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The impacts of current velocity increases on the drift of *Simulium monticola* (Diptera: Simuliidae): a laboratory approach

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Abstract

Current velocity and the associated physical forces are among the most important factors shaping lotic benthic communities. The current increase in the frequency and intensity of flow alterations, especially related to hydroelectric use or irrigation, represent a key element of riverine environment deterioration. Numerous studies have investigated the effect of current velocity increases on the macrobenthic fauna, underlining that, in most cases, these increases lead to enhancement in the drift, i.e. the abandonment of the substrate by macroinvertebrates. The purpose of this study is to examine the drift propensity of *Simulium monticola* (Diptera: Simuliidae) under different water velocities. Simuliidae are one of the most characteristic components of fast flowing environments in rivers. Experiments were conducted in an artificial stream in the laboratories of Politecnico di Torino, analysing the drift of organisms at different current velocities. Velocity increases significantly contributes to explain the observed variability of drift: interestingly, we evidenced an inverse relationship between velocity and drift propensity, with low amounts of drifting organisms at higher velocities. This tendency was absolutely not related with size of Simuliidae larvae: comparing size of drifting organisms with velocity no significant correlations were detected. We hypothesize that the tendency to enter the drift was due to behavioural reasons, and related to the preference for high water velocities. Our findings support the hypothesis that increases in water velocity can cause complex changes in the drift of the macrobenthic community, increasing the propensity for some species to leave the substrate and decreasing it for some other.

Introduction

One of the most intriguing and debated topic in stream ecology is the study of the relationship between distribution of lotic organisms and characteristics of their environment (Allan & Castillo 2007). In particular, stream invertebrates are generally thought to be distributed according to environmental factors that operate at different spatial scales, from regional to local and microhabitat systems (Heino et al. 2003). At large scale, studies investigating the distribution of macroinvertebrates among and within rivers underline the importance of elements such as water chemistry (Collier et al. 1998), temperature (Vannote & Sweeney 1980) and land use (Eyre et al. 2005). At small, microhabitat scale the distribution of invertebrates is mainly shaped by biotic factors, such as competition and predation (Fairchild & Holomuzki 2005), and abiotic factors, such as coarse particulate organic matter availability (Murphy & Giller 2000; Fenoglio et al. 2005), substratum characteristics (Minshall 1984; Bond & Downes 2000) and water velocity (Lancaster 1999). In particular, current velocity and the associated physical forces are among the most important factors affecting organisms presence in lotic environments (Allan & Castillo 2007): this factor influences macroinvertebrate distribution both indirectly (controlling substratum size and food resources availability) and directly (as physical force). Many studies underlined that increases in current velocity, for example in occasion of river discharge enhancements, led to severe population losses and changes in community structure and composition (Statzner & Higler 1986; Holomuzki & Biggs 2000). In particular, it is well known that increases in velocity are frequently associated with increases in drift density (Brittain & Eikeland 1988; Mackay 1992). Reid and Thoms (2008) reported that near-bed water velocity is clearly the most important hydraulic variable influencing both assemblage composition and taxa richness of benthic coenoses while, in contrast, velocities in the transverse and vertical directions appear to have minimal influence on invertebrate distributions.

Simuliidae, also denominated blackflies, are a Diptera family with world-wide distribution, that comprises species with blood-eating and disease-vector adult females (Crosskey 1990). Blackfly larvae are the dominant suspension filter feeders in most running water environments: they are passive filterers, that rely on current to capture most of their food (Chance & Craig 1986). For this reason, blackfly larvae inhabit fast flowing currents, that assure high amount of transported material. At large scale, some studies evidenced that the occurrence of Simuliidae can vary among ecoregions and seasons, according to different parameters such as temperature and percentage dissolved oxygen (McCreadie & Adler 1998), chlorophyll concentration in the water and in the seston (Morin & Peters 1988), and river order (Malmqvist et al. 1999). At a smaller scale, it is well known that the main environmental factor controlling Simuliidae larvae distribution is water current velocity (Phillips 1957; Malmqvist 1994). In an interesting study about Simuliidae larvae behaviour, Kiel (2001) reported that positioning and looping (i.e.: little adjustments or position changes, based on the creation of new silk pads) were affected by current velocity and underlined that drift could be an important mechanism of re-colonisation or repositioning for these organisms.

Aim of this study was to analyse the propensity of Simuliidae larvae to enter the drift in different hydrological conditions, i.e. at different water velocities. We hypothesized that these rheophilic organisms may show an evident diminution of drift propensity at high water velocities, on the contrary to what happens for most invertebrate taxa; we also tested if the relationship between drift propensity and water velocity was related to organism dimension.

Materials and methods

Simuliidae larvae were collected in the upper Po river, in a third order reach near Sanfront (Italy, Cuneo district, UTM: X 367154, Y 4946144). General characteristics of the site are reported in Fenoglio et al. (2007). Larvae were collected with a hand net (250 um mesh), sorted in the field, stored in refrigerated containers and immediately brought to the laboratory. In the experiments, we utilized *Simulium monticola* (Friederichs 1920), an orophilous species with European distribution, that inhabits streams and small rivers between 200 and 700 m a.s.l. (Rivosecchi 1978).

The experiments were performed in a flume at the Giorgio Bidone Hydraulics, DIATI, Politecnico di Torino. The structure of the flume is made of stainless steel with plexiglas walls and bottom, and it is 11.8 m long with a width of 0.44 m (Fig. 1). Water is pumped in an inlet tank at the upstream end of the flume, flows through the channel, and then falls in a V-notched weir which allows to measure the flow rate. A sluice gate at the downstream end of the channel allowed the regulation of water velocity and depth. The mean velocity was calculated as the ratio between the measured flow rate and the channel flow area. A rectangular slab of stone was placed in the central part of the channel and it was used as substratum for the Simuliidae. The stone was 44 cm wide in order to fit the channel width, and its thickness and length were 3 and 60 cm, respectively. A layer of coarse gravel particles was placed at the upstream end of the stone slab to avoid flow detachment at the stone edge and to ensure the development of a rough-wall boundary layer, thus better reproducing the flow conditions of a gravel bed stream. Finally, a metallic wire net (mesh = 250 μm) was placed at the downstream end of the flume so that the nappe was forced to pass through it before entering the weir and the drifting larvae could be collected and counted.

We performed a total of seven experiments, each time following the same experimental protocol which included an initialization phase followed by a sequence of steps of velocity variations. Thus, each experiment was conceived to assess the response of drift to different hydrodynamic conditions, and the adoption of a constant protocol among the different experiments allowed us to test the repeatability of the measured drift propensities. During the initialization of each experiment, the pump was switched on and a known number of Simuliidae were placed on the stone using laboratory volumetric plastic pipettes. During this first phase, lasting approximately 40-45 minutes, initial velocity was kept constant, to allow the settling of the larvae. In this first phase, a number of larvae were transported through the channel and collected in the downstream net. These individuals were discarded and were not included in the analysis. After all the larvae were placed on the stone, the initial number of larvae (N_0) at the beginning of the experiment was recorded. The experimental protocol was composed of a varying number of steps that are summarized in Table 1. During each step, the mean flow velocity was increased approximately 0.1-0.2 m/s (by varying the sluice gate opening and/or the flow rate) and was then kept constant for approximately 20-30 min. This duration was much longer than the time required for the establishment of steady flow in the flume, so the flow properties could be considered almost constant for the whole step duration. After this time elapsed, the net was replaced and the number of drifted larvae (ΔN) was recorded together with the corresponding flow mean velocity (U) and step duration (Δt). The experiment then continued with the following steps, and it ended when the mean velocity reached the value of approximately 1.1-1.2 m/s. At the end of the experiment the pump was switched off and the larvae still attached on the stone and flume bottom were collected and counted. The relationship between the number of drifting Simuliidae and flow characteristics can be better investigated by choosing proper quantities to quantify the drift. We thus evaluated the drift propensity, which represents the probability per unit time of a larva to enter the drift, as

$$k = \frac{\Delta N}{N \, \Delta t} \qquad (1)$$

where *ΔN* is the number of drifted larvae during a velocity step of duration *Δt*, and *N* is the number of larvae attached to the stone at the beginning of the step. The drift propensity *k* is a measure of the tendency of the larvae to detach from the substratum and enter the drift, and its inverse *1/k* represents the average time between two successive entries in the drift.

All collected larvae were stored in 75% ethanol. A sub-sample (n = 150 individuals) was later measured in the laboratory with an ocular micrometer mounted on a Nikon SMZ1500 stereomicroscope (to an accuracy of 0.01 mm): the following two measures were taken from each individual: a) head capsule width, b) total length.

In the experiments, we used water that had been stored for more than a month in the tanks of the laboratory. The absence of organic matter is not a factor that may have appreciably influenced behavioural drift: given the short time elapsed in each experiment, we are confident that concentration and availability of food are not so important factors in our study, also because it is known that locomotory activity and drift of Simuliidae are largely independent of food concentration (Ciborowski & Craig 1989).

Results

In each experiment a varying number of larvae left the stone substratum and entered the drift, resulting in a progressive decrease of the number of Simuliidae individuals on the substratum. All the experiments exhibit a clear decreasing trend, with a steep initial decrease followed by milder variations. We detected a significant correlation between drift propensity (k) and current velocity (Pearson correlation test, r = -0.44, $p < 0.05$ Fig. 2). In order to verify the possible influence of the larval density on drift propensity, we also analyzed the relation between k_0 and the initial number of individuals N_0. Since no correlation was found ($R^2 < 0.1$), we conclude that variations in drift propensity between the experiments were not significantly related to differences in density of Simuliidae individuals on the substratum. The effect of flow velocity on drift propensity was also investigated by means of an analysis of the single experiments, and Table 2 reports calculated values of Pearson correlation coefficient $\rho_{k,U}$ between drift propensity and mean velocity for the seven experiments. Values range between -0.3 and -0.7, indicating a significant inverse relationship between drift propensity and velocity. Analyzing the relationships among the two morphometric parameters measured, we detected a significant correlation between total length and head capsule width (Pearson correlation test = 0.83, p < 0.001, Fig. 3). For this reason, in the subsequent analysis, we only employed total length as a concise indicator parameter of growth. Comparing size of drifting Simuliidae with water velocity in different occasions no significant correlation were detected (Pearson correlation test = -0.112, p = n.s. – Fig. 4).

Discussion

Many studies evidenced that increases in current velocity can lead to decreases in densities and composition of macroinvertebrate communities (Perry & Perry 1986) reporting increases in drift during periods of elevate discharge and water velocity

(Borchardt 1993; Tockner & Waringer 1997; Gibbins et al. 2010a; Gibbins et al. 2010b). Moreover, Poff and Ward (1991) performed field experiments to investigate responses of benthic invertebrates drift to flow manipulation, and realised that drift density generally augmented following flow increases for most taxa. Simuliidae seems to present a different picture. Living as filter feeders in flowing waters, they prefer elevate current velocities that provide ample supply of food, and are able to colonize fast flowing environments by using attaching silk pads and by orienting their body parallel to the current, so that this streamlined posture reduces drag coefficients. This preference for high current velocity was confirmed in our laboratory experiments: in our study, we observed that the relative number of Simuliidae larvae entering the drift decreased as a result of velocity increases, with lowest values recorded at highest velocities. We can hypothesize that drift could be a strategy for *S. monticola* to avoid unfavourable local conditions linked to low current velocity: it is likely that the preference of filterers, such as Simuliidae, for high velocity conditions can be related to both higher feeding efficiency and reduced predation pressures in high flow velocity situations (Hart & Merz 1998). Interestingly, we also noticed no significant correlation between size of drifting larvae and flow velocity: this finding underlines the biological nature of drift, that is not a simple, passive mechanical removal but a complex phenomenon influenced by behavioural and physiological constraints. Changes in flow conditions can have complex and different effects in the drift patterns of the macrobenthic community: at faster flows most taxa show greater propensity to enter the drift while other, for example Simuliidae, minimize their drift propensity. Recent studies underlined the importance to improve our knowledge about hydraulic requirements of stream macrobenthos, especially because of the growing anthropicinduced alterations of river regimes (Dolédec et al. 2007). In this context, current velocity is almost certainly one of the most important environmental variables shaping composition and abundance of benthic communities (Nelson & Lieberman 2002), and therefore the biological effects of anthropic alterations of flow should be carefully considered.

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Captions to Figures

Figure 1: Indoor artificial stream scheme utilised in the study (more explanations in the text).

Figure 2: Relationship between drift propensity and mean flow velocity.

Figure 3: Relationship between total length and head capsule width of *Simulium monticola* larvae. Black line represents linear regression.

Figure 4: Relationship between total length of larvae and mean flow velocity.

Captions to Tables

Table 1: Summary of the characteristics of the experiments.

Table 2: Results of the analysis of drift propensity data for the seven experiments (k_0: average drift propensity, $\rho_{k,U}$: correlation coefficient between drift propensity and velocity).

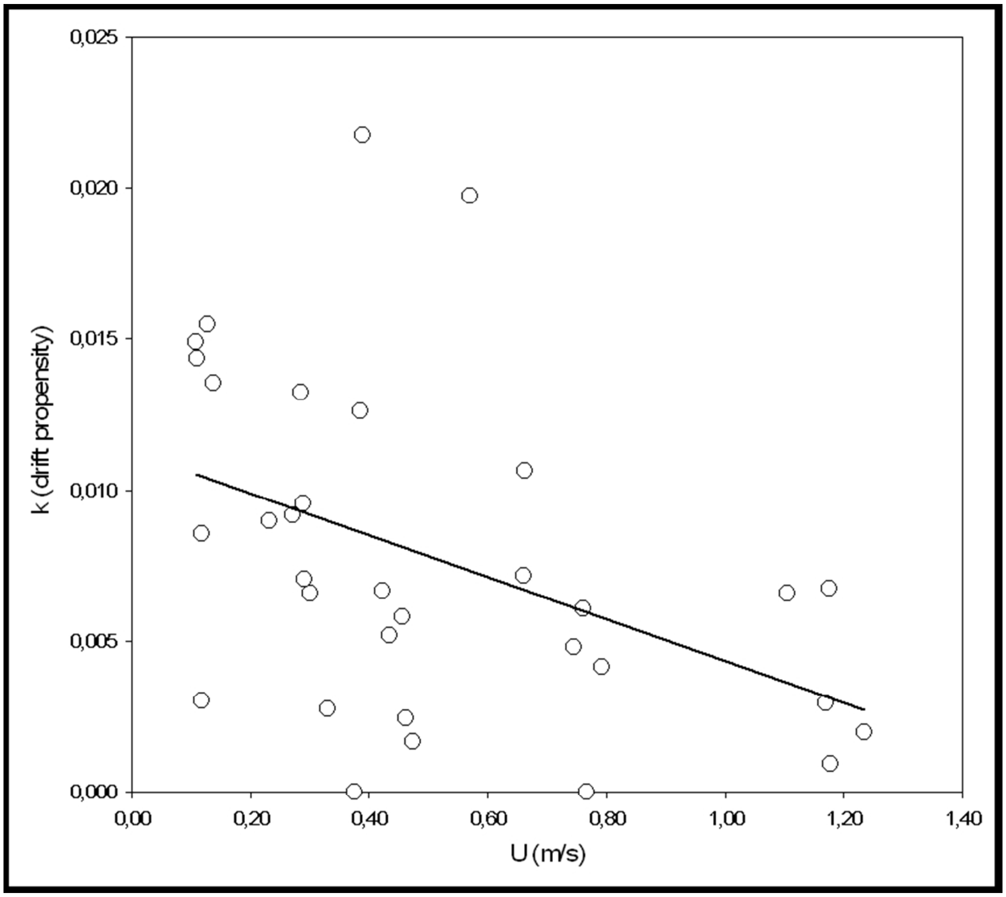
Experiment	Total number of larvae *N0*	Mean velocity *U* (m/s)
1	45	0.14 – 0.23 – 0.33 – 0.38 – 0.47 – 0.77
2	103	0.12 – 0.30 – 0.46 – 0.75 – 1.18
3	51	0.29 – 0.43 – 0.79 – 1.23
4	122	0.11 – 0.29 – 0.46 – 0.76 – 1.11
5	425	0.13 – 0.28 – 0.42 – 0.66
6	1000	0.12 – 0.27 – 0.39 – 0.66 – 1.18
7	204	0.11 – 0.39 – 0.57 – 0.89 – 1.17

Table 1

Experiment	k_0 (h^{-1})	$\rho_{k,U}$ (-)
1	0.24	-0.7
2	0.20	-0.4
3	0.28	-0.7
4	0.58	-0.6
5	0.78	-0.7
6	0.72	-0.3
7	1.50	-0.3

Table 2

15x4mm (300 x 300 DPI)



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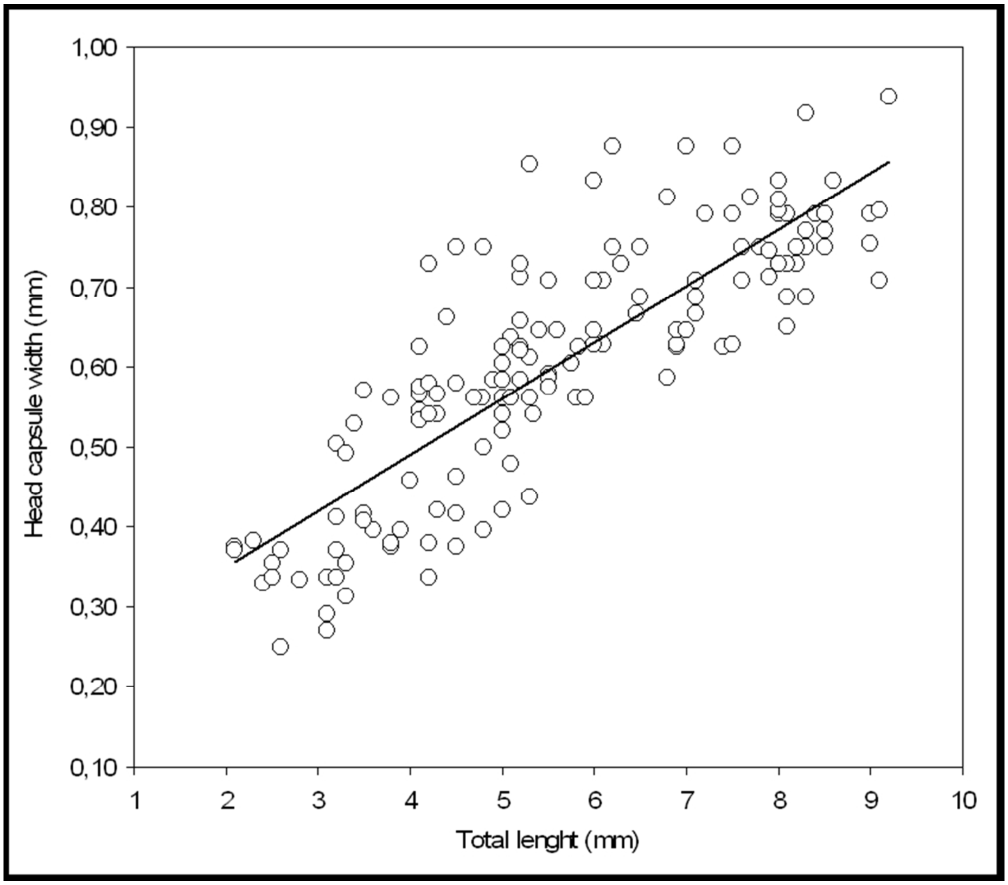

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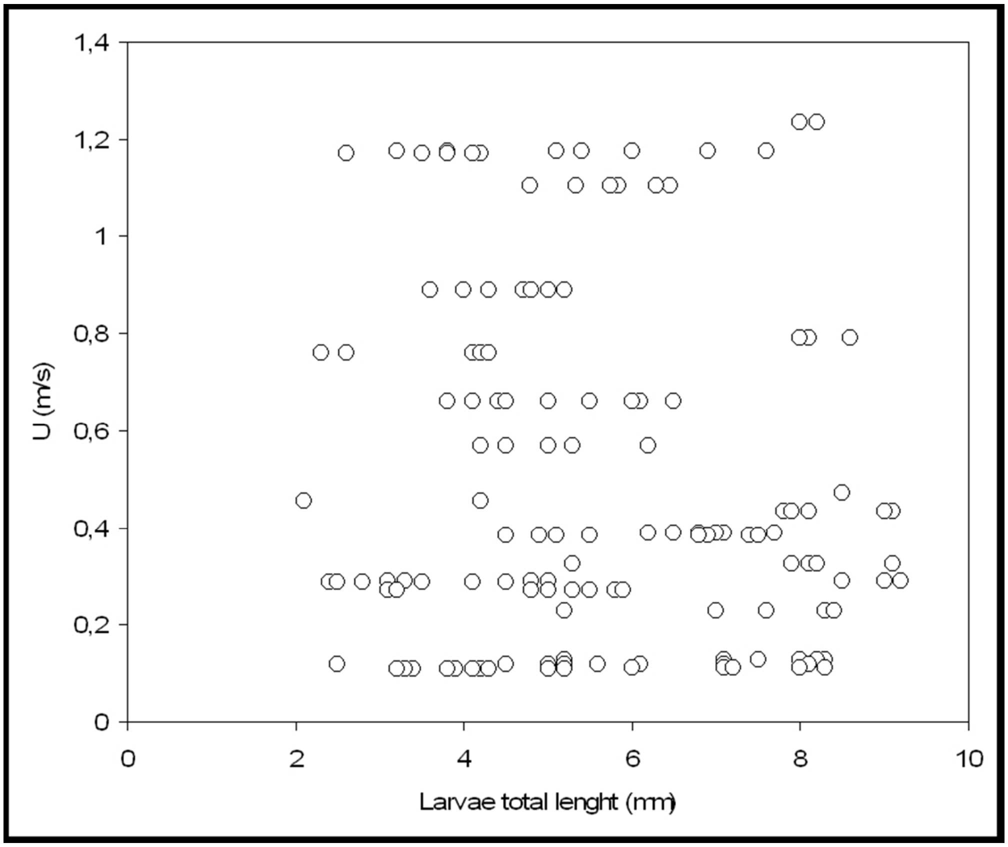

230x193mm (96 x 96 DPI)