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The influence of coastal zonation and meteorological variables on terrestrial isopod populations: a case study in western Sicily (Italy)

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Abstract

Because of their biological and ecological characteristics terrestrial isopods are considered as bioindicators of ecosystem health and several studies have shown that their distribution and abundance are influenced by environmental factors, such as weather, soil texture, composition and vegetation structure. However, few quantitative data are available on the relationship between single species of terrestrial isopods, meteorological variables and coastal zonation. This study aims to clarify relationships between terrestrial isopod populations, coastal zones and weather conditions of a protected area in Sicily. The terrestrial isopods were sampled using pitfall traps, and we verified the association between each species abundance and three different (lower, medium and upper) coastal zones. Furthermore, we analyzed correlations between isopod abundances and meteorological conditions (temperature and precipitation). The results showed a close relationship between some isopod species and coastal zone types, as well as a positive correlation of most of the species abundances with temperature and a negative one with precipitation.

Keywords: *Isopoda*, *Oniscidea*, temperature, precipitation, coastal zones, Italy

Introduction

Terrestrial isopods are an abundant and widespread component of soil fauna, actively contributing to the decomposition processes and recycling of nutrients (Hassall & Sutton 1978; Sutton 1980; Zimmer 2002). Changes in coastal zones and meteorological patterns can cause modifications in soil biodiversity (Wardle 2006).

Furthermore, they are important elements of soil food webs being food sources for other arthropods (Vetter & Isbister 2006) and vertebrates (Bureš & Weidinger 2003; Ben Hassine & Nourira 2009).

Due to their biological and ecological characteristics, they are considered bioindicators of heavy metal pollution (Paoletti & Hassall 1999) and of grassland habitat quality (Souty-Grosset et al. 2005). In Sicily, some studies on the diversity, systematics and geographical distribution of terrestrial isopods have been conducted (Vandel 1969; Caruso et al. 1987), and recently, research has focused on terrestrial isopod

communities of the coastal humid areas (Messina et al. 2011, 2012, 2014, 2015). Several studies have shown that distribution and abundance are influenced by social factors (Devigne et al. 2011; Broly et al. 2015) and environmental variables, such as weather, coastal zonation, and plant associations (David et al. 1999; Zimmer 2004; Antunes et al. 2008; Souty-Grosset et al. 2008; Morón-Ríos et al. 2010; Hamaied-Melki et al. 2011; Khemaissia et al. 2011, 2012).

However, modest quantitative data are available on the relationship between single species of terrestrial isopods, meteorological variables and coastal zones (Messina et al. 2014).

Indeed, only by monitoring and comparing species activities during time and in relation to ecological (coastal zones) and meteorological (temperature and humidity) factors is it possible to acquire information on diversity and distribution (D'Antoni et al. 2011).

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This research had the following aims: (1) verify whether there is a relationship between species of terrestrial isopods and coastal zonation; (2) increase our knowledge on the relation between weather condition and surface activity of isopods.

Materials and methods

Study area

The study was carried out in the Saline di Trapani e Paceco Natural Reserve (NR); the area is a part of a Special Protection Area (“SPA”, in accordance with the European Regulations 79/409/CEE “Birds”), a Site of Community Importance (“SCI”, ITA 010007), an Important Bird Area and a protected humid area under the Ramsar’s Convention. The NR is located in the southern province of Trapani, western Sicily (Figure 1).

The study site has a surface area of 960 ha and consists of a plain characterized by sandy coast with moderate altitude differences (no more than 5 m above sea level) and a large wetland. The humid areas cover most of the SCI surface (about 80%) and are represented by saline (about 750 hectares in the SCI) and salt marshes (more than 30 hectares in the SCI).

The area has a high biodiversity, with respect to both flora and fauna (Troia 2008). It is considered a hot spot, particularly for the presence of endemism and its high number of migrant bird species (Raimondo 2011).

Ecosystem classification and species sampling

The coastal ecosystem was divided in three areas characterized by different ecological conditions: lower, medium and upper zones. Each zone shows differences in vegetation and inundation (Sciandrello et al. 2014). The lower zone is subject to frequent submersion and is

characterized by the following halophilous plant communities: *Arthrocnemo–Halocnemetum strobiliacei*, *Arthrocnemum glaucum comm.*, *Arthrocnemo–Juncetum subulati*, *Arthrocnemeto–Limoniastrum monopetali* and *Halimiono portulacoidis–Sarcocornietum alpini*; the middle zone is characterized by short period submersion and the following halo-nitrophilous plant communities: *Agropyro scirpei–Imuletum crithmoidis*, *Lygeum spartium comm.*, *Sualetum verae*; the upper zone is the dune strip of the study site seldom subject to inundation and characterized by the following plant communities: *Calendulo maritimae–Elytrigietum junceae*, *Parapholidetum filiformis*, *Rostrario–Monermetum cylindricae*, *Senecioni leucanthemifolii–Matthiletum tricuspidatae*, *Avena barbata comm.*

In total, 79 species of vascular plants have been recorded in the study area. Most of the species belong to the Mediterranean vegetation; the dominant life forms are therophytes (n = 40; 51%) and hemicryptophytes (n = 16; 20%), while geophytes (n = 10; 13%), chamaephytes (n = 9; 11%) and nanophanerophytes (n = 4; 5%) show low values.

Phytosociological analysis identified 13 plant communities, of which eight are perennial halophilous communities (six shrubby, two grassy) included in the *Salicornietea fruticosae* class, two annual halohygrophilous communities included in the *Saginetea maritimae* class, one perennial psammophilous community included in the *Ammophilettea* class, one annual psammo-nitrophilous community included in the *Cakiletea maritimae* class, and one annual nitrophilous community of the *Stellarietea mediae* class.

In the lower coastal zone (LZ) five plant communities are included; in the middle coastal zone (MZ) three plant communities are included; and in the upper coastal zone (UZ) five plant communities are included.

Plant communities were determined, in order to characterize each coastal zone, according to the phytosociological method of Braun-Blanquet (1964). Nomenclature and taxonomy were referred to Brullo et al. (2002), Giardina et al. (2007), and Sciandrello and Tomaselli (2014).

In each of these three zones, nine sampling units (replicates for each coastal zone), constituted by pitfall traps filled with a water-saturated solution of sodium chloride, were placed randomly and spatially separated (at a distance of 20 m). This yielded a total of 27 sampling units, which were not directly related with each plant association, but with the coastal zones within which we identified the characteristic plant communities. The use of pitfall traps has the advantage to give an appropriate representation of the qualitative and quantitative data of soil fauna

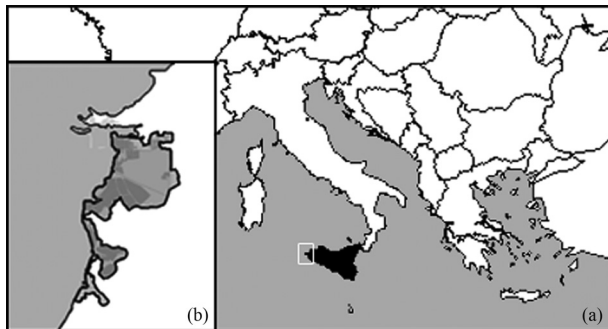


Figure 1. (a) Study-site location in Italy; (b) Natural Reserve of “Saline di Trapani e Paceco”.

(Sutherland 1996). Furthermore, pitfall traps represent one of the main methods for sampling terrestrial invertebrates (New 1999; Brandmayr et al. 2005).

The sampling was continuously carried out for 2 years (from January 2008 to January 2010). The obtained material was stored and evaluated separately for each trap and each exposition period. The pitfall traps were emptied monthly and the material preserved in 70% ethanol. Sampled individuals were identified in the laboratory using a stereomicroscope Zeiss STEMI-SV8, and then counted.

Meteorological data

The study area is characterized by a temperate Mediterranean climate. The rainfall and temperature trends for the 2 years of sampling in the study area are shown in Supplementary Figure 1. The absolute maximum air temperature reported during the 2 years of monitoring was 36.6°C, while the minimum air temperature was -0.2°C (Italian Air Force Meteorological Service). The average maximum air temperature was 30.7°C (± 1.7 ; August 2009), the biannual average minimum air temperature was 6.63°C (± 2.8 ; February 2008). The rainiest month was September 2009, in which 152.5 mm of rain was reported. The percentage of maximum air humidity was 100%; the minimum was 10%. The percentage of biannual average minimum air humidity was 41% (September 2008), while the maximum rate was 97% (March 2008). We evaluated the relation between Isopoda species abundances (as a proxy of activity trends) and the biannual mean temperature/precipitation during the two sampling years.

Data analysis

Statistical analysis, performed utilizing the SPSS software (Version 14.0, SPSS, Chicago, IL), was carried out on data from collected terrestrial isopod species with a total number of individuals ≥ 10 to reduce the errors due to poorly sampled species. Hence, 13 species and the abundances of their adult individuals were considered.

Species and their abundances were tested against ecosystem types (zones) and weather variables, respectively. In order to analyze the potential associations between each species of terrestrial isopods and ecosystems of the study area, a Pearson's χ^2 test was calculated.

Correlation analysis was run to identify how environmental factors (monthly average rainfall (mm) and air temperature (C°)) influence the activity and the abundances of the isopods. Spearman's correlation coefficient (r_s) was calculated, species abundances being not always normally distributed.

Results

Isopoda diversity

During the two sampling years, we collected 13 Isopoda species (with abundances ≥ 10 individuals) accounting for a total of 24,061 individuals (Table I). The two most dominant species are *Armadillidium granulatum* Brandt, 1833 (13,929), *Chaetophiloscia elongata* (Dollfus, 1884) (3488) and the two rarest are *Halophiloscia hirsuta* Verhoeff, 1928 (21) and *Porcellio albicornis* (Dollfus, 1896) (33).

Associations between isopod species and coastal zones

Table II reports associations between isopod species and coastal zones. Ten isopod species out of 13 (76.9%) show significant ($P < 0.01$) association with a specific zone.

Table I. Sampled species abundances (total number of individuals) in each coastal zone (asterisks indicate species with a total abundance over 2 years < 10 individuals). LZ = lower zone; MZ = middle zone; UZ = upper zone.

Species	Coastal zone (abundances)		
	LZ	MZ	UZ
<i>Halophiloscia couchii</i> (Kinahan, 1858)	522	7	324
<i>Halophiloscia hirsuta</i> Verhoeff, 1928	20	0	1
<i>Chaetophiloscia elongata</i> (Dollfus, 1884)	1116	1634	738
<i>Acaeroplastes melanurus</i> (Budde-Lund, 1885)	13	23	26
<i>Agabiformius lentus</i> (Budde-Lund, 1885)	29	28	16
<i>Leptotrichus panzerii</i> (Audouin, 1826)	298	922	220
<i>Porcellio albicornis</i> (Dollfus, 1896)	13	17	3
<i>Porcellio laevis</i> Latreille, 1804	490	164	150
<i>Porcellio siculoccidentalis</i> Viglianisi, Lombardo, Caruso, 1992	0	21	24
<i>Armadillidium badium</i> Budde-Lund, 1885	225	551	820
<i>Armadillidium decorum</i> Brandt, 1833	93	80	253
<i>Armadillidium granulatum</i> Brandt, 1833	9838	1682	2409
<i>Armadillo officinalis</i> Duméril, 1816	803	59	429
Total	13,460	5188	5413
* <i>Tylos ponticus</i> Grebniki, 1874	0	0	5
* <i>Ligia italica</i> Fabricius, 1798	0	0	3
* <i>Armadilloniscus candidus</i> Budde-Lund, 1885	2	0	1
* <i>Armadilloniscus ellipticus</i> (Harger, 1878)	2	0	1
* <i>Stenophiloscia glarearum</i> Verhoeff, 1908	1	0	3
* <i>Porcellionides pruinosus</i> (Brandt, 1833)	0	2	6
* <i>Porcellionides sexfasciatus</i> (Budde-Lund, 1885)	0	1	0
* <i>Agabiformius obtusus</i> (Budde-Lund, 1909)	0	4	0
* <i>Lucasius pallidus</i> (Budde-Lund, 1885)	1	3	0
* <i>Mica tardus</i> (Budde-Lund, 1885)	1	5	2
* <i>Armadillidium album</i> Dollfus, 1887	1	0	4
Total	8	15	25

Table II. Ecosystems and isopod species association (Pearson χ^2 test). LZ = lower zone; MZ = middle zone; UZ = upper zone; ns = non-significant association.

χ^2 test	$P < 0.05$	$P < 0.01$
<i>Halophiloscia couchii</i>	LZ	LZ
<i>Halophiloscia hirsuta</i>	LZ	LZ
<i>Chaetophiloscia elongata</i>	MZ	MZ
<i>Acaeroplastes melanurus</i>	ns	ns
<i>Agabiformius lentus</i>	ns	ns
<i>Leptotrichus panzerii</i>	MZ	MZ
<i>Porcellio albicornis</i>	MZ	ns
<i>Porcellio laevis</i>	LZ	LZ
<i>Porcellio siculoccidentalis</i>	UZ	UZ
<i>Armadillidium badium</i>	UZ	UZ
<i>Armadillidium decorum</i>	UZ	UZ
<i>Armadillidium granulatum</i>	LZ	LZ
<i>Armadillo officinalis</i>	LZ	LZ

Two isopod species (*Acaeroplastes melanurus* (Budde-Lund, 1885) and *Agabiformius lentus*) (Budde-Lund, 1885) show no significant association, while *P. albicornis* shows association at $P < 0.05$ but not at $P < 0.01$ with the related coastal zone type.

Relationships between abundances of species and meteorological conditions

In Figures 2 and 3, we show the abundances of species (as a proxy of activity trends) in relation to annual meteorological conditions (precipitation and air temperature). Results of correlation analysis are shown in Table III. Nine species out of 13 (69%) are significantly correlated with temperature; in particular, *A. melanurus*, *A. lentus*, *Porcellio laevis* Latreille, 1804, *Armadillidium badium* Budde-Lund, 1885, *A. granulatum* and *Armadillo officinalis* Dumeril, 1816 showed a significant positive correlations with temperature, while *Halophiloscia couchii* (Kinahan, 1858), *C. elongata* and *Porcellio siculoccidentalis* Vigliani, Lombardo, Caruso, 1992 showed negative correlations (Table III and Figure 2).

Seven species out of 13 (54%) reported significant results when correlated to precipitation: *A. melanurus*, *Leptotrichus panzerii* (Audouin, 1826), *P. laevis*, *A. badium*, *A. granulatum* and *A. officinalis* showed a significant negative correlation, while only *H. couchii* showed a significant, although weak, positive correlation (Table III and Figure 3).

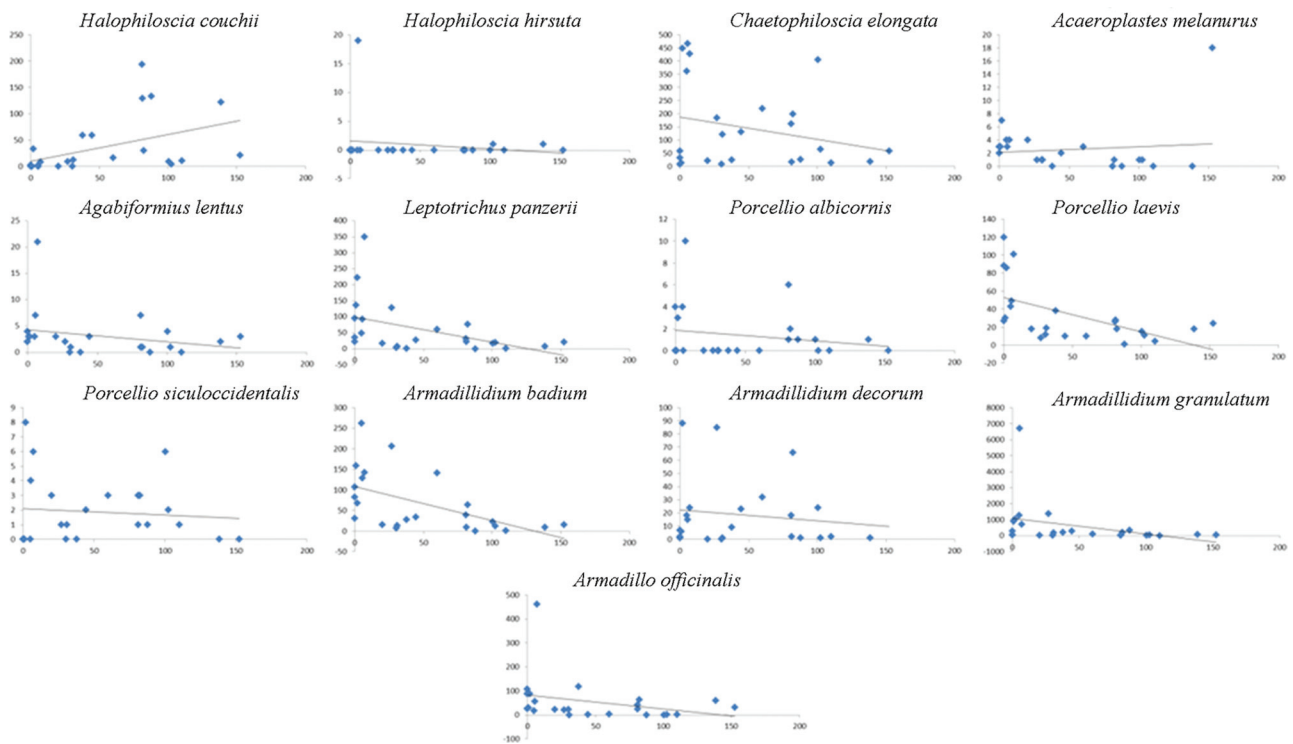


Figure 2. Abundance trends (on x-axis) correlated to precipitation (in mm on y-axis); correlation coefficients and their P values are reported in Table III for each of the 13 terrestrial isopod species sampled.

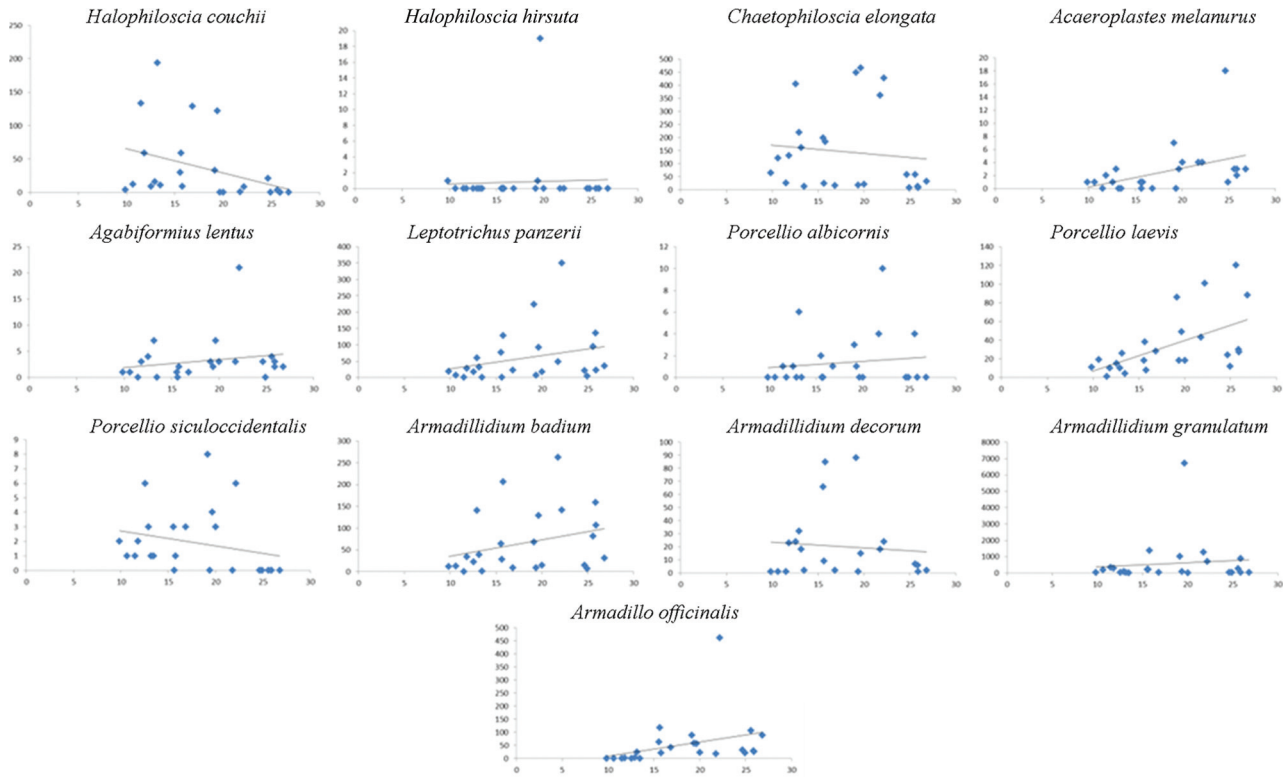


Figure 3. Abundance trends (on x-axis) correlated to temperature (in °C on y-axis); correlation coefficients and their P values are reported in Table III for each of the 13 terrestrial isopod species sampled.

Table III. Correlation analysis between species and meteorological conditions. Spearman's correlation coefficients are reported when significant.

Species	Temperature		Precipitation	
	r	P	r	P
<i>H. couchii</i>	-0.095	$P < 0.05$	0.093	$P < 0.05$
<i>H. hirsuta</i>	-	-	-	-
<i>C. elongata</i>	-0.201	$P < 0.01$	-	-
<i>A. melanurus</i>	0.122	$P < 0.01$	-0.106	$P < 0.01$
<i>A. lentus</i>	0.081	$P < 0.05$	-	-
<i>L. panzerii</i>	-	-	-0.151	$P < 0.01$
<i>P. albicornis</i>	-	-	-	-
<i>P. laevis</i>	0.080	$P < 0.05$	-0.081	$P < 0.05$
<i>P. siculoccidentalis</i>	-0.110	$P < 0.01$	-	-
<i>A. badium</i>	-	-	-0.156	$P < 0.01$
<i>A. decorum</i>	-	-	-	-
<i>A. granulatum</i>	0.098	$P < 0.05$	-0.123	$P < 0.01$
<i>A. officinalis</i>	0.194	$P < 0.01$	-0.148	$P < 0.01$

Discussion

Relationships between terrestrial invertebrates and coastal zone types have been widely documented for many taxa (Southwood et al. 1979; Gibson et al. 1992; Usher 1992; David et al. 1999; Hamaied-Melki et al. 2010). We found that oniscidean communities in our study site are also influenced by coastal zone type. Moreover, our results are in agreement with the fact

that terrestrial isopods prefer open habitats with a mixture of shrubby vegetation, rather than monodominant forest (Hornung & Warburg 1995a; Sfenthourakis et al. 2005).

Although collected species are frequent in almost all the coastal zones surveyed, the statistical analysis underlined that in some specific habitats the presence of some species is more significant. This shows that each Oniscidea species prefers a selected coastal zone, while its presence in the others is only occasional or in passing.

Five species are strongly associated ($P < 0.01$) with the lower coastal zone (LZ) (Table II): *H. couchii*, *H. hirsuta*, *P. laevis*, *A. granulatum* and *A. officinalis*.

The LZ is characterized by high salinity, also being subject to periods, often long, of submersion. Thus, the presence of halophilous species such as *H. couchii* and *H. hirsuta* is completely justified.

About the other species significantly associated to LZ, *A. granulatum* has a high vagility, even if it does not move too far away from littoral zones where it is very abundant. Therefore, it is possible to find high abundances of *A. granulatum* in LZ when it is dry.

Moreover, *A. granulatum* is often related (Vandel 1960) to some particular plant association such as

Arthrocnemeto–Limoniastretum monopetali, a perennial halophilous vegetation growing in areas either enriched by salts and nitrates or exposed to periodical submersion. *Porcellio laevis*, a cosmopolitan and synanthropic species (Caruso et al. 1987), is, instead, often related to *Halimiono portulacoidis–Sarcocornietum alpini*, an association developing on well-drained soils rich in organic matter and flooded for long periods (Sciandrello et al. 2014).

Armadillo officinalis is a species which lives in arid and sub-arid coastal zones (Vandel 1960), but its significant presence in the LZ is not surprising because this species is characterized by a good vagility and can sometimes move to less arid environment (D. Caruso, pers. comm.). Indeed, this species was also sampled in closed areas like *Pinus halepensis* and natural oak-woodland forest (Hornung & Warburg 1995b).

Two species (*C. elongata* and *L. panzerii*) are strongly associated ($P < 0.01$) and one (*P. albicornis*) significantly associated ($P < 0.05$) with the middle coastal zone (MZ) (Table II).

The MZ is characterized by the presence of some halo-nitrophilous plant associations, such as *Suaedetum verae*, which are important habitats for the first two oniscidean species. *Suaedetum verae* grows in the middle zones of salt marshes enriched by organic material (Sciandrello et al. 2014). These ecological features are particularly favorable to the hygrophilous species *C. elongata* (Vandel 1962). These results are in accordance with Caruso and Lombardo (1982), who collected this species in humid habitats in the Maltese islands and with Hamaied-Melki et al. (2010) who collected this species in low-altitude sites and in humid habitats of Tunisia, whereas in Sicily *C. elongata* was found up to 1000 m (Caruso et al. 1987).

Moreover, a halo-nitrophilous plant association could represent not only a source of food for these two species but even protection against dehydration. Indeed, it is well known (Chelazzi & Ferrara 1978) that soils lacking in vegetal cover and organic material do not shelter isopod communities.

Porcellio albicornis, instead, has a low vagility and prefers incoherent soils with perennial grass species, which are often invasive (Caruso et al. 1987).

Three species are strongly associated ($P < 0.01$) with the upper coastal zone (UZ): *P. siculoccidentalis*, *A. badium* and *Armadillidium decorum* Brandt, 1833.

These three species have restricted distributions, where *P. siculoccidentalis* is actually endemic, and prefers environments with stable temperature and humidity (D. Caruso 2016, pers. comm.).

Moreover, *A. badium* is often associated with annual halo-nitrophilous plant communities, such as with

Parapholidetum filiformis, composed by various species typical of open environments (Caruso & Lombardo 1982). This species in the UZ can be also associated with *Rostrario–Monermetum cylindricae*, a therophytic plant community, typical of clearings in perennial halophilous vegetation (Tomaselli et al. 2011).

Two species, *A. melanurus* and *A. lentus*, show no significant association with any coastal zone type. This may be due to the rarity of these species in every zone ($n = 60$; $n = 70$, respectively; see Table I) and to their low vagility.

As for the species with less than 10 total individuals (which were excluded from the statistics, Table I), their presence should be considered occasional. In particular, alophilous species (apart from *Tylos ponticus* Grebnicki, 1874, which moves toward the hinterland during the night), such as *Armadillidium album* Dollfus, 1887, *Stenophiloscia glarearum* Verhoeff, 1908, *Ligia italica* Fabricius, 1798, *Armadilloniscus candidus* Budde-Lund, 1885 and *Armadilloniscus ellipticus* (Harger, 1878), only in particular situations move away from water. This happens when tides, sea waves or coastal storms drive them far from the shoreline (D. Caruso 2016, pers. comm.).

Different research studies have shown the influence of weather on the analyzed species' activity and phenology (McQueen & Carnio 1974; McQueen 1976; Warburg et al. 1984; Miller & Cameron 1987; Zimmer & Brauckmann 1997). These studies show a close relationship between meteorological conditions and isopod abundances.

Our results show a negative relationship between precipitation and isopod activity (Figure 2). Indeed, low abundances were found during the rainiest months, and we documented an increase in the number of adult individuals after the rainfall periods. A similar phenological trend is in accordance with the observation made by Warburg et al. (1984).

We show that abundances drop suddenly following 90–100 mm of rainfall. This could be due to the clayey nature of those soils, which drain water slowly; therefore, the substrate often floods after a threshold of precipitation, creating difficult conditions for isopod survival. For instance, Paris (1963) showed that population of *A. granulatum* presented high mortality through drowning during rainfall.

An exception to the patterns mentioned above is *H. hirsuta*, which seems not to be affected by meteorological conditions, particularly precipitation, likely because it lives very close to the sea, an environment always saturated with water.

Moreover, our analyses show that most of the species abundances rise when temperature increases from 10 to 20°C (Figure 3). At higher temperatures,

some species (such as *C. elongata* and *P. siculoccidentalis*) do not show any activity, while others (such as *A. officinalis*) show tolerance. This latter evidence is in agreement with Khemaissia et al. (2012), whom collected this species in the sub-humid zone characterized by high values of air temperature in Tunisia.

In conclusion, the results of this research provide answers to our two initial questions. The studied isopod species show coastal zonation preferences and their abundances are influenced by weather conditions. Furthermore, this study contributes to clarify the ecological preferences of the 13 studied species.

These data could allow us to predict possible changes in species composition, due to climatic and vegetation changes in the area studied. Some models predict huge variability in the next few decades for Sicily, and in general for the Mediterranean region (Somot et al. 2008): the mean temperature will increase in all seasons, while summers will see a decrease in mean precipitation. These changes, together with related modifications of plant composition and other anthropogenic impacts, will affect isopod species, and our study also provides detailed information to foresee the effects of such changes on their populations.

Finally, we want to point out that humid and protected areas play a fundamental role in the existence and conservation of these crustaceans, in addition to all other species, and at the same time a healthy community of these species is essential for the survival of this ecosystem.

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Supplemental data

Supplemental data for this article can be accessed here: <http://dx.doi.org/10.1080/11250003.2016.1222558>.

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