours. Pour une histoire hydroclimatique. *Méditerranée*, 3-4, 105-116.
- Provansal, M. 1995. The part of climate in morphogenesis from the Bronze Age in Provence, Southeartern France. *The Holocene*, 5, 3, 348-354.
- Rey, V., Devenon, J.L. and Fraunié, Ph. Coastal evolution modelling due to relative sea level rise. *Journal of Coastal Research*, (to be submitted).
- Sánchez-Arcilla, A. and Jiménez, J.A. 1996. Physical impacts of climatic change on deltaic coastal systems (I): an approach. *Climatic Change*, (in press).
- Sánchez-Arcilla, A. and Jiménez, J.A. 1997. Physical impacts of climatic change on the Ebro delta coast. *Climatic Change*, (to be submitted).
- Sánchez-Arcilla, A., Jiménez, J.A., Stive, M.J.F., Ibañez, C., Prat, N., Day, J.W. and Capobianco, M. 1996. Impacts of sea-level rise on the Ebro Delta: A first approach. *Ocean & Coastal Management*, 30,2-3, 197-216.

- Sánchez-Arcilla, A.; Jiménez, J.A.; Gelonch, G. and Nieto, J. 1996. El problema erosivo en el Delta del Ebro. *Revista de Obras Públicas*, Monográfico Delta del Ebro, (in press).
- Sánchez-Arcilla, A., Jiménez, J.A. and Maldonado, A. Coastal dynamics in the Spanish Mediterranean. In, Maldonado, A. and Briand, F. (eds.), *Mediterranean Coastal Changes and Processes*, CIESM Science Series No. 3, (accepted for pub.).
- Suanez, S. 1995. Quelques données nouvelles sur l'évolution mi-séculaire du littoral camarguais à l'embouchure du Rhone (France, Sud-Est). *Bull. Assoc. Géogr. Fr.*, 5, 440-454.
- Suanez, S. and Provansal, M. 1996. Large scale evolution of the littoral of the Rhone delta (Southeast France). *Journal of Coastal Research*, (accepted for pub.)
- Suanez, S. and Provansal, M. 1996. Morphosedimentary behaviour of the deltaic fringe in comparison to the relative sea-level rise on the Rhone delta. *Quaternary Sciences Reviews*, (accepted for pub.)
- Suanez, S. and Provansal, M. Dynamics of beach/dune systems: an example from the deltaic coast of the Rhone delta (Southeast France). *Journal of Coastal Conservation*, (in review).
- Suanez, S. and Simon, B. Utilisation de l'analyse diachronique dans l'étude de l'évolution du littoral du delta du Rhone (France, Sud-Est). *Photo-Interprétation*, (submitted).
- Suanez, S., Prosper-Laget, V. and Provansal, M. Variations relatives du niveau marin dans le delta du Rhone. Implications climatiques ou tectoniques. *Comptes-rendus Académie des Sciences, Paris*, (submitted).
- Vella, C., Boursier, M. and Provansal, M. Montée du niveau marin et sédimentation holocène sur la marge orientale du delta du Rhone. *Bull. de la Société Géol. de France*, (submitted).
- Verdier-Bonnet, C., Angot, Ph. and Fraunié, Ph. Paramétrisation de la turbulence pour le phénomène d'upwelling côtier en milieu stratifié. *Comptes Rendus de l'Académie des Sciences, Paris*, (accepted for pub.)
- Verdier-Bonnet, C., Arnoux, S., Angot, Ph. and Fraunié, Ph. 1996. Three dimensional hydrodynamic numerical model in coastal areas. *Water Science and Technology, IAWQ journal*, (in press).

### Conferences

- Abrami, G. 1996. Research projects to protect saltmarsh area from erosion in Northeastern Italy. *IECA '96*, Seattle, February 1996.
- Arnaud-Fassetta, G. and Chabal, L. 1995. Evolution des paléoenvironnements fluviaux dans la plaine deltaïque du Rhone de l'Antiquité au Haut Moyen-Age d'après la géomorphologie et l'anthracologie. *Actes du Colloque "Crau, Alpilles et Camargue. Histoire et archéologie"*, Arles (France), November 1995.

- Arnoux, S., Durand, N., Rey, V. and Fraunié, Ph. 1995. Three dimensional modelling of the Rhone's deltaic fringe. *MEDCOAST 95*, Tarragona (Spain), 24-27 Oct. 1995, 855-867.
- Arnoux, S., Rey, V., Ouillon, S. and Fraunié, Ph. 1995. Three dimensional modelling of the Rhone deltaic coastal zone. *COASTAL 95*, Cancun (Mexico), 6-8 sept. 1995.
- Arnoux-Chiavassa, S., Baeckeroot, A., Baghdali, N., Broche, P., Devenon, J.L., Forget, P., Gagelli, J., De Maistre, J.C., Ouillon, S., Rey, V. and Rougier, G. 1995. Field Campaign off the Rhone river mouth. *MEDCOAST 95*, Tarragona (Spain), 24-27 Oct. 1995, 869-882.
- Arnoux-Chiavassa, S., Suanez, S., Rey, V., Devenon, J.L., Fraunié, Ph. and Provansal, M. 1996. Long term coastline evolution at the Rhone river mouth: modelling and applications. *ECSA 26/ERS 96*, Middelburg, September 1996.
- Broche, P., Gagelli, J., De Maistre, J.C., Devenon, J.L., Forget, P., Rougier, G., Ouillon, S., Arnoux, S., Rey, V., Baeckroot, A., Baghadi, N. and Fraunié, Ph. 1995. Remote sensing of a river plume by VHF doppler radars. *WMO/IOC Workshop on Operational Ocean Monitoring using surface based radars*, World Meteorological Headquarters, Geneva, 6-8 March 1995.
- Buzzi, C. and Provansal, M. 1995. Impacts des tempêtes sur le cordon dunaire aménagé de la Flèche de la Gracieuse (Delta du Rhone, France Méridionale). *Actes du Colloque "Continuités et ruptures sur le littoral"*, Nantes (France), (in press).
- Canicio, A. and Ibañez, C. 1995. Morphological changes in the southern hemidelta of the Ebro during the past decades: management implications. *MEDCOAST 95*, Tarragona (Spain).
- Canicio, A. and Ibañez, C. 1995. Prevention of breaching events in the Trabucador barrier, Ebro delta. *MEDCOAST 95*, Tarragona (Spain).
- Capobianco, M., Jiménez, A., Sanchez-Arcilla, A. and Stive, M.J.F. 1995. Budget Models for the Evolution of Deltas. Definition of Processes and Scales. *MEDCOAST '95*, The 2nd Int. Conf. on the Mediterranean Coastal Env., Tarragona, Spain, 24-27 October.
- Capobianco, M. and Otter, H.S. 1996. Modelling Land-use and Land-cover Changes in Deltaic Areas, *International Workshop on the State-of-the-Art of ICZM in the Mediterranean and Black Sea: Immediate Needs for Research, Education & Training, & Implementation*, Iberotel Sarigerme Park, Turkey, November 2-5, 201-215.
- Capobianco, M. and Piantoni, R. 1996. Strategie di Gestione di Aree Deltizie in Ipotesi di Innalzamento Relativo del Livello dei Mari. *4° Congresso AIOM*, Padova, October 3-4.
- Capobianco, M., Abrami, G. and Ruol P. 1995. Impact of Climate Change on the Evolution of the Po Delta Plane Framework for the Definition of Boundary Conditions. *MEDCOAST '95*, The 2nd Int. Conf. on the Mediterranean Coastal Env., Tarragona, Spain, 24-27 October.

- Capobianco, M., Jiménez,,J.A., Pont, D. and Sanchez-Arcilla, A. 1996. Integrated Assessment of Deltaic Systems Changes. *28th International Geographical Congress*, The Hague, August 4-10.
- Capobianco, M., Ruol, P. and Abrami, G. 1995. Large-scale, Long-term Impacts on the Evolution of the Po Delta Plain. Definition of Scenarios. *Estuarine Research Federation 13th Biennial International Conference*, Corpus Christi, Texas, 12-16 November.
- Capobianco, M., Ruol, P. and Abrami, G. 1996. The Role of Physical and Ecological Processes in the Morphological Evolution of a Deltaic Area - A Case Study from the Po Delta. *ECSA 26 and ERF 96 Symposium*, September 16-20, Middelburg, The Netherlands. Accepted for Presentation.
- Capobianco, M.; Jiménez, J.A.; Sánchez-Arcilla, A. & Stive, M.J.F. 1995. Budget and spatial distributed models for evolution of deltas. Definition of processes and scales. *MEDCOAST 95*, Tarragona, 737-751.
- Curcó, A., Ibañez, C., Canicio, A. and Prat, N. 1996. Primary production, decomposition rates and soil accretion in wetlands of a Mediterranean delta: the Ebro delta (Catalonia, Spain). *ECSA/ERF Symposium on Transport, Retention, Transformation Processes and their Biological Control in Estuarine and Coastal Systems*, Middelburg (The Netherlands), 16-20 September 1996.
- Day, J.W., Pont, D., Hensel, P. and Ibañez, C. 1995. Pulsing events and sustainability of Mediterranean Deltas. *MEDCOAST 95*, Tarragona (Spain), 781-792.
- Devenon, J.L. and Fraunié, Ph. 1996. Long term coastal evolution modelling considered as an inverse problem. *ECSA 26/ERS 96*, Middelburg, September 1996.
- Devenon, J.L. and Fraunié, Ph. 1996. Long term coastline evolution modelling considered as an inverse problem. *European Geophysical Society Conf.*, The Hague, May 1996.
- Dusek, J., Fraunié, Ph., Dauchy, C. and Danaila, I. 1995. Secondary instabilities and transition to turbulence in wakes and jets. *Three-dimensional complex flows, IMACS-COST Conference on CFD*, Lausanne, 13-15 September 1995, Notes on Numerical Fluid Mechanics vol 53, 78-87.
- Forget, P. and Ouillon, S. 1996. Suspended particulate matter concentration off the Rhone river mouth by SPOT and LANDSAT-TM imagery. *Operational Oceanography and Space Observation Workshop*, Biarritz, 16-19 Oct. 1996.
- Fraunié, Ph. 1996. About the Rhone river Plume. *JONSMOD 96*, Oslo, August 1996.
- Fraunié, Ph. and Rey, V. 1996. Coastline evolution modelling due to Relative Sea Level Rise. *European Geophysical Society Conf.*, The Hague, May 1996.
- Fraunié, Ph., Carte, G. and Dusek, J. 1995. Monochromatic instability computation using a spectral time discretization. *European Geophysical Society XX General Assembly*, Hambourg, 3-7 April 1995.
- Fraunié, Ph., Rey, V. and Devenon, J.L. 1996. Modelling the long term coastline evolution of non tidal seas by use of data assimilation. *MED & Black Sea ICZM 96*, Sarigerme (Turkey), November 1996.

- Gracia, V.; Jiménez, J.A. & Sánchez-Arcilla, A. 1995. Nearshore profiles along the Ebro delta coast. Implications for coastal processes. *MEDCOAST 95*, Tarragona, 1131-1143.
- Hensel, P., Day, J.W., Pont, D. and Day, J.N. 1995. Short-term sedimentation patterns in the Rhone River Delta, France. *13th International Estuarine Research Federation*, Corpus Christi, Texas (USA), November 12-16.
- Ibañez, C., Day, J.W., Canicio, A., Criado, J. and Sánchez, A. 1995. Bases for sustainable management and development of the Ebro delta. *MEDCOAST 95*, Tarragona (Spain).
- Ibañez, C., Day, J.W., Canicio, A., Prat, N. and Curcó, A. 1995. The Ebro Delta: water and sediment management in the context of relative sea-level-rise. *MEDCOAST 95*, Tarragona (Spain), 809-826.
- Ibañez, C., Day, J.W., Pont, D. and Curco, A. 1995. Primary production and relative sea-level rise in wetlands of the Rhone Delta, France, *13th International Estuarine Research Federation*, Corpus Christi, Texas (USA), November 12-16.
- Istituto di Costruzioni Marittime e di Geotecnica and Sclavo, M. 1996. Wave and tidal current effects on a lagoon inlet. *Int. Conf. Littoral'96*, Portsmouth (U.K.), Sept. 1996.
- Istituto di Costruzioni Marittime e di Geotecnica and Sclavo, M. 1996. Sull'azione combinata di onde e correnti in prossimità di un'imboccatura lagunare. *4° Convegno AIOM*, Padova, October 1996.
- Istituto di Costruzioni Marittime e di Geotecnica, Stive, M.J.F., Capobianco, M. and Wang, Z. 1996. The dynamics of microtidal lagoons and adjacent coasts. *Physics of Estuaries and Coastal Seas*, The Hague, 9-10 September 1996.
- Jiménez, J.A. & Sánchez-Arcilla, A. 1995. La vulnerabilidad costera en el Delta del Ebro. *Jornada sobre el Delta del Ebro*, CEDEX, Madrid, November 1995.
- Jiménez, J.A. & Sánchez-Arcilla, A. 1996. Recursos, usos y vulnerabilidad costera en el Delta del Ebro. *II Jornada sobre el Delta del Ebro*, CEDEX, Madrid, February 1996.
- Jiménez, J.A.; Bou, J.; Ortiz, M.A. & Sánchez-Arcilla, A. 1995. Reliability of the use of aerial photographs to analyse short-term shoreline changes. *CoastGIS' 95*, IGU, ICA, Cork, 231-253.
- Jiménez, J.A.; Capobianco, M.; Suanez, S.; Ruol, P.; Fraunié, P. & Stive, M.J.F. 1995. Coastal processes along the Ebro, Po and Rhône deltas. *MEDCOAST 95*, Tarragona, 827-840.
- Jiménez, J.A.; Sánchez-Arcilla, A.; Ruol, P.; Capobianco, M.; Provansal, M. & Stive, M.J.F. 1995. On the definition of the reference situation to study the impact of climatic change on deltaic coastal zones. Application to three Mediterranean deltas. *HYDROCOAST 95*, UNESCO, Bangkok, 306-315.
- LSEET-UTV. 1996. Etude tridimensionnelle du panache du Rhone. *8ème rencontres ARPE*, Nice, 9-10 Oct. 1996.
- LSEET-UTV. 1996. Three dimensional plume of the Rhone river. *5th IMA Conf. on stratified flows, Mixing and dispersion in stably stratified flows*, Dundee, September 1996.
- Ouillon, S., Forget, P., Foidefond, J.M. and Naudin, J.J. 1995. Estimating suspended matter concentrations from SPOT data and from field measurements in the Rhone river



- plume. *Proc. 3rd Int. Conf. Remote Sensing for Marine and Coastal Environments, ERIM 2*, Seattle (USA), 18-20 Sept. 1995, 200-209.
- Pont, D. 1995. Circulation des polluants en eaux superficielles. Le cas du Rhone deltaïque (Conférence invitée). *Journée Scientifique du Pôle Universitaire Européen*, Montpellier, France, 5p.
- Pont, D. 1995. L'expertise dans le cadre d'un plan ORSEC: les inondations de Camargue. Ecologie et Politique. *Natures-Sciences-Sociétés*, Colloque CNRS-Paris (France), 12-13 December.
- Pont, D., Day, J.W., Hensel, P. and Ibañez, C. 1995. L'évolution à long terme du delta du Rhone. Analyse de la dynamique sédimentaire actuelle. *39ème Congrès National de l'Association Française de Limnologie*, Corte (France), 3-7 July.
- Pont, D., Nicolas, Y., Franquet, E., Day, J.W., Hensel, P., Ibañez, C. and Coulet, E. 1995. Impacts of Rhone river floods of 1993-94 on the Rhone deltaic plain. *13th International Estuarine Research Federation*, Corpus Christi, Texas (USA), November 12-16.
- Provansal, M. 1996. Dynamiques littorales et aménagements: la Flèche de la Gracieuse. *Cours pour le Master Environnement de l'Ecole des Mines*, Aix-en-Provence, September 1996.
- Provansal, M. 1996. Les relations du Rhone avec l'occupation du sol dans la plaine deltaïque depuis 5000 ans. *Colloque du service régional d'Archéologie des Bouches-du-Rhone*, Mouriès (France), april 1996.
- Sánchez-Arcilla, A. & Jiménez, J.A. 1996. Modelado a gran escala en el Delta del Ebro. *II Jornada sobre el Delta del Ebro*, CEDEX, Madrid, February 1996.
- Sánchez-Arcilla, A. and Jiménez, J.A. 1996. A morphological mixed type model for the Ebro delta coast. *Proc. 25th Coastal Engineering Conf.*, ASCE, (in press).
- Sánchez-Arcilla, A.; Jiménez, J.A.; Gracia, V. & Valdemoro, H.I. 1995. Sediment budget at the Ebro delta coast: a multiscale approach. *MEDCOAST 95*, Tarragona, 769-779.
- Stive, M.J.F., Capobianco, M. and Ruol, P. 1996. Morphological Evolution of Lagoons in Deltaic Areas. *8th International Conference on Physics of Estuaries and Coastal Zones*, NCK, The Netherlands, September 9-12.
- Stive, M.J.F., Baarse, G. and Misdorp, R. 1996. Coastal management: Global Change....Global Observation?, *EuroGOOS*, The Hague, 7-11 October 1996.
- Suarez, S. 1995. Morphosedimentary behaviour of the deltaic fringe in comparison to the relative sea-level rise on the Rhone delta. *IGCP Meeting*, Antofagasta (Chile), 19-28 november 1995.
- Suarez, S. and Provansal, M. 1995. Dynamics of beach/dune systems: an example from the deltaic coast of the Rhone delta (Southeast France). *MEDCOAST 95*, Tarragona (Spain), October 1995.
- Vella, C. 1996. L'impact de la contrainte naturelle sur le site de Fos-sur-Mer, France. *Actes du Colloque de Montpellier "Anthropisation et milieux naturels"*, 21-22 june 1996.

Verdier-Bonnet, C., Angot, Ph. and Fraunié, Ph. 1995. Modélisation numérique k-E du processus d'upwelling côtier tridimensionnel. *Xxème Colloque Union des Océanographes de France*, "Echelles Spatiales et Temporelles dans l'Océan", Paris (France), 24-25 Nov. 1995.

Verdier-Bonnet, C., Arnoux, S., Angot, Ph. and Fraunié, Ph. 1995. Three dimensional hydrodynamic numerical model in coastal areas. *Black sea regional conference on Environment protection technologies for coastal areas*, Varna (Bulgarie), 13-15 june 1995, 113-122.

### Reports

Broche, P. et al. 1995. *Field Campaign off the Rhone river*. LSEET Report 1995-1.

Bruzzi, C., Provansal, M., Arnoux-Chiavassa, S., Fraunié, P., Guan, C., Rey, V. and Suanez, S. 1996. *Definition of wave climate currents and Mean Water Level regime*. MEDDEL T Final Report, Université Aix-Marseille I.

Capobianco, M. 1994. *Contribution for the Definition of a Modelling Approach*. MEDDEL T Research Report.

Capobianco, M. 1995. *Contribution to the Identification of a GIS Package*. MEDDEL T Research Report.

Capobianco, M. 1996. *Wetlands Classification Scheme*. MEDDEL T Research Report.

Capobianco, M. 1996. *Linking Socio-Economy and the "Natural" Deltaic System. A "Synthetic Delta Example*. MEDDEL T Research Report.

Capobianco, M. 1996. *MEDDEL T Glossary of Terms*. MEDDEL T Research Report.

Capobianco, M. and Otter, H. 1996. *Linking Socio-Economy and the "Natural" Deltaic System*. MEDDEL T Research Report.

Capobianco, M., Stive, M.J.F. and Wang, Z.B. 1996. *Modelling Integrated Lagoon-Coastal Long-term Morphodynamics*. MEDDEL T Research Report.

Istituto di Costruzioni Marittime e di Geotecnica and Tondello, M. 1996. *Waves and tides characteristics in the Northern Adriatic Sea, with reference to the Po delta area*. MEDDEL T Technical Report, Padova, June 1996.

Istituto di Costruzioni Marittime e di Geotecnica and Tondello, M. 1996. *Driving terms controlling coastal processes in three Mediterranean deltas*. MEDDEL T Technical Report, Padova, June 1996.

Istituto di Costruzioni Marittime e di Geotecnica and Tondello, M. 1996. *Sediment transport and balance along the coastal fringe of the Po river Delta*. MEDDEL T Technical Report, Padova, June 1996.

Istituto di Costruzioni Marittime e di Geotecnica. 1996. *Analyses on liquid and solid discharges of the Po river in the last century*. MEDDEL T Technical Report, Padova, June 1996.

IUAV. 1995. *First general methodological report about Po Delta research*. MEDDEL T Report.

- Jiménez, J.A. and Sánchez-Arcilla, A. 1995. *Deltaic Coastal Fringe Analysis. Common Methodology*. MEDDELT Report.
- Jiménez, J.A. 1994. *Field Guide to the Ebro delta*. MEDDELT Report.
- Museu del Montsià. 1996. *Projecte MEDDELT. Estudi socio-economic*. MEDDELT Report.
- Provansal, M., Suanez, S., Arnaud-Fassetta, G. and Vella, C. 1996. *Geological evolution of the deltaic system*. MEDDELT Final Report, Université Aix-Marseille I.
- Suanez, S. 1994. *Evolution actuelle et récente du littoral camarguais (plage Napoléon et Flèche de la Gracieuse)*. Rapport préliminaire pour le Port Autonome de Marseille, Université Aix-Marseille I.
- Suanez, S. 1995. *Abstracts from Arles meeting*. MEDDELT Report, Université Aix-Marseille I.
- Suanez, S. 1995. *Dune-dry beach, common methodology*. MEDDELT Technical Report, Université Aix-Marseille I.
- Suanez, S., Arnoux-Chiavassa, S., Bony, P., Bruzzi, C., Buffet, R., Provansal, M. and Fraunié, P. 1996. *Evaluation of coastal sediment transport*. MEDDELT Final Report, Université Aix-Marseille I.