

## How has restoration of riparian vegetation been implemented and evaluated in the international literature?

Comment la restauration de la végétation riveraine a-t-elle été appliquée puis évaluée dans la littérature internationale ?

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### RÉSUMÉ

Cette étude résume 169 articles rapportant le succès de projets de restauration de la végétation riveraine au cours des 25 dernières années. Plus précisément, nous avons examiné les méthodes d'application et d'évaluation de la restauration à l'échelle de la planète. Les approches hydro-géomorphologiques (gestion des barrages, contrôle des crues, reconfiguration du relief) étaient les plus fréquentes, suivies par l'introduction active de plantes, le contrôle des espèces exotiques, le changement d'utilisation des plaines inondables et le contrôle du broutement par le bétail. Notre revue a révélé des limites importantes dans l'approche spatio-temporelle choisie pour évaluer les retombées de la restauration. Les évaluations étaient surtout locales (i.e. pour un seul projet) et ignoraient souvent la nature multidimensionnelle des rivières : les patrons spatiaux étaient rarement étudiés à l'échelle du paysage, la plupart des projets étant à l'échelle du méandre, et le suivi temporel était restreint, avec peu de projets suivis sur plus de six ans. L'impact de la restauration était évalué principalement en suivant le changement dans le temps plutôt qu'en comparant le site restauré avec un site de référence alors que très peu de projets impliquaient les deux types de suivi. Les évaluations pourraient être améliorées par l'utilisation de traits fonctionnels et la planification de dispositifs expérimentaux plus appropriés de même qu'en rapportant les échecs d'établissement de la végétation.

### ABSTRACT

We reviewed 169 articles that evaluated the success of restoration projects on riparian vegetation during the past 25 years to examine how restoration has been implemented and evaluated worldwide. Hydro-geomorphic approaches (e.g., dam operations, controlled floods, landform reconfiguration) were the most frequent, followed by active plant introduction, exotic species control, conversion of a natural floodplain and grazing control. Our review revealed noteworthy limitations in the spatio-temporal approach chosen for evaluation. Evaluations were mostly local (i.e., from one single project) and frequently ignored the multi-dimensional nature of rivers: landscape spatial patterns were rarely assessed, and most projects were at the meander scale, not monitored for more than five years and were usually not older than five years old. The impact of the restoration was most often assessed by tracking change over time rather than by comparing restored sites to reference sites, and very few projects did both. Future evaluations would benefit from incorporating functional traits and better experimental designs as well as from reporting failure.

### KEYWORDS

Assessment, evaluation, monitoring, restoration, riparian vegetation

## 1 THE NEED OF EVALUATING PAST RESTORATION EFFORTS SYSTEMATICALLY

Evaluation of success has been the Achilles's heel of restoration ecology since this discipline emerged back in the early 1980s. The assessment of restoration outcomes has been traditionally jeopardized by superficial or underfunded monitoring as well as the lack of systematic objective and standard evaluation criteria. However, effective adaptive management requires such evaluation, as does the advancement of the field of restoration ecology as a whole. In this review we examine the actual extent to which recommendations for project monitoring after riparian vegetation restoration are being followed across the globe and where we might improve as a discipline.

## 2 METHODS: SELECTION OF ARTICLES

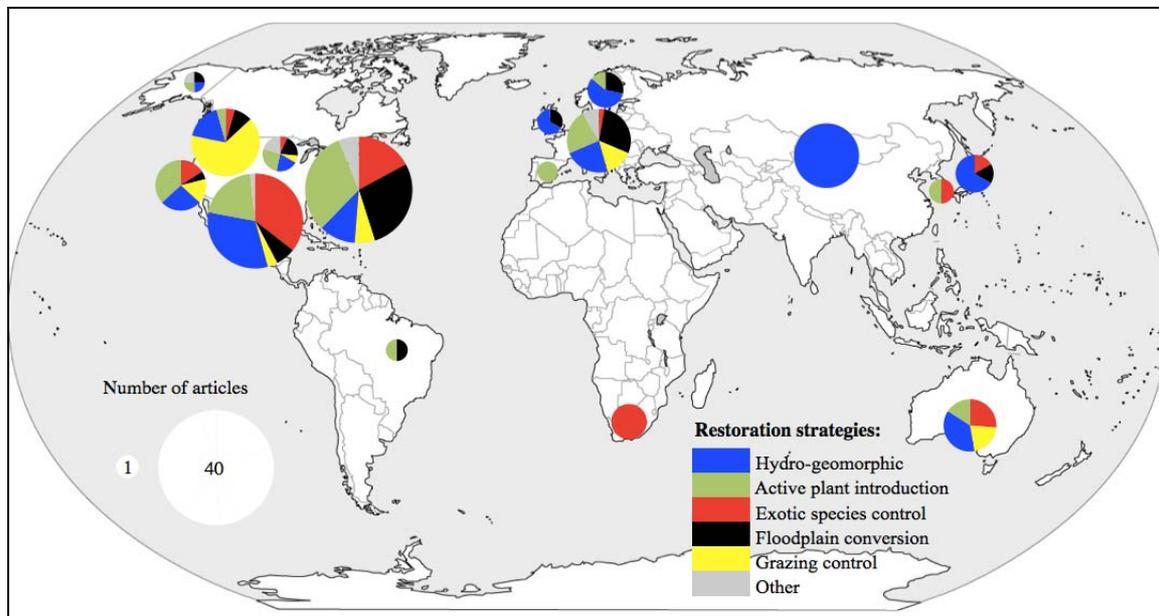
In October 2014, we entered the following motor of search in the ISI Web of Science: "(riparian or floodplain or river or stream) near (vegetation or forest\* or plant\*) and (resto\* or rehabilit\* or recover\* or remov\* or reforest\* or planting) and (success\* or reference or degrad\* or fail\*)". We selected articles that 1) were for restoration projects that were completed or ongoing, 2) had a *primary* goal of restoring vegetation that occurred on the banks or floodplains, and 3) occurred on natural flowing freshwater courses, and 4) included quantitative measures. A total of 169 peer-reviewed articles were retained and used in the study. We examined the articles in order to answer the following questions: (1) Which restoration strategies were evaluated in different regions in the world? (2) Which assessment approaches have been used (e.g., scale of monitoring and use of reference sites)? (3) Which evaluation metrics have been used as success criteria and how have they been computed? (4) Which factors explained success?

## 3 RESULTS AND DISCUSSION

We present here a summary of the main results of this study. More details can be found in González et al. (In press).

### 3.1 Restoration strategies in the world

North America was by far the most studied region (61% of the papers) followed by Europe (15%) and Asia (14%) (Fig. 1).



**Figure 1.** World distribution of the 169 papers included in this review. Pie chart size is proportional to the number of articles (see lower left corner of map for minimum and maximum sizes). Pie chart divisions are proportional to the number of restoration strategies.

Hydrogeomorphic actions included any action that alters the prevalent water and/or sediment regime to induce changes in vegetation composition, structure and/or processes. They could be passive

(water and/or sediment regimes are permanently modified by the removal of stressors such as dikes or dams) or active (water and/or sediment regimes are temporally modified, restoration requiring permanent actions, for example dam operations). Although passive restoration is preferable (Suding, 2011), active hydrogeomorphic restoration was done more often (69 vs. 21 articles). Active plant introduction was the second most common strategy (66 articles) but was used almost always in combination with other approaches. Control of exotic species (53) was the third most common strategy, with *Tamarix* spp. being the main emblematic target species (22). A substantial number of articles (49) examined the outcomes of restoration of former agricultural lands that were abandoned and reincorporated to the natural floodplain (floodplain conversion). Flooded meadows of Central and northern Europe and riparian swamps in the southern US (bottomland hardwood forests) are the two ecosystems where this strategy was most commonly applied. Finally, we found 35 articles focusing on riparian vegetation recovery after grazing and herbivory control. Almost one half of the papers aimed at restoring forests dominated by any species of the Salicaceae family: *Populus* (43 articles) and *Salix* (37).

### 3.2 Assessment approaches

Scale of the restoration itself was primarily local, with hydrogeomorphic and grazing control as the only strategies that had a substantial proportion of projects implemented at the catchment scale. Evaluations have also been primarily local; only 21 projects included metrics computed at a landscape scale such as diversity of habitats. In addition, only 44 articles assessed the outcomes of multiple independent projects, and only 15 of these articles evaluated more than 10 projects. Regarding temporal scales, our study confirmed that, as in other ecosystems (Ruiz-Jaen and Aide, 2005), the effects of restoration in riparian plant communities have been rarely monitored for more than six years. More than one half of the articles (58%) did not use any kind of reference site as defined in this review: positive (natural, desired or un-degraded sites) or negative (degraded, un-restored or control sites); and only 7% utilized the two types of reference sites. However, 124 out of 169 articles used trajectories in their evaluations, defined as change over time of any of the success metrics. Thus, the overall tendency for evaluations focused on in situ change over time rather than SERI (2004) Primer's recommendation of using reference sites.

### 3.3 Metrics used as success criteria

Most of the articles (152) included parameters related to vegetation structure as criteria to evaluate success. Vegetation processes (112) and vegetation composition and diversity (78) were less frequently assessed. Sixty-nine per cent of the articles used indicator species for evaluation. While the evaluation metrics were almost always computed at the species level (156 articles), divisions of the vegetation into other components were also common (83 articles): life form and life span (47), life stage (23), nativity (35), habitat preference (31) and others (15). The division of the vegetation into compartments other than species, such as functional traits, can enrich the evaluation of recovery of riparian vegetation by incorporating a mechanistic perspective. This strategy could also help to scale up restoration evaluations, given that working at the species level in large regions and different rivers is less informative as site effects increase.

### 3.4 Factors explained success

The role of abiotic factors as drivers of restoration success was evaluated in 86% of the articles. Hydro-geomorphic factors, notably the groundwater dynamics, geomorphic and topographic metrics and the five components of the flow regime: flood magnitude, frequency, duration, timing and rate of change, were most frequently assessed, followed by soil properties and management. Biotic factors (i.e., biological interactions, seed dispersal and grazing) were studied in 52% of the articles.

## LIST OF REFERENCES

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