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# Cost-effective river rehabilitation planning: Optimizing for morphological benefits at large spatial scales

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ABSTRACT

River rehabilitation aims to protect biodiversity or restore key ecosystem services but the success rate is often low. This is seldom because of insufficient funding for rehabilitation works but because trade-offs between costs and ecological benefits of management actions are rarely incorporated in the planning, and because monitoring is often inadequate for managers to learn by doing. In this study, we demonstrate a new approach to plan cost-effective river rehabilitation at large scales. The framework is based on the use of cost functions (relationship between costs of rehabilitation and the expected ecological benefit) to optimize the spatial allocation of rehabilitation actions needed to achieve given rehabilitation goals (in our case established by the Swiss water act). To demonstrate the approach with a simple example, we link costs of the three types of management actions that are most commonly used in Switzerland (culvert removal, widening of one riverside buffer and widening of both riversides) to the improvement in riparian zone quality. We then use Marxan, a widely applied conservation planning software, to identify priority areas to implement these rehabilitation measures in two neighbouring Swiss cantons (Aargau, AG and Zürich, ZH). The best rehabilitation plans identified for the two cantons met all the targets (i.e. restoring different types of morphological deficits with different actions) rehabilitating 80,786 m (AG) and 106,036 m (ZH) of the river network at a total cost of 106.1 Million CHF (AG) and 129.3 Million CH (ZH). The best rehabilitation plan for the canton of AG consisted of more and better connected sub-catchments that were generally less expensive, compared to its neighbouring canton. The framework developed in this study can be used to inform river managers how and where best to spend their rehabilitation budget for a given set of actions, ensures the cost-effective achievement of desired rehabilitation outcomes, and helps towards estimating total costs of long-term rehabilitation activities. Rehabilitation plans ready to be implemented may be based on additional aspects to the ones considered here, e.g., specific cost functions for rural and urban areas and/or for large and small rivers, which can simply be added to our approach. Optimizing investments in this way will ultimately increase the likelihood of on-ground success of rehabilitation activities.



## 1. Introduction

In response to the poor conservation status of freshwater biodiversity and the increasing risk of losing services that humans receive from freshwaters ecosystems, river rehabilitation is a global priority (Bates et al., 2008). However, despite the increasing funds devoted towards the recovery of freshwaters (Bernhardt et al., 2005; Giller, 2005; Verdonschot and Nijboer, 2002), the success rate of rehabilitation activities is low (Alexander and Allan, 2007; Roni et al., 2008). Reasons for the poor performance of rehabilitation projects can often be linked to the complexity of decisions involved in the planning: river managers have to choose the right set of actions and locations of implementation to maximize the ecological benefits within the available budget (Hermoso et al. 2012b; Palmer et al., 2005, 2010; Roni et al., 2008).

Additionally, rehabilitation activities are more likely to be successful when planned at a large scale, preferably at the catchment

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level (Alexander and Allan, 2007; Miller et al., 2010; Stranko et al., 2012). Thereby, including longitudinal connectivity in the planning process is especially important (Hermoso et al., 2012a, 2011; Linke et al., 2012), since only connected rivers allow target species to move over the appropriate spatio-temporal scales (Lake et al., 2007), and to function as resources for the recolonization of restored habitats. Source populations e.g. fish or macroinvertebrates, but also riparian zones in good condition located within 5 km (upstream) of the restored sites are particularly valuable for the success of rehabilitations (Lorenz and Feld, 2013; Stoll et al., 2012; Sundermann et al., 2011). However, although splitting rehabilitation efforts into small disconnected pieces does not bring the maximum ecological benefit, most on ground rehabilitation efforts are still targeted at individual sites or stream reaches in an *ad hoc* fashion (Bernhardt et al., 2005; Bond and Lake, 2003; Lake et al., 2007; Rohde et al., 2006).

So far very few attempts have been made to tackle these difficulties in a systematic way (but see (Hermoso et al., 2012b) as well as (Carwardine et al., 2008b; McBride et al., 2010; Wilson et al., 2011) for terrestrial ecosystems), although they are urgently needed: International conventions and directives e.g. the European Union's Water Framework Directive WFD (European Commission, 2000), or country-specific water acts such as in Switzerland (FOEN, 1991) have explicitly called for a full recovery of freshwater systems in the near future. However, the extent of heavily impacted rivers (e.g., 60% in the European Union; (EEA, 2012) or 78% in Switzerland (Zeh Weissmann et al., 2009)) suggests we need to use the available resources more efficiently through the systematic planning of rehabilitation activities, e.g. the prioritization of actions at sites.

Recent advances in systematic conservation planning have the potential to deal with the challenges that accompany large-scale river rehabilitation planning. Traditional systematic conservation planning has been used for prioritizing investments for marine, terrestrial (Wilson et al., 2009) and freshwaters systems (Hermoso et al., 2011; Linke et al., 2011; Moilanen et al., 2008). These conservation exercises emphasized on reserve design to protect existing biodiversity features, i.e. preserving a pre-defined proportion or certain amount of species, while minimizing the costs of the included set of areas. In contrast, a systematic river rehabilitation plan does not need to identify the most cost-effective way of representing biodiversity within protected areas, but the most cost-effective combination of river reaches and actions needed to improve the ecological river condition. This approach adopts the traditional conservation planning framework considering the key principle of complementarity (Margules and Pressey, 2000). This complementarity ensures that the selected areas composing a reserve system cover all biodiversity features. However, compared to traditional conservation planning, the approach taken in this study substitutes biodiversity targets with river condition targets, reserve selection with action prioritization, and the cost of protecting areas with the costs of those actions. Thereby, suitable rehabilitation actions are identified for each area or river stretch *a priori* and are incorporated from the beginning of the planning process to shape the spatial distribution and configuration of priority rehabilitation areas. This will result in more cost-effective rehabilitation plans than those that identify management actions after funds have been allocated *ad hoc* to rehabilitation sites (Carwardine et al., 2008a).

The aim of our study is to build on the body of traditional conservation planning research to develop and apply a new approach to systematically plan for river rehabilitation at a large scale. We demonstrate how to use Marxan (Ball et al., 2009), a spatially explicit conservation planning software to find near-optimal, cost-effective plans for future rehabilitation activities. More specifically, we use information on the cost-effectiveness of already implemented rehabilitation projects to inform the prioritization process. To illustrate our approach with a simple example, we drafted optimal plans meeting rehabilitation targets over 20 years for two neighbouring cantons in Switzerland. To the best of our knowledge this represents the first attempt to utilize a well established systematic conservation planning approach to identify priority sites for river rehabilitation, while considering multiple management actions and longitudinal connectivity, coupling on-ground rehabilitation experience with large-scale condition assessments (Linke et al., 2012).

## 2. Material and methods

### 2.1. Study area

Switzerland is divided into 26 administrative member states called cantons. Zürich and Aargau (Fig. 1) are two neighbouring cantons located north of the Alps on the Swiss Plateau. Together, they encompass an area of 3133 $km^2$ (1729 $km^2$ and 1404 $km^2$, respectively) with approximately 4400 km (2600 km and 1800 km, respectively) of river network (delineated from a DEM 1:25000 with ArcHydro), draining towards the north into the Rhine River catchment. Due to their proximity to the Atlantic Ocean the cantons feature a humid continental climate (Köppen Cfb/Dfb) with four distinct seasons and an annual mean air temperature of 8.6 °C. The moist and mild westerly winds provide continuous precipitation throughout the year with an annual mean of 1048 mm (Federal Office of Meteorology and Climatology MeteoSwiss, data from 1981 to 2010 measured in Kloten, ZH). The cantons of Aargau and Zürich – our focus cantons – are heavily populated (443 and 838 people $km^{-2}$, respectively) with 15%–20% of their areas developed for housing or transportation (roads and railways), and almost half of their areas used for agriculture (45.3% and 43.4%, respectively) (Federal Statistical Office, Statistical Atlas of Switzerland, last accessed December 2012). As a consequence, rivers have been drained, channelized, degraded, piped and deforested to reclaim arable land, control floods and facilitate navigation. This has modified natural channel structure and riparian zones considerably. For example, in the canton of Zürich, 23.3% of all rivers are slightly modified, 18.5% heavily modified, 8% artificial, and 12.8% are piped. In the canton of Aargau the morphological quality of rivers is very similar (31% slightly modified, 16.8% heavily modified, 7.3% artificial, 16.1% piped (Zeh Weissmann et al., 2009)). In both cantons, only a third of all rivers still feature a natural or near-natural morphological condition.

During the last ten years, river rehabilitation has become an important management goal in Switzerland. However, it is mostly an opportunity-based, site-by-site activity, which is not strategically planned (Rohde et al., 2006). Since 2011, rivers that are in less than good morphological condition have to be restored by law (according to the federal law on the protection of water resources article 38a, (FOEN, 1991) and the water protection ordinance article 41a, d, (FOEN, 1998)). Cantonal water authorities are responsible for implementation of the legislation within the cantonal boarders. In addition to on-ground implementations of measures, this includes the identification of priority areas at the catchment scale for periods of 20 years at a time starting in 2014 (Göggel, 2012).

### 2.2. Morphological quality of riparian zones

Information describing the morphological condition of rivers in the cantons of Zürich and Aargau was available from a detailed geo-referenced data set of the Federal Office for the Environment (Zeh Weissmann et al., 2009) that is linked to a digital vector map of