YPCC 2016

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14 octobre 2016

Introduction

Basque coast features

Thirty percent of the marine subregion "Bay of Biscay" coastal zone is made up of rocky substrata ([51]). A large part is located in the north of France ([26] ; [8]). Further south, after a wide sandy shore, there is a less extensive region called Basque coast in France and Spain coastal area. It is exposed to the most energetic waves ([5] ; [20]) and to huge freshwater incomes explained by a weather mainly rainy, a dense river system closed to Pyrenees ([56]). It is also subject to tide swept (mesotidale semi-diurnal tide with a magnitude between 3.85 and 1.85 meters) ([8]). The increase of urbanization, due to an expanding population more citizen (especially during summer), explains also an important urban discharge into the ocean ([1] ; [51] ; [26]).

Study interest

Intertidal boulder fields monitoring and assessment

During the last 25 years, sea level has raised by approximately 3 mm per year with the increasing of pressure areas ([26] ; [51] ; [46] ; [61]). Aquitanian coast responds directly to climate change by various modifications (natural or anthropogenic) as the erosion of rocky shore and the increase of shallow water temperature ([26]). At the ocean/land interface, intertidal zone is particularly sensitive because impacts are concentrated while constituting a refuge and spawning area for many species ([2]). Intertidal communities occupy heterogeneous habitats with considerable spatial and temporal variation of environmental components (tides ([8]), significant energetic waves ([5] ; [30]), water quality and huge freshwater incomes explained by weather rainy and dense river system ([56]), composition (Boulders fields, flat benches), orientation (exposition to swell, slope) and rugosity of substrate). Those characteristics have a strong influence on species distributions and abundances, within and among sites or habitat patches ([45] ; [7]). All parameters described before and the southern character of this region considered as a patrimonial interest justify the presence of specific communities into these remarkable habitats ([8] ; [34] ; [10]).

Biodiversity of this specific area has been described since the late nineteenth century ([36]). While the interest to study benthic fauna on intertidal boulder fields has been widely documented over the world ([15] ; [25] ; [54] ; [50] ; [60]) few studies have been conducted locally and most of them are conducted in Brittany ([38] ; [39] ; [20] ; [6]). Only macroalgae surveys used to assess ecological status on flat benches within the WFD since 2008 and fauna inventoried by the "Centre de la mer de Biarritz" ([18]) are conducted locally.

Ecological indicators are "useful in long-term environmental follow-up, conservation and ecological management" ([4] ; [47] ; [33]). They provide information to understand the environment and health status and allow to highlight changes in the environment by giving early warning signals ([4] ; [39] ; [39]). Among them, the identification of indicator species is current in ecology and biogeography because they add ecological meaning to studied sites and their use is an alternative to sampling the entire biodiversity ([37]).

Submersion events assessment and storms detection

Coastal flooding storms occured when high waves and high water level (tide and water level modification induced by currents, winds...) level meet. When it occurs, seawater reach normally dry land. Consequences can be various : natural erosion, damages on human structures... Historical studies and qualitative works were conducted in the Bay of Biscay [17] [59] [43] to track down historical damaging events. Moreover statistical studies on extreme value theories and multivariate analysis [29] [42] are very popular and provide powerful tools to conduct studies like this one. It exists other ideas to characterize coastal flooding storms [14].

The goal of this study is to provide means to detect and qualify extreme flooding events in the Bay of Biscay. The finality is to have a solid indicator, based on sea level levels parameters (wave heigth, wave period and water level), to build a dataset of historical extreme events. Such dataset gives the possibility of discuss the definition of submersion natural disasters.

To make a relevant analysis, we need informations about damages. City archives and newspapers are explored to allow a comparison with the event database. After correctinf the algorithm, the objective is to have two exactly corresponding databases.

Two king of studies undertaken along this coast

First study : Communities structuration and indicator species/taxa in boulder fields habitat along French basque coast

The aim of this first study is divided in two main objectives : (1) to fill the lack of knowledge concerning rocky biocenosis especially on fauna communities composition and spatial distribution in boulder fields habitats and (2) to highlight species/taxa considered as good indicators of boulder fields habitat in the context of MSFD descriptors implementation and global changes. Two working sites were selected to accomplish these objectives, Guéthary and Saint-Jean-de-Luz (Fig. 1).

FIGURE 1 – The two study sites locations : "les Alçyons" in Guéthary and "les Flots bleus" in Saint-Jean-de-Luz. Blue circles represent rivers Unxin and the Nivelle.

A stratified random sampling design was used. Mobile boulders were sampled in upper and lower mediolittoral zones (microhabitats) established on algal-dominated communities described in the Water Framework Directive (≪ Corallina officinalis and Caulacanthus ustulatus≫ and ≪ Halopteris scoparia and Gelidium spp. ≫ ([9]). 0.33 x 0.33 cm quadrats were used to identify and count macroalgae communities in percentage cover only on the top of the rock in seven abundance classes (0,]0 ;5],]5 ;25],]25 ; 50],]50 ; 75],]75 ; 100[and 100). Mobile macrofauna and fixed macrofauna were identified in abundance and percentage cover respectively everywhere. As far as possible, the identification was realized in situ at a specific level, to limit the sampling impact.

Diversity and spatial distribution of benthic communities

More than 127 species were identified permitting to realize a list of the relative abundance species present in each microhabitat. To have an overview of diversity and to determine the communities structuration per microhabitat, multivariate analysis were firstly computed separately on each database (macroalgae, mobile fauna, fixed fauna). These analysis allowed to indentify a clear distinction between the upper and lower mediolittoral communities distribution (Fig. 2) confirming the stratification based on algal belts ([31]). Lower zone is usually immerged, providing then communities establishment and their maintaining ([44]). Upper zone, submitted to environmental and anthropogenic pressures is only underwater during high tides thus more affected than other benthic communities to urban effluents ([11] ; [12]). It is also impacted by extreme temperatures when low tides occurs ([44]) : high temperature and drying heat during summer and very low temperature in winter ([57]).

Sites distinction in terms of algal and fauna communities

Algal diversity was described as being more important in Guéthary than in Saint-Jean-de-Luz (Fig. 3). Various factors may influence this distinction. Firstly, Saint-Jean-de-Luz is impacted by two rivers, the Nivelle and the Untxin. Consequently, they bring up to the sea surface of the bay an important quantity of freshwater and urban effluents from the whole catchment area ([49]). Rocky shore communities may be then affected, especially for macroalgae highly impacted by turbidity which decreases photosynthesis ([11] ; [16]). Moreover, Guéthary is more impacted by wave action which seems "to be a significant factor for accumulation of macroalgae" ([48]).

Contrary to algal communities, mobile fauna is higher in Saint-Jean-de-Luz than Guéthary (Fig. 3). Intertidal species are highly linked to disturbance frequency ([9] ; [41]). Saint-Jean-de-Luz is west oriented and is protected inside a bay partially closed by a dyke, contrary to

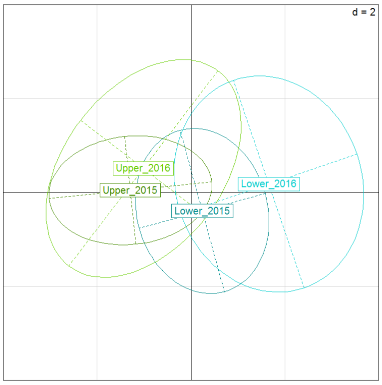

FIGURE 2 – Principal component analysis (PCA) of taxa distribution according to microhabitats (lower and upper mediolittoral zone) and years (2015-2016) in Guéthary. Significant difference between microhabitats in Guéthary during the two sampling years is revealed on the first axis (two-way anova ; $p < 0.05$; Kruskalmc ; $p < 0.05$).

Guéthary, north-west oriented and directly exposed to waves. Their impact affects "species living on the top surfaces of boulders, killed or injured when they are overturned" ([57]). Nutrients, provided by the two rivers, may also explained the higher richness in Saint-Jean-de-Luz ([40]).

A greater quantity of sediment were underlined in Saint-Jean-de-Luz than in Guéthary (Fig. 4). Wave direction, associated to particular wave regime, is susceptible to move an important sediment quantity along the coast and may be then deposited in boulder fields habitat ([52] ; [53] ; [8] ; [5]). Saint-Jean-de-Luz, isolated inside a bay with a lower wave impact, constitutes also a favoring factor to sediment deposit. Hence, they contribute to habitat heterogeneity, especially in the case of coarser deposits ([22] ; [23]). They "reduced pore space and greater load of fine particles and then eliminate a potentially important niche resource" ([24]). In addition to sediment deposits, water turbidity also increases due to an important quantity of organic and mineral matters into the water. Primary productivity is then impacted owing to light attenuation and algal growth is consequently affected ([19]).

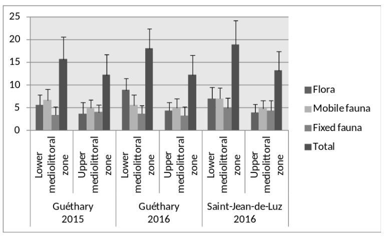

FIGURE 3 – Mean taxonomic richness identified into quadrats per microhabitat, per site (Guéthary and Saint-Jean-de-Luz) and per year for mobile fauna (grey), fixed fauna (light grey), macroalgae (dark grey) and all total biological groups (black). The total of whole biological groups is always significantly higher in lower mediolittoral zone in any year and site (kruskalmc ; $p < 0.05$).

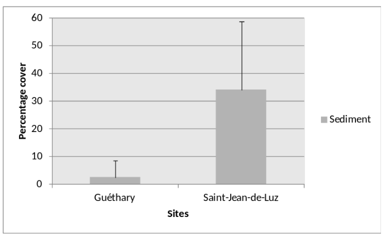

FIGURE 4 – Sediment mean cover into each site (Guéthary and Saint-Jean-de-Luz).

Indicator species

A statistical analyze was performed with "indicspecies" package to bring to light species considered as good indicator of each microhabitat. This method is useful as an alternative to sampling the entire biodiversity ([37]) and add ecological meaning to studied sites and provide information on health status ([4]). It was realized in both studied sites for each biological group (macroalgae, mobile fauna and fixed fauna). This analyze allows to assess the strength and statistical significance of the relationship between species occurrence/abundance and groups of sites (quadrats into microhabitats). The interest of following macroalgae is confirmed by their structural and functional rules in coastal rocky shores, particularly intertidal and subtidal communities ([9] ; [28] ; [35] ; [32] ; [55] ; [21]). The influence of mobile organisms on marine ecosystem function may be significant because small-scale patterns of movement are known to positively influence biodiversity" ([13]). But their follow is often a snapshot in space and time because they respond to environmental changes by short-terms variability of their community structure as "dispersal, movements and migrations" ([13] ; [7]). Interannual changes in population statement or predation should impact abundance of this biological group. Instead of just considering individual species, indicator value of species combinations has to be explored ([47]). Indeed, two or three species, founded together, can contained more ecological information than a single one. Finally, species highlighted in this study are not indicator of a pristine environment, but they could contribute, in a context of long term series approach, to give elements for evaluation of ecological status. In the future, this project will allowed to follow global environmental changes (Natural and Anthropogenic impacts) and assess the ecological health status of the south of the Bay of Biscay. Two questions have been raised and require further studies :

— Question 1 : How it is possible to dissociate anthropogenic impacts and climatic impacts ?

— Question 2 : How wave action impacts biodiversity between each monitoring sites ? And how it is possible to integrate this parameter in our project ?

Statistical study of extreme submersion events

In order to analyze damages related ocean activity, we need to develop indocators based on parameters of each sea state.

Indicators

The sea state at a given location is the general condition of the free surface of the water for a given time window. During a studied time interval, the sea state has to be constant : much longer than a wave period but small enough to avoid wind and swell significant variations.

Before being able to give a precise description of coastal flooding events, we need to present parameters used to describe a sea state. Wave by wave statistics or spectral analysis are used to characterize a given sea state t.

- Wave height : the difference between the maximum and the minimum of the surface elevation for a given wave. To characterize a sea state, the significant wave height $H_{s,t}$ is used.
- Period : the time for a particle to make one complete vibrational cycle. It is denoted Tt.
- Water level : the mean water level : η_t.

The first idea is to calculate the energy flux (denoted $P(J.m^{-1}.s^{-1})$) at a given location for each time window t. Before doing this calculation, we need to introduce some quantities :

- the depth h (m)
- the gravitational force $g = 9.81 m.s^{-2}$.
- the wavelength λ_t (m), solution of the following equation for a given period T_t, for a given time window t, at a given location :

$$(\frac{2\pi}{T_t})^2 = \frac{2\pi g}{\lambda} tanh(\frac{2\pi h}{\lambda_t}) \quad (1)$$

- the wave energy density E $(J.m^{-2})$ at a given location for a time window t.

$$E = \frac{1}{16} \rho * g * H_{s,t}^2 \quad (2)$$

- the phase velocity c_p $(m.s^{-1})$ is the speed at which the phase of a wave propagates in space.

$$c_p = \sqrt{\frac{g\lambda_t}{2\pi} tanh(\frac{2\pi h}{\lambda_t})} \quad (3)$$

- the group velocity is the velocity at which the envelope travels in space.

$$c_g = \frac{1}{2} c_p (1 + \frac{4\pi h}{\lambda_t} \frac{1}{sinh(\frac{4\pi h}{\lambda_t})}) \quad (4)$$

The flux is simply :

$$P = E * c_g \quad (5)$$

Flux is calculated for each time window t. The idea of the following algorithm is to use the flux P_t and the water level η_t to detect storms.
Two thresholds are determined : u_P and u_η. If at a given time window t : $P_t > u_p$ and $\eta_t > u_{eta}$, it is a potential storm. Then, consecutives time windows where potential storms were detected are grouped into storms. If a storm has a realistic duration, it is selected. The figure **??** shows an example with the flux, one storm is selected on the plotted data. The difficulty of this algorithm is the dependance of two datasets : wave parameters and water levels. A selected storm s is described with three characters :

- Its intensity : $I_s = \int P$ $(J.m^{-1})$
- Duration : D_s (s)
- Dates beginning/end : ("DD/MM/YYYY HH :MM/SS" format)

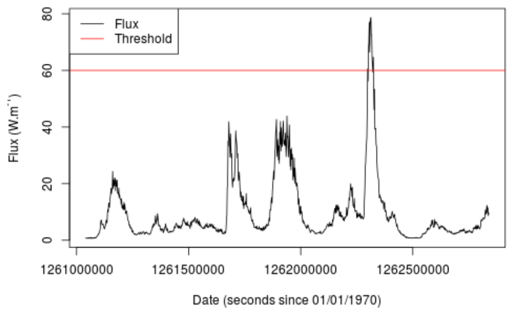

FIGURE 5 – The flux is computed for the whole dataset and depending of the selected threshold storms are detected. Here only one storm is detected in the sample.

To characterize a whole winter n, storms selected between October of a year n and March of year $n+1$ are grouped. Each winter is characterized by the total duration of its m storms and its total intensity :

- Year : n
- Intensity : $S_{I_n} = \sum_{s=1}^{m} I_s$
- Duration : $S_{D_n} = \sum_{s=1}^{m} D_s$

For the second coastal flooding storm descriptor, the runup was chosen. Indeed, the runup is the maximum vertical extent of a wave on a structure or a beach. For a considered time window t, $R_{2\%,t}$ is the value exceeded by 2% of the waves. The only missing notion here is the beach slope β whi represents the beach angle of the considered location. Two means of calculating $R_{2\%,t}$ were investigated here :

- According to Mase [27] :

$$R_{2\%,t} = H_{s,t} * (0.83 * \frac{\beta}{\sqrt{\frac{H_{s,t}}{(\frac{g*T_t^2}{2\pi})}}}) \tag{6}$$

- According to Stockdon [58] :

$$R_{2\%} = 1.1 * (0.35 * \beta * \sqrt{H_{m0} * \frac{g * T^2}{2\pi}} + \sqrt{\frac{H_{m0} * \frac{g*T^2}{2\pi} * 0.563 * \beta^2 + 0.004}{2}}) \tag{7}$$

Because $R_{2\%}$ do not take into account the still water level, the final value calculated is :

$$R_{tot,t} = R_{2\%,t} + \eta_t \tag{8}$$

Then, the same idea as for the flux is used : threshold determination, storms selection and output in a table. The main difference is the use of only one threshold : $u_{R_{tot}}$.

To apply algorithms described in the previous section, two databases were built :

- a buoy located in Anglet (2009-2015) and a simulation with spectra from the BoBWa simulation as border conditions and propagated with the SWAN model (1958-2001).
- the same buoy but with the Homere Simulation (1994/2009) from the database ([3])

Results : Flux

The Flux algorithm was applied , on the BobWa SWAN database, with thresholds $U_P = 83.47W.m^{-1}$ and $U_\eta = 3.72m$ to detect flooding events.

All the events detected are grouped into winters. A bivariate Gumbel copula with log-normal margins is fitted to Intensity / Duration data (seen on the Figure 6). The model gives a probability of 0.004 of having a Winter as bad as 2013/2014.

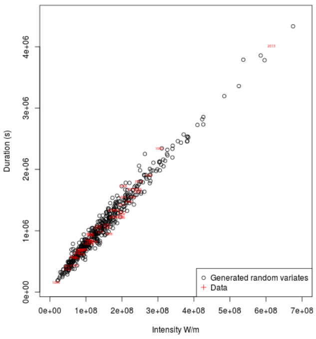

FIGURE 6 – Bivariate plot of each winter of the dataset with the total intensity and the total duration of the storms encountered in the winter. Black dots are 500 random variables from the fitted copula.

Results : Runup

This algorithm was used on the second database, the decided threshold was the wall in front of the Biarritz Casino ($6.647m$). Events detected are presented in the Figure 7. The six strongest events were investigated and we found correspondances with natural disasters declared and damages (numeroted in the Figure 7).

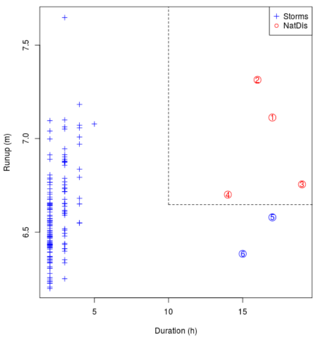

FIGURE 7 – Storms detected for the Runup. Too short durations were erased from the dataZ. Numbers on the right part correspond to biggest events discussed in this document.

Damage database

In order to build a damage database, a geography student was recruited for a period of 6 months.
The goal of the internship was to retrieve and analyze information on all the storms that impacted the coast of the Basque Country from the 1950s to nowadays. First we recorded information from three types of sources : The Regional Archives, the Municipal Archives and the Press Archives. These sources provide access to documents related to the topic of interest. This descriptive information are included in a database table based on three types of information : Hazard, damages and anthropogenic reactions generated after each storm. The recovered data is largely qualitative and through the analysis of these descriptions, we can assess the intensity of hazards, damage and reactions generated after each storm since 1950. This type of research compares the old data storms with the latest in order to know if there is an increase in the occurrence of storms and the intensity of their damage.

Climate change

First study contributes to have a first overview of diversity and to a better comprehension of communities distribution in front of environmental conditions. Then, a sampling protocol could be implemented to provide information over long term of the environment which responds to global changes by assessing its health status.

One of the most important impact brought by the climate change is the global elevation of the ocean water level. The two indicators developped in the second study use quantitatively the water level. A main perspective is to find a correlation between submersion events and this elevation. Indeed, in the Flux indicator, the threshold is calculated as a quantile of a temporal series, changes were not taken into account. In the runup study, the threshold is defined with the studied beach (which is not constant by the way) and $R_{tot,t}$ takes into account η_t. It could be interesting to study this evolution and the correlation with the submersion events.

Both studies have different objectives while they are working on the same area. These two studies have two different approaches, one based on biology and ecology and the second one based on physic . Up to now, the potential correlation between them was not studied. The second study may allow to quantify wave or storm impacts on intertidal zone and therefore on communities. This could be integrated as a new parameter in the future multimetric index which will assess the conservation status of intertidal boulder fields.

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