META-ANALYSIS OF RIPARIAN ZONE WIDTH EFFECTS ON INSTREAM PROCESSES AND TAXA RICHNESS

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EMRRP Webinar Series
January 2024

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PRESENTATION OVERVIEW

- Overview of riparian zones and approach to model development
- A brief primer on meta-analysis
- Meta-analysis of riparian buffers
- Using the meta-analysis to develop a screening model for riparian zones

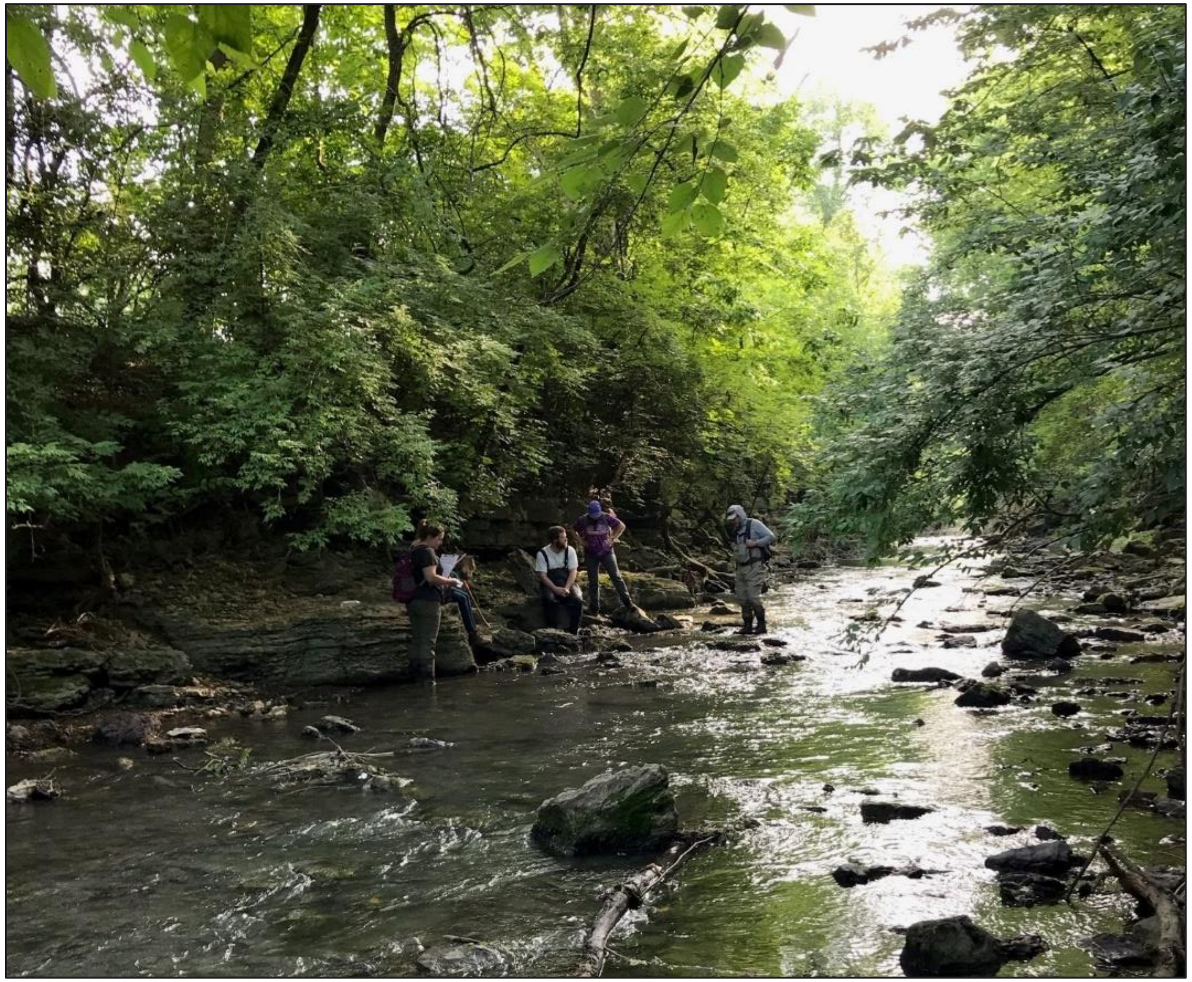


Photo: Beargrass Creek, Louisville, Kentucky (Laura Mattingly)

OVERVIEW OF RIPARIAN FUNCTION AND PROCESS

RIPARIAN ZONES AS KEY TRANSITIONAL ECOSYSTEMS LINKING FRESHWATER AND TERRESTRIAL AREAS

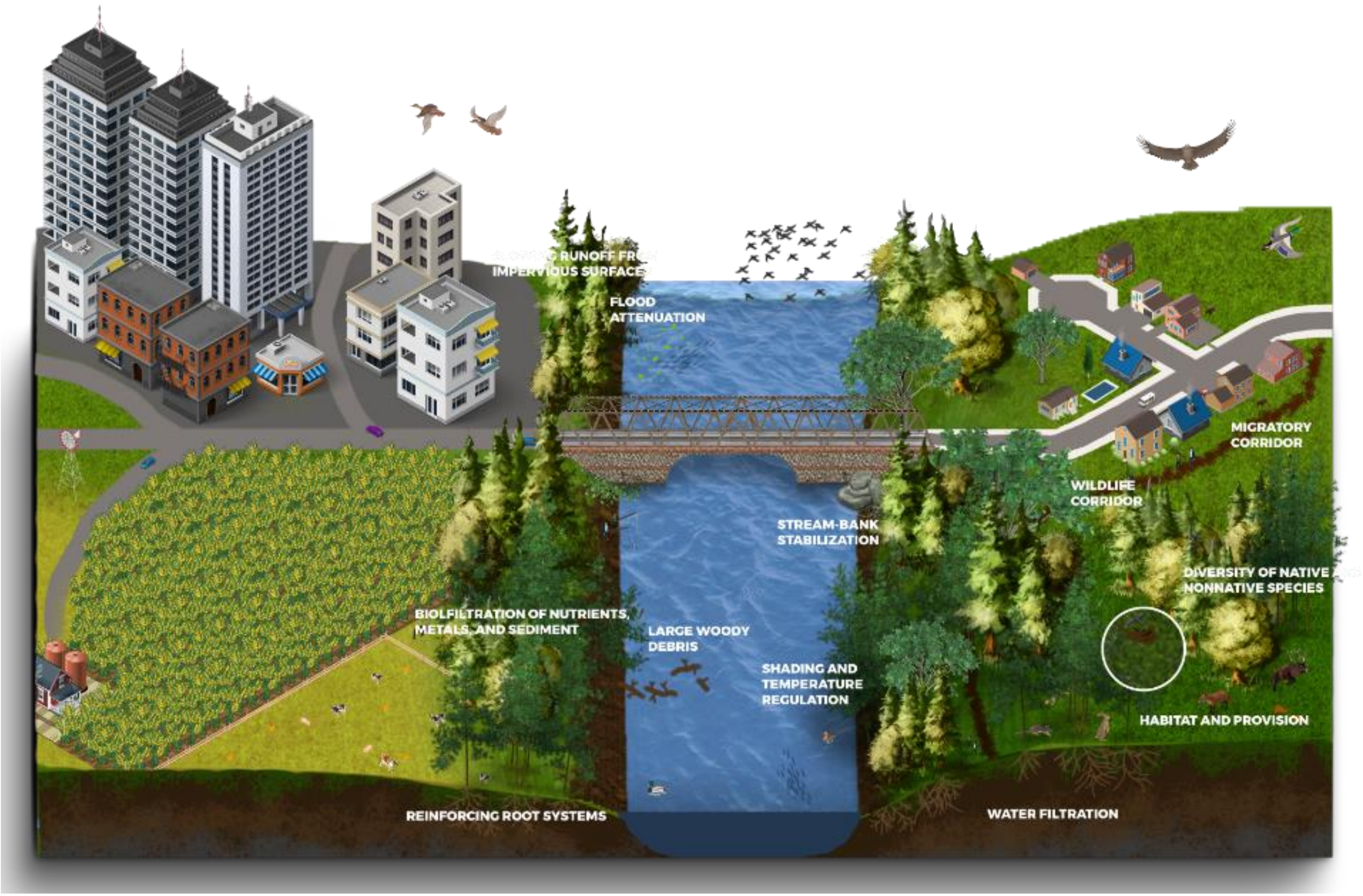
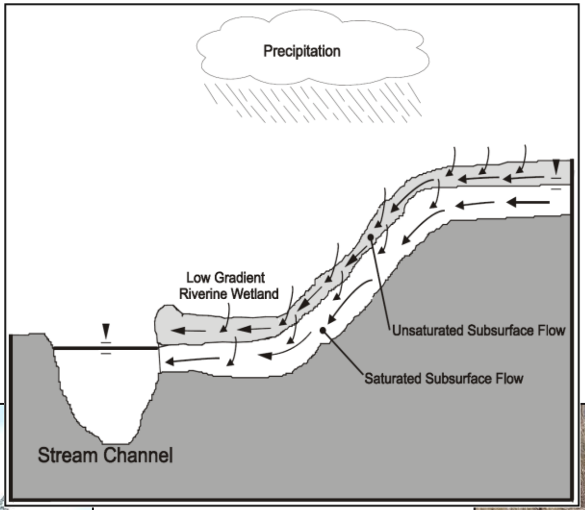


Figure: Conceptual model of riparian functions (Samantha Wiest)

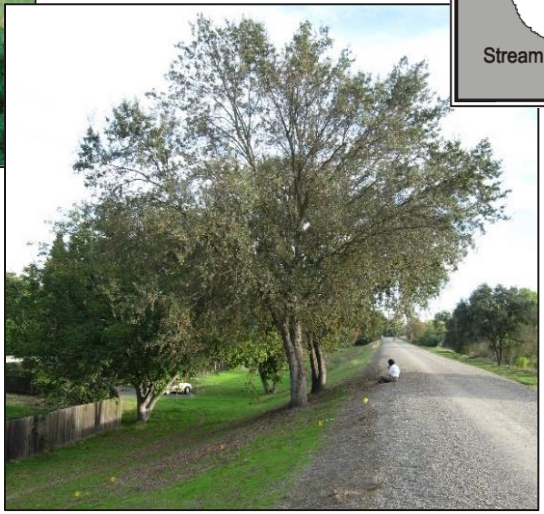
LOTS OF FORMS OF RIPARIAN MANAGEMENT

Regulatory choices about buffer widths (usually state and local)

Regulatory Riparian Wetlands



Impact Assessment



Restoration Benefits

Figures: Mississippi River Basin Conservation Network, Ainslie et al. (1999, ERDC WRP-DE-17), Sacramento levee system, California (McKay), Proctor Creek, Atlanta, Georgia (McKay)

DIFFERENT FUNCTIONS => DIFFERENT WIDTHS

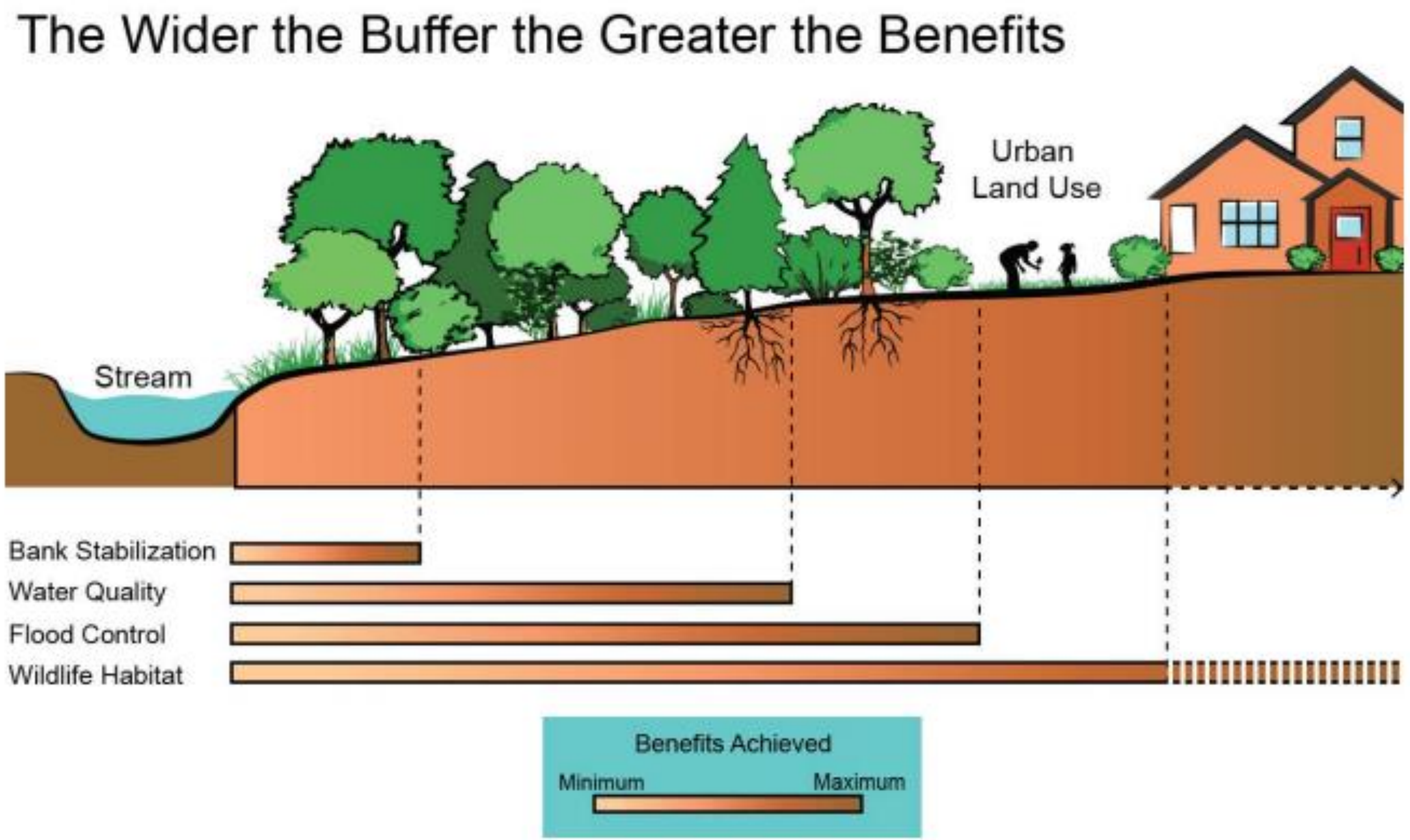
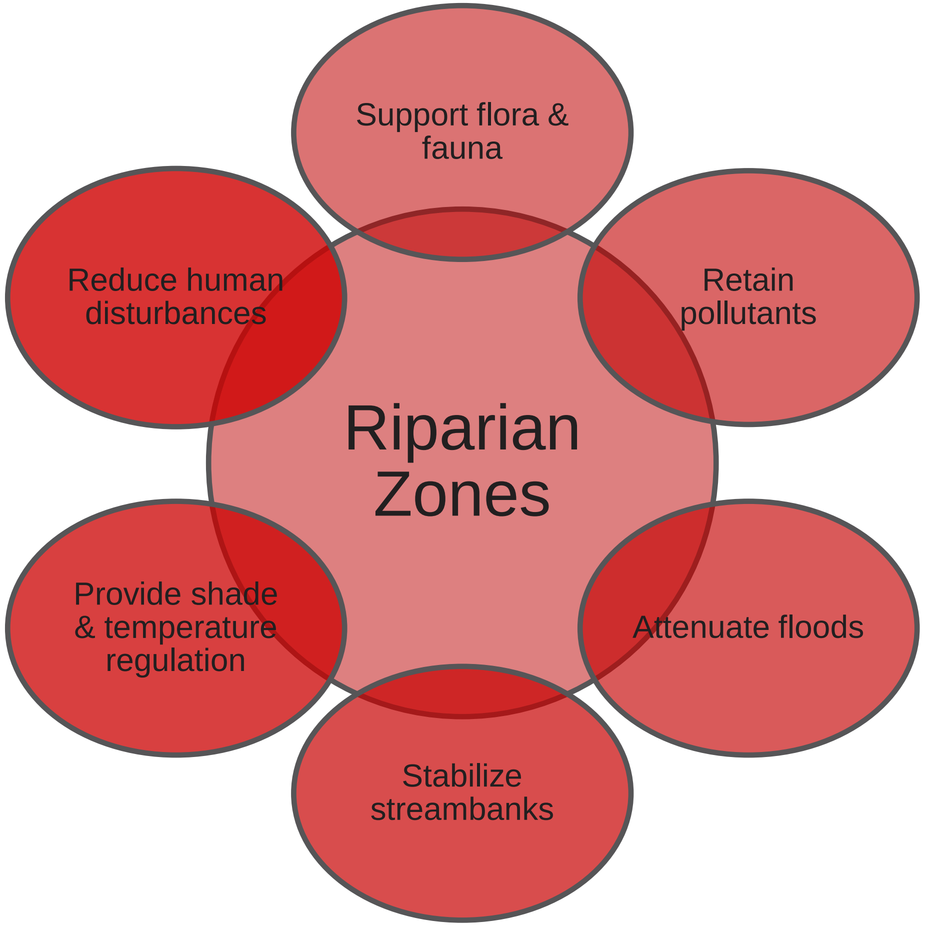


Figure: University of Tennessee (https://riparian.utk.edu/why-riparian-zones/)

WIDTH AS A SURROGATE FOR MANY PROCESSES



Target widths vary widely by jurisdiction, context, and other factors

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

TIERED APPROACH TO RIPARIAN MODEL DEVELOPMENT

	Low level of effort	Moderate level of effort	High level of effort
Scope	Rapid, desktop tools for order-of-magnitude estimates comparing sites	Rapid assessment for comparing the relative effects of alternatives at the site-scale	Regionally tailored methods that target specific ecological targets and have often been field verified
Metric Types	Simple geospatial	Simple geospatial Rapid, semi-quantitative field assessment	Typically empirical measurements
Time commitment	minutes-hours	hours-days	varies
Geography	Global meta-analysis	National, on-the-shelf field assessment tool	Regionally scoped models (compiled into a web applications)
Processes included	Instream processes Taxa-oriented outcomes Corridors	Instream processes Taxa-oriented outcomes Corridors	Instream processes Taxa-oriented outcomes Corridors

Levels of effort in ecological modeling:
Harris et al. (2023, ERDC/TN EMRRP-EM-11)

PROJECT OBJECTIVES

- Develop a simple, desktop method for assessing the relative change in riparian quality as buffer width increases
- Compile globally available data on buffer performance and analyze with meta-analysis
  - Compile empirical evidence building from existing qualitative reviews (Wenger 1999, Fischer and Fischenich 2000)
  - Incorporate studies conducted since seminal reviews (i.e., 2000-2021) and expand the focal geography (i.e., US -> Global)
  - Extend beyond water quality outcomes to taxa-oriented processes (Lind et al. 2019)

Table 1. Recommended Widths of Buffer Zones and Corridors for Water Quality Considerations

Authors	State	Width	Buffer Type	Benefit
Woodard and Rock (1995)	Maine	≥15m	Hardwood buffer	The effectiveness of natural buffer strips is highly variable, but in most cases, a 15m natural, undisturbed buffer was effective in reducing phosphorus concentrations adjacent to single family homes
Young et al. (1980)		≥25m	Vegetated buffer	25m buffer reduced the suspended sediment in feedlot runoff was reduced by 92%
Horner and Mar (1982)		≥61m	Grass filter strip Vegetated buffer strip	Removed 80% of suspended sediment in stormwater
Lynch, Corbett, and Mussalem (1985)		≥30m		30-m buffer between logging activity and wetlands and streams removed an average of 75 to 80% of suspended sediment in stormwater; reduced nutrients to acceptable levels; and maintained water tempertures within 1˚C of their former mean temperature.
Ghaffarzadeh, Robinson, and Cruse (1992)		≥9m	Grass filter strip	Removed 85% of sediment on 7 and 12% slopes
Madison et al. (1992)		≥5m	Grass filter strip	Trapped approximately 90% of nitrates and phosphates
Dillaha et al. (1989)		≥9m	Vegetated filter strip	Removed an average of 84% of suspended solids, 79% of phosphorus, and 73% of nitrogen
Lowrance et al. (1992)		≥7m		Nitrate concentrations almost completely reduced due to microbial denitrification and plant uptake
Nichols et al. (1998)	Arkansas	≥18m	Grass filter strips	Reduced estradiol (estrogen hormone responsible for development of the female reproductive tract) concentrations in runoff into surface water by 98%.
Doyle et al. (1977)		≥4m	Grass filter strips and forested buffers	Reduced nitrogen, phosphorus, potassium, and fecal bacteria from runoff.
Shisler, Jordan, and Wargo (1987)	Maryland	≥19m	Forested riparian buffer	Removed as much as 80% of excess phosphorus and 89% of excess nitrogen

Figure: Fischer and Fischenich (2000)

A BRIEF PRIMER ON META-ANALYSIS

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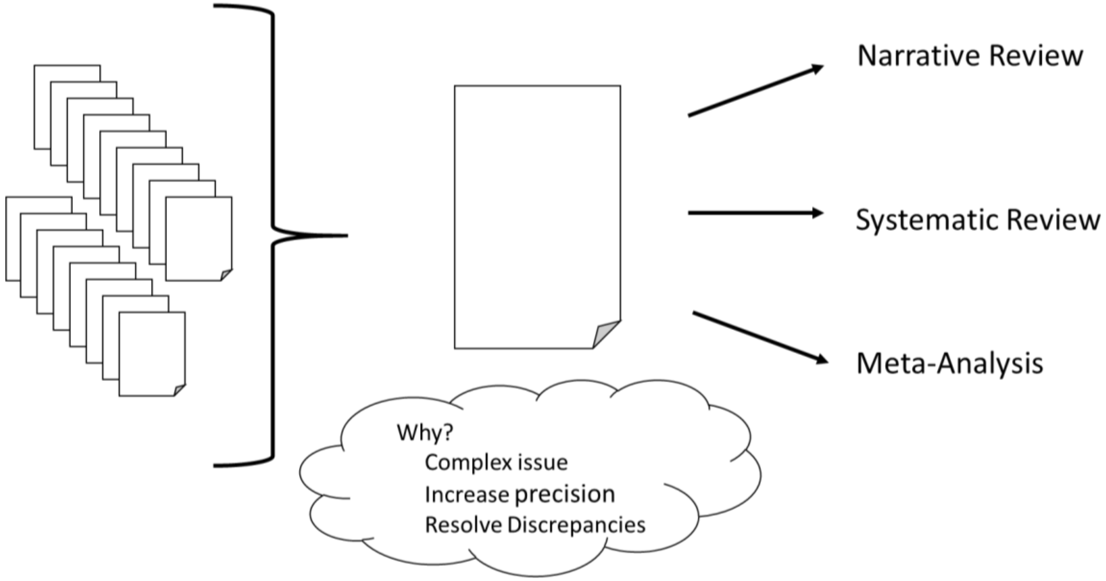
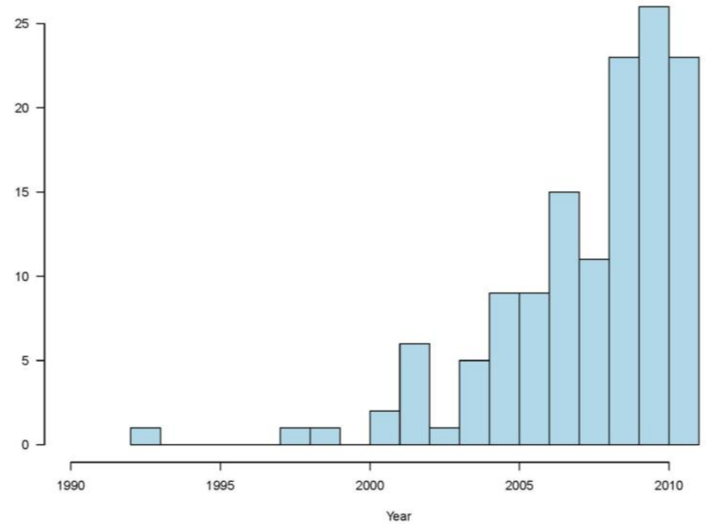
META-ANALYSIS AS A TOOL FOR SYNTHESIZING RESEARCH

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).

- First used on in psychology (Glass 1976) and the medical sciences (Borenstein et al. 2009; Moher et al., 2009).
- Meta-analysis have also been recognized in the fields of ecology and conservation biology with the method becoming increasingly popular since the 1990s (Vetter et al., 2013).





. Increase in publications since 1992 in which meta-analysis appears in the title.

Figure: Vetter et al. (2013)

REPEATABLE TECHNIQUES FOR META-ANALYSIS

Guides:

– PRISMA

Preferred **R**eporting **I**tems for **S**ystematic reviews and **M**eta-**A**nalyses

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Guidelines and Guidance

Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement

David Moher[1,2]*, Alessandro Liberati[3,4], Jennifer Tetzlaff[1], Douglas G. Altman[5], The PRISMA Group[¶]

– Eco-Evo

Ecology and **Evo**lution

REVIEW

doi:10.1038/nature25753

Meta-analysis and the science of research synthesis

Jessica Gurevitch[1], Julia Koricheva[2], Shinichi Nakagawa[3,4] & Gavin Stewart[5]

Meta-analysis is the quantitative, scientific synthesis of research results. Since the term and modern approaches to research synthesis were first introduced in the 1970s, meta-analysis has had a revolutionary effect in many scientific fields, helping to establish evidence-based practice and to resolve seemingly contradictory research outcomes. At the same time, its implementation has engendered criticism and controversy, in some cases general and others specific to particular disciplines. Here we take the opportunity provided by the recent fortieth anniversary of meta-analysis to reflect on the accomplishments, limitations, recent advances and directions for future developments in the field of research synthesis.

BIOLOGICAL REVIEWS Cambridge Philosophical Society

Biol. Rev. (2021), 96, pp. 1695–1722. 1695
doi: 10.1111/brv.12721

Preferred reporting items for systematic reviews and meta-analyses in ecology and evolutionary biology: a PRISMA extension

Rose E. O'Dea[1*], Malgorzata Lagisz[1], Michael D. Jennions[2], Julia Koricheva[3], Daniel W.A. Noble[1,2], Timothy H. Parker[4], Jessica Gurevitch[5], Matthew J. Page[6], Gavin Stewart[7], David Moher[8] and Shinichi Nakagawa[1*]

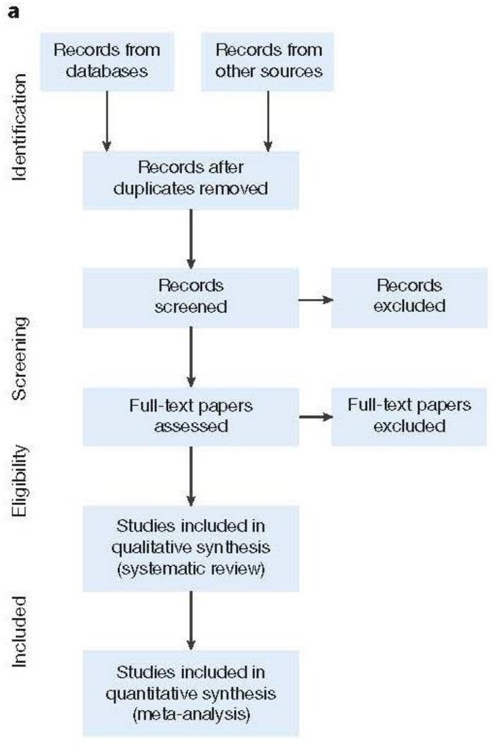


Table 1. Checklist of items to include when reporting a systematic review or meta-analysis.

Section/Topic	#	Checklist Item	Reported on Page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome-level assessment (see Item 12).	
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group and (b) effect estimates and confidence intervals, ideally with a forest plot.	
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., health care providers, users, and policy makers).	
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review level (e.g., incomplete retrieval of identified research, reporting bias).	
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	

doi:10.1371/journal.pmed.1000097.t001

WHAT DATA ARE BEING SYNTHESIZED?

Top three general objectives needed to conduct a meta-analysis:
1) estimating an overall effect size
2) quantifying consistency (heterogeneity) between studies
3) explaining the heterogeneity

EFFECT SIZE
Typically used to refer to the magnitude or strength of an effect of interest or its biological interpretation.

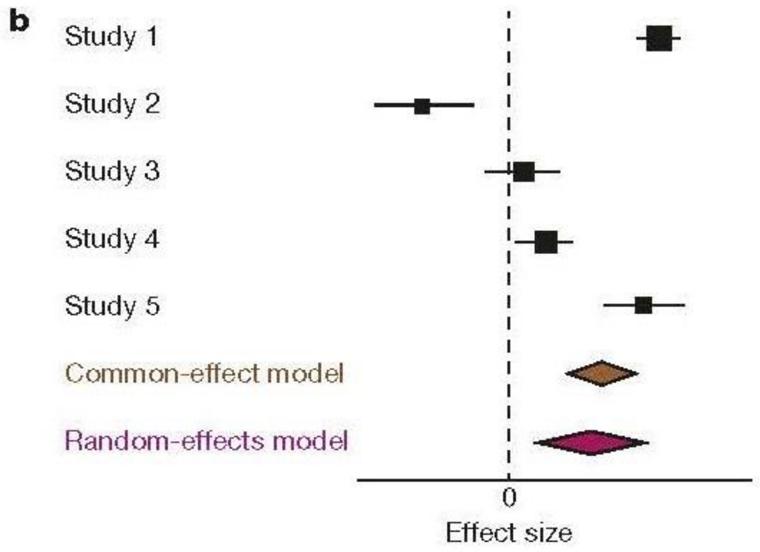
– Three most common types of effect measurements
  - Single
  - Comparative
  - Association

– It is important to note that any measures with sampling variance can become an ‘effect size’.
(Nakagawa et al., 2023)

Single -> average & SD / SE
Comparative -> Control results (X±SD) vs Treatment results (X±SD)
Association -> Pearson correlation, Spearman correlation

WHAT OUTCOMES CAN BE OBTAINED FROM META-ANALYSIS?

Plot B
- Forest plot / graph that visually shows individual studies, effect size, and the overall estimate
  - Common effect model
  - Random effect model



Plot C & D
- Regression / tries to relate the size of the effect to characteristics of the studies involved. (Israel and Richter, 2011)
  - [C] Categorical moderator
    Boxplot
  - [D] Continuous moderator
    Bubble plot

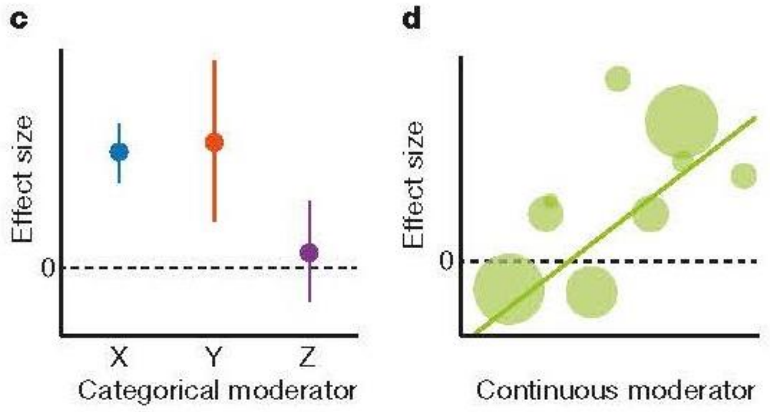


Figure: Gurevitch et al. (2018)

WHAT OUTCOMES CAN BE OBTAINED FROM META-ANALYSIS?

Plot E
- Funnel plot
  - Understanding publication bias based on the funnel asymmetry

Plot F
- Forest plot usually uses on psychology and health studies.
  - Cumulative meta-analysis in which outcomes are added into the analysis, in this example cumulative by time.

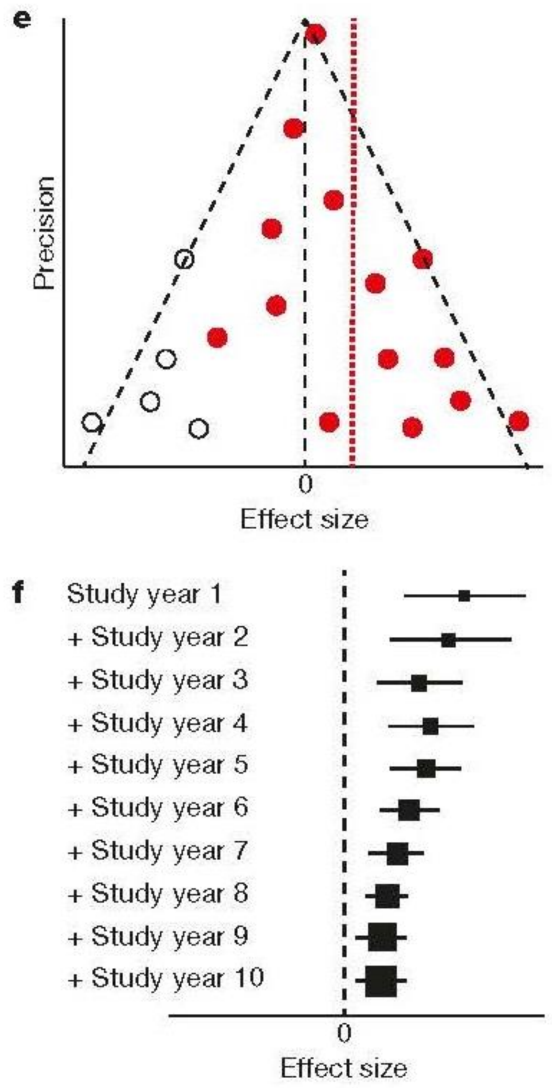
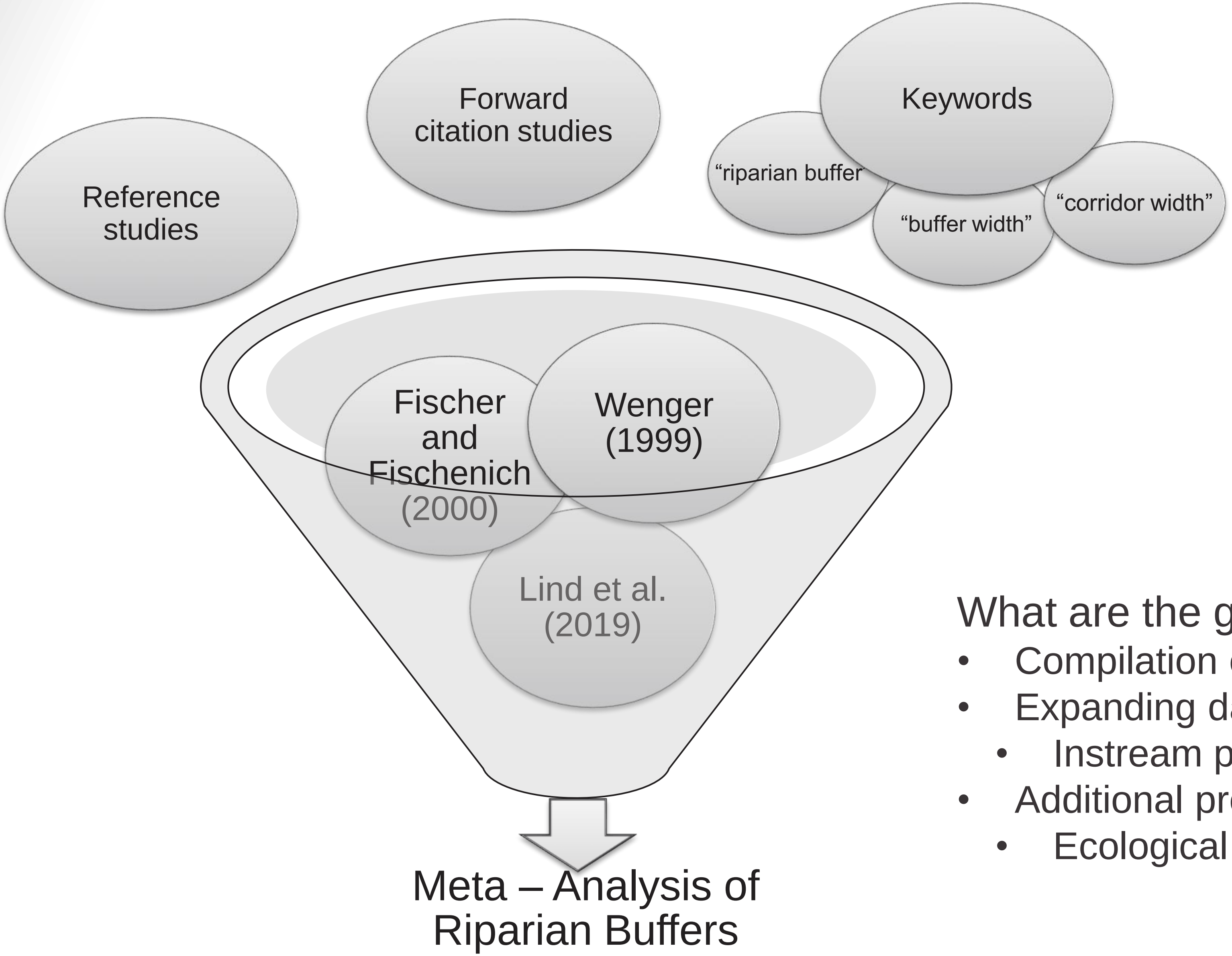


Figure: Gurevitch et al. (2018)

META-ANALYSIS OF RIPARIAN BUFFERS

EXISTING SYNTHESIS ON RIPARIAN BUFFERS



What are the gaps in these studies that we are filling?

- Compilation of empirical evidence rather than judgment
- Expanding data sets
  - Instream processes / removal efficiency
- Additional processes
  - Ecological processes / species richness

STUDY IDENTIFICATION

57 studies included in quantitative synthesis: descriptive statistical analysis

26 studies included in Instream Process Meta-Analysis

31 studies included in Taxa Richness Meta-Analysis

[Response variables -> Effect Size]

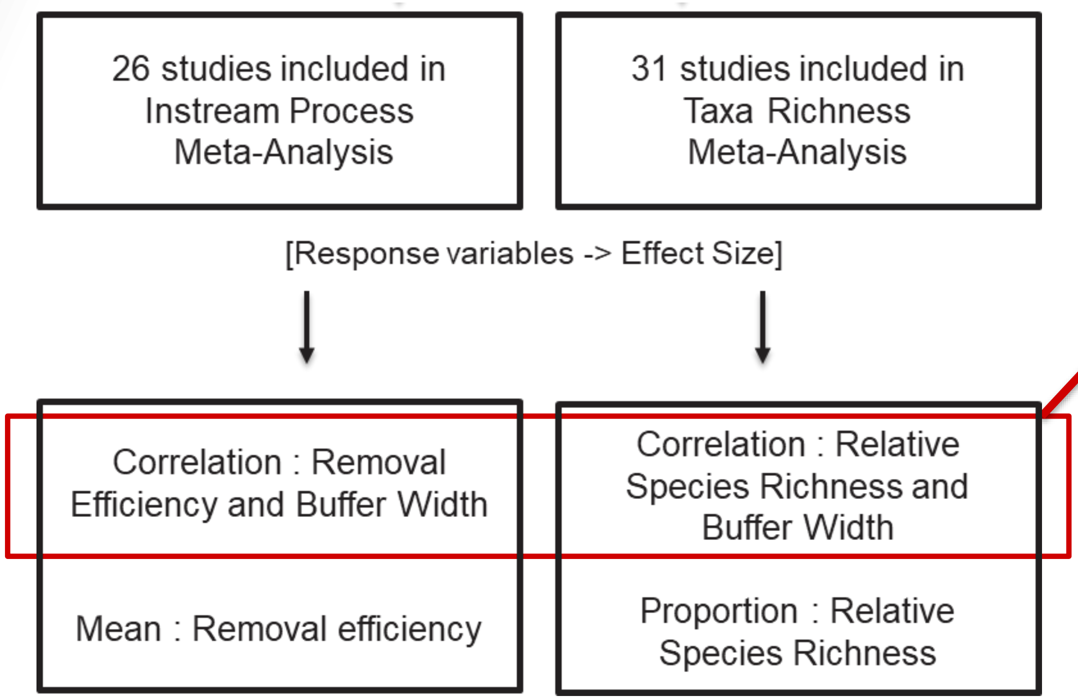
Correlation : Removal Efficiency and Buffer Width

Mean : Removal efficiency

Correlation : Relative Species Richness and Buffer Width

Proportion : Relative Species Richness

DATA COMPILATION AND EFFECT SIZE



Part 1:

Objective:
Compile and synthesize data on the effects of buffer width on *Instream* and *Ecological processes*, to determine if the buffer width is an important factor to asses riparian zone.

Plan:
Use the measurements that already associates the response variable with width as effect size (r) to reexamine the effectiveness of studies interventions.

R packages:
- ‘esc’
- ‘meta’
  - ‘meta-cor’

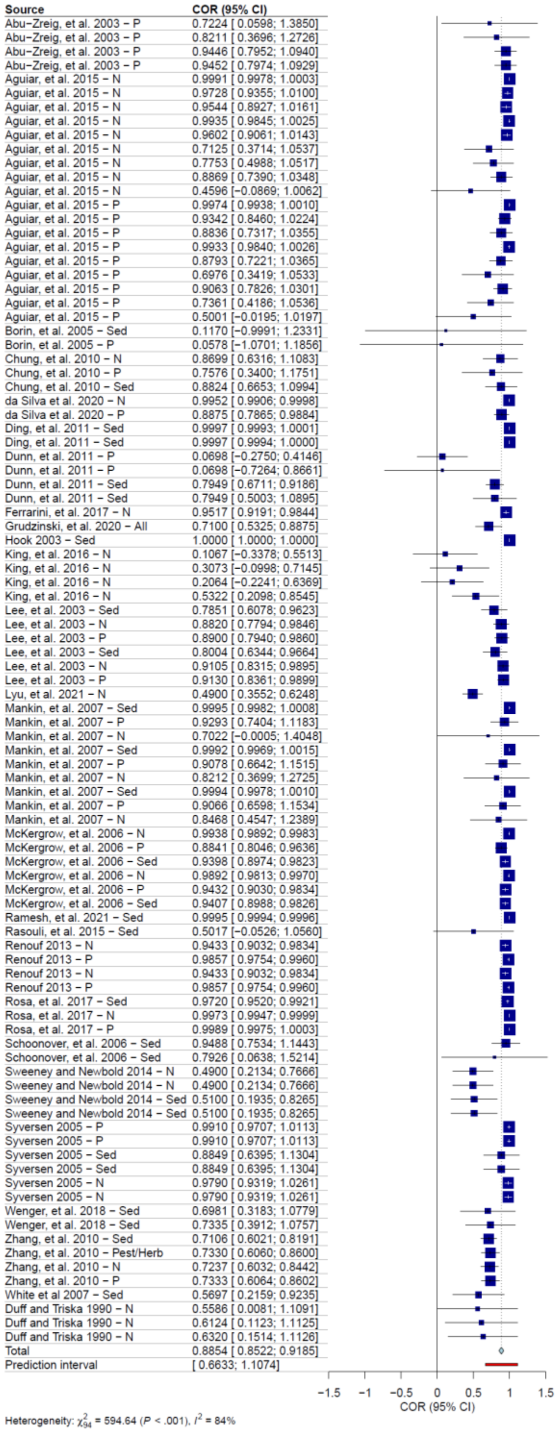
PART 1
INSTREAM PROCESS

DATA DESCRIPTION	
Total Papers	26
Buffer width range	0 – 100 m
Publication Year range	1990- 2021
Contaminants monitored	Nitrogen, Phosphorus, Sediments, Pesticides/Herbicides

OUTCOME	
Meta-correlation (r)	**0.8854**
95% CI	0.8522; 0.9185
I^2	84.2%

Observations:

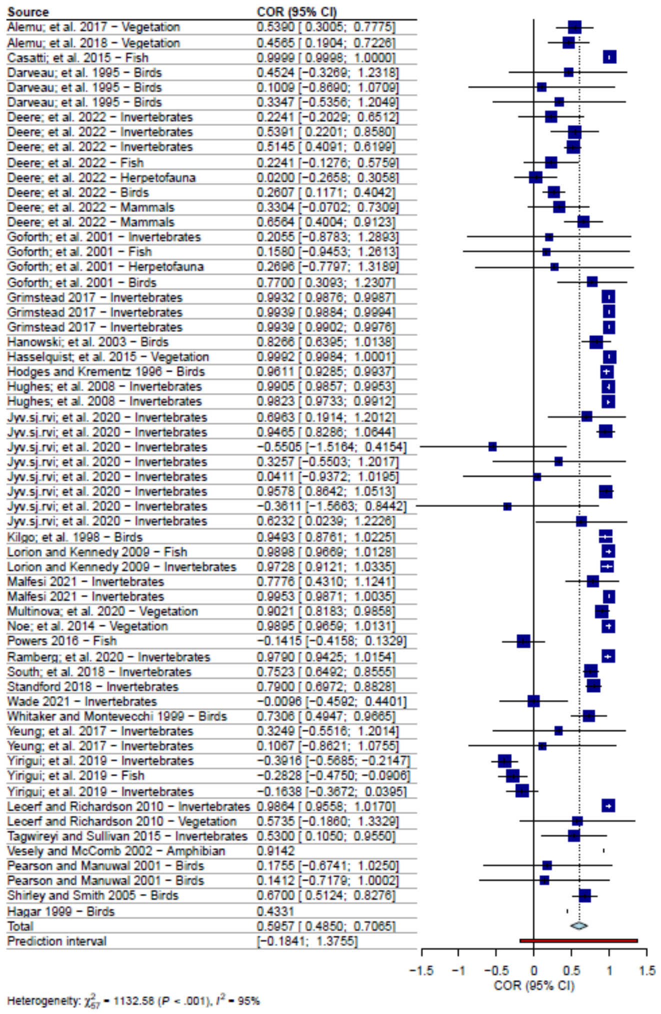
- Consistent with the majority of previous quantitative studies exist a positive correlation between removal efficiency of contaminants and the width of riparian buffer.
- Was not expected the STRONG (r > 0.8) positive correlation.
- Confidence intervals reaffirms the results significance.
- High heterogeneity is the norm in EcoEvo Meta-analysis.



PART 1
ECOLOGICAL PROCESS

DATA DESCRIPTION	
Total Papers	31
Buffer width range	0 – 2088 m
Publication Year range	19953 - 2022
Taxa monitored	Vegetation, Invertebrates, Herpetofauna, Mammals, Birds, Fish

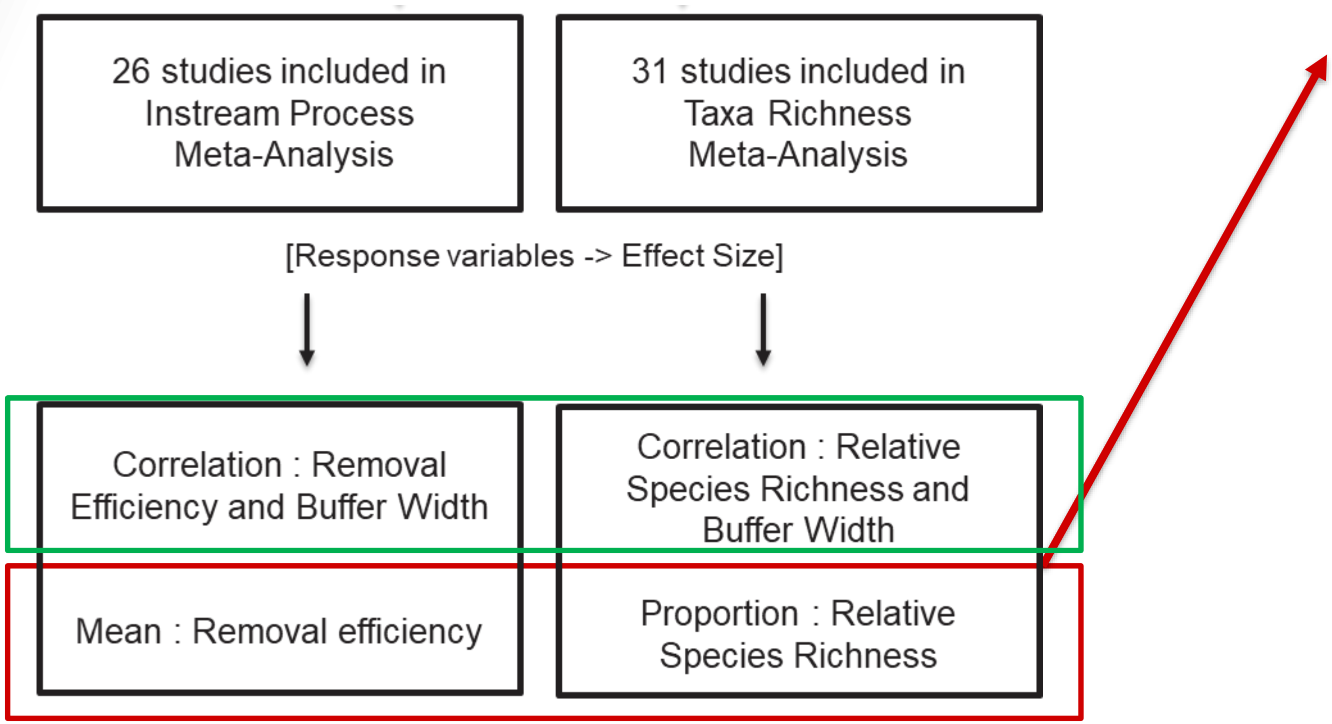
OUTCOME	
Meta-correlation (r)	**0.5957**
95% CI	0.4850 0.7065
I^2	95%



Observations:

- Overall moderate positive correlation (r > 0.5) between relative species richness and the width of riparian buffer.
- Confidence intervals reaffirms the results significance, but the present variance observed on the forest plot.
- High heterogeneity is the norm in EcoEvo Meta-analysis.

DATA COMPILATION AND EFFECT SIZE



Part 2:

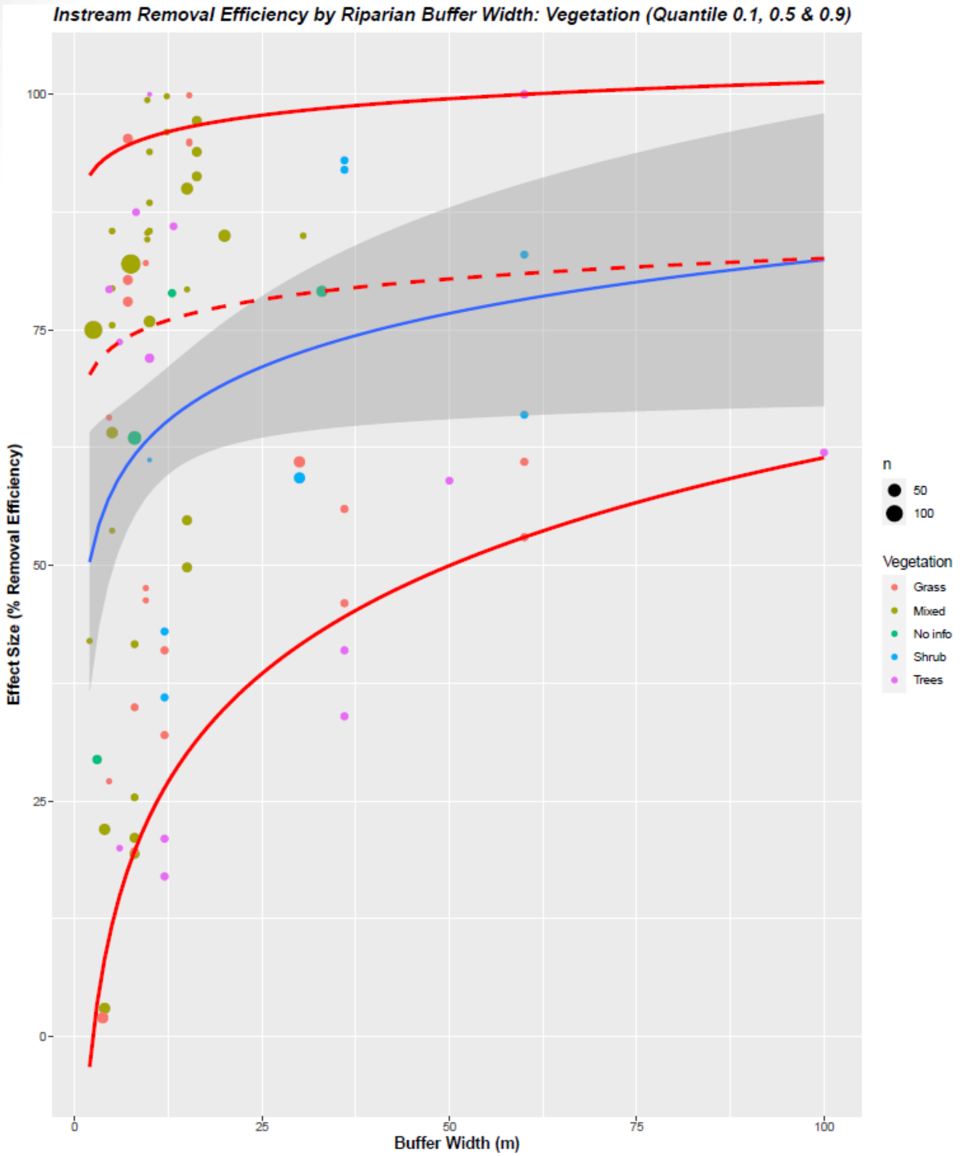
Objective:
Develop essential information for scientists, public and decision makers can estimates riparian buffer width thresholds for functional outcomes based on *Instream and Ecological processes*.

Plan:
Use the single measurements from the response variable as effect size to reexamine the effectiveness of studies interventions and through meta-regression help explaining the variation and provide a tool that help explore best functional buffer width threshold.

R packages:

- ‘esc’
- ‘meta’
    - ‘meta-mean’
    - ‘meta-prop’
    - ‘meta-reg’

PART 2
INSTREAM PROCESS

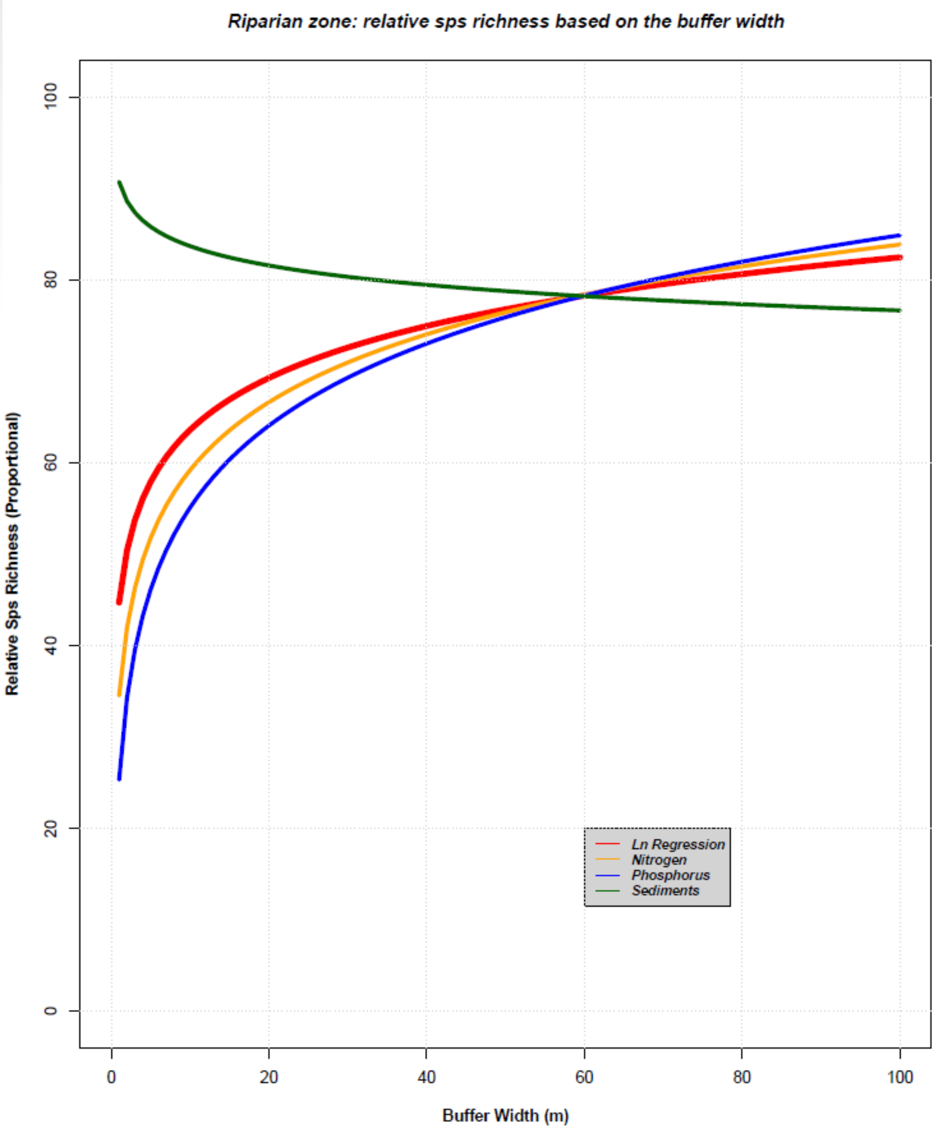


	Instream
Data Description:	
Total Observations	82
Overall Mean	**64.23**
95% CI	58.31; 70.16
Regression	Y = 44.706 + 8.194 ln (x)
p-value	< 0.05 (0.02)

Observations:

- In average, without taken in consideration the width, exists a 64% of removal efficiency, meaning the existence of other moderators that helps the contaminants removal.
- Most of the included studies report a mixed vegetation (dark green dots).

EACH OUTCOME CAN BE FURTHER SUBDIVIDED INTO MORE SPECIFIC INSTREAM PROCESSES

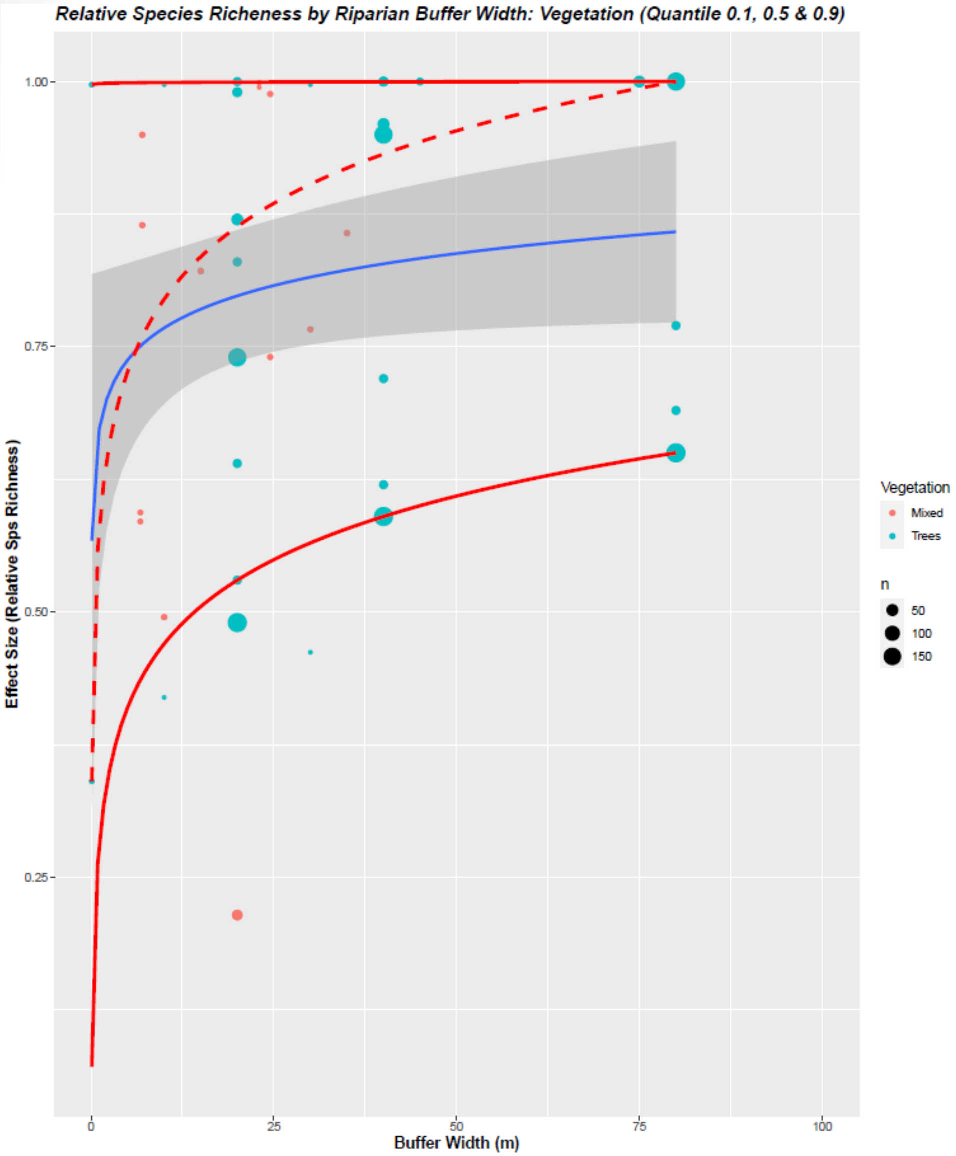


- The excess of nutrients removal regression behaves similar to the overall removal efficiency regression.
  - Using the regression outcomes can estimate that over the **40 m a 75% of removal efficiency** on Nitrogen and Phosphorus removal.

- Sediment removal regression tends to present a different behavior. More studies would like to be add to a better outcome.

	n	Regression	Buffer Width (m) with **75%** effectiveness
All (red)	82	Y = 44.706 + 8.194 ln (x)	40.3
Sub-groups:			
Nitrogen (orange)	35	Y = 34.520 + 10.710 ln (x)	43.8
Phosphorus (blue)	25	Y = 25.314 + 12.929 ln (x)	46.7
Sediments (green)	20	Y = 90.704 – 3.055 ln (x)	170.8

PART 2
ECOLOGICAL PROCESS

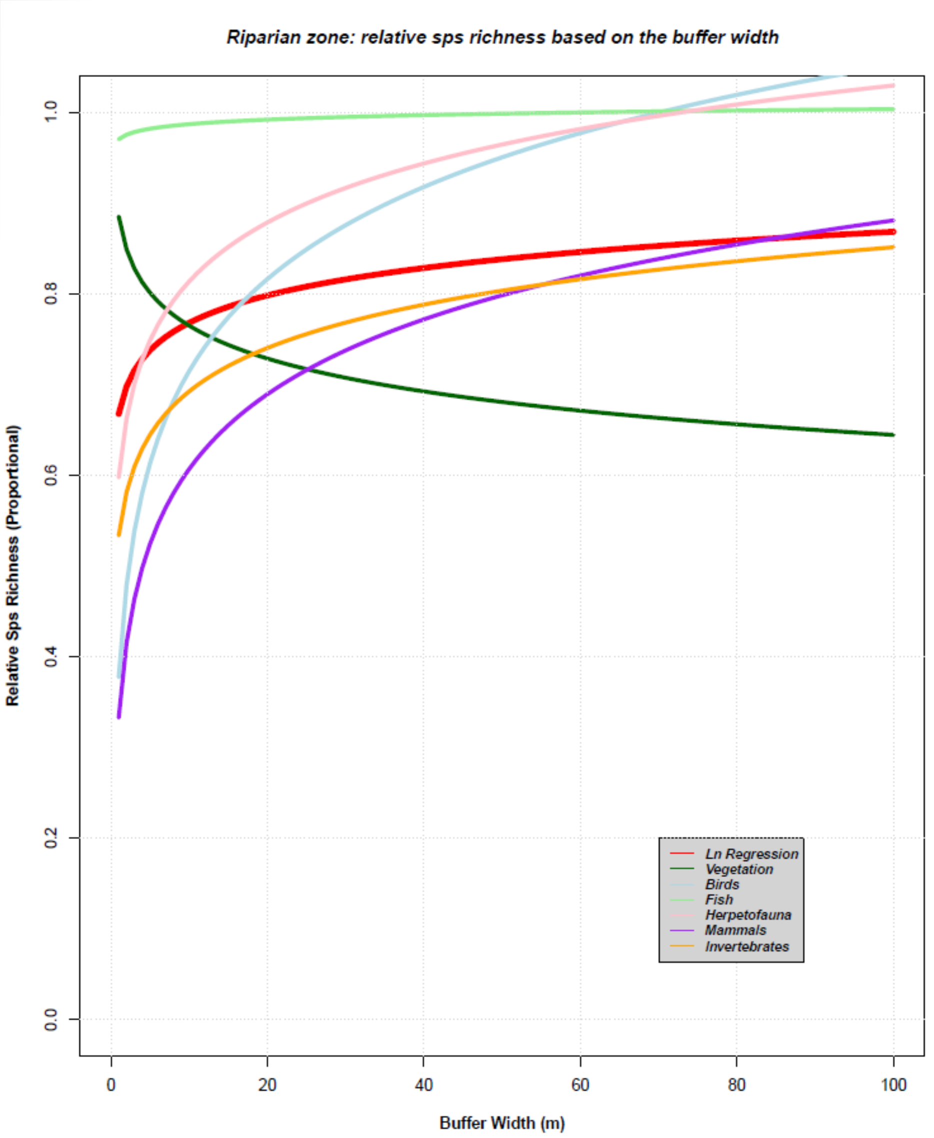


	Ecological
Data Description:	
Total Observations	45
Overall Proportion	**0.8256**
95% CI	0.7645; 0.8867
Regression	Y = 0.667 + 0.044 ln (x)
p-value	< 0.10 (0.06)

Observations:

- In average, without taken in consideration the width exists a 75% of relative species richness, meaning the existence of other moderators that helps species richness on the area.
- Most of the studies that were taken in consideration show the tendency to have trees as the buffer vegetation.

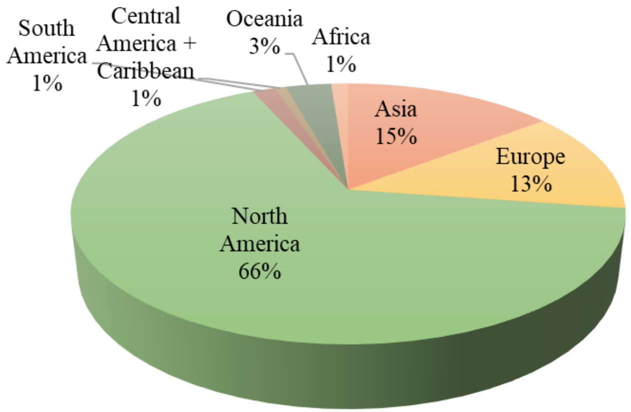
EACH OUTCOME CAN BE FURTHER SUBDIVIDED INTO MORE SPECIFIC INSTREAM PROCESSES



- The overall richness increase with a bigger buffer, and is observed that Invertebrates, Mammals, Birds and Herpetofauna present a similar behavior.
- Vegetation and Fish regression present a different behavior.
- Using the regression outcomes a wide buffer width range was found **5.1 - 30 m to present a 75% (or 0.75)** of relative species richness.

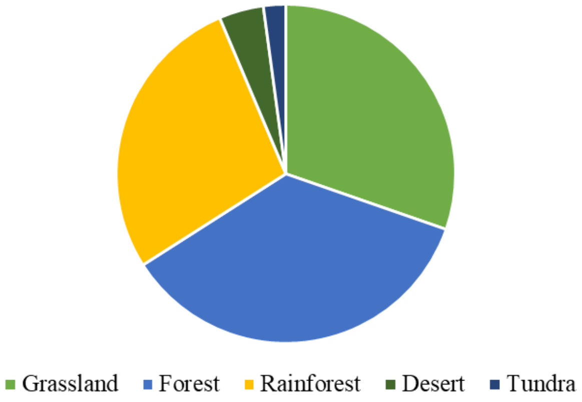
	n	Regression	Buffer Width (m) with **75%** effectiveness
All (red)	45	Y = 0.667 + 0.044 ln (x)	6.6
Sub-groups:			
Vegetation (dark green)	4	Y = 0.885 - 0.052 ln (x)	13.4
Birds (light blue)	7	Y = 0.377 + 0.146 ln (x)	12.9
Fish (light green)	3	Y = 0.970 + 0.007 ln (x)	0.0
Herpetofauna (pink)	3	Y = 0.597 + 0.094 ln (x)	5.1
Mammals (purple)	6	Y = 0.333 + 0.119 ln (x)	33.3
Invertebrates (orange)	22	Y = 0.534 + 0.069 ln (x)	22.9

LIMITATIONS OF META-ANALYSIS



Limitations of meta-analysis in general

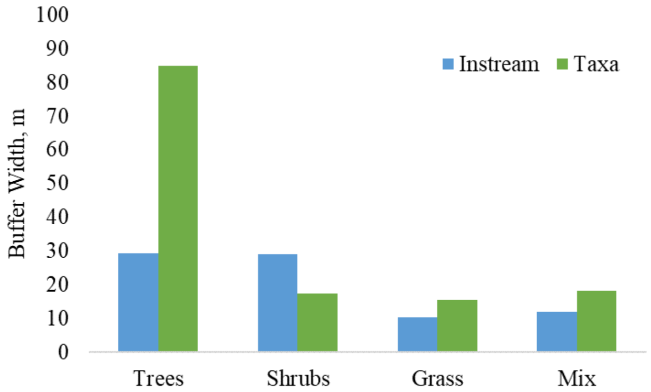
Publication bias
Research bias



Limitations, controversies and challenges in this study

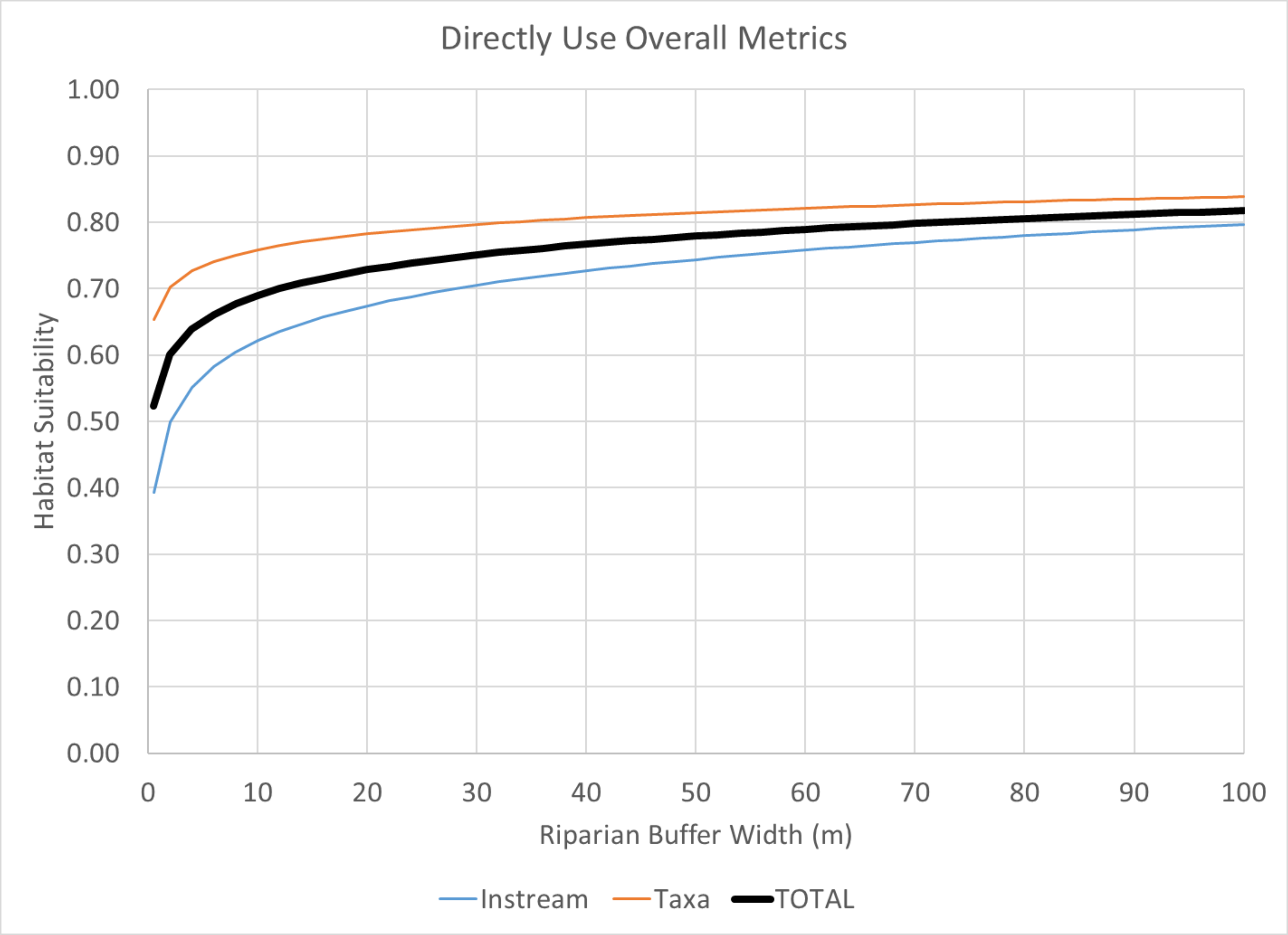
Publication bias
- Location
- Language

Research bias
- Inclusion other moderators
- Limited statistical information provided

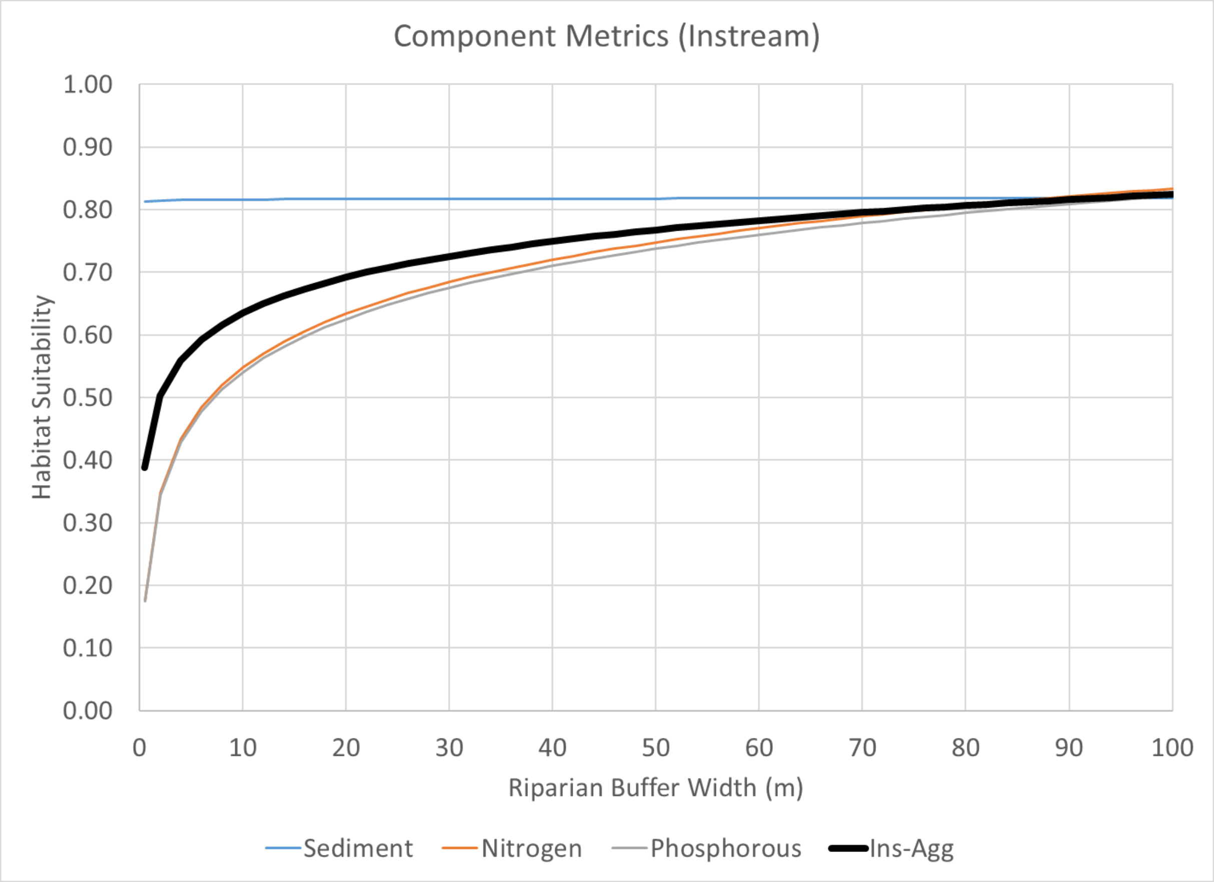


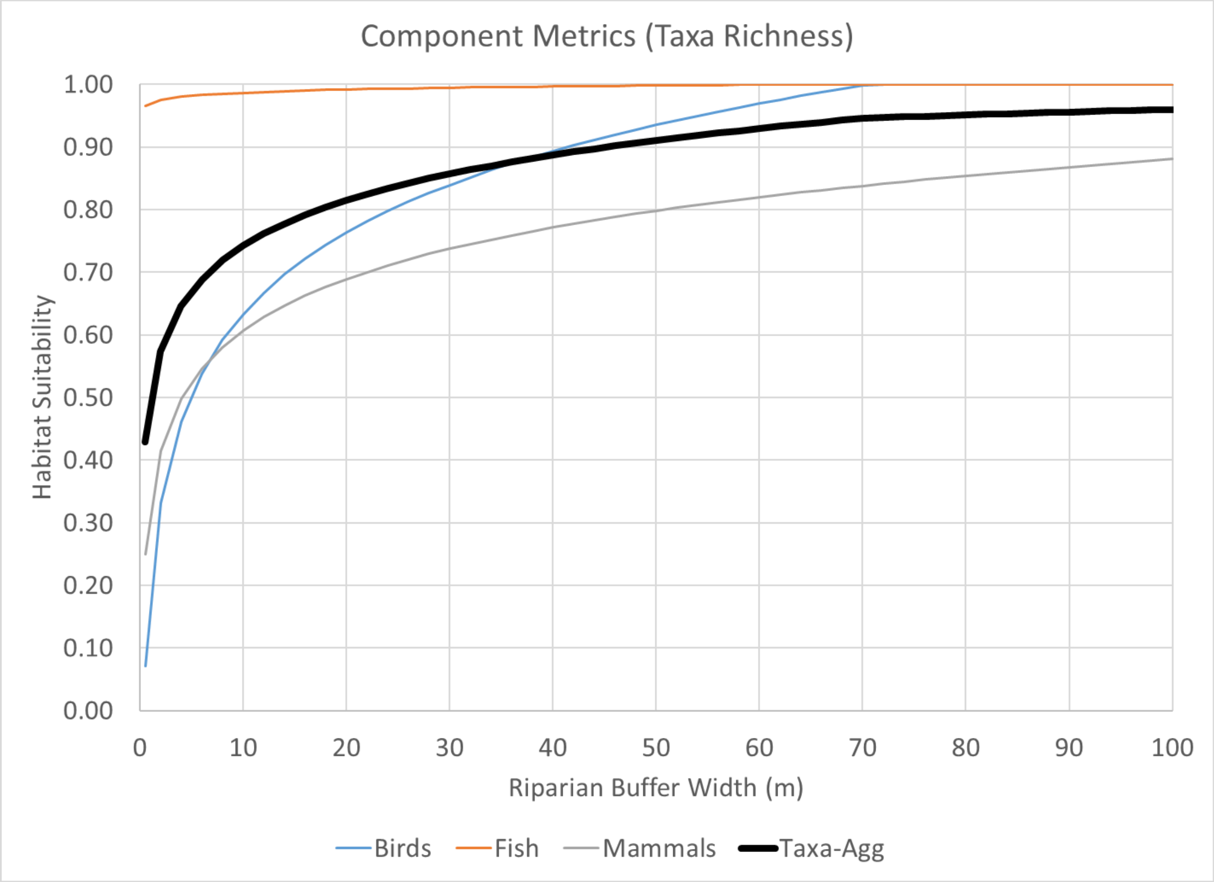
TRANSLATING THE META-ANALYSIS INTO MODELS

TRANSLATING META-ANALYSIS INTO HABITAT SUITABILITY



BREAKING OVERALL SUITABILITY INTO INDICES TARGETING SPECIFIC OUTCOMES





HYPOTHETICAL PROJECT

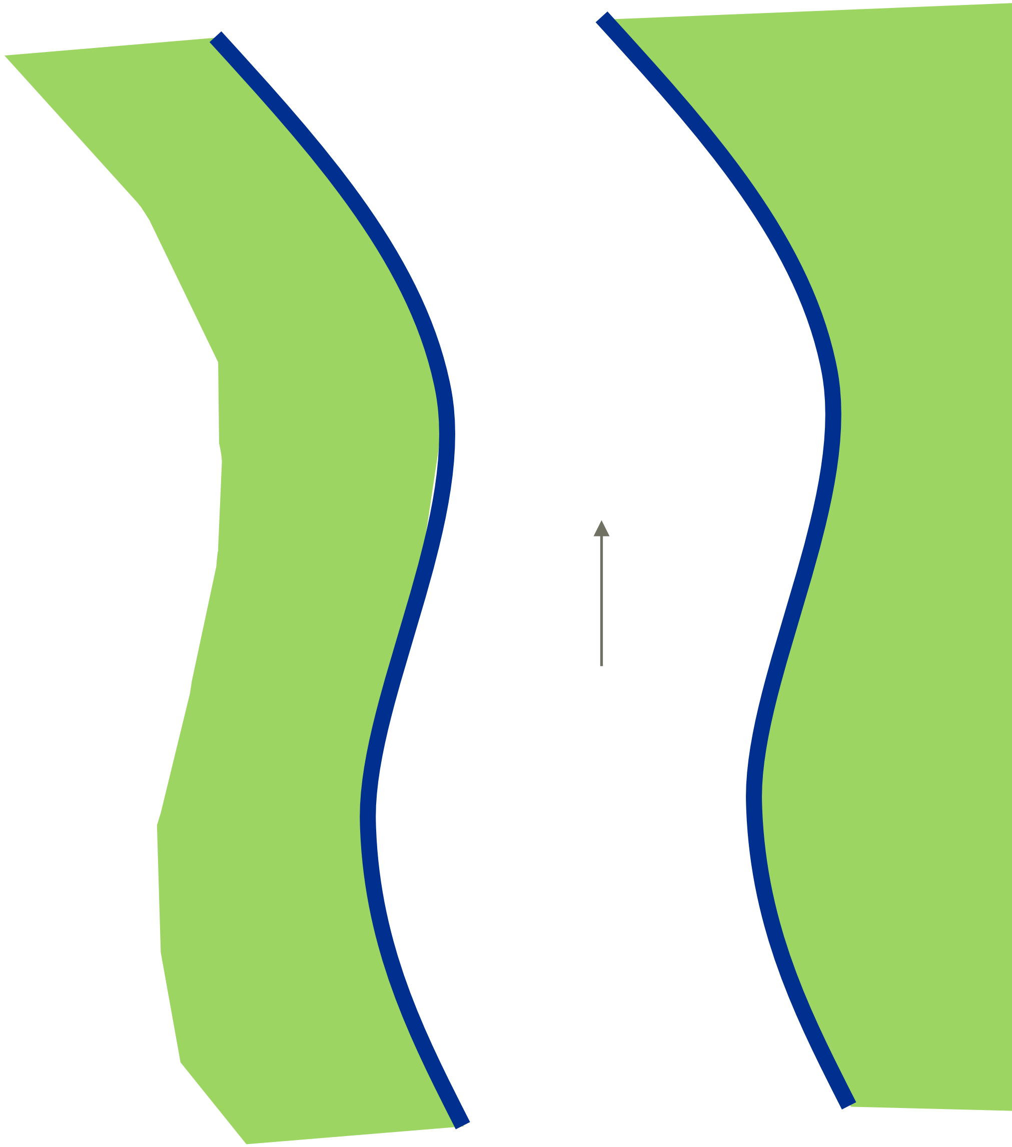
- Example restoration scope
  - Reach length = 1 mile
  - Current riparian buffer width ~ 25 feet on left bank (representative state minimum)
- Three potential objectives and associated actions
  - Increase stream stability: Increase to 50 ft (~15m)
  - Enhance water quality: Increase to 100 ft (~30m)
  - Provide habitat: Increase to 200 ft (~60m)

Table 4. General Riparian Buffer Strip Width Guidelines

Function	Description	Recommended Width[1]
Water Quality Protection	Buffers, especially dense grassy or herbaceous buffers on gradual slopes, intercept overland runoff, trap sediments, remove pollutants, and promote ground water recharge. For low to moderate slopes, most filtering occurs within the first 10 m, but greater widths are necessary for steeper slopes, buffers comprised of mainly shrubs and trees, where soils have low permeability, or where NPSP loads are particularly high.	5 to 30 m
Riparian Habitat	Buffers, particularly diverse stands of shrubs and trees, provide food and shelter for a wide variety of riparian and aquatic wildlife.	30 to 500 m +
Stream Stabilization	Riparian vegetation moderates soil moisture conditions in stream banks, and roots provide tensile strength to the soil matrix, enhancing bank stability. Good erosion control may only require that the width of the bank be protected, unless there is active bank erosion, which will require a wider buffer. Excessive bank erosion may require additional bioengineering techniques (see Allen and Leach 1997).	10 to 20 m
Flood Attenuation	Riparian buffers promote floodplain storage due to backwater effects, they intercept overland flow and increase travel time, resulting in reduced flood peaks.	20 to 150 m
Detrital Input	Leaves, twigs and branches that fall from riparian forest canopies into the stream are an important source of nutrients and habitat.	3 to 10 m

[1] Synopsis of values reported in the literature, a few wildlife species require much wider riparian corridors.

Figure: Fischer and Fischenich (2000)



WHAT IS THE ECOLOGICAL "LIFT" FROM THESE HYPOTHETICAL RESTORATION ACTIONS?

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Width (ft)	Area (ac)	SI (instream)	SI (taxa)	Habitat Suitability (HSI)	Habitat (HUs)	Lift (HUs)
25 (current)	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

THANK YOU FOR YOUR TIME!

Take-away messages

- Developing a suite of riparian modeling tools applicable across a spectrum of low to high effort
- Extensive study of riparian buffers globally provides a basis for empirical thresholds in buffer width (via meta-analysis)
- A simple habitat-style model is being developed for high-level screening across sites

Upcoming Webinars!

- Jan 29: Riparian Ecosystem Function Index (REFI)
- Jan 31: Web App for Riparian Models (WARM)

Acknowledgements

- Meta-analysis team: Sam Wiest, Lee Dietterich
- Riparian team: Garrett Menichino, Darixa Hernandez-Abrams, Ella Dorfmueller, Ashlynn Clark,…

We want to hear from you!

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