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# ENVIRONMENTAL IMPACTS IN BEACH NOURISHMENT: A COMPARISON OF OPTIONS


## ABSTRACT

It is estimated that by 2100 the average temperature increase on our planet will fluctuate between 1.8 and 4ºC. This will lead to coastal retreat, brought about by a rise in sea level of between 20 and 60 m. Data from the *Eurosion Report* presented in 2004 shows that 20,000 km of coastline in European Union countries had serious sustainability problems. The need for corrective measures on the coast is undeniable.

Corrective measures generally fall into two categories – hard and soft solutions. "Hard solutions" such as breakwaters, stone filling, walls, free dykes, and so on, have only proved to be effective in the short term and at a local level. In fact these solutions have sometimes shown negative results such as the unsightly structures and the building up of sand on beaches. On the other hand, the negative effects of "soft" techniques of artificial sand nourishments are only temporary. "Soft solutions", however, depend on extraction of sand and so a lack of sources for extraction (either quarries or marine banks) and/or the biotic effects of extraction must be analysed.

That said, "soft solutions", where replenishment sand is taken to a beach, has generally been proven to be effective and economically feasible. This article focuses on the comparison of the most common two origins of sand: quarries and marine banks. Quarry sand comes from open-air operations and the sequence of operations for obtaining sand (blasting, crushing, sorting, sieving, land transport to the beach and the spreading of it) has notable environmental impacts. Quarries are eyesores that spoil the surrounding landscape and lead to the desolation of the countryside. Quarrying also has an effect on surface and underground waters in the area and causes substantial emissions of $CO_2$ throughout the process.

The process of beach nourishment through dredging – extraction from marine banks, sea transport and final spreading on the beach – will have an effect on nature by changing water levels and currents, turbidity and by causing the disturbance of sediments and the destruction of natural habitats. In each specific case, a rigorous study must be undertaken to evaluate the environmental impact of each of these factors on the chosen process and thus determine the viability of the proposed form of replenishment.

All things considered, in comparison to obtaining sand from a quarry, beach nourishment with sand from marine banks, in many cases and countries, has become a normal practice that has very satisfactory results. The research concludes that the execution period by dredging is of the order of ten times shorter, the price is between two and three times lower, and it emits seven or eight times less $CO_2$.


Above: A dredger discharges sand onto the beach by pumping through floating pipelines. Beach nourishment using sand from marine banks in the sea has unquestionable advantages over using sand from a quarry. It is cleaner, costs less and takes less time.

## INTRODUCTION

In 1995 the IPCC (United Nations Intergovernmental Panel on Climate Change) stated: "Evidence suggests a certain amount of human influence on global climate. The differences in mean temperatures on earth between the glacier age and the present are about 5 or 6ºC. Modifications of 2 or 3ºC could rapidly change the climate".

By the end of this century, the overall temperature of the Earth may rise by between 1.8 and 4ºC and may lead to an increase in the sea level of between 18 and 60 cm,

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became a Naval Architect, at the Polytechnical University of Madrid, Spain. He started his professional career in 1973 at Dragados y Construcciones, S.A. (Spain). For 11 years he worked on site in numerous marine, especially dredging, projects and his experience covers all types of equipment and soils. In 1984 he was placed in charge of scheduling Dragados ´Dredging Division from where he was promoted successively to the Management of the Technical, General Services, Plants and Project Operations Departments, giving him the opportunity to deal with a variety of marine works (dredging, breakwaters, caissons, outfalls). In 1998 he joined Dravosa, a company owned by the Dragados (Spain) and Van Oord (Netherlands), where he is currently Deputy Director .

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graduated in 1997 from the Delft University of Technology, with a Master's degree in Civil Engineering. After working as a civil engineer for Interbeton on marine construction projects in Venezuela and Singapore, and completing an MBA at IMD in Lausanne, Switzerland, he joined Van Oord in 2003. Until 2006 he was stationed in Dubai from where he was involved with various large reclamation and oil and gas projects in the Middle East. In 2007 he was appointed General Manager of Dravosa, the joint company jointly owned by Dragados and Van Oord, with activities in Spain, Portugal and Italy. In 2010 he was transferred to South America where he is presently working as an Area Manager.

Figure 1. With the increase of temperature globally has come an increased risk of flooding along the Spanish coast.

causing a retreat of the coastline of 20 to 60 m, depending on the location an earth. Following the global average, it has been shown that between 1993 and 2005, the sea level in Spain rose by 3.3 mm per year (Figure 1). The coastline is an extremely fragile area. Today, as it is structured, it cannot defend itself against climate change.

Data supplied by the *European Union* are relevant. The Eurosion Report (2004) stated that 20,000 km of European coast (20% of the total) are affected by serious impacts, estimating that public expenditure on coastal protection were 3,200 million euros. In the EU in 2001, protection projects were under way along 7,600 km.

Human presence is intensive along the coast. In Spain, one out of every three inhabitants lives in a 5 km band along the coastline. That is, 35% of the population lives in 7% of the territory. This is an area that generates 14% of the GDP. In the last 50 years, the population of coastal municipalities has more than doubled.

The consequences of coastal flooding would have significant impact in many regions around the globe:

- Damage and economic risk for coastal cities and basic infrastructure. Eight out of the ten largest cities on Earth are located near the sea. In the EU alone, more than 70 million persons live on the coast.
- Losses of territory and frontier disputes, including the disappearance of entire countries located on small island states.
- Massive migrations. In Asia alone, 40% of the population (almost 2,000 million persons) live within 60 km of the coast.
- Generalised conflicts over the possession of resources, because of the reduction of cultivatable land, the lack of drinking water, increased flooding, and so on. In the Nile Delta, for example, the rising sea level will cause the salt pollution of wide agricultural areas; it is estimated that between 12% and 15% of the cultivated land will be lost by 2050, affecting more than 5 million persons.

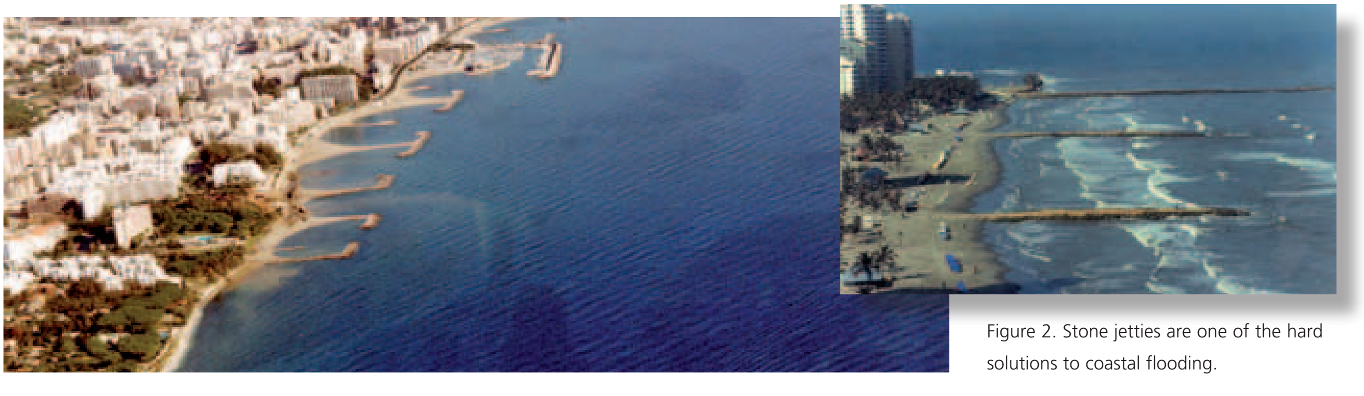

Figure 2. Stone jetties are one of the hard solutions to coastal flooding.

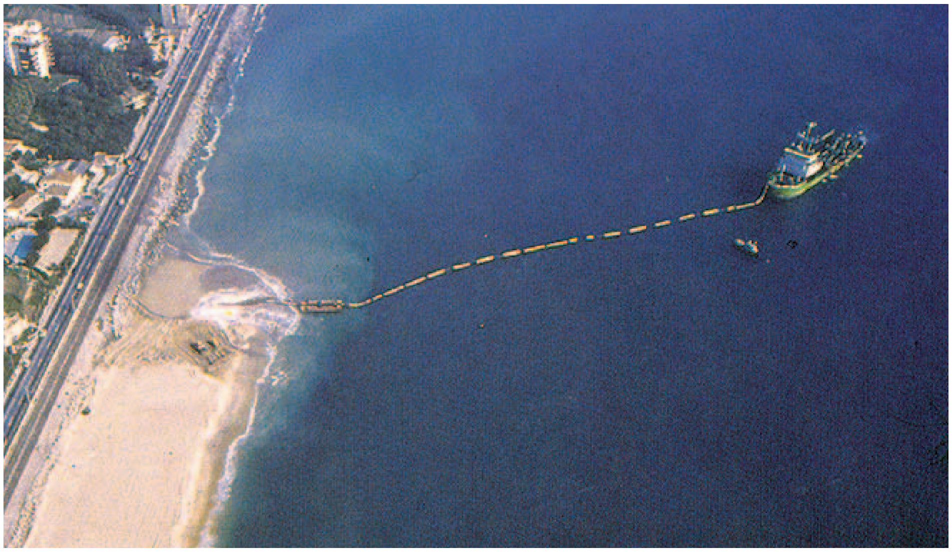

Figure 3. One soft solution is the replenishment of sand, won from a marine bank, by a hopper dredger.

Although a hard solution may be acceptable in many cases, a soft solution is preferable where it is possible.

## ENVIRONMENTAL ASPECTS OF BEACH NOURISHMENT

Although not always, generally speaking sand for replenishment comes from two sources: land, i.e., quarries, and the sea, from marine banks on the seabed. The construction processes and the issues of regenerating beaches are different, depending on the origin of the sand. In each specific case, a rigorous study must be undertaken to evaluate the environmental impact of each of the factors of the chosen process in order to determine the viability of the proposed form of replenishment.

One must also think of oil reserves, a large part of which are in Saudi Arabia and the Arab Emirates, at a very low level above the sea and, therefore, very vulnerable. All of this could lead to instability in many nation states, situations of radicalisation between them and a dangerous pressure on international governability. Corrective measures are absolutely necessary to minimise the probability and effect of coastal flooding as a result of climate change.

## CORRECTIVE MEASURES FOR COASTAL EROSION BY SUPPLYING SAND TO BEACHES: HARD AND SOFT SOLUTIONS

As is well known, corrective measures are often defined as either "hard" or "soft" solutions. "Hard solutions" are based on the installation of breakwaters, blocks, rock fills, sea walls, free dykes, defences and such solutions with the following properties (Figure 2):
– Effective over the short term.
– Effective in limited sections.
– They may have a visual impact.
– Building up of the beach (domino effect).

The "soft solutions" are based on artificial nourishment with sand (Figure 3), the main properties of which are:
– Effects are temporary.
– Resources for extraction whether on land (quarries) or marine banks are scarce.
– Biotic impacts must be evaluated.

Figure 4. Open-air operations for sand-winning at a quarry.

Figure 5. The visual impact of a quarry can be seen on this barren side of a mountain.

## Sand from quarries

If the sand comes from a quarry, the operation will take place in the open air (Figure 4). The sequence of nourishing the beach is:

- Quarrying the rocky material by blasting.
- Loading and transporting the material from the quarry to the crushing plant.
- Crushing the rock in the crushing plant which, for sand, involves four stages of crushing, each with the relevant feeders, sieves, conveyor belts, intermediate stockpiles, sand washers, and such.
- Loading and transporting the sand from the quarry to the beach.
- Spreading the sand on the beach.

What are the most important ecological effects in the process of sand-winning from a quarry?

- Disturbing the natural terrain and animal life as a result of the process of cleaning the area prior to blasting.
- Visual impact: After the stone is extracted and the plant coverage removed, a desolate landscape is left, bare and without live resource (Figure 5).
- Effects on aquifers, canals and surface and underground water courses in the area which could have environmental consequences such as rainwater retention, interruption of underground irrigation to specific ecosystems, dust invasion forming mud, and so on.
- Important emissions of $CO_2$, as will be seen below.

## Sand from marine banks

Sand can also be obtained from marine banks with the following construction process:

- Extraction of the sand from the seabed by dredging.
- Sea transport from the marine bank to the beach.
- Pumping of the sand by pipes from the dredger to the beach.
- Spreading the sand on the beach.

What environmental impacts are involved in winning sand from marine banks?

- Disturbing and burying of habitats and the stirring up the seabed (Figure 6).
- Changes in the flow of water, currents and waves in the area of extraction as a result of creating deeper bottoms.

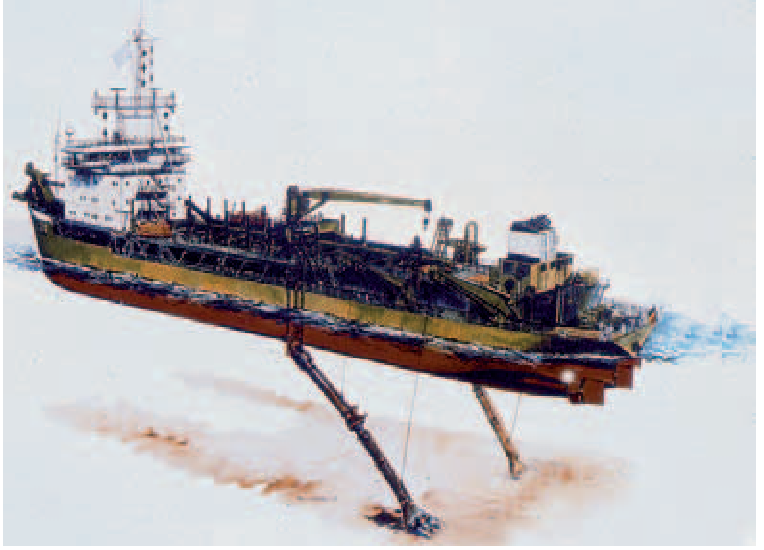

Figure 6. Dragheads can cause disturbances of habitats during dredging.

- Putting contaminated products in suspension, if they exist.
- Turbidity that reduces the supply of light to the system with the consequent damage to the photosynthesis process and the incorporation of oxygen in the water. Coral beds, the breeding grounds for fish and molluscs, for example, are especially sensitive to this phenomenon. The impact could be damaging if it is maintained over the long term.

## Turbidity

It is necessary to open a parenthesis here to mention some questions regarding turbidity in dredging because sedimentation is seen as a highly adverse factor from the environmental point of view. For greater redundancy, sediment plumes are always associated with dredging. There are proofs of this in European Union directives. Dredging is anathematised for this reason. But turbidity is not a phenomenon created exclusively by dredging.

There is natural turbidity (Figure 7) in the estuaries of deltas, flooding of rivers, on beaches after a storm. According to a 1996 study of the Mississippi River, sedimentation extends over 450 km² when the discharge is low and 7,700 km² in times of flooding, with concentrations of between 10 and 30 mg/l. The sediments discharged by the River Guadalquivir in Spain are estimated at 20,000,000 m³ per year.

Figure 7. Turbidity exists naturally where a dynamic river meets a larger body of water. The difference in dark and light colour of the waters can be seen to the right.

Figure 8. Short, limited extent of plume from a dredger (left), and plume being measured by a survey boat.

Turbidity caused by other human actions such as fishing, for example, must also be mentioned. The area of seabed affected by trawling in United Kingdom in 2001 totalled some 1.23 million km².

Some areas were fished four times per year. Nevertheless, the area of seabed affected by maintenance dredging in the United Kingdom in the same year totalled 35 km², representing 0.003% of the area altered by fishing. Another example is in navigation, caused by the effects of the propellers of ships manoeuvring in shallow water. Data taken in 2007 show that sometimes these actions create sediment concentrations of 90 mg/l at 2 m from the surface after 50 minutes of occurring and 40 mg/l after 65 minutes.

Studies carried out in 1993 on a suction dredging process provided average turbidity data. At 100 m from the dredging on the surface, levels of 20-30 mg/l were measured 30 minutes after occurring and 40 mg/l around the same dredging after 15-20 minutes.
To summarise, it must be said that turbidity plumes generated by natural processes, trawling and ships are comparable to those produced by dredging, with this last case being shorter over time and of lesser extent (Figure 8).

Figure 9. A crushing plant for quarried sand.

Figure 10. Trailer suction hopper dredger with 10,000 m$^3$ capacity.

### Table I. Beach regeneration

Volumen: 500,000 $m^3$

| QUARRY | | MARINE BANK |
|---|---|---|
| 30 km | DISTANCE TO BEACH | 30 Km = 18 miles<br>50m depth |
| | EQUIPMENT | |
| Drilling/blasting<br>Chushing plant<br>(1,865 kw - 200 Ton/h) | Extraction | Trailer dredger<br>10,000 $m^3$ |
| 20 Trucks<br>of 20 $m^3$ | Transport & unloading | Trailer dredger<br>10,000 $m^3$ |
| Wheel loaders | Spreading on beach | Wheel loaders |
| 12,800 $m^3$ / week | PRODUCTION | 175,000 $m^3$ / week |
| 40 weeks | EXECUTION PERIOD | 3 weeks |

### Table II. Guideline prices (in Spanish market prices)

| QUARRY | €/$m^3$ | | MARINE BANK | €/$m^3$ |
|---|---|---|---|---|
| Selling price of crushed sand | 8.80 | Extraction, transport & loading | Dredging and sailing | 4.70 |
| Transport by trucks | 3.30 | | | |
| | **12.10** | | | **4.70** |
| Wheel loaders | 0.15 | Spreading on beach | Wheel loaders | 0.15 |
| | **0.15** | | | **0.15** |
| | **12.25** | TOTAL (€/$m^3$) | | **4.85** |
| | **€ 6,125 MILLION** | GRAND TOTAL (500,000 $m^3$) | | **€ 2,145 MILLION** |

### Table III. Carbon dioxide ($CO_2$) emissions

| QUARRY | Kg $CO_2/m^3$ | | MARINE BANK | Kg $CO_2/m^3$ |
|---|---|---|---|---|
| Blasting<br>▪ 0.34 Kg - explos $m^3$<br>▪ 0.30 Kg $CO_2$ /Kg-explos | 0.102 | Extraction | Dredging ▪ 1,560 l/h<br>▪ 0.24 l/$m^3$<br>▪ 2.65 Kg $CO_2$/l | 0.636 |
| Chushing, clasification, sieving<br>▪ 19.7 Kwh/$m^3$<br>▪ 0.372 Kg $CO_2$ /Kwh | 7.328 | | | |
| | **7.43** | | | **0.636** |
| Land transport<br>▪ 5.5 l gasoil/$m^3$<br>▪ 2.65 Kg $CO_2$ /l | | Transport & unloading | Sailing ▪ 1,690 l/h<br>▪ 0.71 l/$m^3$<br>▪ 2.65 Kg $CO_2$/l | 1.881 |
| | | | Pumping ▪ 945 l/h<br>▪ 0.14 l/$m^3$<br>▪ 2.65 Kg $CO_2$/l | 0.371 |
| | **14.575** | | | **2.252** |
| | **22.005** | TOTAL (Kg $CO_2/m^3$) | | **2.89** |
| | **11,000 TNS $CO_2$** | GRAND TOTAL (500,000 $m^3$) | | **1,445 TNS $CO_2$** |

## COMPARISON OF BEACH NOURISHMENT BY ORIGIN OF SAND

"Soft" solutions by nourishing beaches with sand have been shown to be effective and economically feasible. Most European beaches are permanently being artificially regenerated by supplying them with sand.

The Tables I, II and III shown here analyze a beach regeneration project in two cases:
a. when sand is obtained from a quarry and
b. when sand comes from a marine bank.

In both cases a detailed calculation of the $CO_2$ emissions produced is presented.

Table I shows the most important properties of the example, a regeneration with 500,000 m³ of sand, a size of D50 = 0.5 mm.

The origin of the sand is:

**Case a:**
- a quarry 30 km (= 18 miles) from the beach.

**Case b:**
- a marine bank at 30 km from the beach and at a depth of 50 m.

The equipment required is:

**Case a:**
- *Extraction phase*: drilling and blasting equipment.
- *Crushing*: plant of 200 tonnes/hour and a total installed power of 1,800 kW (Figure 9).
- *Transport and unloading phase*: The sand is transported from the quarry to the beach by a fleet of 20 trucks each with a capacity of 20 m³.
- *Phase of spreading* the sand on the beach, using a wheel loader.

**Case b:**
- *Extraction phase*: by trailer suction dredger with a hopper of 10,000 m³ and a total installed power of 12,000 kW in order to dredge the sand from 50 m deep (Figure 10).
- *Transport and unloading phase*: in the dredger's hopper with final discharge of the sand on the beach by pumping through pipes.
- *Phase of spreading* the sand on the beach, using a wheel loader.

## COMPARISON OF THE MOST IMPORTANT RESULTS

The production and execution period:

**Case a:**

– 12,800 $m^3$/week.
  (13 hours - day; 5.5 days - week).
– Execution period: 40 weeks (9 months)

**Case b:**

– 175,000 $m^3$/week.
  (24 hours - day; 7 days - week).
– Execution period: 3 weeks (0.7 months)

*Guideline prices (referring to the Spanish market prices) are given in Table II.*

**Case a:**

– Estimated direct execution cost: € 12.25/$m^3$
– For 500,000 $m^3$, total material undertaking: € 6.125 million

**Case b:**

– Estimated direct execution cost: € 4.85/$m^3$
– For 500,000 $m^3$, total material undertaking: € 2.425 million

*For $CO_2$ emissions see Table III.*

**Case a:**

– 22.005 kg $CO_2$/$m^3$
– For 500,000 $m^3$: 11,000 tonnes

**Case b:**

– 2.89 kg $CO_2$/$m^3$
– For 500,000 $m^3$: 1,445 tonnes

Based on these measurements, regarding length of time, direct execution costs and $CO_2$ emissions, the dredging option from marine banks rather than quarrying yields better economic and environmental results.

## CONCLUSIONS

Climate change studies like the United Nations IPCC demonstrate that the present recession of the coastline, and the continuing threat of recession, is a proven reality in many areas of our planet. The solutions to defending the coastline against recession include both hard and soft techniques. In both cases, it is necessary to carry out an eco-balance for each specific project (economic/ecological, case by case) based on scientific and technical knowledge. Recent research has shown that soft solutions provide more long-term, sustainable protection against receding coastlines.

Of the soft solutions for beach replenishment – winning sand from quarries or from marine banks – beach regeneration using sand from the sea, i.e., marine banks, has unquestionable advantages over those that using sand from a quarry:

– The execution period is of the order of ten times shorter.
– The price is between two and three times lower.
– And this method emits seven or eight times less $CO_2$.

## REFERENCES


Aarninkhof, S.G.J., Rosenband, W.F., Van Rhee, C. and Burt, N. (2007). "The day after we stop dredging: A world without sediment plumes?" *Proceedings*, CEDA Dredging Days, Rotterdam, Netherlands.

Bates, Anthony (2005). "Methods of mitigating environmental impacts." *Maintenance Dredging 2*. Edited by the Institution of Civil Engineers. Thomas Telford, London, UK.

Bray, R.N. (Editor) (2008). *Environmental Aspects of Dredging*. Taylor & Francis/Balkema, London, UK.

Clack, D. and Reine, K. (2007)."Suspended sediment plumes associated with navigation" *Proceedings*, WODCON Conference.

European Commission (2005). *Resultados del estudio EUROVISIÓN*.

European Commission (2008). *Climate change and international security*.

European Dredging Association (2004). *Beach nourishment in perspective*. Brussels, Belgium.

Eurosion (2004). *Living with Coastal Erosion in Europe; Sediment and Space for Sustainability.* http://www.eurosion.org/project/eurosion_en.pdf

Holgate, S.J., and Woodworth, P.L. (2004), "Evidence for enhanced coastal sea level rise during the 1990s", *Geophys*. Res. Lett., 31, L07305, doi:10.1029/2004GL019626.

IPPC (1995). "Second Assessment Report; Climate Change 1995 (SAR)". *Working Group II: Impacts, adaptions and mitigation of Climate Change: Scientific – technical analysis*.

IPPC (2007). "Fourth Assessment Report. Climate change 2007 – Synthesis Report".

John, S.A. *et al*. (2000). *Scoping the assessment of sediment plumes from dredging.*" CIRIA report C547, London, UK.

Losada, Iñigo J. (2007)."*Impactos del cambio climático en la costa española.*" Fundación Juan March, Madrid, 27 November.

Nationaal Onderzoekprogramme Klimaat voor Ruimte (2006). *Deltas on the move*.

PIANC Envicom-Task Group 3 (2008). *Climate change and Navigation*. Brussels, Belgium.

Spanish Ministry for the Environment (2006). *Principales conclusiones de la evaluación preliminar de los impactos en España por efectos del Cambio Climático*.

Spanish Ministry of Industry (2005). *Plan de energias renovables 2005–2010*.

Spanish Ministry of Industry, Trade and Tourism (1991). *Evolución y corrección de impactos ambientales.*" Geological and Mining Institute.

Van Hooydonk, Eric (2006). *The Impact of EU Environmental Law on Ports and Waterways.* Maklu Press, Antwerp, Belgium.

Vidal, Roberto (2006). "Dredging in Spanish Coastal Waters". *Dredging in Coastal Waters.* (editor: D. Eisma). Taylor & Francis. London, UK.

Walker, N.D. (1996). "Satellite assessment of Mississippi River plume variability: Causes and predictability." *Remote Sensing of Environment*, vol. 58, No 1. pp. 21-35.

Williams, Allan and Micallef, Anton (2009). *Beach management: Principles and Practice*. Earthscan, London, UK.