THE EFFECTS OF RIVERBANK STABILIZATION THROUGH ROCK RIPRAPPING ON FISH DENSITY AND DIVERSITY IN STREAMS IMPACTED BY AGRICULTURAL ACTIVITIES

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Rock riprapping revetment is a form of riverbank stabilization that is commonly used to protect road and bridge infrastructures from fluvial erosion. However, little is known about how these may affect habitat selection by riverine fish in streams impacted by multiple stressors stemming from agricultural activities. Nine streams in Southern Québec (Canada) served as study sites, where fish surveys and habitats attributes were measured. Nested linear mixed-models using percent cover of rock, wetted stream width, water depth, and flow velocity as fixed effects, and spatio-temporal variables as random effects, were conducted to assess the ecological effects of rock riprapping revetment across agricultural streams. Results indicated that overall fish density was significantly explained by fixed effects (R^2 = 35.7% : Marginal) and by random effects (R^2 = 24.2) which lead to a model explaining 59.9% (R^2 : Conditional). Nested linear mixed-models was assessed by cross-validation (jackknife leave-one-out procedure) and showed an R^2_{CV} of 57%. An interaction between rock riprapping revetment and wetted stream width on fish densities was also observed (p-value = 0.0195). These findings suggest that the rock riprapping revetment zones had greater fish densities if water depths were maintained, as these zones contributed to stream habitat complexities, providing suitable fish habitats that were not available elsewhere in these streams. The knowledge gained here may further improve on existing riprap zone designs implemented by the Ministère des Transports du Québec (Quebec Ministry of Transportation).

1 INTRODUCTION

The habitat heterogeneity concept in ecology proposes that an area with a wide variety of habitats may increase the number of species occupying these spaces [8]. Heterogeneous environments have often supported higher diversities and densities than homogeneous environments, as more diverse ecological niches are generated by providing more suitable habitats for species [2]. Thus, the loss of habitat heterogeneity in streams has often been linked with negative stream species diversities and densities, through both direct and indirect impacts for several taxa.

Figure 1. Pictures of rock riprapping revetment

Rock riprapping revetment, henceforth referred to as riprap, is a form of streambank stabilization that is commonly used to protect road and bridge infrastructures from fluvial erosion (Figure 1). We know that riprap modifies local hydraulic conditions (i.e. flow velocity, water depth etc.), streambank vegetation and substrate composition [1]. Riprap was suggested to have a negative impact on fish communities by altering the fluvial environment as well as the processes that create fish habitats [4]. However, little is known about how riprap may affect habitat selection by fish communities in streams impacts by multiple stressors. In streams near agricultural activities, the addition of rocks is thought to confer fish community benefits by increasing the habitat heterogeneity by providing better feeding and spawning opportunities [12] and contributing to interstitial spaces between larger rocks used by fishes for rest and protection [6]. In streams impacted by multiple stressors, some studies suggested that the addition of rocks can be beneficial to fish communities by increasing the habitat heterogeneity [13].

Most of the studies so far have focused on cold-water streams inhabited by salmonids [9]. The paucity of studies conducted in warm- water, agricultural streams, with greater species richness, which includes fishes from cyprinid, centrarchid, catostomid, and percid families, is the primary reason for conducting this study. Understanding how riprap in agricultural streams impacts fish communities is an important contribution to proper management of these systems and improved on current riprap zone designs. Thus, this study aims to verify how fish diversity and density was affected by riprap in streams impacted by agricultural activities.

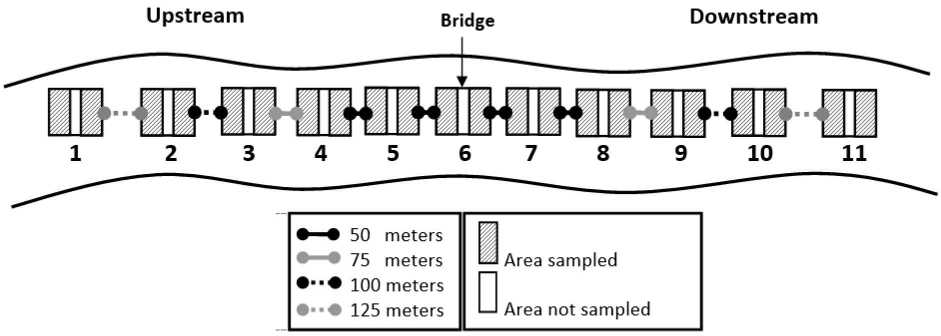
2 MATERIALS AND METHODS

Site stabilized with riprap (RS) and sites not stabilized with riprap (NRS) were compared across nine agricultural streams to estimate the differences in fish community descriptors and environmental conditions.

2.1 Study streams and segment repartition

Nine lowland streams in Southern Québec (Canada), impacted by agricultural activities and with newly constructed riprap zones to stabilize bridges (2004-2012), served as study sites. A comparison between 1 RS and 10 NRS on each stream was realized (Figure 2). 10 NRS were sampled on each stream to assess the variability of physical characteristics. The area directly below the bridge was excluded from surface area surveyed, to avoid confounding effects of the riprap and the shading provided by the bridge. The area downstream and upstream of the bridge were combined together to represent one site and this exact design was reproduced for the 10 NRS conserving the same dimension as the RS (50-120 m^2).

Figure 2. Schematic representation of the distribution of sampling sites in each stream segment. The sampling site 6 is the sampling site stabilized with riprap (RS) and the sampling sites 1 to 5 (upstream the bridge and RS) and 7 to 11 (downstream the bridge and RS) are not stabilized with riprap.



2.2 Fish surveys and habitat attributes

Fish surveys were conducted at each sampling site using a LR-24 backpack electrofishing unit (Smith-Root, Vancouver, WA) between 08:30 and 18:30 in summer 2014 late-june to august. No survey was done on rainy days. Streams were visited twice (except one) which leads to 17 surveys with a minimum of 16 day intervals between the two visits. Electrofishing surveys were conducted by teams of three operators, in accordance to Ontario Ministry of Natural Resources policy standards. The electrofishing unit was set to deliver a standardized power of 200 Watts to minimize variations of sampling effectiveness associated with different water conductivities. Captured fish were identified to species and measured (total length, ±0.1 cm). Fish surveys and habitat attributes were measured at 10 sites evenly distributed around the 1 riprap revetment site (total number (N) of sites per stream=11). The prevailing environmental conditions at each site were estimated immediately after the fish sampling. Wetted width (±10 cm) was measured twice per site, approximately in the middle of the downstream and upstream part of each site. Water depth (±1 cm) and water velocity (at 40% of the water column; ±0.01 cm s^{-1}) were taken with a Marsh-McBirney Flo-Mate 2000 (ACG Technology Ltd & Envirocan Wastewater Treatment Equip. Co. Ltd.; 131 Whitmore Road, Unit 13 Woodbridge, Canada) at 4 locations evenly distributed within each site. The percent of the streambed covered by macrophytes, woody debris (>5cm diameter), and rocks (> 6 cm) were visually estimated over the complete surface area of each site. The percent of the surface area of the stream bed that was shaded by the canopy was also visually estimated. Environmental conditions therefore consisted of variables describing water depth, wetted width, water velocity, macrophytes, woody debris, rocks and canopy.

2.3 Analysis

The first objective was to evaluate how riprap affects physical characteristics and fish community attributes. We addressed this objective by realizing an adapted Student T test (comparison of a single observation with the mean of a sample) for all the variables on each stream [11]. This test compares unbalanced samples to verity if the observation made in RS belongs to the distribution of the 10 NRS by an analysis of variance and according to normality. It was done for the nine streams and for each variable including physical characteristics and fish density. As our hypothesis was bidirectional the test was performed using a bilateral method which allowed us to detect a difference between two states without referring to the sign of the correlation. An alpha threshold of 0.05 was distributed on each side of the normal curve at 0.025 due to the bilateral method [10]. A boxplot was used to illustrate the distribution of the 10 NRS for each variable and for the nine streams and 17 surveys. Performing several independent tests may sometimes not detect the significance individually due to low sample size, while the combination of all of these probabilities can demonstrate a significant trend. The Fisher statistic was realized for each variable and fish density: a vector containing all p-value obtained in those 9 surveys was analyzed to see if there is a general significant trend among all surveys for each variable [3].

Nested linear mixed-models (LMM) were used to develop a model that explained fish density (response variables), as a function of explanatory variables (percent coverage: macrophytes, woody debris, rocks>6cm, canopy and hydraulic features: water depth, flow velocity and wetted stream width) and our random effects (visit and stream). All the explanatory variables were initially included in the model as the fixed effects [14]. LMM were compared using the "Akaike Information Criterion" (AIC), which compares models based on a compromise between the quality and complexity [8,14]. Spatio-temporal variables or the random effects were included in models to assess the ecological effects of RS across agricultural streams and account for the hierarchical nature of the data.

3 RESULTS

The fisher test showed that RS was different from the distribution of the 10 NRS sites for those explanatory variables: higher percent coverage of rock (p-value < 0.001), a higher flow velocity (p-value < 0.001), a smaller wetted stream width (p-value < 0.001) (Figure 3) and a smaller water depth (p-value < 0.01).

The best LMM found combine hydraulic conditions as wetted stream width, water depth, and velocities as fixed effects and also the percent coverage of rock (Table 1). LMM indicated that overall fish density was significantly explained by fixed effects (R^2 = 35.7% : Marginal R^2) and by random effects (R^2 = 24.2) which lead to a model accounting for 59.9% (Conditional R^2). LMM created for density indicates negative impacts of water depth and flow velocity on fish. An increase of flow velocity and an increase of water depth over the initial value will decline the total fish density. An interaction between rocks and wetted stream width on fish densities was also observed (p-value = 0.0195) (Figure 4). This interaction showed that increasing the percentage of rock cover increases the fish density, if the initial wetted stream width is maintained. The RS showed a decrease of water depth and an increase of flow velocity, which are both negative for fish density. The RS showed an increase of rock coverage, but show a decrease of wetted stream width which is negative for fish density as the model indicates.

Figure 3. Boxplot representation of the wetted stream width (left) and flow velocity (right) found in 10 NRS for each surveys. The whiskers were extend to represent 100% of the distribution of all points (range=Inf) and the bold line shows the means of the distribution. The black dots were added to the graph and correspond to the

values found at the RS. Letters represent the streams and the number next to it represent the visit (ex: A1= Stream A at the first visit).

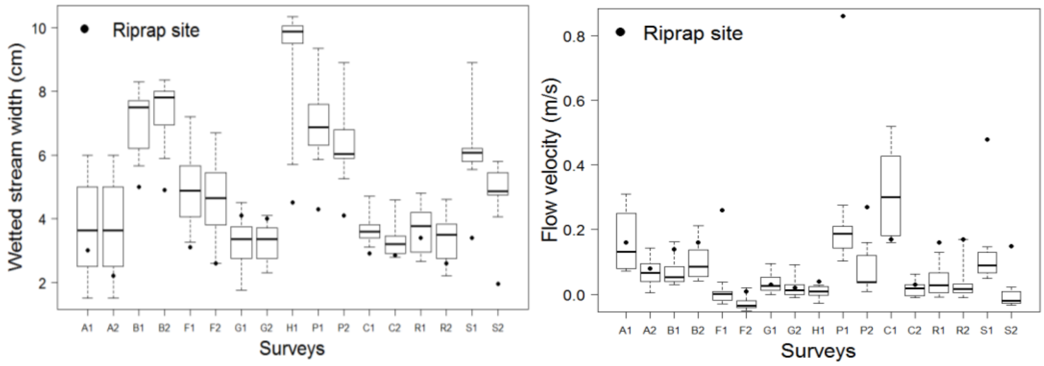
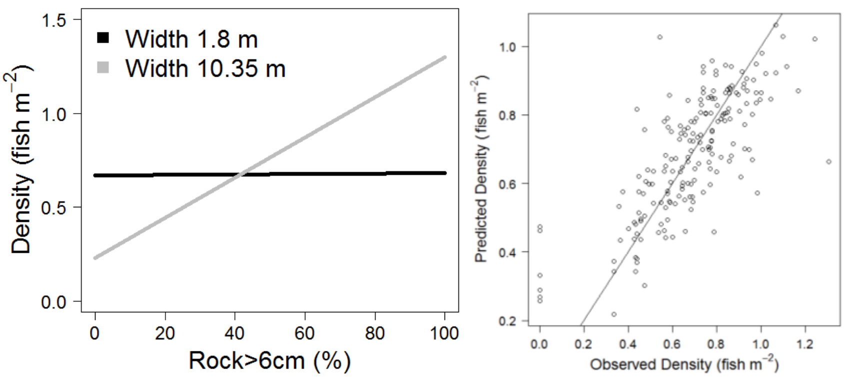


Table 1. LMM quantifying the relative effect of fixed effects (rock, wetted stream width, water depth, interaction between wetted stream width and rock). For each explanatory variable, the estimate and probability are showed.

Explanatory Variable	Estimate	Probability
Rock	0.07722	0.0000
wetted stream width	-0.06934	0.0003
water depth	-0.04071	0.0011
flow velocity	-0.02942	0.0175
wetted stream width : rock	0.04588	0.0195

The predictive power of LMM was assessed by cross-validation (jackknife leave-one-out procedure). This method consists of removing each site sequentially in order to predict fish density based on a model developed with the remaining sites. A R^2_{CV} was calculated for fish density [5]. R^2_{CV} can vary between $-\infty$ and 1. When all predictions perfectly match the observations, R^2_{CV} equals 1, values above 0 indicate accurate predictions, and 0 or negative values indicate that predictions have poor accuracy, being no better than what would be expected from chance alone (Figure 4).

Figure.4. (Left) Diagram representing the interaction between wetted stream width and the percent of rock coverage for the fish density. (Right) Graphic representing the predictive power assed by cross-validation (jackknife leave-one-out procedure) of the predicted density on the observed density.



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