Indicator	
27	Natural, human and economic assets at risk.

Measurement	
27.1	Number of people living in an 'at risk' zone.

What should the measurement tell us?
The coastal zones are particularly threatened by climate change. The scientific community and particularly the Intergovernmental Panel on Climate Change (IPCC), has forecast that climate change will cause: sea level rising, increased levels of inundation and storm flooding, accelerated coastal erosion, seawater intrusion into fresh groundwater, encroachment of tidal waters into estuaries and river systems and elevated sea temperatures.
This measurement will take into account the risk associated with 4 processes that can originate from or be modulated by climate change:

-   Relative sea level rising (RSLR).
 	
   -   Coastal erosion.
 	
   -   Flooding by river floods.
 	
   -   Flooding by marine storms.

Each process will induce a different type of response at different spatial and temporal scales (e.g. coastal erosion is a slow process but of permanent effect whereas flooding is a very rapid process but of a temporary nature). In consequence, to define the measures to fight or counteract them, it would be useful to analyze them separately. Finally, from the managerial standpoint, it is also necessary to consider the area affected by any of these risks, so representing the "worst spatial scenario".
It is very difficult to define a number of people of risk but the results of measurement will estimate the number of people affected by means of the prevision of the referred incidences, the topography of the coastal zone and the human occupation.
Increasingly sophisticated attempts are being made to assess that risk, in terms of both the likelihood and the severity of inundation. However, we also want to know what damage flooding will cause to natural and human resources so that we can plan appropriately.
'Planning appropriately' means *inter alia* striking the right balance between the cost of sea defences and their accruing benefits; preventing further development in areas at risk of flooding; mitigating the worst effects of overtopping and inundation by well-practiced emergency procedures and, ultimately, deciding which assets to abandon to the encroaching sea.

Parameters	
(i)	Coastal population 'at risk' zone by RSLR, coastal erosion, river flooding, marine storms flooding and any others.
(ii)	Proportion of coastal population 'at risk' zone by RSLR, coastal erosion, river flooding, marine storms flooding and any others on the population in the wider reference area.

Coverage	
Spatial	**Temporal**
Coastal municipalities strip.	Currently.

Data sources

The incidence of the climate change on the coastal zones has been evaluated by the Intergovernmental Panel on Climate Change (IPCC) http://www.ipcc.ch/. Chapter 6 of 'Climate Change 2001: Impacts, Adaptation and Vulnerability' focuses on Coastal Zones and Marine Ecosystems. Moreover, the particularity of each continent is specified (Chapter 13 for Europe).

This reference provides criteria for the establishment of the area at risk but, in general, they are not specific enough to be directly applied for delimiting the area at risk.

RSLR: The IPCC has established the evolution of the sea level throughout the century in different scenarios (parts 3.6.2-3.6.6). It presents a common estimation for all seas but the relative rise must incorporate any local component due to vertical displacement of land such as subsidence.

Inundation by river floods: Many countries have produced assessments of the areas at risk of river flooding linked to a defined return period (period with a high probability of registering the incidence that causes the risk one time). On 18 January 2006 the Commission adopted its proposal for a Directive of the European Parliament and of the Council on the assessment and management of floods (COM(2006)15 final of 18.1.2006). The directive will impose the implementation of flood risk management plans in which the first step is to take into account the areas affected. Areas likely to be inundated by river floods will be estimated from existing studies from regional/national agencies. In order to follow the proposal of the Directives, it is recommended to use the delineation of area to be inundated by the flood of 100 year return period.

Coastal erosion: In a few countries, there is an estimation of the area affected by coastal erosion. A typical example is *National Appraisal of Assets at Risk from Flooding and Coastal Erosion* (http://www.defra.gov.uk/environ/fcd/policy/NAAR1101.pdf) produced in 2001. That report computes 'annual average damage' differentially caused by coastal erosion, sea and tidal flooding and fluvial flooding under different scenarios such as, do nothing, improve defences to current standards and improve to enhanced standards. Information is presented for a NUTS 2 geography but is compiled from local data which it should be possible to obtain. Areas subjected to erosion as well as the extension of the erosion (erosion rates) will be taken from existing studies by regional/national agencies.

Inundation by coastal storms: As in the case of river floods, the area 'at risk' is related to a specified return period. The water level must include the contribution of storm surges and wave run-up. For this calculation, long time series of wave and water level data are required. When they are not available, they can be substituted by simulated and/or hindcasted data.

Finally, once the vertical data (projected inundation levels) have been obtained, it will be necessary to define a digital terrain model (DTM) of the area of study to estimate the extension of the affected area. To obtain population living in the area, we must use lists of coastal population and GIS on build-up areas. These can usually be obtained from the land planning administration.

Methodology	
Steps	**Products**
1 Overlap the most recent map of urban occupation[1] with the coastal municipality (NUTS 5) cartography and obtain statistics of the extension of residential areas by municipalities.	Residential land use area by each coastal municipality.
2 From the most recent census, obtain the population living at the coast by NUTS 5, the population living at the coast and the population of the wider reference area.	<u>Population living in coastal municipalities (the total value and also the value of each municipality)</u> and population living in the wider reference area<u>.</u>
3 Using a digital terrain model (DTM), delineate the area with direct connection to the sea located below the elevation of relative sea level rise (RSLR) in year 2100, which is 0.5m[2] modified by the local level of vertical land displacement, if it is known.	Cartography (GIS layer preferably) of the area below RSRL in 2100 at best guess.
4 Delineate the area likely to be inundated by a river flood of 100 year return period (or take it from already existing analysis).	Cartography (GIS layer preferably) of the area affected by a river flood of 100 year return period.
5 Using a DTM, delineate the area with direct connection to the sea located below the wave runup[3] of 100 year return period. The tide elevation might be combined with the run-up for a more exact value of sporadic sea water elevation on land.	Cartography (GIS layer preferably) of the area below sea water level associated to a coastal flood of 100 year return period.
6 Obtain values of coastal erosion rates (m/year). Project these rates to estimate the retreat in 2100 (the process is simplified by assuming that erosion rates will be constant during such period). In protected areas (e.g. urban zones) where coastal retreat is limited, this erosion will not be considered for the analysis (Not necessary for the measurement of population[4]).	Cartography (GIS layer preferably) of the area at coastal erosion risk for a return period of 100 years.
7 Add the risk areas associated with each process (four): coastal flooding, river flooding, coastal erosion and RSLR to obtain the area affected by any risk.	Cartography (GIS layer preferably) of area to be affected by any risk source.
8 Overlap the most recent map of urban occupation with the coastal municipality (NUTS 5) cartography and the different affected areas evaluated in points 3, 4, 5, 6 and	Extension of residential areas 'at risk' by each and any agent and by municipalities.

	7. Obtain statistics of the extension of residential areas 'at risk' by each and any agent and by municipalities.	
9	For each coastal municipality, divide the residential area of the 'at risk' zone by the residential area of the coastal municipality[5].	Portion of residential areas in the 'at risk' zone in each coastal municipality. We assume that this is a better estimation for the <u>portion of the population 'at risk' zone</u> of the population in each coastal municipality.
10	Multiply the portion of residential areas 'at risk' zone of each coastal municipality (obtained recently) by its population.	Estimated population living in the 'at risk' zone by municipalities.
11	Aggregate the population of the 'at risk' zone of each coastal municipality.	<u>Coastal population living in an 'at risk' zone by each and any agent/process.</u>
12	Divide the population 'at risk' (this includes the area of any risk) and the population of the coastal zone by the population of the wider reference area and multiply by 100%.	<u>Percentage of coastal population 'at risk' in the wider reference area</u>

Presentation of the data	
Map 1	Map representing the constructed areas in coastal municipalities and the 4 different areas 'at risk' by means of complementary plot.
Map 2	Map of coastal municipalities coloured according to the portion of coastal population 'at risk' by climate change zone and limit of global area 'at risk'.
Graph 1	Bar chart with double axes: 1 axe: Column graph showing the coastal population 'at risk' zone: RSLR, coastal erosion, river flooding, marine storm flooding and the union of these and the population in the coastal zone (5 columns). 2 axe: Points of the percentage of the 5 referred categories of population on the population in the wider reference coverage.

Population living within 'at risk' zone in xxx coast (2005)

Adding value to the data

Different risk areas might be considered according to different previsions (more or less probable). Moreover, a risk zone it might be defined on account of future protection structures.

Aggregation and disaggregation

'At risk' appraisals can be undertaken on any spatial scale.

Notes

[1] There is specific GIS cartography that contains the location of residential areas or building locations. Its level of precision is very high. If detailed cartography on urban nucleus is not available, the categories of continuous urban fabric (CORINE, 111) and discontinuous fabric (CORINE, 112) from the map of land uses could be used.

[2] The Intergovernmental Panel on Climate Change (IPPC) forecasts that in 2100 the sea level will rise 20-90 cm around the world. A more probable scenario is 38 cm. The option that has been taken for this methodology is the level of 50cm instead of 38cm, because we do not use a level of precision in cm. In addition to absolute sea level modification, there is a vertical displacement of land, with local values.

[3] The wave runup is the temporary elevation of sea level rise when the wave reaches and progresses on the land . It is the sum of setup, the time-averaged water-level elevation at the shoreline due to waves (excluding tides and surge), and swash, the time-varying, vertical fluctuations about the temporal mean.

The most correct parameterisation of the runup is exposed in "Predicting the Longshore-Variable Coastal Response to Hurricanes" - Stockdon, H.F., Holman, R.A., Howd, P.A. & Sallenger Jr, A.H. 2006. Empirical parameterisation of setup, swash, and runup. *Coastal Engineering*, 53, 573–588.

 The elevation of runup maxima has been shown to be dependent on deep-water wave height (H_0), wave period (T_0) and the foreshore beach slope (β_f). The elevation of the 2% exceedence level for runup, R_2, can be calculated using the empirical parameterisation:

$$R_2 = 1.1\left(0.35\beta_f (H_0 L_0)^{1/2} + \frac{[H_0 L_0 (0.563\beta_f^2 + 0.004)]^{1/2}}{2} \right)$$

where L_0 is the deep-water wavelength, defined as $gT_0^2/2\pi$ [Stockdon et al., 2006].

(This equation is extracted from *of the* Abstract of dissertation of Hilary F. Stockdon for the degree of Doctor of Philosophy in Oceanography presented on April 5, 2006. More information in part *4.4.3.3. Estimation of Wave Runup and Setup,* p.83
http://ir.library.oregonstate.edu/dspace/bitstream/1957/1930/1/stockdonPhdThesis2006.pdf,)

For calculating the runup for a return period of 100 years, the values of two required features of waves must be used: deep-water wave height (H_0), wave period (T_0) related to such return period. Therefore, these values must first be estimated from an existing extreme wave climate in each tide gauge available in the coastal area covered. The extreme wave climate is an analysis that provides the probabilistic Weibul function, which relates return periods to wave heights.

In most cases, it will be adequate to calculate the equation with two slope characteristics of the beaches of the selected area: one for reflective, steep and coarse sediment and one for dissipative, mild and fine sediment.

It would be necessary to consider the contribution of the meteorological tide to the run-up. To do this, we shall need a simultaneous water level (ξ) time series of a joint storm-surge wave distribution to associate a probability to each pair of H and ξ, but this is complicated. The value of H used in Stockdon's runup equation might be the sum of both components: height of wave and tide elevation The procedure to include this component to the previous one will be simply adding the value associated with the selected probability to the estimated runup.

[4] If we have to do calculations using the GIS of land uses, because it is the only one available, we initially have to obtain two different coefficients from an 'at risk' zone: one for urban fabric and the other for a discontinuous fabric 'at risk zone'. From the both coefficients, we will obtain the portion of population in the 'at risk' zone from the population of each coastal municipality. For this purpose we have to consider that the density of population in the urban fabric category is higher than the density in the discontinuous fabric category. We therefore apply a factor for a weighted average. It consists of multiplication of the urban fabric coefficient by x, aggregation of the discontinuous fabric coefficient and division of all by x+1. A suggested value for x is 4.

5 Because urban areas are protected, this area cannot be included. Its inclusion or elimination will not affect the value of the population at risk. Consequently, it is not necessary to obtain this area for calculating this measurement. It has been included in defined steps because it is an area that conceptually belongs to the area at risk and it is common for the three measurements.