



# Rapid losses of intertidal salt marshes due to global change in the Gironde estuary (France) and conservation implications for marshland passerines

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## Abstract

We analysed coastline movements between 2000 and 2016 along the 24.5 km of the mesohaline region of the North bank of the Gironde estuary (France). This sector is identified as hosting the largest expanse of salt marshes of the estuary and as an important breeding and stopover site for different marshland passerines of conservation concern. Our results from the study area reveal an average shore retreat of  $14.74 \pm 0.50$  m over the period, corresponding to a loss of 49.96 ha of intertidal wetlands (i.e. 2.04 ha per kilometer of coastline) and reaching on average of more than 30 m for 42% of the coastline. This erosion dynamic, explained by a significant perturbation of the estuary's hydro-sedimentary dynamic (due to decreases in freshwater discharges and relative sea level rise) highlights the rapid disruption that can occur in estuarine eco-complexes in response to global change. Given the impacts that estuarine intertidal wetland losses have on carrying capacity for marshland passerines, experimental management approaches are being tested in the study area to compensate for losses already observed and to anticipate those expected. These approaches reveal in particular that partial reconnection of agricultural polders to tide influences with a regulation system for water ingress may allow interesting trade-off between maintaining polders with agricultural activities such as grazing and conservation plans for vegetation of intertidal salt marshes exploitable by marshland passerines.

**Keywords** Birds · Climate change · Coastal erosion · DSAS · Intertidal wetlands · Sea level rise

## Introduction

Tidal wetlands are among the most productive ecosystems on Earth, contributing to the economic welfare of local and global communities (Costanza et al. 1997; Blankespoor et al. 2014). These ecosystems provide multiple services, including shoreline protection, storm buffering, sediment retention, water quality maintenance, as well as carbon sequestration or preservation of ecological niches exploited by several organisms (Woodward and Wui 2001). Among tidal wetlands, estuarine habitats particularly appear as highly biologically productive ecosystems (Kennish 2002; McLusky and Elliott 2004), sustaining a variety of valuable goods and services for human activities (Costanza

et al. 1997). These habitats also fulfil important ecological functions for marine fish species, providing breeding grounds, nurseries or feeding areas (Beck et al. 2001), and play a key role for several species of waterbirds during different periods of their life cycle (Prater 1981; Baird et al. 1985; Yates et al. 1993; Watkinson et al. 2004). Salt marshes also provide interesting habitats for various marshland passerines, particularly for highly specialized species that exploit these habitats as breeding areas (Marshall and Reinert 1990; Musseau and Beslic 2018), stopover grounds (Musseau et al. 2014) or during particularly energy-demanding events such as moult (Musseau et al. 2017).

Increased pressures on ecosystems, habitat loss or degradation, and climate change are among the main factors impacting biodiversity in the current context of global change (Ehrlich 1988; Butchart et al. 2010; Pereira et al. 2010; Rands et al. 2010). Throughout the world, coastal ecosystem degradation is increasing at a worrying rate (Hinrichsen 1998) and 20–60% of the world's coastal wetlands are at risk of disappearing in the next 100 years (see Titus 1988; Nicholls et al. 2007; Craft et al. 2009). Among these coastal habitats, estuaries tend to be particularly

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affected (Edgar et al. 2000). Different causes explain threats facing estuarine salt marshes. In Texas, for instance, estuarine intertidal wetlands decreased by 9.5% between the mid-1950s and early 1990s given the submergence of marshes due to the extraction of underground water, oil or gas (Moulton et al. 1997) and in Portugal, Rilo et al. (2013) revealed that up to 23.7% of the marginal fringe of the Tagus estuary may be flooded by 2100 given its vulnerability to anthropogenic land exploitation and to sea level rise.

France's Gironde estuary is the largest tidal river mouth in Western Europe. Within this estuary, Sottolichio et al. (2013) highlighted a turbidity maximum zone (high turbidity zone resulting from turbulent resuspension of sediment and flocculation of particulate matter due to the confrontation between freshwater and tidal currents) migrating continuously towards the upstream portion of the estuary and a significant increase of the erosion trend within the bed of the estuary. This trend is explained by an increase of the force of the tidal currents entering the estuary due to two major phenomena: (1) an increase in dry season duration generating a decrease of the fresh water level in summer (see Eaucéa 2008) and (2) a local relative sea level rise (see Eaucéa 2008). In order to study the specific effects of the recent perturbations of the turbidity maximum zone observed in the Gironde estuary towards the estuarine intertidal grounds, we decided to monitor the evolution of salt marshes within the largest expanse for these habitats of the estuary: the mesohaline region of the North bank. In the light of our results, we present examples of conservation policies and management plans being conducted within the study area to conserve salt marshes exploitable by marshland passerines in the context of global change and discuss the particular advantages and disadvantages of these different possible approaches.

## Study area and method

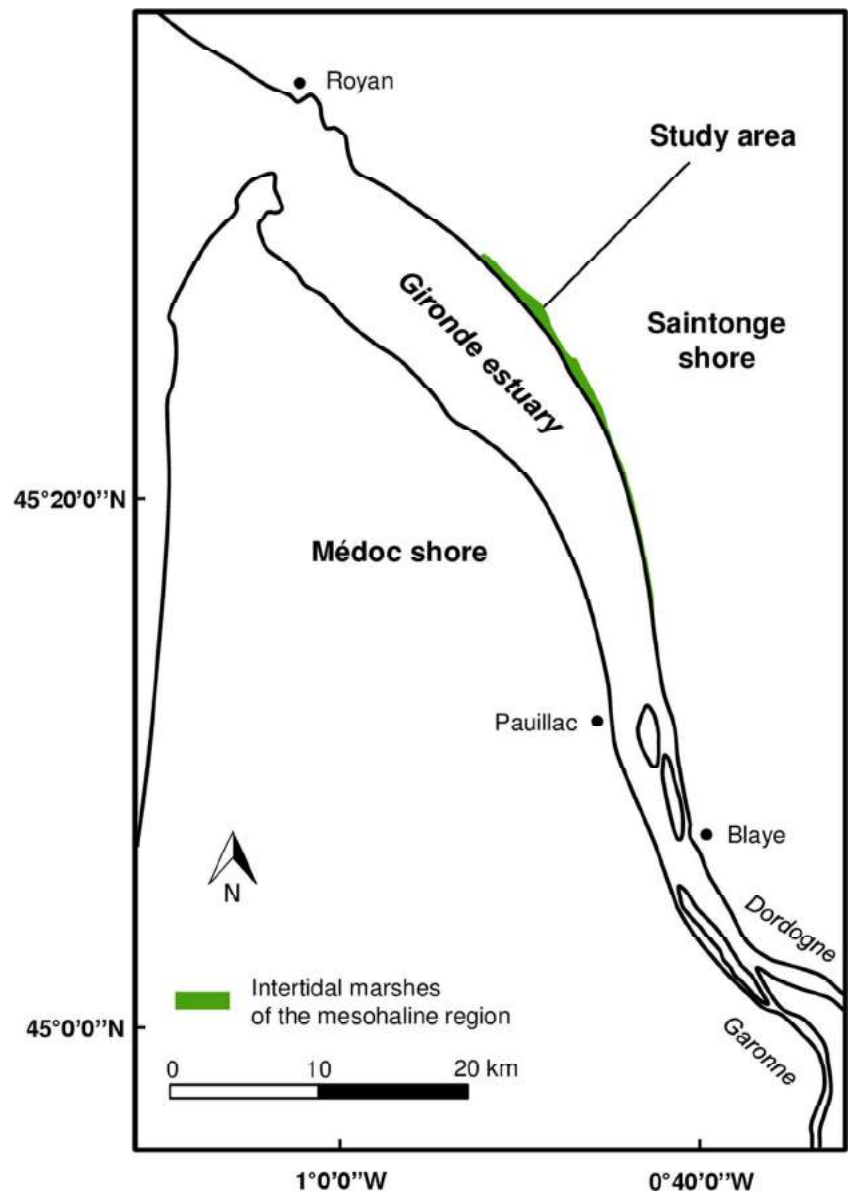
The study was carried out on the North bank of the Gironde estuary (France, 45°25'51.75"N, 00°46'9.30"W, Fig. 1) along its mesohaline region (5–18 PSU - Practical Salinity Unit, see definition in Rince 1983) which hosts the largest expanse of salt marshes of the estuary. The study sector covers approximately 1500 ha and is over 24.5 km in length, with a width ranging from a few tens of meters to over a kilometer. This large area is composed of intertidal submarine sedge and reed beds vegetal communities of brackish mudflats. The lowest parts of littoral slopes include large surfaces of bulrush beds with a vegetation mainly dominated by the Saltmarsh Bulrush (*Bolboschoenus maritimus*) whereas the upper parts of the slopes consist of large reed beds dominated by the Common Reed (*Phragmites australis*) often mixed with dense patches dominated by the Sea Couch (*Elytrigia acuta*) or consist of large meadows mainly colonised by the Saltmeadow Rush (*Juncus gerardii*) (Fig. 2). The site is mainly owned by

the French Coastal and Lake Shore Conservation Authority and managed by the Poitou-Charentes' Conservatory of Natural Areas.

The evolution of salt marshes surfaces was assessed using QGIS software ('Free Software Foundation', version 2.14.12) and satellite images from 2000 and 2016. The satellite image used for 2000 was the 'ortholittorale V1' map (© ORTHOLITTORALE 2000) imported into QGIS using a WMS flux generated from GeoLittoral application. The satellite image used for 2016 was a Google Earth™ image imported into QGIS using the OpenLayers plugin. Both satellite images were taken during low tide conditions, allowing distinguishing clearly mudflats and salt marshes. After importation of satellite images in QGIS, to avoid bias in the calculation of surfaces linked to the projection system, satellite images were registered reprojecting coordinates in the ellipsoid WGS 84 (EPSG 4326). Shorelines (limit between tidal flats and salt marshes) were identified at the scale of 1/1000. These marshland delimitations allowed us to estimate the absolute evolution of intertidal salt marshes surfaces for the considered zone.

The coastline retreat was assessed using the Digital Shore Analysis System extension (DSAS, Thieler et al. 2009) created for ArcGIS software, allowing calculations of different shoreline rate-of-change statistics from a time series of multiple shoreline positions. Files generated under QGIS were registered in a Lambert 93 (EPSG 2154) projection with metric coordinates usable by DSAS. A baseline (reference line as the starting point for all transects generated by DSAS) was manually created with ArcGIS 9.3 using the Buffer and the Editor tools and following the method detailed by Thieler et al. (2009) in order to buffer the shorelines with a buffering distance of 20 m. From the resulting baseline, transects (lines intersecting shorelines of years 2000 and 2016 allowing calculating coastline retreat) were created using the following parameters: transect spacing: 25 m; transect length: 150 m; smoothing distance: 100 m, and finally the closest intersection with shorelines. After cleaning for non-relevant transects automatically generated by DSAS (with no or only one shoreline intersection) we obtained data for 1505 transects all along the 24.5 km length of the study area. We then calculated from DSAS the distance between both shorelines taking into account the direction of the movement (accretion or erosion), called the Net Shoreline Movement (NSM). Standard error and confidence intervals for means of NSM were calculated using a non-parametric bootstrap resampling method, consisting of 3000 random samples taken with replacement from the original dataset of the same size as the original (see details about the method in Efron 1979 and in Efron and Tibshirani 1993). Analyses were performed using the R software environment (version 3.2.3, R Development Core Team 2013) and statistical parameters were calculated using the "boot" R package (Canty and Ripley 2017, based on

**Fig. 1** Geographical location of the study area

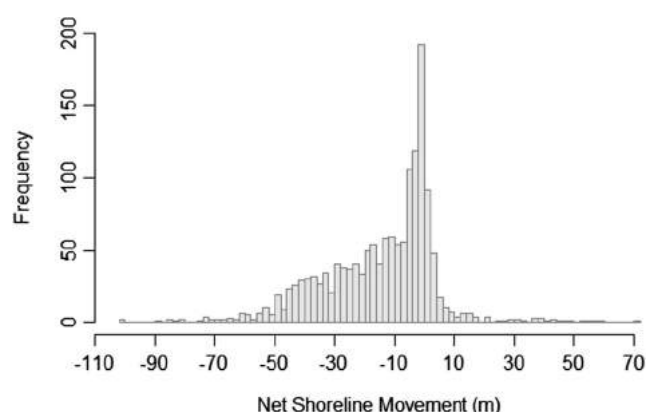


**Fig. 2** Shore unaffected by erosion: gentle slopes with a gradual zonation of intertidal habitats (2015, Mortagne-sur-Gironde, 45°28'36.11"N, 00°49'3.35"W)

methods described by Davison and Hinkley 1997). Confidence intervals (CI) have been calculated using the Bias Corrected and accelerated bootstrap method (BCa, detailed by Efron 1987 and by Preacher and Selig 2012).

## Results

Between 2000 and 2016, movements of the coastline for the 24.5 km of the mesohaline region of the North bank of the Gironde estuary ranged from +70.02 m to −100.70 m (Fig. 3), with an average retreat of  $14.74 \pm 0.50$  m (95% CI = −15.73 to −13.71). This corresponds to a loss of 49.96 ha of intertidal wetlands over the study period (i.e. 2.04 ha per kilometer of coastline). Coastline movements are variable in intensity all



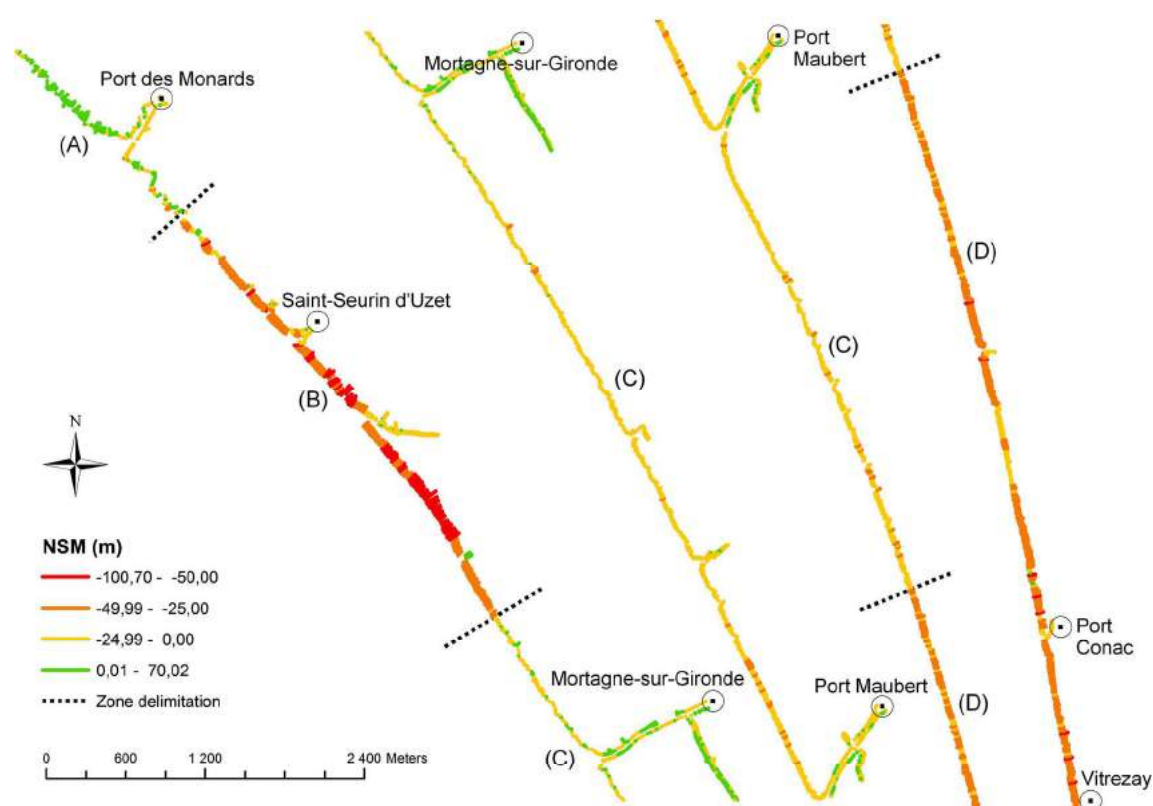
**Fig. 3** Distribution of the Net Shoreline Movement (NSM) from 2000 to 2016 for 1505 transects distributed along 24.5 km of the mesohaline region of the North bank of the Gironde estuary

along the study site and cartographic visualization enables identification of four different zones (see Fig. 4): a small one with an accretion dynamic (zone A: average NSM =  $6.01 \pm 1.50$  m of accretion for 1.8 km of coast); one with a moderate erosion dynamic (zone C: average NSM =  $7.71 \pm 0.31$  m of retreat for 12.4 km of coast); and two with an important erosion dynamic (zone B: average NSM =  $32.29 \pm 1.65$  m and zone D: average NSM =  $30.51 \pm 0.66$  m of retreat for 3.9 and 6.4 km of coast respectively). In the two sectors mainly

affected by the erosion dynamic documented (zones B and D, corresponding to 42% of the coastline studied) field prospection revealed a coastal retreat accompanied by shore transformation profiles with gentle shore's slopes that progressively turn into steep inclines (Fig. 5). Within such sectors, the zonation of coastal habitats appears dramatically impacted, with lowest habitats of littoral slopes (particularly colonised by the Saltmarsh Bulrush - *Bolboschoenus maritimus*) significantly altered by the erosion and having locally completely disappeared (Fig. 5). All along these sectors, the shore's upper parts (sedge and reed beds vegetal communities mainly consisting of dense reed beds dominated by the Common Reed - *Phragmites australis* and mixed with large patches dominated by the Sea Couch - *Elytrigia acuta* or consisting of meadows mainly colonised by the Saltmeadow Rush - *Juncus gerardii*) start to appear locally strongly degraded (Fig. 5), with significant threats starting to appear along dikes protecting agricultural polders.

## Discussion and conservation implications

In the context of global change Kirwan et al. (2016) highlighted that intertidal marshes vulnerability tends to be overvalued



**Fig. 4** Cartography of coastline evolution illustrated by the Net Shoreline Movement (NSM) along the mesohaline region of the North bank of the Gironde estuary, from North (section “A” on the top left) to South (section “D” on the right)





**Fig. 5** Shore affected by erosion: steep slopes with disappearance of the lowest intertidal habitats (2015, Saint-Sorlin-de-Conac 45°20'25.72"N, 00°43'14.50"W)

given a failure to take full account of biophysical processes of soil building accompanying sea level rise and the potential for these grounds to migrate inland. At the same time, Crosby et al. (2016), underlined that the vulnerability of coastal marshes clearly depend on the local sea level rise rates they experience. Today, along the French coast 48.6% of the muddy shores are in accretion and 35.1% remain stable whereas 11.8% are subject to erosion (Spohr 2011). The erosion dynamic of intertidal marshes we observe in the Gironde estuary thus appear as a particular trend of the French coastal environments. Different studies highlighted factors explaining erosion dynamics observed on coastal marshes. For lowest levels of intertidal marshes Gerdol and Hughes (1993) underlined for instance the particular role of fauna's activities (amphipods) in reducing the stability of the sediments. Given the impact of the erosion dynamic noticed on both lowest and uppermost parts of the intertidal marshes, the erosion trend we revealed in our study for the mesohaline region of the Gironde estuary may be more particularly placed in perspective of the significant perturbation of the hydro-sedimentary dynamic measured since the 1970s. Indeed, since 1970 the turbidity maximum zone of the Gironde estuary (resulting from resuspension of sediments and flocculation of particulate matter due to the confrontation between freshwater and tidal currents) has shown a tendency to migrate continuously towards the upstream parts of the estuary with a significant increase of the erosion recorded in the bed of the estuary (loss of about 17 km<sup>3</sup> of sediment in the bed of the estuary between 1970 and 1980, and 60 km<sup>3</sup> between 1980 and 1994, Sottolichio et al. 2013). This hydro-sedimentary perturbation is driven by an increase of the force of the tidal currents entering the estuary, explained by significant decreases of freshwater discharges feeding the estuary, combined with an increase of a relative sea level rise locally recorded in recent decades. Since the 1960s, the average cumulative discharges of the two main rivers feeding the estuary (the Garonne and the Dordogne rivers) decreased regularly (1100 m<sup>3</sup>.s<sup>-1</sup> in 1962–1970, 900 m<sup>3</sup>.s<sup>-1</sup> in 1970–1980 and 600 m<sup>3</sup>.s<sup>-1</sup> in 1980–1994, Sottolichio et al. 2013). Such

decreases in river discharge arose from reduced rainfall observed in different locations of the Gironde estuary's water catchment area, coupled with increased global summer temperatures and evapotranspiration (which induces increased crop irrigation, in particular). These disturbances led to a substantial deterioration in the annual water balance in the estuary's water catchment area (see details in Levraut et al. 2012 and Eaucéa 2008). Despite the lack of studies documenting the meteorological changes occurring globally in recent decades throughout the Gironde estuary's water catchment area, different trends illustrate the ongoing changes. For instance, in the Pyrenees, snowfall has locally dramatically decreased, with a decline of 10 to 15 days between 1971 and 2008 measured at L'Hospitalet (French Pyrenees, altitude = 1400 m, data from Météo France 2008, in DREAL Midi-Pyrénées 2012). We also notice a tendency for summer precipitation to decrease, with a diminution of about 13% recorded between 1900 and 2000 at Merignac, near the city of Bordeaux (Eaucéa 2008). Lastly, summer temperatures in a large part of the Gironde estuary's water catchment area have increased significantly, by about +3 °C over the past 50 years in the Aquitaine region (Le Treut 2013). To these different effects explaining the increase of the force of the tidal currents entering the estuary, must be added the increasing influence of tides related to the relative sea level rise observed in the Gironde estuary (rise from 2.2 to 2.8 mm / year measured between 1914 and 1996, see details in Eaucéa 2008).

Our study thus illustrates the particular sensitivity of estuaries to global changes and the rapid impacts these changes may have on the conservation of estuarine salt marshes and their ecological functions. By their vegetation and abiotic properties, tidal marshes constitute very specific habitats where species establishment is strongly linked to environmental conditions. Intrinsic properties, such as salinity or regular tidal floods, constrain species' ability to live in such habitat and thus shape the structure of resident communities, resulting in a great level of specialists, endemism or local adaptations (Greenberg et al. 2006). These high biologically productive habitats appear as particularly important for the conservation of different bird species given the nutritive resources they provide (Hughes 2004). More specifically, several studies highlighted the key roles of Atlantic estuarine salt marshes for different marshland passerines highly specialized during different periods of their life cycle. For the Aquatic Warbler (*Acrocephalus paludicola*), an endangered songbird with limited range and numbers several studies have highlighted the particular importance of intertidal Atlantic salt marshes of estuaries or bays as stopover sites. Probably all juveniles of this passerine migrate by the Atlantic western flyway and stop in France to refuel during fall migration (Jiguet et al. 2011). Within major French stopover sites identified for this migratory bird (Seine estuary, Loire estuary, Gironde estuary and Aiguillon bay), Provost et al. (2010), Foucher et al. (2011),

Musseau et al. (2014) and Gonin and Mercier (2016), revealed the key role of the low vegetation covering slopes' lowest parts of intertidal marshes as foraging sites for the species. In the Gironde estuary, it has been demonstrated for this species of conservation concern that individuals with important energy requirements (lean birds from the sampled population) were able to gain an average of  $2.81 \pm 0.89\%$  of their initial mass each day when exploiting such habitats (see details in Musseau et al. 2014). The particular importance of estuarine salt marshes has also been underlined for the Western France Bluethroat (*Cyanecula svecica namnetum*), an endemic marshland passerine of the French Atlantic coast. For this taxon of conservation concern given its limited range and numbers, reed-beds (vegetation areas dominated by *Phragmites australis* covering the highest parts of the intertidal zones) have been identified as important breeding sites (see Musseau and Beslic 2018). For this coastal specialised bird, bulrush-reed beds (vegetation areas dominated by *Bolboschoenus maritimus* and by *Phragmites australis* covering the lowest parts of the intertidal zones) have also been identified as important areas in terms of trophic opportunities to compensate for the energy costs of moult (birds in active moult particularly feeding on marine crustaceans: Amphipoda, see details in Musseau et al. 2017).

Given the key role of intertidal wetlands of the Gironde estuary for several species or populations of marshland passerines of conservation concern, and of the rapid erosive dynamic recorded in a major intertidal sector of the estuary, different management experimentations have been tested since 2000 along the study area to compensate for losses of intertidal habitat already recorded and to anticipate expected losses. To this end, two approaches are thus studied at the study region. The first one is a full depolderization (i.e. a reconnection to tidal currents of a land reclaimed from the sea) of an agricultural polder covering about 190 ha that occurred after a dam break due to the storms Lothar and Martin that hit the region in December 1999 (Hérault and Collet 2010). After the dam break, the site was acquired by the French Coastal and Lake Shore Conservation Authority and naturally evolved into a lagoon subject to tidal influence. Today, the site consists of intertidal mudflats colonised by large patches of bulrush beds (dominated by the Saltmarsh Bulrush - *Bolboschoenus maritimus*) mixed with patches of reed beds (dominated by the Common Reed - *Phragmites australis*) (Figs. 6 and 7). These habitats have proved to be very attractive for marshland passerines that exploit salt marshes, in particular for the Aquatic Warbler (*Acrocephalus paludicola*), for which the site has been rapidly identified as a very important stopover site (Musseau et al. 2014). However, this depolderization was not warmly received by the local population given the loss of agricultural land it causes and it appears complicated to systemize this management solution to compensate intertidal habitats losses within a region under



**Fig. 6** Aerial view of a full reconnection of an agricultural polder (depolderization) in the mesohaline region of the North bank of the Gironde estuary (2013, Chenac-Saint-Seurin-d'Uzet and Mortagne-sur-Gironde, 45°28'55.53"N, 00°48'45.06"W)

increasing erosion dynamics and risk of marine submersions. The second method for compensation of intertidal wetland losses studied along the estuary is a partial reconnection to tide influences of an agricultural polder covering about 63 ha. The site is dedicated to grazing and hay production and was reconnected to tidal influences by means of a pipe equipped with a flap in order to limit estuarine water inlets during episodes of extreme tides or during storms. This partial reconnection allowed between the 48 plots of the area (each covering an average surface of 1.3 ha) the development of 47 large wet vegetated ditches. Each of these ditches are characterised by large strips of vegetation dominated by the Common Reed (*Phragmites australis*) and the Saltmarsh Bulrush (*Bolboschoenus maritimus*, Figs. 8 and 9). Such a configuration allows the development of important edges between marshland and grassland vegetation capable of offering interesting transitional zones for arthropods communities exploitable by marshland passerines. Traut (2005) highlighted the interest of transition zones between salt marshes and adjacent uplands, finding a greater plant and arachnid diversity within such habitats. Given the ecotones generated by the development of ditches connected to tidal influences in grassland zones, this management method may offer an interesting



**Fig. 7** Saltmarsh Bulrush (*Bolboschoenus maritimus*) and Common Reed (*Phragmites australis*) colonising an agricultural polder after full reconnection of the area to tidal influence





**Fig. 8** Aerial view of an agricultural polder reconnected to tidal influence by means of a pipe equipped with a flap (2016, Mortagne-sur-Gironde, 45°28'9.99"N, 00°47'40.61"W)

carrying capacity for marshland passerines in inshore coastal areas of regions affected by erosion dynamics. The first indicators collected in 2016 and 2017 began to reveal the interest of such habitats for diverse marshland passerines during different periods of their life cycle. Thus, during the breeding period, a capture-mark-recapture scheme set up in 2017 within the area described above revealed an average capture number reaching 0.88 males of Reed Warbler (*Acrocephalus scirpaceus*) for 10 m of mist nets installed within reed beds growing in ditches delimiting plots (Musseau et al., unpublished observations). For adults of the Western France Bluethroat (*Cyanecula svecica namnetum*), ringing data collected in 2016 during post-breeding moult revealed a minimum mean residence time within the area reaching  $19.7 \pm 4.15$  days (see details in Musseau and Beslic 2016). These first trends recorded (significant establishment during the breeding period of an insectivorous marshland passerine and significant residence time of an endemic taxon feeding on saltmarsh invertebrates during a particularly energy-demanding event) underline the trophic potentialities that agricultural polders reconnected to tide influences may offer to different marshland passerines.



**Fig. 9** Saltmarsh Bulrush (*Bolboschoenus maritimus*) and Common Reed (*Phragmites australis*) colonising large ditches of an agricultural polder after partial reconnection of the area to tidal influence by means of a pipe equipped with a flap

The two management solutions presented above demonstrate that different scenarios may be imaginable to compensate for intertidal wetlands losses resulting from significant erosion dynamics. Such scenarios may provide interesting results in terms of habitat restoration and possibilities for maintaining the carrying capacities for marshland passerines of regions impacted by coastal habitat losses. Full depolderization is likely to be variously appreciated and accepted by human populations, particularly within geographical contexts where major agricultural issues arise (see Goeldner-Gianella 2007a, b). Thus, it would be interesting to consider solutions that allow a trade-off between, on the one hand, maintaining polders and agricultural activities such as grazing, and, on the other hand, the conservation of intertidal wetlands. Such management of inshore coastal areas could gain wide public acceptance more easily than full depolderization while at the same time ensuring a long-term conservation strategy for an important part of the trophic webs threatened by the global change affecting the lowest-lying intertidal areas and particularly within estuarine environments for which changes can be rapid and significant as those documented in the present study.

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