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Model-based evaluation of ecological bank design and management in the scope of the European Water Framework Directive

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ABSTRACT

In the scope of the European Water Framework Directive (WFD) river restoration has received increased attention. By restoring the physical habitat it is expected that the natural dynamics of the aquatic system improve and thus the good ecological status can be achieved or maintained by 2015. To this end, several restoration actions, such as the construction of ecologically sound banks (ESBs) have been implemented. ESBs are sites where the riparian zone is restored to enhance the natural aquatic functions and related physical, chemical and biological variables. However, the impact of typical restoration measures, such as the construction of ESBs, on the ecological water quality is not yet quantified. Currently, few restoration projects rely on scientific evidence.

In this study, the effect of ESB construction on the ecological status of water bodies is analysed and the key elements important for ESB design and maintenance are investigated. In cooperation with six Dutch water boards a large dataset was collected consisting of 926 records comprising data on water quality, ecological status and ESB variables. After data pre-processing, 82 and 112 records were retained for the macroinvertebrate and macrophyte community, respectively. Data-driven classification trees were developed for both biological communities with sufficient reliabilities; the correctly classified instances amounted to $81 \pm 3.5\%$ and $81 \pm 3.6\%$ and the kappa statistic to 0.62 ± 0.06 and 0.61 ± 0.08 for the macrophyte and macroinvertebrate community, respectively. Stakeholders participated in the modelling process and evaluated all statistically reliable modes for their ecological relevance and applicability for decision support in water management.

Our results suggest that ESB construction is beneficial in the scope of the WFD. We found that ESBs contribute to a diverse macrophyte and macroinvertebrate community. The key variables for proper ESB site selection and design are: water type, bank type, water level management, sediment type, ESB type, water function. Also, maintaining the ESB that are constructed is crucial for their effectiveness. Models consisting of rules concerning the design and maintenance conditions were developed and communicated to the river managers by means of the easily interpretable classification trees.

1. Introduction

Since the implementation of the European Water Framework Directive (WFD), all European Union (EU) member states have to assess the ecological status of their water bodies (EU, 2000). The main goal of the WFD is a good ecological status for natural water bodies and good ecological potential for heavily modified water bodies (HMWB) by the year 2015 (EU, 2000). A good status implies that the fauna and flora present and the chemical and hydrological conditions only slightly deviate from conditions of minimal anthropogenic impact (Gabriels et al., 2010). For example, when assessing the biological quality element “macroinvertebrates”, this means that pollution sensitive species are expected to be present (Gabriels et al., 2010). For compliance with the WFD, the good ecological status is to be achieved through programmes of measures as defined in the river basin management plans (EU, 2000; Leewis and Gittenberger, 2011).

River restoration was put forward as a possible measure to improve the water courses' ecological quality (Palmer et al., 2005; Suren et al., 2011). Different river restoration strategies exist (del Tanago et al., 2012), but one way to reach the goals of the WFD is via the construction of ecologically sound banks (ESBs). An

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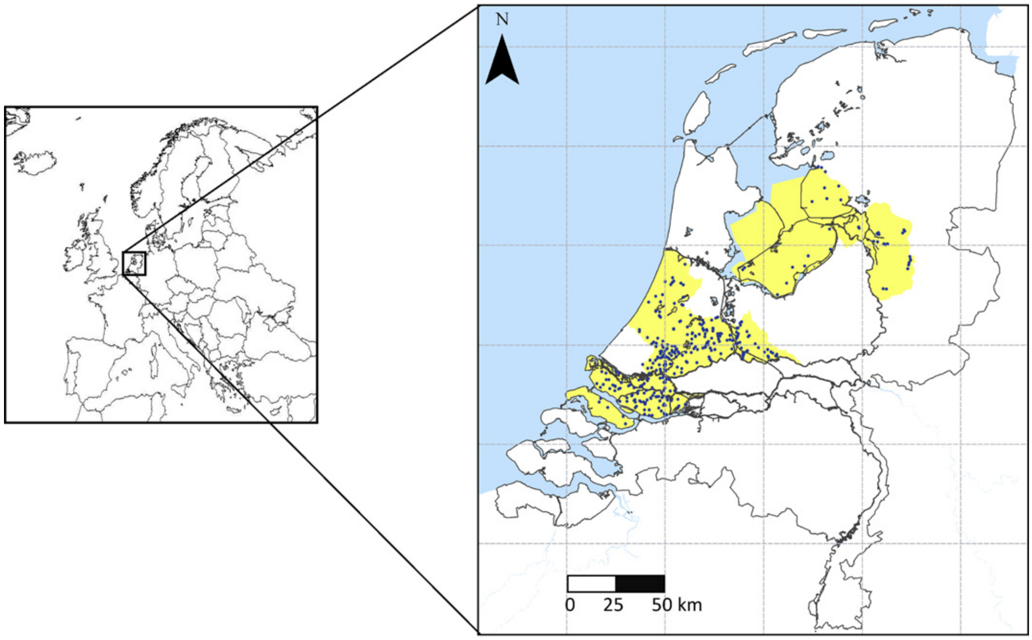

Fig. 1. Overview of the study area in The Netherlands with indication of the participating water boards (shaded) and sampling locations (dots).

ecologically sound bank (ESB) can be defined as a site where the riparian zone is restored, rehabilitated, enhanced, and protected for the purpose of re-establishing the pre-disturbance aquatic functions and related physical, chemical and biological variables. The basic idea of ESB construction is to improve the natural dynamics of the riparian zone by restoring the physical habitats (Boedeltje et al., 2001; Spanhoff and Arle, 2007). Several restoration projects were already initiated to compensate the negative impacts of artificial bank reinforcements (Soesbergen and Rozier, 2004; Bernhardt et al., 2005; Alexander and Allan, 2006; Jähnig et al., 2009), but these do not always yield the expected results (Sundermann et al., 2011). In only two out of 78 restoration projects, Palmer et al. (2010) found beneficial effects for the benthic invertebrate biodiversity. Moreover, in many cases there is no follow-up of the restoration project (Lüderitz et al., 2011). Consequently, there is lack of knowledge on the effectiveness of restoration measures (Kail and Wolter, 2011) and the relationships between the riparian enhancement and the aquatic community composition remain poorly understood (Sundermann et al., 2011; Blettler et al., 2012). In 2009, the Foundation for Applied Water Research (STOWA) summarized and published the available knowledge about ESB design and maintenance, but unfortunately no rules on ESB construction were described. Despite the limited knowledge, ESBs are extensively constructed. In The Netherlands for example, Dutch authorities have been restoring 3500 km of riparian zones in the Rhine delta (Ministerie van Verkeer en Waterstaat, 2008). However, due to the unknown relationships between river restoration measures and their effect on aquatic ecology (Kail and Wolter, 2011), there is a risk that ESB construction will not obtain the desired effects (Palmer et al., 2010). Overall, ESB construction should be based on ecological knowledge (Blettler et al., 2012), but objective tools are currently lacking.

Ecological models help to conceptualize ecosystems and have already been used for decision support in river restoration projects (Salles and Bredeweg, 2006; Adriaenssens et al., 2007; Dedecker et al., 2007; Mouton et al., 2007; Peacock et al., 2012). Classification trees, for example, give insight in complex, non-linear ecological data, where commonly used exploratory and statistical modelling techniques often fail to find meaningful patterns (De'ath and Fabricius, 2000). Classification trees are hierarchical structures, where internal nodes contain tests on the input attributes. Each branch of an internal test corresponds to an outcome of the test and the prediction for the value of the target attribute is stored in a leaf. Each leaf of a classification tree contains a prediction for the target variable (Everaert et al., 2011). Overall, classification trees explain variations in response variables by splitting predictor variables at certain thresholds in the nodes of the tree (Fig. SI1). Classification trees have already been used several times in an ecological context (De'ath and Fabricius, 2000; Goethals et al., 2007; Boets et al., 2010; Dominguez-Granda et al., 2011; Everaert et al., 2011). In the context of ESBs, they provide a quantitative approach to understand the relationships between the ecology, the ESB design and maintenance variables. As such, they are useful to fill the above described knowledge gap since reliable classifications are combined with a transparent set of rules which can be easily understood by decision makers (Goethals et al., 2007).

In this study, data-driven classification trees were used to understand the impact of ESB design and maintenance on the ecological water quality. Based on the collected data we answered three key questions: (1) what are key variables when designing and maintaining an ESB; (2) Is the ecological water quality higher in water bodies with ESBs compared with water bodies with traditional riparian zones, and (3) Is it possible to set up well-founded practical rules for future restoration programs?

2. Materials and methods

2.1. Study area

The study was conducted in cooperation with six Dutch water boards: "De Stichste Rijnlanden", "Schieland en de Krimpenerwaard", "Hollandse Delta", "Zuiderzeeland", "Rijnland" and "Groot Salland" (Fig. 1). Water boards are regional water authorities responsible for the management and the monitoring of the water courses and surface water quality within their territory (Mostert, 2006). The research focused on the riparian zone in lowland ditches, canals and lakes because most ESBs have been constructed in these ecosystems (Sollie et al., 2011).