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SHORT COMMUNICATION

MASS DISPERSAL OF TERRESTRIAL ORGANISMS DURING FIRST FLUSH EVENTS IN A TEMPORARY STREAM

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ABSTRACT

Temporary streams expand and contract seasonally, forming a complex mosaic of aquatic, amphibic and terrestrial habitats. We studied the terrestrial arthropod fauna at the surface of the dry river bed as well as the fauna of Coarse Particulate Organic Matter (CPOM) deposits 0, 5 and 10 days after first flush events (years 2004–2006) along the Pardiela stream (SE Portugal). During the dry period, large amounts of organic material accumulated at the surface of the dry bed, colonized by abundant terrestrial arthropods (mean density: 13.3 ± 15.29 Ind g DM (Dry Mass of CPOM)). Arthropod density peaked in fresh flood deposits (mean density: 35.8 ± 33.4 Ind g DM), and subsequently decreased within time. Concurrently, the relative composition of the arthropod community changed from Day 0 to Day 10. The present results demonstrated that the dry bed of temporary streams served as a major habitat for terrestrial arthropods. During the first flush events, a mass dispersal of terrestrial arthropods, rafting on floating CPOM, occurred, subsequently forming distinct deposits along the channel margin. These deposits may constitute critical habitats, refugia and food resources for local and regional terrestrial arthropod assemblages.

KEY WORDS: first flush event; floating organic matter; temporary stream; terrestrial arthropods

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INTRODUCTION

Temporary rivers occur on every continent, and they are likely more common than perennial rivers globally. At the same time, they are predicted to increase in the spatial extent and in the duration of the dry period due to water abstraction, climate change and land-use alteration (Larned *et al*., 2010). In recent times, many perennial rivers have become temporary including large rivers such as the Rio Grande (USA) and the Yellow river (China) (Ellis *et al*., 2001; Fu *et al*., 2004; Makar *et al*., 2006).

Temporary rivers expand, contract and fragment seasonally, thereby forming a shifting mosaic of aquatic, amphibic and terrestrial habitat types. Temporary rivers have primarily been considered as aquatic (lotic) ecosystems (but see Steward *et al*., 2012; Datry *et al*., 2014), and their dry river beds have been described as biologically inactive habitats, which favoured their exploitation for direct human use. Only most recently, the ecological and economic values of dry river beds have been recognized (Steward *et al*., 2012).

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Dry river beds accumulate large amounts of Coarse Particulate Organic Matter (CPOM), nutrients and contaminants (e.g. Tzoraki *et al*., 2007; Obermann *et al*., 2009; Von Schiller *et al*., 2011), and they are colonized by abundant and diverse terrestrial arthropod assemblages (Steward *et al*., 2011, 2012). During the onset of flow, a mass transfer of material and dispersal of terrestrial organisms to downstream sections may occur (Jacobson *et al*., 2000; Corti and Datry, 2012). Rafting or drifting of terrestrial organisms on floating CPOM may be an effective, long-distance dispersal pathway that increases the likelihood of biota arriving in a suitable habitat (Robson *et al*., 2008). Therefore, it may be a fundamental mechanism for maintaining species and genetic diversity along temporary river corridors (Steward *et al*., 2012).

Flood-deposited clumps of intertwined plant material ('litter hovels') created by flood events accumulate arthropod species from the entire river network (Mason & Macdonald, 1982). Thereby, they may serve as an integrator, and indicator, of the riparian biodiversity of the entire river corridors. At the same time, flood deposits may create a unique, persistent habitat type as well as a shelter and a food resource for local terrestrial arthropod communities (Loeser *et al*., 2006).

In the present study, we sampled CPOM accumulations from the surface of a dry river bed at the end of the summer period during three consecutive years. In addition, we collected fresh deposits of floating CPOM that became entangled at vegetation along the edge of the channel during receding first flush events. Deposits were sampled immediately after flood recession, and 5 and 10 days afterwards (Figure 1).

The main questions were (i) how important are CPOM accumulations at the surface of the dry river bed and flood-related deposits as habitat for terrestrial arthropod assemblages and (ii) how do the density, biomass and composition of the arthropod assemblages change in flood deposits with time. Finally, we discussed the role of rafting on floating organic matter as a highly efficient dispersal mode along (temporary) rivers.

METHODS

Study area

The study was conducted in a third-order section of the Pardiela stream located in southern Portugal (38°38′N, 07°42′W; total catchment area: 514 km^2). Pardiela is a temporary stream that dries at the surface during summer [Figures 1(a) and 2]. Rainfall typically occurs from late autumn to early spring, thereby creating flash floods [detailed description: tempQsim-Consortium, 2006; Lillebø *et al*., 2007; Figures 1(b) and 2].

The riparian zone was characterized by sclerophyllous vegetation intersected with bare areas. *Tamarix africana* Poiret was very common along and within temporary river beds [Figure 1(c and d)] as it can sustain extended dry periods and high discharge events (Biléu, 2008).

Sampling of CPOM deposits

At the end of the dry season, OM deposits and their associated terrestrial arthropods were randomly sampled at the surface of the dry river bed along a 250 m section. OM deposits were sampled within 25 × 25 cm large frames (eight samples each year, 2004–2006). Samples were placed into plastic bags and processed in the laboratory.

At the time of the first flush event, CPOM deposits were sampled immediately after flood recession, and 5 and 10 days afterwards. CPOM accumulations and associated terrestrial arthropods were sampled within frames (25 × 25 cm) and quickly transferred into plastic bags. Samples of drift deposits were collected along the margin of the river channel and around salt cedar stands that retained CPOM [Figure 1(c and d)]. Ten samples per date and year (from 2004 to 2006) were sampled at random positions along the reach. In the laboratory, samples were processed within 24 h of collection. All terrestrial organisms were counted using a dissecting microscope. Arthropods were stored in 96% alcohol and identified to order or family level. CPOM was dried at 40 °C in an oven until constant weight and expressed as g DW (Dry Weight). Arthropod density and biomass were expressed as individuals and dry mass per g DM of CPOM to allow standardization (Ind g DM or g g DM).

Figure 1. Pardiela stream (SE Portugal): dry bed conditions in summer (a), first flush event (b) and coarse particulate organic matter deposits after flood recession (c, d)

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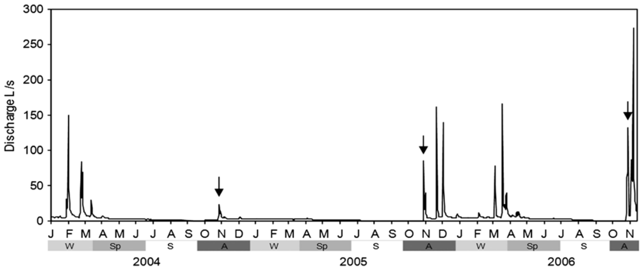

Figure 2. Hydrograph of the Pardiela stream (2004–2006). Arrows indicate the three sampling periods (each before, during and after first flush events). W, winter; Sp, spring; S summer; A, autumn. Data: SNIRH (2007)

Data analysis

Descriptive statistics were calculated for each sampling dates and year. Differences between years and dates were tested with the non-parametric Kruskal–Wallis Test, as data failed to meet the assumptions of normal distribution. Post-hoc Pairwise Comparisons were computed to identify in each group (i.e. dates and years) differences that occur. The Spearman's rho (ρ) was computed to analyse the relationship between the amount of OM deposits and the biomass and density of arthropods. Outliers were removed before applying statistics tests. All statistical analyses were performed in PASW® Statistics 18 (formely SPSS Statistics).

RESULTS

At the end of the dry period, on average 5.71 ± 5.14 g DM of CPOM (sampling area: 625 cm^2) accumulated at the surface of the dry river bed (corresponding to 91 g DM/m^2 river bed). The mean density of arthropods colonizing CPOM accumulations was 13.3 ± 15.3 Ind g DM (maximum: 55 Ind g DM), corresponding to an arthropod biomass of 0.05 ± 0.09 g/g DM CPOM (maximum: 0.43 g/g DM CPOM). Arthropod density and biomass were the lowest in 2004 (Figure 3). Coleoptera (44.8–78.5% of total density, mainly Staphylinidae and Carabidae) and Arachnida (21.5–27.6%, mainly Lycosidae) dominated the arthropod assemblage. Psocoptera (<10.3%), Collembola (<6.9%) and Hymenoptera (<7.1%, mainly ants) were also common taxa of the dry streambed assemblages (cf. Figure 4).

The CPOM deposited during the first flush events along the margins of the streambed mainly constituted of small branches (95.91 ± 6.26% DM). In addition, leaves (1.71 ± 0.98% DM), cork (1.32 ± 5.74% DM), roots (0.78 ± 1.31% DM) and animal excrements (0.28 ± 0.30% DM) were found. Deposits sampled immediately after the recession of the first flush event (Day 0) contained on average 35.8 ± 33.4 Ind g DM (maximum: 156 Ind g DM), corresponding to an arthropod biomass of 0.74 ± 1.30 g/g DM CPOM (maximum: 6.76 g/g DM CPOM). The density and biomass of arthropods peaked in 2006 (Figure 3).

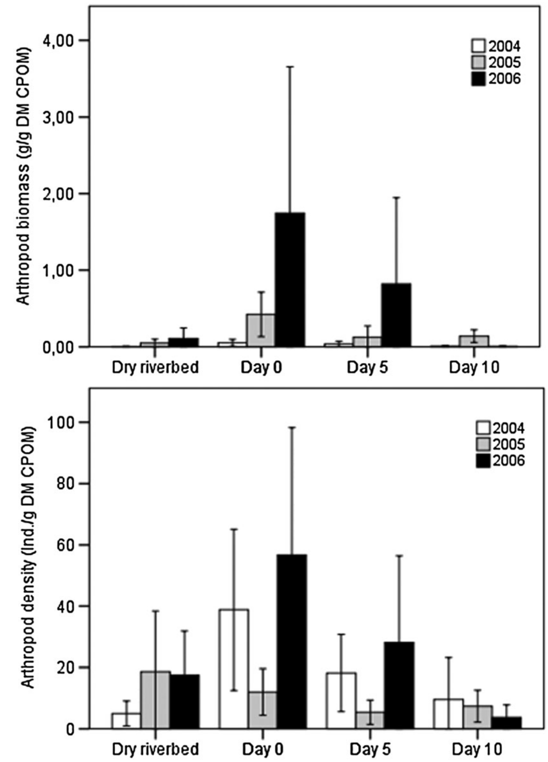

Figure 3. Mean arthropod biomass [g DM Coarse Particulate Organic Matter (CPOM); upper panel] and mean density (Ind g DM CPOM; lower panel) (Mean ± SD; $n = 24$ for 'Dry river bed'; $n = 30$ each for sampling date Day 0, Day 5 and Day 10)

At Day 0, the relative composition of the arthropod assemblage was similar (at high taxonomic level) to the dry riverbed assemblage (Figure 4), albeit the density was always significantly higher in fresh flood. Coleoptera (54.6–87.0% of total density, mainly Staphylinidae and Carabidae) and Arachnida (9.4–26.6%, mainly Lycosidae) were predominant. Hymenoptera (<12.5%, mainly ants) and Hemiptera (<8.0%) were common taxa too (Figure 4).

The density and biomass of arthropods decreased in the flood deposits until Day 10 (Figure 3). At Day 5, deposits contained on average 17.2 ± 19.8 Ind g DM (maximum: 97 Ind g DM), corresponding to an arthropod biomass of 0.33 ± 0.73 g/g DM CPOM (maximum: 3.68 g). At Day 10, deposits contained on average 6.9 ± 8.8 Ind gDM (maximum: 46 Ind g DM), corresponding to an arthropod biomass of 0.05 ± 0.08 g/g DM CPOM (maximum: 0.32 g/g DM CPOM). The relative composition of arthropod assemblage in the OM deposits decreased with time. At Days 5 and 10, Coleoptera (16.7–80.4% of total density), Arachnida (8.9–59.4%), Hemiptera (<22%), Hymenoptera (<16.67%), Collembola (<16.67%) and Chilopoda (<11.11%) dominated the arthropod assemblages (Figure 4).

Results of the Kruskal–Wallis tests showed that total arthropod density was significantly different among sampling dates ($H(3) = 29.094$, $p = 0.000$, $n = 113$) but not among

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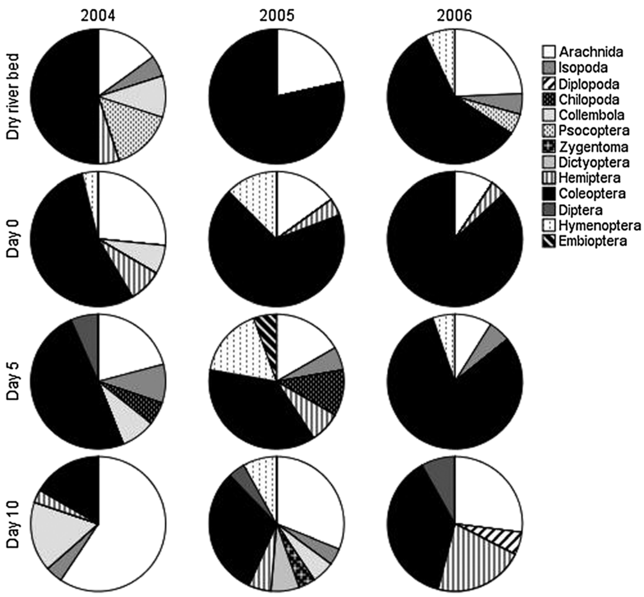

Figure 4. Relative composition (%) of the arthropod assemblages (pooled data for each date and year, 2005–2006; total $n = 114$)

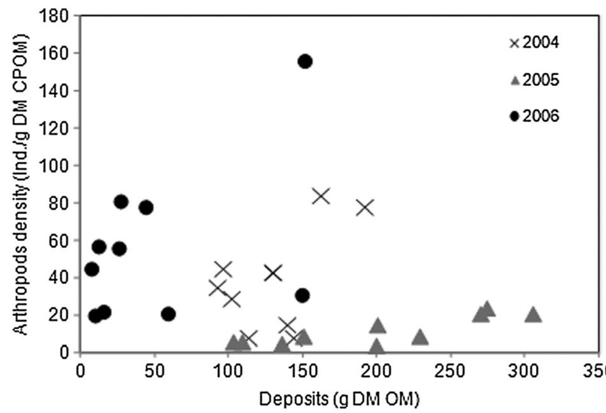

Figure 5. Organic matter deposits (g DM OM) and arthropods density [Ind g DM Coarse Particulate Organic Matter (CPOM)] immediately after flood recession (Day 0, 2005–2006; $n = 30$)

years ($H(2) = 5.661$, $p = 0.059$, $n = 113$). Post-hoc Pairwise Comparisons showed that arthropod density was significantly lower at (i) the surface of the dry river bed compared to Day 0 ($t = -30.893$, $p = 0.004$), (ii) Day 10 compared to Day 5 ($t = 24.233$, $p = 0.025$) and (iii) Day 10 compared to Day 0 ($t = 44.797$, $p = 0.000$).

The total biomass of arthropods was significantly different among sampling dates (days) ($H(3) = 32.792$, $p = 0.000$, $n = 113$) and years ($H(2) = 23.687$, $p = 0.000$, $n = 113$). Post-hoc Pairwise Comparisons showed that biomass was significantly lower at (i) the surface of the dry river bed compared to Day 0 ($t = -40.311$, $p = 0.000$), (ii) in 2004 compared to 2005 ($t = -30.908$, $p = 0.000$) and to 2006 ($t = -32.553$, $p = 0.000$). Biomass was also significantly higher at Day 0 compared to Day 10 ($t = 43.124$, $p = 0.000$).

Overall, Spearman's correlations exhibited no significant relation between the amount of CPOM deposits, expressed as DM, and arthropod density ($\rho = -0.334$, $p = 0.076$, $n = 29$). Likewise, Spearman correlations exhibited no significant relation between the amount of CPOM deposits (expressed as DM) and arthropod biomass ($\rho = -0.152$, $p = 0.431$, $n = 29$) after the first flush events (Day 0). However, there was a positive albeit weak correlation between the amount of CPOM deposits (expressed as DM) and arthropod density in 2005 ($\rho = 0.789$, $p = 0.007$, $n = 10$) (Figure 5).

DISCUSSION

The present study underpins the ecological value of dry river beds. They provide habitat, shelter and resources for diverse terrestrial arthropod assemblages including ants (Formicidae), beetles (Coleoptera) and spiders (Arachnida) (see also Wishart, 2000; Larned *et al.*, 2007, Steward *et al.*, 2011, 2012). Furthermore, an abundant terrestrial predator assemblage along the fringing edge of remaining pools and at recently dried-up bed surfaces benefits from emerging and stranded aquatic invertebrates as high-quality food resource (Hering and Plachter, 1997; Batzer, 2004; Paetzold and Tockner, 2005; Paetzold *et al.*, 2008).

The seasonal and spatial dynamic of CPOM controls ecosystem processes and biodiversity along corridors of temporary streams. CPOM serves as a habitat, dispersal vector during floods, food resource and shelter. Floating OM, for example, is considered an efficient mode to escape and survive floods. Corti and Datry (2012) demonstrated that terrestrial invertebrate density increases longitudinally in an advancing wetted front, and a substantial proportion of the species survived the downstream transport. Flooding acts as a 'reset' mechanism (Crawford, 1991; Gasith and Resh, 1999) that leads to the dislodgement of CPOM and dry river bed arthropod assemblages, and to their subsequent downstream mass transfer, mostly by rafting on floating organic matter (e.g. Corti and Datry, 2012).

With the receding water level, the floating organic material accumulates along the river margin thereby providing refugia for organisms that try to escape the flood as well as providing resources for other species (Wenninger and Fagan, 2000; Bonn *et al.*, 2002). Braccia and Batzer (2001), for example, found that floating woody debris serves as a 'hotspot' for both aquatic and terrestrial invertebrates. Loeser *et al.* (2006) documented the use of elevated litter hovels by spiders as refugia during floods as well as key resources when waters receded. Thereby, OM deposited along river shores and accumulated at vegetation stands could be of major importance to arthropods, whether they are transported downstream by floods or they belong to local communities.

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A few days after the water level started to decline, seedlings germinate within the deposits (pers. observation). Stromberg *et al*. (1991), for example, demonstrated that floods create habitat for seedlings of many riparian plant species. Similarly, Pettit *et al*. (2006) demonstrated the importance of wood debris piles for tree seedling establishment. Therefore, OM deposits not only promote seed germination but also increase the subsequent persistence of the riparian vegetation. Although the composition of the arthropod assemblages is very similar at the surface of the dry river bed and in fresh flood deposits, their density is significantly higher in fresh flood deposits. This is most likely the consequence of the combined dislodgement of arthropods from the upstream dry river bed as well as through an additional input from lateral banks and from tributaries. Floods were responsible not only for the downstream transport of large amounts of organic matter (e.g. branches, leaves) but also for an increased input of arthropods into water, most of them of terrestrial origin (Mason & Macdonald, 1982). Consequently, it will affect the distribution of riparian arthropods such as spiders and ground beetles along the entire river corridors (Bonn *et al*., 2002). By providing an important habitat and refuge, CPOM deposits may increase the opportunity of arthropods to survive flood-related disturbances and to colonize new habitats further downstream. Differences in the density and composition of arthropods after flood recession might be due to the colonization of the deposits through local communities, stimulated by the high availability of prey and food resources. Because habitat selection plays a key function in the survival and reproductive success of animals (Stearns, 1977), CPOM deposits may offer very suitable microhabitats to arthropods, which again mitigates the adverse physical conditions in dry areas (e.g. water and thermal stress, Wise, 1993). Furthermore, Riechert and Gillespie (1986) observed that litter structure and complexity can influence species assemblages. Likewise, Loeser *et al.* (2006) observed that 'litter hovels', OM deposits attached to bushes and trees at different heights, provide shelter during floods, thereby acting as a key recolonization source for spiders after the water level recedes.

The surface-active arthropods, denominated by Crawford (1991) as 'temporary dwellers', typically consisting of beetles, spiders and ants, play an essential ecological role in controlling nutrient and organic matter cycling, shaping food webs and providing prey for many vertebrates (e.g. Kim, 1993; Williams, 1993). Although arthropods dominate terrestrial ecosystems, both in richness and density (Erwin, 1982; Gaston, 1991; Kremen *et al*., 1993), they are often overlooked in monitoring and conservation practices. This is particularly true for dry river beds where terrestrial arthropods are exposed to hydrologic extremes such as the first flush events. Understanding how hydrologic extremes may affect biota is critical to develop management strategies for temporary streams (e.g. Lundberg and Moberg, 2003).

Our results highlight the importance of hydrological events in the transport of organic matter and biota. Human interference in riparian ecosystems through clear-cutting and channelization, among other activities, modifies the natural flow regime and thereby riparian and instream biodiversity. OM deposits and pioneer vegetation can influence the composition and diversity of arthropod assemblages as well as the input of terrestrial invertebrates into streams during floods. In the present study, arthropod biomass and density in CPOM deposits exhibited major inter-annual variability. Although there was no distinct correlation with the first flush intensity, the short-term dynamic of arthropod assemblages remained consistent within each year, independent of the hydrology of the specific year. We expect that the composition and density of the dry river bed arthropod assemblages are a consequence of both local and regional environmental conditions (i.e. hydrology, vegetation dynamics, upland topography and soil properties). As a consequence, dry river beds contain a unique combination of aquatic, amphibious and terrestrial assemblages throughout their wet and dry phases (e.g. Steward *et al*., 2012); and dry river beds may serve as important dispersal and migration corridors for terrestrial organisms, either through downstream rafting during the first flush events or by long-distance migration during the dry phase. Thus, management practices that interfere with riparian corridors alter the food resources in streams, change the diversity and composition of riparian communities and modify key ecological processes. Indeed, this is an important topic for future research activities.

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