Topic 2.2.1 Impacts on aquatic ecosystems: According to the Water Framework Directive this is the major policy-related issue of our times in Europe. The topics involved will be subdivided firstly according to surface water types, secondly according to water quantity and quality, and according to main regions and river basins of Europe. **(P5, GeoEcoMar)**

Marine and Coastal Dimension of Climat Change in Europe.

Contents:

Preambule - Marine and Coastal Dimension of Climat Change in Europe.

(From a report to the European Water Directors, 2006)

Within the last two decades, more and more scientific evidence indicates that environmental changes are occurring at all scales, as a result of climate change and climate variability.
This phenomenon has profound impacts on European Seas and Coasts.
The evolution of the physical variables in response to global warming is adjusting to the regional climate and circulation. Water temperature shows different ways of progression and trends in the northern seas than in the Mediterranean Sea and Atlantic waters.
Sea level around Europe increased at a rate varying from 0.8 mm/y to 3.0 mm/y, interfering with local processes such as water temperatures, tides, sea ice extent, evaporation, and various tectonic developments.
In addition to changes in the mean climatic forcing (rising greenhouse gases, warming of surface temperature, rising sea level), episodes of extreme events (downpours, droughts, storm surges, floods) have become more frequent, affecting human life and causing considerable damage to the environment on land and sea.

These transformations are most clearly observable in low-lying coastal systems, deltas, coastal lagoons, estuaries with higher vulnerability to environmental changes, often aggravated by a severe anthropogenic pressure.

Identified trends/impacts due to climate change and variability in specific marine European systems include:

- *changes in the water characteristics and circulation,*
- *ecosystem modifications with distinct shifts northward of warm-water species associated to a decrease in the mean number of cold water species,*
- *phenological perturbations leading to a mismatch between trophic levels and functional groups,*
- *coastal recession and erosion along the western European coast as a result of sea level rise and storm surges,*
- *coastal floods and other environmental hazards/disasters as a result of tidal/storm surges.*

Long-term projections under various scenarios have a tendency to exhibit similar evolution and trends for the future with more extreme seasonal to-decadal climate fluctuations. However, large uncertainties are associated to each level of the process, from assumptions about greenhouse gases GHG emission and global warming to predictions of local impacts and system feedbacks.

A precise knowledge on the magnitude of these changes and the factors controlling their variability is thus prerequisite to reduce biases in climate models and to perform any decision making process related to coastal protection and marine security issues.

The impact of Climate Change pressure to the coastal system is mainly acting through sea level rise and storm surges (also increasing wave height) which can result in shoreline recession, flooding, and salt intrusion inland, with further consequences on infrastructure and human life. The coastal vulnerability to these pressures depends on the natural properties of the environment (physical, chemical, biological), as well as the socio-economic elements that contribute to modify its natural dynamics. Both components are interacting in different ways and strengths, each element relying on their exposure, sensitivity and adaptive capacity to change in response to climate forcing variables. The physical disparity of European Seas and coastal areas and their various degree of population development commonly leads to regional differences in the causes and extent of vulnerability to climate forcing variables.

THE BLACK SEA – EASTERN FRONTIERE OF EUROPEAN COMMUNITY – A PERMANENT ENVIRONMENT CHANGE AND NATURAL HAZARDS

The Black Sea is one of the largest enclosed seas in the world (420000 km^2, the maximum water depth - 2.212 m, the total water volume of 534,000 km^3, drainage basin - 2 million km^2) and 423,000 km^3 volume of anoxic deep water, contaminated with H_2S, below the depth of 150 - 200 m.

From the physiographic point of view the basin of the Black Sea can be divided into four provinces: shelf (about 29.9% of the total area of the sea), basin slope (27.3%), basin apron (30.6%), and abyssal plain (12.2%) (Fig.1).

For the northwestern Black Sea area one of the most prominent physiographic features is the very large shallow continental shelf (about 25% of the total area of the sea; less than 200 m water deep). Since about 120 million years ago, the area has been a sea basin, with extremely dynamic development and huge sediment accumulation (up to 13 km thickness of bottom sediment in the central part of the basin).

Large-scale sea level changes and consequently drastic reshaping of land morphology, large accumulation of sediments in the deep part of the sea and modifications of environmental settings occurred all along the Black Sea geologic history. The Quaternary was especially characterized by very spectacular changes, which were driven by the global glaciations and deglaciations.

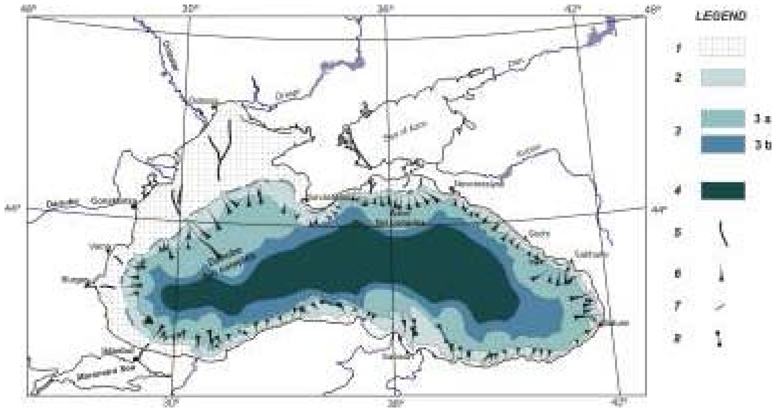

Fig. 1 - Geomorphologic zoning of the Black Sea
Legend; 1, continental shelf; 2, continental slope; 3, basin apron: 3 a - deep sea fan complexes;
3 b - lower apron; 4, deep sea (abyssal) plain; 5, paleo-channels on the continental shelf filled up with Holocene and recent fine grained sediments; 6, main submarine valleys - canyons; 7, paleo-cliffs near the shelf break; 8, fracture zones expressed in the bottom morphology.

During these changes the Black Sea level behavior was influenced by the restricted connection with the Mediterranean Sea by the Bosphorous – Dardanelles straits. When the general sea level lowered bellow the Bosphorous sill, the further variations of the Black Sea level followed specific regional conditions. One of the main consequences of the lowstands was the interruption of the Mediterranean water influx into the Black Sea, which became an almost freshwater giant lake.

The Neoeuxinian basin, during the glacial maximum (~19 ÷ ~16 Ky BP) was completely isolated from the Mediterranean Sea, and, correspondingly, the water became brackish and even fresh (3÷7‰ and even less), well oxygenated, without H_2S contamination. The fauna was brackish to fresh water type with Caspian influence. At about 16 ÷ 15 Ky BP the postglacial warming and the ice caps melting started. As the supply of the melting water from the glaciers through the Dniepr and the Dniestr rivers, as well as the Danube river to the Black Sea was very direct and important, the Neoeuxinian sea-level rose very quickly, reaching and overpassing at ~ 12 Ky BP the Bosphorous sill altitude. At the beginning of the Holocene, some 9-7.5 Ky BP, when the Mediterranean and the Black Seas reached the same level (close to the present day one), the two-way water exchange was established, and the process of transformation of the Black Sea into an anoxic brackish sea started. During the last 3 Ky BP, a number of smaller oscillations of the water level were recorded: "*Phanagorian regression*", "*Nymphaean*" transgression, a lowering of 1÷2 m in the X century AD, a slow rising continuing even today (Panin, 2008).

The northwestern Black Sea receives the discharge of the largest rivers in Black Sea drainage area – the Danube River, with a mean water discharge of about 200 km^3/yr, and the Ukrainian rivers Dniepr, Southern Bug and Dniestr contributing with about 65 km^3/yr. Presently the Danube influence is predominant for the sedimentation on the northwestern Black Sea shelf area (30-40 million t/yr, of which 10-12% is sandy material). The other three tributaries of the north-western Black Sea (Dniestr, Dniepr and Southern Bug) are not significant suppliers of sediments presently because they are discharging their sedimentary load into lagoonal systems.

Threatens from the Black Sea side:

- Sea—level rise
- Subsidence
- Land-slides
- Storms
- Sea-coast erosion
- Gas seeps and gas hydrates
- Tsunamis

SEA LEVEL RISE

Nowadays it is well accepted that the global climate is changing rapidly, largely due to carbon dioxide emissions from human activities (IPCC, 2001; 2007).

Accelerated sea-level rise is one effect of climate warming that will have profound impacts on all coastal regions. The impacts of an elevation of sea level are numerous and include elevation of water table in low-lying coastal areas, salinisation of aquifers, increase of the intensity and frequency of storm effects along the coast, beach erosion, flooding, etc. These physical changes are also leading to biologic responses such as changes in the range of species, loss of habitat, such as coastal wetlands (IPCC, 2007).

According to the last IPCC report (2007) nearly all European regions are anticipated to be negatively affected by some future impacts of climate change. This change is expected to present regional differences in Europe's natural resources and assets. For instance in Southern Europe, climate change is projected to worsen conditions (high temperatures and drought) in a region already vulnerable to climate variability, and to reduce water availability, hydropower potential, summer tourism, and in general, crop productivity.

IPCC estimates that the global average sea level will rise between 0.18 to 0.59 meters in the next century (IPCC, 2007). Evidence indicates that rising sea level will first affect regions with large areas of near sea-level land and areas with low tide rage, such as the Mediterranean (Day and Templet, 1989). It is worth to present some examples:

In Italy, for instance Corbau and Simeoni (2008) indicate an increase of the mean sea level between 1.08 and 1.64 mm/yr according to the method used. The result of using tide measurements of the Northern Adriatic, indicates that the mean sea level increased by 20 cm during the last 100 years. This increase induces a retreat of 3-6 meters in 100 years (3-6 cm/yr) for beaches with a gradient of 2°-4°.

The evolution of the littoral of Emilia-Romagna Region, northern Italy, 130 km length, is characterized by the succession and superposition of complex environmental events and human actions especially during the last century. Erosion of the beaches began after 1940 and was particularly intense between 1960 and 1970. Today 39 km of the littoral of the Emilia-Romagna are in accretion, 59 km are stable and 32 are in erosion.

The stability and accretion trends are principally due to the presence of defense and harbor structures. In addition, the extraction of fluvial inerts, particularly intense in the 1960's, reduced the solid transport: in 1979 the extraction of inerts from the Po was twice the material transported to the sea from 1964 to 1973 (IRDOSER, 1983).

The subsidence rate of this territory, about 2-3 mm/yr, which could be enhanced due to subsurface fluid withdrawal, affects the coastal evolution. The subsidence on the low coastal beaches of Emilia- Romagna induces a shoreline retreat as well as an increase of the nearshore gradient, thus determining a reduction of the sandy coastal body (a subsidence rate of 1,5 to 3 mm/yr induced a lost of 0,6 Mm^3/yr of sand) (Corbau and Simeoni, 2008).

In the framework of the Beachmed-E-Medplan Project three methods were applied in order to identify the coastal stretches with the higher trend to the submersion during sea storms events and "Acqua Alta": scoring proposed by Eurosion (2004), the method developed by Gornitz (1994) and the model of collapse according to the STRUREL code (Gollwitzer, 1994).

The first method, based upon a simplified DPSIR model and using geoindicators, intends to determine the priority of shoreline management. The original method, developed at European scale, has been modified to be applied at a regional scale.

The second method first identifies the potential vulnerability of the coastal stretches and then calculates the real vulnerability according to the mitigation effects of the defense structures. The risk is obtained by multiplying the real vulnerability by the codified land soil use.

Finally, the last method is strictly statistical and may be used as a first approach to identify the most vulnerable stretches due to the limited number of variable used. The mechanism of collapse corresponds to the landward ingression of the sea.

These three methods were applied to determine the vulnerability to submersion related to sea storms characterized by a 5 and 10 years return period. The first results indicate that the southern part of the Emilia-Romagna region presents a high probability of collapse. Furthermore the altimetry asset of the territory (Ferrara and Ravenna) will favor submersion events in the short time, affecting also landward territories. Such phenomenon requires the development of accurate scenarios of risk to define priority intervention to protect the coastal zone (Corbau and Simeoni, 2008).

Mean sea level variation at the Romanian Black Sea Coast

At the Romanian Coast the research and measurements on the sea level date back to 1859, when the European Commission of the Danube, sought to improve navigational conditions at the Danube mouth. The first measurements started at the tide-gauge in Sulina. Observation of the sea level was then initiated by setting up a visual tide staff (VTS) with three daily readings. Later, such measurements were also carried out at the tide-gauges in Constanta and Mangalia. From 1933 a float-operated gauge was put in function at Constantza and is still operational in the same place. Other sea level recorders (e.g. mechanical) were put in function afterwards at Mangalia, Sulina and Tomis marina.

Sea level on the Romanian littoral is strongly influenced by rivers draining in this area. The country's mid latitude location also imposes a certain hydrological regime characterized by high river discharge during the spring season, and minimum discharges in warm seasons when evaporation processes become prevalent.

According to the estimation made by Bondar & Filip (1963), based on the data recorded at Sulina and Constanta tide-gauges, the Black Sea mean sea level[1] is relatively rising with +4 mm/yr., this value being in good accordance with the values of +7 mm/yr. and +3 mm/yr. reported respectively for the tide-gauges in Odessa and Sevastopol. All these values also include the shares due to the local subsidence ± soil compaction.

Reprocessing the raw data for longer and longer time intervals, Bondar (1989, 2007) found a value of +0.5÷1 mm/yr. for the mean sea level rise. The author was also able to estimate the subsidence at Sulina and Constanta at respectively -3.2÷-2.3 mm/yr. and -2.3÷-1.7 mm/yr. These average values of the mean sea level rise are in relatively good accordance with those reported for instance by Pascaru (1968, in Panin, 1996), Diaconu et al. (1985, in Panin, 1996) and Cazenave et al. (2002) for the Black Sea and those reported (Pirazzoli, 1996) for the Mediterranean Sea (+1.5 mm/yr.) and for the Planetary Ocean (+0.5÷3 mm/yr.).

For the period between 1933-1998, the linear rising trend had a value of 0.128 cm/year, in good agreement with the estimates (characterized by linear trend values for different Black Sea sites - Table 1) made by other authors for the entire Black Sea basin ((Malciu, 2000).

Table 1: Average values of the Sea-Level Rise in different points around the Black Sea

Black Sea Sites	cm/year	Period
Constanta	0.128	1933 - 1998
Odessa	0.566	1875 - 1974
Nikolaev	0.202	1916 - 1974
Sevastopol	0.084	1875 - 1974
Anapa	0.158	1923 - 1974
Novorossijsk	0.225	1923 - 1974
Gelendjik	-0.290	1977 - 1996
Tuapse	0,192	1917 - 1974
Tuapse	0.183	1977 - 1996
Sukhumi	0.182	1926 - 1974
Poty	0.646	1874 - 1974
Batumi	0.083	1882 - 1974

Risks and Impacts of Climate Change and Sea Level Rise

Impacts on rainfall and water flow and water resources

In accordance with the generally accepted models the most important changes in the climate would be the northward shift of climate zones, the lengthening of summer at the expense of other seasons, the changes of winter cyclonic patterns etc.

The models show that the increase of the mean temperature by 1.5ºC in these conditions will determine a decline with at least 10% of the river flow. This decline combined with a decrease

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[1] Actually the *"land–mean sea level"* relative relationship.

of water energy by the rising of the base level would substantially lower the fresh water input into the sea.
Lesser and more erratic precipitation will reduce the groundwater recharge and will misbalance the fresh versus marine water equilibrium. Despite an increased need for irrigation water, the average storage in the reservoirs will fall as a consequence of decreased river flow and precipitation and increased evapo-transpiration. Reduction of rainfall during the hot summer period might cause deficiency in soil moisture, thus degrading soil structure and fertility and finally affecting the agricultural production.

Impacts of Global Changes and Sea Level Rise on the Danube Delta Territory and on the Coastal Zone.

In response to the forecasted **SLR** (Sea Level Rise) for 2020-2030, with 20-30 cm, the regression of beaches will, obviously, continue all along the north-western and western Black Sea coast. Despite a non-critical value of **SLR**, the impact on the shore zone will be strong enough because of cumulated effect of the **SLR**, wind set-up, the shortage of beach feeding by decreased river-borne sediment input (especially of the River Danube) and, of course the anthropic pressure on the coast area. According to Bruun theory and formulas and using the specific data for Romanian beaches we can find average values for coast recession of 3-5 m/yr.
The change of the base energy level will diminish significantly the water and the sediment discharge of the Danube River. A very rough model of the **SLR** impact on the Danube water and sediment discharges shows (Panin, 1996, 1999):

- a rise of 20 cm of SL will produce a decrease of water discharge by 10% at a free water table slope of 1.143 cm/km and by 26% at a slope of 0.54 cm/km (at the lowest water level), the current velocity will decrease by 12% and respectively 28,6% and, correspondingly its sediment transport capacity will decline;
- a rise by 30 cm of SL will produce a decrease of the water discharge by 16% for a slope of 1.143 cm/km and by 47% for that of 0.54 cm/km. The mean current velocity will decrease by 19% and respectively 50%.

The reduced fresh water input would influence the general salinity of the Black Sea especially when the general SL will rise continuously. This would involve a greater supply of saline Mediterranean water by the bottom Bosporous current and a decrease of the thickness of the less saline superficial layer of the Black Sea.

At the Danube distributaries mouth zone the penetration of the salt wedge deeper upstream into their course will create a significant disturbance in the processes of transfer of bed-load to the mouth bar and further to the littoral zone. The diminished sediment input would induce a greater deficit in the sedimentary budget of the littoral zone.

As regards the deltaic shore, a rise of SL by 20-30 cm corresponds to an equivalent river water rise with of at least 3-4 hydro-degrees. This means that a very extended area of the delta nearby the shore zone would be flooded and also greater flood risks on the entire delta territory will occur (Panin, 1999).

The deltaic coast will be reshaped by marine processes, but in the more vulnerable sections as Gârla Imputita - Câsla Vãdanei, Ciotic-Perisor and Portita-Periboina conditions will be gathered to transform the corresponding intradeltaic depression or lagoon areas into bays. Such risk is greater in the Gârla Imputita - Câsla Vãdanei section which corresponds to the Rosu-Lumina interdistributary depression, in the Ciotic - Perisor section and in the Portita-Periboina zone (corresponding to the lagoon complex Razim-Sinoie), even if here the beach barrier is at present protected by a setback line of embankments limiting losses of beach material by over-washing.

The budget of the affected sandy beach areas by morphological processes along the whole Danube Delta coast between 1962 – 1997 is dominated by erosions – 1,899 hectars (about 52.8 ha per year, corresponding to an average velocity of coastline recession of -4.14 m per year) (Table 2).

Table 2: Budget of the deltaic beach area affected by coastal morphologic processes between 1962 – 1997 on the representative sectors.

Beach Sectors	Nature of processes and the size of affected areas in Hectars	
	Erosion	Accretion
Sulina-Grindul Saraturile	330.7	
Grindul Saraturile-Gura Sf.Gheorghe	47.3	
Gura Sf.Gheorghe-Ciotic	765.8	
Ciotic-Perisor	379.5	
Perisor-Periteasca		34.4
Periteasca-Portita		60.2
Portita-Periboina	86.2	
Periboina-Chituc	313.3	
Chituc-Sud Vadu	40.9	

As regards the northern sector of the Romanian Black Sea Coast, situated between Musura Bay (in front of the Chilia Distributary mouth) and Midia Cape, almost 164 km long, which corresponds to the Danube Delta and Razim - Sinoe complex (a large protected area named Danube Delta Biosphere Reserve), consequences are difficult to be previewed, but some of them should be mentioned:

- Loss of terrestrial habitats having lowest elevation (near sea level), e.g. *Grindul Chituc*, the narrow belt of sand between littoral lakes and the sea;
- Loss of aquatic habitats, freshwater or brackish water lakes, e.g. Sinoe, Razelm, Zmeica, Golovita Lakes;
- Loss of biodiversity, especially the relicts forms harbored in the paramarine lakes (Mollusks from Fam. Adacnidae);
- Loss of some important fisheries in the Danube Delta Biosphere Reserve;
- Loss of touristic beaches. E.g. along the Grindul Chituc littoral belt.

Crustal movements

The subsiding regime of the Romanian littoral zone and of the Northern Dobrogea was firstly documented by the geophysical-geodetical measurements carried out after 1950 (e.g. Ciocârdel & Esca, 1966). An amplitude of the subsidence of -1 mm/yr. was measured at Mangalia and over -2 mm/yr. was estimated for the Danube Delta area, in good correlation with the value of -5 mm/yr. measured near the Dniester Liman. Later geodynamic researches (Cornea et al., 1979; Popescu & Drăgoescu, 1986) found amplitudes of the littoral zone subsidence ranging from -1 mm/yr. to over -2 mm/yr, higher values being estimated within the Danube Delta area. Even higher values of the subsidence (-2 to -4 mm/yr.) have been reported by Polonic et al. (1999) for the littoral sectors. The intense subsidence of the entire delta area, over the last thousands of years, is also confirmed by the elephant and rhinoceros skeletons found (Murgoci, 1912) during the ditching of the Sulina Canal, about six meters below the nowadays Black Sea level and by the lowered position, two meters below the actual groundwater level, of some Hellenistic and Roman graves discovered at Histria.

Geodetic repetitive measurements carried out by Grigore et al. (1996) within the Moesian Platform pointed out a 1.14-1.85 mm/yr. displacement toward NW of the Dobruja compartment relative to the Wallachian one[2]. A general movement toward SSE (speed of 2.5 mm/yr.) of the entire south-eastern Romanian territory, including the Dobruja region, is documented by the recent GPS measurements (Van der Hoeven et al., 2005).

COASTAL EROSION IN THE BLACK SEA.

The northwestern part of the Black Sea coast has been under the direct influence of the Danube River and its terminal part, the Danube Delta. Here the last century has witnessed drastic changes in the natural coastal dynamics trends, due to the local and regional human interventions (Panin, 1996, Stanica & Panin, 2009, etc.).

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[2] The western part of the Moesian Platform.

The modifications in the present-day coastline evolution trends have been syntethically presented for the entire western Black Sea coast (FP6 IASON Project Report – deliverable D4.2. and Panin, 1999Spataru Arcadie 1984SpatarS). Wave climate, present water and sediment dynamics in front of the Danube Delta have been modelled and the longshore current transport capacity rates are presented (FP 6 CONSCIENCE, Dan et al., 2009).

Factors controlling the erosional process

The coastal erosion in the Black Sea represents one of the main environmental concerns of the riparian countries. The erosion is controlled by:

- ***Global and natural factors.*** The Black Sea coastlines erosion is strengthened as everywhere in the World Ocean by the global changes and the general sea level rise. The coast erosion will depend on the synergetic effect of factors controlling the littoral processes (meteorological regime, wave energy regime, water circulation, sediment supply and drift etc.), global changes and the consequent modification of the energetic level of the coastal sea, general sea level rise and regional characteristics as shoreline morphology, elevation and geologic constitution, subsidence or/ and neotectonic regime.
- ***Anthropogenic factors.*** The coast zone erosion and the state of the coastal sea ecosystems are strongly affected by the anthropic activities, the effect of which is added to the impact of natural factors. The anthropogenic changes of large rivers hydrologic characteristics (water and especially sediment supply, regularisation of floods etc.), men-made littoral structures as breakwaters, dykes, groins, harbours etc. which modify the littoral circulation cells, the uncontrolled use of beach sand, dredging of sand too close to the beaches or within the river mouth bars and many other activities are the enhancing the coastal erosion and endangering the coastal ecosystems.

The „***Low, accumulative coasts type***" is the most influenced by the global changes, specifically by the sea level changes and by the changes in the river sediment inputs. The decreasing of sediment supply and changes in littoral sediment drift due to anthropic activities (river damming, hydro-technical regularisation, littoral structures etc.), especially when the sandy beaches are low, added to the rising of the sea level and the increasing of littoral sea energy could determine in certain conditions a very active and almost continuous recession of the beach line (up to 20 m/y, as it happens in some sections within the Danube Delta littoral). This process is causing land losses, environmental changes and economic degradation of the coastal zone. If the region represents the coastal zone of an important delta which plays essential role in the normal structuring and functioning of ecosystems, any changes of delta/sea interaction zone environments could be fatal and irreparable.

The ***„Erosive coasts*** **type** ***within lowstanding plateaux and plains"*** could be also affected by erosional processes but the rates of coastline regression do not reach the same values as within the first category (only 1-2 m/y). In this case the erosion affects mostly the narrow beaches in front of the cliffs. The environmental transformations are not so important and consequently the economic losses are much lower.

The ***„Mountainous coasts type"*** is the least affected and transformed by the erosional processes. Generally, the littoral of this type is constituted of consolidated rocks, resistant to the eroding process. In front of such rocky littoral there are no beaches or they are very narrow and coarse grained (coarse-grained sand and pebbles). If the development of tourism is intended, one has to build up artificial beaches and pertaining protection structures as wavebrakers, groins etc. In this case one could affirm that the only economic concern is the maintenance of these artificial beaches.

Threats to the Coastal Zone generated by Global Changes and Anthropogenic Pressure

Taking into consideration the above mentioned observations, it clearly appears that the most vulnerable sections of the Black Sea Coastal Zone belong to the "*Low, accumulative coasts* *type”*. Among the coast zone sections referred to this type the Danube Delta is the most significant and important.

The Danube Delta is located in the north-western part of the Black Sea, between 44° 25' and 45° 30’ N and between 28° 45' and 29° 46' E. The delta plain covers an area of about 5,800 km^2 of which the lower, marine delta plain represents ca. 1,800 km^2. The Danube Delta shoreline is about 240 km long, of which about 75 km represents the coastline of Kilia Delta and belongs to Ukraine and 165 km is on Romanian territory.

The marine delta plain is a very low area with marshes, lakes and numerous old beach-ridges (very elongated, narrow and extremely low elevation sand bodies), which in certain zones generate, by juxtaposition, accumulative littoral bodies (the main of them are Letea, Caraorman and Saraturile) with limited dune fields and the highest altitudes within the delta territory (+12.4 m in the Letea Formation, and +7 m in the Caraorman Formation). About 20.5% of the Danube delta-plain represents areas with negative relief, i.e. with an average level below the Black Sea - Sulina reference system, about 54.5% of the Danube delta plain consists of areas having altitudes between 0 and 1 m above the sea-level, and 18% with altitudes between 1 and 2 m.

In front of the Danube Delta, the north-western Black Sea continental shelf is very large (over 100 km width). Here, the largest rivers from Central and Eastern Europe discharge their waters – the Danube with a water discharge of about 200 km^3/yr and the Ukrainian rivers (Dnieper, Southern Bug and Dniester) contributing about 66 km^3/yr.

The present-day longshore sediment drift system off the Danube Delta area is directed toward the south. It is induced by the predominant winds, which are from the north and northeast and the most frequent wind waves recorded also from NE corresponding to the prevailing wind direction. The mean maximum heights of wind waves in front of the Danube Delta reach 7.0 m. The energy of storm waves reaches important values (to 12,242 kWh/m, recorded on February 17, 1979), but generally the energy value is about 2 000 kWh/m (Spataru, 1984). The storm surges from N, NE, E and SE direction induce water level rises to 1.2 – 1.5 m. The tide in the Black Sea has an average period of 12h 25’ and amplitudes of only 7 – 11 cm (Bondar *et al.*, 1973). The general relative sea-level rise in the delta-front area (at Sulina gauge) is estimated at 3.7 mm/a, of which subsidence accounts for 1.5 – 1.8 mm/a (Bondar, 1989).

In such natural conditions, for the Danube Delta the main factors of risk are the river flooding and the littoral beach barrier flooding by the sea. The climate changes and the related sea level rise represent also elements of risk.

River Flooding

Flooding events in the Danube Delta occur when the water discharges of the Danube River are over 10,000 m^3.s^{-1}. According to existent records, catastrophic flooding in the Lower Danube section took place in 1845, 1853, 1888, 1895, 1897, 1907, 1914, 1919, 1924, 1932, 1940, 1941, 1944, 1947, 1954, 1955, 1956, 1958, 1962, 1965, 1970, 1970, 1975, 1980, 1981, 1988, 2005. The statistical analysis of the data set for 161 years (1840 – 2000), concerning the mean annual water discharges of the Danube River, shows that, at the delta apex, were recorded over 89 flooding events. According to the existing data-sets, the flooding events with discharges of 10,000 – 11,000 m^3.s^{-1} along the Lower Danube section have a mean repeatability of occurrence of two years.

For an easier assessment of the river water level and its influence on the delta territory a special measure unit, named hydro-degree, has been defined: a hydro-degree represents one tenth of the highest water level at a given point. The table below (Table 3) demonstrates the impact of flooding on the Danube Delta territory by showing the non-flooded areas at different stages of rising of the Danube water level.

Table 3: Non-flooded areas of the Danube Delta at different water levels of the Danube River

Geomorphological categories	**Non flooded area (ha)**			
	Lowest waters ***3 hydro-degrees***	**Low waters** ***4 hydro-degrees***	**Ordinary waters** ***5-6 hydro-degrees***	**Highest waters** ***10 hydro-degrees***
Natural fluvial levees	19,757	15,343	9,850	-
Lacustrine spits	3,005	2,607	2,210	30
Present day barrier beach	2,400	2,390	2,380	1,800
Old littoral accumulative bodies, of which:	26,215	23,811	21,410	10,000
- Letea (altitude max.+12.6 m)	12,710	12,185	11,660	7,915
- Caraorman (altitude max. +6.5 m)	5,540	4,565	3,590	165
- Saraturile	5,465	4,990	4,515	2,000
TOTAL	**72,542**	**62,131**	**51,045**	**13,775**

Littoral Beach Barrier Flooding by the Sea

The present sandy beach barrier along the Danube Delta Front is very low (+0.7 to +1.5 m) (Fig. 1). The lowest sections are: Girla Imputita-Cisla Vadanei (about 15 Km long, corresponding to the inter-beach ridge depression Rosu-Lumina), Ciotic-Perisor (20 Km long, corresponding to the Zatoane Depression) and Portita-Periboina (about 20 km, the present-day beach barrier bordering the lagoon complex Razim-Sinoie). These sections represent the most vulnerable zones of the delta coastline to the flooding by the sea.

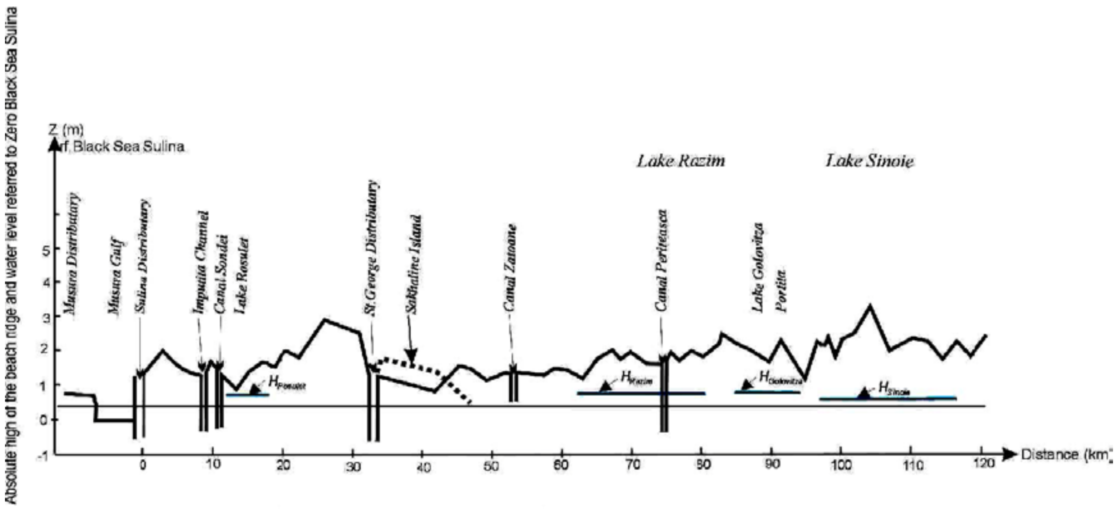

Fig.1: - The profile of the beach ridge along the Danube Delta front between the Ukraine - Romanian border (Musura distributary mouth) and Cape Midia

To the natural high degree of risk the anthropogenic pressure is added. In the last 20-25 years the River Danube sediment supply diminished severely as the Iron Gates I and II dams have been constructed: measurements and computations show that the present day sediment discharge dropped by almost 40% and the real sediment load brought by the Danube into the Black Sea nowadays is not larger than 40 million t/y, of which not more than 10-12% is sandy material taking part at the littoral budget of the delta front zone. The effects of this misbalance added to the impact of other anthropogenic structures and to the rise of the sea level and the increased energy of the coastal sea bring about a very active erosional process of delta-front beaches.

GAS HYDRATES AND GAS SEEPS IN THE BLACK SEA AND OTHER MARINE ENVIRONMENTS – POTENTIAL HAZARD FACTORS

In the last decades gas hydrates (methane hydrates) are seen as an important energetic natural resource, but also as a potential factor for producing geological hazards and influence the global climate. In order to asses the importance of gas hydrate accumulations and the stability of the continental slope in the area of these accumulations many research institutes, including GeoEcoMar, have studied the Black Sea, particularly NW part of its the continental slope **(Bohrmann et. al., 2008; Ion et al., 2002, 2008; Panin, 2008)**.

Methane is a powerful greenhouse gas with a Greenhouse Warming Potential (GWP) 23 times that of CO_2 on a per-molecule basis. Sudden release of methane from gas hydrate therefore has the potential to affect global climate, and current hypotheses attribute past climate variations to methane release from gas hydrates in response to ocean warming and/or sea level change. However, these hypotheses have yet to be confirmed and more research is needed to evaluate hydrate response to environmental change; the fate of steady fluxes of methane from hydrate reservoirs to the seabed, ocean surface and the atmosphere; and the forcing of methane on climate change. The impact of gas hydrate on seafloor stability is important for evaluating the safety of offshore structures as well as for understanding its role in the rapid release of methane, which may affect climate change. Since gas hydrate encases large volumes of methane, when destabilized, these deposits may transform the host sediment into a gassy, water rich fluid. However, any build-up of overpressure from excess gas will depend on the balance between hydrate dissociation and pressure dissipation through possible permeability barriers. Freshening of the pore water may trigger slope instabilities through a possible „quick clay” behavior, which in turns would depend on the clay mineralogy of the sediment. Although massive landslide triggered by gas hydrate destabilization has not been directly observed, various investigators have shown that vast stretches of the oceanic margins where there is evidence for major large-scale slides and slumps coincide with deep water gas hydrate horizons. There are still gaps in our understanding of the mechanisms through which decaying hydrate may affect slope stability, on the triggering mechanisms for gas hydrate decay, and on the environmental response to slope failure, in particular the possible generation of tsunamis.

Geological hazards produced by gas hydrates are related to the instability of the sediment pile due to the decomposition of clathrates or possible violent releases of methane in the water column, and further in the atmosphere. The decomposition of clathrates has to be rapid enough in order to trigger hazard producing phenomena. At geological scale, rapid enough means a certain dynamics of the decomposition processes able to suddenly influence the consolidation process of marine sediments.

During the decomposition the porosity of host sediments decrease and the water content increase. Due to these factors the pore pressure could increase at a level able to trigger a submarine landslide. The slide of sediments on the continental slope, due to other factors than clathrate dissociation, can also trigger gas hydrates decomposition.

Located in the north-western part of the continental slope of the Black Sea the submarine landslides can be triggered by the gas-hydrates dissociation or the collapse of the unconsolidated sediment accumulations. The submarine landslide phenomena could be considered as an auto-feedback response to the gas hydrates dissociation and the collapse of the sediments. As geological hazards produced by gas hydrates, it is worth mentioning the decomposition of clathrates or possible violent releases of methane in the water column, downwards 600 m water depth.

Considering that the shelf area of the Northwestern Black Sea basin is very large and bordered by orogenic areas with high tectonic mobility, the water depth is below 200 m and the sediment accumulation rates are important, it is obvious that this area is typical for formation of tsunami waves.

Recent studies revealed existence of multiple evidences of passage of remarkable waves along the coastal area. Evidences comprise historical documents, instrumental measurements, records on visual observations and geological studies (Panin, 2008).

In front of the Romanian Black Sea littoral the gas hydrate accumulations are placed bellow 600 m water depth, to the NE paleo-Danube canyon. In this area the continental slope presents three major pathways for turbidity currents and a landslide like sea-bottom morphology is present in the SE part of the area (about 140 Km^2). Some preliminary researches (Ion et al., 2008) conclude that the NW continental slope of the Black Sea, in the area of methane hydrate accumulations, is not affected by major submarine landslides.

THE TSUNAMI HAZARD IN THE BLACK SEA

Tsunami hazard is caused by earthquakes, large sub-marine or sub-aerial landslides, volcanic activity or meteorite impact. In the Euro-Mediterranean area, including the Marmara Sea and the Black Sea, there is a potential for the occurrence of large tsunamis, as is testified by historical data and supported by today's knowledge of the seismotectonic setting of the area. The major sources of the Mediterranean tsunamis are submarine and coastal earthquakes, but also landslides and volcanic activity may generate tsunamis (Tinti et al., 2001, 2008), and further there are recognized instances of tsunami-like perturbations caused by travelling air pressure pulses that are known as meteo-tsunamis (Montserrat et al., 2006).
The Black Sea represents a suitable area for the occurrence of natural hazards, including tsunami waves. Surrounded by active fault systems and exposing a high regional seismicity, the Black Sea basin represents a suitable area for the occurrence of natural hazards, as storms, submarine landslides, gas hydrates activity, including the tsunami-type waves. A large shelf area, low water depths, low seashore topography make the sea coast vulnerable to such phenomena. Geophysical studies identified submarine landscapes, active fault and earthquakes hypocenters around the basin, as possible mechanisms for tsunami waves. The geological investigations showed "***tsunamiites***" like sedimentary strata.
Riparian countries, Turkey, Bulgaria and Ukraine, dispose of a large amount of historical evidences. Starting with the Ist century a number of 22 tsunami type events where documented (Yalciner, 2008; Yalciner et al., 2004). Nine major tsunami events occurred in the XXst century.
In Romania, the tsunami phenomenon is poorly documented.
Yalciner et al. (2004, 2005) evaluates the tsunami hazard in the Black Sea basin by comparing historical and measurement data. Based on the analysis of the tsunamis propagation in the northwestern part of the Black Sea, Dotsenko (1998) shows that there is an elevated tsunami hazard in this area. In conformity with the ESPON classification of the tsunami hazard, the Romanian Black Sea coast is assigned to the category of "tsunami hazard areas", as it is dominated by tectonically active zones, submarine landslides and earthquakes.

Threatens from the Black Sea side:

The presence around the Black Sea basin of important seismic activities, the existence of documented gas-hydrates deposits and submarine landslides represent certain tsunami - triggering mechanisms. Holocene geological formations, located along the western Black Sea coast, support the idea that the mentioned coastal area could have been affected by possible tsunami events during the last centuries (Ranguelov, 2003; Oaie et al., 2006, 2007, 2009).

Having in view the potential impact of tsunami events upon the coastal and deltaic ecosystems in the North-Western part of the Black Sea, it is very important to have reliable information on the state-of-the-art of today's research in tsunamis in the Euro-Mediterranean region, and to delineate future perspectives both in terms of knowledge improvement and in terms of the implementation of measures to mitigate the tsunami effects and to protect the coastal communities (Tinti et al., 2008). It is noted that after the big tsunami disaster in the Indian Ocean in 2004, populations and governments in the Euro-Mediterranean area suddenly realized that the region lacked protection from tsunamis since no Tsunami Warning System (TWS) was in place at that time. In the following years the TWS in the Pacific was strengthened, and TWS's were created in the Indian Ocean and in the Caribbean Sea. In the same years, the basis was posed for the creation of a TWS also in the Euro-Mediterranean region, which, according to the TWS implementation plan adopted by the ICG/NEAMTWS (IOC-UNESCO), should be fully operational in 2011(see the ICG/NEAMTWS IV Report, 2008). This goal requires joint efforts from the science community and from all the institutional organizations, such as services and agencies and administrators, which are responsible for emergency management and post-disaster resilience policies and, in the long-term, for setting up integrated strategies of coastal zone management.

The tsunamis in the Black Sea have been observed, described and some of them recorded in more than 25 cases (**Ranguelov, 2008)**. They are not very well known as common phenomena. This does not mean that this threat could be neglected. That is why the investigations, data collection, modeling and risk assessment are important topics about this phenomenon.

During the last 2-3 decades some progress has been achieved. A lot of data have been collected, many new and sophisticated investigations have been performed and some significant results obtained. Several EU projects have been dedicated to the study of the tsunami hazard and risk to the European coasts. GITEC I and II, TRANFER and SCHEMA – the last two projects still in development – focused on all aspects of the tsunami influence on the European coasts, including the Black Sea as well. Several important results have been obtained.

A Black Sea tsunami catalogue has been compiled from all available sources. All events have been assessed in a standard form (GITEC II) including not only the parameters of the main tsunamigenic events, but also reliability of the data collected. A specific point to the Black Sea is that some of the tsunamis have been triggered by the far field earthquakes (for example from Vrancea source and from the North Anatolian fault earthquake in 1939 (M~8.0).

The Black Sea was studied from a point of view of the tsunami energy dissipation/concentration due to the bathymetry and costal geometry. These investigations could explain why all tsunamis observed in the Black Sea had mostly a local influence and most powerful expression to the nearest coast lines.

Some results related to the vulnerability of selected sites have been assessed. This vulnerability refers not only to the man-made structures (port facilities, beaches, tourist infrastructure and cultural heritage, etc.), but also to the natural vulnerable objects – such as steep bays, estuaries, deltas, low lands, lagoons, etc.

Special focus is dedicated to the Bulgarian Black Sea tsunami cases (as the most powerful expression of this phenomenon in comparison to all the other coasts of the sea). The following cases are well documented (Ranguelov, 2003, 2008; Ranguelov et al., 2008):

- 1st (III?) century BC - multihazards event; earthquake, slides and regional inundation reported by ancient chronicle by Strabo; Tsunami intensity IX-X degree of the Papadopoulos - Imamura (P-I) scale. Paleotsunami deposits discovered 20-30 km to the southwest (near Golden Sands Resort)
- 543 AD - multihazards event; earthquake, slides, local inundation reconstructed using the data of the Cybele temple diggings (2007-2008); Tsunami intensity - VII (P-I scale)
- 31st March, 1901 – multihazard event earthquake, slides, rockfalls, subsidence, local inundation observed; Tsunami intensity - V-VI (P-I scale)
- 7th May, 2007 - event by nonseismic origin, only frequent water level oscillations and some damages observed, a lot of visual data collected; Tsunami intensity - V (P-I scale)

Two important events related to tsunami occurred during 2007:

- The tsunami case of 7th May, 2007 and
- The discovery of the Cybele temple in Balchik (in late April), bringing some new and confirming data about the tsunami of 543 AD event.

Special attention is paid to the multihazard threats to the North Bulgarian Black Sea coast.

Earthquakes that can trigger tsunami, landslides, subsidence, soil liquefaction and other secondary effects appear as complex phenomena, which can affect the coastal areas. The simultaneous action of such events (which can occur in case of a strong earthquake) can complicate extremely the emergency actions and population safety.

The recent investigations include some models (elaborated together with the team of the University of Bologna) of the tsunami sources, wave propagation and virtual tide gauge records. They help in the modern approach of solving the problem of the tsunami energy dissipation/concentration in different direction of the sea. Landslide models have been developed to explain the last case of the observed tsunami in the sea – 7th May, 2007. Several other sources have been modeled and wave propagation studied.

The last EU projects (TRANSFER and SCHEMA) are both focused on the data base creation of the main tsunamigenic sources of the sea (of seismic and non seismic origin) as well as the vulnerability elements and population. The preliminary tsunami zonation of the Black Sea is in the near future tasks.

The data collection about the vulnerable elements on the shore line is under execution. The measures of protection of the infrastructure and people lives will be next steps of decreasing the tsunami risk in the region. The establishment of the evacuation roads, the Early Warning System effectiveness assessment, the different physical and virtual (planning, education, etc.) protective measures are in progress.

How to understand, how to manage the effects of potential tsunami in the northwestern part of the Black Sea can be achieved only by specific interpretation and physical descriptions of each event based on deterministic analysis; but, the probability of occurrence of each tsunami scenario can also be used to describe the modeling results in probabilistic terms.

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