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Soft intervention technology as a tool for integrated coastal zone management

Capobianco, Michele[1] & Stive, Marcel J.F.[2]

[1]*Tecnomare S.p.A., R&D, Environment, San Marco n. 3584, 30124 Venezia, Italy, and University of Twente, Civil Engineering & Management, P.O. Box 217, 7500 AE Enschede, The Netherlands;*
Fax +39 41 796800; E-mail capobianco.m@tecnomare.it;
[2]*Netherlands Centre for Coastal Research (NCK), Department of Civil Engineering and Geosciences, Delft University of Technology; Delft Hydraulics, P.O. Box 177, 2600 MH Delft, The Netherlands;*
Fax +31152858582; E-mail marcel.stive@wldelft.nl

Abstract. After introducing soft defence techniques as an alternative to hard defence techniques, the need is emphasized to consider the coastal area as an integral system. By recalling the main driving factors for coastal management: conflict resolution, resilience and sustainability, we logically arrive at the concepts of ecological engineering and ecotechnology, which are increasingly acknowledged as possible solutions to achieve sustainable use of coastal space as a resource. In this context, we refer to the principles of self design and of ecosystem conservation.

In order to deal with real situations we are in need of fundamental 'tools' for the application of the soft intervention technology approach. We therefore introduce the concept of physiographic units and develop an initial elaboration for a coastal stretch and for coastal wetlands. The latter deserve more attention because of the already established practices of ecotechnology, at least as far as water and soil quality are concerned, but certainly also concerning morphology, especially in the future. We conclude by briefly discussing how activities undertaken in two research projects currently being conducted under the framework of the Marine Science and Technology Program of the Commission of the European Communities are expected to contribute to the concepts introduced here.

Keywords: Coastal wetland; Conflict resolution; Ecological engineering; Ecotechnology; Physiographic unit; Sustainability.

Introduction

The coastal zone territory is greatly affected by long and continuous human occupation. This has resulted in a continuous loss of 'natural areas' and in the artificialization of 'natural processes' (particularly due to urban and agricultural developments). This has in many cases created situations that are difficult to sustain.

Of course this has been the result of the dominant culture of the last decades that favours short-term exploitation of natural resources, in which we include the 'coastal space'. For a number of reasons, not the least historical and legislative reasons, coastal space was for a long time seen as a 'low cost' resource. The adoption of hard engineering practices, heavily involving concrete and steel structures, has caused complete artificialization of forcing factors and boundary conditions, further aggravating the problem.

Reflection on these developments has led to the present tendency of developing 'soft defence techniques' as a more appropriate tool to be used in Integrated Coastal Zone Management. Amongst these techniques, periodic shore nourishment is nowadays widely regarded as an environmentally acceptable method of beach and dune protection and restoration for short-term urgencies (viz. storm-induced erosion) as well as for long-term issues (viz. structural erosion and relative sea-level rise). The expected lifetime and effectiveness of the initial nourishment and of subsequent maintenance nourishments are of major importance in the decision making process.

More generally there is a growing need for 'ecological engineering' and 'ecotechnology', in order to counteract and compensate for the continuous loss of natural ecosystems to urban and agricultural development, not only inland but particularly close to the coastline. Ecological engineering and ecotechnology are based on the recognition of the 'value of natural systems', a recognition that is a necessary prerequisite for their 'sustainable utilization'. Like other forms of engineering and technology, ecological engineering and ecotechnology use the basic principles of science (in this case mainly the multifaceted sciences of ecology and geomorphology) to improve living conditions for human society. Unlike other forms of engineering and technology, ecological engineering is based on the 'design of human society together with its natural environment', instead of the 'short-term economic exploitation of nature'. Unlike conventional engineering, the application of ecological engineering to the coastal area includes in the development of its toolbox all the morphological features, ecosystems, communities, and organisms that the coastal area has to offer and it makes use of them and of their natural dynamics. The concept will be better introduced and explained later in the paper.

Ecotechnology involves the acceptance of the concept of a self-designing capability of geomorphological and ecological systems. In this context one may not recogniese the power of natural systems shifting and adapting as individual species and as morphological patterns, and ultimately designing themselves to be ideally suited to the environment and to the boundary conditions that are superimposed. There is a self-designing capability which is recognized as a significant feature in ecological engineering, because it allows nature to do some of the 'engineering'. Humans participate as the choice generator and facilitate the matching of the environment and the boundary conditions to the natural system, but nature should do the rest using its own energy and dynamics.

In order to design soft protection interventions, by translating the above-mentioned principle into conceptual terms and while discussing the state of the art on available modelling approaches, we focus on the problem of an evaluation of the 'conditions of change' for the generation of choices. The discussion will proceed towards the definition of the possible 'toolbox' for soft protection interventions in the coastal area.

The coastal area as an integral system

In the coastal area we basically distinguish natural areas, rural areas, and urban areas, respectively characterised by an increasing degree of influence of human forcing factors and a decreasing degree of influence of natural forcing factors. In defining the 'degree of influence' we follow a structural or landscape-based approach (landscape characteristics) and a functional or process-based approach (dynamics characteristics).

In association with characterization, it is necessary to tackle the difficult subject of delineation. Defining the precise limits of a certain area is a rather complex task. We advocate a geographic definition which complicates this task even further. Both traditional and modern geography considers the definition of land areas and their position on the basis of a series of criteria both natural (annotated as physical geography) and artificial (annotated as human geography). The complexity stems from the very nature of geographical areas as countless features can be found on a single piece of land. Following a 'physiographic unit' approach we will however tackle the problem in a pragmatic way by identifying those areas which are subject to similar (natural as well as anthropogenic) forcing factors and boundary conditions from a number of perspectives (see for instance Capobianco & Stive 1996). In doing so, we incorporate the concept that there exists a coupling between the temporal and spatial scales of both the considered forcing conditions and the system's dynamics.

The landscape, especially in the dynamic coastal area, is strongly affected by anthropogenic influences and therefore, reconstructing potential conditions is particularly difficult. These impacts are the result of long and continuous human occupation of the coastal territory, involving deforestation and overgrazing and, more profoundly, dredging, reclamation and alteration of the hydrological cycle. This has given rise to a great wealth of endemic species (van der Maarel & van der Maarel-Versluys 1996) but also to a continuous loss of 'natural ecosystems' (particularly due to urban and agricultural developments).

An important factor here has been played by the dominant culture of the last decades that favours short term exploitation of the natural resources, where, as a resource, we also consider 'coastal space'. For a number of reasons, not lastly historical and legislative reasons, coastal space was for a long time seen as a 'low cost' resource. The adoption of hard engineering practices, involving concrete and steel structures, and causing a complete artificialization of forcing factors and boundary conditions, further aggravated the problem. In many cases it appears that the most valuable and fragile ecosystems are the ones that we have been and still are losing, at a very rapid rate.

These developments have stimulated the adoption of soft intervention techniques. Amongst these techniques, periodic artificial shore nourishment is regarded today as an environmentally acceptable method of beach and dune protection and restoration for short-term urgencies (viz. storm-induced erosion) as well as long-term issues (viz. structural erosion and sea-level rise). The expected lifetime and effectiveness of the initial nourishment and subsequent maintenance nourishments are of major importance in the decision making process to adopt such soft interventions. Answers to these questions are far from being established and existing engineering tools to predict morphodynamic behaviour of such systems are still very simplified and consequently yield unreliable results.

We should emphasize that judging the quality and integrity of existing coastal zones and of possible impacts and influences of new interventions is more and more a prerequisite for the implementation of coastal zone management strategies. In this context, we refer to the concept of resilience of the coastal system, which seems to be a naturally and universally accepted concept. Intuitively, it refers to the capability of the coastal system to withstand external pressure.

Our long-term objective is to contribute to the development of a framework applicable as a tool in Integrated Coastal Zone Management to assess the integrated response of the coastal system to different forcing conditions either due to actual conditions or to management options**.**

The presence of feedback mechanisms

Since the beginning of scientific research in the environmental field, vegetation and, more generally, ecosystems, have been considered as one of the elements of the 'landscape' indicating the 'conditions' in each type of environment. Vegetation is a clear indicator of both climatic and local geomorphological and hydrological conditions. Recently vegetation has also been used as an indicator of the nutrient and pollution load of a certain area.

The ecological system represents the first 'layer of use' of the physical system (the hydrological and the geomorphological system). Human-induced impacts will affect the ecological components of the coastal system. In the present context, we are most interested in those ecological changes which will induce a change in morphology and *vice versa* (see for instance Capobianco et al. 1993). Changes in sediment budgets are a critical issue as they will affect the state of coastal ecosystems, which in turn influences sediment retention and coastal geomorphology. The role of coastal biota in trapping and affecting the cohesiveness of sediments has often been ignored. There is a need to focus on the interaction of major ecosystem types with the sedimentary and geomorphic environment, as well as assessing the implications of ecosystem perturbations on coastal stability.

Conflict resolution, resilience and sustainability

Policy consistency and conflict management

A generic problem in natural resource management is that of conflicting laws and policies – each with their own political champions, institutions and funding arrangements. The coastal zone is no exception. There exists a large body of legislation and policy which attempts to protect the natural environment. Today this is very much within the context of sustainable development, in particular that aspect of sustainable development, a stated goal of the European Community, which is concerned with maintenance of our biosphere. This legislation and policy is generally science-based. There is also a substantial – and generally more powerful – body of law and policy which exists to promote and facilitate economic development. Often these two areas are in conflict and generally economic imperatives dominate. However, the conflicts are also often of a relatively minor nature and may even be unintended. Examples here are the unintended effects of many regulations or pricing policies, which can be corrected.

In practice, it is often very difficult to simply 'correct' deficiencies due to the organisational interests at stake, budgetary arrangements, training and mission of staff, and other interconnections which might be adversely impacted by change. Because societies generally pursue multiple objectives, conflicts between them are inevitable, at least part of the time. Therefore, the most realistic objective is to develop ways of managing the conflict, rather than attempting to eliminate it.

Precautionary principle

The major policy approach to scientific uncertainty is the precautionary principle (O'Riordan 1992; Dovers & Handmer 1995) – if the possible outcomes of a certain human action may lead to serious adverse consequences we implement precautionary policies in the absence of complete scientific knowledge. Since complete knowledge about natural systems appears an impossible goal, precautionary principles are implicit to most environmental decision making. However, more explicit acceptance of the precautionary principle moves us away from defending the status quo and into a more flexible approach – but it does not by itself constitute a development towards treatment of underlying causes. Nevertheless, moving into that direction could imply a value shift rather than a new operational technique. If this happened it might be very costly for some sectors. A second shortcoming inherent in the precautionary principle is that one cannot always foresee and predict environmental damage (Dovers & Handmer 1995). These are two additional reasons why there is interest in building a capacity for resilient management of natural systems.

Resilience and resilient management

Resilience is conventionally defined as the ability of bouncing back, or as elasticity as a response to pressure or disturbance. Such definitions are not helpful without temporal and spatial scales being defined. In human societies resilience management is about defining strategies that preserve and prepare society for a wide range of possible futures. It is precautionary to combine integrated analytical techniques for management with the consideration of resilience. In contrast, vulnerability, instead of looking at the strength of communities or systems facing stress, looks at their weaknesses.

Handmer & Dovers (1996) identified three types of societal resilience:

- *Resistance and maintenance* – where no change is allowed and the status quo is maintained if at all possible (e.g. sea walls at any cost, representing historical practices in The Netherlands and much of Britain);

- *Change at the margins* – where the underlying assumptions are kept but symptoms are treated (e.g. the new policy of localised managed retreat);
- *Openness and adaptability* – where the underlying assumptions change and fundamental problems are treated (e.g. coastal abandonment and migration of the population to a more suitable location).

While traditionally most human responses have been based on resistance and maintenance, there is increasing interest in policies that work with nature (i.e. change at the margins, openness and adaptability).

In terms of resilience management, a useful analogy is provided by research and policy experience in the field of hazard and disaster management. Here the starting assumption is that there is always significant 'residual risk', for which preparations must be made. Even given perfect integrated understanding, aspects of the future would remain uncertain, such as the timing of extreme events, the amount of climate change and many socio-economic factors. When critical system variables are well understood, typically preventive or other hazard alleviation strategies are adopted and the residual risk may be small. However, when the understanding is low, or perhaps more normally, when we are unsure about the extent of our understanding, then most of the hazard will fall within the residual risk category.

The general attributes of coastal management strategies which are resilient would include adaptability, flexibility, and the ability to 'learn' from experience (especially from mistakes from the past). A key aspect of such strategies would be their ability to incorporate new knowledge as it inevitably emerges.

Ecological engineering and ecotechnology

There is a growing need for 'ecological engineering' and 'ecotechnology' to counteract the continuous loss of natural ecosystems due to urban and agricultural development, both inland and close to the coastline. Mitsch & Gosselink (1993) developed this approach in relation to freshwater wetland ecosystems, but we can easily extend this to coastal wetlands by introducing some more dynamic geomorphological processes.

Like other forms of engineering and technology, ecological engineering and ecotechnology use basic principles of science – in this case mainly ecology – to design better living conditions for human society. In addition, ecological engineering aims at designing human society with its natural environment, instead of the short-term economic exploitation of nature. The application of ecological engineering to the coastal area includes all ecosystems, communities and organisms the coastal area has to offer. It is really 'building with nature'.

Ecological engineering and ecotechnology involve a partnership of humans and natural ecosystems. A systems view and the use of models are necessary if we are to 'manipulate' whole ecosystems to provide public service functions. Ecosystems are flexible and adaptive systems, with self-design capabilities that by far exceed the design capabilities of the most innovative and expensive engineering technologies. Particularly when dealing with long-term and large-scale effects we need to know the ecosystems' relationships with both the hydrological and the geomorphological systems and the human system. The capability to serve as a decision support tool for ecotechnology interventions in the coastal area will follow as a natural outcome of the integrative knowledge that must eventually be developed within yet to be conducted holistic, interdisciplinary research programmes. Fig. 1 summarizes the balance between soft and hard intervention technologies in the coastal zone.

The principle of 'self design'

Ecotechnology is based on the self-designing capability of ecosystems. Even polluted ecosystems have a certain regeneration power by substituting and adapting species and reorganizing food chains and energy fluxes. We participate in generating choices and facilitating the matching ecosystems with their environments, but nature 'does the rest'. By translating such a principle into conceptual terms and modelling approaches and while confirming the importance of the evaluation of the dynamics, models should focus on the evaluation of the 'conditions of change'. It is our philosophical hypothesis that the understanding and the prediction of integrative phenomena would benefit much from the understanding and prediction of the conditions that determine such changes.

The principle of 'ecosystem conservation'

In the same way as an engineer depends on tools and raw material to design and build products and processes,

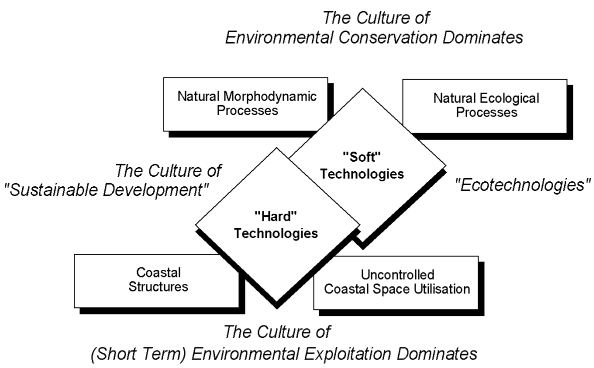

Fig. 1. 'Soft' versus 'hard' technologies.

the ecological engineer depends on species and ecosystems. It would be counterproductive to eliminate, drain, or even disturb natural ecosystems unless absolutely necessary. These are the systems in which biological diversity is preserved which may be required by the ecological engineer one day or another.

This means that the ecotechnology approach will lead to more environmental conservation than has been realised up to now. It has been noted, for example, that as soon as wetlands were recognized for their abiotic importance for flood control and water quality enhancement – this in addition to the long understood (and exploited) values as habitat for fish and wildlife – wetland protection efforts gained a much wider degree of acceptance and even enthusiasm. Recognition of ecosystem values is a fundamental requirement for ecosystem conservation.

Tools for application of soft intervention technology

Physiographic units

An integrated spatial landscape model could be based on a cell division of the study area. Each cell in the grid would contain a copy of individual unit models. Unit model equations will need to be integrated into the spatial grid. Different levels of aggregation of these unit models can be evaluated to determine an optimal compromise between accuracy and manageability. Such cell models will naturally interface with grid-based Geographical Information Systems.

There are, however, situations for which cell models are inappropriate, or inefficient at least, and larger-scale unit based models should be considered. For example, if we are basically interested in integrated systems or activities, such as lagoons, river branches, fisheries or settlements which are localized in space while intermediate, internal features are of no concern, a cell approach would require a considerable amount of data which are in fact not used. This more integral approach may also be promoted by the fact that it is only at a more aggregated level that we can identify areas which are subject to similar (natural as well as anthropogenic) forcing factors and boundary conditions. Because of the link which exists between the temporal and spatial scales of both the considered forcing conditions and the system's dynamics, we logically arrive at more aggregated physiographic units. Alternatively, we can consider geometric data models that include point features, linear features and areal features: each feature being defined by sets of coordinates.

These above-mentioned arguments imply that we should define and use interacting objects that represent real-world physiographic units (see Capobianco & Stive 1996 for an application to deltaic areas). These objects can correspond to physical entities at various levels of aggregation, where each entity is characterized by *state*, *behaviour* and *identity*, and where these properties are manifested through *attributes* (those properties of an object that are accessible to other objects), *operations* (those functions or transformations that may be applied to an object by another object), *associations* (relationships between two objects), *generalizations* (relationships between a class of objects and one or more refined or specialized versions of it). Such physiographic unit-based models naturally interface with vector-based Geographic Information Systems.

The physiographic unit will implicitly define the scales of concern; variables correspond to state and attributes; processes are further distinguished into behaviour (the internal dynamics) and operations, generalizations and associations (the integrative dynamics). Physical/ecological interactions and feedbacks have to be especially emphasized. The objective is to predict major changes in habitat distribution within the area, including losses of habitat to open water and changes in habitat due to community succession. As more details of the system are defined within the model, the model becomes more data-demanding.

The definition of regimes (for water, sediment and salinity) represents a simple way to summarize the conditions to which a site is exposed during a certain period of time (e.g. during a year). As far as modelling is concerned, the definition of classes allows for the formulation of models; the character of the force is strictly related to the formulation of the description of the forcing factors. We distinguish classes such as periodical forcing, random short-term, random short-term periodical, random seasonal, random periodical, periodical, in relation with the river discharge regime, the tidal character, the wave climate and the management practices. Such conditions are of fundamental importance in determining the vegetation characteristics, the morphology and, ultimately, the dynamic character of the physiographic unit (see Capobianco 1996).

It is of particular interest to distinguish between boundaries that are mainly driven by natural forces and those mainly driven by human forces. The first are subject to change because of long-term morphological and ecological processes, while the latter are subject to change because of human actions. The spatial characteristics of the two types of boundaries may be quite different: irregular in case of the natural ones, much more regular in case of the artificial ones.

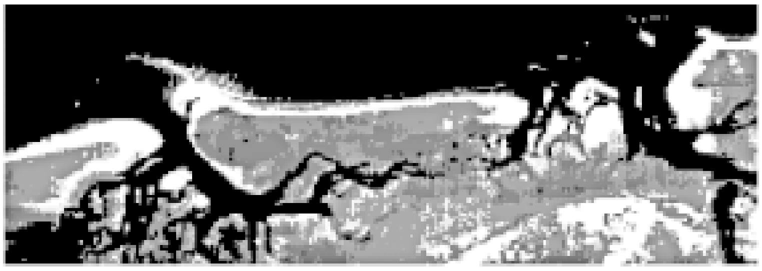

Fig. 2. Elementary coastal stretch. A large number of processes is actually determining its 'morphogenesis' at all scales.

Coastal zone stretch

Here we introduce the concept of generic coastal zone stretch (Fig. 2). This can be subject, on a certain time scale, to a net long-shore influx or outflux of sediment as well as a net influx or outflux of sediment seaward and landward. If we consider the occurrence of natural processes that basically determine such fluxes and the possible occurrence of human interventions to affect them (i.e. to stop the long-shore flux on one side or in one direction; to reduce erosion of the beach; etc.), there could be a large number of situations/combinations and a large number of basic coastal features (i.e. an open beach, a closed beach, a barrier beach if we assume that there is a lagoon on the land ward side, etc.). In fact the possible, 'admissible' combinations (considering all the possible situations that can occur because of natural processes or human factors) are more than 60, while the most significant ones from the practical point of view are ca. 10.

If we now only take into account the existence of sediment transport (wave, current, or wind-induced) and morphological processes, our basic tool is 'sediment', eventually shaped into various morphological features. The simplest interventions we can imagine here are beach nourishment, where we introduce new sediment on the upper beach, or shore-face nourishment, where we introduce new sediment on the upper shore-face. More articulated interventions could be taken into account, for instance a long-shore-periodic beach nourishment, as well as an offshore sand-breakwater. The latter being certainly subject to a quick disappearance but still, potentially, able to trigger significant 'natural redistribution processes'. If we then take into account the presence of other processes, i.e. the ecological processes and, particularly, the presence of vegetation, the possibilities for interventions through natural dynamics, increase substantially. We have the possibility to model the adjacent dune field (if any) or even to create a dune line (if there is enough space available), or maybe to slow down the shore-face dynamics through the introduction of submerged vegetation (if the substratum and the depth allow for it).

Coastal wetlands

Moving further inland, we definitively enter the area where it is more appropriate to talk about coastal wetlands. In the coastal area, at least three types of wetlands are clearly discernible according to their origin or constituent forcing agents. Firstly, those in whose origin only littoral dynamics have played a role. Secondly, those manifesting the combined action of fluvial and littoral dynamics. Thirdly, it will be necessary to take a look at wetlands generated from the deposits of tidal currents. This is only marginally the case in the Mediterranean areas, however on a long term time scale of interest, even small tidal variations, including the occasional occurrence of storm surge induced prisms, can play an important role. In general we distinguish:

- subtidal waters (marine, lagoonal)
- intertidal areas (sand- and mud flats, beach)
- supratidal areas (only inundated at spring tide: salt marshes, flood forests, 'green beach')
- terrestrial areas (dunes, fresh and brackish water marsh, agricultural area, forest)

The functioning of these systems can be summarized in two aspects: hydrological and geomorphological. The hydrological aspect comprises everything connected with water flow while the geomorphological one would involve changes in shape due to erosion and sedimentation processes. Apart from continental sedimentation, wetlands can equally function as areas of sedimentation-marine erosion, provided that they are connected artificially or naturally to the sea. The entering currents supply sediments from the nearby sea floors and/or the threshold to the lagoon basin and the tidal plains (of both the coastline and the spit). For their part, the returning currents involve the remobilization of the sediments making up the lagoon basin and, in some cases, even carry them towards the sea.

Wetlands are complex and sensitive ecosystems, characterized by a water table at, or near, the land surface for some part of the year, by soil conditions that differ from adjacent uplands, and by vegetation adapted to wet conditions. Physiographic units/Wetlands may be classified on the basis of their morphology, hydrology and vegetation. Their areal extent, distribution, and surface as well as the internal structures can be altered by many processes, such as organic and inorganic sediment deposition and erosion, paludification (lateral spread), terrestrialization (colonization of open water by wetland plant communities), and changing hydrology. In the case of coastal wetlands, saltwater intrusion and changes in sea level play a fundamental role.

Wetlands have been shown to be one among the most promising types of ecosystem for application of ecological engineering principles (see Mitsch 1988). This may be due to the usual niche for wetlands on the landscape as ecotones between aquatic and terrestrial systems. Therefore they have always performed an ecological role of protecting and buffering one system from another. They minimise floods and chemical and sediment flushes from uplands before they reach downstream aquatic systems, protect terrestrial systems from storm damages, and are often the leading edge of land accretion even in the face of rising water levels (or decreasing soil levels). These systems thus represent ecosystems whose roles are well suited for amplification through ecological engineering.

Coastal wetlands have significant economic and intrinsic ecological values. Healthy coastal wetlands require the ‘right mix’ of fresh and salt water, sediment, and other physical parameters to provide a stable base for growth of vegetation. They are the most productive ecosystems known, providing nutrients and habitats that support the entire coastal ecosystem. Coastal wetlands also play vital roles as habitats for wildlife, waterfowl, and migratory birds. Wetlands are also able to filter pollutants and to hold and absorb water, which can reduce flood peaks by as much as 80%.

Sediment fluxes and vegetation are linked by complex processes. We can highlight two types of major processes. These are (1) the trapping processes of sediments (organic matter and mineral material) which initiated the deposit patterns and induced impacts on vegetation (succession and structure) and (2), the role of the plant communities on the wetland functioning. Once a vegetation cover has been established, it is shown that both geomorphic and hydrologic parameters change as soon as the allochtonous processes of plant succession develop. Especially in the long term such mechanisms of influence are of paramount importance.

Summary of interventions

Considering at the same time morphology and ecology, the possible soft protection interventions become more articulated. As an example, soft protection interventions have been considered as the approach to achieve renaturalization objectives in the deltaic fringe of the Po Delta in the northern Adriatic Sea (see Capobianco 1996). Such objectives are summarized in Table 1. They represent a possible translation specific for the Po Delta of the idea of allowing for changes at the margins and guarantee open and adaptable solutions, especially for those situations that are seriously compromised by local subsidence and lack of sediment.

Table 1. Objectives for renaturalisation.

1	Diversification of emerged areas level
2	Restoration and maintenance of beach and dune systems
3	Restoration of ‘valli’[1] inland waters
4	Interventions of naturalistic re-qualification
5	Reorganization and coastal vegetation.
6	Improving environmental conditions that are favourable to spontaneous vegetation in the lagoons and valleys inland. Reduce/remove any animal competitors.
7	Wetland restoration
8	Diversion of river branches

[1] ‘valli’ = italian for artificially enclosed wetland.

We can summarize the most significant types of interventions that can be adopted to ‘drive the natural dynamics’ and to ‘trigger changes’ in the three classes listed in Table 2. Few examples are also described as the most significant ones that certainly benefit from the adoption of integrated evaluation models. The external driving forces are susceptible to change by direct and indirect consequences of human activities. Before anthropogenic changes can be addressed, however, the relative importance of various sediment sources, the effects of changes in relative sea level, and the effects of the wave/wind climate on coastal erosion and accretion must be better defined, particularly with respect to the role of episodic events, such as floods and storms, which may have important long-term implications. Moreover, an understanding and description of the role of biological processes in sediment trapping and sediment cohesion is certainly necessary.

The interventions of Table 2 can be episodic in time, repeated, or periodical (consider as an example of artificial beach nourishment or of morphological restoration of salt marshes). The adoption of one solution or another should be justified in relation with the principle of self

Table 2. Classes of soft interventions with examples.

Sediment regulation
- Modification of sediment fluxes (from adjacent rivers as well as the dry beach or dune field and the shoreface)

Geomorphological intervention
- Modification of dune field
- Modification of beach configuration
- Change of marsh configuration
- Progressive adaptation of marsh boundaries
- Maintenance of marsh boundaries

Vegetational intervention
- Introduction of a new plant community

design, the principle of ecosystem conservation and should of course take into account (socio)-economic considerations.

Discussion and Conclusions

In order to contribute to a better definition of soft intervention technologies, it is from the above perspectives that we are developing conceptual models for the quantification of the volumetric budget for the design and analysis of complex coastal zone maintenance strategies based on nourishment techniques. The activities will also focus on the development of behaviour-oriented practical tools for long-term modelling of volume displacements under different scenarios of environmental forces (wave climate, tidal range, wind patterns, etc.) and management options (location, seasonality and repetition of nourishment, etc.).

The morphological part of our soft protection technologies development benefitted from the support of the PACE and the SAFE Research Projects undertaken in the framework of the Marine Science and Technology Program of the Commission of the European Communities. Applying the physiographic unit approach, the integration between coastline modelling, coastal profile modelling and modelling of dune dynamics is considered. The development and validation of beach profile and shoreline evolution numerical models is the core of the application of the new methodology on the seaward side. It shall include improvements of existing medium-term process-based profile evolution models to fill the gap between their present capabilities and the field applications we are focusing on. Such improvements will include the link between the dune and aerial beach with the surf zone, aeolian transport on the beach and the wind effects on return offshore flows, the inclusion and prediction of grain and density sorting. Development of long-term behaviour-oriented practical tools form the basis for the new methodology and will be a large part of this activity including profile and shoreline evolution models.

Careful validation of these models will be an integral part of this development also taking into account that in coastal ecosystems with active benthic systems there are feedbacks from ecology to hydrodynamic and sediment transport processes which make it necessary to directly couple complex ecosystems models to morphodynamic models.

Translation of the modelling efforts findings into performance indicators encapsulating aggregated and integrated behaviour and effects of soft beach and shore protection solutions relevant to management will be aimed at in the context of a more comprehensive development of recommendations so as to enable the application of our efforts by coastal zone managers and policy makers.

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