The suitability of Hester–Dendy macroinvertebrate samplers in fluctuating flows

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INTRODUCTION

Degradation of aquatic environments due to human overexploitation and pollution of rivers and streams have created a need for reliable methods to assess the ecological status of lotic ecosystems. This need has resulted in the development of many bioassessment programs, protocols, and methods (Birk et al., 2012). Bioassessments of a waterbody’s ecological status often includes the use of biotic indicators (Moog et al., 2018), such as fish, periphyton, and benthic macroinvertebrates (Barbour et al., 1999), and they are essential for the identification of major threats to riverine ecosystems and the evaluation of efficient restoration and conservation measures (Moog et al., 2018). The limited migration of many benthic macroinvertebrates makes them suitable indicators of local conditions. Most benthic macroinvertebrates have short lifespans and complex lifecycles, with varying tolerances to disturbances and can thus provide information about cumulative effects of anthropogenic stressors (Barbour et al., 1999), for example, for detecting organic pollutions and negative effects of hydro-morphological modifications at the microhabitat scale. In addition, benthic macroinvertebrates are relatively easy and cost-effective to sample, and are, therefore, the most widely used biotic indicator group in bioassessments of aquatic ecosystems (Barbour et al., 1999; Birk et al., 2012; Moog et al., 2018).

The artificial substrate, multi-plate Hester–Dendy sampler is a commonly used tool for surveys of macroinvertebrates in lotic ecosystems (Hester and Dendy 1962; Valenty and Fisher, 2012). These samplers are typically deployed by attaching them to a submerged object or by suspending them in the water column, enabling sampling of...
benthic and drifting macroinvertebrates in both deep and shallow aquatic habitats. Moreover, the fixed sampling area (i.e., the combined area of the plates) and deployment time of the Hester–Dendy sampler allow for quantitative measurements of local macroinvertebrate communities and colonization rates.

Shear stress and high water velocities are properties of flowing water that affect benthic macroinvertebrate communities by potentially inducing drift. Flow regime variability associated with, for example, hydropneaking can greatly increase drift of benthic macroinvertebrates (Schülting et al., 2016), resulting in reduced benthic biomass (Moog, 1993) and less diverse communities (Valentin et al., 1995). In addition to effects on the communities that are going to be sampled, flow can bias the sampling results. For example, Hill and Matter (1991) reported that the Hester–Dendy sampler plates positioned parallel to the water flow (i.e., interstitial spaces between the plates were exposed to the flow) resulted in reduced abundances for nine out of twelve colonizing benthic macroinvertebrate groups compared to a positioning perpendicular to the flow. Furthermore, Beckett and Miller (1982) showed that a sudden drop in flow induced emigration of macroinvertebrates that had colonized the samplers.

The aim of this study was to investigate if Hester–Dendy samplers assess the benthic macroinvertebrate community in lotic ecosystems equally under different flow conditions. Specifically, we let a controlled composition of benthic macroinvertebrates colonize Hester–Dendy samplers in aquaria that had either a constant or a fluctuating (and increased) water velocity.

2 | METHODS

We constructed six Hester–Dendy samplers of square (75 × 75 mm) 3 mm polymethyl methacrylate plates. Each sampler had a total sampling area of 0.14 m² (Fullner 1971), and 14 plates that were separated by spacers (between plates 1–9:3 mm, 9–10:6 mm, 10–12:9 mm, and 12–14:12 mm spacing). Plates and spacers were mounted on a 200 mm stainless steel M8 rod with a washer and nut at each end. All surfaces of the acrylic plates and spacers were cross-sanded with 80 grit sandpaper, creating a roughened surface to facilitate colonization.

We used six aquaria (length × width × height = 75 × 40 × 40 cm) filled with c. 80 L water. Each aquarium was connected to an Eheim Classic 600 external filter (1000 L h⁻¹), which released cooled water (Teco TK500H and TK2000H) through a spray nozzle. Water intakes were covered with nylon stockings (20 denier) to prevent the benthic macroinvertebrates from being sucked into the pumps. Mean (±1 SD) water temperature, pH, and conductivity (measured before each trial) were 6.1 ± 0.4 °C, pH 6.78 ± 0.12, and 62.4 ± 1.8 µS cm⁻¹. Lights (200 lx) were turned on at 06:00 and off at 20:00 each day.

Two different flow treatments were tested: a flow treatment with constant water velocity and a flow treatment with fluctuating and increased velocity (Figure 1). We used two Eheim CompactON 600 pumps (600 L h⁻¹) to create the constant flow treatment, resulting in a mean water velocity (±1 SD) of 0.18 ± 0.01 m s⁻¹ in the middle of the aquaria. To create the fluctuating flow treatment, we used two CompactON 600 pumps and one additional CompactON 3000 pump (run at 2400 L h⁻¹). In the fluctuating flow treatments, one CompactON 600 pump was constantly running creating a base flow, whereas one CompactON 600 and the 3000 were controlled by timers, separately programmed to switch the two pumps on and off every 15 min according to a random schedule (Figure 1). The resulting fluctuating flow pattern was repeated each day during each trial period. Mean water velocity (±1 SD) in the middle of the aquaria with the fluctuating flow treatment ranged from 0.18 ± 0.01 to 0.44 ± 0.03 m s⁻¹. In the constant flow treatment, we kept the water velocity unchanged during each trial period.

FIGURE 1 | Water velocity measured in the center of the aquaria in the fluctuating flow treatment. In the constant flow treatment, water velocity was stable at 0.18 m s⁻¹.
In the middle of each aquarium, we placed a Hester–Dendy sampler perpendicular to the water flow. A stone (85 × 55 × 45 mm) behind the sampler held the sampler in place (Figure 2). We used four rounds of trials, resulting in 12 replicate trials for each flow treatment. For the first round of trials, three aquaria were randomly assigned to the constant flow treatment, whereas the other three aquaria had fluctuating flow. For each subsequent trial, fluctuating and constant flow treatments were switched for each aquarium, resulting in each aquarium contributing with two trials with constant and two trials with fluctuating flow. When analyzing the results, we excluded one of the constant flow trails due to an incorrect initial number of trichopterans in this specific trial, and our analyses were, therefore, based on 11 trials with constant and 12 trials with fluctuating flow.

Different species belonging to five orders of benthic macroinvertebrates were used in the laboratory experiment: Diptera, Isopoda, Ephemeroptera, Plecoptera, and Trichoptera. The benthic macroinvertebrates were collected (by kick samples and by picking from rocks using tweezers) from five sites in Alsterån (59°23′55″N, 13°36′17″E) and in a small unnamed forest creek (59°24′30′′47″N 13°35′11.83″E). Benthic macroinvertebrates were sampled from different water velocities to obtain individuals with different flow preferences, and the physical conditions at the sites were (data pooled from all sites, means ±1 SD) 5.8 ± 0.3°C, pH 6.78 ± 0.17, 60.0 ± 5.9 μS cm⁻¹ and (water velocity mean ±1 SD and min–max) 0.35 ± 0.18 and 0.11–0.73 m s⁻¹. The water velocities experienced by the benthic macroinvertebrates during this experiment thus lied well within the range of water velocities in which they were sampled.

Benthic macroinvertebrates of the same order were pooled in separate containers. From the containers, 10 randomly selected benthic macroinvertebrates of each order were placed in each aquarium (in total 50 individuals). We allowed the benthic macroinvertebrates to colonize the Hester–Dendy samplers during 5 days. The Hester–Dendy samplers were removed from the aquaria using two fine-meshed aquarium nets, after which we collected the colonized benthic macroinvertebrates by disassembling and rinsing the samplers and the nets. The remaining benthic macroinvertebrates alive in the aquaria and the individuals found dead were collected and stored separately in 70% ethanol.

We counted the number of living macroinvertebrates found on the Hester–Dendy samplers and free in the aquaria, and then identified them to genus (Nilsson, 1996), except dipterans that were only identified to subfamily. We calculated and arcsine square root-transformed the portions of (1) surviving and (2) total benthic macroinvertebrates (initial number of individuals = 50) that colonized the samplers. For each trial in which benthic macroinvertebrates colonized the Hester–Dendy sampler, we also calculated the Shannon–Wiener index, \( H' \) (where \( H' = -\sum_i p_i \ln p_i \), \( p_i \) is the number of species in the sample, and \( p_i \) the fraction of the entire population made up of species) both for individuals colonizing the Hester–Dendy samplers and for all living individuals (colonizing and non-colonizing) in the aquaria.

To test the effects of water velocity on counts of surviving and colonizing individuals, we used generalized linear models (GLM) with a Poisson log link function, and we used linear models (LM) on arcsine square root-transformed proportions and \( H' \). In all analyses, we also included aquarium (1–6) and trial round (1–4) as fixed factors to control for variation among aquaria and trial rounds. All statistical analyses were performed in SPSS 26 (IBM, Armonk, USA).

3 | RESULTS

We used 1150 benthic macroinvertebrates in the 23 trials, and 426 individuals were recaptured alive. The number of surviving individuals in each trial did not differ between the constant (mean ± 1 SE = 19.6 ± 1.7) and the fluctuating flow treatment (17.5 ± 1.5) (GLM: flow \( \chi^2 = 1.99, df = 1, p = .16, \) aquarium \( \chi^2 = 5.35, df = 5, p = .37, \) trial round \( \chi^2 = 8.86, df = 3, p = .03 \); Figure 3). Similarly, there was no difference in the number of colonizing benthic macroinvertebrates between the constant (mean ± 1 SE = 2.2 ± 0.7) and the fluctuating flow treatment (1.8 ± 0.4) (GLM: flow \( \chi^2 = 1.35, df = 1, p = .25, \) aquarium \( \chi^2 = 13.41, df = 5, p = .02, \) trial round \( \chi^2 = 3.29, df = 3, p = .35 \)).

**FIGURE 2** An aquarium setup for the fluctuating flow treatment with timers controlling three pumps that circulated the water [Color figure can be viewed at wileyonlinelibrary.com]
The mean proportion (±1 SE) of surviving benthic macroinvertebrates that colonized the Hester–Dendy sampler in the constant treatments (0.11 ± 0.04) did not differ from that in the fluctuating flow treatments (0.10 ± 0.02) (LM: flow $F_{1,13} = 0.16$, $p = .70$, aquarium $F_{5,13} = 2.25$, $p = .11$, trial round $F_{3,13} = 0.38$, $p = .77$). Furthermore, there was no difference between the constant and the fluctuating flow treatment when the proportion of colonizers was based on the total number of benthic macroinvertebrates placed in each aquarium (LM: flow $F_{1,13} = 0.58$, $p = .46$, aquarium $F_{5,13} = 1.94$, $p = .16$, trial round $F_{3,13} = 0.65$, $p = .60$).

We found living individuals from 16 different taxa (identified to genus), of which nine taxa (56%) colonized the samplers. Hester–Dendy samplers in the constant flow treatment ($n = 6$, mean $H' ± 1$ SE = 0.92 ± 0.19) had a significantly higher diversity than samplers in the fluctuating flow treatment ($n = 10$, mean $± 1$ SE = 0.36 ± 0.12; LM: flow $F_{1,6} = 13.07$, $p = .01$, aquarium $F_{5,6} = 3.34$, $p = .09$, trial round $F_{3,6} = 4.79$, $p = .05$; Figure 4). When analyzing the diversity of all living benthic macroinvertebrates found in the aquaria (colonizing plus non-colonizing), there was no difference between the constant ($1.59 ± 0.06$) and fluctuating flow treatment ($1.60 ± 0.06$) (LM: flow $F_{1,6} = 0.05$, $p = .84$, aquarium $F_{5,6} = 0.86$, $p = .54$, trial round $F_{3,6} = 1.44$, $p = .28$).

4 | DISCUSSION

We found no effect of flow treatment on the number of individuals colonizing the Hester–Dendy samplers. Although previous studies have shown that fluctuating flows rapidly cause increased drift of benthic macroinvertebrates (Schüting et al., 2016), our fluctuating flow treatment did not appear to hinder colonization. The diversity was, however, higher in aquaria with the constant than in those with the fluctuating flow treatment. This effect could potentially have been caused by differential survival rates in the two treatments, but we could not observe such a difference between treatments. Although based on a small sample size, the difference in diversity of the colonizing benthic macroinvertebrates suggests that the different hydraulic conditions caused by the fluctuating flow treatment reduced diversity of species that were able (or selected) to colonize the samplers.

The interstitial area between narrowly spaced plates will be less affected by water flow than plates with a wider spacing (Hill and Matter, 1991). We used both narrow and wide spacings (3–12 mm) and likely created suitable habitats for a wider range of benthic macroinvertebrates. Generalists are normally early colonizers on artificial substrates while specialists colonize later (Milesi et al., 2019). We recaptured living specimens from 16 taxa, of which nine colonized the Hester–Dendy samplers. Hence, those taxa that did not colonize the Hester–Dendy samplers may have chosen not to stay in the Hester–Dendy sampler, presumably because of unfavorable hydraulic conditions, because the sanded acrylic surfaces were inadequate for these macroinvertebrates to grip or attach to or because the individuals did not encounter the sampler during the trial. Most drifting individuals, however, should have encountered the Hester–Dendy sampler multiple times during the 5 days of a trial, because the aquaria were relatively small and the sampler was placed in the middle of the aquaria. We did not control the exact species composition of the group of benthic macroinvertebrates used in each trial (10 individuals from each order were randomly selected), which limits the interpretation of how functional traits relate to our results.

When using the Hester–Dendy sampler, sampled biota are assumed to represent the local assemblage accurately (Rosenberg and Resh, 1982). The accuracy of the representation is potentially affected by several factors, such as the material used and the design of the
sampler (Rinella and Feminella, 2005; Mason et al., 1973). In addition, the environmental conditions at the sampling site can play a major role in the samples’ representativeness of the local benthic macroinvertebrate communities. This study showed that the abundance of colonizing benthic macroinvertebrates was similar in constant compared to a fluctuating flow, and that a fluctuating flow regime may have had a negative bias on species diversity.

ACKNOWLEDGMENTS
We thank Niclas Carlsson and Björn Borgiel for assistance and Conny Hansson, Göran Walan, and Jörgen Persson for their help and ideas during the construction of the Hester–Dendy samplers. This study was funded by Energiforsk (HOPE, ref. VKU19112).

DATA AVAILABILITY STATEMENT
The data that support the findings of this study are available from the corresponding author upon reasonable request.

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