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Revue d'Ecologie (Terre et Vie), Suppt 12 « Espèces invasives », 2015 : 28-32

CHARACTERIZATION OF THE HABITATS COLONIZED BY THE ALIEN GROUND BEETLE *MERIZODUS SOLEDADINUS* AT THE KERGUELEN ISLANDS

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RÉSUMÉ.— *Caractérisation des habitats colonisés par le coléoptère terrestre allochtone* Merizodus soledadinus *aux îles Kerguelen*.— Dans le présent travail, nous avons conduit une étude de terrain visant à identifier les habitats colonisés par *Merizodus soledadinus*, un coléoptère terrestre allochtone afin de comprendre sa dynamique spatiale aux îles Kerguelen. Nous avons pratiqué un piégeage régulier dans plusieurs habitats côtiers sur l'île Haute, combiné à des recherches actives et opportunistes de cette espèce dans d'autres sites de cet archipel subantarctique. Au total 1081 sites ont été visités, et nos données ont révélé que les adultes de *M. soledadinus* se rencontrent très souvent sur la partie supérieure des estrans (372/540 obs., *i.e.* 69 %) (1) sous les laisses de mer et débris de bois jonchant la plage, (2) sous les pierres près des colonies de manchots dans ces zones côtières (3) dans les zones à herbacées et dans les prairies. Même si l'espèce a longtemps été considérée comme cantonnée aux herbages des zones côtières, nous avons relevé sa présence à l'intérieur des îles (265/541 obs., *i.e.* 49 %) (1) au voisinage de plantes en coussinets, (2) au bord des rivières et des mares, sous des pierres ou des déchets animaux et (3) sur les flancs de montage où poussent quelques plantes (*Azorella selago*, *Colobanthus kerguelensis* ou *Lycopodium magellanicum* et/ou des bryophytes). Notre étude permettra l'installation de mesures de biosécurité afin de tempérer les introductions accidentelles dans des zones vierges non encore colonisées par *M. soledadinus*.

SUMMARY.— In the present work, we conducted a field-based study to identify the type of habitats colonized by the alien ground beetle *Merizodus soledadinus* at the Kerguelen Islands, southern Indian Ocean, and to delineate the spatial dynamics of this species. We used periodic trapping at several coastal habitats on Ile Haute (one of the islands from the Kerguelen archipelago), together with opportunistic active searches at other locations on this subantarctic archipelago. A total of 1081 sites were visited. Our data showed that adult *M. soledadinus* were mostly found near the tide drift line (372/540 obs., i.e., 69 %) in various habitats, including (1) in the foreshore under timber, (2) beneath stones in coastal areas near penguin colonies, and (3) in herbfields and meadows. It was previously assumed that the habitat distribution of this species was restricted to the herbfields of coastal areas, with our inland observations showing that *M. soledadinus* (265/541 obs., i.e. 49 %) occupied areas (1) in the vicinity of cushion-carpets, (2) along rivers and ponds beneath stones or mammal carrion, and (3) in fell-fields that contained plant patches (*Azorella selago*, *Colobanthus kerguelensis*, or *Lycopodium magellanicum* and/or bryophytes). Our study is expected to facilitate the implementation of biosecurity measures to mitigate accidental introduction of *M. soledadinus* to pristine areas that it has not yet colonized.

Subantarctic islands are characterized by paucispecific angiosperm flora and insect fauna, reflecting their isolation and severe climatic conditions (Vernon *et al.*, 1998; Bergstrom & Chown, 1999; Chown *et al.*, 2009). However, anthropogenically facilitated invasions have had significant impacts on indigenous biota (Frenot *et al.*, 2005; Convey & Lebouvier, 2009). At the Kerguelen Islands (southern Indian Ocean), native terrestrial invertebrates are particularly threatened by the alien ground beetle *Merizodus soledadinus* (Chevrier *et al.*, 1997; Laparie *et al.*, 2010). This ground beetle naturally ranges from the Falkland Islands to southern South America (Patagonia). *Merizodus soledadinus* was accidentally introduced to the Kerguelen Islands, where it was first observed in 1939 (Jeannel 1940), followed by the South Georgia archipelagos, where it was first

observed in 1963 (Darlington 1970). At the Kerguelen Islands archipelago, ship anchoring records suggest that it may have been introduced as early as 1913 from the Falkland Islands when sheep and fodder were imported to establish a farm (Jeannel 1940, 1964). The geographical spread of *M. soledadinus* was subsequently monitored throughout the Kerguelen Islands archipelago via available literature combined with a general invertebrate survey conducted since the early 1990s (Chevrier, 1996; Lebouvier *et al.,* 2011). The wide distribution of *M. soledadinus* in coastal areas, which are generally covered with low herbaceous vegetation, has been reported (Chevrier *et al.,* 1996; Brandjes *et al.,* 1999). Field observations have also shown that the geographical spread of this species could reach three km per year on Ile Haute (Golfe du Morbihan), where it was first observed in 1992 (Chevrier *et al.,* 1997) (Fig. 1). Even if the dispersal process of *M. soledadinus* is limited by physical barriers, such as rocky cliffs, rivers, or seabird colonies (Lebouvier *et al.,* 2011), the habitats supporting *M. soledadinus* populations on the Kerguelen Islands have yet to be described.

In the present work, we conducted a field-based study using periodical trapping at several coastal areas on Ile Haute, together with opportunistic active searches at other locations of the archipelago. This preliminary study aimed to describe the types of habitats colonized by *M. soledadinus*, enhancing our understanding about its spatial dynamics on the Kerguelen Islands.

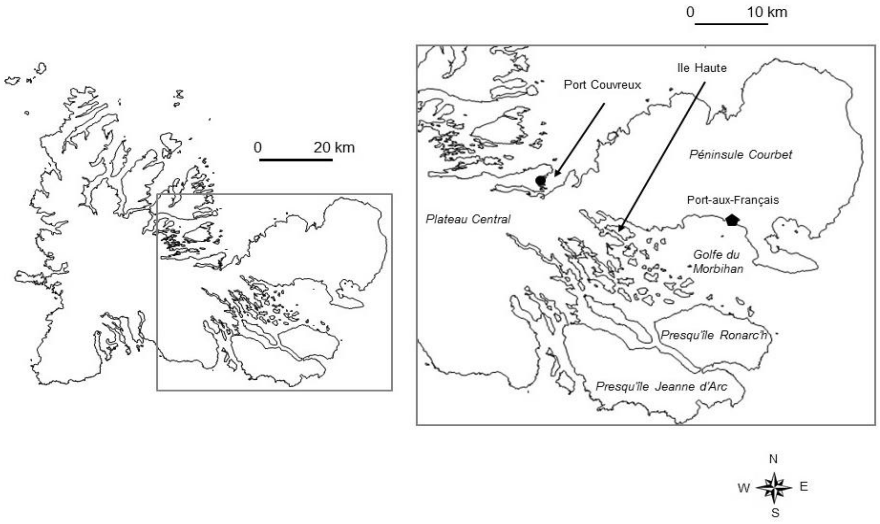

Figure 1.— Map of the Kerguelen Islands with a focus on the eastern part of the archipelago with the geographical area encompassing most of the visited sites. The scientific station is based at Port-aux-Français and the ground beetle *Merizodus soledadinus* was introduced only once at Port Couvreux.

MATERIAL AND METHODS

This study was conducted on the Kerguelen Islands from 1995 to 2009. In the first part of the study, a total of 43 pitfall traps (9 cm diameter and 4 cm height) were positioned around Ile Haute (< 5 m above sea level, Fig. 1). From February 1995 to July 1995, pitfall traps were opened for four days of each month (i.e., six times during the study). The main characteristics of each habitat and microhabitat near to the pitfall traps were noted, leading to four main habitats being defined (A to D, see Tab. I), following the description of Hughes (1987).

In the second part of this study, extensive surveys were conducted throughout the Kerguelen Islands from 2005 to 2009 to directly assess the distribution of *M. soledadinus* in the various habitat types of this archipelago. Inspections were conducted at 22 distinct locations on the eastern part of the Kerguelen archipelago (Péninsule Courbet, Presqu'île Ronarc'h,

Presqu'île Jeanne d'Arc, Plateau Central, and the islands in the Golfe du Morbihan; Fig. 1), covering the known geographical distribution of *M. soledadinus*. A total of 1081 sites were visited. One habitat assessment field data sheet was filled out for each site (i.e., a general habitat description, including GPS coordinates, soil texture, erosion, approximate size of the habitat, surrounding landscape, and vegetation structure). This information allowed three main habitat types to be distinguished: (1) coastal areas under debris, seawrecks and stones (N = 540 sites), (2) inland observations under mammal carrion (N = 157 sites), and (3) driftwood and stones in fell-fields (bryophytes), lowland rock fields (*Ranunculus pseudotrullifolius*, *Azorella selago* and bryophytes), tussock grasslands (*Poa* sp.), meadows (*Leptinella plumosa*, *Poa cooki*, *Deschampsia antarctica*), herbfields (*Acaena magellanica*, *Callitriche antarctica*, *Pringlea antiscorbutica*), peat bogs, and cushion-carpets (*Azorella selago*, *Colobanthus kerguelensis*) (N = 384 sites). At each site, the presence of *M. soledadinus* was determined by active searches for adults and larvae for 10 min per person, allowing a large zone to be checked. In depth searches at ground level beneath stones, debris, mammal carrion, sea wrecks, and within grassland were made for specimens. No in-depth search of the soil profile was completed.

TABLE I

Main characteristics of the habitats where the pitfall traps (N = 43) were positioned on Ile Haute and the number of traps in which M. soledadinus *specimens were sampled*

Habitat	Distance to sea (d)	Orientation	Habitat category; main plant cover	Microhabitat around traps	Traps with *M. soledadinus*/ total	Total number of *M. soledadinus* per trap/day
A	d < 5m	S, NE, NW	Tussock grassland and pebbles; *Poa annua*	*Poa annua*	7/15	0.80
B	5 < d < 10 m	SW	Cushion-carpet and bare soil; *Azorella selago*	Bare soil	4/4	1.00
C	d < 5 m	S, N	Meadow and pebbles; *Leptinella plumosa*	*Leptinella plumosa*	12/19	1.62
D	5 < d < 10 m	NW	Herbfield, bare soil, blocks; *Poa annua*	*Poa annua* and *Taraxacum* sp.	1/5	0.05

RESULTS

Merizodus soledadinus specimens were sampled in 24 of the 43 pitfall traps (56 %) (Tab. I). Few *M. soledadinus* were captured in traps placed near herbfields and bare soil (Habitat D). Additional inspections conducted in the second part of this study showed low (<5 ground beetles per 10 minute search period) to zero beetle densities in fell-fields, rock fields, peat bogs, and other low altitude habitats that contained spongy soil-like wet valleys (bryophytes) and meadows with *Juncus acutiflorus*. Other habitats characterized by very low densities of *M. soledadinus* (<5 ground beetles per 10 minute search period per observer) included tide drift lines in scree areas with high gullies and areas with few plant patches or open meadows with *Crassula moschata* or *Poa annua* and *Taraxacum* sp.

Merizodus soledadinus were regularly sampled in habitats A, B, and C. The second part of the study showed that beetles were mostly found near to the tide drift line (372/540 obs., i.e., 69 %) at sites including: (1) under the seawrecks and timber, (2) beneath stones in coastal areas near penguin colonies, and (3) in the surrounding herbfields and meadows. Interestingly, 200 m inland on Ile Guillou (Golfe du Morbihan), both adults and larvae were found at 25 cm soil depth in the rhizosphere of *A. magellanica*. Overall, we found that this ground beetle is not restricted to coastal areas and inhabits inland areas (265/541 obs., i.e. 49 %), including sites: (1) in the vicinity of cushion-carpets, (2) along rivers and ponds beneath stones or mammal carrion, and (3) in fell-fields that contained some plant patches (*A. selago*, *C. kerguelensis*, *Lycopodium magellanicum*) and/or bryophytes. This ground beetle species was rarely observed in habitats with bare soil or at altitudes of more than 360 m.

DISCUSSION

The habitat distribution of *M. soledadinus* has long been thought to be restricted to the herbfields of coastal areas, near to the ruins of the whaling stations and other human material that were located close to the original introduction points of this species (Jeannel, 1940, 1964; Ernsting, 1993; Brandjes *et al.*, 1999). Today, this ground beetle is also often found beneath stones, debris, and in tussocks in South Georgia (Convey *et al.*, 2011). In the present work, we found specimens of *M. soledadinus* in several distinct habitats on the Kerguelen Islands. Even though no statistical analyses were performed, this preliminary dataset indicates no clear pattern between the occurrence of this species and the main plant cover. The occurrence of *M. soledadinus* is probably regulated by the structure of the communities of invertebrates (characterized by the dominance of decomposers; Vernon *et al.*, 1998) and the moisture level of the microhabitat. This suggestion is consistent with both field observations conducted in Patagonia (Douady C., Kaufmann B., Lebouvier M. & Renault D., unpublished data), and experimental work. For instance, Todd & Block (1997) already demonstrated the low tolerance of adult *M. soledadinus* to desiccation, with this species being mainly active during night to prevent desiccation (Ottesen, 1990). Large numbers of specimens were sampled below the foreshore under the tide drift line, where large amounts of decaying organic matter are present. These habitats support large densities of prey, including the maggots of several native and introduced fly species, as well as those of several native weevil species (see Laparie *et al.*, 2010; Lebouvier *et al.*, 2011).

In contrast, the invertebrate communities of fell-fields and rock fields showed low species richness. However, the spider species, *Myro kerguelensis* and *Neomaso antarcticus*, were found in these habitats, as well as several species of mites, weevils, and the snail *Notodiscus hookeri*. This study is the first to report the presence of *M. soledadinus* adults at 10 to 25 cm below ground level close to the roots of *A. magellanica*. Moisture in this microhabitat may be critical for the life-history of this alien beetle on the Kerguelen Islands; however, further research is required to determine whether the individuals reported here were exclusively teneral adults that had not yet spread, or whether this species is actually able to inhabit this type of microhabitat throughout its adult life. Ground beetle larvae usually exhibit cryptic behavior, and are sampled in low densities; therefore, as already hypothesized by Jeannel (1940), it is likely that the larval development of *M. soledadinus* occurs in the soil, at least for the first instars.

Jeannel (1964) hypothesized that the founding population of *M. soledadinus*, established along the buildings of Port Couvreux, would be prone to extinction when the last ruins disappear. Even if large densities of this species (up to 100-200 individuals over a 10 min search) are still found around human constructions today, the current geographical distribution of *M. soledadinus* on the Kerguelen Islands greatly exceeds the range limits of human activities, demonstrating the tremendous success of this invasive species in this environment. Further studies should examine to what extent the distribution of this species is determined by (1) ground moisture and (2) the occurrence of prey species (maggots of wingless flies, caterpillars, and moths, in addition to the larvae and adults of weevils). Based on the result of this study, biosecurity measures have been set to mitigate the accidental introduction of *M. soledadinus* to pristine areas that it has not yet colonized.

ACKNOWLEDGEMENTS

This research was supported by the “Institut Polaire Français Paul Emile Victor” (programme 136), the CNRS (Zone Atelier de Recherches sur l’Environnement Antarctique et Subantarctique) and the “Agence Nationale de la Recherche” (ANR-07-VULN-004, EVINCE).

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