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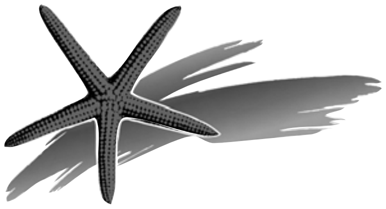

Fluxes of small and medium-size Mediterranean rivers: impact on coastal areas

Trogir, 29 March - 1st April 2006

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A collection founded and edited by Frédéric Briand.
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This synthesis, outlined during the meeting, is based on inputs received thereafter from all the workshop participants, with particular mention to Wolfgang Ludwig, John Milliman, Michel Meybeck, Michael Collins, Serafim Poulos and Oya Algan. The final editing was carried out by Maria Snoussi and Frédéric Briand, with Valérie Gollino overseeing the physical production process.

1. INTRODUCTION

This workshop, the 30th in a long series, took place from 29 March to 1st April 2006 in the historical city of Trogir on the Dalmatian coast. Fourteen scientists from eleven countries attended the meeting at the invitation of CIESM. They were warmly welcomed by Frederic Briand, Director General of the Commission, and by Maria Snoussi, Chair of the Committee on Coastal Systems, who presented the main objectives of the seminar, and expressed their appreciation to Goran Kniewald, Croatian Representative of Croatia on CIESM Board, for his valuable logistic assistance.

1.1. Peculiarity of the Mediterranean and Black Sea rivers

The 30th CIESM Workshop focused upon the rivers of the Mediterranean and Black Seas and their roles in the formation and maintenance of coastal zone areas that are directly and/or indirectly influenced by riverine water/sediment fluxes. Special emphasis was given to medium and small rivers, that is those rivers that drain catchments <5,000 km^2. In the past, many investigations have concerned catchments >10,000 km^2. Because of their relative abundance, their strong relief in their hinterlands (Figure 1), as well as their highly variable runoff (from arid to humid watersheds) and response to episodic events, medium and small rivers play particularly crucial roles in the overall material transport to the Mediterranean Sea.

Fig. 1. Terrestrial drainage basin of the Mediterranean Sea (modified from Poulos and Collins, this volume).

The importance of medium and small rivers in the Mediterranean region can be illustrated by Figure 2a, in which it can be seen that global rivers with drainage basins <50,000 km^2 account for only 30% of the global area, whereas in the Mediterranean (excluding the Nile River, whose discharge has been effectively blocked by the Aswan Dam) they account for 70% of the cumulative drainage area. Reliable budgets for the overall inputs of riverborne materials to the Mediterranean Sea are, hence, more difficult to obtain than for the world oceans. It requires the monitoring of numerous small rivers, in order to obtain representative shares of the overall drainage basin covered by the observations. Moreover, the smaller basins are less represented in compilations of river data (Figure 2b), meaning that extrapolations to regional scales can be biased towards larger basins. This limitation can considerably influence sediment budgets, since small mountainous rivers often have high sediment yields, seasonal freshwater fluxes, and are more responsive to episodic flooding events (Milliman and Syvitski, 1992). Moreover, discharged sediment is more likely to escape the narrow shelves and deposited into the deeper basins (see also Ludwig *et al.*, this volume).

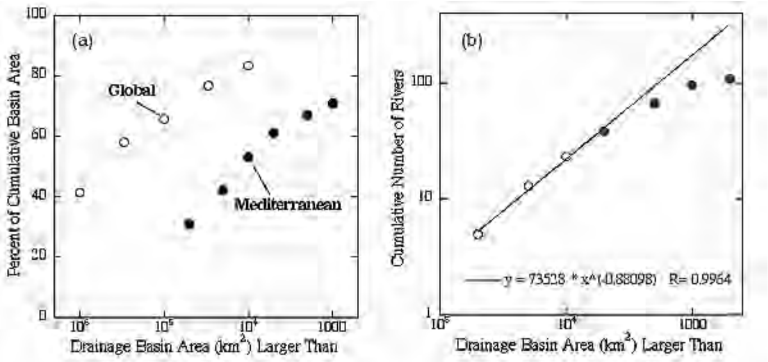

Fig. 2. Percentage of cumulative basin area (a) and cumulative number of rivers (b) towards decreasing minimum basin size for Mediterranean rivers (compilation of 125 rivers based upon data of the Workshop Participants). In b), the black trend line is based upon the cumulative number of rivers with 50, 20, 10 and 5 thousand km^2 basin areas. The trend begins to differ from the data set for rivers <5,000 km^2. Using the equation in the graph one can estimate how many Mediterranean rivers have basin areas greater than any particular number. Basins greater than 1,000 km^2, for example, should be about 167, whereas the data set only includes 99.

1.2. Formation and evolution of the coastal zone, in relation to rivers

River systems play a major role in the formation and evolution of the coastal zone, as they are the principal sources of sediment. Their importance depends primarily upon their sediment fluxes and the oceanographic conditions of their receiving basin. River-influenced sections of coastal zones are related to the seaward progradation of land, which can involve delta formation. However, their effect can be extended many kilometers from their mouth area, thereby influencing much of the continental shelf.

The coastal zone is defined as a strip of land and sea territory of varying width, formed by the interaction of terrestrial, marine and atmospheric processes (Carter, 1988). Furthermore, the role of the coastal zone has been recognized as a buffer in: (a) providing a filter, to remove pollutants and other material transported from the hinterland, before they enter the coastal ocean; and (b) protecting the upland areas from storms and flooding, originating from the sea. Finally, the natural boundary between the terrestrial and marine coastal zones (the coastline) changes constantly, in response to terrestrial and marine processes, incorporating any anthropogenic interference. However, within the context of the present investigation, the broader term coastal system is introduced (IGBP, 1993; Briggs *et al.*, 1997); this is in order to accommodate a much larger geographical area (i.e. river catchment), where terrestrial environments (terrestrial sub-system) influence marine environments (oceanic sub-system), and vice-versa. The terrestrial sub-system acts mainly as the provider, e.g., water and sediment fluxes, whilst the marine sub-system plays primarily the role of the receiver. The terrestrial environment is related to the weather conditions of the region, as they are affected by climatic conditions (precipitation, air temperature); these, in turn, determine vegetation cover and the type of weathering of the hinterland. Furthermore, the oceanic sub-system is involved in the morphometric formation and evolution of the coastline, by: (a) affecting the seaward dispersion and deposition of the riverine suspensates (near shore current and wave activity); (b) participating in the formation and preservation of the estuarine and lagoon environments; and (c) being the controlling influence on the fate of the coastal aquifers (Poulos *et al.*, 2000; Poulos *et al.*, 2002).

2. SPATIAL AND TEMPORAL VARIABILITY OF THE MEDITERRANEAN FLUVIAL AND COASTAL SYSTEMS

2.1. Geography and regional sub-units

The Mediterranean Sea covers about 2.5 million km^2, with an average water depth of about 1.5 km. It is divided commonly into ten sub-basins, which are shown in Figure 3 and listed in Table 1. The length of the Mediterranean coastline totals about 46,000 km, of which 19,000 km represent island coastlines. The entire coastal region covers an area of nearly 1.5 million km^2, that is 17% of the total area of the bordering countries: Spain, France, Monaco, Italy, Slovenia, Croatia, Bosnia and Hercegovina, Montenegro, Albania, Greece, Turkey, Cyprus, Syria, Lebanon, Palestinian Territories, Israel, Egypt, Libya, Malta, Tunisia, Algeria and Morocco.

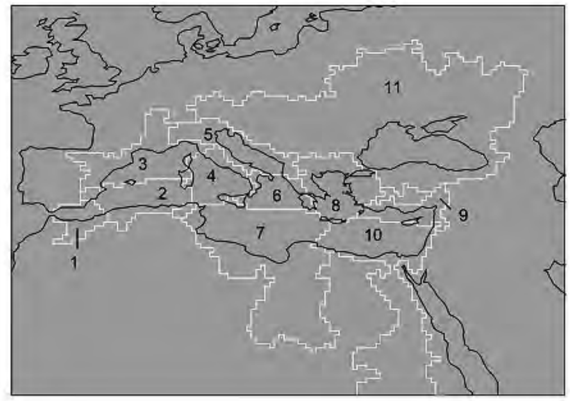

Fig. 3. Drainage basins of the 10 Mediterranean sub-basins, in comparison with the drainage basin of the Black Sea (derived from Doell and Lehner, 2002). For the basin names corresponding to the numbers, see Table 1.

Excluding the Nile River drainage basin, which accounts for nearly 3 million km^2 but is almost completely disconnected from the Mediterranean Sea since the construction of the Aswan High Dam in 1964, the cumulative terrestrial watersheds draining into the Mediterranean Sea represent ~2.5 million km^2. Subtracting also the area of the Central Basin, which is a potential drainage basin and nowadays almost entirely arheic, this value reduces to about 1.4 million km^2. The ratio of the terrestrial over the marine basin area is, hence, about 0.55. This ratio, which provides a rough idea about the potential influence of the terrestrial inputs on the functioning of the coastal and marine systems, is highly variable on the level of the individual sub-basins (Table 1). The greatest value is observed for the Adriatic Sea (1.80), whereas the lowest value is found for the Ionian Sea (0.37).

For the Black Sea, the ratio of the terrestrial over the marine basin area is greater than 5 and therefore very different. Its drainage basin is much larger than that of the Mediterranean (without the Nile), although its sea surface covers only about one-fifth (Table 1). This may explain in part why biological productivity in the Black Sea ecosystems is so much greater than in the Mediterranean.

2.2. Large-scale circulation and basin internal water exchanges

The Mediterranean receives oceanic water from the Atlantic Ocean through the Strait of Gibraltar and into the eastern Mediterranean through the Sicily Straits (Robinson *et al.*, 2001). Because evaporation exceeds precipitation, the Atlantic Water becomes progressively warmer and saltier as it flows eastward into Eastern Levantine Basin, where it becomes Modified Atlantic Water (Malanotte-Rizzoli *et al.*, 1996). Intense evaporation in winter and heat loss under surface winds

Table 1. Terrestrial drainage basin and sea surface areas in the Mediterranean and Black Seas, according to Figure 3 (W. Ludwig, pers. comm.).

basin name	abbrev.	no.	drainage basin area (106 km2)	ocean basin area (106 km2)	land / ocean ratio
Alboran	ALB	1	111	76	1,46
South-Western	SWE	2	129	270	0,48
North-Western	NWE	3	311	252	1,23
Tyrrhenian	TYR	4	112	242	0,46
Adriatic	ADR	5	235	131	1,80
Ionian	ION	6	68	184	0,37
Central	CEN	7	1135	606	1,87
Aegean	AEG	8	286	202	1,42
North-Levantine	NLE	9	131	111	1,18
South-Levantine	SLE	10	3010	436	6,91
Total Western	WMED		662	840	0,79
Total Eastern	EMED		4864	1669	2,91
Total	MED		5526	2508	2,20
Black Sea	BLS	11	2398	460	5,21

change this Modified Atlantic Water into the Levantine Intermediate Water, which is more saline and denser, causing it to sink to depths of 300 to 500 m. This dense water then moves westward from the Northeastern Levantine, crossing the entire Mediterranean, and exiting the Strait Gibraltar as dense bottom water. As the water masses formed in the northwestern Mediterranean (e.g., Gulf of Lions) are confined in the western basin in the layers below 2,000 m, the Eastern Levantine Sea is the "engine" that drives the upper Mediterranean water system (Malanotte-Rizzoli *et al*., 1996). The Aegean Sea provides a warmer, more saline, and denser deep-water mass than the previously existing Eastern Mediterranean Deep (and bottom) Water (EMDW), of Adriatic origin (Robinson *et al*., 2001). Its overall production was estimated for the period 1989-95 at more than 7 Sv, which is 3-fold higher than that in the Adriatic. In the southern Aegean, warmer and more saline Cretan Intermediate Water is formed and exits the Aegean mainly through the western Cretan Arc Straits and spreads in the Levantine Intermediate Water horizons, blocking the westward route of the LIW (Robinson *et al*., 2001).

Two marginal/land-locked seas, the Black and the Marmara Seas, constitute the eastern, extension of the Mediterranean Basin. The Black Sea has an approximate surface area of 435,000 km^2 and a volume of 537 km^3. The Danube River contributes about 200 km^3 of water discharge, which is more than the entire freshwater supply to the North Sea (Mee, 1992; NATO-CCMS, 2000). This large amount of freshwater input (~350 km^3/y) and precipitation (~300 km^3/y vs. evaporation of ~350 km^3/y) maintains a low-salinity surface layer in the Black Sea. This leads to greater outflow through the Istanbul Strait than the mass of saline Mediterranean water entering northward as an undercurrent inflow into the Black Sea (Ünlüata *et al*., 1990). The average fluxes at the Black Sea end of the Istanbul Strait are about 600 km^3/yr (outflowing from the Black Sea) and 300 km^3/yr (inflowing into the Black Sea), respectively. Approximately 650 km^3/yr of Black Sea water enters the Marmara Sea from the Istanbul Strait and 550 km^3/yr of Mediterranean water enters from the Çanakkale Strait. About 25 % of the Mediterranean water influx is entrained into the upper layer at the Istanbul Strait, whilst about 7 % of the Black Sea water is entrained into the lower layer. 45 % of the Mediterranean inflow is entrained into the upper layer in the Çanakkale Strait, and another 45 % of the amount reaching the Marmara is lost to the upper layer, by basin-wide entrainment (Beiktepe *et al*., 1994).

The water budget of the Mediterranean Sea is in deficit and is estimated at about 1.6 Sv (Bethoux and Gentili, 1999). The saline and warm Mediterranean outflow is about 0.7×10^6 m^3 s^{-1} (Bryden and Kinder, 1991). Black Sea outflow constitutes 20 % of the freshwater input into the eastern basin (0.11 m) (Bethoux and Gentili, 1999). A change in the Black Sea outflow thereby could change the water budget of the Aegean Sea, together with dense water formation in that area.

2.3. Climate and water resources

Climatically, the Mediterranean is characterised by generally warm temperatures, winter-dominated rainfall, dry summers, and a profusion of microclimates, reflecting local environmental conditions. Lowest temperatures of <5 °C are found in the higher parts of the Alps, whereas temperatures of >20 °C are typical for Libya or Egypt. Mean annual precipitation also shows a north to south gradient, with decreasing values towards the south. However, orography is a dominant factor. Precipitation exceeding 1,500-2,000 mm/yr is seen in the Alpine and Pyrenean headwater regions of the Po, the Rhone and the Ebro Rivers; it is common also in the mountains bordering the Dalmatian coast, from the Istrian Peninsula down to Albania. As a result, these countries are the most humid regions in the entire Mediterranean area.

The strong summer-winter rainfall contrast is one of the major characteristics of the Mediterranean climate. This contrast becomes increasingly pronounced to the south and to the east. Precipitation falls mainly during winter and autumn, being often less than 10% of the annual precipitation occurring during summer. This pattern contrasts starkly with the continental climate in the drainage basin of the Black Sea, where most of the precipitation occurs during summer (Ludwig *et al*., 2003). During spring, the rainfall contribution to the mean annual precipitation is quite homogenous throughout the entire Mediterranean region. High precipitation during autumn is typical for the coasts of Spain, France, Italy, Slovenia, Croatia, Bosnia and Hercegovina, Montenegro, Albania and Greece. Farther east, such as in Turkey and in Lebanon, autumn precipitation is much less important, with most of the rainfall occurring in the winter.

In certain regions, precipitation - especially in autumn - can occur as heavy downpours, leading to violent flash-floods. The most likely areas for flash-floods are the Côte d'Azur, east Pyrenees, Cevennes and Corsica in France, the north-western areas of Italy, and Catalonia and Valencia in Spain (Estrela *et al*., 2001).

2.4. Hydrological regimes

Due to the strong seasonal contrast of climate as well as their generally small drainage basins, Mediterranean rivers exhibit a rather unique hydrologic character. In the southern part of the Mediterranean, the differences between low and high water discharges can be extreme, with most water discharges often occurring during short floods. In some areas along the Mediterranean coast, the recorded maximum daily rainfall is near the mean annual rainfall (Estrela *et al*., 2001). In contrast, in the larger river basins in the north, wide-ranging and continuous precipitation is commonly the main factor in flood generation, associated often with snowmelt.

As a consequence, the ratio of peak discharge to mean annual discharge in drainage basins of 1,000 to 10,000 km^2, is frequently about one order of magnitude greater than for rivers in non-Mediterranean areas. This relationship represents also a major difficulty in the monitoring of these rivers, as gauging stations must be calibrated for extreme events and the equipment also must resist violent flash-floods. Monitoring of water quality parameters, as far as they can be used in calculating fluxes, is even more difficult; this is so since almost all of the transfer occurs during these floods. As a result, flash-floods often escape regular sampling programs.

Most Mediterranean rivers have their lowest discharge values during summer (July to September), the result of strongly reduced precipitation and elevated temperatures. Maximum discharge normally occurs between February and May. The February maximum is typical for the rivers that are precipitation-dominated (such as the Tiber and Arno Rivers), since precipitation is strongest in winter (see above). When the headwaters are in higher elevations, which often is the case, snowmelt discharge becomes dominant. This delays the maximum discharge to April or May (e.g., the Drini or Ceyhan Rivers). It also should be pointed out that the accentuation of the seasonal contrast towards the south and the east has, naturally, also a strong impact on the rivers in these areas. Almost all of the discharge occurs during the first half of the year, whereas the second half is very dry (e.g., Moulouya and Ceyhan Rivers).

2.5. Water and sediment discharges

Water discharge plays a key role in the transport of riverine matter to the sea. Summing up the overall freshwater inputs that are brought to the Mediterranean and Black Seas by rivers, yields a value of about 1,000 km^3/yr (see Poulos and Collins, this volume); 40% is discharged by the Black Sea rivers. However, these values rather reflect potential values, since they do not take into account the steady decline in water discharge due to climate change and anthropogenic water use (Figure 4a). Present-day freshwater discharge to the Mediterranean Sea may be only half that what it was 100 years ago (Ludwig *et al*., 2003). The decrease was accentuated especially after the 1970s, with strongest reductions in the Alboran and Aegean Seas (Figure 4b).

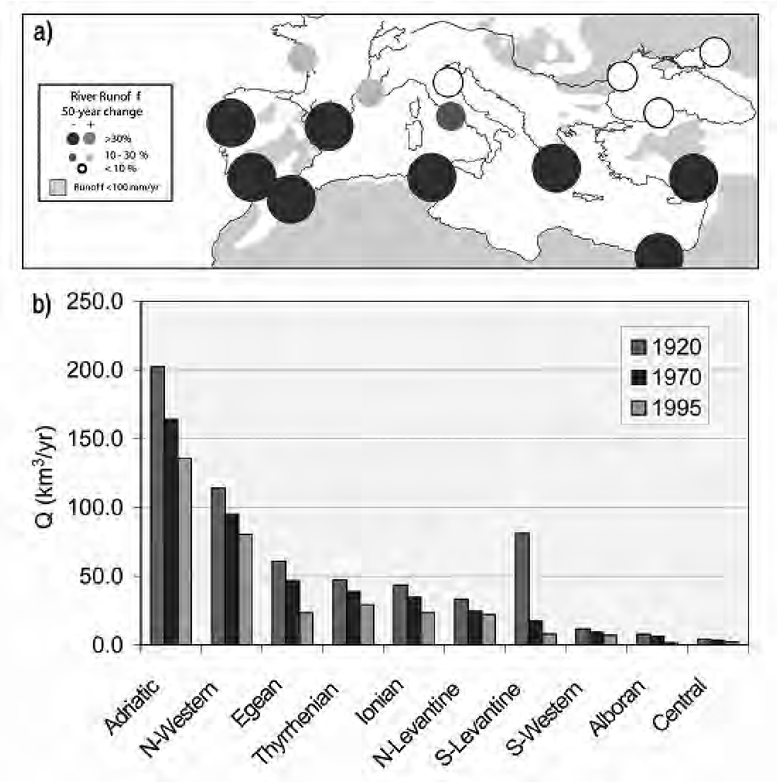

Fig. 4. Evolution of freshwater inputs to the Mediterranean Sea, during the 20th century. a) reduction of water discharge in some Mediterranean rivers – see Milliman, this volume; b) estimated freshwater inputs according to Ludwig *et al.* (2003).

Sediment fluxes are the second key parameter controlling the riverine transfer of terrestrial matter to the sea. Because of the strong seasonality in climate, the presence of elevated mountain ranges, the relative small basin sizes, the wide dominance of younger, softer rocks, and a long history of human activity, Mediterranean rivers tend to have high natural sediment yields, compared to global averages. Collins and Poulos (this volume) estimate that the natural sediment discharges by rivers may be in the range of 1,000 Mt/yr for the Mediterranean Sea, and about 300 Mt/yr for the Black Sea. Because of the massive construction of reservoirs, however, not all of these sediments reach the sea and at least ~45% (Mediterranean) and 30% (Black Sea) of these sediments might be retained behind dams or extracted from the river beds, for sand and gravel.

In Table 2, small (<500 km^2) and medium (500-5,000 km^2) catchments are shown to represent >40% of Mediterranean's drainage basin, when the catchment of the Nile is excluded. Even before damming, however, the Nile provided only 16% of the annual water budget and only 10% of the sediment load, due to its very low precipitation and low sediment yield (42 tons/ km^2). In contrast, the small and medium-sized catchments provide annually >40% of the freshwater inputs and >50% of the total sediment load; the latter is due to the high sediment yields (1,500-2,200 tons/ km^2, on average).

Table 2. Different sized drainage basins of the Mediterranean river systems.

	Catchment (10^3 km^2)		Water discharge [(a)] km^3/ year	Sediment yield [(b)] tons/km^2
Size	Including Nile	Excluding Nile		
<0.5	460 (36.8%)	460 (11.2%)	250.5 (43.9%) [(c)]	1554 (8)
0.5-5	70 (5.6%)	70 (1.7%)		2200 (18)
5-50	380 (30.4%)	380 (9.2%)	101.2 (17.8%)	570 (22)
50–500	340 (27.2%)	340 (8.3)	128.3 (22.5%)	251 (4)
Sub-total:	1,250 (100%)	1,250 (30.3%)	480.0 (84.2%)	
>500 (Nile)		2,870 (69.7%)	90.0 (15.8)	42 (1)
TOTAL:		4,120 (100%)	570.0 (100%)	

Keys: (a) Poulos and Collins (this issue); (b) for the rivers >500 km^2 data are abstracted from Ludwig *et al.* (2003) and for those with catchment <500 km^2, from Poulos and Collins (2002b). In parentheses, the number of rivers used for the calculations is given. The value given in (c) corresponds to rivers with catchments <5,000 km^2 (small and medium).

3. HUMAN IMPACTS ON THE CATCHMENT-COAST *CONTINUUM*

Coasts and river basins, small or large, incorporate important natural environments; they are used also intensively by mankind. Indeed, Mediterranean civilisation has always flourished beside the sea and in nearby river basins. The increasingly intensive human presence over almost 10,000 years has changed radically the landscapes around the Mediterranean. Although these changes vary between the countries, because of differences in geography and in socio-economic conditions, they have altered the flux of materials to the coast, with impacts on coastal morphology (sediments) or the ecosystems (nutrients and contaminants) (Poulos and Collins, 2002b; Ludwig *et al*., 2003; Meybeck *et al*.; Milliman; Simeoni *et al*., this volume).

This alteration is more visible in small and medium-size catchments, than in the large catchments, where the “buffer capacity“ against land-based change is higher.

3.1. From natural to impacted river-basins

Figure 5 represents, schematically, (i) a catchment-coast system under natural conditions, a system impacted by (ii) climate change and sea-level rise and (iii) by human activities.

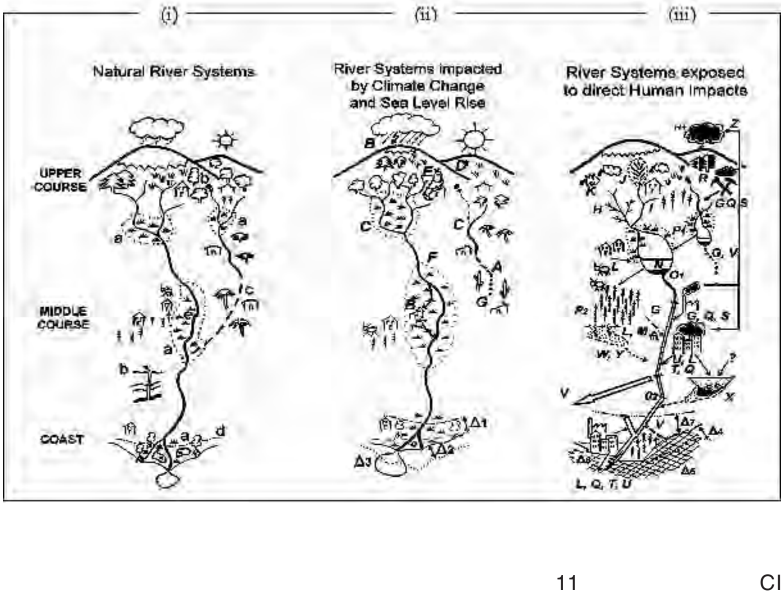

Fig. 5. Schematic analysis of the evolution of river systems under Climate Change and Sea Level Rise and under direct Human Impacts (Meybeck, 2006a) (for explanation, see text).

Under natural conditions, headwaters generally provide most of the riverborne material, particularly the suspended particles; this is eventually processed and/or deposited in wetlands (a), floodplains (e) and deltas. If part of the Mediterranean drainage basin is under a dry climate (c), this leads to seasonal drought. In the estuarine zone, water quality issues are linked mostly to the natural salt-wedge intrusion (d).

Under changing climate conditions, two main scenarios may occur. If the climate is more humid, wetlands (C) and extension of floodplains (F) may increase, threatening crops (B). Erosion and river sediment transport can be affected by increased landslides (E). If the climate is dryer, vegetation and land cover changes (D) will affect river chemistry and solid transport; this is particularly true if the precipitation regime is more irregular. Some tributaries can be cut-off from the main river course. In the estuarine zone, the sea level rise may lead to coastal erosion (Δ2), and to increased salt intrusion (Δ1). Increased upstream erosion could favour higher river solid transport to the sea (Δ3). These long-term changes have actually been observed in southern Mediterranean river systems, from the Maghreb to Turkey, over the last 6,000 years (when the Lower Nile tributaries were still active).

In an anthropogenically-influenced system, forest cutting (K) in the upper river catchments favours land sliding and gullying (J) whilst land use change is associated with moderate water quality issues under rural conditions (I). Wetland drainage (H) is common and may limit these natural filters. Mountain reservoirs (N) may store river particulates, or be exposed to nutrient loadings (L) and become eutrophicated. They may also be part of important water transfers (P), from one catchment to another, particularly for irrigation. Urban, industrial and mining emissions (G, Q, S) to the atmosphere may result in important pollution sources to the catchments soils and to the coast and to acid rainfall (Z) as well, which lead to forest die-back (R). Weathering and erosion of mine tailings, of various ages, may release slowly heavy metals into the aquatic systems. Other pollution sources include: agricultural soil leaching (L, M) and polluted ground waters inputs (W, Y); industrial urban wastewaters, discharged into rivers systems or to the coast (L, Q, T, U); and leakage of old waste dumps (X). The river course is also very much modified, through channelisation (O1-O2), sluice construction, dredging and artificialisation of river courses, from the middle river courses to the estuarine zone (V). Coastline erosion (Δ4) and salt wedge intrusion (Δ7) can be enhanced. The coastline can be artificialised (Δ6) and coastal sediments be contaminated (Δ5).

This diagram shows the complexity and the spatial interaction and inter-connectivity of all parts of the catchment-coast system. Coastal impacts are related generally to more than one pressure, either on the adjacent drainage basin, or directly on the coast.

Differentiating human-induced changes from naturally-forced changes is often difficult (Crossland *et al.*, 2005). It is more difficult in the Mediterranean catchment, as the human activities are among the oldest in the world (Meybeck *et al.*, this volume).

The main coastal impacts related to river-drainage changes and to climate change are presented in Table 3.

3.2. Coastal impacts related to river-basin changes

3.2.1. Deforestation / forestry, agriculture

The largest human modifications to vegetation cover and consequently sediment transport to the ocean, are from deforestation; this, in the Mediterranean region, dates from two millennia before present (Liquete *et al.*, 2004). According to the FAO (Food and Agriculture Organization, 2001), in recent years the overall deforestation rate in North Africa and the Near East has been greater than that of the tropical world (more than 1%, compared with 0.6%). In the European countries (excluding the Russian Federation), with a few rare exceptions such as Albania, due to very strict regulations the forest areas have increased over past decades. The annual growth rate did reach, or even exceeded, 1% for those countries in the Mediterranean area.

Many small and medium-size river catchments, especially those located in semi-arid regions, are presently undergoing important erosional problems; these are caused by the combination of insufficient vegetation cover, soil composition, steep slopes, and inappropriate agricultural

Table 3. Main impacts of river drainage changes and climate change on the coastal areas (Meybeck, 2006a).

A) River drainage changes	**Coastal impacts**		
	Morphology	**Food webs**	**Users**
Enhanced river fluxes			
Increased sediment supply	Increased siltation Accretion of deltas	Increased siltation	Need for channel protection and maintenance
Increased toxic fluxes		Degraded food webs	Loss of marine bioresources
Increased Nutrients		Eutrophication (harmful algal blooms)	Threats to tourism and food security
Episodic coliform inputs			Short-term beach access closure
Increased Organic Carbon		Increased heterotrophic food webs	Loss of seawater transparency
Changes in Redfield ratios		Food web changes (diatom loss)	Loss of bioresources
Retention of river material			
Sediment retention	Sediment starving Coastal erosion		Unsustained beaches and need for protection
Water flow reduction		Oligotrophication of estuarine food webs	Lack of water for delta/coast users Salt intrusion
River/habitat destruction		No migrating species	Loss of bioresources
Delta			
Water/gas extraction	Delta subsidence		Inundation (human safety) Salt intrusion
Artificial delta/habitat destruction	Loss of vegetal protection, against coastal erosion Dune loss/Movement	Limits to aquatic species	Loss of biodiversity
B) Climate changes			
Sea level rise	Coastal erosion maximum in deltas		Inundation Sea salt intrusion
Precipitation regime change/ Dryness	Long term changes in sediment supply	Long term changes in C and nutrient supply	Summer heat waves Floods
Global warming	?	Invasive species	
Sea storminess changes (wave pattern)	Coastal erosion		Risk of inundation and destruction of coastal infrastructures

practices (Ben Mammou; Boumeaza; Touaibia, this volume). It has been estimated that around 75% of the average sediment yield of the Mediterranean headwater river basins may be attributed to human activity (Dedkov and Mozzherin, 1992), mainly deforestation and intensive agriculture. These activities, over hundreds of years, have increased the sediment supply to the coast, prograding most of the deltaic coasts around the Mediterranean.

3.2.2. Damming and irrigation

Globally, more than 3500 small (height >30m) and high (height >60m) dams, devoted to hydroelectrical power production, irrigation, and flood control, together with millions of small hill reservoirs, are in operation in the Mediterranean catchment; they reduce the original natural drainage basin area by some 78% (Poulos and Collins, 2002b). According to the conclusions of Ludwig *et al*. (2003), the overall reduction of the riverine sediment discharge to the Mediterranean Sea may as great as 75% in comparison with the beginning of the 20th century. This means that probably only 25% of sediments actually enter the marine realm every year.

Even if the most impressive cases reported in the literature are those of the large rivers, such as the Nile and the Ebro, where dams trap respectively nearly 98% (Abdel Moati, 1999) and 99% of the solid discharge (Ibañez *et al*., 1996), some smaller rivers show the same percentage of sediment reduction, due to dams (e.g. the Moulouya 95%, Snoussi *et al*., 2002) and Tunisian rivers (Ben Mammou, this volume).

Moreover, due to the high rates of natural and man-induced erosion that characterise many Mediterranean hinterlands, the rapid silting up of reservoirs limits their storage capacity and their lifespan (e.g., dams in Algeria have lost a quarter of their original capacity (www.planbleu.org), whilst the Mohammed V dam on the Moulouya River will fill with sediments within 59 years, having lost nearly 50% of its storage capacity (Snoussi *et al*., 2002). The sediment trapped is abstracted from the coastal budget, leading generally to coastal retreat. Coastal erosion linked to damming is reported in many Mediterranean catchment-coast systems (Ben Mammou; Boumeaza; Simeoni *et al*., this volume). Pressures on water resources will increase significantly in the South and East of the region. Under such conditions, the construction of more dams is likely to have serious environmental and related societal impacts on the coastal zone.

3.3. Coastal impacts related to global/regional changes

3.3.1. Climate change

Climate change will affect the hydrological cycle and sea level, which in turn can be leading factors on shoreline morphology such agriculture, ecosystems and biodiversity. Most of the present climate models in the Mediterranean area indicate increased dryness occurring more often, or longer-lasting dry spells under doubled CO_2 conditions (UNEP/MAP, 2001). Impacts on water resources will be stressed in Southern Europe, North Africa and the Near East where water availability is low. These impacts include: increase of pollutant concentrations, due to decrease of run-off; reduction of the auto-purification capacity of the small rivers; increase of lakes and groundwater salinity, due to global warming; and higher evaporation and sea-level rise. In contrast, over the northern part of the Mediterranean basin, increases in rainfall patterns, during winter and spring, may lead to some extreme events, whereas summer heat waves can have severe implications on forest fire occurrence.

Within the marine realm, Mediterranean ecosystems are also very vulnerable to global warming. Changes in sea-surface temperature, salinity, chlorophyll and nutrient concentration interact with the thermohaline circulation which, in turn, induce significant local changes. Sea-level rise and increased storminess could cause impacts such as: submersion of sensitive deltas and low-lying lands; erosion of fragile coastlines; and salinisation of ground waters and soils, causing severe losses to agriculture.

3.3.2. Population growth and coastal urbanization

The Mediterranean coastal area is one of the most heavily populated regions of the world. The population of Mediterranean countries is expected to follow significant growth rates, from 356 million in 1985 to 520-570 million in 2025. Likewise, the coastal population is expected to increase, from 133 million to 195-217 million, in 2025. It should be noted that future projections show major differences between the North and the South, with the European countries having a nearly stable population, whilst the southern and eastern countries are expected to experience significant population growth (Figure 6).

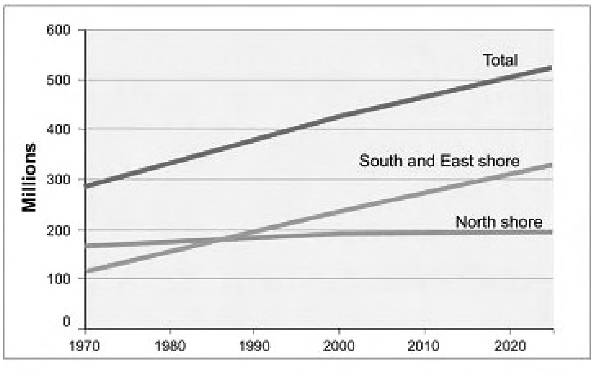

Fig. 6. Population growth in the Mediterranean northern- and southern-rim countries, 1970-2025 (Attané and Courbage, 2001).

The baseline scenario of the Blue Plan (www.planbleu.org) projects by 2025 significant increase in coastal pressures with:

– coastal city populations rising from 70 million in 2000, to 90 million in 2025;

– 312 million tourists in the coastal areas compared with 175 million in 2000, a density per km of coast which could triple in the South and East; and

– the most significant risk is the saturation of coastal areas and the additional artificialisation of 4,000 more km of coastline (reaching 50%, in 2025).

These projected pressures will lead to an increasing competition for space and natural resources, both on land and at sea. Conflicts and interferences between different uses will be reinforced by the seasonal variation in human pressures, with the highest number of people generally present in summer. At this time, the local populations are multiplied by millions of external tourists, when the water availability is at it lowest.

In summary, it is likely that changes in land cover and use, combined with changes in climate conditions and population growth, will have more visible impacts in small to medium Mediterranean catchments; this is due to the shorter time frames which they need to translate these catchment changes into coastal response, compared to large catchments.

4. RECOMMENDED NEEDS AND RESEARCH AGENDA

– Creation of a Mediterranean Database on river fluxes, delta morphology, human impacts, dams, water uses, etc.

– Establishment of a network of Case Studies, based upon the availability of terrestrial and marine long-term data sets/including human impacts and existing national expertise. A network of medium-sized catchments in which the complex human-river relationships can be deciphered, and possibly, modelled is presented tentatively in Table 4. This network encompasses all kinds of Mediterranean river regimes and human impacts, for different sea basins and countries. These rivers are already studied by multiple national and international research teams, but this information is not yet collected, archived and synthesised.

– Definition of key indicators which required a DPSIR framework.

Table 4. Medium-sized Mediterranean rivers suggested for a network of case studies.

River	MED-Basin(1)	Country(2)	Basin Area (10^3 km^2)	Drainage Intensity (mm/yr)(4)	Present Runoff (km^3/yr)	Human Pressures
Têt	NW	FR	1,4	(291)	0,3	reservoir; agriculture (irrigation), major city
Moulouya	SW	MAR	51,0	(31)	1,6	reservoirs; agriculture; mining; tourism
Cheliff	SW	ALG	43,7	(29)	1,3	reservoir, cities
Tevere	TYR	IT	16,6	446	7,4	major city (Rome), agriculture
Krka	ADR	CRO	2,0	1015	2,0	none, exceptional pristine river
Neretva	ADR	CRO	17,7	780	13,8	limited pressures, limited damming; high erosion
Reno	ADR	IT	3,4	412	1,4	multiple impacts (agriculture, industries, river flow regulation)
Majerda	ION	TUN	21,8	(44)	1,0	reservoir cascade, agriculture
Acheloos	ION	GR	5,5	1023	5,7	reservoirs, agriculture, industries
Ceyhan	NLEV	TR	20,0	(346)	7,1	multiple reservoirs
Axios(3)	AEG	GR	24,7	(198)	4,9	urbanisation (Skopje); industries
Aliakmon(3)	AEG	GR	9,5	(123)	1,17	reservoirs, agriculture

Keys: (1) NW: Northwest, SW: Southwest, TYR: Tyrrhenian, ADR: Adriatic, ION: Ionian, LEV: Levantine. (2) Country of river mouth. (3) Common Delta. (4) In parenthesis runoff values already affected by water uses, with present-day figures likely to be lower.

The following questions and responses could be addressed, in a future research programme:

1) How to deal with exceptional events?

– Definition of extreme events for each type of hydrological regime.

– Gauging stations must be calibrated for extreme water levels with the necessary equipment designed to resist to violent flash-floods.

– Automatic samplers, or intensive field measurements.

– Response time is reduced, for smaller rivers.

– Sampling in response to sea storm or rain storm events.

– Interrannuel, long-term monitoring at selected sites should be consolidated.

2) How to deal with the spatial dimension of fluxes?

– Spatial and temporal relationship of river inputs to the coastline, i.e. impact scale.

– Remote sensing of marine waters, for surface plumes.

– Development of more coupled studies, between the drainage basin and the coastal waters.

– Extension of temporal studies on surficial sediment deposition, in offshore waters.

– Delta processes, i.e. between the most downstream river station and the first marine station, should be considered.

3) How to deal with ungauged catchments?

– Build-up typologies of catchment-coast interactions (hydrodynamics, sediment dynamics, etc.), in natural conditions, targeted to the Mediterranean Sea.

– Select representative catchments as a first approach.

– Extrapolate the representative catchments results to the ungauged catchments within each type.

– Extend the monitoring to small and medium catchments, possibly on the basis of the importance of their overall contribution to the Mediterranean Sea.

4) How to deal with human interactions?

– In-depth analysis and mass balances of contaminants, carbon and nutrients sources should be carried out on the selected sites.

– Sediment production, transfers and deposition (i.e. enhanced erosion vs enhanced reservoir retention) should be addressed.

– The impact of decreased water runoff linked to irrigation on riverine fluxes should be considered over long periods (>30 years if possible).

– Human interactions in deltas (wetland filling, channelisation, fertilisation, pollution, aquaculture, etc.) should be assessed in terms of: (i) modifications of river to coast filtering capacity; (ii) new sources/sinks of material; and (iii) regulation of the coastline.

– A typology of human interactions can be developed in parallel to the typology of catchment-coast interactions (developed in step 3).