RECHERCHE
EspacesTemps.net
CONTACT
NEWSLETTER
LES CAHIERS

http://www.espacestemps.net/index.html

Integration of the risk of heritage loss into the vulnerability assessment of the South Brittany coast (France): implications for coastal vulnerability analysis.

Soazig Pian[a], Hervé Regnauld[a] Marie Yvane Daire[b], Jean Noël Proust[c], Benheng Shi[c], David Menier[d], Elias Lopez Romero[b]

[a] *COSTEL, UMR 6554 LETG, UFR CAREN, Rennes 2 University, Campus Villejean – Maison de la Recherche – Bat N, Place du Recteur Henri le Moal, 35043 Rennes Cedex, France, email:* soazig.pian@uhb.fr, herve.regnauld@uhb.fr, *Tel : +33 299141847, Fax : +33 299141895*

[b] *Archéosciences, UMR 6556 CReAAH, CNRS, Rennes 1, Rennes 2 & Nantes University & ministère de la culture, UFR CAREN, Bat. 24-25 Campus Beaulieu, 35042 Rennes cedex, France, email :* marie-yvane.daire@univ-rennes1.fr, lopezelias@ya.com

[c] *Geosciences, UMR 6118 CNRS – Rennes 1 University, Campus Beaulieu, 35042 Rennes cedex, France, email :* jean-noel.proust@univ-rennes1.fr

[d] *Geoarchitecture, EA, 2219, Bretagne Sud University, 56017 Vannes Cedex, France, email :* david.menier@univ-ubs.fr

Abstract

In a context of relative sea level rise, coastal societies are more and more concerned with the increasing threat of shoreline retreat. In the same time, climatic changes, over different time and space scales, lead to new interrogations in regards to risks assessment: risks evaluations as well as risks adaptation and management have to be reviewed.

To evaluate the degree of coastal vulnerability resulting from shoreline retreat, current studies apply a geographic economic approach which attempts to attribute a monetary value to anthropogenic components located on the coast. According to this method, the vulnerability of the coast is generally defined as a function of its monetary value. Consequently, such an approach does not allow for the integration in the analysis of the risk of no famous archaeological heritage losses, which are considered, in this paper, as anthropogenic objects with no monetary value for society but which nevertheless represent objects of scientific interest and a source of knowledge.

This paper proposes to assess in which extend the introduction of the no famous archaeological sites could impact coastal vulnerability analysis. To doing so, a method has been performed, allowing to analysis coastal vulnerability in South Brittany with and without taking into account the risk of archaeological loss. Results put forward that the integration of the risk of heritage losses when mapping coastal vulnerability could increase the vulnerability of the coast and the stretch of coastline which has to be protected. This simple observation leads to more complex discussions dealing with coastal vulnerability analysis. Firstly, it highlights the fact that the degree of vulnerability likely to characterize the coast is highly dependent on the definition of the anthropogenic features incorporated in the analysis. Consequently, coastal vulnerability analyses appear very subjective. Secondly, it put into evidence that the number of archaeological sites to protect can increase with time when the coast retreats. The location of these sites can hardly be established before the coasts have retreating. This last point contributes to increase the uncertainties associated with risks assessment in a context a global changes. In such a context, we assume that a dynamic coastal management approach such as adaptive management is needed to coop with this increasing complexity.

Introduction

Risks associated with natural hazards have been widely studied by social sciences which have developed numerous concepts to identity, describe analysis and quantify the vulnerability of human societies *(Pigeon, 2005)*. In the current context of global change, numerous studies are undertaken in order to assess specific risks linked to climatic changes and relative sea level rise (RSLR). In France, Lamarre (2008) has synthesised most of these researches and has put forward that the risks associated with climatic changes are characterised by a high degree of incertitude which make their analysis and their prediction very difficult. For instance, usual concept such as the frequency/intensity pair are likely to be not relevant as there is no accurate knowledge of what intensity might be and scenarios about possible frequency are highly debatable. Climatic changes, over different time and space scales, lead to new interrogations with regards to risks assessment: risks evaluations, adaptation, management and mitigation should be reviewed. As coastal systems are highly sensitive to climatic changes, such interrogations are likely to affect the analysis of coastal vulnerability associated with coastal hazards.

According to a brief review of recent works, in a context of climate changes and (RSLR), the vulnerability of a coastline is defined in relation to the amount of anthropogenic features that can be threatened by the forecasted coastal changes (*Klein et Nichols, 1999, French, 2001, Ferreira* et al., *2006, Alphar, 2008, Snoussi, 2008)*. Losses of anthropogenic features are often quantified by using a Cost Benefit Approaches (CBA) (*El-Raey, 1997, Carter, 1999,* Williams, et al., 2001, *French, 2001, Nicholls, 2004, De Pippo,* et al., *2007)*. The CBA can be broadly defined as a monetary approach, evaluating costs and benefits linked to both coastal changes and different management strategies likely to cope with the forecasted coastal evolution. Such an approach can hardly integrate the loss of non-economic valuable objects in the analysis, even if numerous attempts have been made in order to quantify losses induced by landscape changes, especially in recreational areas *(Saengsupavanish,* et al., *2007)*. Thus, anthropogenic objects which do not fit into a direct or indirect given land use or economic activity are not considered as anthropogenic objects likely to add vulnerability to the coast. However, such objects are of great importance and they are highly threatened by coastal retreat, especially in the context of RSLR. Examples of such objects are coastal heritage sites seated along retreating coastlines. The most famous of them such as as the standing stones of Carnac in Brittany, which draw visitors and create wealth, would obviously be integrated in a CBA approach. However, coastal heritage sites with no tourist interest, only visited by scientists and composed, for instance, of prehistoric shell midden or burials, Gaulish salt workshops or villages, buildings of the Roman period, fishtraps ... are never taken into consideration when assessing damages linked to coastal retreat. Such sites are not monumental remains and thus do not attract visitors and do not produce wealth. However, such heritage sites represent an interest for coastal societies. Indeed, they represent a source of knowledge about the history of human activity and their study will enhance our understanding of anthropogenic coastal systems functioning. This last point can in turn improve our understanding of coastal hazard occurrence and enhance risks assessment analysis.

In such a context, this paper proposes to assess the risks of coastal retreat associated with RSLR by taking into consideration the loss of archaeological heritage. It provides a method for mapping coastline retreat in a context of RSLR and assesses the vulnerability of the coast by integrating the risk of archaeological heritage loss. Results are discussed in order to assess how the introduction of such new parameter could modify both management practices and risks assessment perceptions.

The study focuses on sandy beaches and weathered cliffs, located along the coasts of the *presqu'île de Rhuys* and the *baie de Vilaine*, in South Brittany *(figure 1 and 2)*. These sites have been retained because different databases concerning both the geomorphologic behaviour of the coast and the coastal heritage sites location were available.

I. Presentation and localisation of the coastal sites.

The area under study encompasses two sites, located in South Brittany and characterised by different geomorphological settings. The first site refers to a large bay, exposed to prevailing winds and waves. The second one is mainly composed of weathered cliffs, fronted by a sandy beach. Both of these sites experience a similar waves and wind climate.

I.1. Waves and wind climate

The South coast of Brittany experiences a wind climate dominated by westerly and southerly winds. Winds records at Belle-Île, located about thirty kilometres seaward of the site under study, indicate that the strongest winds come from the South and West *(Pirazzoli* et al., *2000, Pirazzoli at al, 2004)*. Prevailing waves are characterized by a height ranging from 0.5 m to 2.5 m with a period of 5 to 9 seconds. They mainly come from the Northwest and West. Moreover, the coastline in South Brittany may experience violent storms. Such strongest waves generally come from the West and South West *(Tessier, 2006)*.

I.2. Site 1: the beach-dune barrier of the Presqu'île de Rhuys

The first site is composed of a sandy beach-dune system, located in the *Presqu'île de Rhuys (figure 1)*. It broadly extends from the *domaine des grêves de Suscinio* to the Beg Lann and then Penvins Headlands, which is composed of weathered periglacial deposit cliffs not exceeding 2m high. The beach barrier is composed of heterogeneous sediments ranging from pebble deposits to fine sand. The *Presqu'île de Rhuys* is exposed to the swell and storm waves coming from the South. Seaward extend a complex pattern of submarine rocks and skerries. Beach barriers are backed by sand dune systems and wetlands. Human settlements are reduced in this sector, except Southwest of Suscinio and around Penvins. Beaches are used for recreational purposes during summer time.

I.2. Site 2: Weathered cliffs system of Penestin.

Site 2 *(figure 2)* is located in the East of the *Baie de Vilaine* and refers to a weathered cliff system fronted by a sandy beach, fed to a large extent by the erosion of the cliffs. The coast is exposed to the prevailing winds and waves coming from the West and the South.

Maximum cliff height is around 8 m. Cliffs are elaborated within weathering rocks. Cliff face is divided into three lithostratigraphic units overlying the micaschist basement, from base to top: soft clays of in thick lateritic soil profile, fluvial and tidal gravels, sands and silts, and periglacial loss. The thicknesses of these different units vary along the cliff, leading to the occurrence of different rates of cliff retreat. Cliff evolution depends on folds and /or strike-slip fault *(Brault* et al., *2001).*

The pressures exerted by human activity is important with a footpath running all along the top of the cliffs and backed by newly developed building.

II. Method

The method performed to analysis coastal vulnerability is based on the principles and methodology developed by the Intergovernmental Panel on Climate change *(IPCC – CZMS – 1992)* and discussed by Vellingar & Klein *(1993)*. Three majors steps have been followed:

1. Assessment of current coastal changes and current erosive processes (step 1)
2. Mapping of coastal retreat in a context of RSLR (step 2)
3. Identification of anthropogenic components likely to be damaged by coastal retreat and evaluation of vulnerability profiles (Step 3)
4. Classification of the vulnerability profiles.

Steps 3 and 4 have been run two times. The location of threatened coastal archaeological sites on the coast was only considered the second time in order to assess the effects associated with the introduction of this last parameter.

II.1 Field work data (Step 1)

Depending on the geomorphological setting of the studied sites, different measurements and observations were carried out between November 2006 and June 2008.

In the *Presqu'île de Rhuys*, a beach profiling campaign was undertaken in 2007 and 2008. At a monthly or bimonthly rate, around 10 beach profiles were levelled between winter 2007 and summer 2008, from the dune toes to the lower water level. These profiles were used to compute beach slopes in order to integrate this parameter in the shoreline retreat model. The beach profiling campaign also provided data about the behaviour of the beach face and front dune evolution on a short time scale. From these data, the front dune evolution appears as the most mobile geomorphologic feature, recording evidences of erosion.

Field work carried out on Penestin cliffs essentially aimed at identifying the main processes controlling cliff retreat. The was visited at regular time intervals both in summer and winter to examine the location of the main marks of retreat on cliff and to deduce the main processes acting on the cliff slope. As previously discussed by *Durand and Millon* (1955), our observations put into forward that cliff retreat is mainly driven by sub aerial processes, and waves action is reduced, in a large extend, to mobilise sediments delivered by cliff retreat.

II.2. Measurements of shoreline migration from air photographs (Step 1)

The use of aerial photographs in coastal studies has been widely discussed *(Moore, 2000, Williams* et al., *2001, Graham et al, 2003, Fletcher, et al, 2003, Duffy et al., 2005)*. They allow mapping coastline movements using geomorphologic indicators whose migration during the considered time interval is assumed to represent coastal evolution *(Carter, 1999, Moore, 2000, Parker, 2003)*. On macro and meso coasts, foredune vegetation lines, foredune feet or cliff tops are considered as relevant geomorphological indicators and are often used *(Battiau Queney et al, 2002, Robin, 2002, Ferreira* et al., *2006, Anfuso et al, 2007, Kroon et al, 2007)***.** In this paper, foredune vegetation line and cliff top indicators were used.

Different time series of aerial photographs and three orthophotograph were available for this study, from 1952 to 2004. Coastline variations trends were measured and mapped by comparing the 1952 and 2004 documents. The other time intervals were used only to check that these 52 years trends were coherent with shorter time intervals. Table 2 summarizes the main characteristics for each of these photographs.

Table 1: main characteristics of the air photographs used.

	Available documents	Scale of air photographs	Tidal range	Season	Scan resolution
1952	8 aerial photographs	1: 25 000	Low tide	Late spring time	1 000 dpi
1985	5 aerial photographs	1: 30 000	Low tide	Late spring time	1 200 dpi
1999	Orthophotograph		Low tide	Early summer time	
2000	Orthophotograph		Low tide	Early summer time	
2004	Orthophotograph		Low tide	Early summer time	

The aerial photographs were scanned with a spatial resolution of 1200 dpi and then georectified, using ArcGis9.2 software. Once photographs were geo-rectified, mosaics were carried out using Envi3.0 software. Then, the dune vegetated toes or cliff tops were plotted on each document as a polyline by means of the ArcGis Editor tool. Afterwards, for each site, polylines representing the shoreline position in 1952 and 2004 were merged on a new layer using ArcGis toolbox functions and then converted into a polygon layer. The dynamic behaviour of the coastline was then determined by measuring the area lying between two different polylines. The values of the error margins linked to the geo-rectification and digitalization processes were extracted from the measured areas and rates of shoreline migration were computed from these data.

Table 2: Margins of error determining the accuracy of plotted shoreline position in 1952 and 200

	RMS in m	Cell size in m	Total error in m
Presqu'île de Rhuys – 1952	4.33	0.85	5.20
Bay of Vilaine – 1952	4.26	0.71	4.97
Orthophotograph 2004		0.5	0.5

II.3. Modelling shoreline retreat in a context of RSLR (Step 2)

The behaviour of the coastline faced with RSLR is highly dependent on the geomorphologic features characterising the coast *(Carter, 1999, Masselink, 2003)*. Thus, this paper has performed a method for mapping coastal retreat, which can be applied and easily adjusted to both beach-dune and cliff environments. The method is based on a compilation of previously used empirical models which propose geometrical coastline evolution schemes and match quite well with coastline evolution field data *(Durand and Heurtefeux, 2006, Ferreira* et al., *2006, Suanez* et al., *2007).*

The method follows two major steps:

First, the rate of shoreline migration measured from aerial photographs from 1952 to 2004 is extrapolated to 2100. This suggests that the coastline behaviour observed between 1952 and 2004 reflects a general trend likely to continue in the near future. Such a supposition appears logical for coastal cliffs as long as they are made from homogenous rocks, like the Penestin cliffs. It could appear more questionable when it comes to beach dune systems. However, previous works *(Regnauld* et al., *2004)* have shown that the beach-dune system of Suscinio observes very regular time behaviour. Secondly, the increase of coastal retreat linked to RSLR has been computed and added to the previous results.

1. Extrapolation in time

The method is based on the work of Ferreia *et al*. (2006). When attempting to model set-back lines in a context of RSLR, these authors have proposed to predict the shoreline position likely to characterize the coast under study in 2100 (S1) with equation (1) where *t* referred to the duration of the forecasted period and *r* to the shoreline migration rate between 1952 and 2004.

Equation (1): $S1 = t*r$

2. Addition of RSLR effects

Then, the shoreline behaviour likely to be induced by RSLR has been computed and added to the previous retreat model. Currently, most studies dealing with this question are focusing on shoreface and beach evolution *(Liu, 1997, Kont et al, 200, Ferreira* et al., *2006, Snoussi* et al., *2008)*, and are based on the Bruun rule which presents a geometric model to forecast beach retreat due to RSLR. However, this model has been the focus of severe criticisms *(List et al, 1997, Cooper et al., 2004)*. Suanez et al., (2007), following Durand and Heurtefeux (2006) proposes an alternative and easier method for measuring shoreline retreat due to RSLR (S2). This method takes into account the rate of shoreline migration (r), the value of sea level forecasted for 2 100 (E21), the annual value of sea level rise during the XX^{th} century multiplied by the duration of the prediction (E20) and the slope of the beach expressed in % (P).

Equation (2): $S2 = r\,[(E21 - E20)/ P]$

Thus, the equation used to model coastal retreat by the year 2100 is written as:

(Equation 3): $S_{2100} = S1 + (r\,[(E21 - E20)/ P])$

Adaptation of the model to a cliff environment

To assess the vulnerability of Penestin coast, equation (2) was modify in order to be adapted to cliff environments. The beach slope parameter was removed from the model and the cliff slope value was not integrated because all the cliffs under study have a quasi vertical slope. Moreover, the weathered cliffs of Penestin retreat at different rates along the coastline. In order to take into account these differences, the coastline was divided into different sectors and a mean rate of shoreline migration was computed for each sector. Thus, the shoreline position for cliffs environments (Sc) was computed using the following equation (4):

Equation (4) : $Sc = S1 + (r\,(E21 - E20))$

Adaptation of the model to a beach-dune environment

When modelling the coastline migration in a beach-dune environment, another modification should be added to the model. In such an environment, the shoreline can both retreat and hence move landward, or advance and thus move seaward. When the beach-dune system undergoes shoreline advance, RSLR can reverse or slow down the coastal accretion trends. In order to cope with these different situations, the model has been rewritten as following:

Equation (5): $Sb = S1 - (r\,[(E21 - E20)/ P])$

where r is expressed as a negative value when the shoreline retreats and as a positive value when the coastline advances. For each accretional site, two scenarii were modelled: in case 1, accretional rend is not reversed although in case 2 it is.

Effect of storm wave

Numerous morphodynamic coastal studies *(Lozano* et al., *2004*, *Houser* et al., *2008, Frihy* et al., *2008, Sedrati* et al., *2008)* have put forward that significant changes in coastal environment occur during storm events, characterized by strong and energetic winds and waves *(Forbes* et al., *2004)*. These studies have shown that important quantities of sediments are moved under storm conditions, leading to important accumulation or erosive processes on the coast.

Holman (1986) has elaborated an expression to compute the wave setup parameter which broadly refers to the piling up of water against shoreline due to wave. It is caused by the breaking wave driving water landward *(Masselink* et al., *2003)*. Later, Komar (1998) has modified this initial formula to integrate both the wave set-up and run-up, hence computing the effective maximum reach of wave stress on the shore. Following a number of recent studies such as Benavente et al., (2006), Ferreia et al., (2006) or Suanez et al., (2007), this paper proposes to use Komar's formula (1998) to compute the wave set-up parameter (η) characterizing the area under study during storm events. In Equation (6), H and T are the maximum wave height and its corresponding period in deep water, and $\tan\beta$ is the mean beach slope.

Equation (6): $\eta = 0.36g^{0.5} H^{0.5} T \tan\beta$

II.3.Identification of anthropogenic features (Step 3)

This paper has focused on major anthropogenic features located on the coast and usually taken into account in coastal vulnerability studies. Anthropogenic components likely to be affected by the coastline retreat were inventoried from aerial photographs *(Williams, et al., 2001)*. The analysis of the 2004 orthophotograph has allowed to identify the presence of footpaths, human settlement or developments, agricultural lands, private properties, touristic resorts, car-parks or other hard structures linked to human uses, located within a buffer zone of 100m around the current position of the coastline.

These anthropogenic features were ranked into two categories. Category 1 concerns the presence of current human developments, agricultural lands, and all private or hard structures linked to present human uses. It refers to anthropogenic features which can be hardly be lost or moved without involving a high cost for society or individual. Category 2 includes anthropogenic components which can be more easily moved landward, such as footpaths or camping sites.

Then, the location of threatened coastal archaeological sites was taken into consideration. Regarding site 1, the list of the heritage sites present on the coast was given by the Regional Agency of Brittany Archaeology *(Culture Ministry)*. Concerning site 2, the location of archaeological sites on the coast was conducted by us on the basis of formerly published data *(Gauthier, 2006)* and then integrated into a geo-referenced database. For the purpose of this study, all coastal archaeological sites were considered as having the same scientific value, since their disappearance would lead to the loss of a source of knowledge. In addition, they can not be moved before having been hollowed and analysed without loss of scientific information. Thus, they were included into category 1.

II.4. Evaluation of coastal vulnerability (Step 4)

To determine the vulnerability of the coast, a qualitative grid associated with different degree of vulnerability was performed. The grid recognises three degrees of coastal vulnerability. The first and higher degree was associated with the presence on the coast of anthropogenic features member of category 1. A medium level of vulnerability was assigned to the coast when it was only occupy by anthropogenic features of category 2. The third and lower degree of vulnerability is archived when no anthropogenic feature is threatened on the coast.

To map the vulnerability of the coast, the forecasted coastline previously computed was displayed for each site upon the orthophotograph dating from 2004. Afterwards, a visual analysis was carried out aiming at identifying the class and the amount of anthropogenic features located between the current position of the coastline and the set back line defined for 2100. When one or more anthropogenic features recorded on the coast belong to category 1, the higher degree of vulnerability was assigned to the coast. In the same way, when one or more anthropogenic features belong to category 2, the medium degree of vulnerability was allocated to the coast. When no anthropogenic feature was found a degree of vulnerability null was credited.

The mapping process was carried out twice. The first time, no threatened coastal anthropogenic sites were taken into consideration. The second time, the risk of archaeological heritage losses or damages was added to the analysis. For this second mapping, sites located within an only buffer area of 100m from the shoreline were retained. Such a limit corresponds to the French law which controls human developments within a belt of 100m in a landward direction *(Bécet & Rezenthel, 2004)*.

III. Results

Main results obtained from the different steps of the performed method are displayed below.

III.1 Shoreline evolution rate between 1952 and 2004

In the *Presqu'île de Rhuys*, beach-dune systems have been undergoing erosive processes during the last fifty years. The total eroded area on the whole sector reached 5 158 m² between 1952 and 2004 which broadly corresponds to a mean rate of retreat of around 0.07m/year *(table 4)*. This sector also experienced some local coastline advance between 1952 and 2004 which indicates local sand accumulation in the beach profiles upper parts and dune vegetation growth. The accretion total area over the considered time interval reaches 5 930m², with an annual mean rate of advance of around 0.14m/yr.

	Total area	Mean shoreline movement value (area / length)	Mean rate of shoreline migration
Accretion area	5 930 m²	7.28 m	0.14 m/year
Erosion area	9 158 m²	3.74 m	0.07 m/year

Table 3: Mean values of shoreline retreat and advance, computed by taking into account the whole area of the two studied sites – Site 1 Presqu'île de Rhuys -

Cliffs located at Penestin retreat at different rates according to both local human pressures and geomorphological settings such as folds, strike-slip and variations of facies. These various rates were integrated into the model by sorting them into two main classes using the natural break method. The first category encompasses coastline retreat less than 50m and represents around 87% of the coastline under study *(figure 4)*. The second category concerns coastline retreat exceeding 50 m. For each class, a mean retreat rate was worked out and later used to forecast the evolution of the coastline *(table 5)*.

Table 4: Main characteristics of shoreline movements between 1952 and 2004 at Penestin

Category 1 – cliff retreat lenght < 50 m	Category 2 – cliff retreat lenght > 50 m
87% of the studied coastline	13% of the studied coastline
Mean cliff retreat = 11 m	Mean cliff retreat = 97 m
Mean rate of retreat (r) < 0.2m/year	Mean rate of retreat (r) > 1.8m/year

III.2 Predicted shoreline position obtained from equation (4) and (5)

The shoreline position for 2100 was worked out for each site. For the *presqu'île de Rhuys*, erosion and accretion sectors were separately processed although for Penestin only the cliff retreat was modelled.

Equations (3) et (4) was applied by taking into account the shoreline evolution rate measured in the previous section. Following Suanez *et al*. (2007), the value of E20 was computed from data taken from Pirazooli (2000). To calculate the value of E21, the predictions of sea level rise for 2100 computed by IPCC (2007) were used. These predictions range betweenfrom +0.13m to +0.58 m. This last higher value was used in order to determine extreme values of shoreline retreat.

.

	R	S1 – (eq 1)	Sc or Sb (eq 4 & 5)
Presqu'île de Rhuys			
Accretion areas- *case 1*	0.14 m/year	13.44 m	**+ 13.45 m**
Accretion areas- *case 2*		13.44 m	**+ 13.43 m**
Erosion areas	0.7 m/year	6.72 m	**- 6.76 m**
Penestin			
Category 1	0.2m/year	19.2 m	**- 20 m**
Category 2	1.8m/year	172.8 m	**- 174 m**

Table 5: Shoreline position forecasted for 2100 by taking into account both current processes driven by shoreline evolution and the retreat due to RSLR.

Equation (5) was worked out for site 1, by taking into account the maximum significant wave height recorded at Belle-Îîle and its associated period. The wave set-up parameter reaches 3.56m and was used in order to map the maximum reach of storm waves in 2100.

The wave setup parameter is then used to create a buffer zone in the landward direction around the shoreline position obtained with equation (4) for the beach-dune system of Suscinio. The extreme set back line associated with the position of the shoreline in 2100 is thus computed by adding results of equations 4 and 5. For the cliff system, the influence of storm waves was ignored since cliff retreat is mainly controlled by sub aerial processes and the model does not consider the effect of wave attacks on the cliff feet.

III.3 Coastal vulnerability – Case 1

For each site of interest, a map was established with values obtained from equation (4), (5) and (6). On these maps, *(figures 5 & 6)* different categories of vulnerability were defined according to the amount and category of anthropogenic features likely to be threatened by coastline retreat. The first graphical band shows the vulnerability of the coasts to shoreline retreat in a context of RSLR, without taking into account the risk of heritage loss.

On the *Presqu'île de Rhuys*, where dune systems and wetlands remain free of human settlements, the vulnerability of the coast is not important. Few areas are concerned by a high degree of vulnerability, except the eastern coastline where the spatial distribution of properties and settlements is denser.

On the other hand, the cliff system of Penestin is much more settled and, as a consequence, experiences a more severe degree of coastal vulnerability. Indeed categories 2 and 3 are well represented and, all along the coast, cliff retreat is threatening pathways, roads, agricultural lands or properties.

Figure 5

Figure 6

III. 4. Coastline vulnerability including the risk of cultural heritage loss – Case 2

When taking into account the risk of heritage loss, the map of coastal vulnerability displays some differences. For both sites, the introduction of this new parameter has led to a local increase of coastal vulnerability *(figures 5 & 6, graphical band 2).*

Such phenomena are well represented in site 1 where human pressure features are less important. Indeed, the coast is mainly composed of an unsettled barrier system backed by sand dunes and wetlands no longer used for agricultural purposes. As a consequence, a low degree of vulnerability was first assigned to the coastline. But, in two specific areas, the presence of archaeological sites within the wetlands, likely to be threatened by coastal retreat, led to a slight increase of the vulnerability.

In the same way, in the cliff system of Penestin, in three different and local areas, the coast appears more vulnerable when taking into account the risk of heritage loss.

I. Discussion

The method preformed has allowed mapping the coastline vulnerability to shoreline retreat in a context of RSLR by integrating the risk of archaeological loss. It is to be noted that this remains a qualitative method which could be developed further by integrating more variables related to anthropogenic factors, such as the effects of land uses or planning policies. However, such developments do not belong to the scope of this paper whose main aim is essentially to show how the integration of usually poorly considered new anthropogenic variables, can affect the definition of coastal vulnerability.

Results obtained have put into evidence that RSLR is not expected to modify to a large extent the current trend of the shoreline evolution at Suscinio and Penestin. Thus, coastal vulnerability appears to be more influenced by current coastal processes and by anthropogenic features likely to be affected by shoreline retreat than by RSLR. In this context, the degree of vulnerability likely to characterise a given stretch of coastline appears closely related to the definition of the anthropogenic components integrated into the analysis as well as to the value they are given. Amongst these anthropogenic features, cultural heritage and especially archaeological remains seems to be of some importance. When an economic approach, as a CBA approach, is adopted, an "objective framework" can be used in order to assign a precise monetary value to each item. Thus, the map showing which of these components are threatened may become an effective tool to predict the cost of possible damages. However objects not related to economics are left out of such an "objective framework", despite the fact that they are able to provide scientific knowledge. We argue that the scientific value of coastal archaeological sites, famous and non-famous, could be of great importance for coastal studies since they are likely to provide data about the past occupation of the coastal fringe and hence improve our understanding of the feedback occurring between anthropogenic components and physical factors on a long time scale. In this way, the study of coastal archaeological sites could lead to improving the knowledge of the functioning of highly anthropogenic coastal systems, a mechanism that is still not fully understood *(Nordstorm, 2000)*. Thus, when taking into account objects with no monetary value, such as non-famous cultural heritage sites, the definition of coastal vulnerability is likely to become much more subjective since it depends on the value the scientist will attribute to these objects. On the other hand, the choice of restricting the analysis to an economic geographical approach only, also relies on a subjective choice. Therefore, the measure of the coastal vulnerability appears clearly to be related to the subjectivity of the researcher in so far as the results obtained depend on both the hypothesis and method which support the analysis.

In addition, the differences displayed by figures 5 and 6 highlight the fact that the location of a threatened archaeological site along the coastline could locally increase coastal vulnerability. Such sites usually occupy very local spaces and by consequently the vulnerability increases only on a very local scale. However, when dealing with coastal management, it would make sense to consider the entire stretch of coastline characterized by an increase of coastal vulnerability induced by the presence of coastal archaeological sites. This would help keeping coherent coastal management plans. To protect some archaeological sites from coastal retreat, managers will thus have to prevent a larger part of sand dune or cliff from erosive processes. To be efficient, the management will have to take into consideration the geomorphological functioning of the coast and thus protect the whole considered geomorphological shape. On beach-dune environment, the sediment cell is recognised as the relevant spatial unit for coastal management *(Cooper et al., 2001)*. Therefore, coastline management should include the whole sediment cell where the threatened archaeological site is located. On cliff environment, management plans would focus on the cliff face geologic structure in order to determine homogeneous stretch lines likely to retreat at the same rate. It follows that the introduction of these new parameters could produce very different maps of coastal vulnerability, leading to the need of protecting stretches of coastline which were not considered as vulnerable when the risk of heritage loss was not taken into account. In addition, as most of the coastal strip archaeological remains have been discovered after the coast had retreated, it can be stated that any coastline retreat could in theory lead to the discovery of “new” archaeological sites, especially if we assume that South Brittany has possibly been established at some time during the late Pleistocene or Holocene periods. Thus, the stretch of coastline which could be protected until coastal archaeological sites have been studied is likely to increase with time. This last point increases uncertainties associated with coastal risks management and make more complex decisions making processes: the definition of coastal vulnerability is evolving both in time and space according to the nature of anthropogenic components integrated into the analysis *(Hooke, XXX)*. In addition, because we have no information about the spatial distribution of undiscovered archaeological sites, uncertainties associated with the prediction of coastline vulnerability is hardly gradable.

Thus, the integration of non famous archaeological sites for scientific purposes increases the complexity of coastal vulnerability analyses by revealing their subjectivity and by increasing uncertainties associated with risks management. In such a context, integration of coastal archaeological sites appears as a real task for coastal studies and we can ask whether coastal management bases are able to cope with it. As said before, numerous coastal vulnerability analyses integrated within coastal management plans are mainly conducted through the use of CBA approaches to quantify accurately losses arising from coastal hazards. This method provides an adequate framework to map and measure coastal vulnerability on a short time scale, but is does not take into account all the complexity associated with coastal vulnerability analyses on longer time scale. Uncertainties linked to coastal vulnerability subjectivities as well as its changing definition over time are hardly taken into account. However, we assume that some current coastal management practices such as adaptive management could provide the theoretical basis for dealing with such a complexity. Adaptive management is defined as “a systematic process for continually improving management policies practices by learning from the outcomes of operational programs” *(Holling, 1978)*. In others word, adaptive management promotes the use of experimental approach in order to reduce negatives impacts associated with uncertainties linked to environment management practices. To be efficient, such approach should assess a wide range of different objectives dealing with environment management, such as economic, social and environmental ones. This implies political choices controlling decision making processes *(Gregory, et al., 2006)*. However, a number of experiences have put into evidence that adaptive management approach can be used to develop holistic coastal management approach by favouring the integration of different stakeholders and by taking into consideration environmental, social and economic consideration. Bennett et al. (2005) provides an example of advantages associated with such an adaptive management. In addition, adaptive management is clearly related to the development of Integrated Coastal Zone Management (ICZM). Adaptive management is recommended by the European Union's 2002 report to improve the development of ICZM. In the same time, Dobbs *(2006)* have put into evidence that adaptive management as a management tool is being utilised in European countries. In the same way, Deboudt et al. *(2008)* have pointed out that the evolution of the French institutional framework for coastal zone management aims at providing some basis for encourage the implentation of ICZM in France since 2001. Similar evolutions are recorded in the UK, Portugal or Norwegian *(Ballinger & Lymbery, 2006, Calado et & al, 2006, Edvarsen, 2006)*. In such a context, adaptive management could be applied and allow to cope with the subjectivities and uncertainties associated with coastal vulnerability assessment by bringing together new information dealing with coastal evolution and coastal planning. It could allow coastal management to evolve and adapt to changing situations. This dynamic coastal management processes could provide the basis for taking into account anthropogenic features (such coastal archaeological sites) whose social values and need to protect are changing with time.

Conclusion

In South Brittany, taking into account the presence of coastal archaeological sites when mapping coastal vulnerability contributes to increasing the length of coastline threatened by coastal retreat. This simple observation lead to more complex discussion dealing with the subjectivities and uncertainties associated with coastal risks assessment in a context of sea level rise. This agrees the statement of *Lamarre* (2008) which put into evidence new difficulties induced by global change in risks assessment, prediction and management. In the same time, numerous current coastal management practices, based on CBA approaches, promote an economic approach to evaluate the vulnerability of the coast. Such approaches are not likely to encompass all the complexity and subjectivity associated with coastal vulnerability analyses. However recent developments in coastal management theoretical basis, especially regarding adaptive management and ICMZ, are likely to provide relevant tools to cope with such a complexity and favour the integration of the risk of coastal archaeological loss into future coastal management plans. Moreover, when accurate data about coastal damages are needed, adaptive management practices do not impede the use of CBA approaches, but provide a progressive framework to integrate into the analysis some of the uncertainties associated with coastal vulnerability analyses.

Bibliography

Alpar, B., 2008. Vulnerability of Turkish Coasts to Accelerated Sea-level Rise. doi: 10.1016/j.geomorph.2007.05.021

Anfuso, G., Dominguez, L., Gracia, E.J., 2007. Short and medium-term evolution of a coastal sector in cadiz, SW spain. Catena., 70, 229-242.

Ballinger, R. & Lymbery G., 2006. ICZM in the North West of England – an Example of the Assessment and Implementation of ICZM at a Sub-national, Regional scale. In: Integrated Coastal Zone Management – Theory and Practices, Forkiewicz (eds), Eurocoast Littoral, Gdanck.

Battiau-Queney. Y., Billet, J.F., Chaverot, S., Lanoy-Ratel, P., 2003. Recent shoreline mobility and geomorphologic evolution of macrotidal sandy beaches in the north of france. Marine Geology. 94, 31-45.

Bécet, J.M. & Rezenthel, R., 2004. Dictionnaire juridique des ports maritimes et de l'environnement littoral. Presses Universitaires de Rennes, Rennes.

Benavente, J., Del Rio, L., Gracia, F.J., Martinez-del-Pozo, J.A., 2006, Coastal flooding hazard related to storms and coastal evolution in valdelagrana spit (cadiz bay natural park, SW spain). Continental Shelf Research. 26, 1061-1076.

Bennett, J., Lawrence, P., Johnstone, R., Shaw, R., 2005. Adaptive management and its role in managing Great Barrier Reef water quality. Marine pollution Bulletin. 51, 70-75

Brault, N., Guillocheau, F., Proust, J.N., Naplas, T., Brun, J.P., Bonnet, S., Bouquin, S., 2001, Le système fluvio-estuarien Pleistocène moyen supérieur de Pénestin (Morbihan): une paléo Loire. Le Bulletin de la Société Géologique de France. 172, 5, 563-572.

Bruun, P., 1962, Sea level rise as a cause of shore erosion. Journal of Waterway, Port, Coastal and Ocean Engineering. 88, 117-130.

Calado, H., Porteiro, J., Botelhlo, A., Lacerda, S. Quintela, A., 2006. Coastal Management Plans in Portugal: What is changing? In: Integrated Coastal Zone Management – Theory and Practices, Forkiewicz (eds), Eurocoast Littoral, Gdanck.

Carter, R.W.G., 1999, Coastal environments, an introduction to the physical, ecological and cultural systems of coastlines. Academic Press, San diego.

Cooper, N.J, Hooke, J.M., Bary, M.J., 2001, Predicting coastal evolution using a sediment budget approach: a case study from southern England. Ocean & Coastal Management. 44, 711-728

De Pippo, T., Donadio, C., Pennetta, M., Petrosino, C., Terlizzi, F., Valente, A., 2007, Coastal hazard assessment and mapping in northern campania, italy. Geomorphology. doi:10.1016/j.geomorph.2007.08.015

Deboudt, P., Dauvin, J-C., Lozachmeur, O., 2008. Recent developments in coastal zone management in France: The transition towards integrated coastal zone management (1973-2007). Ocean & coastal Management. 51, 212-228

Dobbs, W., 2006. Adaptive Management in ICZM: Theory vs. Practice. In: Forkiewicz, M. , Integrated Coastal Zone Management – Theory and Practice, Gdansk University of Technology. Eurocoast – Littoral 2006, Gdansk.

Duffy, M., Psuty, N.P., Pace, J.P., 2005. Geomorphological monitoring protocol - part I ocean shoreline position. U.S. Department of the Interior report. 1-61.

Durand, P. and Heurtefeux, H., 2006. Impact de l'élévation du niveau marin sur l'évolution future d'un cordon littoral lagunaire: Une méthode d'évaluation. exemple des étangs de Vic et de Pierre blanche (littoral méditerranéen, france). Zeitschrift für Geomorphologie N. F. 50, 2, 561-573.

Durand, S. and Million, Y., 1955. Le Pliocène de l'estuaire de la Vilaine. Etude des falaises de Pénestin (Morbihan). Bulletin de la société géologique et minéralogique de Bretagne ,1.

Edvardsen, M., 2006. The Coastal Zone Under the EU Water Framework Directives Regulations. Policy Implementation Problems in a Norwagian Setting. In: Integrated Coastal Zone Management – Theory and Practices, Forkiewicz (eds), Eurocoast Littoral, Gdanck.

El-Raey, M., 1997. Vulnerability assessment of the coastal zone of the nile delta of egypt to the impacts of sea level rise. Ocean and Coastal Management. 37, 1, 29-40.

Ferreira, O., Garcia, T., Matias, A., Taborda, R., Dias, J.A., 2006. An integrated method for the determination of set-back lines for coastal erosion hazards on sandy shores. Continental Shelf Research. 26, 1030-1044.

Fletcher, C., Rooney, J., Barbee, M., Lim Siang, C., Richmond, B., 2003. Mapping shoreline change using digital orthophotogrammetry on maui, hawaii. Journal of Coastal Research. 38, 106-124.

Forbes, D.L., Parkes, G.S., Manson, G.K., Ketch, L.A., 2004. Storms and shoreline retreat in the southern gulf of st lawrence. Marine Geology. 210, 169-204.

French, 2001. Coastal Defenses: Processes, problems and solution, Routledge, London.

Frihy, O.E., Hassan, M.S., Deabes, E.A., Badr, A.E.M., 2008. Seasonal wave changes and the morphodynamic response of the beach-inner shelf of abu qir bay, mediterranean coast, egypt. Marine Geology. 247, 145-158.

Gauthier, C., 2006. Le patrimoine archéologique de l'Estuaire de la Vilaine, du Néolitique à la période gallo-romaine: l'occupation humaine protohistorique. Bulletin de l'Association Manche Atlantique pour la Recherche Archéologique dans les Iles. 19, 41-56.

Graham, D., Sault, M., Bailey, J., 2003. National ocean service shoreline, past, present and future. Journal of Coastal Research. 38, 14-32.

Gregory, R., Failing, L., Higgins, P., 2006. Adaptive management and environmental decision making: A case study application to water use planning. Ecological Economics. 58, 434-447.

Holling, C.S., 1978. Adaptive Environmental Assessments and Management. John Wiley and Sons, London.

Hooke.

Houser, C., Hapke, C., Hamilton, S., 2008. Controls on coastal dune morphology, shoreline erosion and barrier island response to extreme storms. doi:10.1016/j.geomorph.2007.112.007

IPCC CZMS, 1992. A Common Methodology for assessing Vulnerability to Sea Level Rise. Appendixe C of Ref.12

Klein & Nicholls, 1999

Komar, P.D., 1998. Beach processes and sedimentation. Printice Hall, New Jersey.

Kont, A., Jaagus, J., Aunap, R., 2003. Climate change scenarios and the effect of sea level rise for estonia. Global and Planetary Change. 36, 1-15.

Kroon, A., Larson, M., Möller, I., Yokoki, H., Rozynski, G., Cox, J., Larroude, P., 2008. Statistical analysis of coastal morphological data sets over seasonal to decadal time scales. doi.10.1016/j.coastaleng.2007.11.006

Lamarre, D., 2008. Climats et risques: changements d'approches, Edition TEC & DOC, Lavoisier, Paris.

Liu, S.K., 1997. Using coastal models to estimate effects of sea level rise. Ocean and Coastal Management. 37, 1, 85-94.

López-Romero González de la Aleja E., Daire M.Y., 2008 - El proyecto "ALERT": un mapa de riesgos para la gestión y protección del patrimonio arqueológico litoral./ "ALERT" Project: a risk map for the management and protection of coastal archaeological heritage. *In* : Rovira Llorens S., García-Heras M., Gener Moret M., Montero Ruiz I. (eds) - *Actas del VII Congreso Ibérico de Arqueometria,* Madrid, 8-10 de octubre 2007. Madrid, E-publishers Quadro, p. 532-538, http://www.ih.csic.es/congreso_iberico.pdf.

Lozano, I., Devoy, R.J.N., May, W., Andersen, U., 2004. Storminess and vulnerability along the atlantic coastlines of europe: Analysis of storm records and of a greenhouse gases induced climate scenario. Marine Geology. 210, 205-225.

Masselink, G. and Hughes, M., 2003. Introduction to coastal processes and geomorphology. Hodder Arnold, London.

Moore, L.,J., 2000. Shoreline mapping techniques. Journal of Coastal Research. 16, 1, 111-124.

Nicholls, R.J., 2004. Coastal flooding and wetland loss in the 21st century: Changes under the SRES climate and socio-economic scenarios. Global Environmental Change. 14, 69-86.

Nordstorm, K.F., 2000. Beaches and Dunes of Developed Coasts, Cambridge University Press, Cambridge.

Parker, B.B., 2003. The difficulties in measuring a consistently defined shoreline: The problem of vertical referencing. Journal of Coastal Research. 38, 44-56.

Pigeon, P., 2005. Géographie critique des risques. Economica, Paris.

Pirazzoli, P.A., 2000. Surges, atmospheric pressure and wind change and flooding probability on the atlantic coast of france. Oceanologica Acta. 23, 643-661.

Pirazzoli, P.A., Regnauld, H., Lemasson, L., 2004. Changes in storminess and surges in western france during the last century. Marine Geology. 210, 307-323.

Regnauld, H., Pirazzoli, P.A., Morvan, G., Ruz, M., 2004. Impacts of storms and evolution of the coastline in western france. Marine Geology. 210, 325-337.

Robin, M., 2002. Télédétection et modélisation du trait de côte et de sa cinématique. In : Baron-Yellés, N., Goeldner-Gianella, L., Velut, S. (Eds), Le Littoral : Regards, Pratiques et Savoirs, Presses de l'Ecole Nationale Supérieure, Paris, 95-115.

Saengsupavanish, C., Seeprachawong, U., Gallardo, W.G., Shivakoti, P., G., 2007. Port-induced erosion prediction and valuation of a local recreational beach. Ecological Economics, doi:10.1016/j.ecolecon.2007.11.018

Sedrati, M. and Anthony, E.J., 2007. Storm-generated morphological change and longshore sand transport in the intertidal zone of a multi-barred macrotidal beach. Marine Geology. 244, 209-229.

Snoussi, M., Ouchani, T., Niazi, S., 2008. Vulnerability assessment of the impact of sea level rise and flooding on the moroccan coast: The case of the mediterranean eastern zone. Estuarine, Coastal and Shelf Science 77, 206-213.

Suanez, S., Fichaut, B., Sparfel, L., 2007. Méthode d'évaluation du risque de submersion des côtes basses appliquée à la plage du vougot, guissény (bretagne). Géomorphologie: Relief, Processus, Environnement. 4, 319-334.

Tessier, C., 2006. Caractérisation et dynamique des turbidités en zone côtière: L'exemple de la région marine bretagne sud. Ph.D. Thesis. Ifremer. France.

Vellingar, P. & Klein, R.J.T., 1993. Climate Change, Sea level Rise and Integrated Coastal Zone Management: An IPCC Approach. Ocean & Coastal Management, 21, 245-268.

William, A.T., Alveirinho-Dias, J., Garcia Novo, F., Garcia-Mora, M.R., Curr, R., Pereira, A., 2001. Integrated coastal dune management: checklists. Continental shelf research, 21, 1937-1960.