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Aspects of coastal erosion and protection in Europe

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Abstract The wide variety of physical, political, economic and cultural attributes along European coasts has led to different national management approaches to coastal protection. In all countries, this became problematic when the coast underwent anthropogenic impact and acquired relevant economic value for uses, such as, transport, military, tourism or conservation. However, common ground technology developed according to each country's political traditions, technical restrictions and economic viability. This paper outlines the major management aspects of coastal erosion and defence in Europe and discusses the large spectrum of shore protection strategies used. It depicts the current coastal defence scene for 25 European countries, and points to the major trends and challenges faced by coastal managers, land owners and users of European coasts, as coastal management embraces both engineering as well as socio-economic aspects.

Keywords European · Coast · Erosion · Shore protection · Policies

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Introduction

The European coastal scene varies greatly in both its physical and cultural identities. Geologically it covers the spectrum from old hard Palaeozoic rocks, e.g., Norway, to boulder clay coasts, e.g., eastern England, together with areas where current geomorphological processes are, for example, building new delta and beach areas, e.g., the Ebro delta, Spain. Even more variable is tidal range, from approximately null in several Mediterranean and Black Sea coasts, to the 16.4 m of the Bristol Channel, UK; similarly for the exposition to sea storms, with waves higher than 5 m for more than 10 % of the time, occurring along the western Irish coast, to the lake-like seas washing the Black Sea coast.

It is in this latter environment that historically, a mosaic of civilizations spread from the Euro-Asian steppes and Lebanon, through countries such Italy and Greece to northern Europe. Throughout the region, a diversity of economic activities has taken place, the coastal region bearing the brunt of these, as populations migrated and tended to concentrate around the coast in most countries, particularly since these areas became healthier (malaria eradication) and safer (pirates, plus the decline of Viking and Saracens invaders). Coastal areas have always attracted man for the many economic, social and recreational opportunities and management of some sort, to a greater or lesser degree, has always been carried on throughout time - see later. Currently, >50 % of the world's coastline is being threatened by development, and by 2025 it is estimated that *circa* 75 % of the world's population will live within 60 km of the sea (Small and Nichols 2003). Management essentially embraces two distinctly differing disciplines that are very dissimilar in their practices: engineering and the socio-economic. Most management research/papers deals with the latter but it behoves coastal managers to be aware of what is happening on the engineering end of the

management spectrum, i.e., the discipline's coastal protection side, which is the aim of this paper.

A variety of political regimes have set out the parameters for coastal development, e.g., Russia made large swathes of the immediate coast a 'no go' area, reserving it purely for defence purposes, which brought into question the consequent management protection strategies needed to counteract erosional processes. Standard prevention measures (breakwaters, seawalls, groins) have evolved in different countries, plus a variety of novel ones have been introduced, many related to the politics associated with the area and technical excellence. Today, under the political and economic umbrella role of the European Union (EU) there is an over-riding emphasis on co-operation with a sharing of technical expertise. This is especially relevant in the realm of coastal erosion and protection strategies, where the EU has stimulated and supported many research projects (Fig. 1) whose budgets exceeded many millions of Euros (e.g., Eurosion, BeachMed, OurCoast, CoastGap, Conscience, etc.).

Erosion

It is *accelerated* erosion rates that appear to be the problem and these have mainly been imposed as a result of anthropogenic impact, e.g., sea level rise as a result of global warming, river sediment input decrease for river damming, river bed quarrying, land use changes, harbours and coastal defence structures, etc. These factors work at different scales in each coastal segment (Fig. 1, top). Nicholls et al. (2007) have hypothesized an accelerated sea level rise of up to 0.6 m or more by 2100; whilst Church and White (2006) suggested that a 1990 to 2100 sea level rise could range from 28 to 34 cm. IPCC (2013) forecasts for 2081 to 2100, compared to that of 1986 to 2006, gives a mean sea level higher than given in the period according to other different scenarios, 26 to 98 cm (Stocker et al. 2013). The jury is still out.

It is an axiom that when any structure, e.g., groins, breakwaters, jetties are built into the sea, they affect the physics of water motion and therefore erosion/deposition rates. So by definition, ports/harbours built in any country have a special role in the erosion processes, especially on longshore sediment transport. The end result is that the European coast has been threatened by severe erosion along most of its length, and if this process can be ignored in natural areas (Fig. 1a), it stimulates human ingenuity when developed coasts are threatened (Fig. 1b). Unless there is a paradigm change in life styles, which are hardly likely, hard engineering structures will always have an essential use on the world's coasts, as most world major cities are cited there. For all talk of abandoning the coast, managed retreat, etc., most anti-erosion hard engineered and technology based solutions are perhaps an inevitable management tool.

Shore protection

For most of Mediterranean historical time, the coast was uninhabited due to a persistent risk of raids by enemies, as well as the presence of malaria, so there was no need to protect coastal settlements. Along the North Sea coast, the climate was unfavourable but a similar set up occurred regarding enemy attack, so hamlets/villages were located a kilometre or two away from the coast: in convents of the northern coast of France you could hear a prayer, "*Deliver us, Lord, from the wrath of the Northmen*" (Brøndsted 1965).

Coastal settlements mostly military and coastal roads had to be protected against erosion. In Germany, the first dikes date to 10 BC and, in Italy, rip-rap was built in 238 AD to protect the Via Severiana, a Roman coastal road connecting the harbour of Osta with Terracina but before executing this work, artificial nourishment was undertaken to restore the beach, perhaps a world first!

Due to generalized coastal accretion characterizing historical times, shore protection works have been carried out in limited areas, i.e., subsiding coasts, e.g., Germany, or the barrier islands enclosing Venice lagoon. Usually, protection structures were built when man commenced reclamation and polderization, e.g., Belgium (14th century; Charlier 1955), France (Middle Ages; Anthony and Sabatier 2013), dikes in Denmark (1550; CERC 1996), the Netherlands (land reclamation in the twelfth century; van der Meulen et al. 2013).

Technical solutions were similar all over Europe, both for the limited type of available material (generally wood and stones) and for circulation of ideas in an Europe fragmented through several reigns, but open to artists, scientists and technician movement, i.e., Dutch hydraulics engineers worked in many countries, e.g., Belgium, France and Italy, mostly for coastal marsh reclamation (CERC 1996). North Sea wooden dikes and groins are not structurally different from embankments built on the Venice Lagoon and the first known rock detached breakwater, built at Parenza (now Croatia) by the Romans in 19 AD (Franco 1996), was later replicated all over Mediterranean countries.

Matters altered in the 19th century, when land use changes, hill slope stabilization, river bed quarrying and damning trigged coastal erosion, starting at river mouths and gradually extending to lateral beaches. As a consequence, a variety of protection measures were introduced into various countries (Fig. 2). Pre WWII, coastal protection/defence structures (what most people considered to be the definition of coastal management) were very similar apart from maintenance costs etc. as logically few alternatives existed. Post WWII, technology mushroomed with numerical/physical models, computing power, etc. becoming available to help with an understanding of the processes impinging upon coastlines, a vital step pre any *effective* management consideration. Unless a decision is made that a coastline is '*not useful*' any more, it is inevitable

Fig. 1 Beach erosion in Europe. Source: Eurosion (2004), updated and integrated with information from Pranzini and Williams (2013). **a** Coastal erosion in an undeveloped area in Tuscany (Italy); **b** Erosion in the centre of Alexandroupolis (Greece)

that coasts have to be managed and everything that is done in this step will have a knock on effect on someone, something and somewhere. However, even a'no management' decision, is in fact a management decision!

Groins

The first protection structures described in the literature are dykes, rip-raps and detached breakwaters, but they cannot be classified as devises to counteract beach erosion, being mostly constructed to delimit reclaimed areas or protect mooring points. It is highly probable that the most frequent shore protection projects (well before the 16th century) were groins, e.g., Belgium (Charlier 2013). Diffusion was favoured by ease of construction and availability of material, rocks or/and timber.

However, 'real' beach erosion was a minor problem in those days, and groins are documented in Denmark and Poland only in the 1870's and shortly after in Bulgaria, but only in 1950 at Ystad, Sweden, in the 1960's (the Ukraine), and even later in Spain (1970's; Pranzini and Williams 2013). Groins are sparingly used as a single element, usually occurring as long sequences, especially in the UK, Ireland and many Mediterranean sites. The first Italian sequence was at Viserba (1918), but after WWII, groin fields of >200 elements occurred, e.g., the 20 km in southern Italy at Puglia (Pranzini and Williams 2013). In the late 1980s, between Espino and Cortegaca, Portugal, a density of 2 groins/km occurs (Dias 1990); in Crimea (Ukraine) 700 ferro-concrete groins were built between 1960 and 1980's in order to stabilize 80.6 km of coast (Goryachkin 2013).

From their original linear configuration, groins evolved in T, Y and Γ (gamma) shapes, to prevent oblique wave reflection on their stem; in some cases added segments are submerged and designed to rotate wave fronts along a diverging

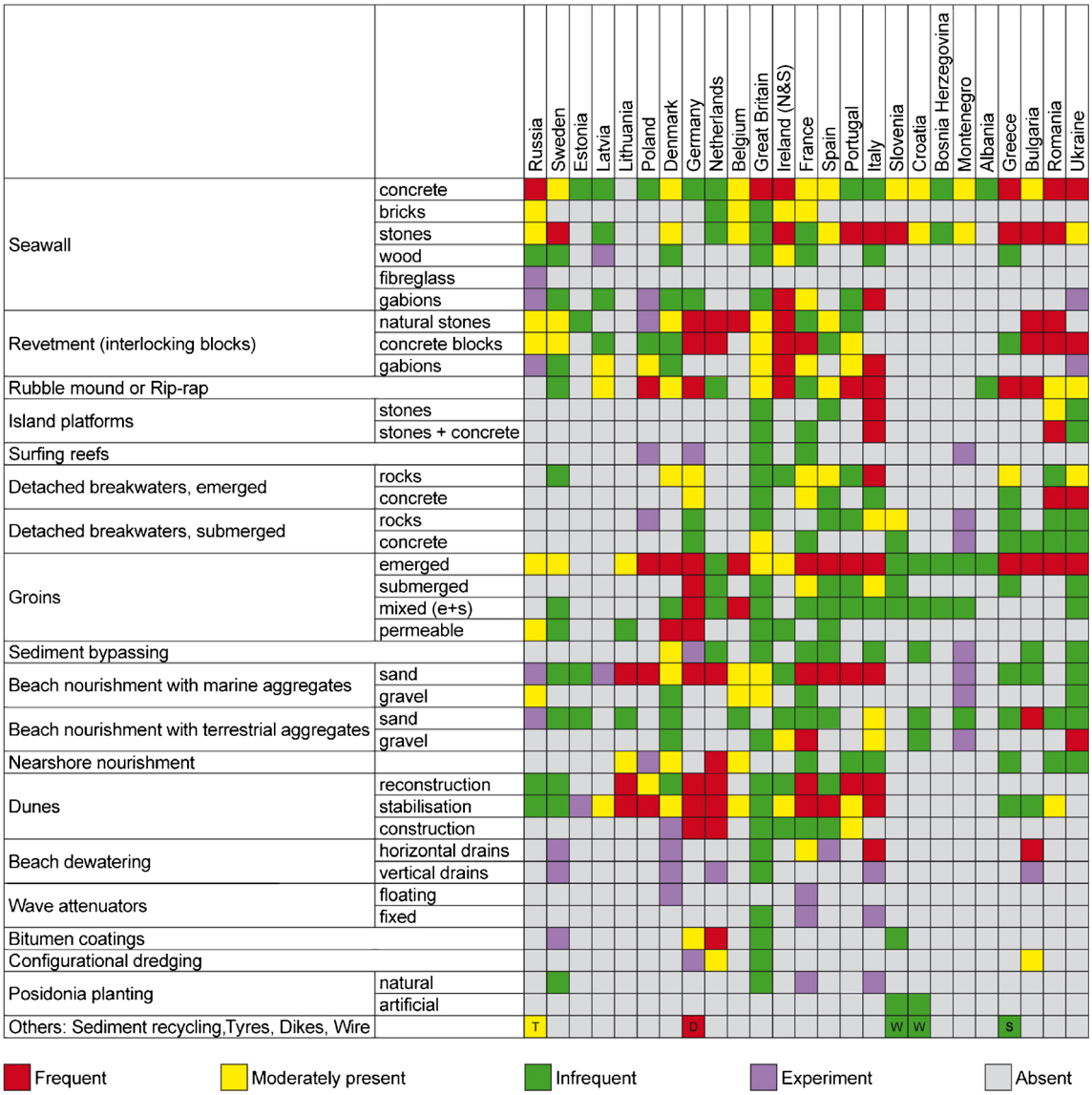

Fig. 2 Current coastal protection structures present along the European coast

pattern, e.g., Ireland, France, Italy and Bulgaria (Fig. 3a-d). Only Estonia and Latvia lack groins, but other countries also have very few, e.g., Lithuania, and eastern Adriatic countries. Due in the main to their need for unending replication, there is a growing movement towards removal (Spain, Greece) or razing below sea level (Italy), although their revaluation is under discussion.

Permeable groins, generally of timber, are specific to the North Sea and Baltic coasts, long sequences being found in Poland (Fig. 3e); limited applications occur in the Mediterranean. In contrast, submerged groins (rocks, concrete, geocontainers) are apparently completely unknown in Northern Europe, but used in Italy and Greece, frequently as short traditional groin extensions (Fig. 3f). Sometimes, the submerged extension has a Y shape (e.g., Terracina, Italy).

Seawalls, revetments, rip-raps

These (Fig. 4), were first used to reclaim areas and protect erosion hotspots at coastal military settlements, e.g., revetments around the Neva bay coast (Pertodvorets, Strelna), Russia, or for the few villages built close to the shoreline. In ancient times they were rare and not built on sand beaches. Timber fences and 'fascinate' were used when rocks were unavailable and maintenance was a hard task; they were eventually substituted with seawalls composed of rock or brick in the 19th century, e.g., Ostend, Belgium (1850). Very frequently, revetments and rip-raps were built illegally by private owners to defend property, e.g., Sweden (Larson and Hanson 2013). During the middle Ages, storm surges were mainly responsible for flooding along the North Sea coast, with fatalities as high as 20,000 in Northern Germany in 1164 (Jensen

Fig. 3 Typologies of groins and breakwaters: **a** Linear groins (Rosslare, Ireland); **b** T-groins (Marina di Pisciotta, Italy); **c** Y- or Fishtail groin (Bulgaria, courtesy of Margarita Stancheva); **d** Gamma groin (Montpellier, France); **e** Permeable groins (Poland); **f** Groin with submerged extension (north of the River Arno mouth, Italy); **g** Detached breakwaters (Gombo, Italy); **h** Island platforms (Liguria, Italy)

and Schwarzer 2013), which trigged construction of an almost continuous sea dike that even entered river mouths.

With the growth of coastal urbanization, resulting from safer conditions (military and health) and communication network expansion (19th century), new settlements had to face a change in the trend of coastal evolution. Toponyms containing "Marina" or "Scalo" denote gemmation from a previous hill settlement into a new coastal one or close to the railway station.

Seawalls were an obvious answer to defend settlements, roads and railways when the beach was not viewed as an economic resource. In Italy the first appeared in the late 1800's, in Ukraine in the early 20th century; in Romania at Eforie in 1920, and now are extensively developed. Seawall and similar structures are the most common defence in many countries (Fig. 2), e.g., along the Hellenic coast of Greece, vertical seawalls (concrete/rock) protect coastal roads, e.g., Nea Makri. In Poland, some 41 km of coastline was

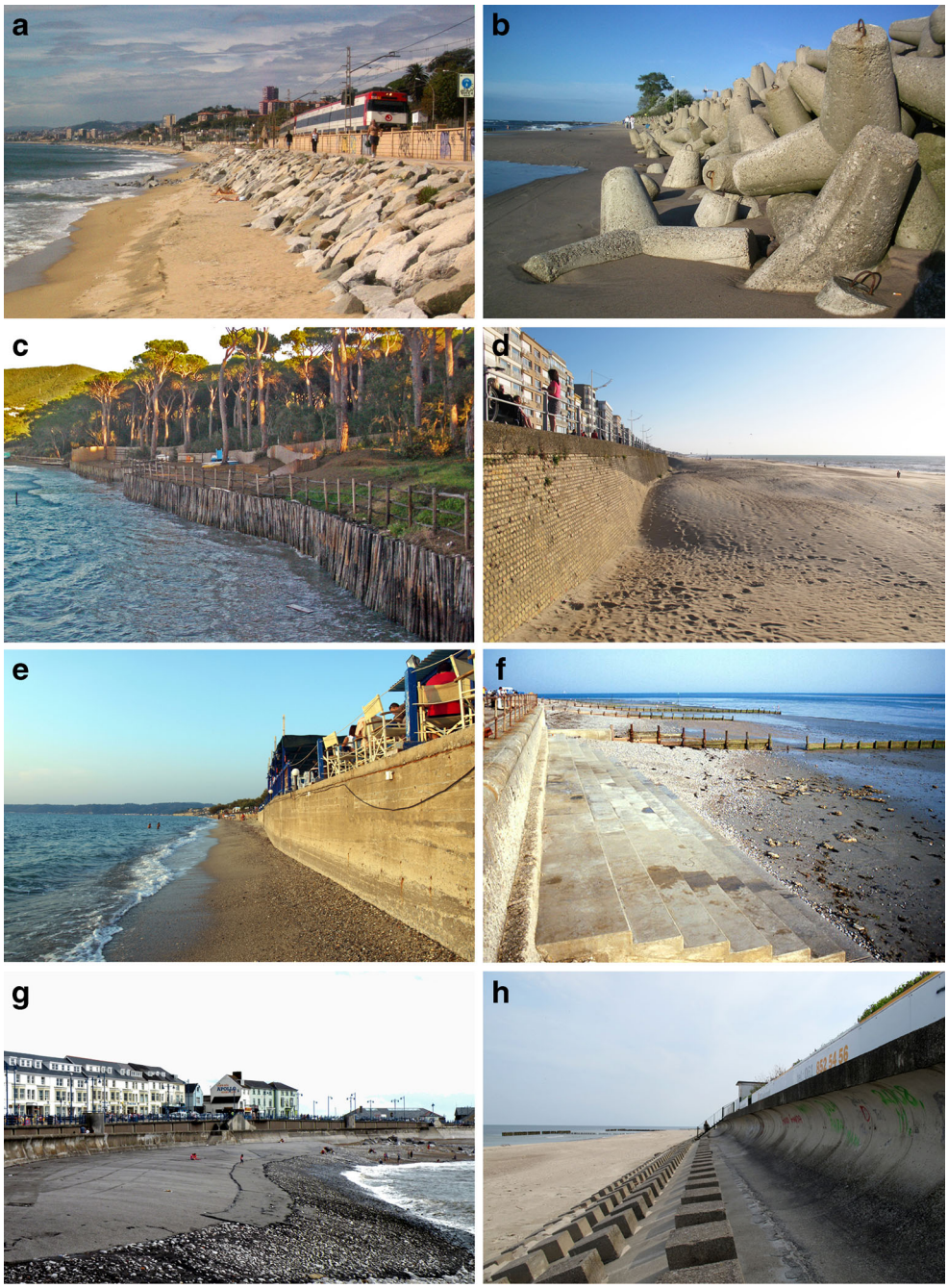

Fig. 4 Structures adherent to the coast. **a** Revetment (El Masnou, Spain); **b** Rip-rap in tetrapods (Poland); **c** Wooden seawall (Punta Ala, Italy); **d** Masonry seawall (Koksijde Bad, Belgium); **e** Linear concrete seawall, Glifoneri, Kasandra Peninsula, Greece); **f** Stepped seawall (Channel coast, UK); **g** Seawalls with tarmacadam pavement (Porthcawl, UK); **h** Concrete concave seawall with lower rough surface (Poland)

strengthened with various kinds of seawalls, including gabions (Przyszłość 2006). In Germany 1200 km of dykes protect an area of >12,000 km^2 from flooding (Garbrecht 1985). The need to reduce seawall height (cost, landscape impact, etc.) but maintaining efficiency, preventing overtopping, reducing backwash velocity to limit toe-scouring, is the rationale for different profiles, and numerical/physical studies still continue even after years of research (Anand et al. 2011).

Currently, concrete and stones are the main materials used in construction. Old-style wood constructions remain mostly found in northern countries. However, brick seawalls, a sign of the great care taken in settlement defences, are still present as architectural masterpieces, e.g., Belgium and Great Britain. Concrete seawalls, with their different profiles (vertical, oblique, stepped, concave, etc.) are replacing older structures and some of these support famous and fashionable coastal promenades, the Promenade d'Anglais, Nice, being a prime example. Seebees revetments (Skegness, UK), high stepped revetments (Cleveleys, UK) or low stepped with curved upper walls (Sea Palling, UK), rock-filled gabions baskets, and sand and shingle-filled geotextile bags (Thorpeness, UK), together with old wooden fences and rock revetments make the UK an

atlas of seawall typologies. Where rocks quarries are far from the coast, or great stability is required, concrete elements can be used for rubble mound structure construction: dolos, tetrapods, seabees, etc., originally designed to be used in harbour breakwaters, but now found along European beaches (Fig. 2). But they greatly reduce beach access and usability.

Expensive concrete structures were built in Ukraine in the Soviet time and maintenance is now an impossible task for the economy: their collapse leaves a coast essentially unfit for tourism and even replacement with softer protection solutions incurs expensive demolition (Goryachkin 2013). The German army built 14,000 bunkers along the Atlantic Wall, from France-Norway, which still has a heavy presence. Casemate remains can be found on dunes and beaches in many coastal sectors and when disconnected from the coast by shoreline retreat, can function as island platforms, sometimes forming small tombolos, e.g., Belgium, Italy and Albania.

Detached breakwaters

If groins and seawalls join most European countries, the same cannot be said for detached breakwaters, found frequently in Italy (Fig. 3g), Romania and the Ukraine, but completely absent in many others, e.g., Russia, Poland, the Baltic republics, and Belgium (Fig. 2) In some cases the high tidal range could be responsible (countries facing the North Sea), but Denmark has >500 and this reason cannot be used to explain Mediterranean Sea differences. Detached breakwaters, more expensive and unstable than seawalls, were built to defend the coast without losing the beach. In Spain only 87 structures exist, almost all in the Mediterranean, 34 in the Catalan coast, Andalucía having 22.

The first known one is the Roman defence in Parenzo providing shelter to boats, but diffusion is more recent, e.g., 1905, Salerno, Italy (Franco 1996). A frequent building technique was sinking boats filled with rocks and even today they are mostly built with rocks, except in Romania and Ukraine, where concrete is adopted; more recently geocontainers filled in situ with sand have been applied (Italy). Downdrift erosion, poor water quality and increased rip currents in gaps have been experienced in most sites and for new projects a submerged segment at approximately -0.5 to1.0 m is built into the gaps. Several deaths by drowning have occurred, due to currents exiting gaps.

Detached breakwaters can provide complete shelter for waves, or be overtopped during storms (low-crested breakwaters), the latter being preferred due to the limited impact on landscape and water quality. Wave energy dissipation requires wide, and therefore expensive, structures. Russia, Sweden, Baltic republics, Netherlands, Belgium, Croatia, Bosnia and Albania have none, whereas in the other countries, emerged ones are more frequent (Fig. 2). In many places emerged structures are razed at mean sea level or at 0.5 m below, but to maintain their efficiency in terms of wave energy dissipation, their width must be greatly increased, which necessitates increased construction cost.

Precast blocks (Tecnoreef©, Reef ball© and unpatented elements) have been used in Europe over the last 40 years to attract fish and are now proposed for artificial reef construction in order to protect the shore. These have the advantage that breaking waves do not trigger piling-up, this process being one of the most negative feed backs of traditional impermeable or semi-permeable structures; however problems of stability exist under extreme waves.

Island platforms, round islands built some tens of metres from the shoreline (Fig. 3b), were first built at Loano, Liguria, in 1967 (Berriolo 1985) and proved to be very efficient, reducing structure foot scour, creating a thin, flat tombolo, which is overflowed by waves and has a limited impact on longshore transport. Unexpectedly, they basically remain confined to the Italian coast.

Beach dewatering

The technique is known in Europe mostly through different commercial names and has been applied in Sweden, Denmark, Great Britain, France, Spain, Italy, and Bulgaria (Fig. 2), but independent comprehensive monitoring has been performed only at Alassio, Italy (Bowman et al. 2007), showing limited results. Ciavola et al. (2008) analysed beach response at several Italian installations and was critical on its efficiency in limiting erosion.

Even less effective is considered to be the Pressure Equalization Module©, i.e., vertical drains, which connected upper sand layers with deeper ones (Jakobsen and Brøgger 2007). Installed in Denmark, Netherlands, Sweden and Italy, the discussion on efficiency is still ongoing and no independent beach response monitoring has been published, but Fredsøe et al. (2009), through modelling flow though a vertical perforated pipe and looking at beach response in Denmark, excluded the effectiveness of this device.

Surfing reefs

'Surfing reefs', effective in creating 'surfable waves', have been proposed. Geotextile structures have been installed in Germany, Great Britain, France and Montenegro. No data exists on the beach response after construction, but one built at Bournemouth, southern Britain has been closed probably due to geocontainer deformation.

Beach nourishment

Nourishment is the most popular shore reconstruction strategy in Europe; absent only in Slovenia, Bosnia Herzegovina and Albania (Fig. 2). However, differences in borrow sediment origin, grain size and volume are huge, going from the few lorries of crushed stone that created Croatian artificial beaches (Pikelj et al. 2013) to 21.5 Mm^3 of marine aggregates deposited on the *Sand engine* nearshore in The Netherlands (Fig. 5; Stive et al. 2013).

Nourishment history is different between northern and southern Europe. Induced sand dredging/passing techniques, developed in the north to counteract erosion, were adopted later in the Mediterranean. This, together with deficiency of accessible sands and coastal rock availability on nearby mountains, favoured hard protection adoption. Nourishment started with inland sources, i.e., river bed gravels from alluvial plains, or crushed stones from mountain quarries. Many famed Liguria beaches were fed since the 1930s with all sorts of material coming from excavated material discharged from the coastal road at headlands. These were moved and sorted by waves to form/expand pocket beaches (Berriolo *pers. com.)*. An operational ban is a main cause of erosion of those beaches. Similarly, in the France Riviera, material excavated during building operations (banned in 1926) was deposited on the beach (Anthony and Sabatier 2013).

Differences amongst European countries derives not only from historical reasons or resource availability, but also from administrative and legislative issues (COST 638 2009), which make marine aggregate extraction and use easy, e.g., the United Kingdom, or extremely difficult, e.g., Italy. Structured beach nourishments - mostly shelf sand, started in the 1950s (Germany and Portugal), 1970's (Denmark and Russia), 1980's (Spain), the late 1990s (Poland). Large beach nourishments in the Mediterranean, sometimes linked to international events have their origins here, e.g., Spain before the Barcelona Olympic Games (1992). The seminal paper of Hanson et al. (2002) estimated that some 28 Mm^3 of sediments/year were used in Europe for nourishment; little has changed, except the fore-mentioned Netherlands big nourishment. The recent global economic crisis has caused reduction in this activity.

Dune stabilisation

Dunes are a natural defence against coastal erosion, preventing inland flooding during extreme storms and for constituting a sand reserve, which provides beach compensation for any occasional sediment deficit; sand that will be given back in 'fat cat' times. Dunes were frequently razed to build coastal settlements, holiday villages, promenades and bathhouses (Fig. 6a); when not developed, they tend to suffer by summer season crowding, with vegetation cover reduction and blow out formation (Salman and Strating 1992). Van der Meulen and Salman (1996,190) have commented that, '*along the Spanish and French Mediterranean coasts and along the Italian mainland coast, 75–80 % of the coastal sand dunes have been destroyed by tourism, urbanisation and industry.*'

Awareness of their importance in shore protection was limited to people living in low-lying land areas protected by a dune system from sea storms; elsewhere they were nothing but an obstacle to reach or to admire the sea. During the last decades things changed, thanks to a growing environmental awareness, EU directives for nature conservation and NGO work in the field and with local communities. Dune preservation and restoration are now part of the strategies in many EU countries for environmental protection and coastal management. The EU contribution was fundamental in good practice implementation through several projects, such as, LIFE, ELOISE, e.g., Williams et al. (2001).

Lithuania, Ireland, Germany, Italy and Spain all utilise dunes for protection, but the prime example remains the Netherlands (Figs. 2 and 6d). This has a sand barrier dune coast backed by low land and has the largest sand reservoir in Europe. Dunes form *circa* 75 % of the defence line for the country, the rest being dykes. In 1990, the Government introduced a policy of 'dynamic preservation, whereby the coast was to be kept in the 1990 position and a soft protection measure (nourishment) was the preferred option to counteract erosion. Laws protect the area between MSL and the 20 m depth contour where mining is prohibited. Access prohibition, vegetation planting (mostly *Ammophila arenaria, L.*), wind fences (Fig. 6b), delimited paths and raised walkways (Fig. 6c) are the ubiquitous elements for coastal dune preservation.

Discussion

Coastal Zone Management (CZM), a recommendation for many European countries, e.g., the Barcelona convention, is to be subsumed into Marine Spatial Planning. A plethora of documents on this topic has come out of Brussels, e.g., EC (2001a, b; 2004), and the EUCC (2004) and the EUCC all pointing to the links between coastal sediment management and wider CZM to better improve synergy of sectoral objectives within plans/programmes. Many countries have laws/programmes of this nature, e.g., Portugal, Montenegro and Spain, and other countries might have shoreline plans that lack co-ordination with other sectors of the coast, e.g., Poland, Albania, Lithuania. Good coastal governance is a pre-requisite for countering erosion and lack of this is evident in the many piece-meal approaches to counter coastal erosion that can be traced to inadequate competencies, e.g., utilisation of a water jetting exercise to dislodge blocks from a coastal cliff (Williams et al. 2002).

In the case of Sweden, a Do It Yourself approach is common due to a lack of public funds. The 'stone chaos'- abandoned pill boxes, military installations etc. that characterises

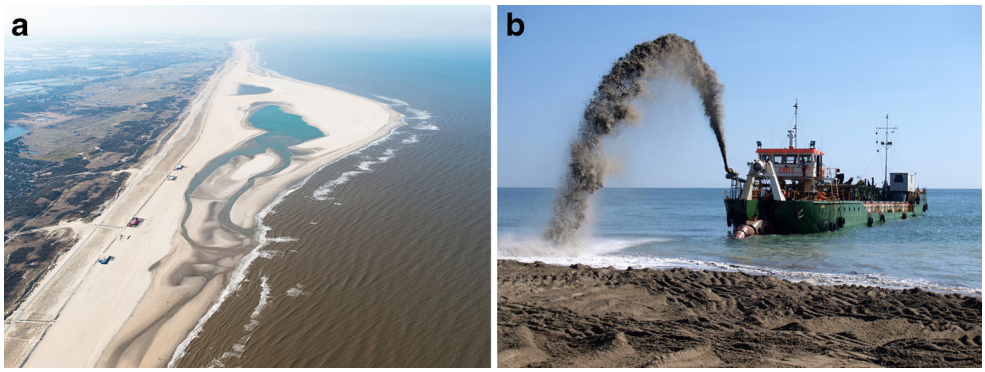

Fig. 5 **a** Beach nourishment, The Netherlands; **b** 'Rainbowing.'

many ex-Soviet empire coastlines exemplifies this. The whole coast, and not simply parts, needs to be managed, i.e., a holistic approach is needed and the driving force is frequently economic, as erosion is seen as a problem associated to money, welfare, properties, and investments. For southern European counties, tourism is the key factor for coastal protection hence soft engineering tends to prevail. Tourism demands wide beaches which have to be maintained/increased to provide a soft surface (if possible) for the increased density of personnel flocking to sun, sea, and surf locations. In northern latitudes, protection is usually geared to erosion/flooding.

Houston (2013) has written exhaustively regarding the economic value of beaches, as they are worth billions of dollars to countries. Houston and Dean (2013, 3) have commented upon the fact that, '*nourished US beaches have won worldwide fame for their beauty, aesthetic, environmental, and storm damage reduction services they provide*', some having remained stable for >60 year. Piqueras (2005) has pointed out that with only 0.001 % of space occupied by Spanish beaches they generate some 10 % of the Spanish GDP.

A summary follows of European erosion, strategies, trends and challenges.

In **Russia**, Black Sea coast recreation started in the XX century, the area hosting important ports, industries and communication structures, but now faces severe storms and sediment shortage. On the Baltic coast the first settlements started in the XII century, where flood protection measures were in place three centuries ago, and structures from the late 1800s. In the first shore protection master plan (the 1960's), coastal defence followed uniform USSR schemes. Hard structures presented technical limitations, often having no concern for future impacts, which has produced undesirable side-effects. Soft protection developed in the 1970's, allowing protection whilst keeping a tourism economic value. Protected artificial beaches seem to be effective for both coastal protection/recreation purposes.

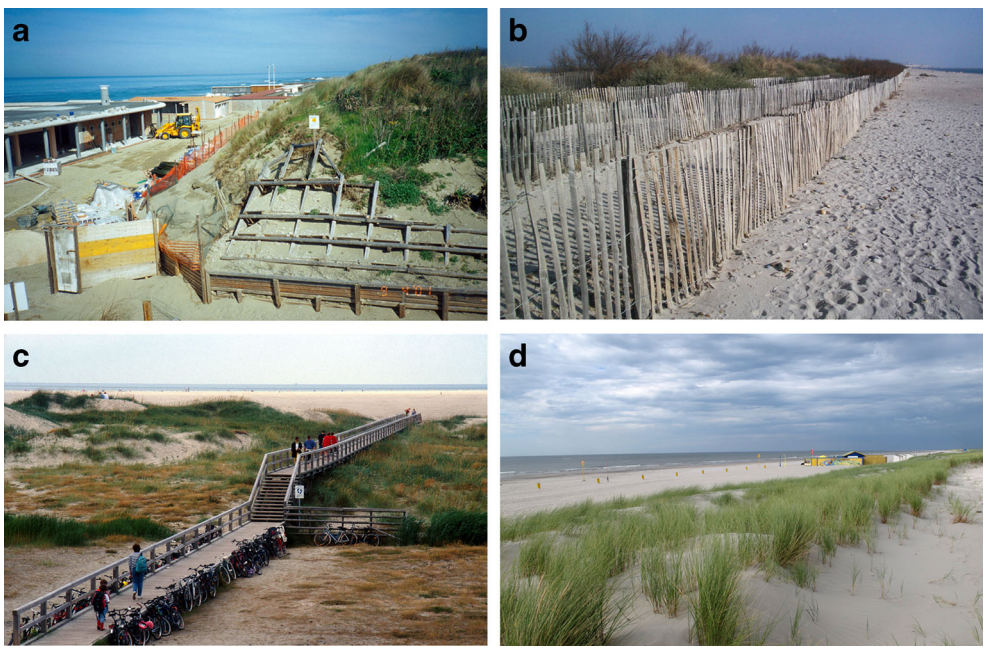

Fig. 6 **a** Trench in the dune system to give access to new bath houses on the Tuscany coast (Italy); **b** Sand fences at Montpellier (France); **c** Dune walkway in Denmark; **d** Dune vegetation planting (The Netherlands)

Coastal recreational usage started in the 1950's in **Sweden** so counter erosion (15 % of the shoreline is erodible) measures are recent. From the 1950's to 1970's, a lack of planned governmental action led to a 'Do It Yourself' approach, where private owners/local authorities led protection works, often without permits and limited technical knowledge. Since the 1980's, permits became a more rigorous process and conservative authorities continued to follow a structure-oriented path. Currently, soft solutions are being considered as alternatives, but major problems are the lack of well-defined roles in coordinating nearshore activities, and the difficulty in dividing costs between government, private owners and local communities, since, usually, government does not fund shore protection projects.

Estonia's first economic activities (fishing, agriculture) required little infra-structure and were placed away from the shore. After WWII, Soviet occupation limited housing; people were deported from islands, some buildings taken by guards, others remained abandoned and collapsed. Post-independence (1991), the coast became a popular leisure destination, with summer houses and residences. Erosion, due to storminess, is a problem. The government is not responsible when erosion affects private buildings, but other threats (erosion near a coastal nuclear waste depository) require especial management efforts.

Latvia's coastline suffered deforestation from the XVI century, causing dune migration until the mid XX century. It was sparsely populated until the XIX century due to low fertility, but industrialisation led to large port constructions. The coast remained "protected" due to Soviet government access restrictions and buildings allowed were basically used for border protection, pre-existing fishing villages disappearing. The trend today is migration towards coastal areas, and the natural landscape is being degraded. Hard defences protect 4 % of the coast. Remaining military fortifications are now partly destroyed but affect coastal morphodynamics. Nourishment is not a trend and used episodically. Dune planting since the 1960's accelerated deposition and enhanced recreation quality.

Lithuania's shores were closed and access restricted to few areas for daytime recreation only from WWII to independence (1990). Today fast economic growth is linked to ports and tourism, but large coastal areas are safeguarded as Protected Areas or *Natura2000* territories. The first defence measures (100 year ago) aimed at mitigating aeolian process impacts rather than halting erosion, hard defence being limited to one small segment. The National coastal policy states that protection procedures be applied only where erosion endangers human activities, Protected Areas or cultural heritage values. Soft protection is preferred, including foredune maintenance, e.g., dune planting. Long-term Integrated Coastal Managment (ICM) programmes prioritise coastal segments according to functions, erosion rates, and usage.

The first shore protection attempts of the **Poland** coastline date back from the XIX century, hard defences being most popular, but many structures were abandoned during and after WWII. Poland has long invested in soft techniques: dune fencing and planting started in the XVIII century and nourishment is dominant today. Coastal tourism is growing especially after the democratisation process of the late 1980's, and many resorts now need erosion protection. A Seashore Protection Act, passed in 2003, described what should be accomplished until 2050.

The entire population of **Denmark** lives within 50 km from the sea. Holiday homes built following the economic growth from early XIX century often disregarded the erosion risk and the coastline today is highly protected by hard defence structures often financed by individual land owners. Today softer alternatives are in place. Coastal management (CM) has existed for decades, with many important approaches transformed into law, i.e., dune protection (1792), public beach access, construction permits and set-back lines (1937). A dike protection law (1874) and coastal defence law (1927) consider individual owners responsible for shore protection, but from 2006 a wider approach to erosion was incorporated into CM. Construction defence work permits depend on the Municipalities and via the Danish Coastal Authority between 12 NM and 100 m from shore. Future strategy scenarios will be guided by national climate adaptation and socio-economic models based on a risk approach.

The **German** coastline is very sensitive to storm effects. The population has long been threatened by storm surges, and damages increased along with progressive urbanisation and industrialisation of coastal areas. Erosion affects both cliffs and low areas and hard defence has been the preferred strategy for over 100 years. Beach nourishment started in 1950 and was also used in combination with hard structures. Currently attempts have been done for foreshore zone nourishment.

In **The Netherlands**, sand is abundant offshore and large dune fields exist. Coastal environments have been reclaimed from the XII century and the barrier coast was cut in the 1860's to provide entrance for ports. Retreat is moderate. *Effective* coastal protection started in the XIX century with hard defence mostly used until the 1990's; nourishment has been systematically applied/monitored for the past 15 years. The current protection trend is a shift towards shoreface nourishment and dynamic coastline preservation. The coastline is to be kept at the 1990 position, but "abandonment" preferred where human safety is not a concern. No sand extraction is allowed from -20 m depth to the dunes. This is a shift from coastline management to coastal zone management, where ecology, morphodynamics and civil engineering combine in an integrated manner.

Belgium has dealt with erosion and flooding from early times, as the coast has retreated some 5 km since medieval times. In the 1800's, erosion started to affect tourism,

nevertheless coastal urbanization continued forming an almost continuous settlement along the 65 km coast. Therefore, many structure types have been built and recently nourishment and dune stabilisation have occurred. The newest strategy is called "*Let nature have its way*" and may be used instead of more expensive nourishment schemes.

In **Scotland**, a country of hard lithology and low human density, only *circa* 12 % of the shoreline is subject to erosion and 6 % is defended, mostly by hard structures, virtually in all settlements. Soft strategies developed in the 1980's, and planting, fencing and geotextile/jute membranes are mostly used; nourishment is rare. Previously, the lack of a clear strategy and piecemeal approach led to inappropriate defences being installed, with associated problems. CZM today is done through voluntary Local Coastal Partnerships (LCPs) and Shoreline Management Plans (SMPs), based on sediment cells. The Marine Scotland Act, approved in 2010, will face the challenge on how to integrate management of marine regions and the coastal zone.

Twenty three percent of the coast of **Wales** is undergoing erosion and 70 % of the coastline has been designated for environmental quality. Hard defences have been widely used. The current policy centres on hard and soft techniques and risk management approaches, as "managed realignment", "hold-the-line", "advance-the-line" and "no active intervention". Sea defence is the responsibility of maritime local authorities and Natural Resource Wales, but a complex ICM approach requires coordination of government, public sector bodies and private stakeholders, encompassing the traditional sectorial view. SMPs have been completed and shoreline management options identified as part of the challenge of working with nature in a holistic approach.

In **England**, the main coastal areas at risk occur at soft cliffs, where erosion is episodic, or in places of unconsolidated material, which undergoes severe retreat during storm events. Structures protect 44 % of the coast against erosion and flooding, especially low-lying, populated areas of the south and east. Soft techniques have been increasingly used in the past 20 years. The Coastal Protection Act defined coastal defence attributions in 1949, and today Shoreline Management Plans and Coastal Strategy Studies establish guidance on shore protection policy. Managers must deal with the prediction of future climate change and unsustainability of hard structure maintenance. In a joint Wales-England effort, a national coastal erosion risk management scheme is expected to complement the national flood risk assessment, providing a complete risk picture.

In **Ireland**, coastal erosion shows mild or cyclic long-term shoreline retreat, but in some localities exceptional accretion builds extensive dunes. A sparsely occupied agricultural coast that once fluctuated freely underwent rapid development in the 1980–1990's economic boom, and many properties were built at risk zones. Hard defence is the dominant approach. Nourishment is uncommon in the Republic of Ireland, where the choice for retreat usually reflects lack of funds instead of a proper policy, whereas the National Trust, the biggest land owner of Northern Ireland, adopted the "non-interference in coastal processes" approach. A National Coastal Erosion Committee in the 1980's made recommendations to managers. A National Coastal Protection Strategy Study (Republic of Ireland) and a review on flood and erosion protection (Northern Ireland) have been delivering management tools since 2002, but erosion management is still fragmented and sectorial.

France's coastline has long been characterised by many uninhabited areas, urbanisation and infrastructure being linked to major ports. In the past 50 year the tourism boom led to development, including leisure marina construction. Flooding protection (hard structures) dates back to the middle Ages. The old coastal protection law was rarely efficient, but evolved in modern times considering environmental needs, *i.e.,* set-back lines definition. Soft techniques started in the 1980's, with dune rehabilitation, beach drainage, preservation of seagrass prairies and nourishment. Creation of the 'Conservatoire du Littoral et des Rivages Lacustres' (1975) allowed Government to acquire and protect coastal areas of natural interest, deciding on land use, conducting coastal restoration and entrusting management to local authorities or conservation groups. A wider approach includes a national observatory and multi-party sea and coastal forums. Controls by DREAL (the Sustainable Development Agency that oversees protection works) are becoming stricter. Some important issues are lack of monitoring after works, management fragmentation and lack of sediment cell approaches.

Since Phoenician times, the maritime tradition in **Spain** led to widespread port and harbour construction. These were enlarged following the discovery of America. Many coastal structures were abandoned after the XVII-XVIII century economic recession, but human pressure increased again from the XIX century, when the coast became a reclaimed, safer and drier area. Development in the 1970's lacked a general management strategy, affecting the environment and enhancing erosion leading to a reactive approach with protection focussed on hard structures and widely-used groins from the 1970s had to be reshaped or replaced by other alternatives. Nourishment has been used since the 1980s, especially to reconstruct urban beaches. Some achievements in coastal management include designation of the coast as public domain by the Spanish Coastal Law (1988), with set-back lines; regional responsibility of most issues on land planning and environmental protection; use of zoning as a conflict solution tool.

Over 50 % of the sand coast of **Portugal** is under significant shoreline retreat. Creation of the Public Maritime Domain in the end of the XIX century restricted urban occupation, but hard structures proliferated in the 1950's to protect property. A strategy shift led to focussing on protection of people/property

and recovery of pristine areas. Soft strategies have been successfully implemented and constitute a clear trend: a first nourishment (Estoril, 1950) being followed by many others, including works for conservation of long dune and Barrier Island stretches. The absence of governmental action towards ICM led to a fragmented approach often dictated by urbanization and tourism pressure, but in 2009 Portugal approved a National Strategy towards ICM, following EU recommendations. Current challenges to managers include the Portuguese legal framework complexities, and disarticulation between government levels.

Italy experienced historic alternate times of economic growth and decay, reflecting on cycles of accretion (agriculture development) and erosion (expansion of forests). Development started in the early 1800s, characterised by competition between tourism and industry. From the mid XIX century, the coast has been facing an erosion phase, due to impacts from changes to land use and rivers (quarrying and damming). The law has been tackling shore protection since 1907. Today *circa* 42 % of beaches are retreating with the highest rates at deltas. Hard defence dates back to Roman times and has been the preferred strategy since, but innovative approaches are being tested and put into practice. Soft strategies, e.g., nourishment, are increasingly used, especially in tourism areas. Responsibility for CM and protection is decentralised, as it shifted from national to regional governments in 1989.

In **Slovenia** fisheries, commerce, tourism, transport and industrial sectors are prominent, whereas infrastructure is still below carrying capacity. Erosion is of low intensity, and most cliff erosion happens in uninhabited areas and natural reserves. Defence is by hard structures, and is considered efficient. Since 2002 the country has been implementing successful regional development initiatives with strong ICZM contents.

The coastal zone of **Croatia** is narrow and bordered by high mountain ranges, which limits sediment load due to poor river networks. Beaches are less urbanised than neighbouring countries, but intense changes have occurred in the past 15 years. Erosion has been counteracted mostly by hard defences, in unplanned, randomly built combinations that had negative side-effects. Nourishment using crushed stone has been used in important tourism zones. Waste disposal from constructions provided a surplus of sediments but had a negative landscape impact. Laws and regulations on ICM are not enough for sustainable management, but ICM initiatives could be supported by an existing set of instruments, e.g., the Spatial Strategy (1997), Programme for Spatial Development (1999), National Environmental Action Plan (2002) and Decree on the Protection of Coastal Area (2004).

In the very short coast of **Bosnia-Herzegovina**, beaches have also been modified due to tourism and hard structures defend the only coastal town. Tourism pressure presents challenges, such as, overuse, and increase in infrastructure and holiday homes.

The **Montenegro** coast is more urbanised, but shares the same physical conditions as Croatia. The coastal zone law dates from 1992 and protection includes both hard and soft defences, many beaches being created and rock shores adapted to provide extra tourism areas. The government formed the 'Public Enterprise for Coastal Zone Management' to manage use, protection and maintenance of the coast and its infrastructure. Nourishment was reduced due to negative impacts on the marine environment. In 2007, a spatial plan for the coast as an 'Area of Special Purpose' made further considerations on shore protection. The country is working on legal and institutional adjustments according to IUOP and the Barcelona Convention.

Circa 36 % of **Albanian** beaches erode at specific sites with hard defence structures commencing in the 1990s, increasing the coastal population. Environmental legislation was poor but is now improving. The coast belongs to the State, and beach management/protection is the responsibility of many national/local authorities. Management and maintenance (cleaning and safety) is left to the private sector which rents beaches, but shore protection remains with the Government. An ICM strategy has existed for years but little is done to prevent erosion. Challenges include the absence of regular monitoring and poor law enforcement.

In **Greece**, 25 % of the Aegean coast is eroding, There are State restrictions to coastal property and use and limits imposed regarding structure construction (need to follow EIA, public property of hard defence structures even when built by private owners), but nevertheless defence actions have often been taken without knowledge of public authorities or lacked monitoring. Hard structures are common, soft strategies being associated with areas of high economic interest, e.g., nourishment for tourism or conservation value. Future challenges are designing and implementing coastal defence proposals and the need for a broader coastal management plan associated to a modern legal framework

The **Bulgarian** coast is particularly sensitive to higher sea levels and some 20 % is vulnerable to inundation at extreme sea level rise scenarios. Coastal defence history is linked to public and private property protection, since the early XX century largely based on traditional hard structures. These were enhanced when large coastal migrations followed the 1990's political changes. Soft alternatives have scarcely been applied; but mostly relate to recreation and must deal with the reduced availability and high costs of fill material. Existing structures, often built without clear standards or guidelines, lack proper maintenance and prove inefficient. In spite of having established a long–term scheme for shoreline management and protection in the 1980's, and recently adopting the Black Sea Coastal Development Act, the country depends largely on a few fragmented shore protection coastal tools, requiring sustainable management plans for a more integrated approach.

In **Romania**, coastal settlements were initiated 26 centuries ago. After cycles of economic growth and decay, the coast started to develop at the end of the XIX century. Soviet occupation restricted/blocked trade with other countries, causing port decline and limiting development, but a population boom took place in the XX century. The coast faces sediment shortages and protection relies on hard structures, with the usual negative outcomes. It hosts the Danube Delta Biosphere Reserve and a southern chain of tourist resorts, towns and harbours. Political regime changes and the end of a centralised economy led to no maintenance investment, causing structure decay. Although the use and administration of beaches may be "rented" to private sector, to avoid fragmented development strategies, beaches remain under centralised management, coordinated by the Ministry for Environment and Forests. A master plan for coastal protection is now under design and softer methods have started to be adopted. The country is in need of modern policies incorporating new concepts and investment in soft techniques.

The **Ukraine** coastline began usage as a resort area in the late 1800's, and development intensified in the 1960s–1980s, along with associated erosion problems. The formation of Ukraine (1991) led to an increase in second home construction and tourism infrastructures, but without proper technical support. Hard and soft protections have been used with different degrees of effectiveness. Large investments were made, but structures and artificial beaches have deteriorated as their maintenance depended on Soviet financing. Legal chaos after independence was followed by a new law that defines coastal protection belts and the beach area, with set-back zones and public access. Coastal defence challenges include managers' lack of knowledge on natural processes and world trends, administrative inactivity and inability. Trends and achievements in this country will also depend on the future status of geopolitical changes.

So how does the above fit into coastal planning? Legislation has been given relating to many of the above mentioned countries and it is obvious that, until recently, coastal protection/defences were constructed ad-hoc over relatively short lengths of coasts, with end points being administrative boundaries - an approach which failed to consider the impact on adjacent coastlines frequently resulting in downdrift erosion and flood problems. To counter this, for example, in the UK, England & Wales Coastal Groups and local authorities introduced in 1994 22 non-statutory, *Shoreline Management Plans (SMPs),* to provide a strategic and sustainable approach to coastal defence, i.e., a management policy to combat coastal flooding and erosion. Time scales envisaged were: short (0–20 years), medium (20–50 years) and long term (50–100 years) planning for flood /coastal risk management. This infers that a stretch of coast under pressure from erosion can be defended on the short term for up to 20 years and then no further protection will be undertaken due to costs, e.g., the lower end of Beach Road, Porthcawl, Wales. Plans were based on the sediment cell (erosion, transportation and deposition) principle, four universal options being considered:

1). Hold the Line: where defences are maintained /upgraded or replaced in situ.
2). Managed Realignment: forward/backward shoreline realignment, usually in low lying areas.
3). No Active Intervention (do nothing): no investment in the provision/ maintenance of any defences. This is the avowed remit for National Trust properties in the UK.
4). Advance the Line: build defences seaward of existing defences thereby reclaiming land.

Postulated future changes of climate will need to be considered in any envisaged new coastal protection scenario, which would involve adaptation in the policies/strategies within ICM/MSP, but whatever choice is made, some of the aforementioned structures will inevitably be utilised in any of the countries mentioned in this paper

An EU Directive (2014), based upon an earlier Directive (MSP 2008), introduced a common framework for European Maritime Spatial Planning (MSP), as a 'cross-cutting policy tool' for public authorities and stakeholders to produce a coordinated, integrated and trans-boundary approach to coastal issues for when and where human activities take place at sea. Specifically, points 13 and 16 refer respectively to erosion and accretion, and erosion and social and economic factors. Into this European framework have been subsumed Integrated Coastal Management and any plans, e.g., the SMPs mentioned previously.

MSP is a public process with a host of legal aspects, which analyzes and allocates the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic and social objectives that usually have been specified through a political process. Its characteristics include ecosystem-based, area-based, integrated, adaptive, strategic and participatory. Each EU country can plan its own maritime activities, so that local, regional and national planning in shared seas would be made more compatible through a set of *minimum common requirements*. European areas covered include: MASPNOSE (North Sea); Plan Bothnia (Baltic Sea); TPES Transboundary Planning in the European Atlantic (Atlantic, Celtic Seas and Bay of Biscay) and ADRIPLAN (Adriatic).

Conclusions

A review of current protection strategies has been undertaken concluding no one solution to coastal problems exists but a range of practical possibilities, which socio-economic planning must realise. Severe weather conditions expected once

in a 100 years may now occur more frequently due to radical weather changes as climate changes. A much broader co-operation that crosses boundaries between developed/developing world's needs to be put into practice and the journey from beach to coast to watershed (where appropriate) is a management philosophy to be considered, as is the choice of implementing protection structures and/or deciding which areas have to be sacrificed. The current European emphasis on Marine Spatial Planning (MSP) will play a large role in this matter. The coast has a glut of functions, which are often in conflict and erosion/protection is but one of these for which planners must consider.

A conflict of interest exists between populations living far from the coast, requiring protection from landslides and river flooding, and those living along low lying, flood prone coasts, for which watershed sediment delivered to the coast by exceptional floods is a lifeblood against erosion. This conflict is hard to be resolved and only within a wider approach, even wider than ICM and MSP, can a possible solution be found, e.g., merging ICM with River Basin Management.

The change from harmless coastal evolution to threatening erosive phenomena has been part of cultural, political and economic processes which produced different reactions to the problem by countries worldwide. Well-developed technical foundations exist as a common ground, but strategies chosen in European countries vary greatly according to each country's characteristics and evolved according to their historic unfoldings.

In spite of such particularities, countries share a common trend towards replacement of hard defence with soft strategies, the need for modern legislation and administrative solutions that enable integration in resource management. Add consideration to coastal conservation with beach defence and recovery of environments to a more natural, pristine state, and then environmental awareness and aesthetics have to play a new part. This new approach is associated to the higher value that users find in healthy beaches, where water quality is good, sand is clean and the environment is in balance. Another important aspect is the degree of State action determining rights and duties in coastal defence: who is responsible for shore protection, who implements it, and who bears the cost? A trend may also be outlined here from public to private when governance is poor, the coast remains abandoned and the DIY approach wins, but this may pose further problems to the efficiency of master planning strategies and integrated management.

If in early years the first technical solutions for coastal defence benefited from circulation of ideas in the continent, EU-funded programmes, projects and research groups have a fundamental role today in the exchange of experiences and scientific development, allowing each country to follow its own path, over a more solid, shared base ground with MSP providing the necessary framework in Europe. Innovative solutions may thus acquire a quicker and wider reach and, once adapted to other countries' realities, contribute for widespread sustainable shore protection strategies and integration at continental level.

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