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Sediment composition mediated land use effects on lowland streams ecosystems

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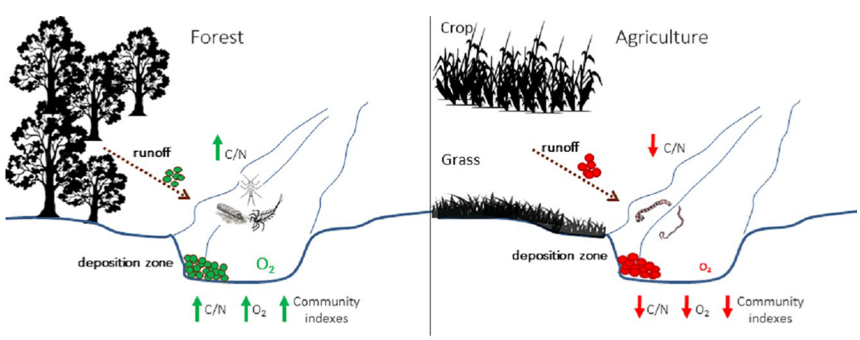
HIGHLIGHTS

- Instream deposition zone sediment composition is land use specific.
- Agricultural land use affects streams at the species, community and ecosystem level.
- Agricultural land use effects are linked to lower C/N ratios and higher SOD levels.
- Stream deposition zone sediment C/N ratio reflects runoff sediment C/N ratio.
- Agriculture affects stream via altered food quality and sediment oxygen demand.

GRAPHICAL ABSTRACT



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ABSTRACT

Despite the widely acknowledged connection between terrestrial and aquatic ecosystems, the contribution of runoff to the sediment composition in lowland stream deposition zones and the subsequent effects on benthic invertebrates remain poorly understood. The aim of this study was therefore to investigate the mechanisms by which runoff affects sediment composition and macroinvertebrates in deposition zones of lowland stream ecosystems. To this end, sediment from runoff and adjacent instream deposition zones from streams with different land use was chemically characterized and the biological effects were assessed at the species, community and ecosystem level. Runoff and deposition zone sediment composition as well as biological responses differed clearly between forest and agricultural streams. The stream deposition zone sediment C/N ratio reflected the respective runoff sediment composition. Deposition zones in the forest stream had a higher C/N ratio in comparison to the agricultural streams. Growth of *Hyalella azteca* and reproduction of *Asellus aquaticus* were higher on forest stream sediment, whereas chironomids and worms suffered less mortality on the agricultural sediments containing only natural food. The forest stream deposition zones showed higher values for indices indicative of biological integrity and had a lower sediment oxygen demand. We concluded that agricultural land use affects lowland stream ecosystem deposition zones at the species, community and ecosystem level via altered food quality (C/N ratio) and higher oxygen demand of the sediment.

1. Introduction

The strong connection between terrestrial and aquatic ecosystems is a central issue in understanding ecological processes in freshwater

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environments (Allan, 2004; Palmer, 2010; Ward, 1998; Wiens, 2002). Stream ecosystems receive allochthonous detritus, wood debris and sediment-bound chemicals from the adjacent terrestrial environment (Cummins and Klug, 1979; Jordan et al., 1997; Schriever and Liess, 2007). These allochthonous materials represent a key source of resources for stream food webs, supporting biodiversity and ecosystem services (Dodds, 2002; Bunn et al., 1999; Rosi-Marshall et al., 2016; Tank et al., 2010; Vannote et al., 1980; Webster et al., 1999). Yet, intense agricultural activities may lead to a lower input of course particulate organic matter and to increased concentrations of nutrients in the receiving streams (Bernhardt et al., 2017; Collins and Anthony, 2008). This may cause changes in instream detritus and sediment quality (Allan, 2004; Ekholm and Krogerus, 2003; MacDonald et al., 2001; Rabení et al., 2005), which is posing pressure on freshwater ecosystems worldwide (Leal et al., 2016; Wood et al., 2005).

Once allochthonous material reaches a stream, it may partly accumulate in deposition zones (Callisto and Graça, 2013; Pusch et al., 1998; Haan et al., 1994; Golladay et al., 1987). Previous studies argued that alterations in the input of fine particles in stream deposition zones often lead to changes in the amount and type of organic matter, nutrient dynamics (Jordan et al., 1997; Stelzer et al., 2014), oxygen concentration (Jones et al., 2012) and the presence of potentially toxic substances (Jones et al., 2012; Larsen and Ormerod, 2010). Due to these changes, organisms inhabiting sediment deposition zone, such as benthic invertebrates, are confronted with altered food quality (Graham, 1990; Jones et al., 2012; Lenat and Crawford, 1994; Parkhill and Gulliver, 2002; Rowe and Dean, 1998), and physico-chemical conditions, such as oxygen concentration (Larsen and Ormerod, 2010; McDonald et al., 1991; Zweig and Rabeni, 2001; Von Bertrab et al., 2013).

Despite the well documented qualitative effects of land use on stream ecosystem structure and functioning (Jones et al., 2012; Rabení et al., 2005; Schriever and Liess, 2007), the contribution of altered runoff to sediment composition in deposition zones and the subsequent effects on benthic invertebrates still remains poorly understood (Bernhardt et al., 2017; Larsen et al., 2009; Kefford et al., 2010; Larsen and Ormerod, 2010; Von Bertrab et al., 2013; Zweig and Rabeni, 2001; Allan et al., 1997). This knowledge gap is even greater in lowland streams, where the runoff from the surrounding land may be less frequent, but more intense due to the accumulation of high amounts of nutrients on the upper layer of the soil in flat areas (Stieglitz et al., 2003), leading to accumulation of contaminated material in stream deposition zones. The aim of this study was therefore to investigate the mechanisms by which runoff affects sediment composition and macroinvertebrates in deposition zones of lowland stream ecosystems. We hypothesized that land use specific runoff substantially affects deposition zone sediment composition and benthic ecosystem structure and functioning by changing food quality and oxygen availability. To test this hypothesis, sediment from runoff and adjacent instream deposition zones from streams with different land use was characterized chemically and the biological effects were assessed at the species (whole sediment bioassay), community (macroinvertebrate community composition) and ecosystem level (sediment oxygen demand).

2. Materials and methods

2.1. Study area

This study was conducted in three tributaries of the Hierden stream (52° 23′ N, 5° 41′ O) in the Netherlands (Fig. 1). The Hierdense stream catchment is characterized by sandy soils and a slope of 1.3 m/km (Martin-Ortega et al., 2012; Klein and Koelmans, 2011). The headwater is surrounded by agricultural areas followed by a forested area downstream. The three selected stream are no more than four kilometers apart from each other, maintaining similar climatic and geological conditions. However, the intense human occupation in this relatively small catchment created a patchy landscape formed by diverse land uses.

For each stream, the cover percentages of land use types were estimated using the topographic map from the Kadaster (https://www.kadaster.nl) and confirmed in the field (Table 1). The catchment of the forest stream was dominated by deciduous and coniferous forest (98%); the grass stream was surrounded mainly by fertilized grasslands used for animal grazing (50%) and urban areas (31%); and the crop stream was surrounded by non-perennial fertilized crop fields (36%) and urban areas (31%) (Table 1).

In each of the three lowland streams (flow velocity and depth, respectively in: forest 0.097 m/s ± 0.08 m/s, 11 cm ± 3 cm; grass 0.111 m/s ± 0.005 m/s, 24 cm ± 3 cm; and crop 0.091 m/s ± 0.003 m/s, 12 cm ± 1 cm) a downstream sampling site was selected (Fig. 1) to collect sediment from runoff and instream deposition zones. The runoff was sampled adjacent to the stream in the forest, the grasslands and the crop fields respectively, representing the dominant land use surrounding the sample site (Table 1). In each stream, a 15-meter-long stretch was selected in order to estimate substrate cover percentages according to Hering et al. (2003) (Table 2). Additionally, deposition zones were identified, defined as deeper areas where current velocity was low and where fine particulate organic matter (FPOM) accumulated, quantified based on Hering et al. (2003).

2.2. Runoff and deposition zone sediment composition

Sediment from runoff was collected simulating soil erosion by wash (Bryan, 1974), flushing the soil with demineralized water (5 to 6 L) over an area of 283 cm^2 by pouring water from a container vertically on the soil of the river bank. Per site, five replicate runoff sediment samples were taken. Water and sediment were collected in 3 l glass bottles and stored in a refrigerator at 4 °C for about 15 h, decanted and the remaining particles were analyzed.

From each stream deposition zone, the 2-cm top layer of the sediment was sampled using an acrylic core and a scaled core-cutter (Uwitec). Five replicate sediment samples were collected per site for chemical analysis, freeze-dried, sieved over a 2 mm sieve and ball-milled for 5 min at 400 rpm. For the bioassays, five replicate sediment samples per site were first frozen at −20 °C for two days and thawed at 4 °C for a period of three to four days.

2.2.1. Chemical analyses

Carbon (C) and nitrogen (N) concentrations were determined using an elemental analyzer (Elementar Vario EL, Hanau, Germany). Phosphorus was determined by first igniting one to 2 g of sediment at 500 °C for 16 h, after which the remaining sediment was extracted with 0.5 M sulfuric acid and finally, total orthophosphate content was determined by the colorimetric molybdenum blue method (Murphy and Riley, 1962). The inorganic phosphorus (IP) corresponds to the orthophosphate fraction determined from unburned samples, according to the method described by Murphy and Riley (1962). Organic phosphorus (OP) was calculated by subtracting inorganic from total orthophosphate. The organic matter (OM) content of the sediment was measured by loss-on-ignition. After overnight drying at 105 °C, the sediment was weighted using a precision scale (0.1 mg) before and after burning at 550 °C for 16 h.

2.3. Biological analyses

2.3.1. Sediment bioassays

To measure the chronic (sub)lethal biological effects of the sediment samples at the species level, five benthic invertebrate species, *Asellus aquaticus*, *Chironomus riparius*, *Hyalella azteca*, *Lumbriculus variegatus* and *Sericostoma personatum* were tested in a series of whole sediment bioassays. There were five replicates per treatment, each replicate consisting of a 150 ml jar containing a ratio of 4:1 local stream water