Validation of a sediment connectivity binary model improved with a probabilistic approach in the effect of prairie strips

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Introduction

Several studies of prairie strips have proven their effectiveness in reducing sediment transport, so they can **partially disrupt sediment connectivity (SC) in agricultural landscapes.** These studies are complemented with models like the one of Mahoney et al. (2018), who developed a catchment scale SC binary model. However, in this model, sediment disconnectivity caused by prairie strips might not be accurately represented, as it does not entirely interrupt SC. Muñoz et al. (2023) noted that the impact of similar structures as vegetative barriers on **sediment trapping (ST) could be described through a probabilistic approach, appraising the probability that vegetative barriers would achieve a given sediment trapping.**

This communication presents a preliminary version of the validation of a SC binary model improved with a probabilistic approach to the effect of prairie strips to achieve the following objectives:

1- To validate the introduction of structures such as prairie strips for SC models.

2- Analyze the performance of prairie strips in buffer disconnectivity.

Materials and Methods

1- The STRIPS project's sediment load results were obtained from a catchment-scale experiment at Neal Smith National Wildlife Refuge (NSNWR) in the Walnut Creek watershed in Jasper County, Iowa, USA (Helmers et al., 2012). This experiment involved 12 catchments (3 controls, 9 treatments) in three zones within the refuge: Basswood (Bsw), Interim (Int), and Orbweaver (Orb). It consisted of **different treatments altering the proportion of prairie strips concerning the overall catchment** area (0, 10, 20%) **and the position or number of the prairie strips** (*Foot* for one strip at the end of the catchment and *Side* for two or more prairie strips): *0Row* (Control), *10Foot*, *10Side* and, *20Side*, respectively.

2- Mahoney et al. (2018) developed a **SC model that depends on intersecting probability hydrological and non-hydrological theory.** With a binary system, they combined some secondary individual probabilities to create an approach for SC probability *P(C)* (**Fig. 1**) where *P(S)* is the probability of sediment supply, *P(D)* is the probability detachment (hydrologic and non-hydrologic), $P(T_H)$ is the probability hydrologic transport (upstream and downstream), and *P(B)* is the probability buffer:

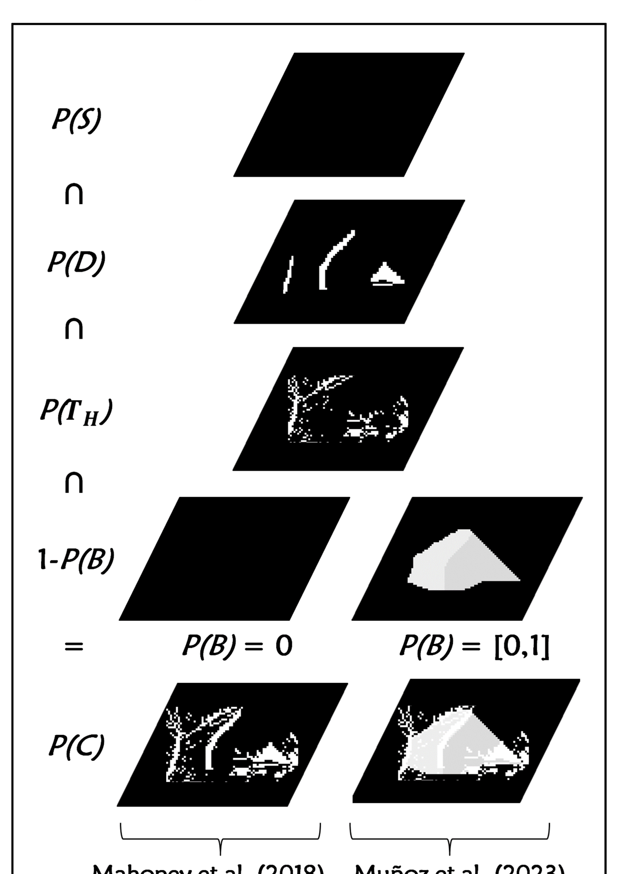

Figure 1: Probability-based models of sediment connectivity of (left) Mahoney et al. (2018), and (right) the proposed approach of Muñoz et al. (2023).

$$P(C) = \{P(S)\} \times \{P(D)\} \times \{P(T_H)\} \times \{1 - P(B)\}$$

P(B) is susceptible to features that can disconnect the entire upstream area.

3- We **modified the *P(B)* function** (originally being a binary probability; 0 or 1). This modification was based in **the probabilistic approach of Muñoz et al. (2023), considering the whole range from 0 to 1 (Fig 1)**. In this approach, we assimilated sediment trapping efficiency (STE) to the hydrologic disconnectivity of a single buffer.

4- **We calibrated the SC model using the ST efficiency (STE) of a catchment with buffers**, calculated as the ratio of the sediment loss of the catchment divided by a similar control catchment without buffers.

We estimated the model parameters according to Mahoney et al. (2018), except ***P(B)* which underwent calibration.** The calibration consisted of a linear relationship between *P(B)* and STE, with *P(B)* being 0 when STE is 0% and 1 when STE is 100%.

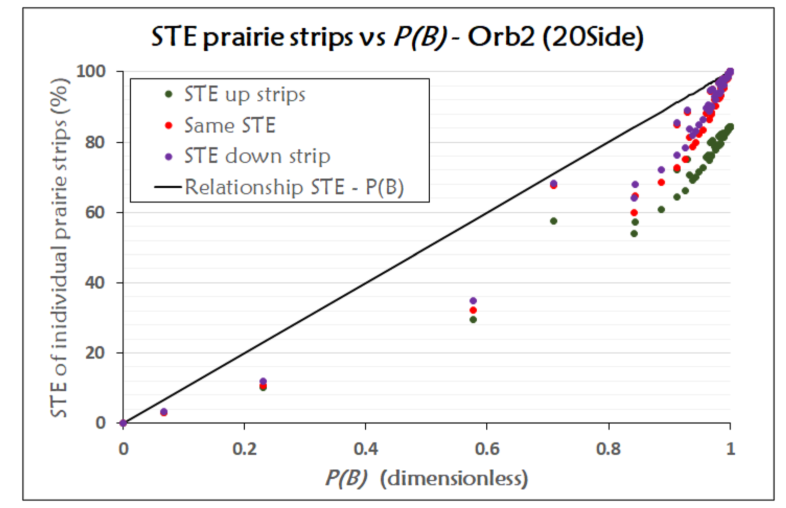

Figure 2: STE values of the individual prairie strips to obtain the estimated *P(B)*. Red dots: same value; purple and green: proportional values based on the width.

5- This evaluation allowed a backward estimation of buffer efficiency across different events, leading to a significant improvement of the model to develop results for practitioners, as showcased in this poster.

To facilitate calculations for catchments with multiple buffers, we evaluated different assumptions. One is that all buffers had the same STE. The other is that *P(B)* is proportional to the buffer width using a logarithmic relationship calculated from a combination of experimental results from this study and a literature review (**Figs. 2 & 3**).

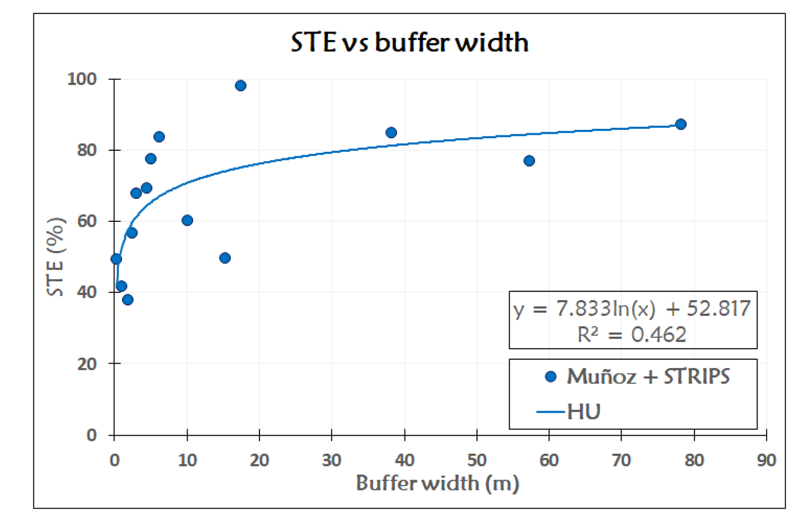

Figure 3: Logarithmic trend of the average STE (%) regarding the vegetative strip width (m). Based of Muñoz et al. (2023).

A complementary analysis explored the correlation between sediment load (for events and cumulative for the whole study period) **and *P(C)* at the end of the catchment.**

We executed the model in PyQGIS; **Table 1** shows the primary inputs.

Table 1. Inputs employed in the model. R is raster file; V is vectorial file.

INPUT	NAME	R/V	ud.	SOURCE
Elevation Filled	DEM_Filled_2010m.tif	R	m	https://acpfdata.gis.iastate.edu/ACPF/DEM/
Soil Management	Neal_Smith_CORN.shp Neal_Smith_SOY.shp	V		2 different shapefiles due to the crop rotation. Prairie strip areas delimited manually
Prairie strip area	"Basin_Name".shape	V		Prairie strip area delimited manually. Each basin has an individual shapefile
Organic Matter	mo_Ave_030_Calc.tif	R	%	https://soilgrids.org/
Sand	Sand_Ave_030_Calc.tif	R		
Silt	Silt_Ave_030_Calc.tif	R		
Clay	Clay-Ave_030_Calc.tif	R		
Soil Hydrologic Group	GH_Soil_STRIPS.tif	R		https://acpfdata.gis.iastate.edu/ACPF/
Curve Number	Values_CNII.csv	-		Values from Hawkins et al (2009)
Precipitation	-	-	mm	numerical manual input
Antcedent moiture conditions	-	-		String manual input with 3 options (I, II, III)

Preliminary results

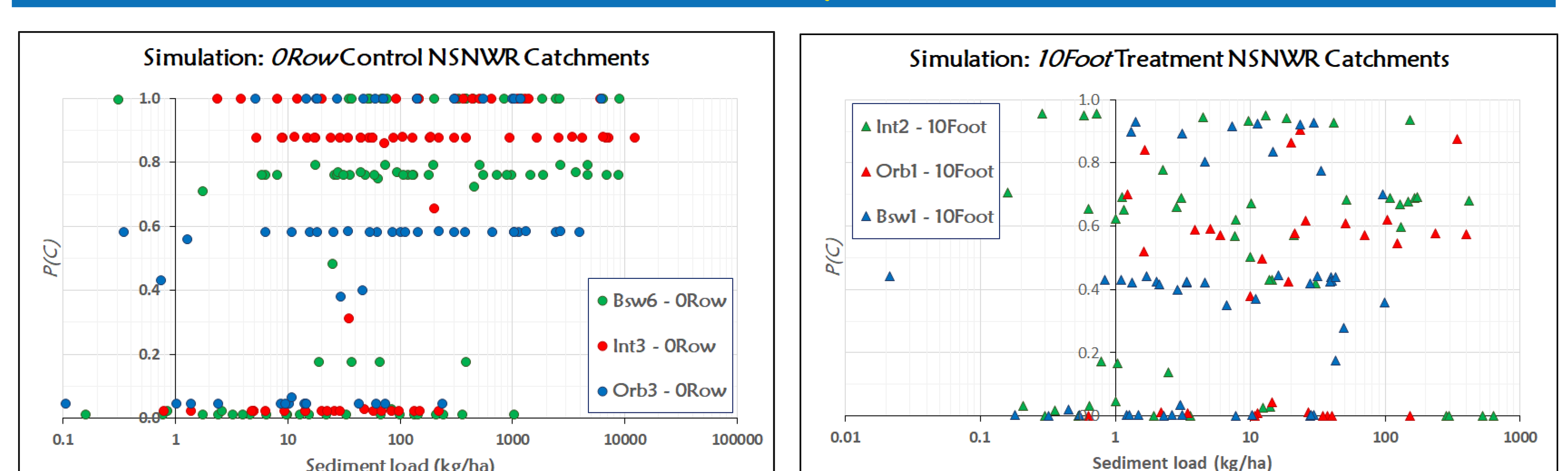

Figure 4: Relationship between final *P(C)* (dimensionless), and sediment load (kg/ha). Left: Control catchments with no prairie strips (*0Row*); right: Treatment catchments with 1 strip at the footslope of the catchment with an area ratio of 10% (*10Foot*).

Fig. 4 shows the results of the events' simulations comparing *P(C)* (model calculated) with measured sediment load. It illustrates that despite identical *P(C)* values, sediment load presents a high variability, stating that the same absolute values of connectivity can be quite different. This variability might be due to model limitations in mimicking key factors (e.g., antecedent moisture condition, rainfall intensity) that can have a large impact on soil losses.

Due to this large variability, we opted to analyse relationships between average values of sediment connectivity *P(C)* and sediment load of the entire study period (2007 – 2013). The average trapping efficiency values were obtained from an arithmetic mean of the estimated trapping efficiency event by event.

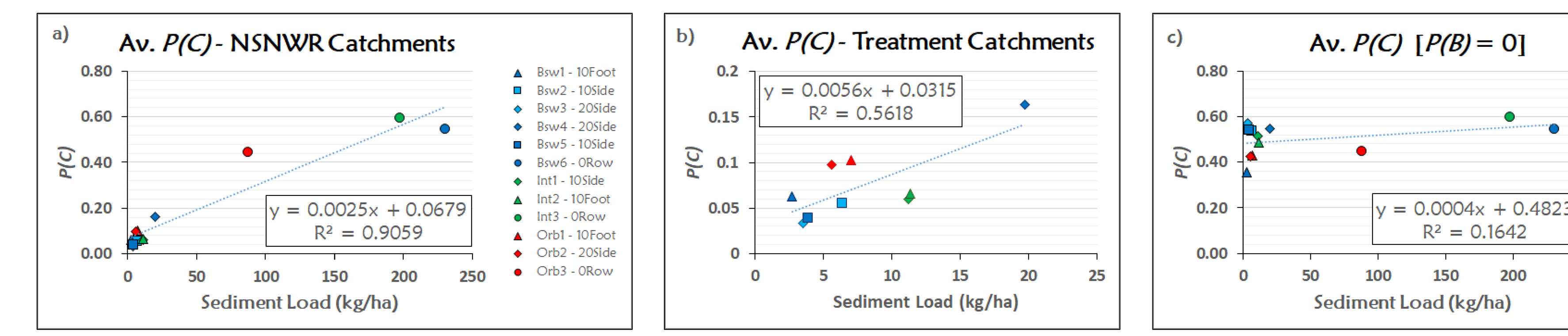

Figure 5: Relationship between average *P(C)* and sediment load (kg/ha). a) NSNWR catchments; b) prairie strips treatment catchments; c) NSNWR catchments without our modification in the *P(B)* function [*P(B)* = 0].

Figs. 5a & b display the relationship between average calculated *P(C)* and sediment load. The correlation with control and prairie strip treatment catchments shows a better relationship than if only prairie strip treatment catchments are considered, but still with a good correlation.

Fig. 5c shows the same relationship as **Fig. 5a** but without our modification in the *P(B)* function (considering that prairie strips are not buffers, being *P(B)* is equal to 0 in all the catchments). In this case, the correlation is weak as the model does not find differences in the performance of SC of the catchments.

Preliminary conclusions

1- The inclusion of a continuous probability (within 0 to 1) in the *P(B)* factor of the Mahoney et al. (2018) model allows appraisal of the STE of prairie strips from experimental studies at the event scale. This analysis shows a large variability in event STE, which ranges from 0 – 100% at the event scale and 70 – 95% in average terms during the study period.

2- We did not find a good correlation between *P(C)* and sediment load at the event scale, but yes at the study period time scale. It implies that the models may be valuable for analyzing long-term trends but may lack precision at the level of individual events.

3- Our communication reflects the utility of the model in understanding relative changes in connectivity at catchment scale. Converting these findings into absolute values requires the combination of the model with erosion predictions at catchment scale with a model providing these predictions of absolute values (as already noted by the authors).

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Acknowledgments

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