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Evaluating the impacts of sea level rise on coastal wetlands in Languedoc-Roussillon, France

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ABSTRACT

Sea-level rise due to climate change creates new risks of submersion in coastal areas that must be taken into account. Although these are long-term risks for 2100, it is important to anticipate possible consequences in order to identify the most vulnerable areas or issues and develop the appropriate adaptation policies. The aim of this paper is to examine the consequences of such sea-level rise for wetlands in the Languedoc-Roussillon region (France) which is particularly at risk of submersion. The analysis is based on the worst case scenario of a one meter sea level rise by 2100, with a variety of adaptive strategies: denial, laissez-faire and strategic retreat of infrastructure and buildings. This latter strategy assumes that the retreat wetlands is unconstrained. The evaluation examines the losses and transformations of ecological habitats, depending on their distance from salt water. Estimating damages and benefits requires first, to study the evolution of the services supplied by different habitats and second, to estimate the value of the economic impact. This approach demonstrates the superiority of a strategic retreat policy which would halve the damages resulting from submersion.

1. Introduction

The prospect of sea-level rise due to climate change creates new long-term risks for coastal natural assets which could have very significant consequences for the coastal physiognomy. Many research studies deal with the vulnerability of infrastructures and buildings, as they frequently are a priority in adaptation policies to climate change (Kelly and Adger, 2000; Tompkins et al., 2010; Cooper and Pile, 2013; Hurlimann et al., 2014). Important topics in the research area are the social impact (Adger et al., 2009) or the acceptability of such policies (Turner et al., 2007; Cooper and Lemckert, 2012; Gibbs et al., 2013; Graham et al., 2013). However, few articles consider the impact of sea level rise on coastal wetlands, which provide numerous ecosystem services, are particularly sensitive to this problem. Analyzing the impact of sea-level rise on these ecosystems and on the services they provide to the population can help guide public coastline development strategies concerning coastal inundation. However, approaches in environmental economics are usually centered on a particular natural asset or on a micro-area and tend to emphasize the adaptation of evaluation methods. Likewise, ecosystem approaches in ecology are also often centered on a single habitat or species. Here, our objective is very different. The aim is to evaluate, at a regional level, all the impacts on services provision, generated by a transformation of the ecosystems due to sea level rise. This approach requires, in a first step, GIS-based modeling in order to identify the spatial heterogeneity of ecosystem services and therefore the services threatened by sea level rise. Then, in a second steps, we propose an evaluation of economics impact of the gains and losses of ecosystem services based on a combination of different methods.

The ecosystem services approach enables a precise evaluation to be made of the studied impacts. Commonly found in ecology (Daily, 1997) in particular in the case of wetlands (De Groot and Stortenbeker, 1992; Simas et al., 2001), this type of approach is more recent in economics even though some authors (Gomez-Baggethun et al., 2010; Mooney and Ehrlich, 1997) point to much

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older precursory work. Gomez-Baggethun et al. (2010) distinguish several phases beginning with the identification of the service functions, followed by their monetary evaluation and, more recently, institutional mechanisms enabling payments to be made for these services. The gradual operationalization of these approaches is clear, usually based on geographical modeling tools (Chen et al., 2009). According to Nicholls (2004) the stakes are particularly great in the case of wetlands which are extremely vulnerable to sea-level rise and for which these transformations are poorly evaluated. They note that *"the wetland model is more difficult to validate as most national scale studies have assumed no wetland response to sea-level rise. Hence, these national results overestimate the likely losses due to sea-level rise. Improved validation of the wetland loss model remains an important issue for future research."* There seem to be few studies in this area. Several authors (Park et al., 1989; Craft et al., 2009) use SLAMM (Sea Level Affects Marshes Model) to model the evolution of coastal wetlands that are affected by sea-level rise, i.e. coastal inundation, sedimentation and accretion, and the evolution of salinity and erosion. This gives spatialized results of the effects of sea-level rise on coastal natural areas. For example, Craft et al. (2009) use this model to evaluate the loss of ecosystem services due to sea-level rise in coastal Georgian marshes (USA) focusing on biomass production and water purification services. It is important to emphasize however that, although its methodology overlaps substantially with our approach, this latter paper focuses on physical environmental variation in terms of surface area loss and gain by habitat type, with no evaluation of the economic fallouts.

The scope of our study is the Languedoc-Roussillon coastline. It includes the 58 towns and villages ("communes") at risk from coastal inundation, that is, the 54 communes covered by the Coastal Law and 4 communes in the Gard department (Aigues Mortes, Saint Laurent d'Aiguouze, Vauvert and Saint Gilles). Adapting the hypotheses of the Intergovernmental Panel on Climate Change (IPCC) to the case of Languedoc-Roussillon gives a worst-case scenario of a one-meter-rise in sea level by 2100 with increased storm impacts due to the higher water levels. On the basis of this scenario, the multidisciplinary research project MISEEVA[1] studied the vulnerability of the Languedoc-Roussillon coastline. Its objective was to evaluate the level of risk for the population, the activities and the natural assets and what might be the damages or benefits. This paper presents the results obtained for lagoon ecosystem wetlands (Mediterranean lagoons and related habitats).

The first part of the paper evaluates the exposure of natural assets to submersion risk. The second part discusses the methodologies developed to evaluate the potential impacts of submersion on the services supplied by each type of ecosystem. On this basis, the third part estimates the economic impact resulting from the losses and gains in each type of service. Finally, the fourth part discusses the results.

2. Exposure to submersion risk

In Languedoc-Roussillon, wetland habitats represent 24,396 ha. They are almost all community-interest habitats under the European "Habitats" Directive (Council directive of 21 May, 1992) and belong to the Natura 2000 network. They are ecosystems which contribute to the landscape's identity and represent significant ecological wealth, both locally and more broadly. For example, Mediterranean wetlands represent 17% of French wetlands of international importance (DIREN-LR et al., 2007).

Risk exposure depends on water height but also on storm frequency. Several types of submersion can be distinguished. Permanent submersion corresponds to the lowest astronomical tides with a 1 m rise. Recurrent submersion is related to the highest astronomical tides occurring at least once a year. These tides are 44 cm high which gives a total height of 1.44 m. The progressive nature of sea-level rise must be taken into account in possible future public policies, guidelines for which have already been proposed (Cousin, 2011; Turner et al., 2006). It is important first to consider the natural adaptation of ecosystems, which may progressively retreat onto new land or on the contrary disappear, depending on land usage (whether anthropogenic or not). Various adaptation possibilities for coastal communities were then considered. Denial assumes that there is neither foresight nor adaptation. The permanent nature of infrastructure and buildings then leads to a "coastal squeeze" (Luisetti et al., 2008), because wetlands can only retreat onto agricultural land, which can no longer be exploited due to submersion. A laissez-faire approach assumes the absence of collective adaptation regulated by the State, in particular concerning the relocation of infrastructure. However, the population gradually moves away leaving behind urban wasteland, onto which wetlands cannot retreat. Finally, the option of a strategic retreat of infrastructure and buildings (with no wasteland) assumes a planned operation. Indeed, some research recommend to move back urban areas or to 'depolderise' (Goeldner-Goanella, 2007), in order to favor natural resilience by allowing wetland habitats to move inland (Abel et al., 2011). This option corresponds to the proposed policy (Cousin, 2011) of allowing the unconstrained retreat of wetlands.

Submersion-risk modeling undertaken in the MISEEVA project (Lecacheux et al., 2011) provided a map of impacted areas for each type of submersion (permanent, recurrent and exceptional). Exposed areas can be estimated by relating these maps to soil occupancy (SIG L-R OCCSOL 2006, DDE). Overall, areas of permanent submersion were not of great significance, accounting for 7% of the studied ecosystems (Table 1). In this type of submersion, it was considered that the affected areas were transformed into lagoon ecosystems. A fifth of wetlands suffered recurrent submersion (Table 1). In this type of submersion, it was considered that the increased salinity would lead to the transformation of habitats, a process that required the development of an appropriate methodology (cf. § 2). The structural impact of the creation of permanent channels between the lagoons and the sea ("graus" in occitan) could not be studied because estimating the probability and location of this particular type of impact would have required a large amount of data that was not available.

In order to evaluate submersion impacts, we referred to the services supplied by these ecosystems (MEA, 2011; Chevassus-au-Louis et al., 2009) which have been widely studied (Birol et al., 2009; Carlsson et al., 2003; Fisher et al., 2009; Milon and Scrogin, 2006). The Ecosystem Services approach developed in the Millennium Ecosystem Assessment (MEA, 2011) provides a standardized framework to identify and evaluate the links between ecological processes and economic systems. Impact

Table 1
Exposure of wetlands to various types of submersion.

	Surface area (ha)	% of regional total
Permanent submersion	1732	7%
Recurrent submersion	5165	21%
Exceptional submersion	5976	24%
Unaffected	11,523	47%
Total	24,396	100%

[1] Marine Inundation exposure hazard and Social Economic and Environmental Vulnerability Assessment. A project funded by the NRA and coordinated by the Orléans Bureau of Mines and Geology (BRGM).