Effect of riparian vegetation on habitat metrics

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ABSTRACT: In natural channels, velocity magnitude, as well as spatial velocity gradient, are among the main drivers of aquatic organism motion, mainly related to feeding, reproduction and searching for optimal environmental conditions. Such hydrodynamic heterogeneity can be described with habitat metrics based on velocity gradients as M_1 and M_2, that quantifying local changes in kinetic energy, approximate the energy expended by fish and all other aquatic organisms to move from one point to another within the flow. Riparian lands and their vegetation, recognized as areas of high biodiversity, are characterized by a strong shear developing at the interface between two approximately parallel streams of different velocities, such as the main channel and the vegetated zone. In this study, the effect of riparian vegetation density on the above metrics was experimentally investigated. Riparian plants were modeled with rigid cylinders arranged in different streamwise and spanwise spacing distances. It was found that, vegetation density significantly affects the metrics M_1 and M_2 in the channel cross-section, with peak values in the shear layer, while the lower values observed in the vegetated zone, can allow aquatic organisms to exploit a water volume for feeding, resting, refugee, and reproduction.

1 INTRODUCTION

The riparian zones have an important role in the maintenance of aquatic ecosystems and affects composition and characteristics of the aquatic organisms as fish (Leite et al. 2015). Riparian vegetation largely affects the flow structure. In fact, in the vegetated area the velocity, due to the increased flow resistance, is lower than in the main channel, and a strong shear layer develops between the two zones of the channel (Caroppi et al. 2021; Yan et al. 2022). Such hydrodynamic heterogeneity can strongly influence habitat selection by the aquatic organisms as fish (Lacey et. al. 2012; Trinci et al. 2017).

Crowder and Diplas et al. (2000, 2002) proposed two potential habitat metrics related to local velocity gradients and changes in kinetic energy:

$$M_1 = U_{avg}\left|\frac{U_2-U_1}{\Delta s}\right| \tag{1}$$

$$M_2 = 2U_{avg}\left(\frac{\left|\frac{U_2-U_1}{\Delta s}\right|}{U_{min}^2}\right) \tag{2}$$

where U_1 and U_2 are the average velocity magnitudes at points 1 and 2, measured a distance Δs

apart in the direction in which the spatial change in kinetic energy is being computed, U_{avg} is the average velocity magnitude between U_1 and U_2, U_{min} is the minimum value of U_1 and U_2, and s indicates the direction of the line between points 1 and 2.

M_1 is the spatial gradient of kinetic energy per unit mass and per unit distance (J/kg•m). It is proportional to the drag force on an organism and a measure of the amount of power expended in moving from one location to another. M_2 is similar to M_1 but scaled by kinetic energy of the flow at the point of lower velocity, so it is indicative of the average rate of change in kinetic energy per unit mass and unit length between two points (1/m). M_2 provides a measure of how much energy an aquatic organism must expend moving from the lower velocity location to the higher velocity one.

Such metrics have been adopted to characterize and describe the stream habitat heterogeneity in area with complex features and higher velocity gradients such as confluences and boulders (Gualtieri C. et al. 2017, 2020; Kozarek et al. 2010; Golpira et al. 2022). Therefore, in this study M_1 and M_2 are used to quantify the habitat heterogeneity of the riparian vegetation.

In laboratory studies, cylindrical-shaped objects areoften used to model vegetation in fluvial environments (Caroppi et al. 2018; Zhao et al.2019) and to study swimming mechanics and behaviour of fish in altered flows (Liao 2007; Liao et al. 2013).

Riparian vegetation is frequently composed of rigid, erect, and non-submerged elements. Thus, in this study, vegetation stems were represented as rigid cylinders arranged in different streamwise and spanwise spacing distances, to model different densities. The aim of the research is to experimentally evaluate the effects of riparian vegetation density on the lateral distributions of M_1 and M_2.

2 MATERIAL AND METHODS

Riparian vegetation was experimentally investigated in a 8 m long and 0.4 m wide flume at the Laboratory of Hydraulics at the University of Naples Federico II (Figure 1). The flume slope was set to 0.48%. The bottom of the flume was fully covered with perforated acrylic plate, in which wooden cylinders of height k=45 mm and diameter d=4mm, were arranged in an aligned grid pattern. Three different spacing between the cylinders, in the streamwise Lx and spanwise Ly directions, were considered, to model different densities or frontal area per canopy a=d/(LxLy) (Table 1). In the tree test case, the flow rate was equal.

The flow velocity was investigated along a transversal mid depth transect using Acoustic Doppler Velocimetry (ADV). All the velocity measurements were performed in the reach of the flume where uniform flow conditions were restored, approximately 4.5m upstream of the channel outlet. In the range of considered flow rates, the uniform flow reach was identified analyzing the backwater profiles. The cross-section distribution of flow depth was measured at different locations observing a negligible variability. Details on the laboratory flume and full research data associated with this study can be found in Caroppi et al. (2020a, 2020b, 2020c).

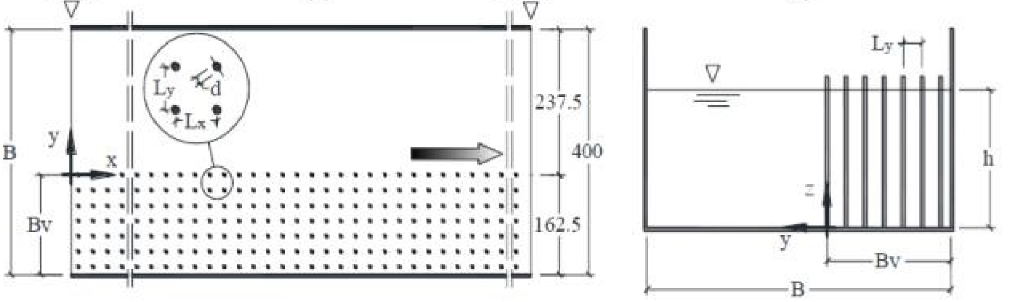

Figure 1. Sketch of the experimental research setup and vegetation canopy configurations: (a) plan view; (b) cross-section view (from Caroppi et al. 2020)

For the coordinate system employed, x=0 is set at the flume inlet, positive downstream; y=0 is set at the interface between the vegetated area and the main channel, positive to the main channel; and z=0 is set at the bottom of the flume, positive upwards. In this coordinate system, the longitudinal velocity component was denoted as U.

Habitat metrics M_1 and M_2 were calculated for the different hydrodynamics conditions and vegetation density (Table 1), in a lateral section within a stream reach of the riparian vegetation.

Table 1. Details of experimental conditions

Test case	I	II	III
L_x (mm)	25	100	200
L_y (mm)	50	50	50
φ (-)	0,0127	0,0032	0,0016
a (m^{-1})	3,6	0,9	0,45
Q (l/s)	31,7	31,7	31,7
h (mm)	135	122	111

3 RESULTS AND DISCUSSION

3.1. Lateral profiles of the mean streamwise velocity

The lateral profiles of the mean streamwise velocity of all tests are shown in Figure 2. The profiles are smoothed to remove the cylinder-scale heterogeneity (White and Nepf 2008). As a result of the riparian vegetation resistance, flow velocity decreases within the vegetated area while it increases in the main channel, and a shear layer develops, with a characteristic inflection point in the lateral profile of the mean streamwise velocity. The velocity tends to reach a constant value both within the vegetated area and in the main channel.

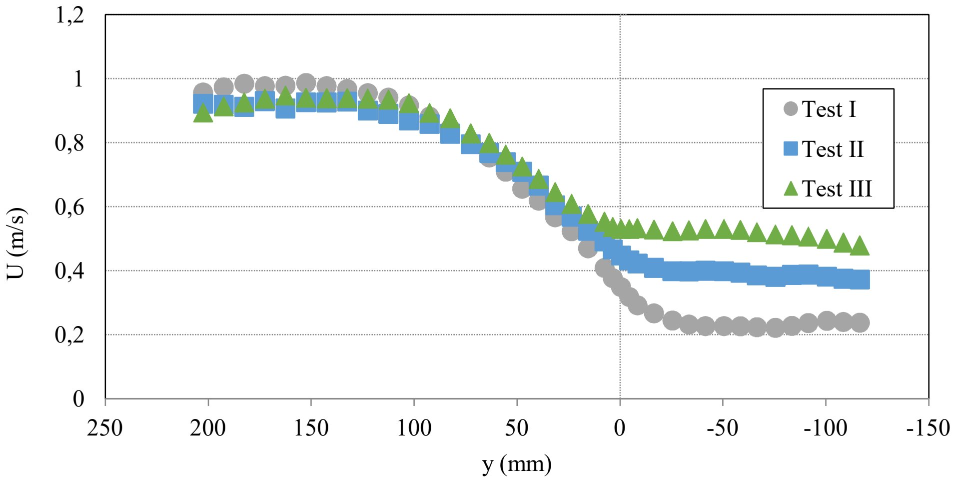

Figure 2. Lateral profiles of the mean streamwise velocity

3.2. Habitat metrics

The lateral distributions of M_1 and M_2, are shown in Figures 3 and 4, respectively. The profiles are smoothed to remove the cylinder-scale heterogeneity.
In Figure 3, M_1 peaks in the main channel, near the interface with the vegetated zone, and a decreases towards both the main channel and the vegetated zone, where M_1 has a constant value. As the vegetation density decreases, the peak decreases and slightly moves towards the main channel.

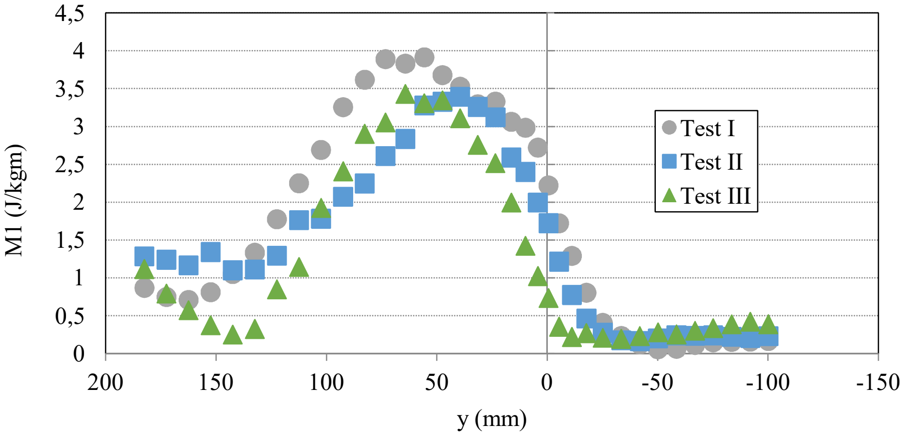

Figure 3. Lateral distributions of the habitat metric M_1

In Figure 4, M_2 peaks around the interface clearly decreases towards constant values, in both the main channel and the vegetated zone. Moreover, as the vegetation density decreases, M_2 peak decreases and tend to move from the vegetated zone to the main channel.

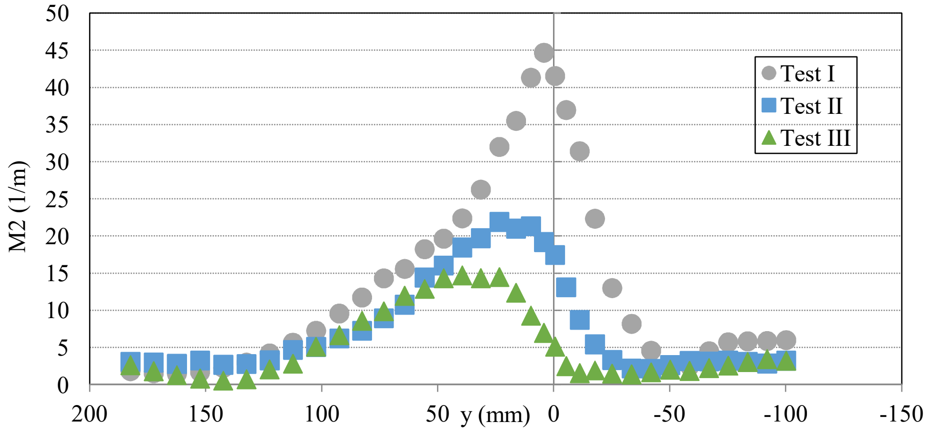

Figure 4. Lateral distributions of the habitat metric M_2

Thus, for each riparian vegetation density, the energy expend for an aquatic organism to move across the interface is larger than that within the two flow layers. The peak value at the interface increases with the vegetation density. Those smaller values of M_1 and M_2 in the vegetated zone, suggest that it could be a resting area and a refuge for aquatic organisms.

4 CONCLUSIONS

Hydrodynamic heterogeneity due to riparian vegetation can strongly influence habitat selection by aquatic organisms. In fact, the energy expended by fish to move from one point to another within the channel is fundamentally proportional to the velocity gradient existing between these points. Two habitat metrics, namely M_1 and M_2, have been proposed to approximate such energy expenditure.

In this study , the preliminary results about the effects of riparian vegetation density on M_1 and M_2 of riparian vegetation, are presented. Riparian plants were represented as rigid cylinders arranged in different streamwise and spanwise spacing distances, to model different vegetation densities. It was found that riparian vegetation density significantly affects the distribution M_1 and M_2, which increase as the vegetation density increases. The small values of the metrics found in the vegetated zone suggest that this region could be suitable as resting zone and refuge as for the aquatic organisms.

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