Impact of cutting and sheep grazing on ground–active spiders and carabids in intertidal salt marshes (Western France)

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Abstract

Impact of cutting and sheep grazing on ground–active spiders and carabids in salt marshes (West France).— The aims of this study were to characterize spider (Araneae) and ground beetle (Coleoptera Carabidae) communities in managed (cutting and sheep grazing) and non–managed salt marshes and to assess the efficiency of management regimes in these particular ecosystems. The two groups were studied during 2002 in salt marshes of the Mont Saint–Michel Bay (NW France) using pitfall traps. By opening soil and vegetation structures cutting and grazing enhanced the abundances of some halophilic species of spiders and ground beetles. Nevertheless, grazing appeared to be too intensive as spider species richness decreased. We discuss the implications of management practices in terms of nature conservation and their application in the particular area of intertidal salt marshes.

Key words: Management, Conservation value, Halophilic species, Arthropods.

Resumen

Impacto de la siega y el pastoreo de las ovejas en arañas y carábidos activos del suelo de algunos marjales salinos intermareales (oeste de Francia).— El objetivo de este estudio es caracterizar las comunidades de arañas (Araneae) y escarabajos del suelo o cárabos (Coleoptera, Carabidae) en marjales salinos gestionados (siega y pastoreo) y no gestionados y, por lo tanto, valorar la eficacia de lo regímenes de gestión en estos ecosistemas particulares. Ambos grupos fueron estudiados durante el año 2002 en distintos marjales salinos de la bahía de Mont Saint–Michel (NO de Francia) mediante trampas de intercepción. La siega y el pastoreo, al abrir el suelo y las estructuras vegetales, hacían aumentar la abundancia de algunas especies halófilas de arañas y cárabos. No obstante, parece ser que el pastoreo era demasiado intensivo ya que la riqueza de especies de arañas disminuía. Se discuten las implicaciones de las prácticas de gestión en términos de la conservación de la naturaleza y también su aplicación en zonas tan especiales como son los marjales salinos intermareales.

Palabras clave: Gestión, Valor conservativo, Especies halófilas, Artrópodos.

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Introduction

Salt marshes are intertidal ecotones between terrestrial and marine systems. They are among the most restricted habitats in the world, covering less than 0.01% of the planet's surface (Desender & Maelfait, 1999; Lefeuvre et al., 2003). In Europe, the area of salt marshes has decreased dramatically in recent decades (Dijkema et al., 1984) and they currently have a linear and very fragmented distribution along coasts; conservation of these habitats is therefore of high interest (e.g., Bakker et al., 2002). These ecosystems also have a high conservation value as they are subjected to periodical flooding by tides and thus exhibit specific characteristics concerning plant cover (spatial succession from the high to the low marsh) and invertebrate assemblages that resist regular submergence by seawater (monthly in Europe) and the resultant high soil salinities (Foster & Treherne, 1976; Irmler et al., 2002; Pétillon et al., 2004, 2006).

European salt marshes are currently endangered by many direct or indirect human impacts such as habitat destruction, diffuse soil pollution from adjacent agricultural fields, eutrophication and overgrazing (Desender & Maelfait, 1999; Goeldner–Gianella, 1999; Adam, 2002). Furthermore, cessation of grazing may lead to dominance of a single plant species such as the tall grass *Elymus athericus* (Bockelmann & Neuhaus, 1999; Valéry et al., 2004), and hence to loss of plant (Bos et al., 2002; Bakker et al., 2003) and halophilic spider (Pétillon et al., 2005a, 2005b) biodiversity. Several studies have emphasized the role of abandonment of agricultural practices in the expansion of *Elymus athericus* in northern Europe (e.g. Dijkema, 1990). Management is therefore necessary to reduce the effects of invasion, to decrease the rate of spread of the invasive species and, in a general way, to conserve young stages of salt marshes. The present study was conducted to determine whether salt marshes should be managed in order to conserve young successional stages and their related biodiversity. Both direct (via changes in vegetation structure and heterogeneity) and indirect (via changes in microclimate and other aspects of the microhabitat) effects of management practices are expected to alter community composition (Zulka et al., 1997; Georges, 1999), especially in comparison to those associated with the invasive grass *E. athericus*.

Spiders (Marc et al., 1999; Bell et al., 2001) and ground beetles (Luff et al., 1992; Rainio & Niemelä, 2003) are known to react strongly to changes in microhabitat conditions and are consequently often used as indicators of the effects of management practices. According to McGeoch (1998), such groups are qualified as ecological indicators in function of their sensitivity to environmental stress factors. In the present work we studied communities of spiders and ground beetles at stations submitted to management plans to determine whether practises tended to favour or disfavour species of high conservation value inhabiting salt marshes. The practises most likely to modify the initial composition of the salt–marsh fauna were mowing and sheep grazing. Management impacts were studied by comparing habitat variables and communities between managed and non–managed plots.

Material and methods

Study sites and habitat characteristics

The Mont–Saint–Michel Bay (NW France) is an extensive littoral zone (500 km^2) located between Brittany and Normandy (48° 40' N, 1° 40' W). This macrotidal system is characterized by a high tidal range (mean tidal range: 10–11 m, maximum: 16 m). The intertidal area is unique in Europe for its size, consisting of 180 km^2 of intertidal flats and 40 km^2 of salt marshes. These marshes are drained by a dense creek system (Lefeuvre et al., 2003) and are flooded during 43% of tides when the tidal range is greater than 11.25 m (spring tides). Flooding lasts on average 2 h per tide but the drainage time determines the whole submersion period. The marshes are delimited in their upper part by seawalls that are not submerged during high tides. Two sites were investigated on either side of Mont Saint–Michel: one to the west ("Ferme Foucault" site: code F, 48° 37' N, 1° 32' W) and the other to the east ("la Rive" site: code R, 48° 37' N, 1° 29' W) (fig. 1). The stations close to the seawall at both sites were subjected to human interference: station F1 at the "Ferme Foucault" site is cut annually in mid–June whereas station R1 at the "la Rive" site is subjected to heavy sheep grazing (up to 100 sheep per hectare: Legendre & Schricke, 1998). Managed and non–managed stations (stations F2 and R2) were compared at similar salt–marsh zones (upper zone: from 0 to 300 m) and the only apparent varying factor between stations was the presence / absence of management practises (cutting and grazing).

Biotic habitat characteristics at each station were described within a radius of 1 m around each pitfall trap (i.e. four replicates per station). Four variables were used: litter depth (to the nearest mm), vegetation height (to the nearest cm), percentage cover of each plant species and percentage cover of bare soil (%). Soil salinity (estimated by pore water electrical conductivity), soil water content and temperature were also measured using a W. E. T. sensor connected to a moisture meter HH2 (both by Delta–T Devices Ltd., Cambridge, UK). All abiotic measurements were made with a specific clay soil calibration and repeated four times at each station during the summer of 2002.

Sampling techniques and species identification

Cursorial (i.e. ground active) spiders and ground beetles were sampled with pitfall traps, consisting of polypropylene cups (10 cm diameter, 17 cm deep) with ethylene–glycol as preservative. Traps were covered with a raised wooden roof to keep

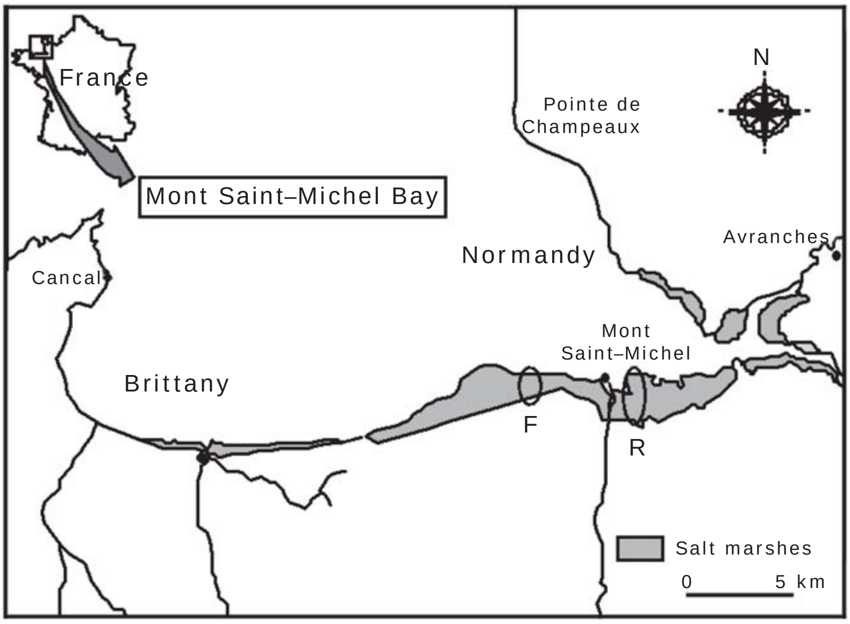

Fig. 1. Location of the two sites studied (Mont St–Michel Bay, France): F. "Ferme Foucault"; R. "La Rive".

Fig. 1. Localización de los dos lugares estudiados (bahía de Mont Saint–Michel, Francia): F. "Ferme Foucault"; R. "La Rive".

out rain and were visited weekly when tides permitted (i.e. about three weeks per month) from April to November 2002. Four pitfall traps were installed at each station. They were spaced 10 m apart, the distance considered the minimum to avoid interference between traps (Topping & Sunderland, 1992). Traps were consequently considered true replicates of each type of area studied (grazed *vs*. ungrazed and cut *vs.* uncut). Catches in pitfall traps were related to trapping duration and pitfall perimeter, which calculates an "activity trappability density" (number of individuals per day and per m: Sunderland et al., 1995). Ground beetles and spiders were preserved in 70% ethanol, and identified and conserved at the laboratory. Ground beetles were identified using Jeannel (1942) and Trautner & Geigenmüller (1987) and adult spiders using Roberts (1987, 1995) and Heimer & Nentwig (1991). Nomenclature follows Lindroth (1992) as far as possible for ground beetles and Canard (2005) for spiders, except for *Pardosa purbeckensis*, absent from this work but now considered a valid species (Canard, pers. comm.).

Data analyses

Human impact was assessed by comparing two conservation criteria, i.e. abundance of halophilic species and species richness, between natural and disturbed stations. Species richness is widely used as a conservation target (e.g., Noss, 1990; Bonn & Gaston, 2005). The use of stenotopic species is also recommended in studying the impact of human activities on arthropod communities (Samways, 1993; New, 1995; Dufrêne & Legendre, 1997). In this study, the target species were halophilic species, defined by their preference or exclusive presence in salt marsh habitats, which can be assessed using distribution maps (the relevant British atlases are Harvey et al., 2002 for spiders and Luff, 1998 for ground beetles). Statistics on the abundances of halophilic species were performed only for species represented by at least 10 individuals. All means in the tables and figures are presented with their standard error (mean ± SE). Mean environmental and community variables were compared with MINITAB version 12.1. using one–way ANOVA (management treatment as fixed term) tests because the data had a normal distribution (according to Kolmogorov–Smirnov tests).

Results

The grazed station was characterised by very short vegetation dominated by *Puccinellia maritima* (table 1), much lower than that of reference station (R1 *vs*. R2: ANOVA, 7 df, F–ratio = 90.34,

Table 1. Habitat characteristics (mean ± SE, four recordings per station) of the sampling stations (S): F. "Ferme Foucault" site; R. "La Rive" site; F1. Cutting; R1. Sheep–grazing; F2 and R2. References; Plant. % cover of the dominant plant; Bsoil. % cover of bare soil; L. Litter depth; V. Vegetation height; H. Soil water content; S. Soil salinity; T. Soil temperature.

Tabla 1. Características del hábitat (media ± EE, cuatro registros por estación) de las estaciones de muestreo (S): F. "Ferme Foucault", R. "La Rive"; F1. Siega; R1. Pastoreo de ovejas; F2, R2. Referencias; Plant. % cubierto por la planta dominante; Bsoil. % de suelo desnudo; L. Profundidad del mantillo; V. Altura de la vegetación; H. Contenido de agua del suelo; S. Ssalinidad del suelo; T. Temperatura del suelo.

S	Dominant plant	Plant (%)	Bsoil (%)	L (mm)	V (cm)	H (%)	S (mS / m)	T (°C)
R1	*Puccinellia maritima*	98 ± 1	0	0	1. 0 ± 1.0	33.8 ± 1.6	377.3 ± 73.7	23.8 ± 0.23
R2	*Elymus athericus*	94 ± 2	1 ± 1	0.3 ± 0.3	53.8 ± 3.8	33.0 ± 4.3	487.0 ± 122.0	19.5 ± 0.3
F1	*Elymus athericus*	86 ± 6	0	1.0 ± 0	55.0 ± 0	26.2 ± 1.1	425.6 ± 61.1	24.0 ± 1.4
F2	*Elymus athericus*	90 ± 4	3 ± 1	4.5 ± 0.3	78.8 ± 2.4	23.3 ± 0.5	539.9 ± 9.2	22.5 ± 0.3

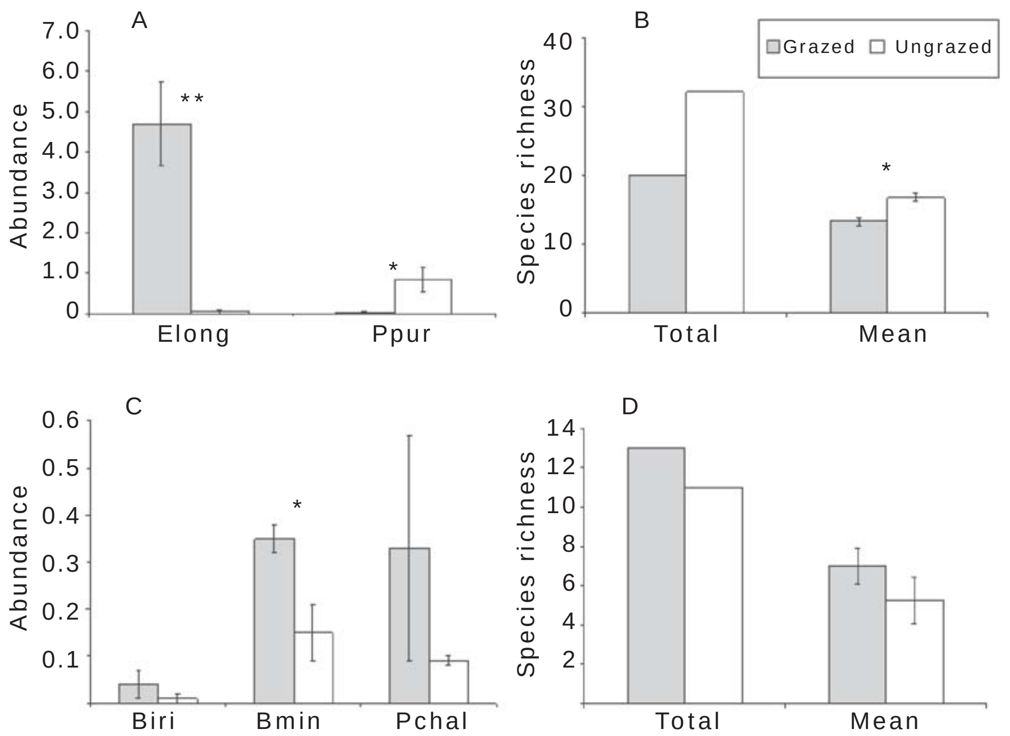

Fig. 2. Comparison of mean abundances (number of individuals / day / meter) and total and mean species richness between grazed and non–grazed stations (A, B for spiders; C, D for ground beetles) and significance by ANOVA (7df; * $p < 0.05$; ** $p < 0.01$): Elong. *Erigone longipalpis*; Ppur. *Pardosa purbeckensis*. Biri. *Bembidion iricolor*; Bmin. *B. minimum*; Pchal. *Pogonus chalceus.*

*Fig. 2. Comparación de las abundancias medias (número de individuos / día / metro) y riqueza de especies total y media entre las estaciones pastoreadas y no pastoreadas (A, B para arañas; C, D para cárabos) y significación mediante ANOVA (7gl; * p < 0,05; ** p < 0,001). (Para las abreviaturas, ver arriba.)*

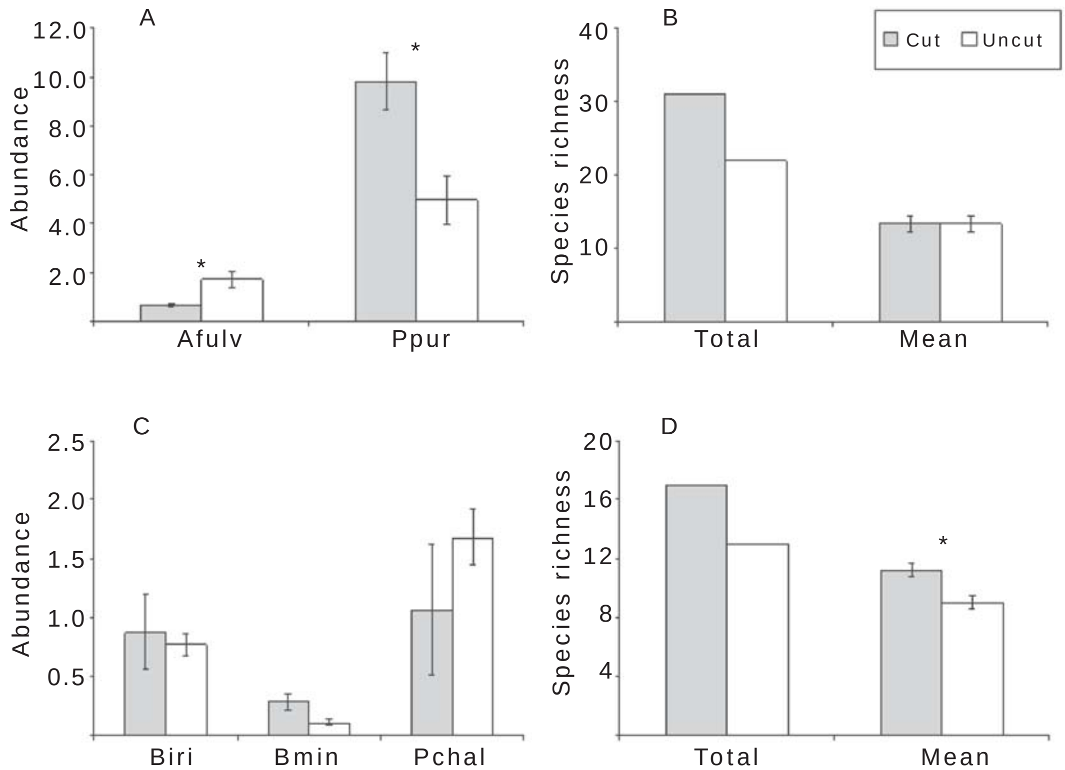

Fig. 3. Comparison of mean abundances (number of individuals / day / meter) and total and mean species richness between cut and non–cut stations (A , B for spiders; C, D for ground beetles) and significance by ANOVA (7df; * $p < 0.05$, ** $p < 0.01$): Afulv. *Arctosa fulvolineata* (for other abbreviations see figure 1).

Fig. 3. Comparación de las abundancias medias (número de individuos / día / metro) y riquezas de especies total y media entre localizaciones segadas y no segadas (A, B para arañas; C, D para cárabos) y significación mediante ANOVA (7gl; * p *< 0,05,* ** p *< 0,01): Afulv.* Arctosa fulvolineata *(para las otras abreviaturas ver figura 1).*

$p < 0.001$). The cut station was characterised by a lower percentage cover of *Elymus athericus* (*Festuca rubra* represented another 10% of cover), a shorter vegetation (F1 *vs*. F2: ANOVA, 7 df, F–ratio = 98.45, $p < 0.001$) and a thinner litter layer (F1 *vs*. F2: ANOVA, 7 df, F–ratio = 147.00, $p < 0.001$) than the reference station.

A total of 3,974 spiders belonging to 46 species and 54 taxa (including immature and unidentified species) were caught. The percentage of halophilic species was low, with six species being recorded at both sites (see taxonomic list in appendix 1). A total of 924 adult ground beetles belonging to 27 species were caught. Ten of these are considered halophilic (see taxonomic list in appendix 2).

Species and taxonomic richness of spiders (both total and mean richness) were significantly lower at sheep–grazed stations (fig. 2). Sheep grazing did not affect ground beetle species richness. Mean abundances of the spider *Pardosa purbeckensis* were lower with grazing, whereas those of *Erigone longipalpis* were higher. The same was true for the ground beetle *Bembidion mimimum*.

Mean taxonomic and species richness of spiders did not differ statistically between the cut and the non–cut stations (fig. 3). Mean and total species richness of ground beetles was significantly higher in the cut stations. The dominant spider species, *Pardosa purbeckensis,* was significantly more abundant in the cut station than in the non–cut stations. The co–dominant spider species, *Arctosa fulvolineata,* was less abundant in the cut stations.

Discussion

In this explanatory study, despite the existence of true replicates within each station, stations were confounded with management treatment. This sampling design can thus be considered as a case of pseudoreplication in the sense of Hulbert (1984). Our problem was to reduce possible differences between stations (that were consequently within the same site) because comparing stations between different sites often leads to an increase of variance due to the existence of other co–varying factors (Oksanen, 2001). This assumption consequently merits a larger–scale study and the following recommendations for managing salt marshes are not only based on our own results but also on the existing bibliography.

Cutting tended to favour the spider *Pardosa purbeckensis* and disfavour *Arctosa fulvolineata*. Harvey et al. (2002) suggested that adult *P. purbeckensis* prefers low vegetation, which is in accordance with our results. In contrast, *Arctosa fulvolineata* prefers deep litter where it is often found during the day at 3–4 cm depth (Pétillon, pers. obs.). This species might be disfavoured by the structure of the cut habitats that have a thinner and less complex litter due to organic matter export. Typical mesophilic ground beetle species such as *Amara sp., Bembidion lampros* and *Calathus melanocephalus* and species belonging to the genus *Pterostichus* (*P. cupreus*, *P. versicolor*, *P. vernalis*) occurred in the cut station with short grassland vegetation. By creating above–surface ground conditions close to those existing in lower parts of the salt marsh, cutting therefore has a positive effect on the abundances of some halophilic species. As a general rule, by providing new microhabitats and microclimate conditions (Wise, 1993), litter tends to favour nocturnal wanderers, ambush hunters and "litter–sensitive" sheet–weavers (Bell et al., 2001). These groups are therefore likely disfavoured by cutting (shown by Cattin et al., 2003 in wet meadows), as would also be the halophilic species belonging to families of these groups (as in the case of the nocturnal wander *A. fulvolineata*). In general, cutting tended to increase total and mean species richness for both spiders and ground beetles, although the difference between mean richness by pitfall traps was not significant for spiders. These results can be related to the fact that cutting, independently from its effects on species abundance, allows halophilic species to survive and more ubiquitous species to establish.

Sheep grazing tends to favour some halophilic species of both ground beetles (*Bembidion minimum*: Desender & Verdyck, 2001) and spiders (*Erigone longipalpis*: Harvey et al., 2002) that are characterized by high dispersal capacities. As dispersal capacity is often related to the succession of species within a habitat (Southwood, 1962), our results are consistent with the general assumption that pioneer species are most successful in stressed habitats (Bell et al., 2001). Grazing, like cutting, opens the soil and vegetation structure and is therefore likely to favour some characteristic halophilic species (present study; for spiders, see Zulka et al., 1997; Harvey et al., 2002). However, species of high conservation interest, particularly spiders such as *Pardosa purbeckensis*, declined in grazed habitats. The negative impact on spider species richness is explained by a homogenous cover with no refuges that tends to disfavour cursorial species, and especially diurnal wanderers. Like cutting, grazing has an impact on communities not only regarding structural habitat changes, but also in respect to changes in micro–climate conditions. Grazing can therefore have direct and indirect effects on species abundances, for both stenotopic (present study; Bonte et al., 2000) and ubiquitous species (Gardner et al., 1997; Dennis et al., 2001). The effects of grazing on species richness were different between spiders (decrease of richness) and ground beetles (no significant effect), tending to support the idea that grazing is too intensive in the Mont Saint–Michel bay. Over–grazing is in fact likely to reduce species richness (Gardner et al., 1997; Zulka et al., 1997), mainly because of heavy trampling effects (Bell et al., 2001).

Despite its potential as a good method, for biological control of invaders (Shea & Chesson, 2002), sheep grazing in the Mont Saint–Michel Bay is presently too intensive. Although a few halophilic species are enhanced, spider species abundance and richness has decreased. Cessation of intensive sheep–grazing has been recommended for salt marsh biodiversity conservation (Kiehl et al., 1996), but such change can lead to an increase of *Elymus athericus*, with possible loss of typical halophilic species (Pétillon et al., 2005a, 2005b). It is consequently recommended to maintain a low stocking rate (i.e. between 0.5 and 1.5 sheep ha^{-1}), as positive effects are considered greatest at intermediate disturbance intensities (hypothesis well known for vegetation diversity and positively tested for arthropods: e.g. Dennis et al., 2001; Suominen et al., 2003). Cutting presently appears to be a recommended technique for enhancing species richness for both ground beetles and spiders, in accordance with Pozzi et al. (1998) who concluded that cutting was needed for the conservation of the most valuable grassland rather than grazing by sheep or cattle. Finally a cutting regime in June is recommended because spring and autumn cuttings are known to have few effects on spider communities than summer cuttings (Bell et al., 2001). The impact of different dates of cutting is currently being studied in the Mont St–Michel Bay to verify this assumption.

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Appendix 1. Taxonomic list of the spiders collected by pitfall traps during 2002 in the Mont Saint-Michel Bay (France): * Halophilic species.

*Apéndice 1. Lista taxonómica de las arañas recogidas por las trampas de intercepción durante el año 2002 en la bahía de Mont Saint-Michel (Francia): * Especies halófilas.*

Agroeca lusatica (L. Koch, 1875)
Agyneta conigera (O. P.–Cambridge,1863)
Agyneta decora (O. P.–Cambridge,1870)
Alopecosa accentuata (Latreille, 1817)
Alopecosa pulverulenta (Clerck, 1757)
* *Arctosa fulvolineata* (Lucas, 1846)
Arctosa leopardus (Sundevall, 1833)
Argenna patula (Simon, 1874)
Bathyphantes gracilis (Blackwall, 1841)
Clubiona neglecta O. P.–Cambridge, 1873
Clubiona stagnatalis Kulezynski, 1897
Crustulina sticta (O. P.–Cambridge,1861)
* *Enoplognatha mordax* (Thorell, 1875)
* *Erigone arctica* (White, 1852)
Erigone atra (Blackwall, 1841)
Erigone dentipalpis (Wider, 1834)
* *Erigone longipalpis* (Sundevall, 1830)
Gongylidiellum vivum (O. P.–Cambridge,1875)
Larinioides cornutus (Clerck, 1757)
Meioneta rurestris (C. L. Koch, 1836)
Meioneta simplicitarsis (Simon, 1884)
Microlinyphia impigra (O. P.–Cambridge, 1871)
Oedothorax apicatus (Blackwall, 1850)
Oedothorax fuscus (Blackwall, 1834)
Oedothorax retusus (Westring, 1851)
Ozyptila simplex (O. P.–Cambridge, 1862)
Pachygnatha clercki Sundevall, 1823
Pachygnatha degeeri Sundevall, 1830
Pardosa prativaga (L. Koch, 1870)
Pardosa proxima (C. L. Koch, 1847)
Pardosa pullata (Clerck, 1757)
* *Pardosa purbeckensis* (Westring, 1861)
Pelecopsis parallela (Wider, 1834)
Prinerigone vagans (Audouin, 1826)
* *Silometopus ambiguus* (O.P.–Cambridge,1905)
Silometopus reussi (Thorell, 1871)
Stemonyphantes lineatus (Linnaeus, 1758)
Tenuiphantes tenuis (Blackwall, 1852)
Tibellus maritimus (Menge, 1875)
Tiso vagans (Blackwall, 1834)
Trachyzelotes pedestris (C. L. Koch, 1837)
Trochosa ruricola (DeGeer, 1778)
Walckenaeria acuminata Blackwall, 1833
Walckenaeria obtusa Blackwall, 1836
Xysticus cristatus (Clerck, 1757)
Zelotes latreillei (Simon, 1878)

Appendix 2. Taxonomic list of the ground beetles collected by pitfall traps during 2002 in the Mont Saint–Michel Bay (France): * Halophilic species.

*Apéndice 2. Lista taxonómica de los cárabos recogidos por las trampas de intercepción durante el año 2002 en la bahía de Mont Saint–Michel (Francia): * Especies halófilas).*

Agonum marginatum (Linnaeus, 1758)
Agonum muelleri (Herbst, 1784)
Amara plebeja (Gyllenhal, 1810)
Amara tibialis (Paykull, 1798)
* *Anisodactylus poeciloides* (Stephens, 1828)
Badister bipustulatus (Fabricius, 1792)
* *Bembidion iricolor* Bedel, 1879
Bembidion lampros (Herbst, 1784)
* *Bembidion minimum* (Fabricius, 1792)
* *Bembidion normannum* Dejean, 1831
Bembidion obtusum Serville, 1821
Bembidion varium (Olivier, 1795)
Calathus melanocephalus (Linnaeus, 1758)
Calathus mollis (Marsham, 1802)
Clivina collaris (Herbst, 1784)
* *Dicheirotrichus gustavii* Crotch, 1871
* *Dicheirotrichus obsoletus* (Dejean, 1829)
* *Dyschirius salinus* Schaum, 1843
Harpalus distinguendus (Duftschmid, 1812)
Harpalus melancholichus Dejean, 1829
* *Pogonus chalceus* (Marsham, 1802)
* *Pogonus littoralis* (Duftschmid, 1812)
Pterostichus cupreus (Linnaeus, 1758)
Pterostichus vernalis (Panzer, 1795)
Pterostichus versicolor (Sturm, 1824)
Stenolophus teutonus (Schrank, 1781)
* *Tachys scutellaris* Stephens, 1828