Science of the Total Environment 613–614 (2018) 1048–1054

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Headwater streams in the EU Water Framework Directive: Evidence-based decision support to select streams for river basin management plans

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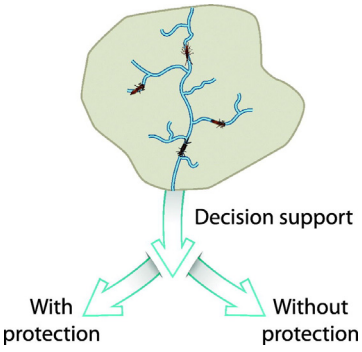
HIGHLIGHTS

- Lowland headwater streams have a high potential to reach good ecological status.
- Pressure-response curves can identify critical physical habitat thresholds.
- A decision-support for prioritizing headwater streams for protection is presented.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 17 August 2017
Received in revised form 18 September 2017
Accepted 18 September 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
Water Framework Directive
Headwater streams
River basin management plans
Decision support
Macroinvertebrates
Hydromorphology
Protection

ABSTRACT

Headwater streams are important contributors to aquatic biodiversity and may counteract negative impacts of anthropogenic stress on downstream reaches. In Denmark, the first river basin management plan (RBMP) included streams of all size categories, most being <2.5 m wide (headwater streams). Currently, however, it is intensely debated whether the small size and low slopes, typical of Danish streams, in combination with degraded habitat conditions obstruct their ability to fulfill the ecological quality objectives required by the EU Water Framework Directive (WFD). The purpose of this study was to provide an analytically based framework for guiding the selection of headwater streams for RBMP. Specifically, the following hypotheses were addressed: i) stream slope, width, planform, and general physical habitat quality can act as criteria for selecting streams for the next generation of RBMPs, and ii) probability-based thresholds for reaching good ecological status can be established for some or all of these criteria, thus creating a sound, scientifically based, and clear selection process. The hypotheses were tested using monitoring data on Danish streams from the period 2004–2015. Significant linear relationships were obtained between the ecological quality ratio assessed by applying the Danish Stream Fauna Index ($DSFI_{EQR}$) and stream slope, width, sinuosity, and DHI. The obtained models were used to produce pressure-response curves describing the probability of achieving good ecological status along gradients in these parameters. Next, threshold values for slope, width, sinuosity, and DHI were identified for selected probabilities of achieving minimum good ecological status. The obtained results can support managers and policy makers in

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https://doi.org/10.1016/j.scitotenv.2017.09.199

prioritizing headwater streams for the 3rd RBMP. The approach applied is broadly applicable and can, for instance, help prioritization of restoration and conservation efforts in different types of ecosystems where the biota can be significantly linked to separate and quantifiable environmental characteristics.

1. Introduction

Headwater streams are the smallest parts of river and stream networks, but they represent a large majority of the river network in the world. In Europe, for instance, headwater streams comprise 80–90% of the total river network (Globevnik, 2007) and the catchment area to these streams covers 58% of the European continent (Globevnik, 2007). Headwater streams are not only abundant but may also have highly distinct chemical and/or hydromorphological characteristics, even within small geographical areas due to high spatial and temporal variability of the surrounding landscape (Buffam et al., 2007). Headwater streams therefore offer a multitude of habitats for microbial, plant, and animal life (Meyer et al., 2007; Göthe et al., 2013; Baattrup-Pedersen et al., 2015).

Most organism groups contribute to the biodiversity in headwater streams, and of these aquatic insects are among the most ubiquitous (Voelz and McArthur, 2000) and diverse (Strayer, 2006). The taxonomic richness of macroinvertebrates is highly variable among continents and regions, and although alfa diversity may be low in individual headwater streams, beta diversity can be very high (Clarke et al., 2008; Finn et al., 2011). Therefore, the contribution of headwater streams to regional taxonomic richness (gamma diversity) can be higher than that of larger streams (Clarke et al., 2008). However, headwater streams may be at higher risk of biodiversity loss than larger rivers as the intrinsically tight aquatic-terrestrial linkages make them particularly vulnerable to anthropogenic disturbance in the surrounding catchment (Lowe and Likens, 2005). This connection was confirmed in a recent study demonstrating that the beta diversity of headwater streams was comparable to that of downstream sites in a highly degraded landscape (Göthe et al., 2015).

Despite the spatial dominance of headwater streams, their importance for biodiversity at catchment scale, and their vulnerability to human perturbation, they are often neglected in management policies. Headwater streams (catchment size < 10 km^2) are usually not recognized as surface water bodies in the EU Water Framework Directive (WFD; EC, 2003), and most headwater streams are therefore omitted from River Basin Management Plans (RBMP). Importantly, however, it is recommended to include small water bodies in the RBMP when they influence the purposes and objectives of the WFD (e.g. if they have significantly adverse impacts on downstream surface waters) (EC, 2003). Notably, if the hydromorphological and ecological quality of headwater streams is low, the headwater stream networks have severe negative effects on the downstream macroinvertebrate communities, even when downstream habitat quality is high (Stoll et al., 2016). Conversely, high quality headwater streams may counteract some of the negative impacts of urban water discharges (Burdon et al., 2016), agricultural pesticide pollution from diffuse sources (Liess and Von der Ohe, 2005), and habitat degradation (Stoll et al., 2016) on downstream macroinvertebrate communities. Therefore, including high quality headwater streams in RBMP may strongly benefit the ecological quality and biodiversity in the river networks.

In Denmark, the first generation of RBMPs included streams of all size categories of which the majority were <2.5 m wide (headwater streams). Recently, however, an intense debate has arisen about whether these small streams can comply with the ecological quality objectives of the WFD. It has been argued that the small size and low slope characterizing most headwater streams in Denmark, in combination with comprehensive physical habitat modifications (channelization and dredging of the stream channel), can obstruct their ability to fulfill ecological quality objectives. Consequently, the Danish EPA now considers excluding a number of headwater streams from the next generation of RBMPs.

In order to provide a scientific basis for the decision process with the aim to decide whether or not to exclude an individual headwater stream from the next generation of RBMPs, the possible influence of a number of criteria including stream slope, width, planform, and physical habitat characteristics on the potential to achieve minimum good ecological status (using the Danish Stream Fauna Index (DSFI)) were investigated. The criteria were selected by the Danish government as a part of the agreement for the agricultural sector (Anon, 2015). In more detail, the following hypotheses were addressed: i) stream slope, width, planform, and general physical habitat quality can be scientifically validated as criteria for selecting streams for the next generation of RBMPs, and ii) probability-based thresholds for reaching good ecological status can be established for some or all of these criteria, thus creating a sound, scientifically based, and clear selection process. We tested our hypotheses using monitoring data on Danish streams from the period 2004–2015. The sites included encompass all stressors of importance for macroinvertebrate communities in Danish streams (Friberg et al., 2005). As the stream sites covered existing gradients in landscape settings as well, this site selection was ideal for examining the importance of stream width, slope, and physical habitat quality for their ability to reach good ecological status under the existing stressor regime in Danish streams.

2. Materials and methods

2.1. Site description

In our study, we used data collected under the Danish national monitoring program (NOVANA) covering two monitoring cycles (2004–2010 and 2011–2015). A total of 366 stream sites with catchment areas <10 km^2 were included, each representing a 100 m long reach. The network of stream sites covered all biogeographical areas of the country as well as gradients in the dominant pressures on the streams (e.g. hydromorphological degradation, agriculture, and urban water discharges; Friberg et al., 2005).

Macroinvertebrate samples and supporting hydromorphological and chemical parameters (see descriptions below) were consistently assembled within the same year and at least once per monitoring period. For 131 sites, these parameters were assembled every year, and for the remaining sites once per monitoring period. However, for various reasons, data gaps occur (e.g. sample loss and failure to meet the criteria of the data quality check), and the total number of sites for which data is available therefore varied among parameters (Table 1).

2.2. Macroinvertebrate sampling and the Danish Stream Fauna Index

Macroinvertebrate sampling was consistently conducted between February 1 and April 30 using a standard kick net (25 × 25 cm, mesh-size: 0.5 mm) (European Standard EN 27828). Four standardized kick samples were collected at four equidistant points along three transects (n = 12). All kick samples were pooled into one sample. The kick sampling was supplemented with 5 min hand-picking from submerged stones and large woody debris. All habitat types present (e.g. riffle, glide/run, pool, and edge habitats) were sampled to ensure that the pooled sample was representative for the site. Subsequently, the macroinvertebrates were sorted and identified to species level except for