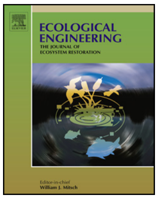
Ecological Engineering 66 (2014) 141–149

Contents lists available at ScienceDirect

Ecological Engineering

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



10 years after the largest river restoration project in Northern Europe: Hydromorphological changes on multiple scales in River Skjern

E.A. Kristensen[a,*], B. Kronvang[a], P. Wiberg-Larsen[a], H. Thodsen[a], C. Nielsen[a], E. Amor[a], N. Friberg[a], M.L. Pedersen[b], A. Baattrup-Pedersen[a]

[a] *Aarhus University, Department of Bioscience, Silkeborg, Denmark*
[b] *Aalborg University, Department of Civil Engineering, Aalborg, Denmark*

ARTICLE INFO

Article history:
Received 26 February 2013
Received in revised form 22 August 2013
Accepted 7 October 2013
Available online 30 October 2013

Keywords:
River restoration
Long-term
Physical condition
Floodplain
Low-land rivers

ABSTRACT

The lower river Skjern (Denmark) historically contained a large variation in habitats and the river ran through large areas with wetlands, many backwaters, islands and oxbow lakes. During the 1960s the river was channelized and the wetland drained. A restoration during 2001–2002 transformed 19 km of channelized river into 26 km meandering river. The short-term effects of this restoration have previously been reported and for this study we revisited the river and with new data evaluated the long-term (10 years) hydrological effects of the restoration. The evaluation was done on three different scales: (1) in-stream habitats, (2) channel stability and (3) re-connection with the floodplain. In-stream habitats had changed little over the past 10 years and the habitats today showed close similarity with the habitats recorded immediately after the restoration. Measurements of channel stability showed that erosion and sedimentation have changed the cross-sectional profiles over the last 10 years, resulting in a net input of sediment to the lower reaches of the river. However, the change of channel form was a slow process and predicted bank retreat over a 100 year period was only up to 6.8 m. Hence the formation of lost habitats (islands, backwaters and oxbow lakes) is a very slow process and the spontaneous development of these habitats will take centuries. Furthermore, the evaluation also showed that the restoration re-connected the river with its floodplain and large areas of riparian areas are today periodically flooded, but that the flooding is controlled and tamed due to the restoration design. The restoration of River Skjern has therefore failed to re-create the natural habitats formerly present and the natural dynamic processes that shape these habitats are slow. To speed up this process we therefore recommend restoration engineering using a natural guiding image when restoring lowland rivers in the future and through this restoring the lost habitats and the dynamic processes characteristic of natural rivers.

1. Introduction

Habitat degradation is a serious threat to biodiversity (Dobson et al., 1997; Vitousek et al., 1997; Wilcove et al., 1998) and aquatic ecosystems are among those most severely impacted (Allan and Flecker, 1993; Sala et al., 2000). Over centuries, streams, rivers and their floodplains have been modified (e.g. Sparks, 1995; Kronvang et al., 1998; Bernhardt et al., 2005) as a result of land drainage, flood plain urbanization, flood defence and navigation (European Environment Agency, 1998). In North-western Europe, modification and channelization of watercourses have been particularly extensive and have left less than 10% of lowland streams in Great Britain, the Netherlands and Denmark in their natural physical state (Brookes and Long, 1990; Verdonschot and Niiboer, 2002). Thus, extensive damage has been caused to the river ecosystems with a widespread loss of habitats for biota, and the biodiversity of European rivers and floodplains is today significantly reduced.

As a consequence of the widespread damage to stream and river ecosystems, and based on a growing recognition of the conservation values within them, the number of river restoration projects has increased substantially in recent years (Bernhardt et al., 2005). River restoration efforts have primarily focused on channel re-configuration, and in-stream habitat improvements increasing heterogeneity, by re-meandering and adding physical structures such as wood, boulders and artificial riffles (e.g. Larson et al., 2001; Kasahara and Hill, 2008; Miller et al., 2010). However, during the last 10 years there has been a growing scientific and management-oriented recognition of the importance of restoring the natural processes of river ecosystems (Williams, 2001;

---

[*] Corresponding author at: Aarhus University, Department of Bioscience, Vejlsøvej 25, DK-8600 Silkeborg, Denmark. Tel.: +45 87158753.
E-mail address: ek@dmu.dk (E.A. Kristensen).

0925-8574/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ecoleng.2013.10.001

Kondolf et al., 2006). This paradigm shift has resulted in a transition from small-scale engineering-dominated restoration approaches toward catchment-scale approaches that focus on enhancing both in-stream habitats and re-connection of the river with its floodplain and through this restoring freshwater wetlands (Hillman and Brierly, 2005; Kondolf et al., 2006). Therefore, there is a need to focus on the entire freshwater ecosystems including the riparian wetlands and through this the restoration of ecosystem processes and functioning which is vital to sustain the services these systems provide (Loomis et al., 2000). Scientific evaluations of catchment-scale restoration projects are however rare, especially studies that monitor the long-term responses (Friberg et al., 1998; Feld et al., 2011). Long-term evaluations are highly relevant as such studies can help us to advance the science of river restoration (Wohl et al., 2005) and ultimately help us achieve a higher rate of restoration success (Palmer et al., 2005).

The overall aim of this study was to evaluate the longer-term effects of restoring River Skjern, Denmark. This restoration project is the largest river restoration project in Northern Europe to date, aiming to enhance the nutrient retention capacity of the river by re-creating a natural hydrology in the river valley including re-connection of the river and the riparian wetlands and to enhance biodiversity by restoring the physical and hydrological dynamics of the river and the floodplain (Pedersen et al., 2007a). River Skjern is located in Western Denmark and drains a catchment of 2490 km^2. Land use in the catchment is dominated by agriculture and the geology of the area is a combination of sandy outwash plains and mostly sandy moraines (Smed, 1982). The river has the highest discharge of any Danish rivers (annual mean 35 m^3/s) why the river is of high regional importance as a biodiversity hotspot (Ovesen et al., 2000; Andersen et al., 2005). From historical maps dating back to the 1800th century the lower 10 km of the river can be classified as anastomosing with numerous channels between low relatively stable vegetated islands (Miall, 1977; Richards, 1997). During the late 1960s the lower 19 km of the river was channelized and riparian wetlands were drained as a result of increasing demand for agricultural production. River channelization and drainage was at the time considered a prerequisite condition for agricultural growth in the Danish society. However, 25 years later the area had lost its agricultural value and in 1987 the Danish government initiated plans to restore the area. The restoration was conducted in 2000–2002 and resulted in the transformation of the lower 19 km of channelized river into 26 km of meandering river (Pedersen et al., 2007a). The short-term effect of the restoration on in-stream habitats, macrophytes and macroinvertebrates has previously been reported (Pedersen et al., 2007b), however, the longer-term effects are unknown. The aim of this study was therefore to re-visit the River Skjern and analyze the development in channel morphology and habitats 10 years after the completion of the restoration. We investigated morphological development using three different spatial scales: (1) in-stream habitats, (2) channel stability and (3) the re-connection of the river with its riparian wetlands. We hypothesized that significant changes have occurred during these 10 years and that the River Skjern has developed into a river system with near-natural hydromorphology. The term hydromorphology is used as defined by Šípek et al. (2009), for discussion see Vogel (2011).

2. Methods

2.1. *In-stream habitats*

The short-term effects of the restoration on in-stream habitats have previously been evaluated in three 300 m long reaches along the restored River Skjern (R1, R2, R3, Fig. 1) based on a comparison with a 300 m long control reach (C, Fig. 1) located upstream of the restoration area (Pedersen et al., 2007b). All four reaches was sampled once before the restoration (2000) and again immediately after the restoration (2003; Pedersen et al., 2007b). After the restoration the location of R2, R3 and C remained at the same location as pre-restoration, while, as a results of the restoration and filling-up of major parts of the channelized river, reach R1 was in 2003 moved from the northern drainage channel to the newly excavated river channel located app. 2 km south (Fig. 1). For this study, we re-sampled these four reaches in 2011 providing data for a long-term evaluation (app. 10 years) of the restoration on in-stream habitats. Identical surveying methods were used in all three years to allow for cross-year comparison, for a detailed description of the methodology, see Pedersen et al. (2007b). In brief, six transects were placed equally spaced along each of the four reaches and each transect was divided into 1 m × 1 m quadrats across the entire width. A GPS was used to exactly identify location of each transect. At each quadrat, depth (to nearest cm), current velocity (at 10 cm above the stream bed), dominating substrates (using seven categories according to the Wentworth-scale (Wentworth, 1922) and macrophyte coverage (%) was recorded. Recording of in-stream variables was done in September 2000, August 2003 and September 2011 and it was aimed to collect data at similar discharge levels. However, the summer 2003 was drier than normal and mean monthly discharge for August 2003 was 12.7 m^3/s, while mean monthly discharge for September 2000 and September 2011 was 19.4 m^3/s and 19.1 m^3/s, respectively.

To evaluate the long-term changes to in-stream habitats we divided the recordings from each transect into two groups two groups termed a “Vegetated zone” and a “Main current zone”. The first group was defined as quadrats with depths from 0 to 130 cm, often located along the edges of the river channel supporting vascular macrophytes, as these rarely occur at depths larger than 130 cm. The second group was quadrats with depths larger than 130 cm, often located in the mid-channel and being without vascular macrophytes. We preformed this a priori separation of the data to obtain a river-zone-specific evaluation of the physical changes during the 10 year period because these two main channel zones are expected to form different in-stream habitats for plants, macroinvertebrates and fish. For this study, we calculated a number of in-stream parameters using the transect data recorded in 2000, 2003 and 2011. For each transect, we calculated Coefficients of Variation (CV) for depth, mean current velocity and mean macrophyte coverage separate for the two habitat zones. In addition, we used substrate recording to calculate percent occurrence of four substrate types (peat, mud, sand and gravel) and produced transect means for each substrate type separately for the two zones. Finally, we used three different variables (domination, diversity and score) to describe changes in substrate for each transect divided into the two zones according to O’Hare et al. (2006). A value between 1 and 4 was allocated to the four substrate categories with values increasing with particle size. Domination was defined as the dominant substrate, i.e. the category occurring in most quadrats, diversity was the number of categories occurring and score the weighted average of the categories present in each transect. All physical variables used to evaluate changes to in-stream habitats for the four reaches and the two different zones are summarized in Table 1.

To investigate the effect of the restoration on in-stream habitats and the long-term development in the habitats we preformed Principal Response Curve analyses (PRC, Van den Brink and Ter Braak, 1999). The analyses were done with year 2000 as reference points (Van den Brink et al., 2009) thus enabling us to investigate the change of in-stream habitats relative to the physical condition