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Pioneer macrophyte species engineer fine-scale physical heterogeneity in a shallow lowland river

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ABSTRACT

Macrophyte responses to disturbance provide a short-term opportunity to document and interpret plant succession and related hydrogeomorphological interactions relative to the long-term, concomitant evolution of river morphology. Macrophyte colonisation may drive changes, e.g., increasing heterogeneity in physical characteristics that define broad-scale hydrogeomorphology. Relationships between macrophyte presence and key physical descriptors were investigated within channelized river reaches of a low gradient river. Plant species within two morphotypes sharing similar traits were the most abundant colonisers of the wetted channel. The standard deviation of depth, flow velocity and substrate were used in turn as response variables expressing physical heterogeneity across the channel. A second substrate response variable was the summed coarseness score based on substrate size (fines = 1, gravel = 2 and cobble = 3) across the channel. Macrophyte presence showed strong fine-scale relationships to heterogeneity in flow velocity and depth but not to heterogeneity in substrate. Substrate coarseness score was positively related to increasing heterogeneity in flow velocity, with increased presence of coarse substrate indicative of greater heterogeneity in velocity. Certain macrophyte species appear to play an important pioneer role in initiating and driving physical changes that underlie hydrogeomorphological processes. Likely mechanisms are flow manipulation, sediment interception and sorting.

1. Introduction

Fluvial geomorphology has traditionally focused on the role of abiotic factors such as stream energy and erosion/deposition processes in changing channel morphology (James, 1999; Rice et al., 2010). In contrast, following the concept of succession (Clements, 1916), ecologists have been concerned with the processes by which plants themselves internally modify their environment to determine the successional sequence. There is now a recognition that vegetation dynamics can be driven by allogenic processes (for example, the creation of fresh substrate patches by erosion during a flood disturbance) and shifting-mosaic processes whereby dynamic changes are evident at the patch scale leading to a mosaic of patches at different stages of succession (Bormann and Likens, 2012; Andel et al., 1993; Glenn-Lewin et al., 1992; McCook 1994). More recently, research on plant-hydrogeomorphology interactions suggests that plant species with particular traits can create morphological channel adjustments that stimulate physical recovery in channelized rivers, which has important implications for river restoration schemes (Clarke et al., 2003; Gurnell et al., 2010a; Gurnell et al., 2010b; Gurnell, 2014; O'Hare et al., 2016).

These plant species cause adjustment in fluvial morphodynamics and create physical heterogeneity by dampening/accelerating flow velocity which, in turn, enhances both sediment erosion and deposition. Indeed, plants have been described as 'ecosystem engineers' (see Corenblit et al., 2007; Gurnell et al., 2012; Gurnell 2014; for a review) because of the hydrogeomorphological changes that occur as a response to circular interactions between plant succession and fluvial-sediment processes. In summary, vegetation establishing in the benthic, marginal and riparian zones encourages aggradation by trapping and stabilising sediment within its roots and canopy. This fluvial "biogeomorphic succession" (Corenblit et al., 2009) supports the development of embryonic bed forms that may evolve into more substantial physical forms e.g. bars, islands and berms. In turn, this enables plant species with different environmental tolerances to establish and continue to anchor sediment, thus enabling evolution of biogeomorphic form.

Within Europe, macrophytes achieve their greatest biomass and corresponding influence on hydrogeomorphology, in shallow lowland rivers. This is because the forces that check macrophyte growth (e.g., high stream energy) are least- and those that encourage growth such as light and nutrient rich sediments are

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most-readily available in this river type. Hence, where macrophytes occur in abundance, they modify flow, sediment and nutrient processes and therefore act as an important component in river ecosystem functioning of lowland rivers (Clarke, 2002).

To date, much work has been concerned with the geomorphological role of the tall linear emergent *Sparganium erectum* (L.), because its physical attributes allow it to obstruct flow, trap sediment and seeds, and encourage development of successional biogeomorphic forms such as vegetated lateral berms (King, 1996; Liffen et al., 2011; O'Hare et al., 2012; Gurnell et al., 2013; Liffen et al., 2013). These studies demonstrate that *S. erectum* establishes in low energy fluvial systems and rapidly creates channel adjustments through sediment retention and flow manipulation, which stimulates plant succession on the channel margins. In a similar context, O'Hare et al. (2016) have proposed a plant-hydrogeomorphological interaction classification based on plant traits. Traits that were considered relevant to a plant species capacity to interact with hydrogeomorphological processes included: size and morphology, establishment traits, root form and perennation/winter biomass.

The environmental impacts of river channelization have been recognised for many years and have been widely documented (e.g., Swales 1982; Brookes, 1986; Ward 1998; Bunn and Arthington, 2002). Natural restoration of channelized rivers involves catchment-wide successional, hydrological and geomorphic processes that bring about a characteristic and integrated recovery process. The sequence of channel bed aggradation, macrophyte and woody vegetation establishment, progressively enhanced hydraulic diversity, bank erosion and accretion all lead to channel recovery (Hupp, 1992). However, any recovery usually occurs in the context of substantial increases in sediment transport following channelization and/or maintenance works (Wilcock and Essery, 1991; Evans et al., 2006). Macrophyte species possessing morphological traits that allow them to survive increased sediment and profit from associated nutrient loads can have an asymmetrical influence on morphological responses. The ability of such pioneer macrophyte species to readily establish after channelization works provides an opportunity to investigate plant colonization and succession, and the physical effect of these processes on channel attributes.

We collected data on plant community structure and aspects of hydrogeomorphology in sample sites of a channelized river reach, with varying levels of macrophyte cover. Subsequently, all vegetation was removed from the study reach as part of stream management works aimed at improving water conveyance. We then documented the macrophyte species that established post-removal, and their effect on descriptors of physical state within the channel. We classified plant species recorded at each sample site according to morphotype and plant traits (O'Hare et al., 2016), and developed statistical models to test for relationships between macrophyte presence and re-naturalisation (defined as increasing heterogeneity) in key physical descriptors (flow velocity, depth and substrate type). In order to explain fine-scale interactions between macrophytes and physical attributes, we undertook intensive sampling within sites of one river section. However, the interactions we observed can be expected to be important at larger scales given the tendency of many freshwater plant species to form extensive patches at the reach scale and to be widely distributed at the macro scale (Dawson, 1988; Spencer et al., 1994; Santamaría, 2002).

2. Materials and methods

2.1. Study area

N = 5 30 m sample sites were distributed within a 1.5 km non-shaded section of the Stonyford river, a tributary of the River Boyne, in the east of Ireland. The average bed width was approximately 4 m and average water depth was 0.4m. The Stonyford River is a characteristic Irish lowland river with low-moderate flow velocities (maximum recorded velocity at sample sites = 0.75 $m\,s^{-1}$), abundant macrophytes and a mixed bed load. Its fluvial patterns are typified by a meandering single-thread channel, bounded by cohesive alluvial plains. The river supports populations of brown trout (*Salmo trutta* L.) and Atlantic salmon (*Salmo salar* L.). Water quality was reported as achieving good ecological status based on the macroinvertebrate community recorded in the study site between 2012 and 2015 (EPA, 2016). The river has been arterially drained and channel morphology exhibits many characteristics typical of channelization e.g., deeply incised, trapezoidal form that isolates the river from its historical floodplain, and uniform flow dominated by extended glides. The channel has also been subject to cyclical river maintenance which has helped to maintain a very homogenous physical form. Consequently, sample reaches were very similar in terms of morphology in cross section and planform. Prior to data collection, visual inspection indicated that sample sites varied in macrophyte cover from low (<15%) to high (≥70%), primarily as a results of livestock herbivory via unenclosed cattle drinks at some locations.

In November 2014, instream and marginal vegetation was removed using a hydraulic excavator in all sample sites. Maximum vegetation rootstock was extracted while retaining substrate material and an undisturbed hard bed. Shortly afterwards, the entire 1.5 km section was fenced to exclude any livestock so that 'undisturbed' secondary succession by pioneer species could be observed across all sample sites.

2.2. Sampling

Data were collected in late July of 2013 and 2014 before vegetation removal and subsequent fencing. Additional data were collected in July 2016 to assess vegetation and morphological response and recovery. A series of cross-sectional (lateral) transects (*T*) were used to estimate plant frequency/distribution and physical attributes (depth, flow and substrate type) in N = 5 30 m sample sites within the experimental river section. Sampling followed a grid pattern with N = 5 equally-spaced point samples (*Sa*) being taken across each *T* at each sample site (Figs. 1 and 2).

Plant presence was recorded in N = 31 *T* spaced every 1 m at each sample site. Physical attributes (depth, flow and substrate type) were recorded in N = 11 *T* spaced every 3m. Bed gradient at each site was calculated by completing a longitudinal survey using standard engineering practices involving the use of a theodolite and 5 m telescopic survey staff. Substrate type was determined in the field by visual inspection and categorised as fines (≤3 mm), gravel (4–64 mm) or cobble (65–190 mm) (Fluskey, 1989), according to

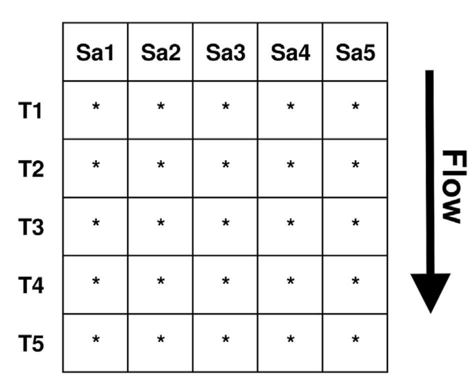

Fig. 1. Schematic of sampling design on a 30 m sample site of the Stonyford River; *Sa* are samples and *T* are transects.