Ecological engineering: from concepts to applications

Assessment of the success of headwater restoration through the vegetation diversity analysis of four Oir river’s tributaries (Normandy, France)

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Abstract

Safeguarding of riparian ecosystems is a field of major study in the comprehension and the maintenance of the health of rivers. The aim of our study is to analyze vegetation changes after passive restoration on two headwaters. Follow-ups of vegetation were carried out using 36 permanent plots of 15 m² per brooks during five years. Our results suggest that after restoration, vegetation assemblages are comparable to those present on other headwaters considered in good ecological health. The effectiveness of the passive restoration method employed is discussed in terms of strong potential of resilience for comprehension of ecological functions and in term of sustainability for river managers.

Keywords: catchment area; landscape; passive restoration, riparian ecology, vegetation community

1. Introduction

The intensification of agriculture has drastically modified the structure of rural landscapes by changing field size, destructing hedgerow networks, and increasing nutrient and fine sediment fluxes to rivers [1]. In this context, restoration ecology is a necessity to avoid those perturbations on river and more particularly on headwaters. Indeed, the importance of headwaters is due to their strong influence on both physical structure and functioning of superior order rivers, as illustrated by the River Continuum Concept [2,3,4].

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River banks are a part of the riparian ecosystem. Their preservation is essential in order to prevent potential degradation of this system: because they constitute the interface between aquatic and terrestrial environments they are of great ecological interest [5]. Thus, vegetation colonizing this ecotone fulfills several functions: it filters pollution, limits the eutrophication phenomenon, stabilizes banks thanks to its root system, it filters light, is involved in trophic networks and structures physically faunal habitats... Vegetation can also have an important impact on the dispersion of nutrients, terrestrial plants propagules or woody debris [6].

The solutions frequently employed for riparian restoration, such as the plantation of ligneous vegetation or the bed race modification, constitute rather heavy and expensive methods to set up. Furthermore, the monitoring in case of success or not is rare in the majorities of restoration projects [7]. Authors however agree on the need for a scientific base and monitoring funds before beginning any project of river restoration [7,8]. This is a part of the aim of this study on headwaters: managers have implemented restoration measures for years without getting any feedback on the efficiency of these measures and without any integration of more recent practices of ecological restoration.

Our study focused more particularly on a passive project of river restoration. It is carried out on the catchment basin of Oir (Manche, France), a Sélune’s tributary on which ecological surveys are carried out for 20 years to connect the salmon population quality with the quality of habitat. Passive restoration, with minimal intervention, takes into account concepts of restoration ecology and has many ecological as economical advantages. If a correction of the physical environment is sufficient to initiate the recovery of the biota, then the practitioner would limit restoration activities to correcting this physical environment. If recovery occurs without any intervention, it should be called natural reestablishment or designated by another term besides “ecological restoration” [9].

Here, we follow two brooks initially heavy degraded by cattle. Trampling of river banks and beds by cattle, in particular in “wild watering places”, highly increase the suspension of matter in water [10]. Few studies have so far targeted vegetation diversity on several rivers located on the same catchment basin [11]. This is paradoxical since many authors recommend studying riparian ecosystems and their restoration at the landscape scale, taking into account aspects such as connections between river corridors [12]. This is why our study focuses on brooks from the same catchment area.

The question which underlines our study is the following: can passive restoration lead to a return to a good ecological status after such perturbations? How long do we need to wait before seeing the effects? What are the problems encountered? Thus, we compared these two degraded brooks with two near-by brooks from the same catchment but considered in a good ecological health. To reach these goals, we followed during 5 years the natural recovery by vegetation species of the river banks.
2. Materials and methods

2.1. Study site

Oir is a small river with a highly patrimonial fish species (trouts, seetrouts, salmons) value, draining a catchment area of 86.6 km². It is located in the South of Normandy, France (Fig. 1). Its source is situated at the height of 225m and runs out on 20km with an average slope of 1.1%. The Oir River is a right bank affluent of the Selune River and joins it to approximately 8 km of the estuary zone. Located in an area with a dense hydrographic network (Strahler order = 4; drainage density = 1.41 km/km²), the Oir receives five left bank tributaries and six left bank tributaries. In addition, the Oir catchment area drains an area of fodder cultures coupled to extensive breeding where agricultural practices strongly influence the brooks morphology and the water quality. Our study took place on four tributaries of Oir: Vallée-Aux-Berges (named VAB in the figures), Violette, Roche and Moulinet (Fig. 1).

2.2. Restoration and sampling method

Initially, Vallée-Aux-Berges and Violette were highly degraded by the cattle action: intensive trampling and grazing of their banks. Restoration begun in 2004 for Vallée-Aux-Berges and in 2006 for Violette.

All brooks were protected by enclosures and many watering places for cattle were fitted out there. Thus all perturbations due to cattle were eliminated and then no other actions were made to initiate or accelerate the recovery of the banks. We sampled vegetation during the restoration to follow its recovery. The Roche and Moulinet brooks are enclosed since more than ten years by their owners, and in spite of punctual damages, these brooks can thus be considered in “good ecological status”. We sampled these two last brooks in 2009 as an ecological reference.

Each brook was divided into four zones, respectively upstream to downstream: zone 1, zone 2, zone 3, and zone 4. In each zone, we sampled the vegetation in permanent surfaces of one meter large and 15 meters long. We examined nine of these plots per zone, i.e. 36 per brooks. Exhaustive plant species surveys were made and their abundance was scored according to Tansley’s scale, from 1 (few) to 5 (very abundant) [13].
2.3. Statistical analysis

Various indices are used to describe variations of vegetal communities [14]. The Shannon index (H') is classically used to characterize changes in the specific richness after restoration, and also to characterize biodiversity [15,16], particularly in comparative studies and we hypothesize that it should reflect the response of the vegetation community to the set up of passive restoration. Shannon’s diversity index was calculated for each zone of the four brooks at the initial state, and after restoration for Vallée-Aux-Berges and Violettes. Shannon's diversity indices were compared between sites using Hutcheson's test [17,18]. Then, a correspondence analysis (CA) enabled us to better understand the changes in the vegetation community following the restoration set up. All statistical analysis were made with the statistical softwares R [19] and Statistica 8 [20].

3. Results

3.1. Specific diversity along the upstream-downstream gradient

First, Fig. 2-a shows the initial state for each brook. Violettes is always the less diversified brook of this catchment area (p<0,05). In spite of a heavy degraded status, Vallée-Aux-Berges is as diversified as the Moulinet and Roche brooks. Furthermore, there is no variation of this index within the brooks along the upstream-downstream gradient.

Secondly, few years after the set up of the passive restoration on Vallée-Aux-Berges and Violettes (Fig. 2-b), Violettes is still the less diversified stream but its Shannon’s index significantly increases for the zones 3 and 4 (p<0,05). A more important increase is observed for Vallée-Aux-Berges (p<0,01). These increases lead to an upstream-downstream gradient of the Shannon’s diversity index. Inside these two brooks, the zones 3 and 4 (downstream) are always more diversified than the zones 1 and 2 (upstream) (VAB: p<0,01; Violettes: P<0,05).

![Fig. 2. Variation of Shannon diversity index (a) before restoration on the four tributaries and (b) after restoration on Vallée-Aux-Berges (VAB) and Violettes](image-url)
3.2. Passive restoration leads to a change in the composition of vegetation community

Fig. 3 is a two-dimensional factorial analysis ordination using the original abundance matrix of all surveys of the four brooks. Factor 1 and factor 2 accounts for 28% of the total variation. In the matrix, there are both initial and after restoration status of the brooks. There are different vegetation species assemblage between the initial state of Vallée-Aux-Berges and Violettes and the other brooks considered in good ecological health (the Roche and Moulinet brooks). Passive restoration did change the plant species assemblage and, a few years after restoration, plant communities of Vallée-Aux-Berges and Violettes were quite similar to on the ones of the Roche and Moulinet brooks.

![Factorial analysis ordination of all sites based on the matrix of abundance. Circles represent the two restored brooks at different status (initial and restored); 1 & 2 respectively Vallée-Aux-Berges and Violettes before restoration; 3 & 4 same brooks after restoration](image)

4. Discussion

Species diversity, for which species richness and evenness contribute to a varying degree, is the subject matter of biodiversity and conservation biology because it acts as an indicator in ecological studies [18]. Our results revealed that on the two restored brooks, diversity always increases in the downstream zones. Before restoration, many
meadow and generalist species such as *Cynosorus cristatus*, *Poa trivialis* or *Bellis perennis* were found on the river banks. After restoration, there is an increase of many characteristic species of this type of brooks as *Juncus effusus*, *Athryum felix-femina* or *Geranium robertianum*. There are also many new species that appear and expand on different zones, e.g. *Cardamine pratensis*, *Mentha aquatica* or *Festuca gigantea*. Indeed, on Vallée-Aux-Berges and Violettes, there is an increase of this diversity, located principally at the downstream level of these two brooks. Thus, our study suggests that passive restoration leads to a deep change in plant diversity. These results are not completely congruent with other studies that revealed a systematic increase in the specific richness on the whole restored systems [21,22]. We hypothesize that the diversity gradient observed here is due to a delay in the response of the upstream zones to restoration. Our monitoring should go on for more years to check this hypothesis. Other restored brooks will be studied in this catchment to confirm these results and extend them at a catchment scale. It is indeed surprising to observe such an important diversity gradient on small size brook systems: such variations are generally observed for studies at large scales like long rivers [23]. If these observations become widespread on first order streams, it will then be interesting to determine how these results could contribute to the optimisation of restoration practices. If recolonisation really occurs more quickly downstream after passive restoration, we could perhaps think about implementing more restoration measures to the upstream area.

The aim of this work was to study the effectiveness of passive ecological restoration on small headwaters. As we can see with the multivariate analysis, plant community of restored brooks and Roche/Moulinet brooks were different at the initial state and quite similar after restoration. Passive restoration thus seems to be successful and has permitted to improve the vegetation state of the Vallée-Aux-Berges and Violettes banks after a few years. These results are in agreement with McIver and Starr [24] who revealed that passive restoration may be the first and most important step in riparian restoration, especially in smaller order streams where flow regimes are still intact. This question of the effectiveness of passive approaches is very discussed in the literature. Indeed, Prach & Hobbs [25] suggested that a minimum intervention approach is advisable. Nevertheless, utilizing spontaneous succession as a restoration tool gives the potential to save both time and effort and allows the development of a less anthropized ecosystem. Active restoration may be necessary when invasive plants have become established as observed by Reinecke et al. [26] who advises human intervention under such circumstances.

The potential of spontaneous succession, either reasonably manipulated or not, still needs to be more fully exploited. This type of results could help scientists to interact with practitioners. This is a new view for ecological restoration practice and could become a new way to work on river management. To compare both “active” vs. “passive” restoration approaches in this type of headwaters, this study will continue by the survey of other brooks where an active restoration approach was chosen (i.e. ligneous plantation on the banks).

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