Arquipelago - Life and Marine Sciences ISSN: 0873-4704

Arthropod diversity patterns in three coastal marshes in Terceira Island (Azores)

PAULO A.V. BORGES, C. PIMENTEL, M.R. BRITO, L. BORDA-DE-ÁGUA & R. GABRIEL

Borges, P.A.V., C. Pimentel, M.R. Brito, L. Borda-de-Água & R. Gabriel 2017. Arthropod diversity in three coastal marshes in Terceira Island (Azores). *Arquipelago*. Life and Marine Sciences 34: 61- 83.

The coastal wet areas of Praia da Vitória (Terceira, Azores) were investigated to describe the ground and aerial (herbaceous and canopy) arthropod communities by comparing patterns of species composition, abundance and diversity. Three wet areas were studied: Paul da Praia da Vitória (PPV), Paul do Belo Jardim (PBJ) and Paul da Pedreira do Cabo da Praia (PPCP). A standardized protocol (based on the COBRA protocol) was performed with day and night sampling of arthropods with a total of 56 samples per site. Common diversity metrics (Hill series) were calculated and abundance patterns were investigated using species abundance distributions (SAD). All investigated communities were dominated by native non-endemic and exotic species; only seven out of the 132 endemic arthropod species and subspecies existing in Terceira Island were found in the area. The logseries described well the communities, with a prevalence of rare species. The three sites seem to work as a complementary network of wet areas with specific arthropod communities possibly related to their specific features. However, Paul do Belo Jardim (PBJ) performed better for many of the investigated indicators, and two IUCN endangered species, the true weevil *Drouetius oceanicus oceanicus* and the Azorean cone-head grasshopper (*Conocephalus chavesi*) are relatively abundant there. Due to habitat changes that occurred between 2006 and 2010 in PPV, only one of the three most abundant ground-beetles recorded in 1991-1993 and 2003 was found but only after some additional sampling in a small remnant of the original habitat.

Key words: Arthropods, Azores, coastal areas, community structure, diversity metrics, SADs.

Paulo A.V. Borges (email: paulo.av.borges@uac.pt) & Rosalina Gabriel, cE3c – Centre for Ecology, Evolution and Environmental Changes / Azorean Biodiversity Group and University of the Azores, Faculty of Agricultural and Environmental Sciences, Rua Capitão João D´Ávila, PT-9700-042 Angra do Heroísmo, Azores, Portugal; C. Pimentel & M.R. Brito, LIFE CWR – LIFE project "Ecological Restoration and Conservation of Praia da Vitória Coastal Wet Green Infrastructures" PT-9760 Praia da Vitória, Azores, Portugal; Luís Borda-de-Àgua, Theoretical Ecology and Biodiversity, and Infrastructures, Portugal Biodiversity Chair, CIBIO – Research Centre in Biodiversity and Genetic Resources - InBIO Associate Laboratory University of Porto, Campus Agrário de Vairão, PT-4485-661 Vairão, Portugal.

INTRODUCTION

Azores have a unique arthropod fauna extremely impacted by human historical and current activities, mainly associated with the synergic effects of land-use changes, habitat degradation and fragmentation, and the introduction of alien species (Cardoso et al. 2010; Triantis et al. 2010; Terzopoulou et al. 2015). In islands, coastal areas are historically, and still currently, the most impacted areas by human activities. It is known that human occupation on the Azorean islands led to the complete deforestation of these areas, used by the settlers for agriculture and urban occupation. As a consequence, it is impossible to find near pristine coastal habitats. One possible exception are the coastal saltmarsh habitats that occur in several islands, notably two of them at Terceira island, the Paul Praia da Vitória and the Paul da Pedreira do Cabo da Praia, a new and near pristine wetland that was created by rehabilitation of the quarry at Cabo da Praia (Morton et al. 1997).

The knowledge about the coastal arthropod fauna of Azores is relatively incipient. In fact, the most recent inventories on the Azorean arthropod fauna were conducted in medium to high elevation native forests (Borges et al. 2005, 2006, 2016; Ribeiro et al. 2005) or in other land-uses (Borges 1999; Cardoso et al. 2009; Meijer et al. 2011). A possible exception is the study conducted in 1991-1993 by Borges (1995) (see also Dias et al. 1991) and later repeated in 2003 (Borges & Melo 2003) that described in detail a ground-beetle community adapted to the Paul da Praia da Vitória saltmarsh.

In the current study we performed for the first time a standardized inventory of arthropods in three wet coastal areas in Praia da Vitória (Terceira, Azores). The aims of this study were: (1) to investigate the current status of the saltmarsh adapted ground-beetles studied in 1991-1993 and 2003 (Borges 1995; Borges & Melo 2003), performing a third assessment; (2) to compare de diversity of arthropods in ground and aerial habitats (herbaceous, shrubs and trees) in the three wet areas; and (3) to characterize the diversity and relative abundance of endemic, native and introduced arthropod species.

MATERIAL AND METHODS

STUDY SITES

The Azores archipelago is composed of nine islands located in North Atlantic, roughly between 37º to 40º N latitude and 25º to 31º W longitude and divided into three groups: Occidental (Corvo, Flores), Central (Faial, Pico, São Jorge, Graciosa, Terceira), and Oriental (São Miguel and Santa Maria). The climate in the Azores is temperate oceanic, with regular and abundant rainfall, with high levels of relative humidity and persistent winds, mainly during the winter and autumn seasons (Azevedo 1996).

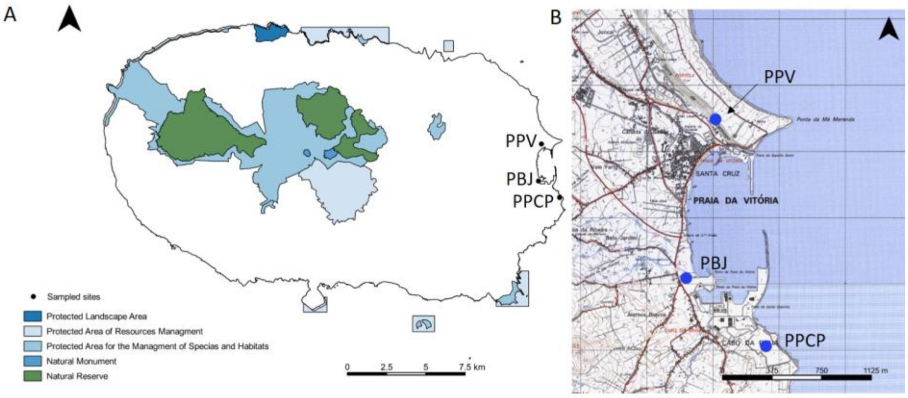

Fig. 1. General location of the three studied areas in Terceira, Azores (A) and detailed view (B). PPV – Paul da Praia da Vitória; PBJ – Paul Belo Jardim; PPCP – Paul da Pedreira do Cabo da Praia.

The current study was performed in the third largest island of the Azores (Terceira, with 400,6 km^2), with a few natural areas still remaining at lower elevations, notably in Praia da Vitória council. Three wet areas, Paul da Praia da Vitória (PPV), Paul do Belo Jardim (PBJ) and Paul da Pedreira do Cabo da Praia (PPCP) (Figs. 1 and 2) were studied in this project. These areas have common coastal vegetation, namely *Juncus acutus*, and still include some arboreal cover by the native *Morella faya*. However, the *Erica-Morella* coastal woodlands as described in Elias et al. (2016) are not present and the exotic invasive species *Arundo donax* is very common. The bryophyte diversity is low but some coastal rare species are present (Gabriel et al. 2016).

Fig. 2. General aspect of the three studied sites: a) Paul da Praia da Vitória, b) Paul do Belo Jardim and c) Paul da Pedreira do Cabo da Praia (Photos by Paulo A.V. Borges, taken in 2009 [a] and 2016 [b, c]).

Before human occupation, PPV (Fig. 2a) was a large coastal marshland, which was reduced for urban development and underwent several dynamic changes in the last 500 years. Now it is characterized by the presence of a large waterbody with islands isolated by channels after a major work performed between 2006 and 2010. Most of the herbaceous vegetation is now dominated by *J. acutus*. PBJ (Fig. 2b) was originally a large dune area, but it is currently a very small wet area, with a dune covered partially by *J. acutus*. A small stream is present and adds some diversity of vegetation. PPCP is a recently created wet area, resulting from the removal of large amounts of stones for the construction of the Praia da Vitória harbour, around 1980 (Fig. 2c). In practice, a new ecosystem was created, the quarry of Cabo da Praia (Morton et al. 1997) and this site is now a hotspot for bird sightings (Pereira & Melo 2017). Some coastal plants, rare in the archipelago, are present here, such as *Ruppia maritima*, that is disappearing in other Azorean Azorean coastal wet areas due to human disturbance (see Morton et al. 1995).

SAMPLING

In each site, arthropods were sampled during summer 2016 using a combination of standardized methods inspired by the COBRA protocol (Cardoso 2009):

-Nocturnal active aerial searching (AAS) – Four samples were obtained by four trained collectors targeting active arthropods found above knee-level by hand, forceps, pooter or brush, immediately transferring them into vials containing alcohol. All the time spent searching (one hour per researcher) was accounted for.

-Foliage Beating (FB) – During day time ten samples of each main tree or brush were sampled. A 110 cm × 80 cm sheet with a frame was used as a drop-cloth (beating tray) and a wooden pole of at least 1.5 m was used to beat tree branches, as high as possible. The plants selected were: *A. donax* and *M. faya* in PPV and PPCP, and *A. donax* and *J. acutus* in PBJ.

-Foliage sweeping (FS): – A round sweep net with an opening diameter of 46 cm was used to sweep bushes and tall herbs. All time spent sweeping or searching for dislodged arthropods was accounted for. Two samples during day time (FSD) were obtained (one hour each sample).

-Pitfall (PIT) – Pitfall traps (4.2 cm wide at the top, and approximately 7.2 cm deep) were placed immediately outside the perimeter of each lake, spaced 10 meters. Traps were filled with 3 – 4 cm of 100% propylene glycol and left in the field for seven days. Traps were protected from predation, inundation with rain water, and unwanted vertebrate capture by using plates sitting on stilts 2 cm above the ground surface. In PBJ two transects were performed with 30 traps in the main transect and 15 traps in a secondary transect covering a small stream. In PPV and PPCP a single transect of 30 traps each was setup in the margins of water bodies. In PPV half of the traps were in the margins of the largest "island".

For each site a total of four samples of AAS, 20 samples of FB, two samples of FS and 30 main samples of PIT were obtained, totaling 56 samples per site and an overall 168 samples. The additional pitfall traps in PBJ small stream added 15 more samples totalling 183 samples. The main 56 samples per site included the sampling of two main sub-habitats, the aerial vegetation with 26 samples (20 beatings during the day, two sweeps during the day and four nigh aerial searches) and the ground habitat with 30 pitfall samples.

SPECIES IDENTIFICATION

The following two steps were performed to identify arthropod species: (1) for arthropod orders for which there was taxonomic expertise, one of us (CP) performed morphospecies sorting using a parataxonomy approach *sensu* Oliver & Beattie (1993) with a reference collection, and (2) a trained taxonomist (PAVB) corrected all the splitting and lumping errors and identified the species. Taxonomic nomenclature followed Borges et al. (2010) checklist.

For species identification we targeted the following arthropod groups: Diplopoda, Chilopoda, Arachnida (excluding Acari) and Hexapoda (excluding Collembola, Lepidoptera, Diptera and Hymenoptera [but including Formicidae]) were identified to species level. All specimens were preserved in 96% ethanol and stored in the Dalberto Teixeira Pombo insect collection at the University of Azores.

DATA ANALYSES

All species were categorized into three colonization categories following Borges et al. (2010): endemic, native non-endemic and introduced. Species composition similarity was investigated using Ward´s clustering method with Euclidean distance, in which the most similar sites are those that will produce a group with the lowest variance (see Seaby & Henderson 2007). Abundances of species were log transformed prior to analyses.

Since the data did not have a normal distribution even after logarithmic transformation, a non-parametric analyses of variance (Kruskal–Wallis test by ranks) was performed in SPSS v.22 to identify potential differences between the three sites using abundance and richness as variables. For this purpose, the additional pitfall samples of PBJ small stream were not considered and the aerial (using beating, sweeping and AAS samples; n= 26) and ground communities (using pitfall samples; n= 30) were investigated separately.

Even with equivalent sampling effort and similar standardized methods in different habitats (arboreal, herbaceous, ground), differences in the target arboreal plant species in the three sites, herbaceous plant diversity and abundance (see Borges and Brown 2001) and soil structure (rock vs. sand vs. mud), may still generate differences in inventory completeness. Therefore, accumulation curves were constructed using EstimateS program v. 9.1.0 (Colwell, 2013), with 100 runs, for the observed number of species, species richness estimates, singletons, and doubletons, using the non-parametric estimators Chao1 and Jackknife 1. Sampling completeness was calculated as the ratio of observed richness to estimated richness with both estimators, due to their higher accuracy (Hortal et al. 2006). From EstimateS we also extracted the number of singletons, doubletons, uniques and duplicates.

Common indices of diversity were also calculated for the two main habitats (aerial and ground), following the Hill series: species richness (S); Shannon-Wiener (exp H´); Simpson´s index (1/D); Berger-Parker index (1/d) (Magurran 2004). A statistical test was applied to

Shannon-Wiener since this index is highly sensitive to species richness (Magurran 2004). All indices and the statistical test were calculated in Species Diversity and Richness 4.0 (Seaby & Henderson 2006).

Patterns in species relative abundances were investigated for aerial (n= 26) and ground communities (n= 30), using species abundance distributions (SAD) (Matthews & Whittaker 2015). We compared the SAD distribution (geometric, logseries, truncated lognormal and broken stick) using the R software package (R Core Team 2005), with libraries "stats4", "VGAM" and "sads", to estimate the maximum likelihood for each model, from where the AICs were calculated (Burnham & Anderson 2002).

RESULTS

OVERALL DATASET DESCRIPTION

A total of 6,103 individuals were collected in the three sampling sites belonging to 168 arthropod morphospecies (see Appendix 1). Only seven species are endemic, all of them occurring in PBJ and three in each of the other sites. Two of the species were particularly abundant, namely the spider *Emblyna acoreensis* (in the three sites) and the true bug *Nysius atlantidum* (in PPCP).

A total of 43 species were considered native non-endemic species and 90 species were categorized as exotic species. So far it was not possible to obtain an identification and colonization status for 28 species (17%), but they appear to be all exotics. Therefore, indigenous species totalled 50 species (30% of the overall species).

The most abundant species belonging to the first quartile when ranking species abundances accounted for 5,578 individuals (Appendix 1), i.e. 91% of all adult sampled specimens belong to 25% of the species (42 species). From these 42 species, three are endemic, 16 are native, 21 are exotic and one with unknown status. Seventeen species had more than 100 specimens and four of them were particularly abundant: the native harvestman *Leiobunum blackwalli* (Opiliones) with 836 individuals, the native ant *Lasius grandis* with 809 individuals, the exotic beetle *Phaleria bimaculata* with 608 individuals and the native ant *Monomorium carbonarium* with 427 individuals.

None of the three most abundant ground-beetles recorded for PPV in 1991-1993 and 2003 were found in the current samples. However, after additional sampling performed in the spring of 2017 in a small remnant of habitat near the original location, 24 specimens of *Bembidion semipunctatus* were collected in six pitfall traps.

Hymenoptera (Formicidae only), Coleoptera and Araneae, were the most abundant orders with more than 1000 individuals each and accounted for 64% of all abundance (see Appendix 1). Concerning species richness, Coleoptera, Araneae and Hemiptera were the most diverse groups having respectively 58, 45 and 25 species (see Appendix 1).

Regarding individual abundance in the three colonization categories, 50% of the sampled individuals were native, while 43% belonged to the introduced colonization status and only 5% were endemics (Appendix 1).

In terms of species composition, aerial and ground fauna exhibited clear differences, with Paul da Praia da Vitória (PPV) and Paul do Belo Jardim (PBJ) being more similar to each other than to Paul da Pedreira do Cabo da Praia (PPCP) (Fig. 3).

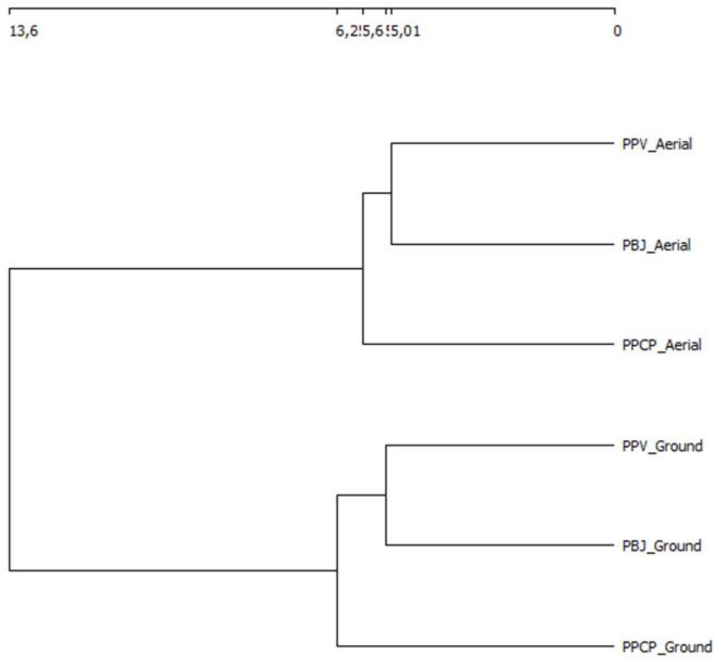

Fig. 3. A dissimilarity dendrogram for ground and aerial arthropod species in PPV – Paul da Praia da Vitória; PBJ – Paul Belo Jardim; PPCP – Paul da Pedreira do Cabo da Praia.

Diversity comparisons between sites

When comparing the mean abundance of individual aerial samples between the three sites we observed a significant difference (Kruskal–Wallis test; $p = 0.002$), a consequence of a higher mean abundance in PPCP (mean abundance = 44.60±27.50) in comparison with similar mean abundances in PPV (25.36±16.88) and PBJ (24.46±21.15). Concerning ground data, a significant difference was observed (Kruskal–Wallis test; $p < 0.001$), but in this case because of a higher mean abundance in PBJ (56.43±27.69) in comparison with PPV (27.43±21.83) and PPCP (10.13±6.57). Concerning the aerial indigenous species, we also observed a significant difference (Kruskal–Wallis test; $p = 0.002$), as a consequence of a higher mean abundance in PPCP (mean abundance = 34.24±26.38) in comparison to lower mean abundances in PPV (17.64±13.08) and PBJ (14.27±13.55). For the ground indigenous species a significant difference was observed (Kruskal–Wallis test; $p < 0.0001$), but in this case because of a higher mean abundance in PBJ (35.4+24.28) in comparison with PPV (17.41±17.04) and PPCP (2.90±2.17).

When comparing the mean number of species of individual aerial samples between the three sites we observed a marginally significant difference (Kruskal–Wallis test; $p = 0.046$), as a consequence of very similar diversity in PPCP (mean S = 10.92±4.22), PBJ (9.42±6.21) and PPV (8.64±4.68). Concerning ground data, a significant difference was observed (Kruskal–Wallis test; $p < 0.0001$), because of a higher mean species richness in PBJ (9.43±3.08) in comparison with PPV (8.30±4.15) and PPCP (3.63±1.92). The same results hold for indigenous (endemics + natives) species. The mean number of indigenous species of individual aerial samples differed among the three sites (Kruskal–Wallis test; $p = 0.006$), as a consequence of a high diversity in PPCP (mean S = 6.52±1.85), followed by PPV (5.28±2.20) and PBJ (4.61±3.03); The same applies to the ground indigenous species, with a significant difference (Kruskal–Wallis test; $p < 0.0001$), due to a high mean species richness in PBJ (3.46±1.17) and PPV (3.26±1.70) and a very low diversity in PPCP (0.63±1.03).

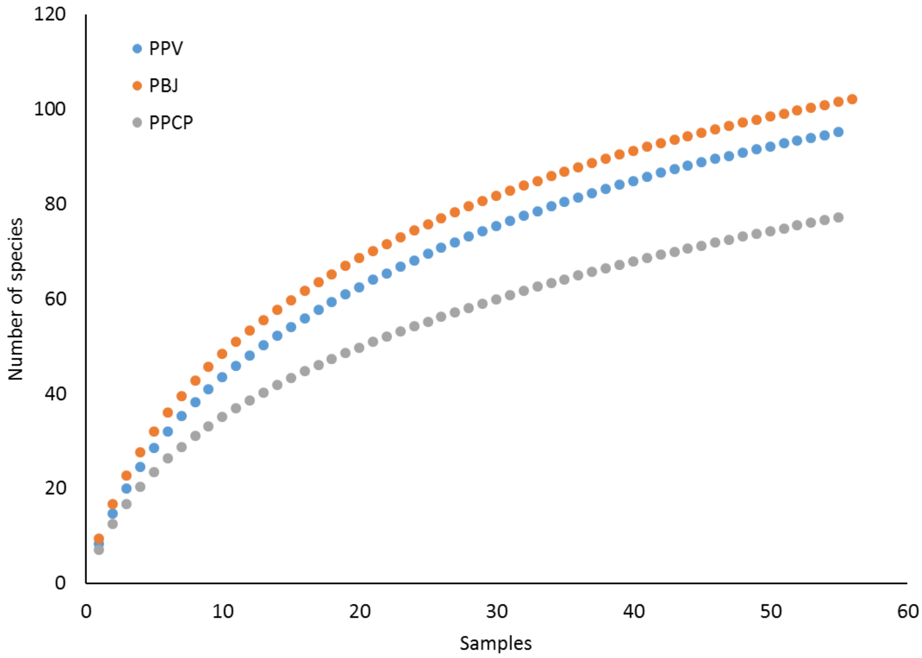

Fig. 4. Mean species accumulation curves for the three sites based on 100 randomized curves. PPV – Paul da Praia da Vitória; PBJ – Paul Belo Jardim; PPCP – Paul da Pedreira do Cabo da Praia.

As shown in Fig. 4 and Table 1, PBJ was the site with the highest observed diversity. However, based on Chao 1 estimator, PPV could have a slightly larger number of species than PBJ (Table 1). Completeness was high for all sites when considering Chao 1 estimates, but just above the adequate limit for Jackknife 1 (Table 1). In general, uniques tended to surpass singletons, which showed some level of spatial beta diversity, since many species occured in a single sample. Considering gamma diversity for the several colonization categories (Table 1), in general PBJ was the most diverse site for all categories, but PPV attained similar values at least for native non-endemic species. PPCP hosted the highest abundance of endemics but with few species.

The Hill diversity metrics showed clear differences between sites and habitats (Table 2).

Table 1. Diversity metrics for the three sites, PPV – Paul da Praia da Vitória; PBJ – Paul Belo Jardim; PPCP – Paul da Pedreira do Cabo da Praia. N - number of individuals; S - number of species.

	PPV	PBJ	PPCP
Global			
N	1457	2329	1419
S	95	102	77
Chao 1	115.3	112.49	96.24
Jackknife1	125.44	134.41	106.45
Completness Chao1	0.82	0.91	0.80
Completness Jackknife1	0.76	0.76	0.72
Singletons	26	27	22
Doubletons	15	12	11
Uniques	31	33	30
Duplicates	22	13	13
Endemics			
N	64	71	153
S	3	7	3
Natives			
N	882	1362	735
S	29	29	22
Indigenous			
N	946	1433	888
S	32	36	25
Introduced			
N	492	850	499
S	54	57	42
Status Unknown			
N	19	46	32
S	10	10	10

Aerial samples tended to be more diverse and with less dominance, whereas within ground PPV is more diverse and within aerial PBJ is more diverse (Table 2).

Table 2. Hill diversity metrics for the three sites (PPV – Paul da Praia da Vitória; PBJ – Paul Belo Jardim; PPCP – Paul da Pedreira do Cabo da Praia). S – Number of species; H´ - Shannon-Wiener index; D – Simpson index; d –Berger-Parker index. H´ values with a different letter are significantly different from each other (post hoc tests; P < 0.05).

	PPV	PBJ	PPCP
Ground			
S	47	50	26
H´	2.57a	2.2b	1.93c
exp H´	13.07	9.03	6.89
D	6.8	4.23	4
1/D	0.15	0.24	0.25
d	0.33	0.46	0.39
1/d	3.03	2.17	2.56
AERIAL			
S	57	73	59
H´	2.94a	3.58b	2.78a
exp H´	18.92	35.87	16.12
D	9.44	25.34	8.63
1/D	0.11	0.04	0.12
d	0.28	0.09	0.25
1/d	3.57	11.11	4.00

SPECIES ABUNDANCE DISTRIBUTIONS

All samples have a large number of rare species (see Fig. 5). We fit the species abundance distributions with the truncated lognormal, the logseries, the geometric and the broken stick distributions and calculate the corresponding AIC_c values. Adopting the criterion of Burnham & Anderson (2002) that a difference between (AIC_c - AIC_{cmin}) < 2 reveals substantial differences among models, the lognormal and the logseries gave the best fit to the distributions (Tables 3 and 4).

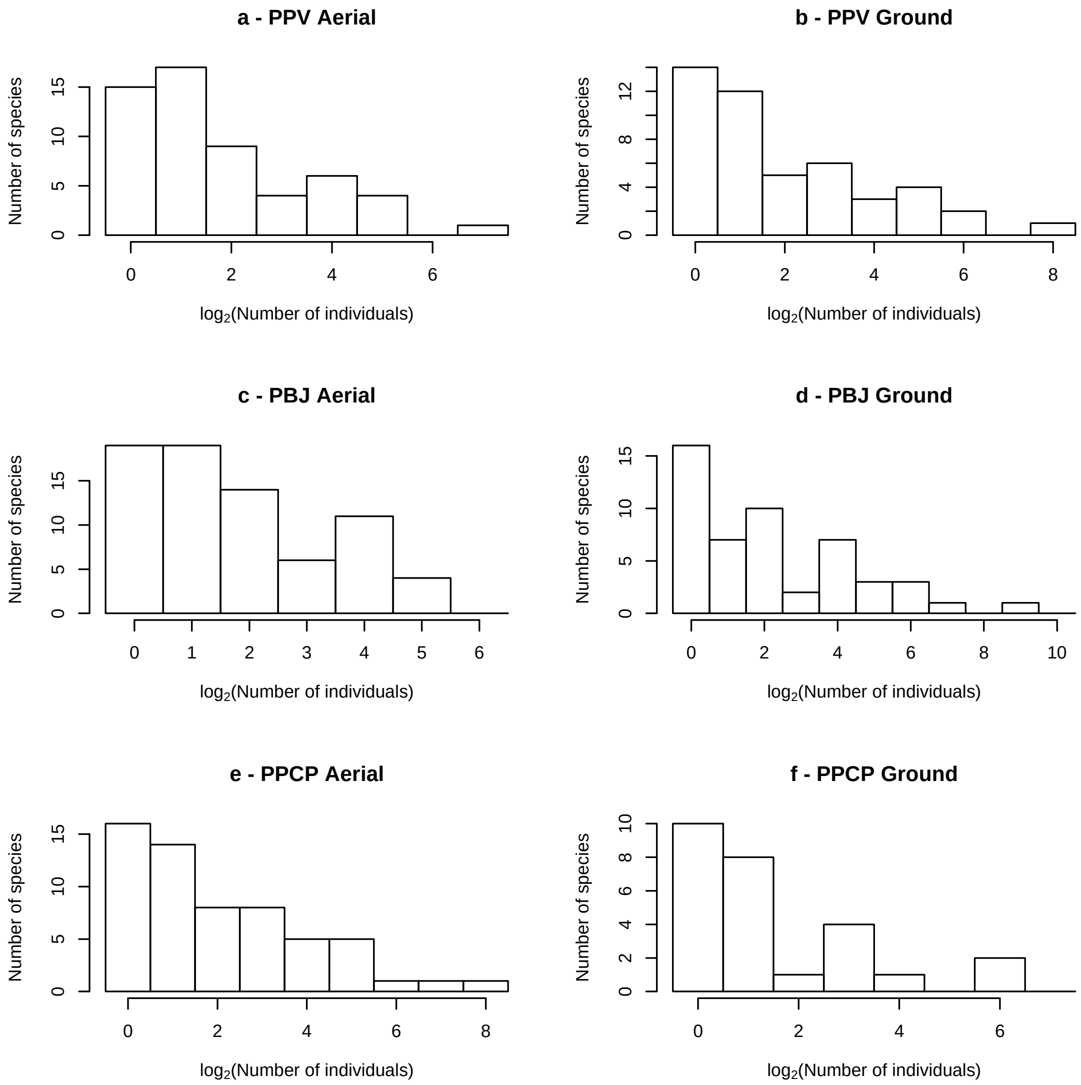

Fig. 5. The species abundance distributions for the three sites for the aerial and ground arthropod species. The x-axis corresponds to classes of the logarithm of the number of individuals as follows: 1 individual, 2 to 3 individuals, 4 to 7 individuals, *et seq.* PPV – Paul da Praia da Vitória; PBJ – Paul do Belo Jardim; PPCP – Paul da Pedreira do Cabo da Praia.

Table 3. AIC_c values for the six species abundance distributions assuming four different distributions.

	Trunc. lognormal	Logseries	Geometric	Broken stick
PPV_Aerial	337.63	336.19	390.67	391.41
PPV_Ground	305.33	303.44	367.83	372.19
PBJ_Aerial	431.18	425.67	472.18	467.26
PBJ_Ground	355.46	356.73	455.77	467.07
PPCP_Aerial	391.19	391.49	469.95	473.94
PPCP_Ground	147.82	147.61	184.19	187.46

Table 4. ΔAIC_c (= $AIC_c - AIC_{cmin}$) values for the six species abundance distributions assuming four different distributions. In bold are the values that have ΔAIC_c <2.

	Trunc. lognormal	Logseries	Geometric	Broken stick
PPV_Aerial	**1.44**	**0.00**	54.48	55.21
PPV_Ground	**1.89**	**0.00**	64.39	68.75
PBJ_Aerial	5.51	**0.00**	46.52	41.60
PBJ_Ground	**0.00**	**1.27**	100.31	111.61
PPCP_Aerial	**0.00**	**0.30**	78.76	82.75
PPCP_Ground	**0.21**	**0.00**	36.59	39.85

DISCUSSION

After conducting an intensive standardized sampling program we were able to record only seven out of the 132 endemic arthropod species and subspecies existing in Terceira Island, including five widespread species: two spiders (*Pardosa acorensis* and *Emblyna acoreensis*) (see Borges & Wunderlich 2008), one click beetle (*Heteroderes azoricus*), a Lygaeidae true bug (*Nysius atlantidum*) and the neuropteran *Hemerobius azoricus*. However, two very rare species were also found, the true weevil *Drouetius oceanicus oceanicus* (see Machado 2009) and the Azorean cone-head grasshopper (*Conocephalus chavesi*) (Fig. 6). The species *C. chavesi* was recently evaluated by IUCN as Endangered (see Hochkirch & Borges 2016) due to its restricted geographic range, a severely fragmented population, small number of subpopulations and continuing decline in the area of occupancy, number of subpopulations, extent and quality of the habitat as well as in the number of mature individuals. However, the species can be found in relatively high densities at least in Paul Belo Jardim, occurring in all the three wet areas. Concerning the weevil *D. o. oceanicus*, this is also a very are species (Machado 2009) that was recently assessed by IUCN as Endangered (see Borges & Lamelas-Lopez 2017), due to the small area of occupancy, the decline in area of occupancy, the decreasing extent and quality of

Fig. 6. The Azorean cone-head grasshopper (*Conocephalus chavesi*) in Paul Belo Jardim (Photo: Paulo A.V. Borges, 2016).

habitat as well as the number of mature individuals as a result of the invasions of non-native plants, urbanization and pollution. The finding of few individuals in Paul Belo Jardim implies that this site should be target to habitat restoration.

It was not possible to find a great part of the community of ground-beetles recorded for PPV by Lindroth (1960), Borges (1995) and Borges & Melo (2003). This result was probably the consequence of two processes: (1) for the ground-beetle species *Bembidion ambiguum* and *Licinus punctatulus* recorded by Lindroth (1060) the major land-use changes in the last century in Terceira island (Cardoso et al. 2009; Triantis et al. 2010) may have promoted species extinctions (Cardoso et al. 2010; Terzopoulou et al. 2015); (2) for the ground-beetle species *Bembidion semipunctatus*, *Omasseus aterrimus nigerrimus* and *Agonum marginatum* recorded by Borges (1995) and Borges & Melo (2003) the change in the original structure of the margins of Paul da Praia da Vitória salty lake (Fig. 7a), due to an intervention between 2006 and 2010 that created several lakes and islands, steep margins and a dominance of *J. acutus* (Fig. 7b), may have promoted local species rarity. However, despite the absence in the summer 2016 main samples of the three hygrophilous ground-beetle species *B. semipunctatus*, *O. aterrimus nigerrimus* and *A. marginatum*, which were dominant in PPV in 1991-1993 and 2003 (Borges 1995; Borges & Melo 2003), after some additional sampling already in the spring of 2017 in a small remnant of the original habitat, it was possible to capture *B. semipunctatus.* The major changes that occurred in this site (Fig. 7b) may have limited the current distribution of all ground-beetle species. In addition to the changes regarding margins, the whole structure of the water dynamics, as well as soil and vegetation characteristics, changed, with impacts on the biological cycle of these spring-breeding beetles that were adapted to specific conditions (Fig. 7a; see also Borges 1995). However, the recent finding of *B. semipunctatus* in a very restricted

Fig. 7. Paul Praia da Vitória (PPV) with a) the biotope adequate for salty adapted ground-beetles (Insecta, Carabidae) (Photo: Paulo A.V. Borges, 2004) and b) the current situation after the major interventions in the area between 2006 and 2010 with the site now inundated and with *Juncus acutus* (Photo: Paulo A.V. Borges, 2017).

area of PPV will imply the creation of a strategy for the restoration of its habitat.

Not surprisingly, about 70% of the arthropod species found in this study are exotics, which is in tune with the overall figures for the Azores arthropod list (Borges et al. 2010), but contrasts with the dominance of indigenous species in the native forests (Borges et al. 2008, 2011). Interestingly, three of the top four most abundant species are considered native to the Azores (Borges et al. 2010). However, the colonization status of three of the four most abundant species can be challenged since: (1) the sandy beach darkling beetle *Phaleria bimaculata*, which is currently considered exotic, might be a native species well adapted to the beaches of the Azores; (2) the native colonization status of the two ants was indicated by Wetterer et al. (2004), but this can be a wrong assessment at least for *Monomorium carbonarium*, which is very rare in native habitats.

The logseries fitted the SADs in all sites with a dominance of rare species. However, species of intermediate abundance were relatively more abundant at PBJ for both ground and aerial samples, and in PPCP for aerial samples. This pattern can be explained as follows: (1) the young age of PPCP and its rocky substrate may lead to a lower abundance of the target epigean arthropods, but we also observed a high density of amphipods that may outcompete the remaining species, with a strong impact in indigenous species; (2) the high abundance of the target epigean arthropods in PBJ is a consequence of the presence of a community well adapted to sandy soils; (3) the high abundance of aerial arthropods in PPCP is a consequence of the high cover of *M. faya* and other vegetation in comparison to the two other sites. The presence of *M. faya* in PPCP favours the permanence of a high density of arboreal indigenous arthropod species.

CONCLUSIONS

In general, the three sites seem to work as a complementary network of wet areas with specific features and arthropod communities. However, we have also observed that Paul do Belo Jardim (PBJ) in spite of not having a clear arboreal tree cover (absence of *M. faya*) performed better for many of the investigated indicators than the two other sites. Likely explanations for this result are: (1) the small patch with sandy wet characteristics still remaining in PBJ keeps some of the conditions necessary to sustain some rare ground epigean species; (2) the PBJ small stream adds a unique habitat that works as a high productive habitat to sustain a large number of species; (3) PPCP is a recent habitat with rocky substrate not adequate for many species; (4) PPV underwent major changes in the whole habitat in the last twenty years.

The coastal wet areas of Praia da Vitória underwent major changes in the last 600 years of human occupation and now very few original arthropod communities remain. Historical descriptions of the biota in these areas (Lindroth 1960; Borges 1995) clearly show that human additional interference in the last 50 years promoted further dramatic changes in these habitats, with the local extinction of species and ground-beetle communities. The presence of subpopulations of the IUCN rare species *Drouetius oceanicus oceanicus* and *Conocephalus chavesi* in PBJ, with relatively high densities of at least the grasshopper *C. chavesi*, call for urgent management measures for this small patch of wet dune biotope.

The future impact of climatic changes will have a strong impact on the distribution of Azorean arthropods (Ferreira et al. 2016). These coastal areas will be surely highly impacted and urgent measures should be implemented for the correct management of these three sites with, if possible, the restoration of Pául da Praia da Vitória biotope.

ACKNOWLEDGEMENTS

We acknowledge the inspiration given by Elisabete Nogueira and her hard work in leading the LIFE CWR – Ecological Restoration and Conservation of Praia da Vitória. We also thank Luís C. Crespo (University of Barcelona) for the identification of several species of spiders. Many thanks also to Simone Fattorini and Virgílio Vieira for their suggestions during the review process, that greatly improved the manuscript. This study was financed by the project LIFE CWR – Ecological Restoration and Conservation of Praia da Vitória Coastal Wet Green Infrastructure (2013-2018). SADs were analyzed within the framework of project FCT project MOMENTOS (PTDC/BIA-BIC/5558/2014). The trip of PAVB to University of Barcelona for the identification of spiders was financed by the project FCT-UID/BIA/00329/CE3C-GBA.

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Received 09 Jul 2017. Accepted 18 Jul 2017. Published online 29 Aug 2017.

Appendix 1. List of species and morphospecies of arthropods identified for Paul da Praia Vitória (PPV), Paul do Belo Jardim (PBJ) and Paul da Pedreira PPCP). The colonization status are the following: E: endemic from Azores; N- native non-endemic; I- introduced species.

Coloniz.	Order	MF	Species	PPV	PBJ	PPCP	Grand Total
E	Araneae	17	*Pardosa acorensis* Simon		5		5
E	Araneae	539	*Emblyna acoreensis* Wunderlich	61	31	48	140
E	Coleoptera	540	*Heteroderes azoricus* (Tarnier)	1	2	1	4
E	Coleoptera	1284	*Drouetius oceanicus oceanicus* Machado		3		3
E	Hemiptera	496	*Nysius atlantidum* Horváth		2	104	106
E	Neuroptera	200	*Hemerobius azoricus* Tjeder		1		1
E	Orthoptera	612	*Conocephalus chavesi* (Bolivar)	2	27		29
N	Araneae	198	*Macaroeris cata* (Blackwall)	1			1
N	Araneae	516	*Clubiona decora* Blackwall	38	23	16	77
N	Araneae	793	*Macaroeris diligens* (Blackwall)	41	16	57	114
N	Araneae	1283	*Argiope bruennichi* (Scopoli)	3	31	2	36
N	Coleoptera	68	*Sepedophilus lusitanicus* (Hammond)		1		1
N	Coleoptera	69	*Stilbus testaceus* (Panzer)	23	61	53	137
N	Coleoptera	88	*Ocypus olens* (Müller)		1		1
N	Coleoptera	262	*Rugilus orbiculatus orbiculatus* (Paykull)		0	1	1
N	Coleoptera	541	*Hirticollis quadriguttatus* (Rossi)		9		9
N	Coleoptera	646	*Scymnus interruptus* (Goeze) + *Scymnus nubilus* Mulsant	1	8	5	14
N	Coleoptera	734	*Chrysolina bankii* (Fabricius)	4			4

Coloniz.	Order	MF		Species	PPV	PBJ	PPCP	Grand Total
N	Coleoptera		771	*Astenus lyonessius* (Joy)		1		1
N	Coleoptera		791	*Aspidapion radiolus chalybeipenne* (Wollaston)	1	4	2	7
N	Coleoptera		822	*Kalcapion semivittatum semivittatum* (Gyllenhal)			3	3
N	Dermaptera		1238	*Labidura riparia* (Pallas)		30	3	33
N	Hemiptera		101	*Geotomus punctulatus* (Costa)	6	1		7
N	Hemiptera		118	*Scolopostethus decoratus* (Hahn)	6	7		13
N	Hemiptera		167	*Kleidocerys ericae* (Horváth)			2	2
N	Hemiptera		230	*Nabis pseudoferus ibericus* Remane			1	1
N	Hemiptera		254	*Megamelodes quadrimaculatus* (Signoret)	2			2
N	Hemiptera		321	*Kelisia ribauti* Wagner			1	1
N	Hemiptera		476	*Monalocoris filicis* (Linnaeus)	1			1
N	Hemiptera		537	*Cinara juniperi* (De Geer)	1			1
N	Hemiptera		645	*Orius laevigatus laevigatus* (Fieber)	1	7		8
N	Hemiptera		774	*Emblethis denticollis* Horváth		1		1
N	Hemiptera		926	*Anoscopus albifrons* (Linnaeus)	3			3
N	Hemiptera		1058	*Pilophorus confusus* (Kirschbaum)	25		6	31
N	Hemiptera		1137	*Trigonotylus caelestialium* (Kirkaldy)	6	28	22	56
N	Hemiptera		1266	*Pyrrhocoris apterus* (Linnaeus)		7	1	8
N	Hymenoptera	F2		*Hypoponera eduardi* (Forel)	21	4		25
N	Hymenoptera	F20		*Lasius grandis* Forel	448	71	290	809
N	Hymenoptera	F4		*Monomorium carbonarium* (F. Smith)	61	168	198	427
N	Hymenoptera	F7		*Temnothorax unifasciatus* (Latreille)	3			3

Coloniz.	Order	MF	Species	PPV	PBJ	PPCP	Grand Total
N	Hymenoptera	F8	*Tetramorium caespitum* (Linnaeus)	99	33	16	148
N	Lithobiomorpha	27	*Lithobius pilicornis pilicornis* Newport		3		3
N	Opiliones	6	*Leiobunum blackwalli* Meade	49	787		836
N	Opiliones	33	*Homalenotus coriaceus* (Simon)	8	132		140
N	Orthoptera	1051	*Phaneroptera nana* Fieber	13	10		23
N	Psocoptera	191	*Valenzuela flavidus* (Stephens)	5	35	24	64
N	Psocoptera	218	*Ectopsocus strauchi* Enderlein	3	1	28	32
N	Psocoptera	478	*Trichopsocus clarus* (Banks)	3		2	5
N	Thysanoptera	13	*Hoplothrips corticis* (De Geer)		7		7
I	Araneae	21	*Tenuiphantes tenuis* (Blackwall)	34	28		62
I	Araneae	24	*Mermessus fradeorum* (Berland)	2			2
I	Araneae	28	*Dysdera crocata* C.L. Koch	2	29	5	36
I	Araneae	122	*Clubiona terrestris* Westring	1			1
I	Araneae	127	*Steatoda grossa* (C.L. Koch)	2	3		5
I	Araneae	133	*Metellina merianae* (Scopoli)		5		5
I	Araneae	140	*Ero furcata* (Villers)	1	4		5
I	Araneae	233	*Oedothorax fuscus* (Blackwall)	70	108	94	272
I	Araneae	234	*Erigone autumnalis* Emerton	3	6		9
I	Araneae	235	*Pelecopsis parallela* (Wider)		1		1
I	Araneae	246	*Erigone dentipalpis* (Wider)		4	3	7
I	Araneae	249	*Mermessus bryantae* (Ivie & Barrows)		1		1
I	Araneae	250	*Xysticus nubilus* Simon	3	48	4	55

Coloniz.	Order	MF	Species	PPV	PBJ	PPCP	Grand Total
I	Araneae	331	*Arctosa perita* (Latreille)	1	58	1	60
I	Araneae	333	*Ostearius melanopygius* (O.P.-Cambridge)		4	3	7
I	Araneae	488	*Cryptachaea blattea* (Urquhart)	5			5
I	Araneae	489	*Tegenaria domestica* (Clerck)	2	1		3
I	Araneae	618	*Nigma puella* (Simon)	2		41	43
I	Araneae	653	*Oecobius navus* Blackwall		1		1
I	Araneae	761	*Pachygnatha degeeri* Sundevall	3	5		8
I	Araneae	789	*Entelecara schmitzi* Kulczynski		8		8
I	Araneae	804	*Salticus mutabilis* Lucas	2	4	10	16
I	Araneae	871	*Synageles venator* (Lucas)	3	3	14	20
I	Araneae	998	*Zelotes aeneus* (Simon)	11	4		15
I	Araneae	999	*Trachyzelotes lyonneti* (Audouin, 1826)			1	1
I	Araneae	1047	*Heliophanus kochii* Simon			2	2
I	Araneae	1057	*Zygiella x-notata* (Clerck)		2	1	3
I	Araneae	1075	*Parasteatoda tepidariorum* (C.L. Koch)			1	1
I	Araneae	1100	*Zelotes tenuis* (L. Koch)		2		2
I	Araneae	1131	*Theridion melanostictum* O.P.-Cambridge	1	7	1	9
I	Araneae	1142	*Zoropsis spinimana* (Dufour)	1			1
I	Araneae	1185	*Rhomphaea* sp. (*rostrata* ?)	6			6
I	Araneae	1207	*Tetragnatha extensa* (Linnaeus)	19	2		21
I	Araneae	1285	*Cheiracanthium mildei* L. Koch	24	3	1	28
I	Araneae	1286	*Theridion hannoniae* Denis			1	1

Coloniz.	Order	MF	Species	PPV	PBJ	PPCP	Grand Total
I	Araneae	N05	*Agyneta* sp.		1		1
I	Araneae	N06	Gen. sp.	4	18	3	25
I	Araneae	N11	Gen. sp.	2			2
I	Coleoptera	16	*Atheta fungi* (Gravenhorst)		5	3	8
I	Coleoptera	40	*Cercyon haemorrhoidalis* (Fabricius)			3	3
I	Coleoptera	45	*Anisodactylus binotatus* (Fabricius)	2	9		11
I	Coleoptera	52	*Cordalia obscura* (Gravenhorst)	7	17		24
I	Coleoptera	65	*Sericoderus lateralis* (Gyllenhal)	6	5		11
I	Coleoptera	72	*Ptenidium pusillum* (Gyllenhal)		4	1	5
I	Coleoptera	108	*Cryptamorpha desjardinsii* (Guérin-Méneville)	8	4	4	16
I	Coleoptera	113	*Typhaea stercorea* (Linnaeus)		1		1
I	Coleoptera	145	*Cryptophagus* sp.	10	3		13
I	Coleoptera	173	Gen. sp.1	10			10
I	Coleoptera	247	*Aleochara bipustulata* (Linnaeus)		1		1
I	Coleoptera	264	*Anotylus nitidifrons* (Wollaston)	42	2		44
I	Coleoptera	265	*Xantholinus longiventris* Heer		1		1
I	Coleoptera	292	*Aeolus melliculus moreleti* Tarnier	3			3
I	Coleoptera	523	*Sphenophorus abbreviatus* (Fabricius)		1		1
I	Coleoptera	549	*Trixagus* sp.		1		1
I	Coleoptera	673	*Gymnetron pascuorum* (Gyllenhal)	1	2	2	5
I	Coleoptera	691	*Otiorhynchus cribricollis* Gyllenhal (N30)	3	2	20	25
I	Coleoptera	705	Gen. sp.1	2			2

Coloniz.	Order	MF		Species	PPV	PBJ	PPCP	Grand Total
I	Coleoptera		733	*Cartodere bifasciata* Reitter		1		1
I	Coleoptera		769	*Heteroderes vagus* Candèze	11	129	5	145
I	Coleoptera		773	Gen. sp.	1	2		3
I	Coleoptera		777	Gen. sp.			8	8
I	Coleoptera		802	*Rodolia cardinalis* (Mulsant)			2	2
I	Coleoptera		833	*Epitrix hirtipennis* Melsham		2		2
I	Coleoptera		1000	*Naupactus leucoloma* Boheman	21	30	52	103
I	Coleoptera		1048	*Calymmaderus solidus* (Kiesenwetter)		1		1
I	Coleoptera		1056	*Cryptophagus* sp.			11	11
I	Coleoptera		1198	*Lixus pulverulentus* (Scopoli)	1			1
I	Coleoptera		1282	*Phaleria bimaculata* (Linnaeus)		608		608
I	Coleoptera		1287	*Enochrus bicolor* (Fabricius)	4		1	5
I	Dermaptera		56	*Forficula auricularia* Linnaeus	1	1	5	7
I	Dermaptera		352	*Euborellia annulipes* (Lucas)	50	29	120	199
I	Hemiptera		320	*Rhopalosiphum rufiabdominalis* (Sasaki)	2			2
I	Hemiptera		326	*Buchananiella continua* (White)			1	1
I	Hemiptera		537	*Empicoris rubromaculatus* (Blackburn)	2	3	1	6
I	Hemiptera		738	*Nezara viridula* (Linnaeus)	2	2	5	9
I	Hemiptera		781	*Taylorilygus apicalis* (Fieber)	45	41	15	101
I	Hemiptera		1197	*Oxycarenus lavaterae* (Fabricius)			1	1
I	Hymenoptera	F6		*Tetramorium* sp.		6		6
I	Julida		9	*Ommatoiulus moreletii* (Lucas)	18	198	14	230

Coloniz.	Order	MF	Species	PPV	PBJ	PPCP	Grand Total
I	Julida	53	*Proteroiulus fuscus* (Am Stein)	1			1
I	Julida	544	*Cylindroiulus latestriatus* (Curtis)	2			2
I	Orthoptera	123	*Gryllus bimaculatus* (De Geer)			3	3
I	Orthoptera	245	*Eumodicogryllus bordigalensis* (Latreille)	4	144	12	160
I	Polydesmida	37	*Polydesmus coriaceus* Porat	18			18
I	Polydesmida	71	*Oxidus gracilis* (C.L.Koch)	1			1
I	Pseudoscorpiones	103	*Chthonius tetrachelatus* (Preyssler)		1		1
I	Psocoptera	121	*Ectopsocus briggsi* McLachlan	9	3	13	25
I	Scutigeromorpha	336	*Scutigera coleoptrata* (Linnaeus)	1	4	9	14
I	Thysanoptera	276	*Heliothrips haemorrhoidalis* (Bouché)			2	2
Unknown	Araneae	N07	*Gibbaranea* sp.	9	10	10	29
Unknown	Coleoptera	N03	Gen. sp.		1		1
Unknown	Coleoptera	N08	Gen. sp.		1		1
Unknown	Coleoptera	N13	Gen. sp.		17		17
Unknown	Coleoptera	N17	Gen. sp.		9		9
Unknown	Coleoptera	N20	Gen. sp.		1		1
Unknown	Coleoptera	N21	Gen. sp.		1		1
Unknown	Coleoptera	N43	Gen. sp.		1		1
Unknown	Coleoptera	N47	Gen. sp.			1	1
Unknown	Coleoptera	N50	Gen. sp.			9	9
Unknown	Coleoptera	N52	Gen. sp.			1	1
Unknown	Coleoptera	N55	Gen. sp.	1			1

Coloniz.	Order	MF	Species	PPV	PBJ	PPCP	Grand Total
Unknown	Coleoptera	N57	Gen. sp.	1			1
Unknown	Coleoptera	N58	Gen. sp.	1			1
Unknown	Coleoptera	N59	Gen. sp.	1			1
Unknown	Coleoptera	N60	Gen. sp.	2			2
Unknown	Hemiptera	N04	Gen. sp.	1	2	1	4
Unknown	Hemiptera	N10	Gen. sp.	1			1
Unknown	Hemiptera	N32	Gen. sp.			2	2
Unknown	Hemiptera	N39	Gen. sp.			4	4
Unknown	Odonata	N29	Gen. sp.		1		1
Unknown	Orthoptera	N16	Gen. sp.	1	2		3
Unknown	Orthoptera	N18	Gen. sp.			1	1
Unknown	Orthoptera	N24	Gen. sp.		6		6
Unknown	Orthoptera	N27	Gen. sp.		2		2
Unknown	Orthoptera	N38	Gen. sp.			2	2
Unknown	Pseudoscorpiones	N62	Gen. sp.	1			1
Unknown	Psocoptera	N51	Gen. sp.			1	1