META-ANALYSIS OF RIPARIAN ZONE WIDTH EFFECTS ON CONTAMINANT REMOVAL AND BIODIVERSITY

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Abstract

Globally, riparian ecosystems have been extensively studied to determine the influence of buffer width on contaminant removal and biodiversity functions, resulting in many recommendations for widths necessary to conserve riparian functions. This study conducts a meta-analysis of buffer width efficacy to develop empirically based width recommendations for protecting and restoring riparian areas. We compiled existing studies that observed the effect of varying riparian buffer widths on contaminant removal (i.e., removal efficacy) and biodiversity (i.e., species richness). Results indicate that a 40-m corridor width removes 75% of sediment and nutrient inputs across geographies and constituents (n = 26 studies, p-value = 0.022) with grass, as vegetation type, and lower slopes increasing retention. A 30-m corridor provides 75% of species richness outcomes across taxa studied (n = 31, p-value = 0.066). Few studies were available based on the removal of emergent contaminants and herpetofauna, fish, and vegetation as taxa for relative species richness, suggesting potential areas for future research. Overall, meta-analysis results revealed a positive correlation between buffer widths and contaminant removal and biodiversity outcomes, confirming the importance of functional riparian buffers. Through meta-regression, simple equations are provided as a first-order tool for scientists and decision-makers to estimate functional riparian buffer widths.

Keywords: riparian buffer zones; buffer width; removal efficiency; relative species richness; meta-analysis, PRISMA, ecosystem management, stream restoration; conservation; regulations.

Riparian Zones

- Transitional areas between terrestrial and aquatic ecosystems that are located adjacent to a freshwater system (i.e., rivers, lakes, streams, reservoirs, wetlands).

- These zones:
  - Support diverse flora and fauna
  - Retain pollutants (i.e., sediments, nutrients, pesticides, herbicides) from entering freshwater systems
  - Attenuate floods
  - Stabilize streambanks to prevent erosion
  - Provide shade and temperature regulation for nearby water bodies

- Human disturbances can reduce system performance and associated ecosystem services.

Figure 1. Visual aid from the conceptual model that displays (white captions) the riparian zone functions. The visual is divided into four quadrants (urban, agricultural, suburban, natural) to represent the riparian zone functionality adjacent to differing land uses.

Minimum buffer width
- Are essential for reducing disturbance in riparian areas and maintaining ecological functions.

- Studies have reported the effects of buffers on:
  - Contaminant removal outcomes such as sediment, nutrient, pesticide, and herbicide removal efficiency (Lind et al. 2019).
  - Biodiversity outcomes such as species richness for different taxa (Fischer and Fischenich 2000).

Table 1. Worldwide riparian buffer width regulations overview.

Geographic region	Mean (m)	Range (m)	Number of regulations
USA	35	1.5 – 815	62
America (without USA)	83	5 – 500	22
Europe, Asia, Africa, and Oceania	88	5 - 1000	32

Needs
- USACE practitioners need tools for assessing impacts and benefits of riparian management actions with:
  - Immediate screening
  - Interagency adoption of multi-taxa modeling approaches
  - Field evaluation of models

Project Objectives

- Compile and synthesize data on the effects of buffer width on contaminant removal and biodiversity.
- Develop thresholds riparian buffers needed for functional outcomes.

Main Goal
- Provide a complete analysis that compiles and presents a friendly, understandable format to managers faced with trade-offs about conserving, regulating, or restoring riparian zones.

Techniques and Statistical software used

- Method used to synthesize evidence across studies to detect effects, estimate magnitudes and variations and to analyze the factors that influence (Gurevitch et al., 2018).

- PRIMA Guide (Preferred Reporting Items for Systematic reviews and Meta-Analyses) (Moher et al., 2009).
  - Eco-Evo (O'Dea et al., 2021).

R packages:
- 'esc'
- 'meta'
- 'metafor'

Meta-Analysis Information Flow Diagram and Software

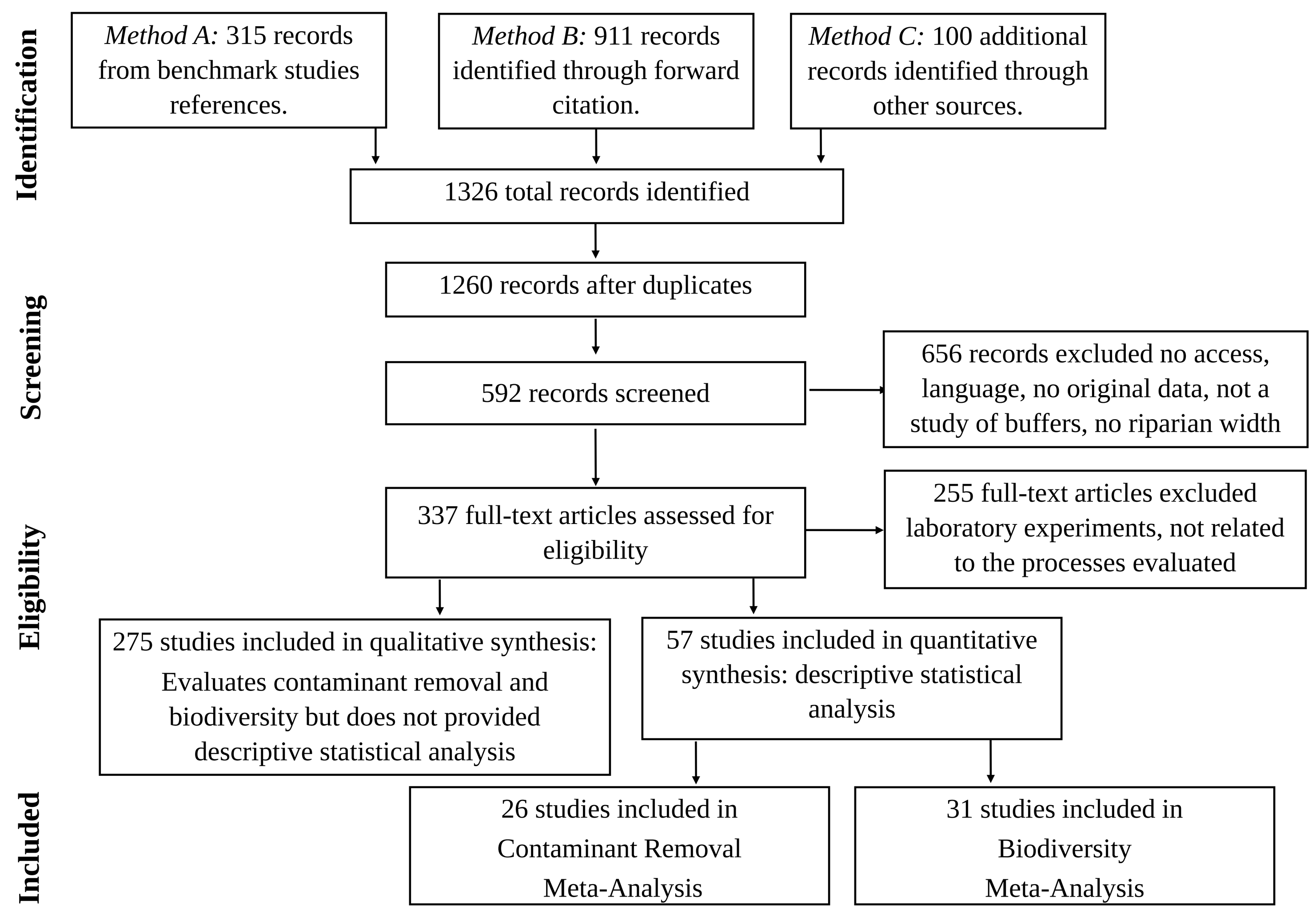


Figure 2. The PRISMA flow diagram shows an overview of the selection, screening, and data compilation process, focusing on riparian area buffer width, contaminant removal and biodiversity. The diagram model was obtained from Moher et al. (2009).

Meta-Analysis: Dataset properties and Outcomes

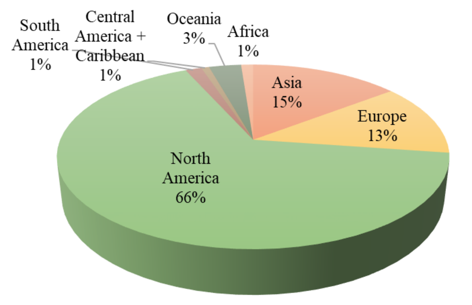


Figure 3. Percentage of studies found by continent.

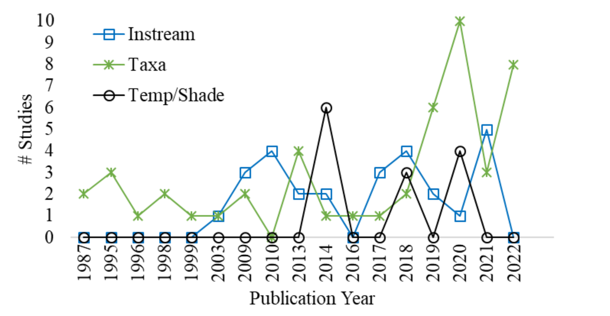


Figure 4. Number of studies published between 1987-2022.

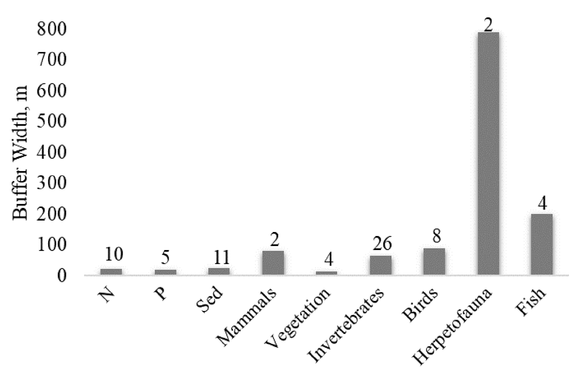


Figure 5. Average riparian buffer width from studies focused on the contaminant removal and biodiversity. Instream processes focus on the removal efficiency of Nitrogen (N), phosphorus (P) and sediments (Sed) are components from contaminants removal included. Biodiversity outcome are divided by taxa (vegetation, mammals, invertebrates, birds, fish and herpetofauna). Number over the bars correspond to the total number of studies.

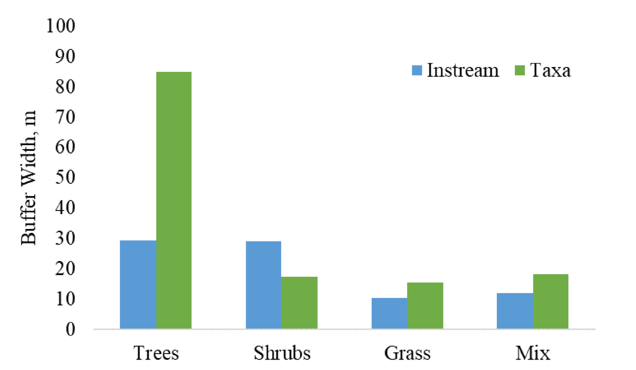


Figure 6. Average riparian buffer width of studies by buffer vegetation composition and outcome variable type (contaminant removal and biodiversity).

Table 2. Data description and meta-analysis outcome for contaminant removal and biodiversity, using correlation as effect size.

	Contaminant removal	Biodiversity
Data Description:		
Total Papers	26	31
Buffer width range	0-100 m	0 – 2088 m
Outcome:		
Meta-correlation (r)	**0.8854**	**0.5957**
95% CI	0.852; 0.918	0.485; 0.706
p-value	< 0.0001	< 0.0001
I^2	84.2%	95.0%

Riparian buffer width was **positive** correlated: **strongly**/contaminant removal **moderate**/biodiversity

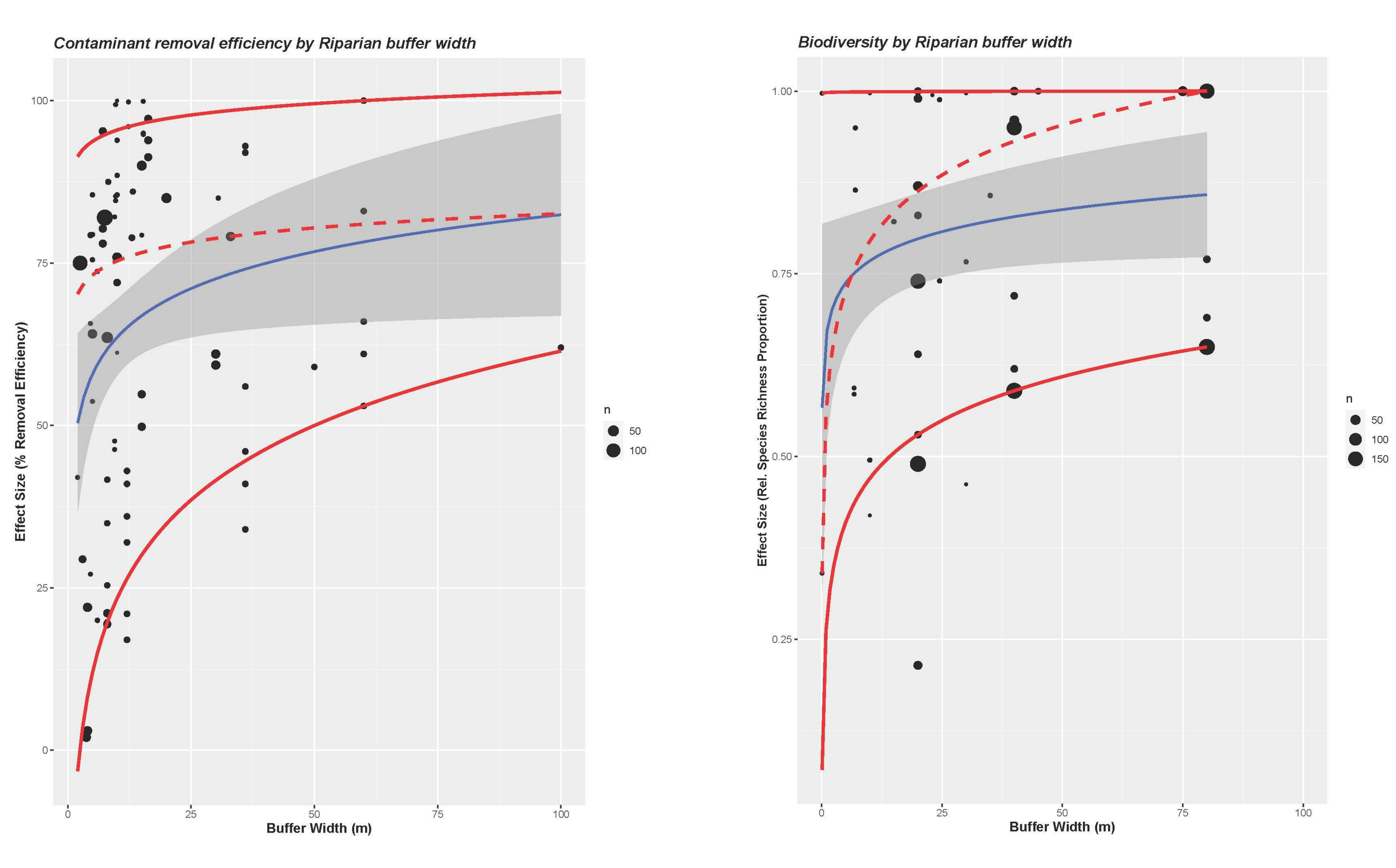


Figure 7. Scatter plot of buffer width and effect size with mean random-effect model regression (blue line) and quantiles (τ = 0.1, 0.5, and 0.9). Left graph corresponds to the contaminant removal model regression; right graph corresponds to the biodiversity model. Red lines are represent the quantile regressions: the top red line is τ = 0.9, the bottom red line is τ = 0.1, and the broken red line in the middle is τ = 0.5. The gray shadow represents the 95% confidence. Each data point represents a study added to the meta-analysis, and the size of the data points represents the sample size from each study.

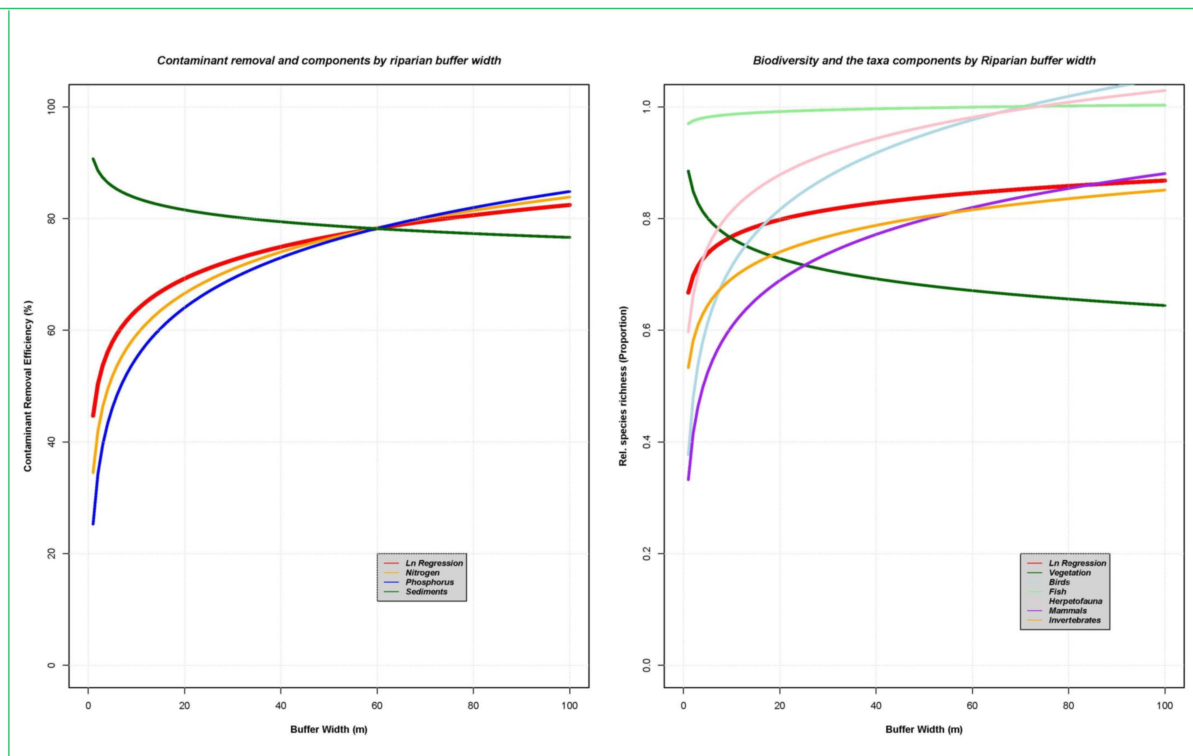
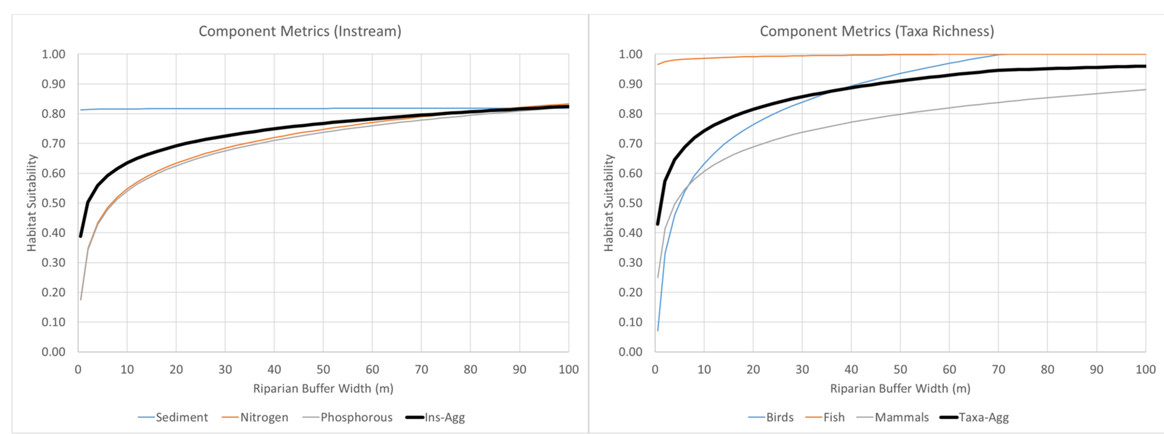


Figure 8. Left graph: Contaminant removal outcome: logarithmic random-effect model regression for all contaminants (red line) and the following sub-groups: sediment (dark green line), nitrogen (orange line) and phosphorus (blue line).
Right graph: Biodiversity outcomes: Random-effect model regression a logarithm model (red line) and sub-groups regressions. The taxa: vegetation (dark green line), birds (light blue line), fish (light green), herpetofauna (pink line), mammals (purple line) and invertebrates (orange line) are the sub-group classification.

Table 3. Contaminant removal and biodiversity outcome regressions (Together and by component). Predicted riparian buffer width outcome based on a 75% response variable efficiency of contaminant removal and biodiversity outcome regressions.

Outcome		Logarithm Regression	Buffer Width (m) with 75% effectiveness
Contaminant removal	**All**	**Y = 44.706 + 8.194 ln (x)**	**40.3**
	N	Y = 34.520 + 10.710 ln (x)	43.8
	P	Y = 25.314 + 12.929 ln (x)	46.7
	Sediment	Y = 90.704 - 3.055 ln (x)	170.8
Biodiversity	**All**	**Y = 0.667 + 0.044 ln (x)**	**6.6**
	Vegetation	Y = 0.885 - 0.052 ln (x)	13.4
	Birds	Y = 0.377 + 0.146 ln (x)	12.9
	Fish	Y = 0.970 + 0.007 ln (x)	0.0
	Herpetofauna	Y = 0.597 + 0.094 ln (x)	5.1
	Mammals	Y = 0.333 + 0.119 ln (x)	33.3
	Invertebrates	Y = 0.533 + 0.069 ln (x)	22.9

Translating the Meta-Analysis into Habitat Suitability



HYPOTHETICAL PROJECT

Example restoration scope:
Reach length = 1 mile. Riparian buffer width ~ 25ft. (representative state minimum)

Three potential objectives and associated actions:
- Increase stream stability: Increase to 50 ft (~15m)
- Enhance water quality: Increase to 100 ft (~30m)
- Provide habitat: Increase to 200 ft (~60m)

Width (ft)	Area (ac)	SI (CR)	SI (B)	HSI	Habitat (HUs)	Lift (HUs)
25	3.2	0.62	0.72	0.67	2.1	0.0
50	6.4	0.67	0.79	0.73	4.7	2.6
100	12.8	0.73	0.86	0.80	10.2	8.1
200	24.7	0.79	0.93	0.86	21.2	19.1

Conclusions

- Worldwide studies suggest a riparian buffer width over the 6m, which will improve the water quality and provide an healthy corridor.

- Meta-analysis results revealed a positive correlation between widths and the contaminant removal/biodiversity outcomes observed, suggesting that riparian protection and restoration is crucial to improving biological processes and diminishing instream impacts.

- Contaminant removal and biodiversity models were generated, intended for managers to estimate functional buffer thresholds with the aim of conserving, regulating, or restoring riparian zones.

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References are available on request.

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