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Vulnerability of reed beds to climate change in the Occitanie region

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Abstract:
Reed beds communities play important structural and functional roles in wetland ecosystems, as they work as efficient filters for pollutants and provide habitat for fauna species and avifauna in particular. In the Mediterranean (GIGANTE *et al.*, 2014), a decline of these ecosystems has been observed during the last decades, resulting mainly from eutrophication together with anoxic conditions. Intrusions of seawater by coastal flooding during storms can radically transform the balance of the environments making them, for a certain period, unsuitable for the development of the reed beds and the species they shelter. The reed beds are so vulnerable to climate change in the near future (ADENA, 2022).
This study aims at assessing the vulnerability to climate change of reed beds ecosystems along the Mediterranean coast of Occitanie by comparing the topography of 29 reed beds, approximated as accurately as possible by recent topographic datasets, with marine flooding scenarios calculated for two periods: 2030-2050, 2100 and 2100+ (pessimistic scenario).
A simplified static approach is used without considering duration of flooding nor the speed of water propagation. Three different scenarios are proposed at each time scale: permanent flooding, recurrent (flooding once a year without storm event) and exceptional (100y return period storm event). Water levels are defined using hypotheses of the 4th IPCC report together with the previous studies of extreme water levels and regional storm characteristics.
The first finding from the analysis is that 50% (16) of the regional reed beds will be already impacted by 2030-2050 permanently (most of the year) and seven recurrently, corresponding to a sea level rise of between +40 cm and +70 cm NGF.
Most of the regional reed beds areas are impacted by the less severe scenarios, pointing out the important vulnerability of these coastal ecosystems.

Keywords:
Coastal management, Reed beds, Coastal ecosystems, Vegetation resilience.

1. Introduction

Reed beds develop in wetlands and, particularly in coastal areas, they are located at altitudes very close to the level of lagoons and the sea or close to them. In this context, the groundwater is strongly influenced by the salty environments.

The root system of reed beds is generally shallow (less than 1 m), and the development of these plants is possible thanks to the presence of a low salinity surface water table. The reed bed is in fact tolerant of salinity as long as the water remains at a brackish stage (salinity below 10 g/l). A direct supply of seawater is thus directly harmful to the plant. When the salinity of the surface water becomes high, the plant will eventually die.

The number of reed beds in the Occitan region, censed in the context of the study from PALVADEAU *et al.,* (2021) is 29, and each one of them is unique with its own way of functioning. This is linked to its history and developments (e.g. former saline activity, wastewater plant, dyke, irrigation canals, anti-salt dam), its current management (irrigation or low input, input of fresh or salty water, input from a lagoon station) and its relationship with the surrounding environment (connection lagoon environment, etc.) throughout the overall year or only during specific periods (floods, storms). Almost all of the reed beds are sensitive to salinization, due to their proximity to lagoons or the sea. In the context of climate change, salinization phenomena will increase under the effect of two main interconnecting phenomena: (1) the sea level rise, (2) the potential increase in flooding during storm events, as a direct consequence of the sea level rise and (3) a decrease in available water resources for irrigation due to increased periods of drought. The intrusion of seawater during storms can radically transform the equilibrium of the environment by greatly increasing its salinity, making it unsuitable for the development of reed beds and the species they shelter for a certain time. It is therefore likely that an increase in the frequency and intensity of these episodes and the associated flooding could eventually have a greater or even lasting impact.

The vulnerability of reed beds to climate change is assessed in this study by comparing their topography, approximated as accurately as possible by recent topographic datasets, with marine flooding scenarios calculated for two main timeframes: 2030-2050 and 2100.

2. Method

The method used here for flooding areas is based on that of the MISEEVA project conducted by BRGM in 2010 (SERRAND *et al.,* 2013). It uses a simplified approach of static projection of sea level on land characterized by:

- No notion on the duration of the submersion nor on the speed of water propagation;
- The same sea level is considered for the entire coastline despite the differences from one site to another.

The chosen scenarios, based on MISEEVA project consider two main timeframes, 2030-2050 and 2100. The chosen sea levels here are those used in the CEREMA-BRGM study carried out in 2020 for the EPF Occitanie (*Etablissement Public Foncier d'Occitanie*) to

characterise the impact of sea level rise on the property values of the Occitanie coastline (CEREMA-BRGM, 2020). These levels (see Table1) are those closest to knowledge and recommendations (at year 2020) for carrying out this type of analysis: DGEC-ONERC (2010) synthesis - considering sea level rise in order to estimate the impacts of climate change and possible adaptation measures ; DGPR (2014) Methodological guide - Coastal risk prevention plan.
For each scenario, the submerged areas are estimated as:
- *Permanent*: represents land that will be under water for a large part of the year. The corresponding sea level currently considered is the average level at Sète (0.17 m);
- *Recurrent*: level reached once a year under calm weather conditions and average waves (without storms);
- *Exceptional*: corresponds to a storm of 100-year occurrence (probability of 1/100 of occurring each year).

Tableau 1. Flooding scenarios selected for the study (rounded up to the nearest ten centimeters).

Scenario	*2030-2050*	*2100*	*2100+*
Permanent	+0.4 NGF	+0.8 NGF	+1.2 NGF
Recurrent	+0.7 NGF	+1.1 NGF	+1.5 NGF
Exceptional	+2.0 NGF	+2.4 NGF	+2.8 NGF

2.1 <u>Water propagation on land</u>

For marine flooding propagation, on land, several methods exist, from the simple projection on land of a water surface, which fill the basins to the more complicated non-hydrostatic numerical modelling (NICOLAE LERMA *et al*., 2017).
At the regional scale of this work, methods that are more refined would be too much expensive. The processing of the digital terrain model (DTM) in a homogeneous and exhaustive way (enriching the DTM precisely with all the obstacles present on the physical path of the flooding) and the calculation of the volumes of water overtopping the natural and human infrastructures or entering from the lagoons' sides would have high computational demand and time.
In this study, for the scenario used, the water level is propagated on land using a homogeneous way, so over the entire coastal zone concerned, according to two methods implemented by the CEREMA-BRGM (2020) study.
The first method, the so-called '*Low Zone*' method, consists of filling in all low zones below sea level in each scenario (figure 1). This method is realistic in the case of a rise in mean sea level. The level of the lagoons connected to the sea will follow the evolution of the mean sea level. It is very likely that the water basins in the littoral area will fill up even if they are not directly connected to the sea or to a lagoon; because the water table will also rise and the low areas will not be able to drain by gravity.

The second method, the *'Connected Zone'* method, is to fill in low-lying areas below sea level but stop at the first obstacles (figure 1), as there is no known or proven connection with the areas behind. Incoming volumes cannot fill large areas.
These methods are based on altimetry analysis and flow directions and not on numerical modelling of the phenomena.

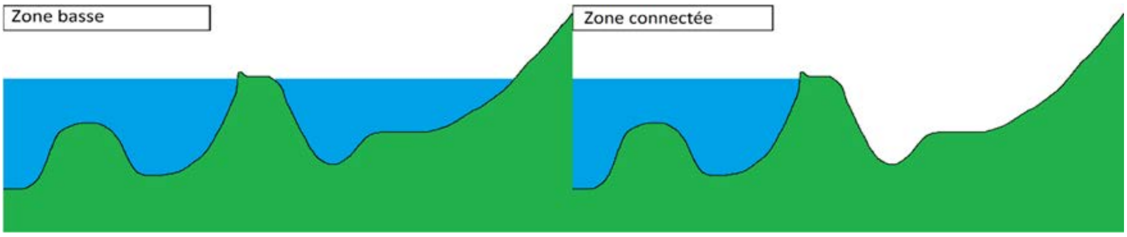

Figure 1. Methods for filling in the flooded areas for a given sea level according to the "Low Zone" on the left and the "Connected Zone" method on the right.

In this study, the *Connected Zone* method is applied to all the reed beds except for two, *Grande Palude* and *Grau du Roi* (Espiguette). For these two cases, the study of their hydrogeological context (PALVADEAU *et al.*, 2021) showed that their flooding will most probably be controlled by the rise in the water table, even though the reed beds are not directly connected to the sea by channels or lagoons. For these two reeds beds the *Low Zone* method is therefore applied. For the application of the *Connected Zone* method, the existing connections between the reed beds and the coastline (maritime or lagoon) were therefore sought in order, if necessary, to propagate the flooding further inland. The coastline used is the HISTOLITT® coastline of SHOM.

2.2 Data used

The topographic data available on the regional territory where the reed beds are distributed are:
- IGN data, digital terrain model (DTM) representing a regular grid 25 metres-spaced;
- LiDAR Litto3D® points cloud data (SHOM-IGN, 2009) and DTM with a regular grid of one point every meter.

An initial analysis carried out by ADENA in 2019 showed that the IGN topographic data (5-metre step) and Litto3D® 2009 (1-metre DTM) are unsatisfactory for reliably describing the topography of reed beds. There is still a significant difference (until around 1 metre, locally) between the field data (reed bed bottom) and Litto3D® data. As the bathymetry of reed beds is not available now of the study, it is therefore proposed to work on the point clouds from the 2009 LiDAR Litto3D survey. A preliminary analysis shows that these points are closer to real topography of reed beds then the DTM, which is a modelled approximation. With the help of Cloud Compare© software, these original points were filtered using the Cloth Simulation Filter (CSF) plugin (ZHANG *et al.*, 2016)

to exclude the tallest portion corresponding to the vegetation, particularly. Principle of the CSF under Cloud Compare© is in figure 2.
A preliminary test was carried out on the *La Matte* reed bed shows that the DTM surface created from the points filtered is indeed locally below the Litto3D® DTM and closer to observations. The spatial distribution of the differences, in metres, between the altitudes given by the Litto3D® DTM 2009 and those from of the DTM created with the point clouds of the same Litto3D® survey, filtered with the Cloth Simulation Filter (CSF) is presented for the reed bed "La Matte" (reaching several decimetres) in figure 3.
The measurement points from the 2009 Litto3D survey were therefore extracted and processed at each polygon, representing a reed bed. A regional new DTM has been built. The method therefore makes it possible to determine which scenarios will impact the reed beds permanently, recurrently or during an exceptional event, for each of the selected timeframes, and to estimate the level of impact in terms of the percentage of surface area potentially covered.

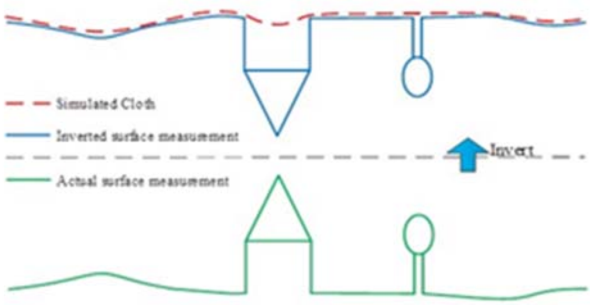

Figure 2. Cloth Simulation Filter (CSF) principle (ZHANG et al., 2016) in Cloud Compare©.

3. Results

The mapping results of the flooding scenarios applied to each reed bed studied in this project have been post-processed.
Examination of this mapping and the statistical values associated to the different layers produced for each scenario provides the elements for analysing the vulnerability of the reed beds according to three (3) main criteria, which are summarised in the columns of figure 4:
- The first scenario of flooding reaching each reed bed;
- The first scenario of permanent flooding, where the reed bed will be partially or totally under seawater for a large part of the year;
- The first scenario where the reed bed will be totally covered, with a distinction made between permanent, recurrent and exceptional scenarios.
For each criterion, the percentage of the total surface area of each reed bed affected is specified.

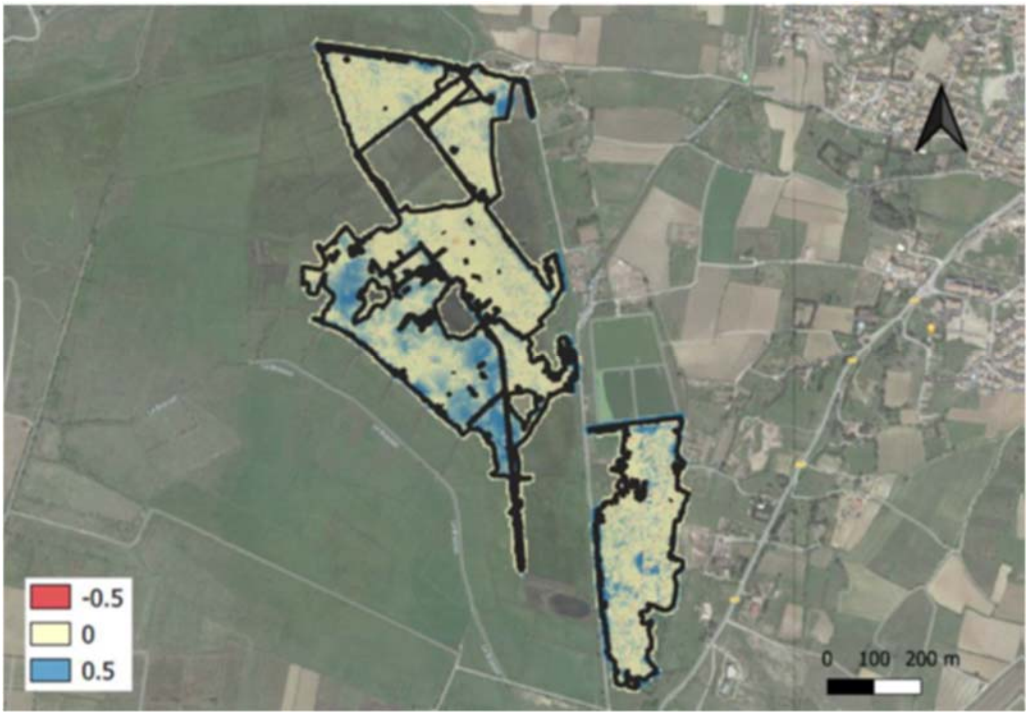

Figure 3. Difference, in meters, between the altitude given by the Litto3D® 2009 DTM and that of the DTM created with the measurement points (point cloud) of the same Litto3D® survey filtered with the Cloth Simulation Filter (CSF) plugin of the Cloud.

The main result from the analysis is that 50% (16) of the reed beds in the study will already be impacted by 2030-2050: nine (9) in permanent way (most of the year) and seven (7) recurrently, corresponding to a rise in sea level between +40 cm and +70 cm NGF. Unsurprisingly, figure 4 shows that the reed beds most affected are mostly located close to the coastline or lagoons. From the reed beds already permanently concerned by 2030-2050, four (4) are particularly affected with a concerned area in the range of 50% to 100%: Bagnas (50%), Grande Palude (100%), Bentenac (52%) and Pierre Fiche (100%).

Some of them are no permanently impacted: La Matte, l'Estagnol and La Tour Carbonnière. Only one reed bed, that of Capestang, is not affected by any of the scenarios analysed, due to its huge distance to the sea and the absence of communication with lagoons.

4. Conclusions

In this context, due to their proximity to the sea or lagoons, almost all of the reed beds surveyed are highly vulnerable to climate change in the near future. Indeed, a direct supply of seawater salinizes the surface water table, which is linked to the root system of the plants, which ultimately leads to their death. However, by 2030-2050, almost half of them will already be impacted, permanently or recurrently. The approach proposed here concerning flooding is static and therefore tends to maximize the impacts, although the "connected zone" is applied. However, it should be noted that the sea levels currently reached during certain storms already exceed the levels of the first two scenarios, and natural protection (clay barriers) may be damaged during these episodes, leading to impacts (case of the Méjean reed bed).

			Premier scenario submersion		Premier scenario permanent		Submersion en totalité
N°	Nom roselière	Surface (m^2)	N°	% surface totale	N°	% surface totale	N°
1	Canet - St-Nazaire	650 948	1 P	3%	1 P	3%	4 R
2	Sagnes d'Opoul	899 908	1 P	42%	1 P	42%	7 E
4	Petit Castelou (Marais du Narbonnais)	511 121	4 R	94%	5 P	96,50%	6 R
5	Pissevaches	202 327	3 P	35%	3 P	35%	5 P
6	Capestang	1 999 847	-	-	-	-	-
7	La Matte	299 134	8 E	93%	-	-	9 E
8	Vendres	2 353 207	4 R	100%	5 P	100%	4 R
9	Grande Maire	103 230	2 R	54%	3 P	68,50%	6 R
10	Bagnas	503 520	1 P	50%	1 P	50%	6 R
11	Castellas	33 104	1 P	12%	1 P	12%	6 R
12	Prés du Baugé	152 513	3 P	95%	3 P	95%	4 R
13	Grande Palude	36 591	1 P	100%	1 P	100%	1 P
14	Vagaran-Boulas (salines de Villeneuve)	159 405	3 P	100%	3 P	100%	3 P
15	Estagnol	384 525	8 E	100%	-	-	8 E
16	Méjean	613 298	1 P	13%	1 P	13%	5 P
17	Saint-Marcel	120 383	2 R	93,5%	3 P	95%	4 R
18	Bentenac	19 956	1 P	52%	1 P	52%	3 P
19	Marais de Plagnol	82 938	2 R	100%	3 P	100%	2 R
20	Cros-Martin	51 441	2 R	100%	3 P	100%	2 R
21	Pierre Fiche	82 245	1 P	100%	1 P	100%	1 P
22	Saint Nazaire (étang de l'Or)	256 600	2 R	99,5%	3 P	100%	3 P
23	Benezet (étang de l'Or)	88 827	2 R	98%	3 P	100% (99%)	3 P
24	Grau du roi (Espiguette)	32 056	1 P	25%	1 P	25%	3 P
25	Tour Carbonniere	322 448	6 R	100%	-	-	6 R
26	Mahistre et Musette	243 083	3 P	29%	3 P	29%	4 R
27	Canavérier	1 582 005	2 R	100%	3 P	100%	2 R
28	Bouvau (Scamandre)	370 973	4 R	100%	5 P	100%	4 R
29	Gargattes	847 744	4 R	100%	5 P	100%	4 R

	2030-2050	2100	2100 +
Scénario permanent	① + 0.4 m NGF	③ + 0.8 m NGF	⑤ + 1.2 m NGF
Scénario récurrent	② + 0.7 m NGF	④ + 1.1 m NGF	⑥ + 1.5 m NGF
Scénario exceptionnel	⑦ + 2.00 m NGF	⑧ +2.40 m NGF	⑨ +2.80 m NGF

Figure 1. Table of criteria for analyzing the vulnerability of reed beds in Occitanie to marine flooding. The type of flooding is associated with the scenario number: "P" for Permanent, "R" for Recurrent and "E" for Exceptional.

Finally, the analysis carried out on the current behavior of the reed beds shows that these environments could be maintained by adapting the management of water resources, in particular by maintaining a low mineralized water lens in the water body throughout the year. Indeed, maintaining a column of low mineralized water makes it possible to maintain a hydraulic load gradient in the reed bed and thus to guarantee the salt water table at greater depth (PALVADEAU et al., 2021, ADENA, 2022). Water resource management, where possible (sufficient resource) could thus reduce the vulnerability of the reed bed to climate change.

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