MAREMED Project
MAritime REgions cooperation for the MEDiterranean

# Adaptation to Climate Change on Coastal Area

## Book 2
## Shared tools for the forecast and management of the climate change effects along the coast

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# Summary

# 1. Introduction

The European project MAREMED "Maritime Regions Cooperation for the Mediterranean" was approved in the MED SPACE program (2010-2013) and gathers Region PACA (lead partner) and other 13 Mediterranean regions. It includes 6 thematics of interest:

- Coastal Pollution
- Integrated Coastal Zone Management
- Coastal Adaptation to Climate Change
- Fishery
- Coastal Geo-data management
- Governance

Lazio Region is in charge of the Coastal Adaptation to CC and is responsible for developing four specific issues:

1. Compared analysis between coastal vulnerability maps (Book n.1);
2. Shared tools for the forecast and management of the CC effects along the coast (Book n.2);
3. Implementation of a coastal observatory network in the Mediterranean basin (Book n.3);
4. Coastal Intervention Line CIL: the coastline that must be kept unchanged to respect the steadiness of the "highest winter water" and "set-back line" (Book n.4).

This second volume concerns the "**Shared tools for the forecast and management of the climate change effects along the coast**".

The first part of this volume is dedicated to the description of the results obtained by the application of COFLERMap Model to a pilot site in the Lazio Region (see the COFLERMap description on BOOK n.1 - www.maremed.eu).

The second part of this volume is dedicated to the description and application of Coastal Flood/Erosion Risk Management Tools Model (COFLERTools).

During the Diagnosis phase of MAREMED project, partners expressed their need to build new management tools for evaluating the net benefit of coastal adaptation works increasing the resilience of coastal zone to climate change effects.

Moreover the Flood Risk Directive 2007/60/EC is very clear on this aspect: art.7 " ...*On the basis of the maps referred to in Article 6, Member States shall establish flood risk management plans..."* and "... "*Flood risk management plans shall take into account relevant aspects such as costs and benefits,..."*

In accordance with all the Maremed partners, a management tools model (COFLERTools) was proposed and elaborated by Lazio Region as coordinator of this thematic. The objective is to provide Mediterranean coastal Administrations with a management tool to in order to evaluate the benefits of coastal adaptation measures against the costs required for their implementation and the potential damages caused by extreme events.

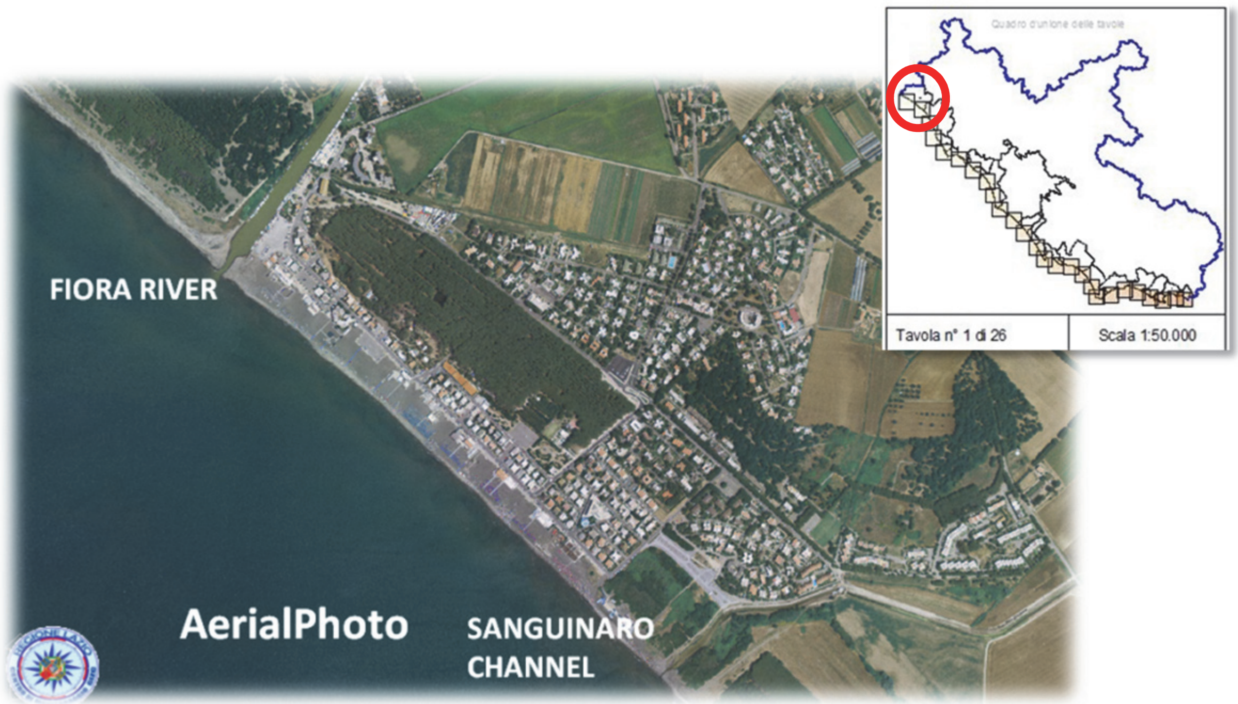
A project commissioned by the European Commission has already worked on these aspects (PESETA, 2009). In this work, PESETA results were taken into consideration thanks to a cooperation with Prof. Athanasios Vafeidis from University of Kiel - author and developer of DIVA Model - who processed some new DIVA Elaborations for Maremed Project in order to get results on the costs of damages caused by climate changes in the Mediterranean. DIVA results are expressed exclusively for Maremed Project subdivided by Regional Administrations. These results are described and commented in chapter 5 of this volume.

# 2. COFLERMap study case in a coastal pilot area of Lazio: Montalto di Castro (VT)

## 2.1 Why the coastal area of Montalto di Castro?

The Municipality of Montalto di Castro is part of the northern coast of Lazio. It represents an important pilot area for the application of COFLERMap due to the high level of heterogeneity of its coastal territory and high quantity and quality of geographic data collected by Lazio Region on this area. A recent monitoring LiDAR campaign commissioned by Lazio Region ICZM Monitoring Centre made it possible to have a morphological characterization of the Montalto coastal territory. These data are available in the Lazio region ICZM Geodatabase.

This Pilot Area is comprised between Fiora river on the north and Sanguinaro channel, for a total length of the coast of about 1.4 km.




Starting from the inland shoreline we have about 50÷70 m of beach equipped with bathing establishments. Behind the seafront, the territory is characterized by the presence of residential building, dunes, forest and sparse vegetation. This analysis refers to the area comprised between quote +0,00 m and +6,5 m above sea level.

We had access to morphologic data, land use, socio-economic data and hydrodynamics for risks computation.

## 2.2 The Geodatabase supporting the model

The application of the model is subdivided in three different Steps: starting from the elaboration and restitution of geographic data from the Geodatabase (Step 1), all the data are reported on a spreadsheet. Hydrodynamics, vulnerability and economic values are assigned to the spreadsheet (Step 2) in order to have the computation of the risks (COFLERMap - Maremed Book n.1, 2012). Third and last step, the values are assigned again to the Geodatabase for the graphic restitution of the hazards, damages and risks values on thematic maps.

All the steps are thoroughly described below.

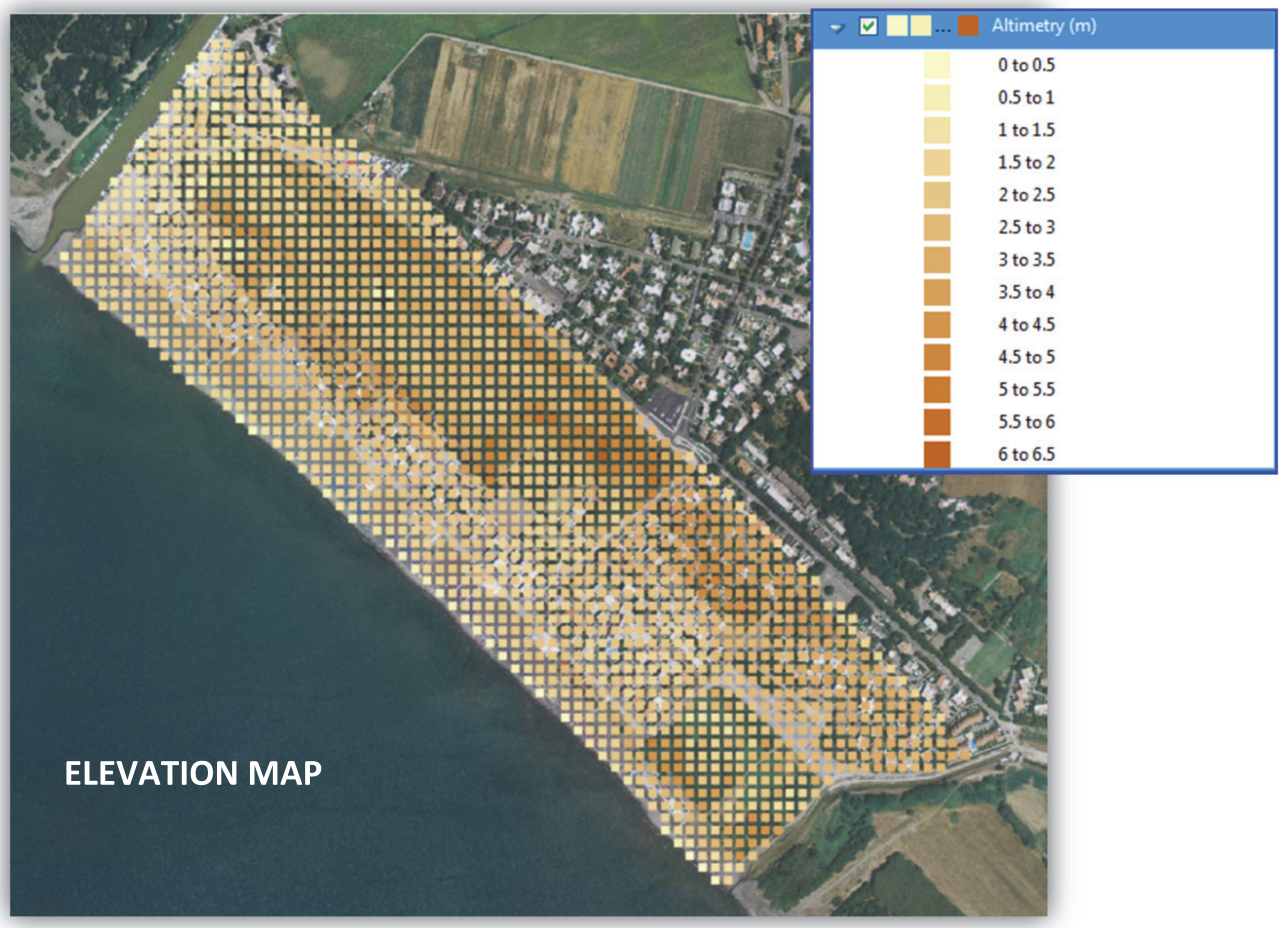
### Step 1 - Extracting geographic data from the Geodatabase

Coastal territory was subdivided into squared cells 20x20 m. Each cell represents the smaller territorial unit of computation of the model. The Geodatabase extracted a number of 1756 cells and assigned to each of them the values of elevation (LIDAR campaign, 2010) and land use (Corine land cover 4th level). In this area the Geodatabase found out 7 different types of land uses:

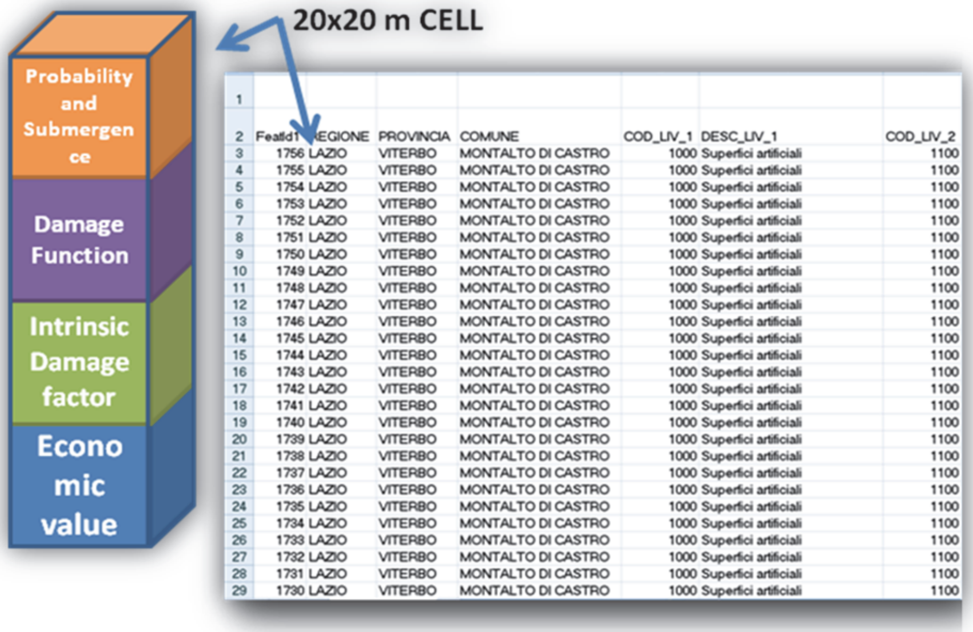
- Agricultural areas;
- Woods, forests, vegetation and sparse vegetation;
- Natural Dunes;
- Equipped beaches;
- Free Beaches;
- Beach Establishments;
- Residential.

First step consist on the graphic representation of:

- the morphology of the area (elevation map) and
- the land use characterization (land use map).


Altimetry (m)
0 to 0.5
0.5 to 1
1 to 1.5
1.5 to 2
2 to 2.5
2.5 to 3
3 to 3.5
3.5 to 4
4 to 4.5
4.5 to 5
5 to 5.5
5.5 to 6
6 to 6.5
ELEVATION MAP


Elevation data and land use data are reported on a spreadsheet where each 20x20 m cell is inserted in a raw of the computational table.




| | FeatId1 | REGIONE | PROVINCIA | COMUNE | COD_LIV_1 | DESC_LIV_1 | COD_LIV_2 |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | FeatId1 | REGIONE | PROVINCIA | COMUNE | COD_LIV_1 | DESC_LIV_1 | COD_LIV_2 |
| 3 | 1756 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 4 | 1755 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 5 | 1754 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 6 | 1753 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 7 | 1752 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 8 | 1751 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 9 | 1750 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 10 | 1749 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 11 | 1748 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 12 | 1747 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 13 | 1746 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 14 | 1745 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 15 | 1744 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 16 | 1743 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 17 | 1742 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 18 | 1741 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 19 | 1740 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 20 | 1739 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 21 | 1738 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 22 | 1737 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 23 | 1736 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 24 | 1735 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 25 | 1734 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 26 | 1733 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 27 | 1732 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 28 | 1731 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |
| 29 | 1730 | LAZIO | VITERBO | MONTALTO DI CASTRO | 1000 | Superfici artificiali | 1100 |

This approach enables us to assign the submersion level, damage function and economic values to each 20x20 m cell (step 2).

## Step 2 - The computation of potential damages and risks

Starting from the UNESCO formula of the risk (Varnes, 1984 UNESCO report), where the risk is proportional to the potential damages of exposed assets and the probability of occurrence of the harmful event, second step consists in assigning all the parameters required for the computation of these two values. For each 20x20 m cell, the following values where assigned:

- *Probability of occurrence of extreme evenst* - Three levels of return period (30, 200 and 500 years as suggested by Italian Legislative Decree D.Lgs 49/2010).

- *Submersion level* - obtained by the difference between the flood level and the cell elevation;

- *Damage Function* - proportional to the intrinsic damage factor and the submersion level. The damage function curves are expressed for each of the 7 types of land use individuated. They are compared with VNK project publication (Ministerie van Verkeer en Waterstaat);

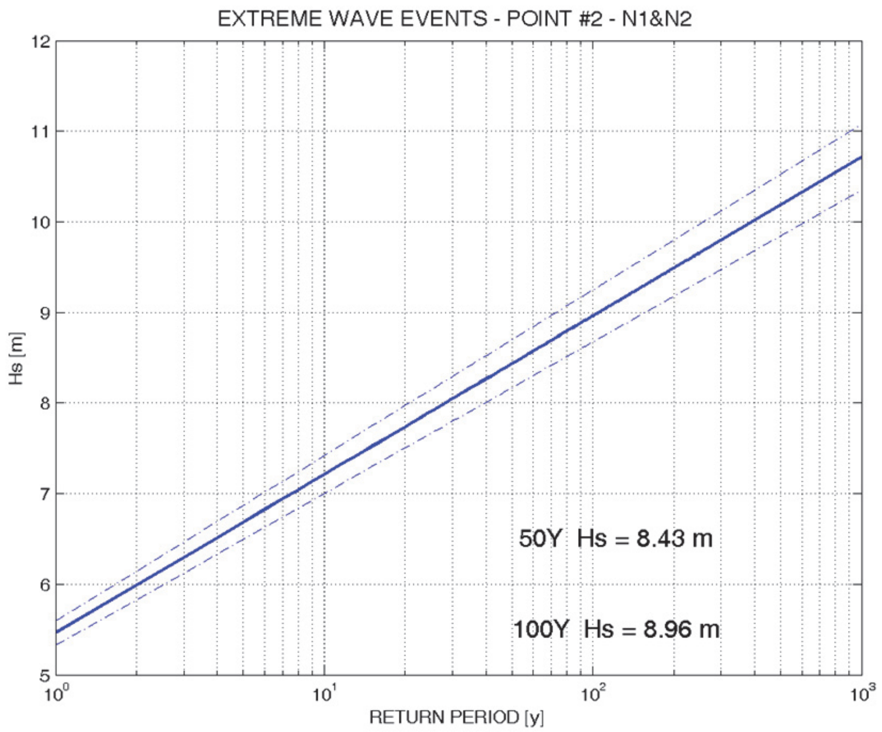
- *Reconstruction values of exposed goods* - obtained by the comparison with the values already published by the University of La Tuscia of Viterbo and VNK Project.

A more detailed description of COFLERMap model is available at www.maremed.eu Maremed deliverable ACC BOOK n.1.

*Probability and Flood levels numeric assumptions:*

The intensity of the event in relation to its occurrence probability was determined through standard statistical analysis (CNR-ISMAR/Lazio Region Convention, 2010 - Wave climate Characterisation of Lazio's coasts).

The exceeded values of the wave in deep sea Hso were calculated for every return period.




Extreme wave events at Montalto Di Castro (-100 m depth).

CNR-ISMAR, 2010

As concerns the elementary processes significantly contributing to the sea level changes, we have to consider a series of mathematical expressions for each physical process that significantly contribute to submersion (COASTANCE Project, 2012) such as: Wave setup contribution; Storm Surge; Astronomical tide effect; Effects driven by climate or similar very low contributions.

The water level of flooding in the generic point $i$ of the assessment coastal area, was represented by HLF$i$ where Runup, Storm surge, Astronomical tide, Atmospheric pressure and Sea level rise were considered. We recommend anyway a more thorough evaluation of these physical processes in order to make the results of this model as much realistic as possible. A publication on these aspects is available on COASTANCE project website (www.coastance.eu).

In order to evaluate the reaction of coastal morphology in case of extreme events, we adopt different beach slopes for different typologies of beach profiles. We assume a stable beach profile in the case of nourishment works (2% slope) and the eroded beach profile in the case of "do nothing" with growing slopes in the years.

Another important assumption is represented by the natural defence that storm banks ensure during extreme events. We consider that extreme events lower than 2.5 m cause damage only on the part of emerged beach. This defence rate is different for each typology of coastal defence works: 3.5 m in case of pure nourishment and 2.8 m in case of nourishment protected by hard structures.

These diversifications are necessary to the COFLERTools model in order to evaluate different levels of damages for different levels of protection.

*Numerical assumptions for Damage functions and Reconstruction values*

The table below shows the "Intrinsic Damage Factor" and "Reconstruction values" assigned to 7 different land uses:

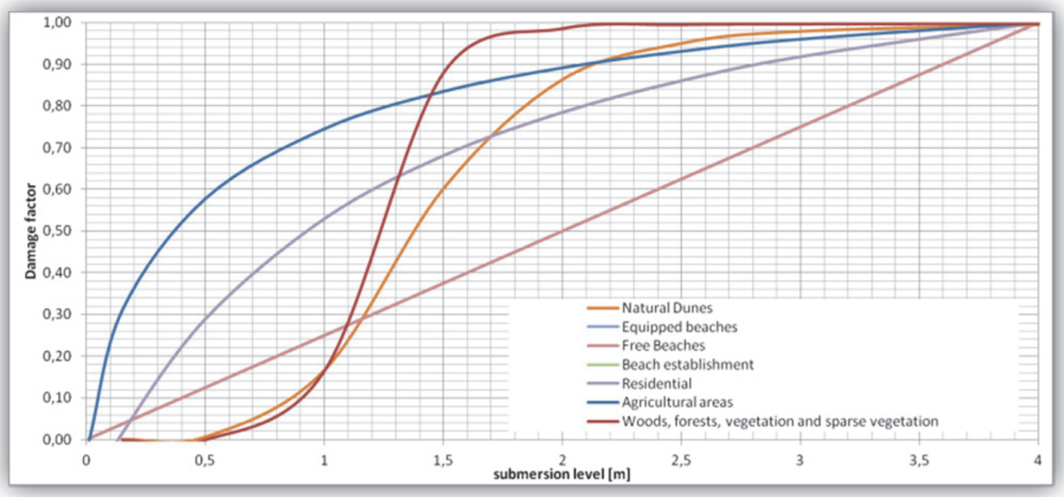
| LAND USE TYPE | Reconstruction value (euro/m$^2$)* | Intrinsic Damage Factor IDF** |
|---|---|---|
| Agricultural areas | 1,60 | 1 |
| Woods, forests, vegetation and sparse vegetation | 0,65 | 1 |
| Natural Dunes | 80,00 | 0,7 |
| Equipped beaches | 25,00 | 0,3 |
| Free Beaches | 25,00 | 0,3 |
| Beach establishment | 570,00 | 1 |
| Residential | 114,00 | 0,8 |

*Values obtained by a comparison of different works already published on this area (BEACHMED-e, 2008 and VNK, 2010)

**Values obtained by a comparison with Dutch experiences on damage function assignment (VNK Project, 2010)

In particular the values assigned to "Agricultural Areas" and "Woods, forests, vegetation...." are published on MEDPLAN subproject of RFO Beachmed-e and came out of a study conducted by Real Estate Observatory of National Territory Agency (2006). "Natural Dunes" refer to a comparison between values reported by past Mediterranean experiences of Natural Dunes reconstructions, Albufera (Generalitat Valenciana, ES) and Sète à Marseillan (Département de l'Hérault, FR). "Equipped Beaches" and "Free Beaches" refer to a study carried out by NOMISMA for BEACHMED project (2003). "Residential" reconstruction values are obtained starting from Dutch VNK Project (2009) values, expressed in euro per item and transformed in square meters unitary values in proportion to the residential land coverage in Montalto area (by aerial photo). "Beach establishment" reconstruction value is proportional to residential value, considering the minor entity of each damaged item.

Different damage factor curves were assigned in order to express the different behaviours of exposed goods to the flooding impacts.




Damage Factor Curves - represent the different behaviours of exposed assets to flood impact.

Also in this case curves refer to VNK Project (ANNEX II, Maremed BOOK 1) and are expressed for each land use.

After assigning the parameters, we obtained a risk value (euro/year) for each cell and for each level of probability.

Third and last step consisted in assigning the risks values to the Geodatabase to get the graphical representation of Risk Maps.

## Step 3 - Hazard map and risk map graphical representation

This third step consisted in assigning the risk values to the Geodatabase to get the graphical restitution of the hazard map (submersion values) and risk map. The chromatic graphical representation makes it possible to get an immediate interpretation of results as reported below: dark blue/red for high submersion/risk values and light blue/red for low submersion/risk values.

This type of graphical representation of results fulfills the requirements of the flood risk directive 2007/60/EC.


Submersion Level (m)
0 to 0.5
0.5 to 1
1 to 1.5
1.5 to 2
2 to 2.5
2.5 to 3
3 to 3.5
HAZARD MAP


Risk (euro/year)
10000 to 25000
5000 to 10000
1000 to 5000
500 to 1000
250 to 500
100 to 250
50 to 100
0 to 50
RISK MAP
Return Period = 500 years
$R_{500}$ = 1.45 Million €/year
RISK MAP
Return Period = 200 years
$R_{200}$ = 1.38 Million €/year
RISK MAP
Return Period = 30 years
$R_{30}$ = 1.01 Million €/year

## 2.3 Results and Conclusion

### Results

Risk results are reported below subdivided by Land Use typologies. This representation of results provides a clear interpretation of the results and potentiality of the model. Results are expressed in case of no adaptation.

| LAND USE TYP | Area ($m^2$) | Medium Elevation (m) | Reconstruction Values | $Ri,p_{30}$ (€/year) | | $Ri,p_{200}$ (€/year) | | $Ri,p_{500}$ (€/year) | |
|---|---|---|---|---|---|---|---|---|---|
| Agricultural areas | 3200 | 1,78 | € 5.120,00 | € 174,25 | 0,02% | € 228,71 | 0,02% | € 235,99 | 0,02% |
| Woods, forests, vegetation and sparse vegetation | 197600 | 2,74 | € 128.440,00 | € 773,59 | 0,08% | € 1.618,60 | 0,12% | € 1.786,29 | 0,12% |
| Natural Dunes | 22400 | 2,92 | € 1.792.000,00 | € 10.497,56 | 1,05% | € 17.208,62 | 1,24% | € 18.626,18 | 1,28% |
| Equipped beaches | 42000 | 1,67 | € 1.050.000,00 | € 11.131,01 | 1,11% | € 13.316,91 | 0,96% | € 13.722,06 | 0,95% |
| Free Beaches | 51200 | 1,85 | € 1.280.000,00 | € 11.037,91 | 1,10% | € 13.505,93 | 0,97% | € 13.975,42 | 0,96% |
| Beach establishment | 23600 | 2,21 | € 13.452.000,00 | € 411.576,77 | 41,09% | € 527.721,09 | 38,00% | € 545.603,77 | 37,60% |
| Residential | 354000 | 2,29 | € 40.356.000,00 | € 556.441,16 | 55,55% | € 815.290,90 | 58,70% | € 857.115,44 | 59,07% |
| **TOTAL** | **694000** | | **€ 58.063.560,00** | **€ 1.001.632,24** | | **€ 1.388.890,76** | | **€ 1.451.065,15** | |

We can immediately see that differences between risks per return period 200 and 500 years are not very significant. This could be due to the decision to apply statistical computation of flood levels.

Another clear aspect is linked to the different weights of risks for different land uses. About 96% of risks refer to the Beach establishment and Residential Use typologies.

The following table shows the risks results subdivided by elevation zones :

| Elevation | Area ($m^2$) | Reconstruction Values | $Ri,p_{30}$ (€/year) | | $Ri,p_{200}$ (€/year) | | $Ri,p_{500}$ (€/year) | |
|---|---|---|---|---|---|---|---|---|
| 0,00 ÷ 0,50 | 5200 | € 343.600,00 | € 10.267,32 | 1,0% | € 12.975,71 | 0,9% | € 13.344,77 | 0,9% |
| 0,51 ÷ 1,00 | 18400 | € 1.139.420,00 | € 30.344,99 | 3,0% | € 39.137,18 | 2,8% | € 40.355,19 | 2,8% |
| 1,01 ÷ 2,00 | 269200 | € 25.237.000,00 | € 649.209,01 | 64,8% | € 843.030,85 | 60,7% | € 871.287,98 | 60,0% |
| 2,01 ÷ 3,00 | 291600 | € 24.649.860,00 | € 307.943,21 | 30,7% | € 473.054,72 | 34,1% | € 500.057,32 | 34,5% |
| 3,01 ÷ 4,00 | 84800 | € 5.834.220,00 | € 3.867,72 | 0,4% | € 20.479,69 | 1,5% | € 25.441,62 | 1,8% |
| 4,01 ÷ 6,47 | 24800 | € 859.460,00 | € - | 0,0% | € 212,61 | 0,0% | € 578,27 | 0,0% |
| **TOTAL** | **694000** | **€ 58.063.560,00** | **€ 1.001.632,24** | | **€ 1.388.890,76** | | **€ 1.451.065,15** | |

The area most exposed to flood risks is comprised between 1.00 and 2.00 m above sea level. This result could be useful for Coastal Administrations in case of risk prevention and planning in coastal zones.

### Conclusion

Montalto area represented a good choice to test the potentiality of COFLERMap model thanks to the wide range of data available.

Future application of the model could be made on other Mediterranean coastal areas with a good level of knowledge of coastal territory and its uses (geographical data, socio-economic data and hydrodynamic data).

The model could be further developed to make it more user-friendly thanks to the support of a Geodatabase integrated with a spreadsheet for the computational aspects.

Moreover, the model could be further developed for the simulation of the flood levels. The hypothesis of COFLERMap is that the flood level is the same on the entire area analyzed (statical approach). The objective for the future development of the model is to assign different flood levels compared to the distance of the territory from the shoreline. This approach could be very important also for the evaluation of risks in case of adaptation measures (coastal defense works).

Some difficulties during the implementation of the model were due to assigning reconstruction values to exposed assets. This choice could be very significant on the final results of the model, so a specific study on the evaluation of the economic assets in the specific area was taken into account.

COFLERMap results represent the input data for the application of COFLERTools model. So its application is preparatory for the evaluation of the benefits of adaptation works on coastal area. The following chapters of this volume will explain the links between the two models.

# 3. Coastal Flood/Erosion Risk Management Tools (COFLERTools). Management Tools for the evaluation of the benefits of coastal adaptation to climate change in the Mediterranean coastal areas

COFLERTools model receives input data from COFLERMap model (monetary sum of the risk values expressed in terms of monetary cost per year) and its outputs data are a feasibility study of coastal defense works in terms of costs and benefit for the community.

The application of the model is subdivided in three steps:

- Step 1 - Computation of risks in case of Adaptation measures;
- Step 2 - Study of the economic feasibility of an Adaptation measure;
- Step 3 - Choice between different typologies of Adaptation measures.

In the first step, the COFLERMap model is used to recalculate the risk values in case of adaptation measures. The protection level of defense works reduces the impact of the flood and the risk level.

The second step is necessary to evaluate the economic feasibility of coastal defense works compared to implementation and maintenance costs and the benefit obtained during the lifetime of the work (reduced risks). We assumed that the adaptation measure is feasible from the economic standpoint when the following simple inequality is verified:

Risk without adaptation - (Risk with adaptation + Cost of adaptation) > 0

The third step consists in choosing between different typologies of adaptation measures. Which is the most suitable from an economic point of view? This evaluation could be made only if we know the net benefit of adaptation (difference between benefit and costs) of each typology of feasible adaptation.

COFLERTools Model was applied to Montalto di Castro study case area of Lazio Region and results are reported in chapter 4 of this volume.

## Step 1 – Risk computation in case of Adaptation measures

The parameter that induces the reduction of risks in case of adaptation measures including the implementation of coastal defence works (nourishment, groynes or barriers/dikes) is the defence level of the work. The model assigns different levels of flooding depth for each level of defence of the work.

We expected that it was reduced in the case of adaptation, but the computation of risks obviously depends on the level of flooding depth.

The defence level represents a cost (implementation and maintenance) that could be compared with the reduction of risks (benefit for the community) in order to demonstrate the economic feasibility of the coastal intervention work. This computation is feasible thanks to the fact that risks are expressed in terms of monetary sum per year (euro/year). It is worth reminding that COFLERMap and COFLERTools did not consider the risks for the human health and natural resources for the reason described in MAREMED Book n.1.

## Step 2 - Study of economic feasibility of a coastal defense work

Costs of adaptation measures are obtained by the sum of realization and maintenance costs of coastal defense works. This two costs have different temporal competence in terms of financial flux, during the period of life of the opera. For this reason we applied the compound interest formula for the actualization of monetary fluxes:

$C = Ci/(1+s)t$

with C actualized monetary flux, Ci monetary flux at year i, s the tax of interest and t the year of computation.

The feasibility of adaptation measures is assumed positive in the case that costs of coastal defense works (realization + maintenance) summed to the values of inundation risks (in the case of adaptation) results lower than the inundation risk (in the case of no adaptation).

Total costs, actualized at today, of typology A work "CA" are expressed by the following:

$CA = CA0 + \sum_{j=1}^{T} \frac{CAj}{(1+s)j}$ (Costs of Adaptation measure typology A)

with "T" the entire period of life of the opera.

And the expressions of actualized risks even in the case of no adaptation (R) and in the case of adaptation with typology A (RA), are:

$R = R0 + \sum_{j=1}^{T} \frac{Rj}{(1+s)j}$ (Risk without adaptation)

$RA = RA0 + \sum_{j=1}^{T} \frac{RAj}{(1+s)j}$ (Risk with adaptation typology A)

where CA0, R0 and RA0 are costs and risks values referred to the first year of computation (year zero).

We can say that typology A work results economically feasible only in the case the following inequality is verified:

$R - (CA + RA) > 0$

Risk without adaptation - (Cost of Adaptation + Risk with adaptation) > 0

## Step 3 - Choosing between different typologies of Adaptation measures

Once proved the feasibility of Adaptation Measures, we can choose between different adaptation typologies. Which is the most suitable from an economic point of view? and which one has the shortest return period on investment?

We can answer these questions only with a benefit/cost analysis study. Third and last step of this model consists in evaluating the cumulated net benefit values of more than one adaptation measure and compare them in order to choose the one which provides the best investment.

The benefits of adaptation measures are represented by a decrease of risks expressed in terms of monetary sum for one year. COFLERTools evaluates the measure of this decrease and compare it to the adaptation costs in order to analyze the net benefits of the adaptation: a decrease of risk over time represents a benefit for the community today.

It is worth reminding that this method was created to support coastal Administrations in their planning activity in order to analyze the economic suitability of the implementation of adaptation measures. All considerations linked to the damages for human health and natural resources have not been considered in this publication.

# 4. COFLERTools study case in a coastal pilot area of Lazio: Montalto di Castro (VT)

We have compared the net benefits of three different typologies of defense works: pure nourishment, nourishment protected by hard structure such as barriers or dikes, nourishment protected by medium structure as groynes.

| | | |
|---|---|---|
|  |  |  |
| Pure nourishment | Nourishment protected by hard structure | Nourishment protected by groynes |

For each typology of adaptation we evaluated the risks in case of adaptation measures (Step 1), work feasibility (Step 2) and economic convenience of the work (Step 3).

## The hypothesis of computations

We adopted a cost analysis tool (Medcoast, 2005) for the implementation and maintenance of coastal defence works, in order to get a computation of the implementation and maintenance costs. The hypothesis at the basis of the computation is that nourishment protected by hard structures is more expensive at the beginning of the investment, but maintenance costs are lower during the lifetime of the work because erosion is lower compared to pure nourishment.

The second hypothesis concerns the defence level. We assume that nourishment protected by hard structures has a dissipation effect in case of Max Runup on the beach. But the level of storm banks is higher in case of pure nourishment due to the higher volumes of sand required to maintain a stable beach profile.

For the computation of actualized costs and benefits we adopted an interest rate equal to 1.5%. The unit costs for nourishment and maintenance operations amounts to 7 €/m$^3$ for sand and about 40 €/m$^3$ for rocks.

The lifetime of the work is equal to 30 years. We used the risk with a 30 year return period to evaluate the effects of the work for risk reduction.

Please see the results below.

## Results

A spreadsheet was used for the computations. The following table shows the results of the new computation of risks (with adaptation) and the defence level for three typologies of coastal defense works considered:

| Typology of adaptations | Defence Level (m) | Ri,p30 (€/year) | Ri,p200 (€/year) | Ri,p500 (€/year) |
|---|---|---|---|---|
| No Adaptation | 0 | € 1.001.632,24 | € 1.388.890,76 | € 1.451.065,13 |
| Pure Nourishment | 3,5 | € 163.462,95 | € 230.496,54 | € 242.110,97 |
| Nourishment + Hard Dikes or barrier | 2,8 | € 10.638,48 | € 27.426,87 | € 32.517,28 |
| Nourishment with groynes | 2,8 | € 45.015,98 | € 119.562,99 | € 146.400,55 |

These results refer to the entire area of computation, i.e. 1.4 km of coast.

The intervention of nourishment protected by hard structures (barrier/dike) is the most efficient in terms of risk reduction. But its feasibility and economic convenience depend on the implementation and maintenance costs. Step 2 takes into consideration these aspects, too.

The implementation and maintenance costs are obtained by analogy with the works already done by Lazio Region in the littoral of Ostia (Rome) in 2005. The maintenance costs are proportional to the typology of the work and its effect on coastal erosion over time. Interventions are planned for a lifetime of the work equal to 30 years.

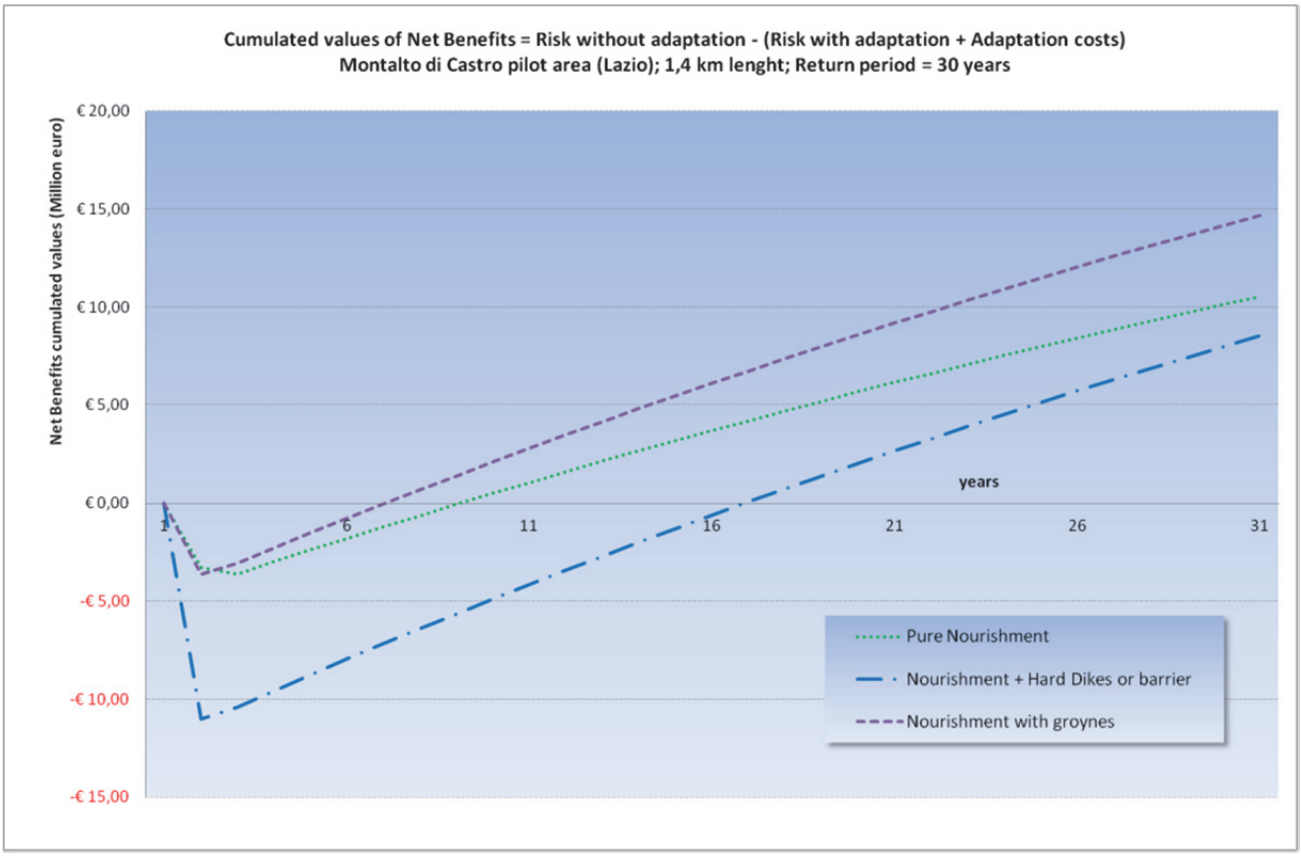
The costs of pure nourishment are redistributed over the entire lifetime of the work. Maintenance works are planned according to the erosion trend of this littoral area. Nourishment protected by barriers or dikes represent the most expensive intervention. Compared to pure nourishment, the implementation costs are higher in the first year (hard structures), but the maintenance costs are lower if we consider the the reduction of erosive trend caused by the presence of the barrier. The third typology of intervention (groynes) halfway in terms of costs and efficiency of the work against the erosion trend.

All the three typologies are feasible from an economic standpoint for a lifetime of 30 years. The following table shows the results of the feasibility study.

| T = 30 years | A | B | C | A-(B+C) | (A-B)/C |
|---|---|---|---|---|---|
| **Typology of adaptations** | **Risk without Adaptation (M€)** | **Risk with Adaptation (M€)** | **Cost of Adaptation (M€)** | **Net Benefit of Adaptation (M€)** | **Benefit/Cost ratio** |
|  Pure Nourishment | 24,1 | 3.9 | 9.6 | 10.6 | 210% |
|  Nourishment + Hard Dikes or barrier | | 0.26 | 15.2 | 8.6 | 156% |
|  Nourishment with groynes | | 1.1 | 8.3 | 14.7 | 278% |

The computations made in the last step provide us with the net benefits curves over time.

This example refers to the risks calculated with a return period equal to 30 (high probability of occurrence).




The picture above shows that higher values of net benefits are obtained in case of nourishment protected by groynes, after 30 years from the implementation of the work.

All the three typologies of interventions give negative results at beginning of the lifetime of the work. This is due to the initial investment required to implement the work. Pure nourishment becomes a positive investment 9 years after the implementation of the works. Nourishment with groynes become positive after 7 years and nourishment with barrier after 17 years.

The slope of the investment curves gives us information about the difference between the reduction of risks (benefit) and the maintenance costs during the lifetime of the work. We can say that the hard solution (blue curve) will become convenient compared to the other solutions a few years after the thirtieth year, because of the more significant reduction of risks and lower maintenance costs after its implementation.

## Conclusion

This pilot action was useful to understand the potentiality of the model in terms of representation of results and their comprehension. We also see a good response of the model for simulating the efficiency of coastal defence works in terms of implementation costs and benefits created for the community. During the planning phase, these aspects could be very important in order to understand the best political option to adopt.

The challenge for the future development of the model is its application in the different contexts of coastal Administration. We assume that the current approach of the model is ready for external application, but this aspect has to be confirmed with other pilot actions in the Mediterranean coastal zones.

The model could be further developed in order to make it more flexible for the computation of adaptation costs in case of different levels of protection. This will enable us not only to choose options according to the economic convenience of the investments, but also to understand the defence level we want to reach over time.

For its future development and improvement, it is recommended to disseminate the model as much as possible among regional coastal administration. Its application on different coastal contexts could be simplified if the tools were shared using a web-based tool.

# 5. Impacts of SLR in EU Mediterranean Countries - DIVA Model preliminary results

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## Introduction

This study presents some first results of an analysis of impacts of sea-level rise (SLR) in the EU-Mediterranean countries for the 21st century. For this purpose we have employed the DIVA (Dynamic Interactive Vulnerability Assessment) model to perform a series of runs under different socio-economic and SLR scenarios. Results are presented by country but also disaggregated, at the level of first-order administrative units.

The document is structured as follows: first, a general introduction on sea-level rise trends in the study area is presented and the potential impacts are discussed. Then, the DIVA model is briefly described and the assumptions and scenarios employed for the selected DIVA runs are outlined. Finally results are presented and evaluated and the potential for future work is assessed.

## Background

Global sea levels have been rising throughout the 21st century and, due to the lag in the response of the oceans to warming, they are expected to continue to rise for centuries even under the most optimistic mitigation scenarios. SLR estimates based on tide-gauge measurements since 1950 indicate an average rate of rise of approximately 1.7cm/yr (Church and White, 2006). Recent estimates based on satellite measurements suggest a significant acceleration in the rate of SLR, which amounts to 3.1 mm/yr (Ablain et al, 2009). Accelerated SLR is expected to continue in the 21st century; but the magnitude of the rise remains uncertain due to factors that include the potential contribution of the Greenland and West Antarctic ice sheets and regional sea-level variations. In its Fourth Assessment Report (AR4), the Intergovernmental Panel on Climate Change (IPCC) projects a mean global sea-level rise of 59 cm by the end of the century, not taking into account possible contributions from the melting of the large ice sheets of Greenland and Antarctica (Nicholls et al., 2007). Later studies based on semi-empirical methods that take into account these contributions suggest that sea levels may rise up to 1.8 m by 2100, compared to 1990 levels (e.g., Vermeer and Rahmstorf, 2009).

The main physical impacts of SLR include increased flooding and submergence, increased coastal erosion, loss of wetlands and saltwater intrusion in coastal aquifers (Nicholls et al., 2007). These impacts will be primarily felt in low-elevation coastal regions, which are characterized by high population densities and will lead to further socio-economic impacts that are expected to be overwhelmingly negative (Nicholls and

Cazenave, 2010). SLR is also expected to have other types of impacts, such as potential changes in the maritime boundaries of nations (Houghton et al., 2010), but our current understanding on those is limited. Damages resulting from the impacts of SLR are forecasted to be significant but available estimates are highly uncertain; total damages will not only depend on the absolute amount or rate of SLR but also on socio-economic development and on the implementation of adaptation measures and policies (Hinkel et al., 2010).

**Sea-level rise in the Mediterranean**

Based on existing findings, the estimation of sea level rise in the Mediterranean is highly uncertain. Trends obtained from tide gauge records spanning from 1960 to 2000 indicate a rise in the Mediterranean of 0.3 to 0.7 mm/yr (Marcos and Tsimplis, 2008a). However, decadal sea level trends are not always consistent with global values, in particular for the 1990s, during which the Mediterranean has shown enhanced sea-level rise of up to 5 mm/yr (Marcos and Tsimplis, 2008a). Recent studies suggest that the Mediterranean will experience smaller increases in sea levels compared to other regions (Tsimplis et al., 2008a). However, results from the application of twelve Atmosphere-Ocean General Circulation Models (AOGCMs) for forecasting and assessing potential changes in sea levels in the Mediterranean for the 21st century, under a range of climatic and socio-economic scenarios, showed large uncertainties regarding future mean sea level while discrepancies on the patterns of change are even larger (Marcos and Tsimplis, 2008b).

The above uncertainties are important for assessing the impacts of sea-level rise in the region as mean sea-level changes were found to cause the interannual and decadal variability in the occurrence of extremes (Marcos et al., 2009). This variation in sea levels represents one of the most important aspects for assessing the impacts of SLR in the coasts of the Mediterranean and the Black Sea. For many countries the effects of higher water levels will result in high impacts as: the tidal range is small, increasing susceptibility to sea-level change; the littoral strip holds most if not all economic activities; most predictions show high demographic and economic growth in the region but many countries do not have a tradition of coastal defence (Hanson et al., 2008).

## Methods

### The DIVA model

The DIVA model is a global integrated model of coastal systems that assesses biophysical and socio-economic impacts of sea-level rise and socio-economic development (Vafeidis et al. 2008; Hinkel and Klein 2009). The model operates on a linear representation of the world's coastline, which comprises 12,148 linear segments and associates about 100 physical, ecological and socio-economic parameters with each of these segments. DIVA is driven by climatic and socio-economic scenarios. The climatic scenarios consist of the variables temperature change and sea-level rise. The socio-economic scenarios consist of the variables land-use class, coastal population growth and GDP growth. The impact assessment comprises a number of modules representing physical processes and economic costings as described in Hinkel and Klein (2009). One important innovation introduced by DIVA is the explicit incorporation of a range of adaptation options;

impacts do not only depend on the selected climatic and socio-economic scenarios but also on the selected adaptation strategy. Possible adaptation strategies in the DIVA tool are building of sea and river dikes and sand nourishments for tidal basins, beaches and wetlands. Choosing no adaptation, the DIVA tool calculates the maintaining costs of existing dikes. A more detailed description of the DIVA model and database can be found in Vafeidis et al. (2008), Hinkel and Klein (2009), Hinkel et al. (2010), and Hinkel et al. (2012). In the present study, all model runs were performed using DIVA version 3.1.0 and the database version 1.5.

Socio-economic and scenarios and adaptation options

We ran DIVA using two sets of scenarios based on the IPCC SRES A2 and B1 storylines (Nakicenovic and Swart 2000), which have been selected to represent a range of potential future development directions in the region. The A2 storyline assumes a socio-economically heterogeneous world and a continuously increasing global population. Global emissions increase throughout the century. The B1 storyline assumes a socio-economically converging world; global population and emissions peak in 2050 and decline thereafter. Per capita economic growth is slower under A2 than B1. A2 can be considered a business as usual scenario, and B1 is sometimes seen as a (costless) mitigation scenario with stabilization during the twenty-second century, although formally none of the SRES scenarios represent mitigation. Therefore, A2 represents the world with higher mean air temperature and higher mean sea level rise than the B1 scenario. Moreover, the A2 scenario is more oriented towards an economic than environmental pathway with high $CO_2$ emissions in this century, where B1 scenario is more oriented towards environmental sustainable development and low $CO_2$ emissions in this century. Estimated population by 2100 is 15.1 billion under the A2 scenario, and 7 billion under the B1 scenario. Due to slow economic growth under the A2 scenario comparing to economic growth with rapid changes under the B1 scenario, expected GDP per capita is higher under the B1 scenario. A further no-SLR scenario has been used to identify impacts due exclusively to socio-economic development and relative SLR resulting from subsidence. Given that global sea levels have been rising throughout the 20th century to the present day (see Church and White 2011), this is a non-plausible scenario. However it is a useful baseline for assessing impacts and costs due only to socio-economic change and changes in relative land levels, such as natural uplift and subsidence.

The climatic component of the scenarios was derived with the climate model of intermediate complexity CLIMBER-2 of the Potsdam Institute for Climate Impact Research (Petoukhov et al. 2000). A high climate sensitivity and globally uniform sea-level rise (reflecting the uncertainties in regional projections) were assumed. Due to the slow response of the ocean to global warming, differences between the two scenarios in terms of global mean sea-level rise only become significant after the middle of the 21st century (Hinkel et al., 2010).

Each scenario set is run without and with adaptation in the form of heightening the dikes and nourishing the beaches as described above. The following simulations are available:

1. A2 sea-level rise (high) and socio-economic development; without adaptation (A2+NO)
2. A2 sea-level rise (high) and socio-economic development; with adaptation (A2+AD)
3. B1 sea-level rise (high) and socio-economic development; without adaptation (B1+NO)
4. B1 sea-level rise (high) and socio-economic development; with adaptation (B1+AD)
5. A2 socio-economic development and no sea-level rise; without adaptation (A2+NO)

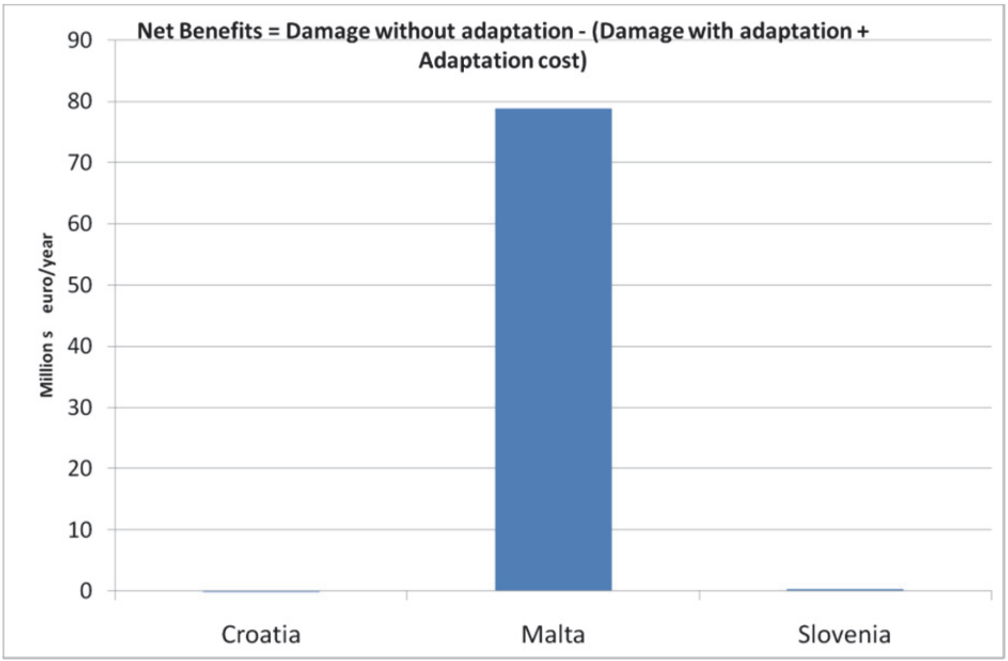
In the cases with implemented adaptation, building dikes is considered for sea flood protection with a minimum of 100 years protection from over floods, which is commonly employed for protection in many European coasts. Beach nourishment is implemented on the basis of cost benefit analysis, therefore nourishment takes place only when it is economically justified. We assumed no nourishment for the tidal basin and wetlands. When no adaptation is considered, protection against floods relies on maintaining already existing dikes. In this case no nourishment is used for beaches, tidal basins and wetlands.

## Results and discussion

The indices presented in the tables include total adaptation costs, beach nourishment costs, length of the coast, total residual damage costs, net loss of wetland areas, people at a risk of flooding, coastal floodplain population, and relative sea level change. Results are given in ten year time steps from 2010 to 2080.

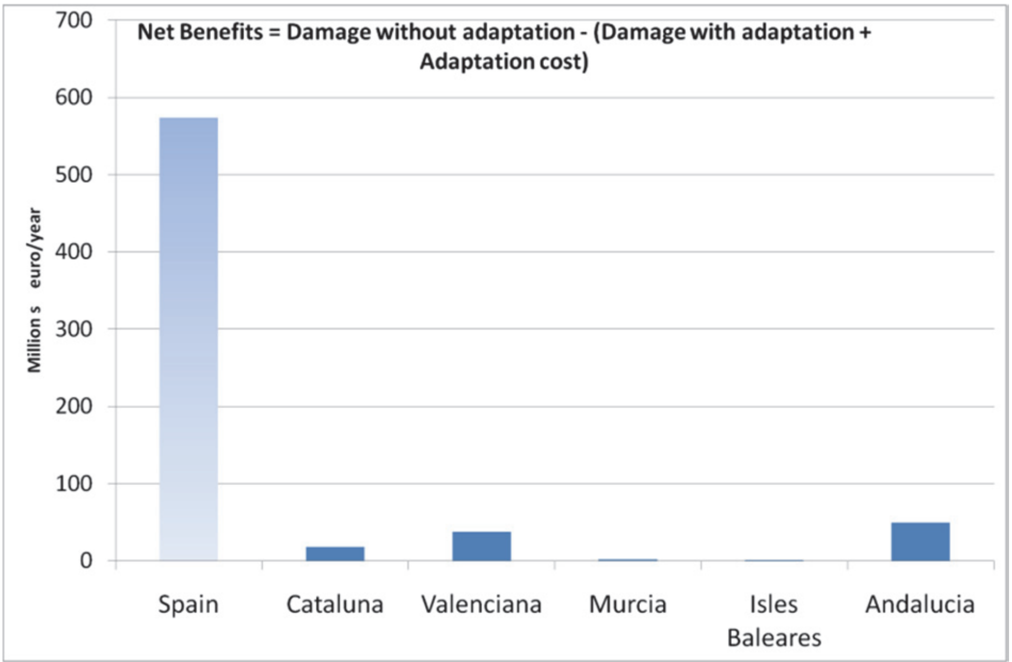
Under the A2 scenario, Italy appears to be the most heavily impacted country in terms of damages, followed by the Mediterranean parts of Spain and France and by Greece. Socio-economic development is responsible for a large proportion of the damages, mainly until the middle of the century. However, even towards the end of the century, socio-economic development still accounts for about a third of the total residual damage for Italy, under the no-adaptation scenario. In terms of people annually flooded, Italy is the most impacted country if adaptation is not implemented, with Greece following second. Under the B1 scenario, economic damages are not very different compared to the A2 (also higher in some cases) despite the lower sea-level rise. This is due to faster economic growth in B1 and therefore more assets being concentrated in the coast. The higher numbers of people flooded in A2 however reflect the higher sea levels and the faster population growth in this scenario.

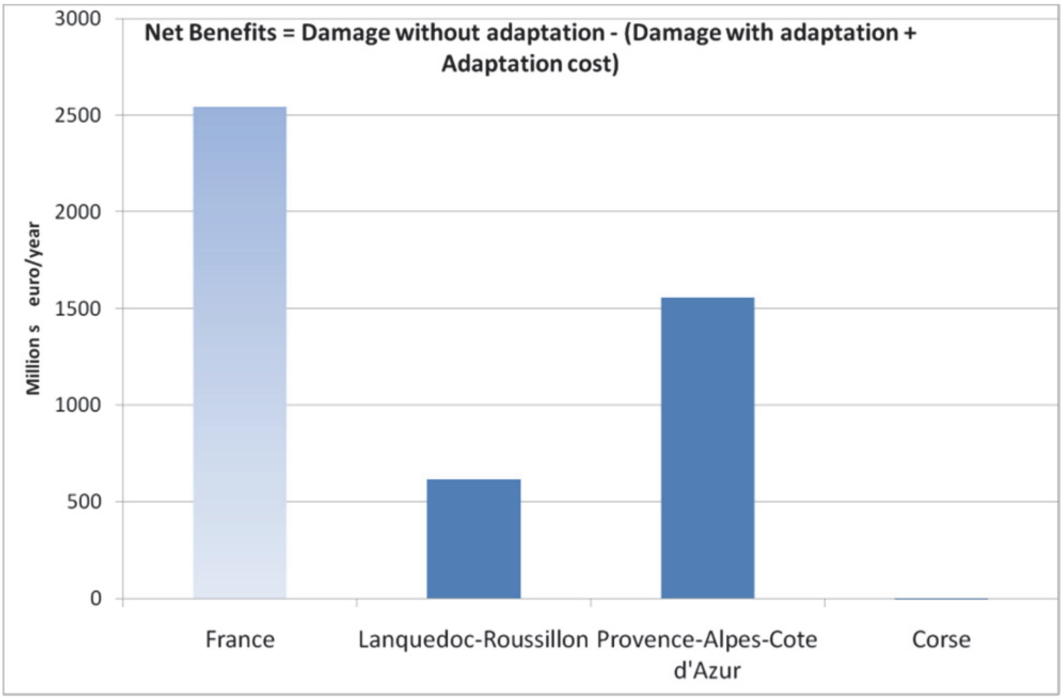
Implementation of adaptation measures, in the form of building dikes and nourishing beaches, reduces significantly the number of people flooded annually (over 10-fold in some cases). Adaptation also results in reduced damages but only becomes cost-efficient (from a pure monetary perspective) at the end of the century. This is possibly due to increasing costs of building and maintaining dikes and the large costs of monetary damages due to extreme events, which may exceed the 1 in 100 year frequency period that has been employed for building dikes. Overall, adaptation, despite not always being cost-efficient, delivers significant benefits and looks affordable as it does not exceed 0.5% of the countries' annual GDP (see also Hinkel, 2010). When taking these social impacts into account, there is a strong argument for adaptation, despite the annual costs of adaptation being higher than the costs avoided without adaptation throughout the largest part of the century. However, this also indicates that adaptation measures should concentrate in areas where there is the greatest need (e.g. densely populated regions, industrialised areas) where the cost to benefit ratio would be the highest. Finally, it must also be noted that the no-adaptation scenarios have in some cases lower damages than the adaptation scenarios. This is due to the fact that the protection level is initialised in 1995, with DIVA employing a demand-for-safety function in 1995 which is most likely higher than the 1 in 100 year value used in the adaptation scenarios.

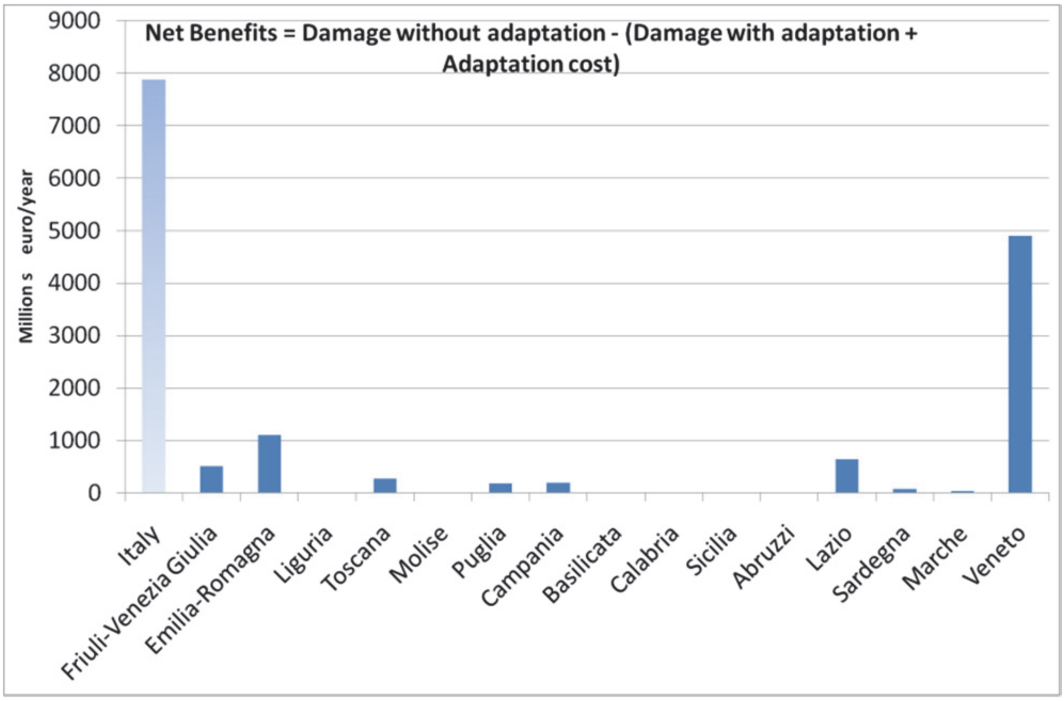


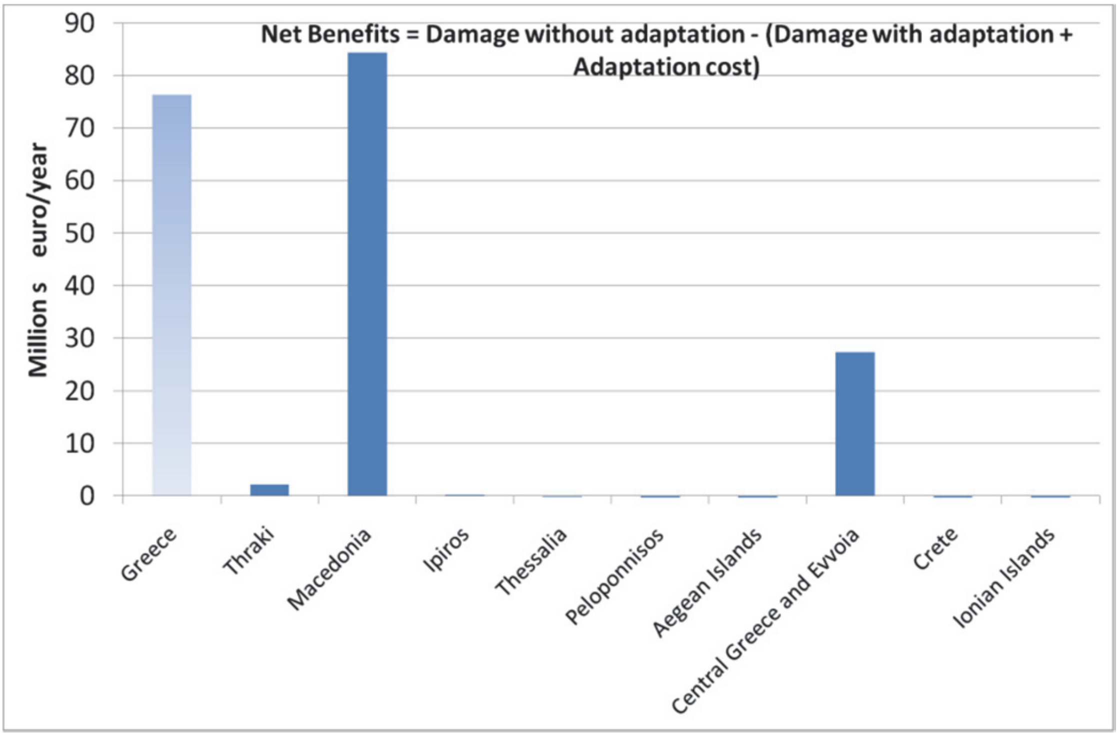

Peseta, 2009 results elaborated for Maremed Project. Values of Net benefit of adaptation measures to climate changes are subdivided for European regional coastal administrations of Mediterranean.

Scenario IPCC A2 high SLR, years 2080




Net Benefits = Damage without adaptation - (Damage with adaptation + Adaptation cost)
Million s euro/year
3000
2500
2000
1500
1000
500
0
France
Lanquedoc-Roussillon
Provence-Alpes-Cote d'Azur
Corse


Net Benefits = Damage without adaptation - (Damage with adaptation + Adaptation cost)
Million s euro/year
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Italy
Friuli-Venezia Giulia
Emilia-Romagna
Liguria
Toscana
Molise
Puglia
Campania
Basilicata
Calabria
Sicilia
Abruzzi
Lazio
Sardegna
Marche
Veneto


Net Benefits = Damage without adaptation - (Damage with adaptation + Adaptation cost)
Million s euro/year
90
80
70
60
50
40
30
20
10
0
Greece
Thraki
Macedonia
Ipiros
Thessalia
Peloponnisos
Aegean Islands
Central Greece and Evvoia
Crete
Ionian Islands

**Limitations**

We must stress that this study does not constitute in any way a comprehensive analysis of potential impacts of, or vulnerability to, SLR for the EU Mediterranean countries. Such an analysis would require a much more extensive number of model runs and a wider selection of socio-economic and SLR scenarios and adaptation strategies. Furthermore, disaggregation of results to first-order administrative-unit level may be subject to numerous data- or model-related limitations and therefore results should be viewed with caution. Further work is required to understand the implications of sea-level rise for the region. Additionally, DIVA results, especially at the level of administrative units, can be improved by using new datasets and by including information on a wider range of socio-economic pathways and adaptation options and strategies. Despite the above limitations, this study provides a first-order indication of potential impacts of SLR and the possible benefits of adaptation strategies for the EU Mediterranean countries and can be used as a starting point for further, more detailed, analysis.

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