INTRODUCTION

In many terrestrial ecosystems, the majority of animals are soil invertebrates. This soil fauna involves arthropods which occupy the widest diversity of micro-habitats and niches, and play more ecological roles than any other group of animals. Among them, oniscideans are important players in soil ecology enhancing the decomposition rate of leaf litter and participate in the regulation of organic matter and nutrients (Zimmer et al. 2003). Indeed, in oak forests of western France, 10% of the annual litter is fragmented by isopods (Jambu et al. 1988, Mocquard et al. 1987). They also serve as food for many animals such as spiders (Vetter & Isbister 2006), amphibians (Ben Hassine & Nouira 2009) and birds (Bures & Weidinger 2003). Their diversity in temperate regions was studied in grasslands (Souty-Grosset et al. 2005) and humid zones (Souty-Grosset et al. 2008, Messina et al. 2011, 2012) and their abundance is estimated at up to 1800 individuals/m², from 50 to 200 ind/m² in forest and 500-7900 in meadows and their biomass at up to 4 g/m² depending on soil type (Gobat et al. 2010). In Tunisia, studies on terrestrial isopods are still sparse, being concentrated on systematics, population dynamics and biogeographical distribution (Di Maio & Caruso 1990, 1991, 2006, Caruso & Di Maio 1993, Medini-Bouaziz 2002, Hamaïed & Charfi-Cheikhrouha 2004, 2007, Hamaid-Melki, 2008). Studies related to isopod communities have indeed received little attention (Achouri et al. 2008a, Hamaïed-Melki et al. 2010). For instance, Colombini et al. (2003) focused mainly on beetles and terrestrial isopods living in coastal areas of the sandy beaches of Morocco, Tunisia (Zouaraa), Malta and Italy and Achouri et al. (2008a) on the diversity of terrestrial isopods in a coastal area of Berkoukech (north-west of Tunisia). In this context, this preliminary analysis aims to: (1) improve our knowledge of the species occupying the supralittoral zones of the mainly coastal wetlands, (2) establish the distribution of isopods according to the environmental factors, and (3) determine the environmental factors influencing their spatial distribution.

MATERIALS AND METHODS

Study site: According to the Tunisian Ministry of Agriculture, Environment and Water Resources and based on Emberger classification, five regions – from North to South – corresponding to different bioclimatic zones can be distinguished: (i) the humid (annual rainfall ranging from 800 to 1200 mm/year), sub-humid (600-800 mm/year), semi-arid (300-600 mm/year), arid (100-300 mm/year) and the Saharan or desert zone (up to less than 100 mm/year).

The Tunisian climate is marked by aridity, as more than 75% of the Tunisian territory is located in the arid and Saharan zones (Le Houérou 1976). This is why the majority of the prospect ed coastal wetlands are located in the semi-arid or arid zones. Wetlands can be divided into several types according to their physico-chemical and geomorphological characteristics, their distance from the sea and whether they are natural or artificial (Hamdi & Charfi-Cheikhrouha 2011). In the present study, three wetland types belonging to different bioclimatic zones were...
found, comprising one lake, nine lagoons and eighteen sebkhas (Fig. 1; Table I). This last zone is defined as a saline flat or salt-crusted depression, commonly found in North Africa. This area, usually temporary, is surrounded by halophile vegetation such as Salicornia and is present in central and southern areas from the semi-arid to the desert zone. A lagoon is a stretch of salt water partially or completely separated from the open sea by barriers of sand or coral, distributed along the Tunisian coasts, while a lake is a body of relatively still fresh water of considerable size, localized in a basin that is surrounded by land. Most lakes are fed and drained by rivers and streams.

_Sampling method:_ Field work was done in April 2010. Terrestrial isopods were collected in the morning by hand search each time with the same sampling effort: one hour per site was employed by the same person. Sampling was done in the supra littoral zones of the prospected wetlands.

During collection, soil temperature and humidity were measured in situ using a thermo-hygrometer and vegetation was determined and recorded at each site. The soil temperature ranged from 18 to 31.6 °C, humidity from 31 to 80 % and soil pH from 4.4 to 9.4. Soil sodium content oscillated between 0 and 11.5 mg/g and calcium content between 0.3 and 38.2 mg/g of soil.

The collected specimens were preserved in 70 % ethanol. In the laboratory, identification of species was carried out using a stereomicroscope Leica MS 5.

_Soil analysis:_ Physicochemical analyses were performed on soil sampled at each site. Three soil samples were taken at a depth of 0 to 10 cm. Each sample was free of organic debris and gravel. These three samples were collected at three different points of the station at least 5 m apart, and then mixed to form a composite sample. Once in the laboratory, the following analyses were made:

- Soil pH: 5 g of soil previously dried and ground into fine particles were placed with 12.5 ml of double distilled water. The samples were left in contact for 1 hour and agitated from time to time. The values of pH were measured using a EUTECH instruments pH 510 meter.
- Soil sodium and calcium content were determined by atomic absorption. To obtain a usable sample, we put 5 g of soil in 50 ml of distilled water. After one hour, the solution was filtered through a 50 micron mesh. To obtain reliable measurements, it was necessary to carry out successive dilutions.

_Data analysis:_ In order to characterize the Oniscidea community, the following ecological parameters were used: (1) species richness, expressed by the number of species encountered at each station; (2) species abundance (\( A_e = \frac{n_i}{N} \times 100 \)) where \( n_i \) is the number of individuals for each species and \( N \) is the total number of isopods; and (3) mean value of the species diversity, expressed by the Shannon-Weaver index (\( H' = -\sum p_i \log_2 p_i \)) (Frontier 1983) and the Pielou’s evenness index (\( J' = H'/ \log_2 S \)) (Pielou 1966). These analyses were carried out using the PRIMER 5.0 software.

ANOVA test was used to compare the diversity parameters (species richness and relative abundance) depending on wetland types and bioclimatic zones. Multivariate analysis was also applied to relate the species abundance and environmental factors using canonical correspondence analyses (CCA) performed with the free version of XLSTAT 2011.5.01 software (http://www.xlstat.com).

RESULTS

Species richness, mean abundance and diversity

A total of 951 isopod individuals were captured, corresponding to 13 species (Table II) belonging to 7 families: Armadillidiidae, Ligiidae, Philosciidae, Porcellionidae, Tylidae, Armadillidae and Agnaridae. Total species richness is 10 species in the supra littoral zone of lagoons and of sebkhas, but only one species was collected in the supra littoral zone of the lake (Table III). ANOVA test
shows no significant difference in species diversity between the three wetland types ($F = 2.51; \text{dF} = 2; p = 0.101$). The highest mean abundance is respectively recorded in the supra littoral zone of lagoons (138 individuals/per site) and in sebkhas (18 individuals/per site) (Fig. 2). A highly significant difference in mean abundance is observed in the distribution of isopods depending on wetland types ($F = 6.06; \text{dF} = 2; p = 0.007$).
Table III. – Species richness, abundance of the species and diversity parameters of the study sites: S: species richness; Sz: Species richness per bioclimatic zone; H': Shannon Wiener index; J': Equitability; □: presence prospected by observation of burrows.

<table>
<thead>
<tr>
<th>Bioclimatic zones</th>
<th>Lakes</th>
<th>Lagoons</th>
<th>Sebkhas</th>
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<tbody>
<tr>
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<td>S1</td>
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<td>Sz</td>
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<tr>
<td>Porcellio laevis</td>
<td>1</td>
<td>9</td>
<td>5</td>
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<tr>
<td>Porcellio variabilis</td>
<td>7</td>
<td>29</td>
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<tr>
<td>Porcellio arenatus</td>
<td>12</td>
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<tr>
<td>Porcellionides pruinosus</td>
<td>2</td>
<td>21</td>
<td></td>
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<tr>
<td>Porcellionides sexfasciatus</td>
<td>69</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Leptotrichus panzeri</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Armadillidium granulatum</td>
<td>24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chaetophiloscia elongata</td>
<td>119</td>
<td>21</td>
<td>3</td>
</tr>
<tr>
<td>Ligia italica</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Armadillo officinalis</td>
<td>42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tylus europaeus</td>
<td>1</td>
<td>7</td>
<td></td>
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<tr>
<td>Hemiphilistus reaumurii</td>
<td>1</td>
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<td>S</td>
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<td>Total S</td>
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<td>10</td>
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<tr>
<td>H'</td>
<td>0</td>
<td>0.76</td>
<td>2.35</td>
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<tr>
<td>J'</td>
<td>0.29</td>
<td>0.90</td>
<td>0.90</td>
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</tbody>
</table>

*Note:* Chaetophiloscia elongata is the most common species identified (40.3%). It is present in the supra-littoral zones of both lagoons and sebkhas. Apart from the humid zone, C. elongata is also the most abundant wetland species whatever the bioclimatic zone, with a relative abundance ranging from 36% to 73.6% in the semi-arid and arid zones, respectively. Porcellio laevis, the second most abundant species (22.3%), is also found in the lagoons and sebkhas. However, Porcellio variabilis is found at all wetland types from the humid to the semi-arid zones, but with a lower abundance. Armadillo officinalis, Armadillidium granulatum and Leptotrichus panzerii were sampled from the sub-humid to the semi-arid zones. Hemilepistus reaumurii was exclusively sampled from the supra-littoral zone of the sebkhas. This species was expected to be present in the supra-littoral zone of sebkhas from the semi-arid to the arid zones. In one station (S20), this species was exclusively sampled at a lower abundance. Porcellio laevis occurs only in the lagoons and its distribution is limited to the sub-humid zone. From our data, it is apparent that the two species, Tylus europaeus and Porcellionides pruinosus, are restricted to the sub-humid zones of lagoons. Another species, Ligia italica, is found only in the sebkhas but it is also known to be present in lagoons (Khemaissia, unpublished data). Tylos europaeus, the most common species identified (40.3%), is present in the supra-littoral zones of both lagoons and sebkhas. Apart from the humid zone, C. elongata is also the most abundant wetland species whatever the bioclimatic zone, with a relative abundance ranging from 36% to 73.6% in the semi-arid and arid zones, respectively. Porcellio laevis, the second most abundant species (22.3%), is also found in the lagoons and sebkhas. However, Porcellio variabilis is found at all wetland types from the humid to the semi-arid and sebkha zones. The second most abundant species, Ligia italica, is also found in the supralittoral zones of both lagoons and sebkhas. Another species, Ligia italica, is found only in the sebkhas but it is also known to be present in lagoons (Khemaissia, unpublished data).
No significant difference is observed in the distribution of terrestrial isopods in different bioclimatic zones, whatever the wetland types (F = 0.195; DF = 3; p = 0.89), since 39.1 % of collected isopod are found in the sub-humid and 52.1 % in the semi-arid zone. Considering each type of wetland separately, within lagoons, 9 of the 10 species collected in the supra littoral are found in the sub-humid zone. Moreover, a decreasing gradient of species richness (from North to south) is noted (Table III), although, statistical analysis reveals no significant difference in isopod distribution within lagoons (F = 1.41; df = 2; p = 0.26) based on bioclimatic zones. For the sebkhas, the highest diversity is observed in the semi-arid zone (8 species) and among them, 5 species were collected in S16 characterized by dense vegetation (Table I). On the basis of Fig. 3, two groups of sebkhas are defined; the first one consists of S5 only and the second is composed of all of the remaining sebkhas. The high values of air temperature and humidity that characterize the sub-humid zone could explain the highest diversity value in S5 (5 species) and its remoteness from the rest of the sebkhas but no significant difference exists in the distribution of isopods based on bioclimatic zones (F = 0.32; df = 2; p = 0.72).

**Isopod distribution according to environmental factors**

Among the analyzed soil parameters, no significant correlation is found between species richness and soil humidity (R = 0.42; df = 27) (Fig. 4A). Similarly there is a non significant relationships with soil sodium (R = -0.15; df = 27) and calcium content (R = -0.2; df = 27) (Fig. 4B).

According to the Canonical Correspondence Analysis (CCA), 54 % of information is obtained on the first axis and 29.9 % is explained in the second axis (Fig. 3, Table IV). *Armadillo officinalis*, which is abundant in S16, is clearly associated with soil sodium content on the one hand and negatively with soil pH on the other. The effect of soil sodium content and pH on the distribution of *L. panzerii* and *P. pruinosus* cannot be deduced since these species are encountered in low numbers, equal to 2 and 3 individuals in S16 and S8, respectively.

However, of a second group of terrestrial isopods which are abundant in S5, *A. granulatum* and *L. italica* are positively correlated with soil temperature and humidity. As expected, the distribution of *C. elongata* seems to be independent of all environmental factors compared to other species.

**DISCUSSION**

The results of this preliminary study reveal the presence of thirteen isopod species in the supra littoral zones of the prospected wetlands. The species richness is quite similar to that in previous studies on the isopod diversity in the Kroumirie Mountains of Tunisia, where 12 species were collected in four biotopes of the...
Berkoukech catchment area (Achouri et al. 2008a) and 11 species in nine habitats of wadi Moula-Bouterfess catchment (Hamaïed-Melki et al. 2010). Higher isopod abundance is observed in the sub-humid and the semi-arid bioclimatic zones, although no significant difference was noted. This result could potentially be explained by the favorable environmental factors for isopod survival; suitable humidity conditions are critical and have a basic role in determining tolerance ranges at a habitat and micro-habitat scale (Hornung 2011). Moreover, north to south, the gradient of species richness is inversely related to soil salinity. Desender & Maelfait (1999) showed that arthropod distribution in 28 tidal marshes in a gradient from fresh to salt water of the Flemish part of the river Schelde (Belgium) was explained by the salinity gradient: a higher salinity clearly corresponded to species-poor communities. From the Mediterranean to the northern regions in Europe, a latitudinal gradient in species richness has been shown: a gradual decrease of species richness towards the north is consistent in total species number and in species number within species-rich families (Hornung & Sólymos 2007). It is also the case for other arthropods such as saltmarsh beetles; few species are adapted to high salinity and regular submergence of salt marshes (Treherne & Foster 1977, Verschoor & Krebs 1995a, b).

It has been shown in the present study that vegetation influences the distribution of terrestrial isopods. In fact, the highest species richness is recorded in the sites with a high degree of vegetation cover that can exceed 70%. In a previous study, it was demonstrated that the highest species diversity was related to high flora diversity (Achouri et al. 2008b). Furthermore, open areas are more favorable for isopods than forests with very dense vegetation and dense maquis (Hamaïed-Melki et al. 2010). Additionally, open habitats with a mixture of shrubby vegetation are more favorable for isopods than mono-dominant forests, or very dense vegetation (Sfenthourakis et al. 2005).

A significant difference is shown in mean abundance among wetland types. In some arid zone sites, and because of high temperatures, the water level of the sebkhas dropped so the wetland habitats where isopod species live become unsuitable for them. However, no significant difference is observed between wetlands in relation to bioclimatic zones. This result could be related to the fact that, along the coast, the influence of the sea tends to homogenize the climate. Among the collected species, P. laevis – a widespread species in Tunisia (Medini-Bouaziz 2002) – and C. elongata – a holomediterranean species (Caruso & Lombardo 1982, Taïti & Ferrara 1996, Schmalfuss 2003) – are the most frequent species in the supra littoral zones of sebkhas and lagoons, respectively. In a similar study carried out in the supra littoral zone of Bizerte lagoon (North of Tunisia), C. elongata was the most frequent species (Jelassi et al. 2012). It was also the most common species identified and present in all sampling sites in a protected area characterized by a salty coastal ponds in southeastern Sicily (Messina et al. 2011), and in four habitats of Berkoukech area (Achouri et al. 2008a). In fact, C. elongata was considered as a common species by Legrand (1954) and present in humid habitats (Vandel 1962). Prior to the present work, C. elongata was considered independent of all environmental factors,

![Relationship between soil humidity (a) and soil sodium content (b) and species richness.](image-url)
compared to other species, and that can explain its high relative abundance. In salt marsh habitats of the Ria Formosa lagoon system (southern Portugal), and among the four characteristic species of isopod, *Tylos ponticus* was the most abundant (Dias et al. 2005). However, *T. europaeus* was the most abundant species in the majority of Mediterranean studies on the diversity of macrofauna communities in sandy beaches; in the western coast of Portugal (Goncalves et al. 2009, Goncalves & Marques, 2011) in the northern coast of Spain (Rodil et al. 2006), in the northwestern coast of Tunisia (Colombini et al. 2003), in the north east of Morocco (Achouri et al. 2008b) and in the Maltese beaches (Deidun et al. 2003). The observed differences in faunal composition between supra littoral zone of wetlands and sandy beaches can probably be combined in terms of differences in sediment grain size or to the beach dune profile and orientation that exists between the two different ecosystems. It has been shown that the association of isopod species with habitat types is strongly affected by soil and humus types (Judas & Hauser 1998).

Because of its ecological preferences, the distribution of *A. officinalis* is generally limited to arid environments (Vandel 1960). In Sicily, for example, it was only collected far from the sea and from ponds, reflecting their xerophilous characteristics (Messina et al. 2011), whereas, in the present study, individuals were collected in both lagoons and sebkhas from the sub-humid to the arid zones. Additionally, *L. panzerii*, another example of xerophilous species, was occasionally present in the sub-humid zone. During our survey, *P. sexfasciatus*, a west-mediterranean-atlantic species (Taïti & Ferrara 1996, Schmalfuss 2003), was found from the sub-humid to the semi-arid zones. This result was also obtained by Achouri & Charfi-Cheikhrouha (2001); the species is limited to coastal habitats and to specific bioclimatic zones from the humid to the semi-arid ones, and has never been reported in southern Tunisia. Despite the fact that *P. pruinatus*, a cosmopolitan species (Taïti & Ferrara 1996, Schmalfuss 2003), was distributed in all bioclimatic zones (Achouri & Charfi-Cheikhrouha 2000), the species has not been reported in the arid zone.

*Porcellio variabilis*, a species very widespread across North Africa, was found whatever the wetland type from the humid to the arid zones. In a previous study, the species was known to be present from the forests of Ain Drahem in the extreme north-west to the oasis of Nafta in the southwest of Tunisia, its abundance decreasing progressively along a north-south gradient (Medini & Charfi-Cheikhrouha 1998) as in the present study. *Armadillidium pelagicum*, endemic to the circum-Sicilian islands and the North of Tunisia (Caruso et al. 1987, Caruso & Lombardo 1985) and normally encountered from the humid to the semi-arid zones (Hamaied-Melki et al. 2010), was found in lower counts only in the sub-humid zone. A recent study showed that *A. pelagicum* colonizes open and sunny habitats (Hamaied-Melki et al. 2010).

The canonical correspondence analysis shows that the distribution of *Armadillo officinalis* appears to be driven mainly by soil sodium content and negatively with soil pH. Concerning species *Leptotrichus panzerii* and *Porcellionides pruinatus*, no correlation was found between soil parameters and species abundances. Soil pH did not appear to be significant for other arthropods such as millipedes, but occurrence was related to low annual temperature (Zimmer et al. 2000). By contrast, *Oniscus asellus*, an acidophile species, *A. vulgare* and *A. nasatum* prefer a neutral pH (Van Straalen & Verhoef 1997).

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