The landscape drives the stream

Unraveling ecological mechanisms to improve restoration

dos Reis Oliveira, P.C.

Publication date
2019

Document Version
Other version

License
Other

Citation for published version (APA):

General rights
It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

Disclaimer/Complaints regulations
If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: https://uba.uva.nl/en/contact, or a letter to: Library of the University of Amsterdam, Secretariat, Singel 425, 1012 WP Amsterdam, The Netherlands. You will be contacted as soon as possible.
Chapter 1

General introduction
1.1 The landscape drives the stream

Stream networks are an integrated part of landscapes and cannot be viewed in isolation from the surrounding terrestrial environment (Fausch et al., 2002; Ward, 1989; Wiens, 2002; Poole, 2002). In 1975, H.B.N. Hynes stated that “In every respect, the valley rules the stream”. In accordance with Hynes, it is essential that any action aiming to improve aquatic ecosystem quality should be underpinned by knowledge of valley-stream interactions. Since anthropogenic activities continuously change the landscape and impoverish as well as disconnect aquatic and terrestrial ecosystems (e.g. Malmqvist and Rundle, 2002), unraveling the underlying ecological mechanisms is crucial to be able to protect and restore stream biodiversity and ecosystem processes.

To increase biodiversity and to achieve water quality goals (United Nations Millennium Development Goals; United Nations, 2008), around the world many attempts to reverse and mitigate degradation of stream ecosystems have been undertaken. Especially in the USA and in Europe legislation to support stream ecosystem restoration has been implemented, such as the Water Framework Directive (WFD) in Europe (Carvalho et al., 2019) and the Clean Water act in the USA (Doyle and Shields, 2012). Simultaneously, existing knowledge on stream ecology was translated more and more into restoration practices (Palmer et al., 2005; Lake et al., 2007). Nevertheless, many restoration projects remained unsuccessful (Palmer et al., 2005; Jahning et. al, 2010; Roni et al., 2008; Verdonschot et al., 2016).

In stream restoration, outcomes below expectation are usually associated with a lack of a proper definition of goals and a consequent mismatch in the selection and implementation of measures (Jahning et al., 2011). Stream restoration projects mostly targeted problems related to hydromorphological degradation, mainly focused on local interventions in stream channels and riparian zones (Lake, 2007). This made sense, because many stream ecosystems were hydromorphologically homogenized due to channelization and flow regulation, and riparian zones were often converted into agricultural or urban areas, isolating the streams from the valleys (Violin et al. 2011; Verdonschot, 2006). Moreover, since stream morphology and hydrology are strongly interrelated, artificial changes in flow regime and a low hydromorphic habitat diversity are associated with low biodiversity and the loss of ecosystem processes (e.g. Kingsford, 2000). Hence, hydromorphological measures may indeed restore biodiversity, as riverine species are adapted to natural hydraulic dynamics (Garcia et
al., 2017), and habitat quality and many ecosystem processes are directly related to stream hydromorphology (Ward, 1989; Resh et al., 1988; Bunn and Arthington, 2002).

In addition to the beneficial effects of hydromorphological measures on stream ecosystems, physico-chemical and biological aspects should be addressed as well (e.g. Lake and Bond 2007; Palmer et al., 1997). Streams are impacted by a wide range of stressors, including changes in temperature (Rader et al., 2008), light (Liboriussen et al., 2005), nutrients (Friberg et al., 2010) and toxicants (Lenat et al., 1994). Moreover, also biological factors such as species composition (Atkinson et al., 2014), population dynamics (Tonkin et al., 2014) and the introduction of invasive species (Matsuzaki et al., 2012) can impact stream ecosystem functioning (Muotka and Laasonen, 2002). Yet, these factors are less frequently targeted in restoration projects, mainly because many of these stressors act on larger spatial scales, like entire streams, stream valleys or even catchments (e.g. Frissell et al. 1986, Poff et al., 1997; Allan, 2004), while in contrast most restoration measures consider small scales only (e.g., Sudduth et al., 2007). The lack of selecting the appropriate spatial scale is recognized as an important cause of the low success rates of restoration projects (Vehanen et al., 2010; Sundermann, et al., 2011). Moreover, when stream restoration measures are carried out in isolation, targeting only short stream stretches with a strong focus on instream effects, the connection between the stream and the surrounding terrestrial ecosystems in the valley is ignored (Pilotto et al., 2018).

Thus, improving restoration measures requires integrating hydromorphological, physico-chemical and biological aspects (Nõges et al., 2016) and addressing these over the appropriate spatial scales of catchment, valley and stream (Bernhardt and Palmer, 2011; Schiff et al., 2011; Verdonschot et al. 2012; Kail and Hering, 2009; Stranko et al., 2012; Weigelhofer et al, 2013).

1.2 Terrestrial inputs from the valley into the stream

To study the effects of the stream valley on the stream, analysing the relationship between instream processes and the land use in the valley could be a starting point. Stream ecosystems receive, amongst others, sediment, detritus, woody debris and nutrients from the adjacent terrestrial environment (Cummins et al., 1979; Jordan et al., 1997; Schriever et al., 2007). Many streams are predominantly fueled by allochthonous organic matter (Bernhardt et al., 2018), supporting most of the aquatic food-web. However, streams under influence of anthropogenic activities in the stream
valley receive less (course) particulate organic matter in comparison to un-impacted streams, whilst receiving more nutrients and toxicants (Collins et al., 2008; Bernhardt et al., 2017), as well as fine sediments (MacDonald et al., 2010; Guan et al., 2017). These fine sediments accumulate in low flow deposition zones, such as pools and other depressions in the streambed (James, 2010; Zhang, 2017). Especially in slow flowing streams, such as low gradient lowland streams, the amount of accumulated sediment could be substantial (Naden et al., 2016).

Deposited fine sediments change the physical structure of the stream bed as well as the chemical composition of the sediment and the overlaying water. Consequently, benthic invertebrates inhabiting these stream deposition zones are confronted with several physical and chemical stressors. The accumulation of fine particles in organs, such as gills and filter feeding apparatus, may cause disruption of respiration and feeding (Iglesias et al., 1996), while sessile or semi-sessile aquatic organisms may be buried by the deposited material (Wood et al., 2005). 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; Stelze et al., 2014), oxygen concentration (Triska et al., 1993; Mulholland et al., 2005), the presence of potentially toxic substances (Larsen et al., 2010; Lopez-Doval et al., 2010), an increased turbidity (Sutherland et al., 2002), a decreased light availability for primary producers (Quinn et al., 1992), a reduction of habitats for aquatic invertebrates (Burdon et al., 2013; Larsen et al., 2011; Ramezani et al., 2014) and a decrease of instream detritus and sediment quality (Ekholm and Krogerus, 2003; MacDonald et al., 2001; Rabení et al., 2005; Graham, 1990; Rowe et al., 1998). Nonetheless, the underlying mechanisms linking these adverse instream ecological effects to stream valley land use in terms of quality and quantity of terrestrial inputs are still not fully understood.

1.3 Aim and objectives

Since land use determines the origin, nature and quantity of the terrestrial inputs (Kellner, 2019) and the instream deposited particles (Phillips, 1991; Kronvang et al., 2013), we postulate that their effects on in-stream functioning and biodiversity are strongly land use specific. But only by unravelling the underlying mechanisms we will be able to better identify the stressors involved and to determine the pathways to restore degraded lowland stream ecosystems.
The aim of this thesis was therefore to unravel the mechanisms by which land use affects structure and functioning of lowland stream ecosystems.

To this end the following objectives were defined:

- To evaluate 40 years of stream restoration practices by assessing the influence of policy goals on stream restoration efforts, the biophysical restoration objectives, the restoration measures, the scale on which these measures were applied and the accompanying monitoring efforts.
- To unravel the mechanisms by which terrestrial runoff affects sediment composition and macroinvertebrate community composition in deposition zones of lowland stream ecosystems.
- To determine if lowland stream sediment characteristics in terms of food resources and habitat structure are land use specific and if they shape macroinvertebrate communities.
- To assess the impact of catchment land use on the structure (macroinvertebrate community composition) and functioning (instream oxygen regimes) of lowland stream ecosystems.
- To improve the success of stream restoration projects by applying a novel approach, consisting of the addition of sand to the stream channel in combination with the introduction of coarse woody debris, to restore sandy-bottom lowland streams degraded by channelization and channel incision.

1.4 Outline

In chapter 2, 40 years of ecological lowland stream restoration practices were evaluated based on an analysis of the influence of policy goals on stream restoration efforts, biophysical restoration objectives, restoration measures applied, the scale of application of these measures, and the accompanying monitoring efforts. To this purpose we combined information from five stream restoration surveys that were held among the regional water authorities in the Netherlands over the last 40 years and from an analysis of the international scientific publications on stream restoration spanning the same time period.

In chapter 3, we studied the effects of land use type related runoff on sediment composition and the subsequent impact on macroinvertebrates community composition in lowland stream deposition zones. The results of this chapter pointed at
a crucial role of sediment oxygen demand and sediment quality in linking land use to instream ecological effects. Therefore, in the chapters four and five we unraveled the mechanism of land use specific sediment deposition in lowland streams impacting instream oxygen regimes and macroinvertebrate habitat and food quality. To this purpose, in chapter 4, we studied the land use specific effects of sediment composition and substrate cover on dissolved oxygen regime, sediment oxygen demand and macroinvertebrate community composition. In chapter 5, we studied the role of habitat structure and food quality of the sediment as an environmental filter on macroinvertebrate community composition in streams impacted by different land use types in the valley.

In chapter 6, a novel experimental stream restoration technique used to improve stream hydrology and morphology and to reconnect the lowland stream to its valley was introduced. Here, we tested the addition of sand in combination with woody debris in a previously incised, channelized lowland stream.

Finally, in the synthesis we proposed a framework to evaluate the main pathways by which land use type affects the structure and functioning of lowland stream ecosystems. Therewith we will be able to better identify the stressors involved and to determine the pathways to restore degraded lowland stream ecosystems.