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**Conservation and restoration of coastal reed beds in the context of global change:
potential effects of habitat fragmentation for specialist marshland passerines**

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Abstract

In the context of coastal marshland reduction due to sea level rise, we evaluated the value of fragmented reed beds located within agricultural polders for the conservation of habitats exploited by marshland passerines characterized by different ecological requirements. Although our study was carried out within sites sampled over different years, analyses of body condition and diet of birds during the breeding period, as well as the local daily survival rate and the body mass evolution of birds during the post-breeding period, reveal trends illustrating that fragmented reed beds within inland meadows can: (i) generate habitats that may be significantly exploited by species with a large ecological plasticity, such as the Reed Warbler that could benefit from edge effects of habitat fragmentation; (ii) offer low attractiveness for specialised species such as the Aquatic Warbler, a migratory species apparently very sensitive to the effects of reed bed fragmentation. These results underline the reed beds fragmentation effects that may impact specialised marshland passerines and which should be taken into account in wetland conservation and restoration plans.

Keywords: Aquatic Warbler, coastal marshes, Reed Warbler, sea level rise, wetland conservation

Introduction

Tidal wetlands are among the most productive ecosystems on Earth ([Costanza et al. 1997](#), [Blankespoor et al. 2014](#)). These grounds, recognized for the different services they provide, such as water quality maintenance or carbon sequestration ([Woodward & Wui 2001](#)), are also known to support different ecological niches exploited by a large diversity of organisms ([Woodward & Wui 2001](#)). Tidal marshes are composed of a wide variety of vegetation (differing in their composition and structure) where different bird species have the possibility to exploit important trophic resources during particularly energy-demanding events such as reproduction, migration or moult ([Marshall & Reinert 1990](#), [Musseau & Beslic 2018](#), [Musseau et al. 2014](#), [Musseau et al. 2017](#)). Due to the drying-out of marshes, and human shoreline development throughout the world, the degradation of coastal ecosystems increases at a worrying rate ([Hinrichsen 1998](#)). In the context of climate change and sea level rise, coastal marshes may be also considerably exposed to high erosion phenomena caused by perturbations of hydro-sedimentary dynamics ([Day et al. 1995](#)). These dynamics may generate important modification of the foreshores' geography with soft substrates and it has been estimated that 20 to 60% of coastal wetlands may disappear in the next 100 years ([Titus 1988](#), [Nicholls et al. 2007](#), [Craft et al. 2009](#)). Interfaces between continental zones and oceans, the tidal estuarine wetlands may be particularly affected by degradation resulting from the effects of global change, ongoing and forthcoming (see [Wolanski & Chappell 1996](#)). For instance, in Portugal, [Rilo et al. \(2013\)](#) revealed that up to 23.7% of the Tagus' banks may be flooded by 2100 given their vulnerability to anthropogenic pressure on lands and to sea level rise. In France, the Gironde estuary is also subjected to a significant erosive dynamic, explained by high perturbation of its hydro-sedimentary functioning (combined effects of sea level rise and a significant decrease of fresh water flows (see details in [Musseau et al. 2018](#)).

Throughout the Gironde estuary, erosion impacting the sedimentary budget appears particularly important: loss of 60 km³ of sediment throughout the estuary bed over the 1980-1994 period ([Sottolichio et al. 2013](#)), combined with a significant loss of tidal wetlands (average shore retreat of approx. 1.5 m over the 2000-2016 period in the mesohaline region of the right bank of the estuary, see [Musseau et al. 2018](#)).

Given the key role of tidal marshlands in the conservation of different highly specialized marshland passerines, the alteration of these habitats raises the question of possible solutions to compensate ongoing and future loss of habitats. It is known that a total reconnection of lands reclaimed from the sea to marine influences (depolderization) may offer an interesting solution for compensating the loss of habitats within coastal regions subjected to high erosion dynamics (see details in [Musseau et al. 2018](#)). Nevertheless, renaturing coastal grounds may be met with resistance by the local populations, particularly within geographical contexts experiencing important agricultural issues and land pressures ([Goeldner-Gianella 2007a & 2007b](#)). As a result, solutions allowing to define trade-offs between maintaining agricultural use of these polders and conservation plans of tidal marshes remain to be defined and evaluated. This search of trade-off solutions presents important risks of habitat fragmentation that may, in particular, affect high specialized marshland passerines subject to worrying increased degradations and loss of their habitats related to global change.

With this in mind, from 2016 to 2018, we evaluated the ecological interest for marshland passerines of an inshore coastal meadow supporting a fragmented reed bed (FRB), located within the right bank of the Gironde estuary. Under the assumption that such habitats may present interesting trophic potentialities for insectivorous birds, we compared ecological potentialities for marshland passerines of this fragmented reed bed to a reference native

habitat: a large uniform reed bed (URB). Our work was focused on comparing two species with marked differences in terms of ecological plasticity and which both exploit the tidal marshes of the French Atlantic coast: the Reed Warbler (*Acrocephalus scirpaceus*) and the Aquatic Warbler (*Acrocephalus paludicola*). The Reed Warbler is a common breeder largely distributed along the Eastern Atlantic coast which can exploit an important diversity of habitats (Catchpole 1974, Cramp 1992). By contrast, the Aquatic Warbler is a highly-specialized migratory species of the Eastern Atlantic coast with a relative broad food spectrum (see Kerbiriou et al. 2011), feeding on surfaces with low wet vegetation, most often with a homogenous structure (Le Nevé et al. 2018). By assuming the important trophic potentialities for marshland passerines of FRB particularly due to edge effects, during the breeding period, we compared between FRB and URB: (i) the density of Reed Warblers' singing males; (ii) the variety of prey exploited by the species; (iii) the body condition of birds. Then, in order to compare the use of FRB and URB by the Reed Warbler and by the Aquatic Warbler, we compared between the two sampled sites the average local daily survival rate of juveniles and the daily body mass variation of birds.

Study sites

The study was carried out on the North bank of the Gironde estuary (France, 45°25'51.75"N, 00°46'9.30"W, see Fig. 1) along its mesohaline region (5 to 18 PSU – Practical Salinity Unit, see definition in Rince 1983). This area hosts the largest reed bed eco-complex of the estuary, subject to tidal influence and exploited by different marshland passerines during the breeding period or during migration (see Musseau et al. 2018). Within this region, we sampled two sites, each covering approximately 40 hectares, belonging to the same habitat complex and separated by a distance of approx. 2 km. The first site consists of a fragmented reed bed

(FRB), located in an agricultural polder that is mowed and later used for grazing sheep. This reed bed extends within a network of ditches partially reconnected to the tidal dynamics and regularly flooded by means of a canal connected to the estuary by a pipe flap system. This water management system allows free water circulation and a regulation of water ingress during strong tidal episodes. The reed bed developing within the ditches of the site covers about a quarter its area. The composition of vegetation of this reed bed is relatively similar to the native uniform reed beds located along the shores of the estuary: assemblies of large patches covered by the Common Reed (*Phragmites australis*) in association with patches covered by other helophyte species such as the Saltmarsh Bulrush (*Bolboschoenus maritimus*, see Fig. 1 and 2 in electronic supplementary material). The main difference between the two structures of vegetation lays in the fragmentation of the reed bed. The FRB consists of strips distributed in lines along the ditches separating the plots of meadows (average width of 10 m), interspersed by large patches (average 25 m) dominated by mesophilic grass species that are regularly mowed and used for grazing (Fig. 2). By contrast, the second site studied is a large tidal reed bed (URB) with vegetation dominated by large areas of Common Reed, bordered by broad surfaces covered by Saltmarsh Bulrush and regularly interspersed with patches dominated by Sea Couch (*Elytrigia acuta*, see Fig. 3).

Sampling design

Are trophic potentialities equivalent for marshland passerines within FRB and URB?

We firstly compared the occupation potentialities by marshland passerines of the two sites assessing during the breeding period of 2018 the density of Reed Warblers' singing males. This metric has been measured adapting the method of count points to the sampled sites. We thus have defined six count points distributed on a line, every 100 m within each site, which

was the maximum possible given the surface area of the two sites. Counts of singing males were done by counting songs detected within a square shaped area covering 60 m by 60 m, and delimited by landmarks. From the 12 count points, singing males were counted during five counting sessions. Counts were carried out on average every seven days between mid-May and mid-June, under standard conditions: (i) from the legal time of sunrise until two hours after this time, under light wind conditions ($< 10\text{km/h}$) and felt temperature equal to or greater than 10°C ; (ii) over a period of five minutes (five minutes after the arrival of the observer on the centre of the plot in order to limit the intrusion effect of the observer within the sampling site (see distribution of the plots sampled [Fig. 3 in electronic supplementary material](#)). Despite the risk of underestimation or double counts (equiprobable between count points), the method is known to provide reliable results for inter-habitat comparisons of relative bird abundance (see [Blondel 1985](#), [Verner 1985](#), [Bibby & Burgess 1992](#)). The relative density of singing Reed Warblers related to the surface of reeds was assessed from the surface of reed bed calculated using the QGIS software (version 2.14.12; [QGIS Development Team 2020](#)) after importation of satellite imageries for which vegetation surfaces had been checked in the field. For the two sampled sites, captures of Reed Warblers were performed from mid-May to mid-June in 2016, 2017 and 2018 in order to compare the body condition of adult birds at first capture (ratio mass / wing length). Captures occurred from one hour after sunrise to four hours after sunrise, using “Japanese” mist-nets. Given the possibility of significant variation in female mass during the breeding period due to egg production, analyses were performed using only data collected from male adults. The spectrum of prey exploitable by birds within the two sites was assessed by analyzing droppings of adult Reed Warblers collected from breeding birds captured during ringing sessions in 2017 and 2018. We used dropping analyses to assess the diversity of prey exploited by birds because this method allows to: (i) provide easily reliable data to analyse the diet of insectivorous birds (see [Ralph](#)

et al. 1985); (ii) assess trophic resources genuinely exploited by birds, in contrast with analyses of insect traps that may not predict prey exploited by individuals as insectivorous birds do not necessarily consume insect prey in relation to abundance, see Todd et al. 1998. During capture sessions, birds were removed from the nets within a maximum of 30 minutes after capture and, in order to collect fecal samples, the birds were kept for a maximum of five minutes in cloth bags equipped with a plastic bag fixed at the bottom before being ringed and released. Droppings were individually stored in small tubes with 70% alcohol. They were further dissected under a binocular microscope. Identifiable chitinous fragments were counted in each sample in order to estimate the minimum number of individuals in each taxonomic group (for instance, four Hymenoptera wings were counted as one individual while four Diptera wings counted as two individuals consumed). This method is likely to lead to some bias in diet evaluation because small or soft-bodied prey are less easily detected. However, Davies (1977a & 1977b) demonstrated a strong correlation between the remains of prey in droppings and the composition of the true diet of other insectivorous passerines.

Do Reed Warblers and Aquatic Warblers use equivalently FRB and URB during the post-breeding period?

We focused on the post-breeding period to compare the use by Reed Warblers and Aquatic Warblers of the fragmented reed bed (FRB) and of the uniform reed bed (URB). We measured three different metrics to monitor the use of the two sites by the two species: the local daily survival rate, the daily body mass variation and the bird body condition at first capture (this last variable could explain a potential trend for birds to exploit one site differently from the other one given different energy needs upon their arrival within the sites). The local daily survival rate of birds within the two sites (corresponding to the probability, ranging from 0 to 1 for a bird captured at day t to remain within the site at day $t+1$) was

assessed by means of a capture, mark and recapture (CMR) scheme organized from the 1st to the 31st August using the “ACROLA” protocol (see [Jiguet et al. 2012](#)). The protocol involved to the installation of three units of similar “Japanese” mist-nets, 36 m long, with a tape lure broadcasting the song of the Aquatic Warbler from the centre of each unit. During capture sessions, mist-nets were opened for five hours every morning, starting at one hour before the official time of sunrise. The tape lure started 1.5 hours before sunrise and stopped at the time of net closure. Birds were removed from the nets every 30 minutes throughout the net opening period. In the two sampling sites, mist-net units were distributed in order to homogeneously sample a surface covering approximately one hectare. Capture sessions were set up during 2011 and 2012 within the uniform reed bed (URB) and during 2016, 2017 and 2018 within the fragmented reed bed (FRB). As the very small number of adults captured during the post-breeding period does not allowed running robust statistical analyses, we focused our analyses on juveniles. To validate the use or non-use of FRB by the Aquatic Warbler, a sample of juvenile birds captured within this site was equipped with radio tags. We used “pico-pip” tags (0.29 grams) manufactured by Biotrack Ltd. that cover a range from 80 to 300 m (see methodological details in [electronic supplementary material](#)). During all capture sessions, birds were identified (species, age and sex) according to the criteria detailed by [Svensson \(1992\)](#) and ringed with a metal “Museum Paris” ring engraved with a unique number. Wing length measurement was achieved using the flattened wing method ([Svensson 1992](#)) with a stopped ruler to the nearest 0.5 mm, and body mass was measured with an electronic scale to the nearest 0.1 g.

Statistical analysis

Means and standard errors (SE) of the number of singing males / sampled plots, of the bird body conditions and of the daily body mass variations, were calculated using a non-parametric bootstrap resampling method, consisting of 1,500 random samples (with the same size as the original sample) generated by a random draw with replacement of the values in the original data set (see details about the method in [Efron 1979](#) and [Efron & Tibshirani 1993](#)). These statistical parameters were calculated using the “boot” *R* package ([Canty & Ripley 2021](#), based on methods described by [Davison & Hinkley 1997](#)). We compared the relative density of Reed Warbler singing males and the daily body mass variation of birds between FRB and URB using a Fisher-Pitman Permutation Test (FFP test). The test was performed using the “Coin” *R* package ([Hothorn et al. 2008](#)) with 10,000 resamplings. Comparisons between the two sampled sites (FRB and URB) of the Reed Warbler’s diet and of the bird body condition at first capture (Reed Warbler and Aquatic Warbler) were done using Generalized Linear Models (GLM). Given the nature of the data, we used a Gaussian error distribution to analyze bird body condition (beforehand log-transformed) and a Poisson error distribution for the examination of prey abundance (counting data). The potential site effect was tested using a type-II analysis of variance ([Shaw & Mitchell-Olds 1993](#)) run with the “car” *R* package ([Fox & Weisberg 2019](#)). For the study of the Reed Warbler’s diet composition, we evaluated the sample size representativeness using accumulation curves produced with the function “specaccum” run with the “vegan” *R* package ([Jari et al. 2013](#)). All the analyses described above were performed using the *R* software environment (version 4.0.0, [R Development Core Team 2020](#)). Local daily bird survival rate during the post-breeding period within FRB and URB were calculated using the Cormack-Jolly-Seber model (CJS), an open population capture-recapture model (see details in [Lebreton et al. 1992](#)), performed using Mark software ([White & Burnham 1999](#)). Calculations were done testing possible site and time effects (possible daily effects during the sampling periods) on bird

survival (ϕ) and recapture probabilities (p). For these two parameters, five possibilities were therefore tested: constant parameters, i.e. no time (daily) and no site effects (ϕ_{est} and p_{est}); time effect without site effect (ϕ_t and p_t); site effect without time effect (ϕ_{site} and p_{site}); time and site effects cumulated with time variations similar between the two sites (ϕ_{site+t} and p_{site+t}); and finally time and site effects cumulated but with time effect different between the two sites (ϕ_{site*t} and p_{site*t}). This allowed testing 25 different models resulting from combination of the five possibilities for the parameter ϕ and the five possibilities for the parameter p . Model relevance was assessed by means of the Quasi Akaike Information Criterion corrected (QAICc: correction of the Akaike Information Criterion corrected, see [Burnham & Anderson 2002](#)). In the case of equiprobable models (QAICc < 2), the parameter ϕ was calculated taking into account the most parsimonious model (see [Lebreton et al. 1992](#)).

Results

Comparison of trophic potentialities between FRB and URB

For the analysis of the relative density of singing Reed Warbler males within FRB and URB, 251 song occasions of Reed Warbler males were recorded during the breeding period in 2018: 121 within the FRB plots and 130 within URB plots. The average number of singing males per plot and counting session was 4.03 ± 0.22 for the FRB and 4.33 ± 0.21 for the URB. Relative to the area covered by the reed bed, the number of birds was higher in the FRB than in the URB 28.39 ± 1.89 birds/ha of reed bed vs 16.07 ± 0.94 birds/ha of reed bed respectively (FPP test: $p < 0.05$). Bird body condition was assessed from 131 captures of adult Reed Warbler males achieved during the breeding periods in 2016, 2017 and 2018 within the two sampled sites: 59 captures in the FRB and 72 within the URB. Models run for bird body condition analyses revealed no site effect: mean = 0.16 ± 0.00 for the two sites ($F_{1,129} = 2.77$;

$p = 0.10$). For the comparison of invertebrates exploited by birds within FRB and URB, a total of 104 Reed Warblers' droppings were collected during 2017 and 2018 (46 for the FRB and 54 for the URB). Accumulation curves revealed that for the two sampled sites the number of fecal samples collected was statistically enough to compare the number of type of prey exploited by birds (e.g., increase of the 0.01% of richness from 40 to 41 samples, see [Fig. 4 and 5 in electronic supplementary material](#)). Analyses of these samples revealed that the main prey (taxa representing more than 10% of total prey abundance) tended to be relatively equivalent within the two sites, with the exception of Hemiptera, which appeared significantly more abundant in the FRB, and Lepidoptera, exclusively detected within the FRB (see details in [Table 1](#)). A slight, non-significant trend ($p = 0.07$) revealed possible higher abundance of Aranae in FRB than in URB.

Use of FRB and URB by the Reed Warbler and the Aquatic Warbler during the post-breeding period

For the post-breeding period, we captured during each sampling season within the FRB and the URB an average of 473 vs 497.50 yearlings of Reed Warblers and 19.67 vs 38 yearlings of Aquatic Warblers. The number of captures presented slight variations between years: number of Reed Warblers for FRB = 516 for the year 2016, 297 for the year 2017 and 606 for the year 2018; for URB = 484 for the year 2011 and 511 for the year 2012; number of Aquatic Warblers for FRB = 25 for the year 2016, 15 for the year 2017 and 19 for the year 2018; for URB = 32 for the year 2011 and 44 for the year 2012. For the Reed Warbler, bird body condition was slightly different between FRB and URB ($p = 0.003$, $F_{1,2892} = 8.61$), but with an identical mean (0.17 ± 0.00) for the two sites. For the Aquatic Warbler, the bird body condition did not present any difference between the two sites ($p = 0.13$, $F_{1,322} = 2.36$, mean = 0.18 ± 0.00). For the Reed Warbler, the local daily survival rate (φ) appeared

equiprobable for the two sampled sites with an average estimate of 0.95 ± 0.11 (best model = $\phi_{\text{cst}} p_{\text{cst}}$, see [Table 2](#)). The Reed Warbler's average daily body mass variation was $-0.53 \pm 0.35\%$ within the FRB and $-1.88 \pm 1.06\%$ within the URB, without a significant difference between the two sites (FPP test: $p = 0.41$). For the Aquatic Warbler, no recaptures were done within the FRB, whereas within the URB we obtained a local daily survival rate of 0.60 ± 0.45 (best model = $\phi_{\text{cst}} p_{\text{cst}}$, see [Table 3](#)) with an average daily body mass variation of $4.21 \pm 1.34\%$. The nonexploitation of the FRB by the Aquatic Warbler after the first capture was confirmed by the monitoring of 15 birds radio-tagged after within the site and which were never retrieved the days following the capture, confirming a rapid dispersion of birds from this location after capture (10 birds tagged during the 2017 season and 5 birds tagged during the 2018 season).

Discussion

For the breeding period, our results revealed that the relative density of Reed Warbler singing males per hectare of reed bed was about 1.5 times higher in the fragmented reed bed (FRB) than in the uniform reed bed (URB) this result highlights that the FRB was not a marginal habitat for the species relatively to native uniform reed bed (URB). We did not detect significant between sites differences for the bird body condition and the spectrum of prey of the Reed Warbler during the breeding period. These results suggest that trophic potentialities within the FRB are relatively equivalent (from a quantitative and a qualitative point of view) to the potentialities of the URB. This conclusion is supported by results obtained during the post-breeding period for the Reed Warbler: equivalent local daily survival rate and equivalent bird body mass variations for the two sites.

Despite the absence of obvious difference of trophic potentialities between the FRB and the URB, the FRB appeared not used as stopover site by Aquatic Warbler juveniles, whereas 60% of individuals captured within the URB at day t remained within the site at day $t+1$, with individuals presenting a positive evolution of their daily body mass variation. The nonexploitation of the FRB by the Aquatic Warbler is confirmed by the radio-tracking data, demonstrating that the juveniles of this species did not remain within the habitat. The body condition of birds upon arrival at stopover sites varied among year and influences the length of their stopover duration due to different energy needs (Morris, 1996). Nevertheless for the Aquatic Warblers sampled as part of our study, this possible bias, due the sampling of the two sites on different years, may be reasonably discarded given there was no site effect for the body condition of birds at first capture.

Due to the important field effort needed (31 days per year) to collect sufficient amount of data to assess robust estimation of local survival (i.e. the daily probability of birds to remain within the two sampling sites during the post-breeding period), FRB and URB were sampled during different years. We are thus not able to disentangle the effects year and site and our results could potentially be biased by a year effect impacting the trophic potentialities of the sampled sites (possible differences of arthropod abundances). Nevertheless, the results related to the Reed Warbler during post-breeding period (i.e. similar daily body mass variation within the two sites and identical daily survival rate), reinforce the idea that FRB and URB had similar trophic potentialities during the post-breeding period.

Considering that the two sampled sites are composed of reed beds ecologically identical in terms of vegetation typology, the fragmentation of the reed beds clearly accounts for the difference of habitat use between the two species, able to exploit the same food spectrum but

having different plasticity in terms of habitat exploitation. Indeed, during the breeding period, the Reed Warbler is a species exploiting an important diversity of habitats that are at times relatively dry (Catchpole 1974, Poulin & Lefebvre 2002, Poulin et al. 2002). During migration, this species is also able to exploit very different kind of habitats where it can adopt a very opportunist feeding strategy (see Cramp 1992, Chernetsov & Manukyan 1999, Chernetsov & Titov 2000). As well as the Reed Warbler, the Aquatic Warbler has a relatively broad food spectrum during post-breeding migration, exploiting prey also identified in the diet of the Reed Warbler (see Kerbiriou et al. 2011, Musseau et al. 2014). Nevertheless, contrary to the Reed Warbler, during post-breeding migration, the Aquatic Warbler mainly feeds within habitats with a rather homogenous structure (Le Nevé et al. 2018).

Our results related to the Reed Warbler, highlight that within coastal areas affected by global change, water management of agricultural lands reclaimed from the ocean (polders), allowing the development of wetland patches to compensate for the loss of intertidal wetlands, can be favourable for the conservation of trophic resources exploited by such a species. Trnka et al. (2014), demonstrated the beneficial edge effects of fragmented reed beds for arthropods, and our results regarding the Reed Warbler confirm that arranging reed bed patches within agricultural lands may offer interesting ecological trophic potentialities for such a species. However, our results also underline the risk of habitat fragmentation effects that must be considered in wetland restoration plans to ensure the ecological functionalities of reed beds for bird species particularly sensitive to the structure of these habitats, independently of their biological richness.

Our study was conducted on two rather small sites, limiting the possibilities to multiply sampled locations and to take into consideration issues such as microhabitat parameters.

Furthermore, our results are based on data exclusively collected on juvenile birds. It thus cannot be excluded that, given their experience, adults of species such as the Aquatic Warbler for which juveniles appear sensitive to the fragmentation effects of reed beds, could exploit differently fragmented habitats. Finally, we are aware that the sampling design implemented as part of our study generated data collected on different years, which constitute a critical point for the discussion of the results. Nevertheless, our results present significant statistical trends allowing alerting toward the risks of habitat fragmentation effects which may be particularly unfavorable for species sensitive to the habitat structure, such as the Aquatic Warbler.

Habitat fragmentation is considered as one of the most significant threats to biodiversity ([Harris 1984](#), [Wilcox & Murphy 1985](#)). Throughout the world, intensification of human land use is considered as the most important large-scale cause of habitat fragmentation ([Burgess & Sharpe 1981](#)). Until now, the effects of habitat fragmentation have been mostly documented to measure the effects on the structure of animal populations during the breeding period (see [Andr  n 1994](#)) and for marshland passerines, [Foppen \(2001\)](#) and [Paracuellos \(2008\)](#) noticed the negative effect of reed bed fragmentation, leading to the dispersal of breeding birds within inhospitable landscape matrices.

In the context of sea level rise, impacting intertidal areas, wetlands are subject to important risks of disappearance ([Titus 1988](#), [Nicholls et al. 2007](#), [Craft et al. 2009](#), [Musseau et al. 2018](#)). This implies the necessity to develop management plans of inshore coastal areas allowing compensating for recorded or expected losses of intertidal habitats such as reed beds particularly important as stopover sites for different marshland passerines ([Musseau et al. 2018](#)). Such management strategies may present important risks of reed bed fragmentation.

The effects of reed bed fragmentation remain poorly studied in terms of impacts within stopover sites exploited by migratory birds. This question is nevertheless important to consider and further studies dedicated to issues of habitat fragmentation would be important to develop to allow a better integration of this question for management plans of wetlands.

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Conflicts of interest / competing interests: the authors declare that they have no conflict of interests.

Ethics approval: our study was carried out in agreement with the laws of the French Republic dedicated to the protection of wildlife. Ringing sessions and the GPS-tracking scheme implemented for this study, and which involved the capture of wild birds, have been conducted with the authorization of the Centre de Recherches sur la Biologie des Populations d'Oiseaux (CRBPO – Muséum National d'Histoire Naturelle, Paris).

Consent to participate: not applicable.

Consent for publication (include appropriate statements): not applicable.

Availability of data and material (data transparency): the datasets used for the current study are available from the corresponding author upon reasonable request.

Code availability (software application or custom code): not applicable.

Authors' contributions: RM managed the design of the research, the analyses of the data and wrote the manuscript. MC contributed to collect data on the field and to data analysis. CB

contributed to collect data on the field. CK managed analyses of bird food spectrum and contributed in writing the manuscript.

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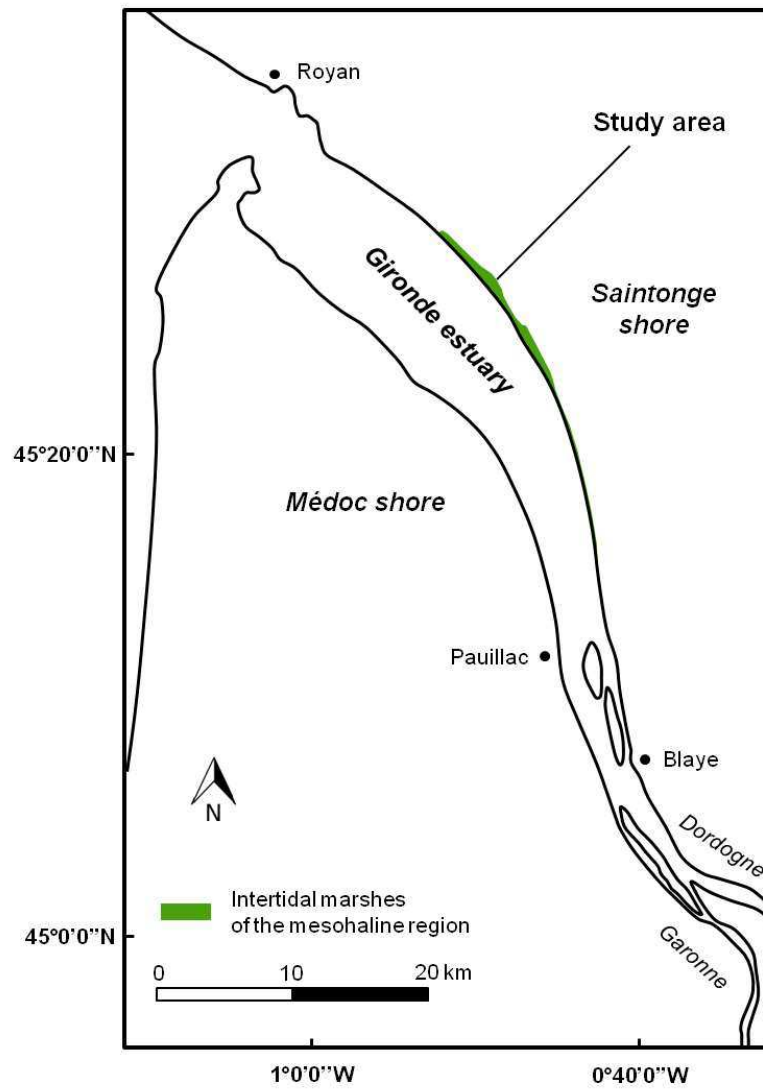


Fig. 1 Location of the study area



Fig. 4 Aerial view of the fragmented reed bed (FRB)



Fig. 5 Aerial view of the uniform reed bed (FRB)

Table 1 Taxonomic groups found in faecal samples of Reed Warblers collected during the breeding period within reed beds of the Gironde estuary.

Order	Total: no. of prey counted, occurrence and % of the abundance	FRB: no. of prey counted, occurrence and % of the abundance	URB: no. of prey counted, occurrence and % of the abundance	Abundance: habitat effect
HYMENOPTERA	165 68.27% 41.04%	74 71.74% 37.37%	91 67.24% 44.61%	$F_{1,102} = 0.01$ $p = 0.93$
DIPTERA	107 72.12% 36.62%	39 63.04% 19.70%	68 79.31% 33.33%	$F_{1,102} = 2.79$ $p = 0.10$
HEMIPTERA	44 29.81% 10.95%	30 39.13% 15.15%	14 22.41% 6.86%	$F_{1,102} = 4.30$ $p = 0.04$
ARANEAE	41 33.65% 10.20%	24 45.65% 12.12%	17 24.14% 8.33%	$F_{1,102} = 3.26$ $p = 0.07$
COLEOPTERA	25 22.12% 6.22%	13 26.09% 6.57%	12 18.97% 5.88%	$F_{1,102} = 0.65$ $p = 0.42$
LEPIDOPTERA	14 12.50% 3.48%	14 28.26% 7.07%	0 0% 0%	-
HETEROPTERA	5 4.81% 1.24%	3 6.52% 1.52%	2 3.45% 0.98%	-
OPILIONIDAE	1 0.96% 0.25%	1 2.17% 0.51%	0 0% 0%	-

Table 2 Summary of the 5 best fitted models among the 25 models tested to assess the survival rate of the Reed Warbler (*Acrocephalus scirpaceus*) within fragmented reed beds (FRB) and uniform reed beds (URB). φ = survival probability, p = recapture probability, cst = constant, t = time (daily) effect, site = site effect.

Model	QAICc	Δ QAICc	QAICc W	Mod. Likelihood	Nb. Par.	Q Deviance
$\varphi_{\text{cst}} p_{\text{cst}}$	39.356	-	0.534	1.000	2	15.873
$\varphi_{\text{site}} p_{\text{cst}}$	41.348	1.993	0.197	0.369	3	15.860
$\varphi_{\text{cst}} p_{\text{site}}$	41.353	1.998	0.197	0.368	3	15.865
$\varphi_{\text{site}} p_{\text{site}}$	43.355	4.000	0.072	0.135	4	15.860
$\varphi_{\text{cst}} p_t$	94.039	54.683	0.000	0.000	31	11.691

Table 3 Summary of the 4 models tested to assess the survival rate of the Aquatic Warbler (*Acrocephalus paludicola*) within uniform reed beds (URB) with test of time effects. ϕ = survival probability, p = recapture probability, cst = constant, t = time (daily) effect.

Model	QAICc	Δ QAICc	QAICc W	Mod. Likelihood	Nb. Par.	Q Deviance
$\phi_{\text{cst}} p_{\text{cst}}$	10.552	-	1.000	1.000	2	3.539
$\phi_{\text{cst}} p_t$	110.180	99.628	0.000	0.000	31	1.240
$\phi_t p_{\text{cst}}$	110.411	99.859	0.000	0.000	31	1.471
$\phi_t p_t$	537.819	527.266	0.000	0.000	59	0.497

Electronic supplementary material for:

Conservation and restoration of coastal reed beds in the context of global change: potential effects of habitat fragmentation for specialist marshland passerines

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Appendix 1: study sites



Fig. 1 Vegetation structure of the fragmented reed bed (FRB) located within an agricultural polder mowed and grazed by sheep after mowing, and developing within a network of ditches partially reconnected to the tidal dynamics.



Fig. 2 Vegetation structure of the uniform reed bed (URB) located along the right bank of the Gironde estuary.

Appendix 2: Census of Reed Warbler singing males

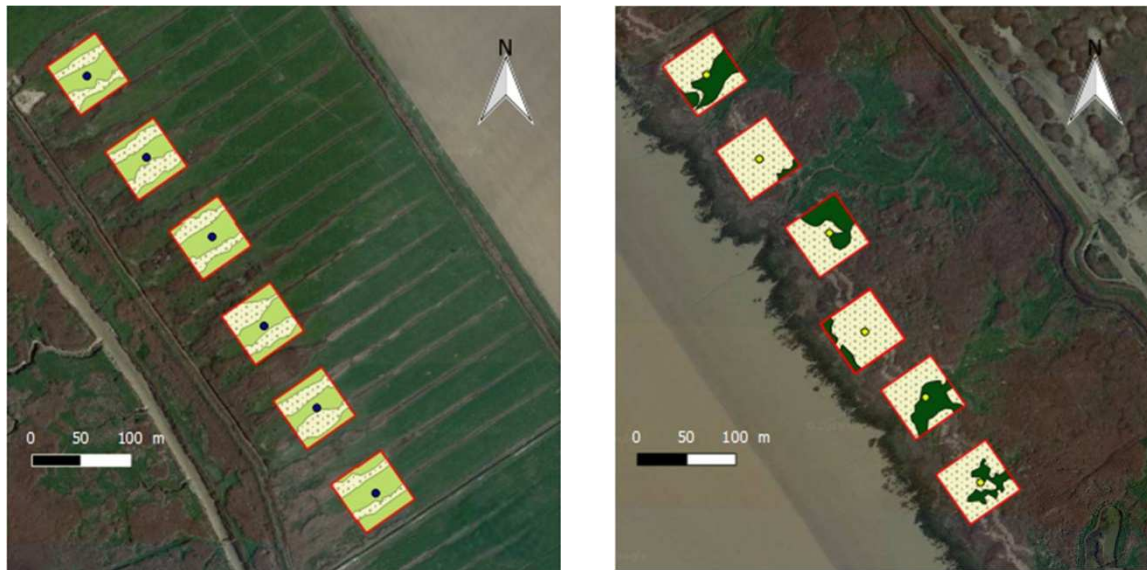


Fig. 3 Left: grassland's mosaic reed bed (FRB). Light green: mowed and grazed meadows within the FRB. Right: uniform tidal reed bed (URB). Dark green surfaces: intertidal meadows dominated by the Sea Couch (*Elytrigia acuta*) within. Dotted surfaces: reed beds. Red squares: plots sampled to assess relative densities of Reed Warblers' singing males.

Appendix 3: modeling preys exploited by the Reed Warbler

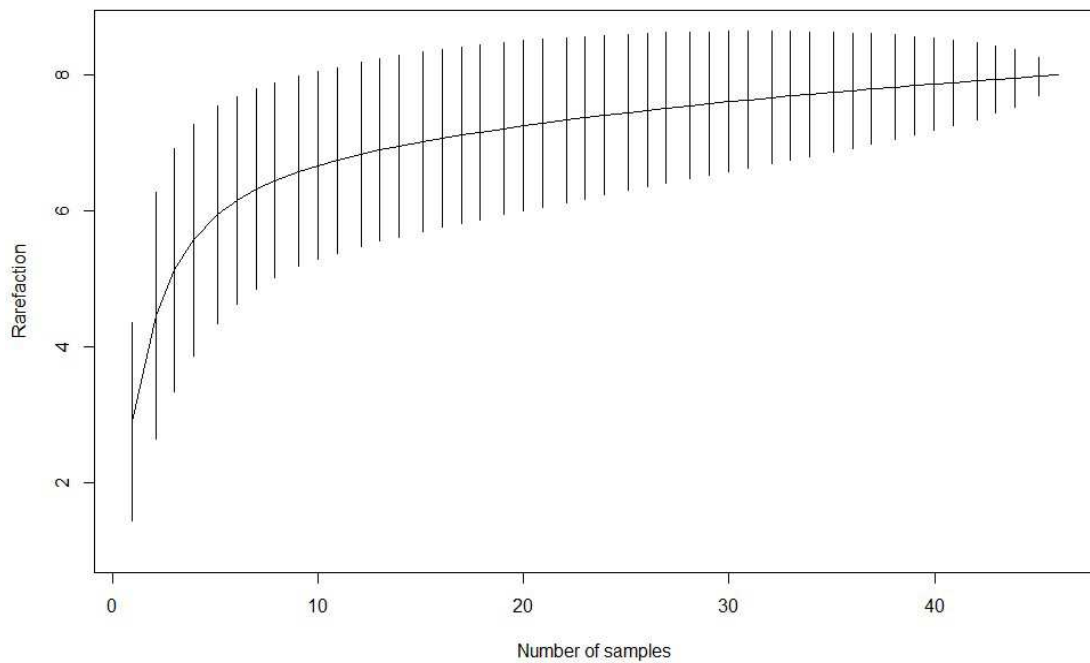


Fig. 4 Rarefaction curves of preys identified in faecal samples of Reed Warblers collected within fragmented reed bed (FRB) of the Gironde estuary.

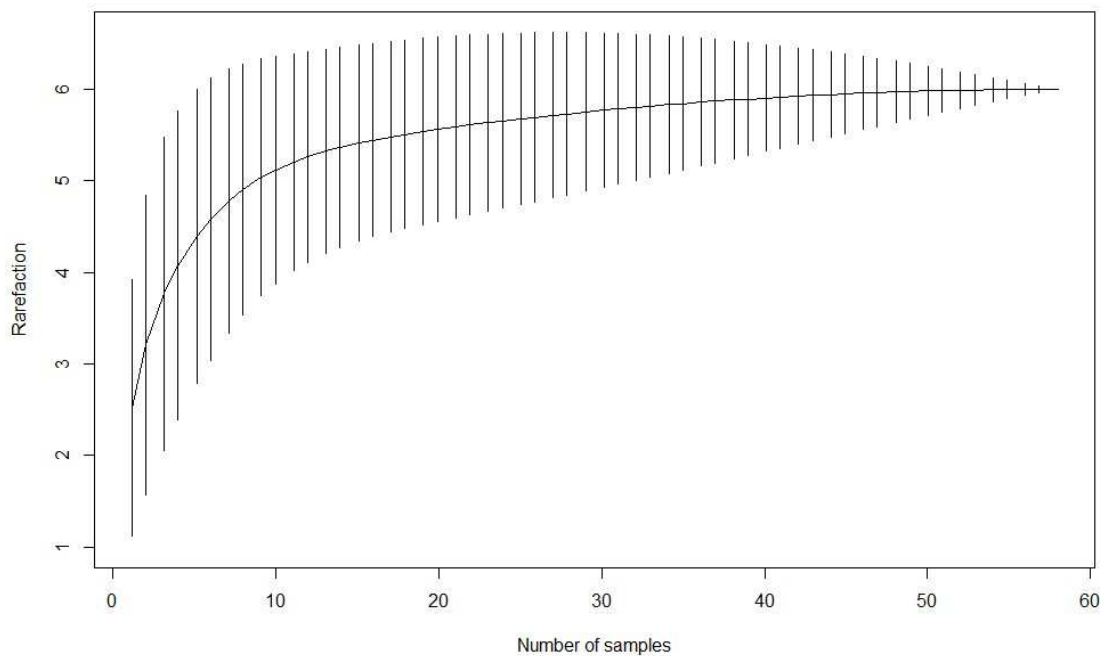


Fig. 5 Rarefaction curves of preys identified in faecal samples of Reed Warblers collected within uniform reed bed (URB) of the Gironde estuary.

Appendix 4: Radio-tracking scheme

Radio-tags were configured to radiate in the 148 MHz frequency range with the emission of one 20-millisecond signal per second. These tags were chosen in order to not exceed 5% of the body mass of birds (fixing kit included) as recommended by [Caccamise & Hedin \(1985\)](#). The transmitters were fitted to sampled birds with a leg harness made with a 0.5 mm natural rubber thread (round section) glued on the tags using glue Loctite® 454 and the activator Loctite® 7455 (see method described by [Rappole & Tipton 1991](#)). Lengths of harness loops were adjusted following the Naef-Daenzer allometric function ([Naef-Daenzer 2007](#)). Tagged birds were released at the location of their capture and, once released, tracked using a directional Yagi-Uda antenna and a “Sika” receiver manufactured by Biotrack Ltd.

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