The Reference Reach: A template for Natural Channel Design (NCD) and a tool to gauge ecological functional uplift

Barbara Doll, PE, Ph.D.,
Assistant Extension Professor and Extension Specialist
NC Sea Grant and Biological and Agricultural Engineering Department, NC State University

NC STATE UNIVERSITY

NC STATE UNIVERSITY Bio&Ag ENGINEERING Stream Restoration Program

Sea Grant North Carolina

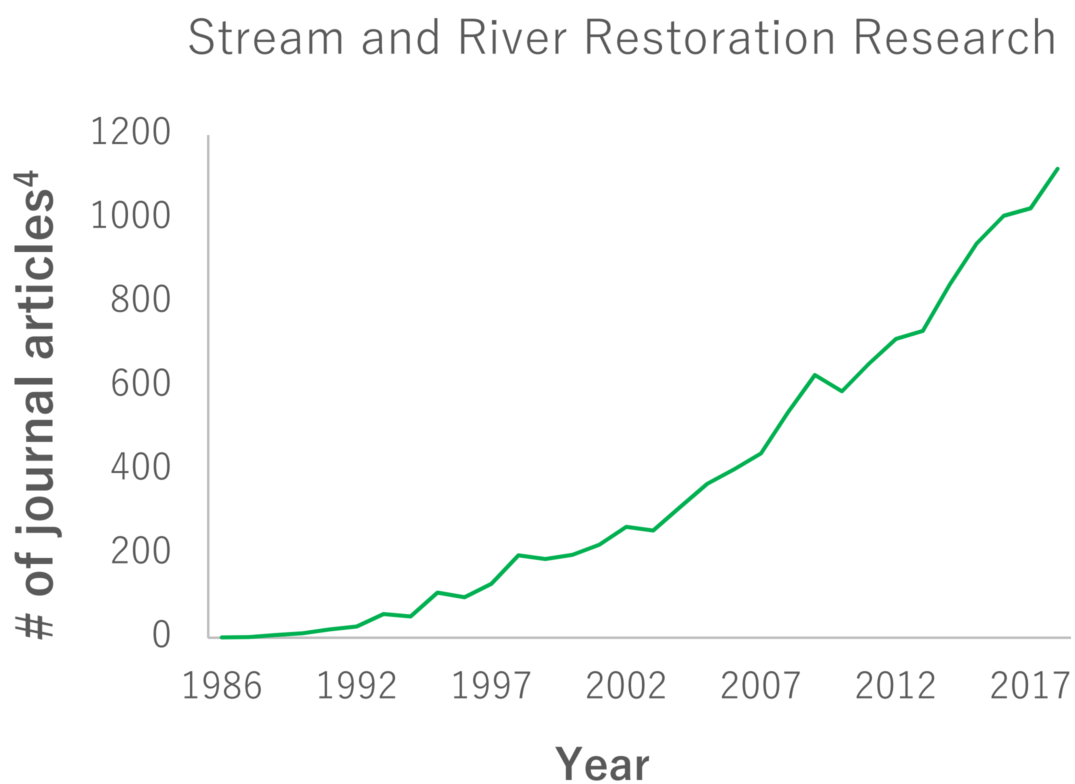
Stream Restoration: Growing Science and Practice

North America

- > $1 billion spent annually[1]

North Carolina

- Tens of millions spent annually[2]
- Mitigation projects cost ~$285 per linear foot[3]



[1]Bernhardt et al., 2005, *Science*
[2]Miller and Kochel, 2010, *Earth and Environmental Sciences*
[3]Personal communication, NCDMS, Jeff Jurek
[4]Web of Science

Natural Channel Design

- Fluvial geomorphology based method for designing natural stable channels developed by Dave Rosgen
- Analogue procedure – morphology measurements are scaled from a natural stable reference stream to determine the restoration design

High-quality “reference” streams serve as design templates

The Reference Reach

- What makes a stream "reference quality"?
  - Dynamic equilibrium
  - Little to no incision
  - Well connected to floodplain
- Requires extensive survey of dimension, planform & profile
- Data is scaled from the reference stream to the design stream using dimensionless ratios

The Reference Reach: Data Collection

Channel Dimension

- A_{bkf}, W_{bkf}, D_{bkf}, D_{max}, ER, BHR
- A_{bkfp}, W_{bkfp}, D_{bkfp}, D_{maxp}

Planform Geometry

- Radius of Curvature, R_c
- Meander Length, L_m
- Meander Belt Width, W_{blt}

Longitudinal Profile

- Pool Length, L_p
- Pool to Pool Spacing, p-p
- Riffle Length, L_{rif}
- Riffle Slope, S_{rif}

Substrate

- D_{15}, D_{35}, D_{50}, D_{85}

Stream mitigation policies

2008 Federal mitigation rule update

- **Replace function** (i.e. physical, chemical, and biological processes[6])
- Evaluate projects using function-based **performance standards**[7]

NC Mitigation crediting

Prior to 2008 update:

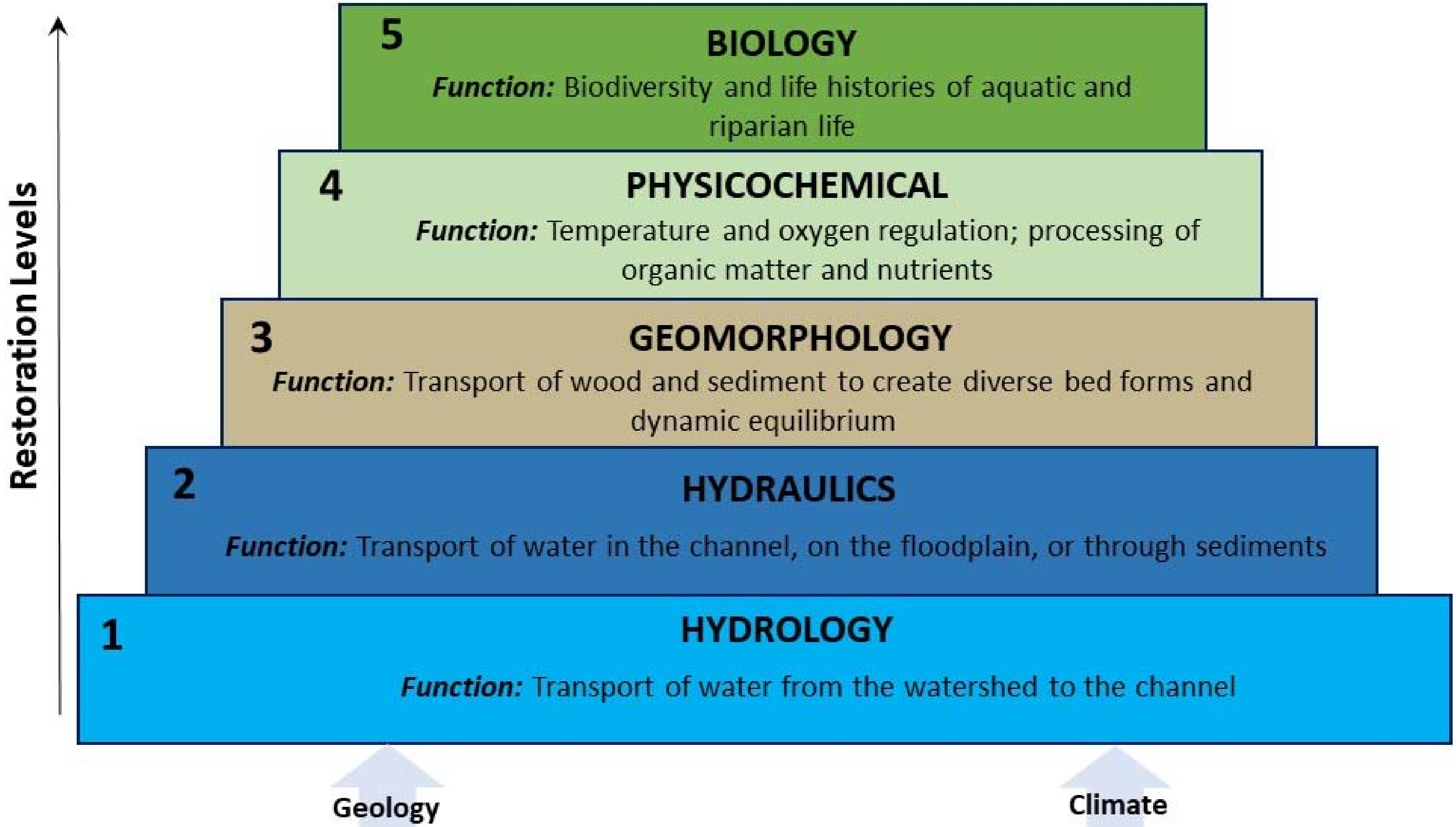
- Restored **linear feet** and **geomorphic uplift** (physical processes only)[8]
- Credits linked to design effort, not results

Currently:

- **Not** uniformly based on **function**
- Credits remain linked to design effort, not results

[6] SER Primer, 2004
[7] *33 CFR 332.5; 40 CFR230.95*
[8] Lave et al., 2008, *Restoration Ecology*

Stream functions pyramid framework



Adapted from Harman et al., 2012, *US EPA*

Determine Functional Uplift

Restored Streams

Performance Range

Reference Reaches

Disturbed Channels

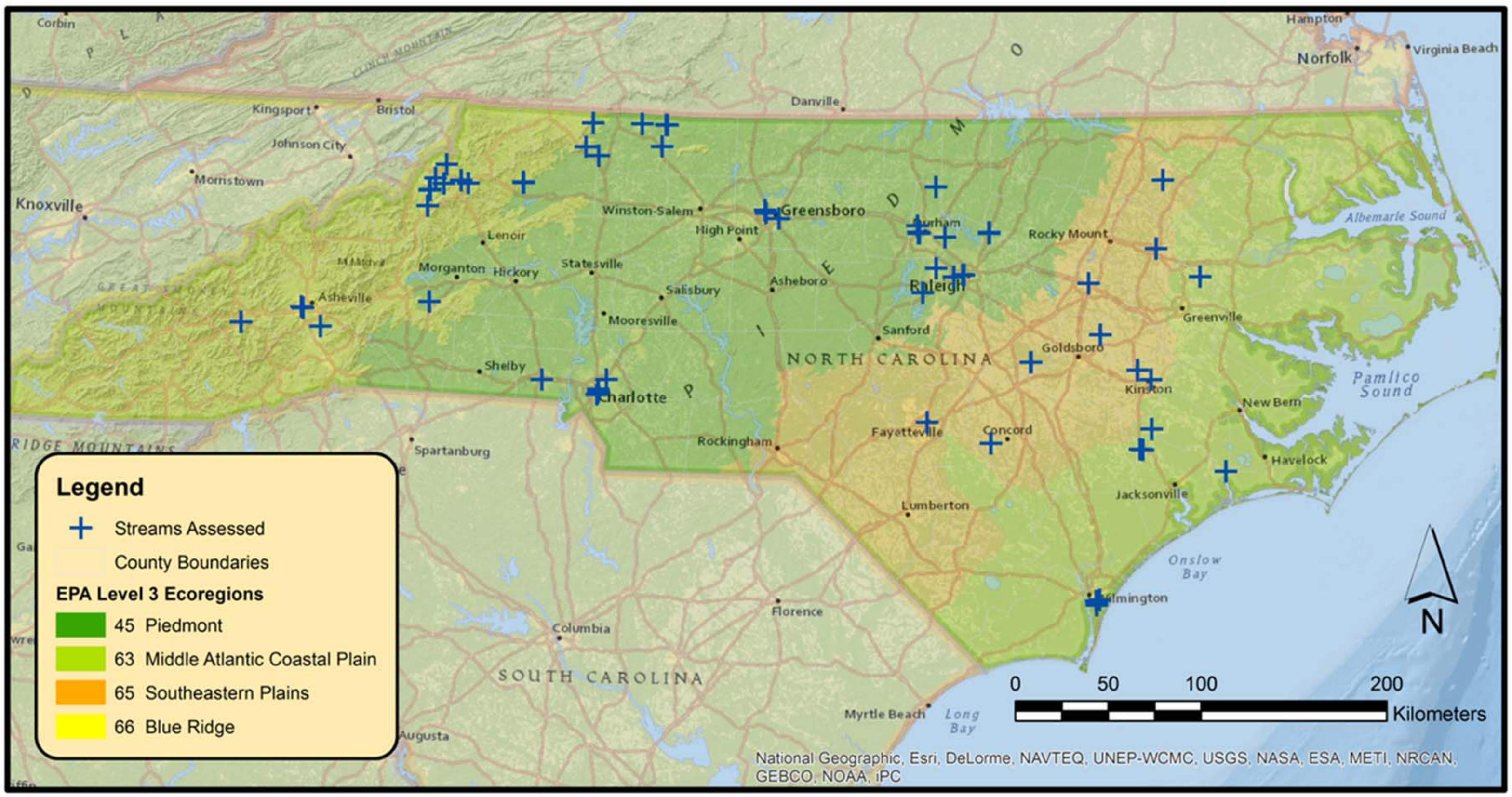
First, you must define the performance scale

Research Questions

- What tools should be used to evaluate ecological functional uplift of restored streams?
- How do restored streams compare to high quality reference channels?
- What factors (e.g. watershed, landscape and design) influence the condition and function of restored streams?
- What innovative restoration approaches can be implemented to maximize ecological function?

Evaluating Rapid Assessments of Eco-geomorphological Condition of Restored Streams

Five stream assessment methods applied at 65 restored streams – EGA, SPA, RBP, RCE & SVAP

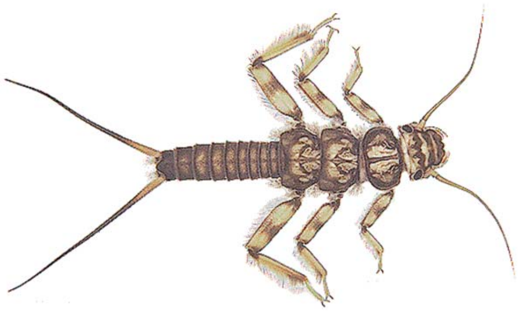


Assessment Methods

Acronym	Assessment Name	Source	Quantitative	Qualitative	Variables
EGA	Eco-geomorphological Assessment	NCSU	X	X	44
SPA	Stream Performance Assessment	NCSU		X	17
RBP	Rapid Bioassessment Protocol	EPA		X	13
RCE	Riparian, Channel and Environmental Inventory	Peterson (Sweden)		X	18
SVAP	Stream Visual Assessment Protocol	USDA		X	11

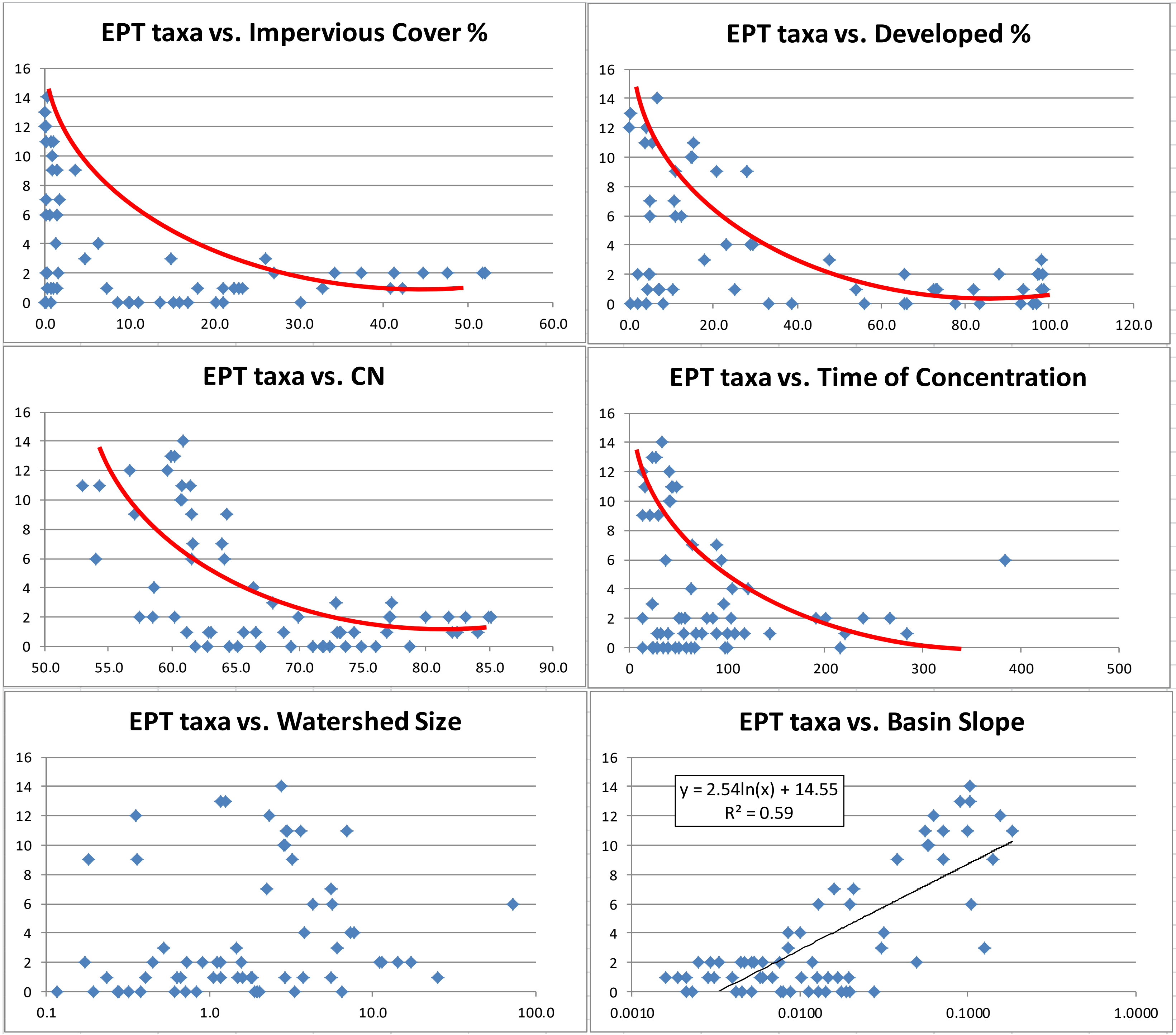
How well do the Stream Assessments predict stream biology?

- Response Variable: Macroinvertebrates:
- No. of dominant taxa
- No. of dominant EPT taxa
- EPT abundance
- Dominant taxa in common DIC (%)
- % shredders and predators
- Number of indicator taxa



Hypotheses:

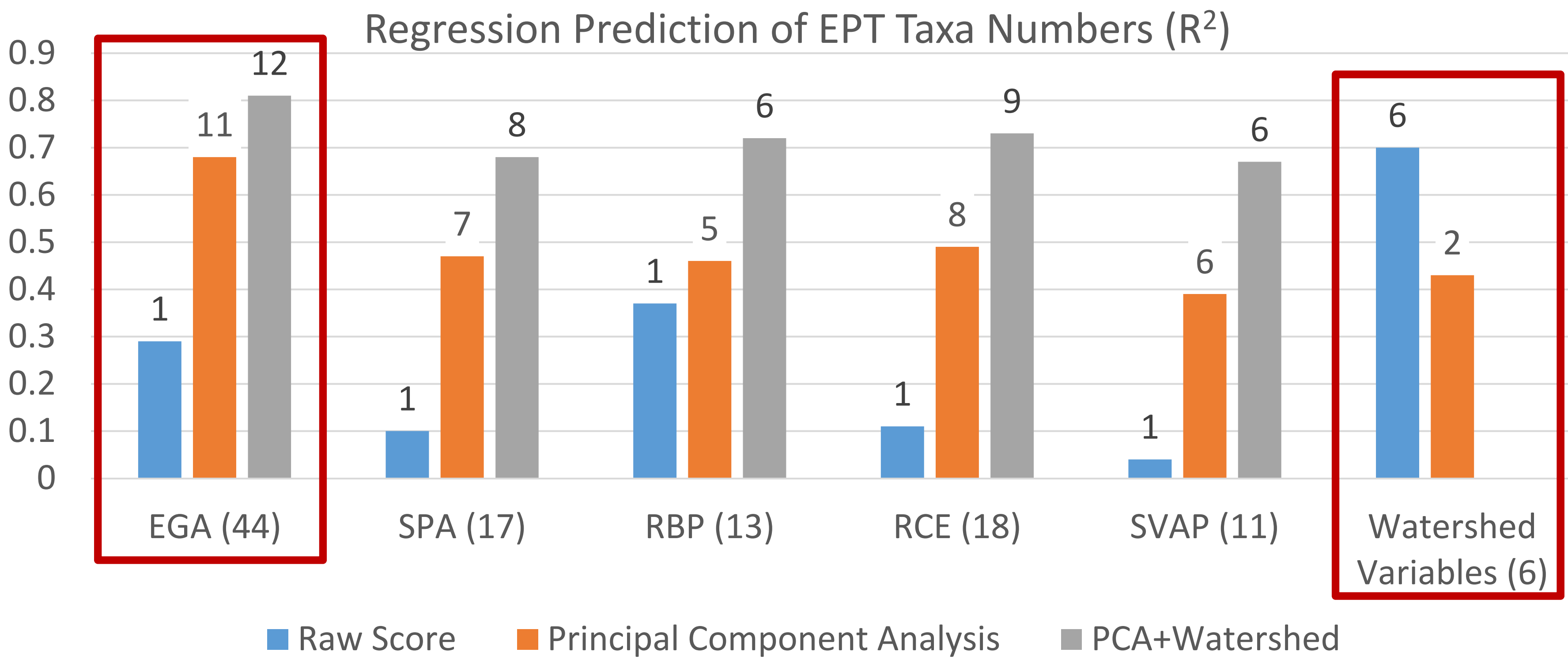
- Prediction of Macroinvertebrate Indices can be improved by eliminating arbitrary variable weights and adding watershed factors.



EPT taxa vs. Impervious Cover %
16
14
12
10
8
6
4
2
0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
EPT taxa vs. Developed %
0.0
20.0
40.0
60.0
80.0
100.0
120.0
EPT taxa vs. CN
50.0
55.0
60.0
65.0
70.0
75.0
80.0
85.0
90.0
EPT taxa vs. Time of Concentration
0
100
200
300
400
500
EPT taxa vs. Watershed Size
0.1
1.0
10.0
100.0
EPT taxa vs. Basin Slope
y = 2.54ln(x) + 14.55
R² = 0.59
0.0010
0.0100
0.1000
1.0000

Can Rapid Assessments Predict EPT Taxa?

- Eliminate arbitrary averaging and summing of variables & add watershed factors
- Re-weight variables and address collinearity of variables using ordination statistics (Principal Component Analysis)
- Apply Multiple Linear Regression using Principal Components that explain 70% of the variability

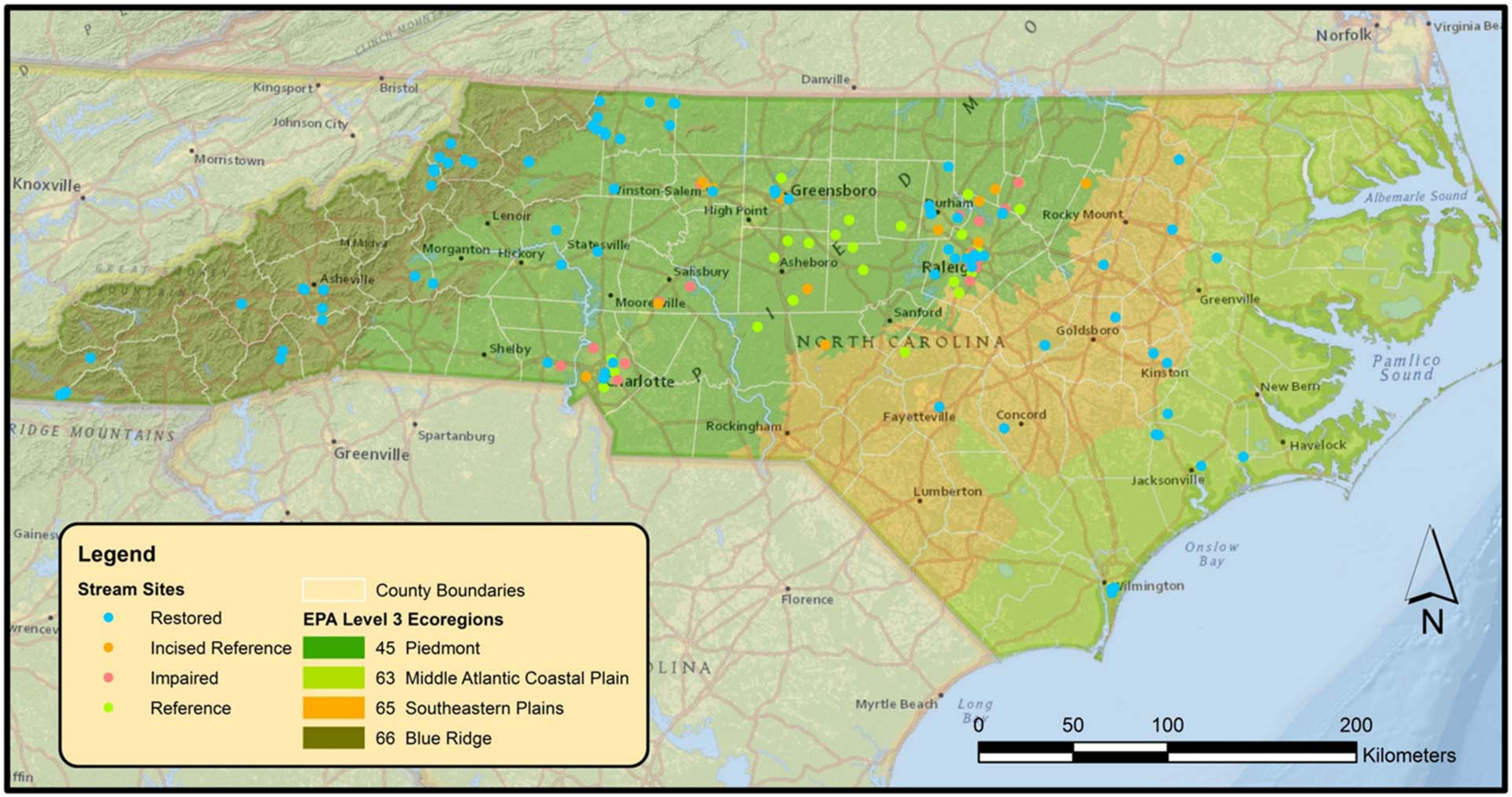


Conclusion

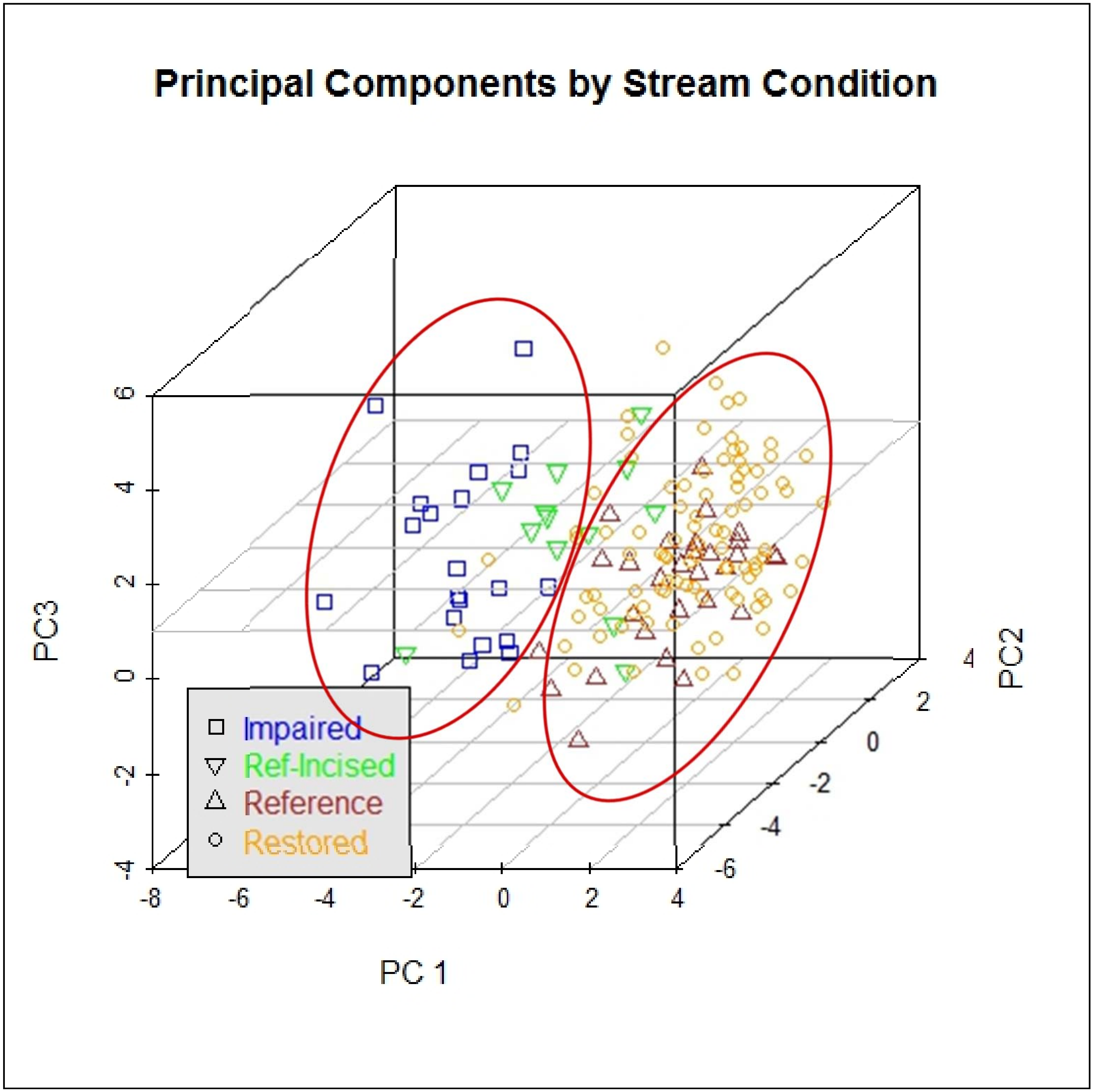
- Rapid stream assessments combined with watershed condition can be used to predict aquatic macroinvertebrate metrics in restored streams.

How does the condition of restored streams compare to high quality reference channels?

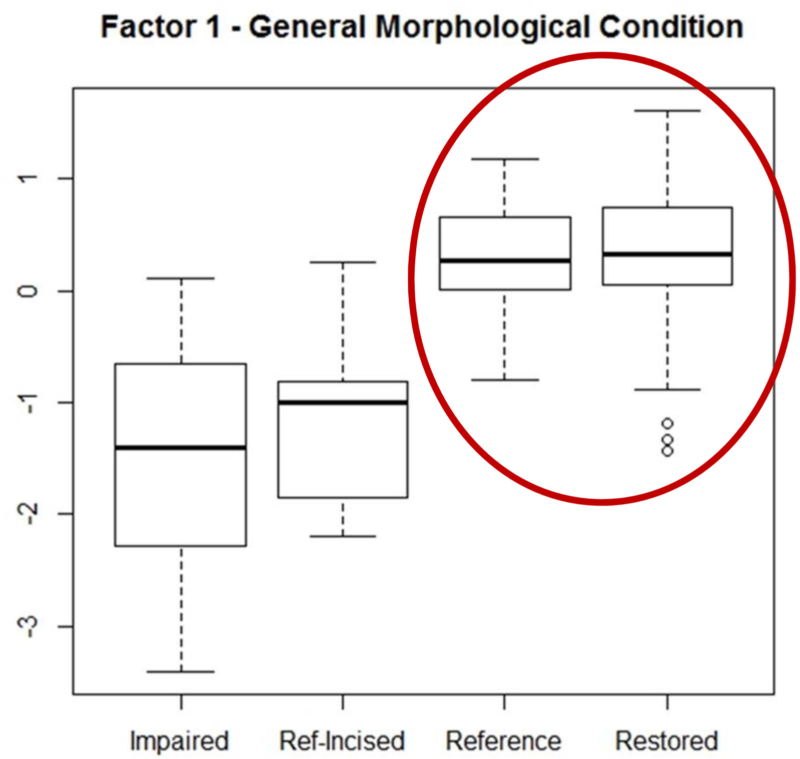
SPA applied at 156 Streams: 93 restored, 21 impaired, 29 reference quality, and 13 reference streams with minor incision



First 3 SPA PC's explain 57.5 % of variance n=156



Factor 1: Morphologic Condition

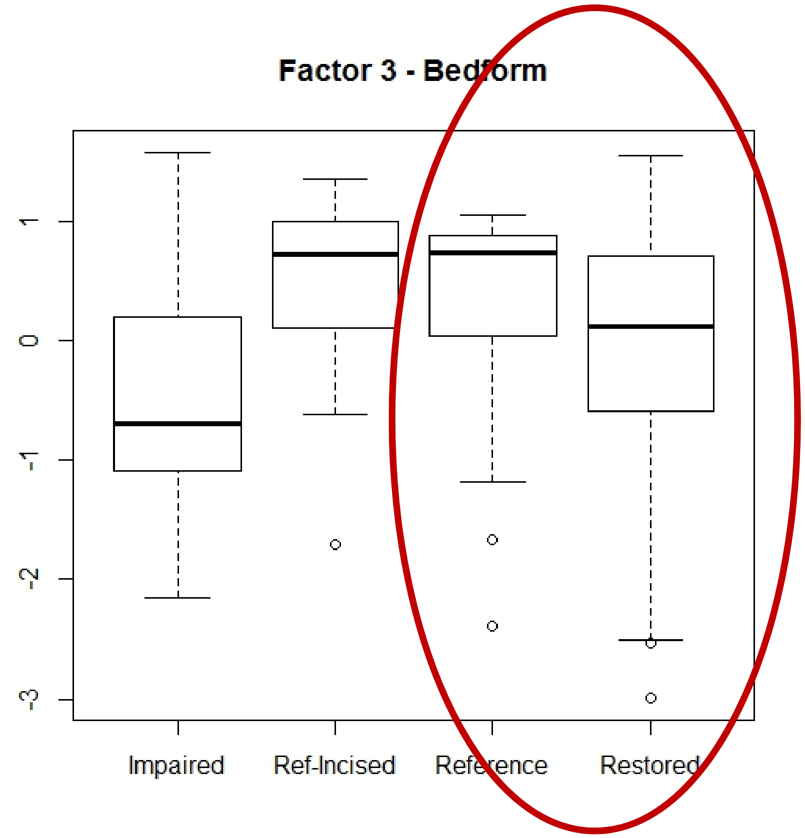


#	Variable	F1
15	Streambank condition	0.85
17	Floodplain function	0.78
16	Streambank vegetation	0.77
14	Sediment transport	0.72
6	Pattern	0.64

Factor 2: In-Stream Habitat

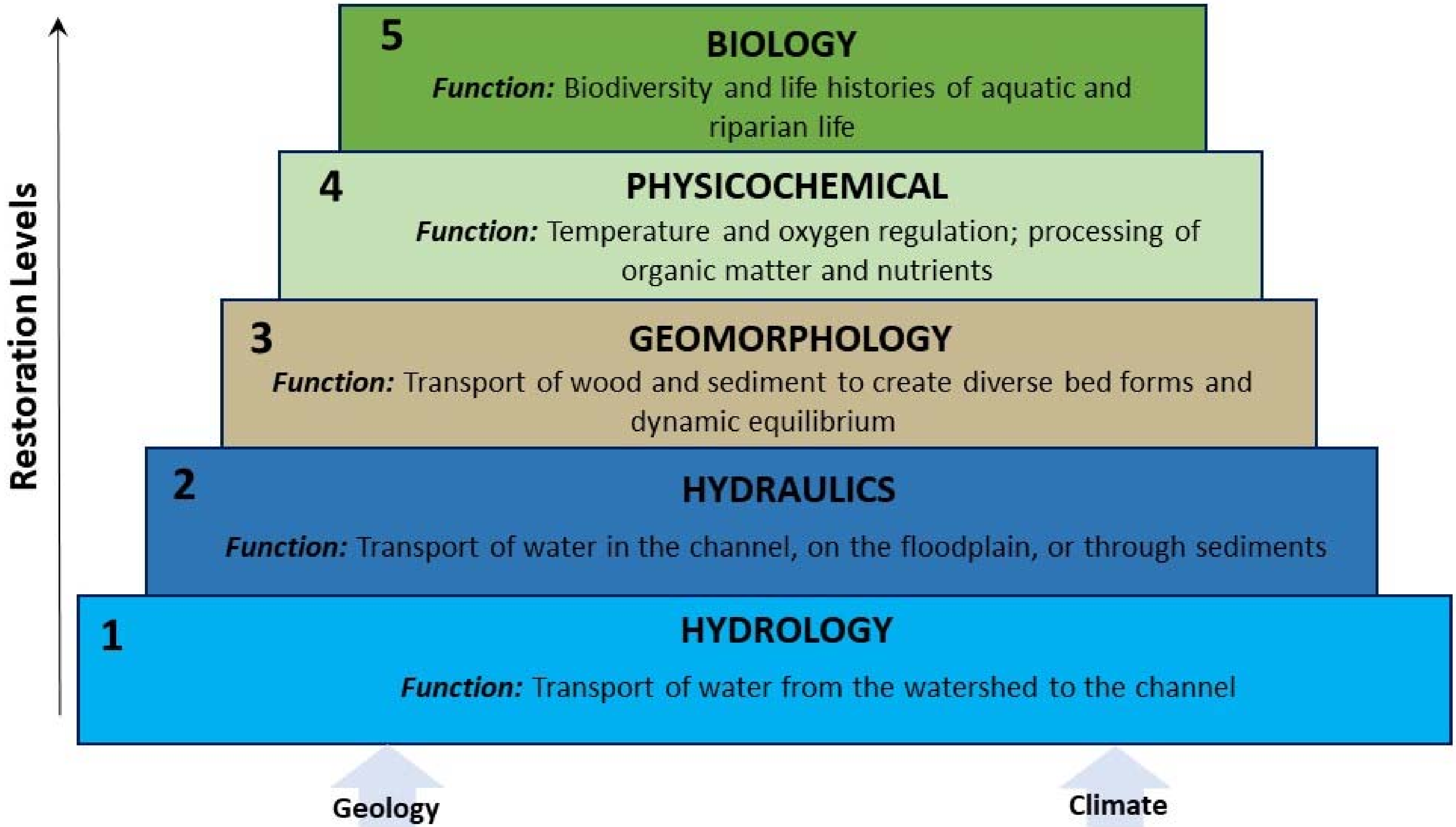
#	Variable	F2
10	Rootmats	0.82
11	Overhanging veg	0.74
8	Leaf packets	0.71
9	Undercut banks	0.68

Factor 3 - Bedform



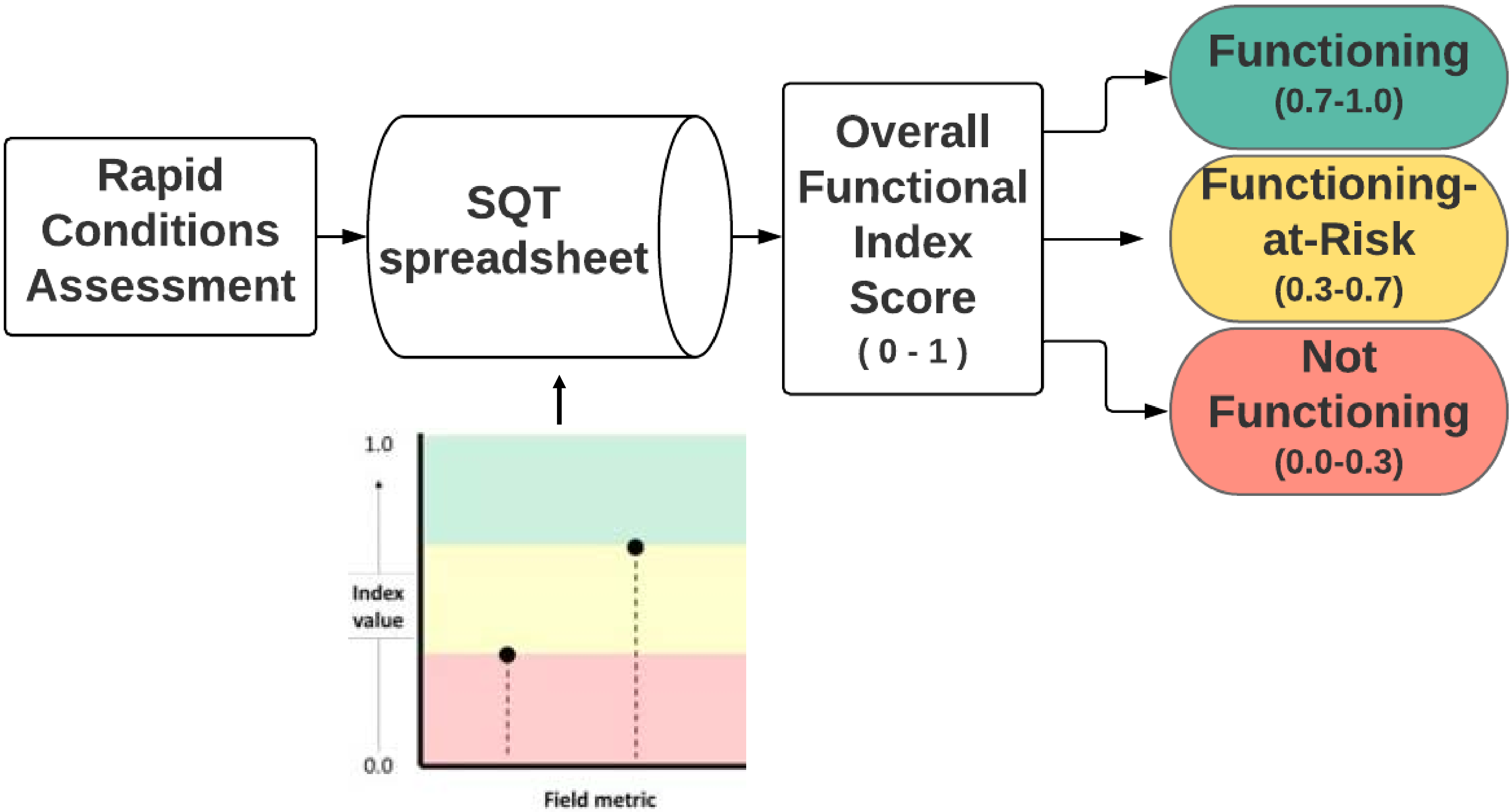
#	Variable	F3
3	Riffles length slope	0.86
1	Riffles pools alternating	0.76
2	Riffles pools located	0.73
4	Riffles clean material	0.62

Stream functions pyramid framework



Adapted from Harman et al., 2012, *US EPA*

Stream quantification tool (SQT)



SFAM, Version 1.0, *US EPA*, 2018

Adapted from Harman et al., 2017

Functional Category	Measurement Method
Hydrologic	Curve Number
	No. of Concentrated Flow Points
	Soil Compaction
Hydraulic	Bank Height Ratio
	Entrenchment Ratio
Geomorphic	LWD Index
	Large Woody Debris Piece Count
	Erosion Rate
	Dominant BEHI/NBS
	Percent Streambank Erosion
	Canopy Coverage
	Buffer Width
	Basal Area
	Stem Density
	Pool Spacing Ratio
	Pool Depth Ratio
	Percent Riffle
	Aggradation Ratio
	Sinuosity
	Size Class Pebble Count Analyzer

Functional Category	Measurement Method
Physico-chemical	Total Nitrogen
	Total Phosphorus
	Leaf Litter Processing Rate OR Percent Shredders
	Fecal Coliform
	Summer Daily Max. Temp.
Biological	NC Biotic Index for Macroinvertebrates
	EPT Index
	NC Index of Biotic Integrity for Fish
Restoration Potential	Watershed Catchment Assessment

Total SQT Variables= 28

Research questions

Does the NC SQT **accurately detect** and **quantify** ecological function?

1. How **accurately** does the SQT **measure restoration success?**

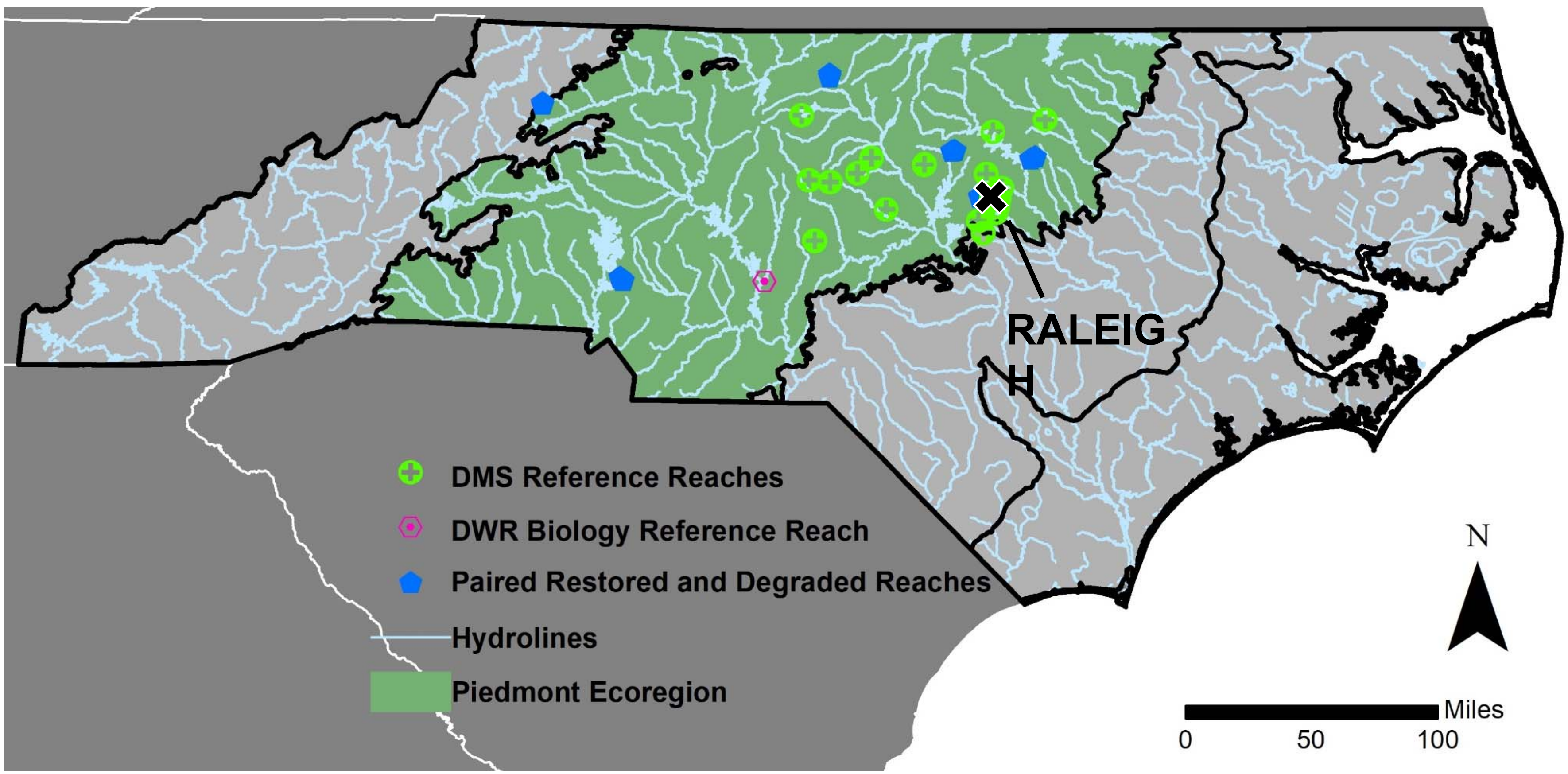
2. What is the **natural variability range** for stream function-based variables in the NC Piedmont?

3. Which function-based variables **correlate** best with **“good” biological composition**?

Site locations and selection

- DEQ DMS geomorphic reference sites *(n=18)*
- DEQ DWR biological reference site *(n=1)*
- Paired restored & degraded sites *(n=12; 6 pairs)*

- DAs < 8.6 sq. mi.
- Watershed land use range
- Stream orders 1 - 3
- Restored sites > 5 years old



Functional Category	Measurement Method
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	Large Woody Debris Piece Count
	~~Erosion Rate~~
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	Percent Streambank Erosion
	Canopy Coverage
	Buffer Width
	Basal Area
	~~Stem Density~~
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Functional Category	Measurement Method
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	~~Fecal Coliform~~
	~~Summer Daily Max~~. ~~Temp~~.
Biological	NC Biotic Index for Macroinvertebrates
	EPT Index
	~~NC Index of Biotic Integrity for Fish~~
Restoration Potential	Watershed Catchment Assessment

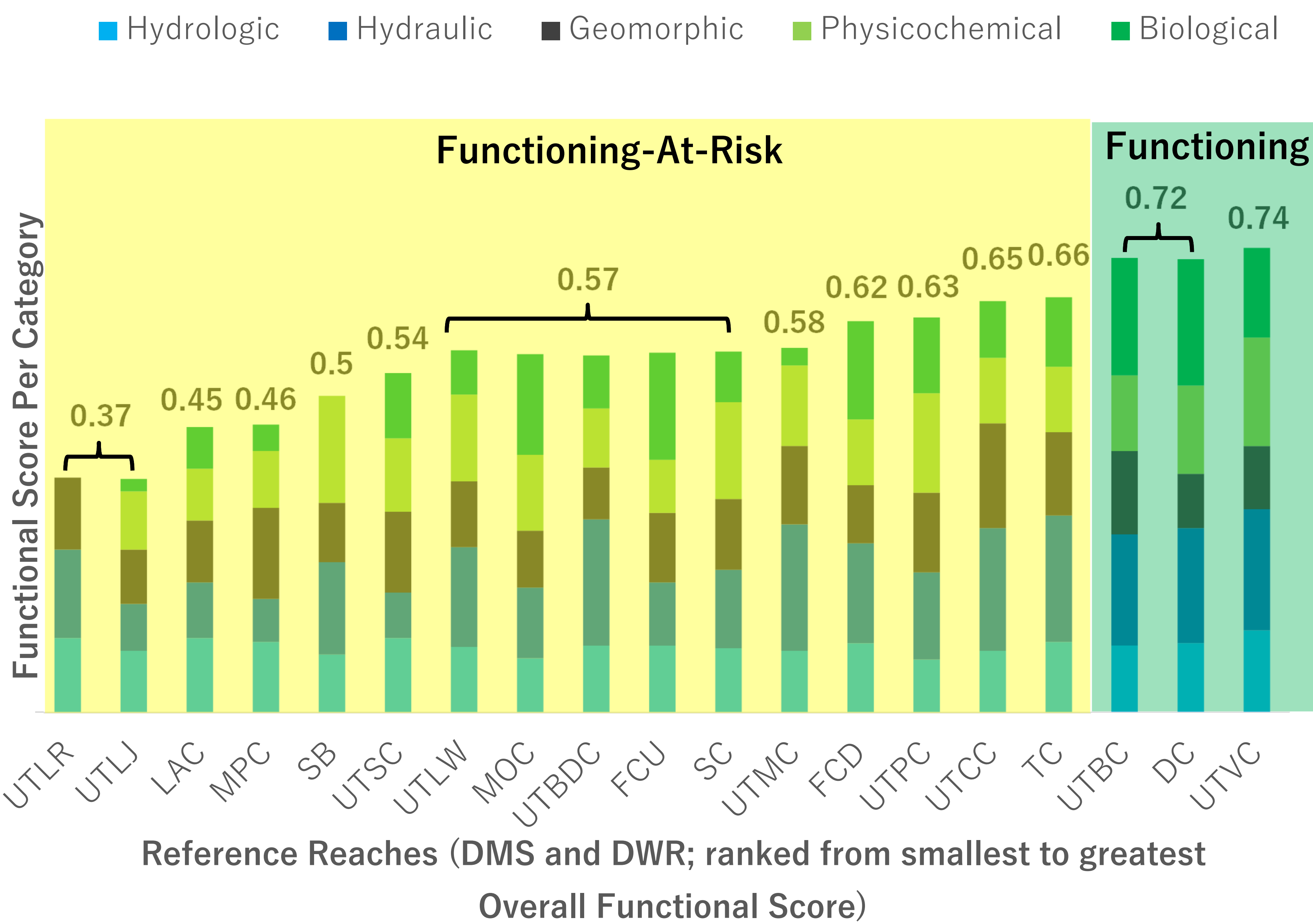
Total variables = 21
(out of 28 total variables)



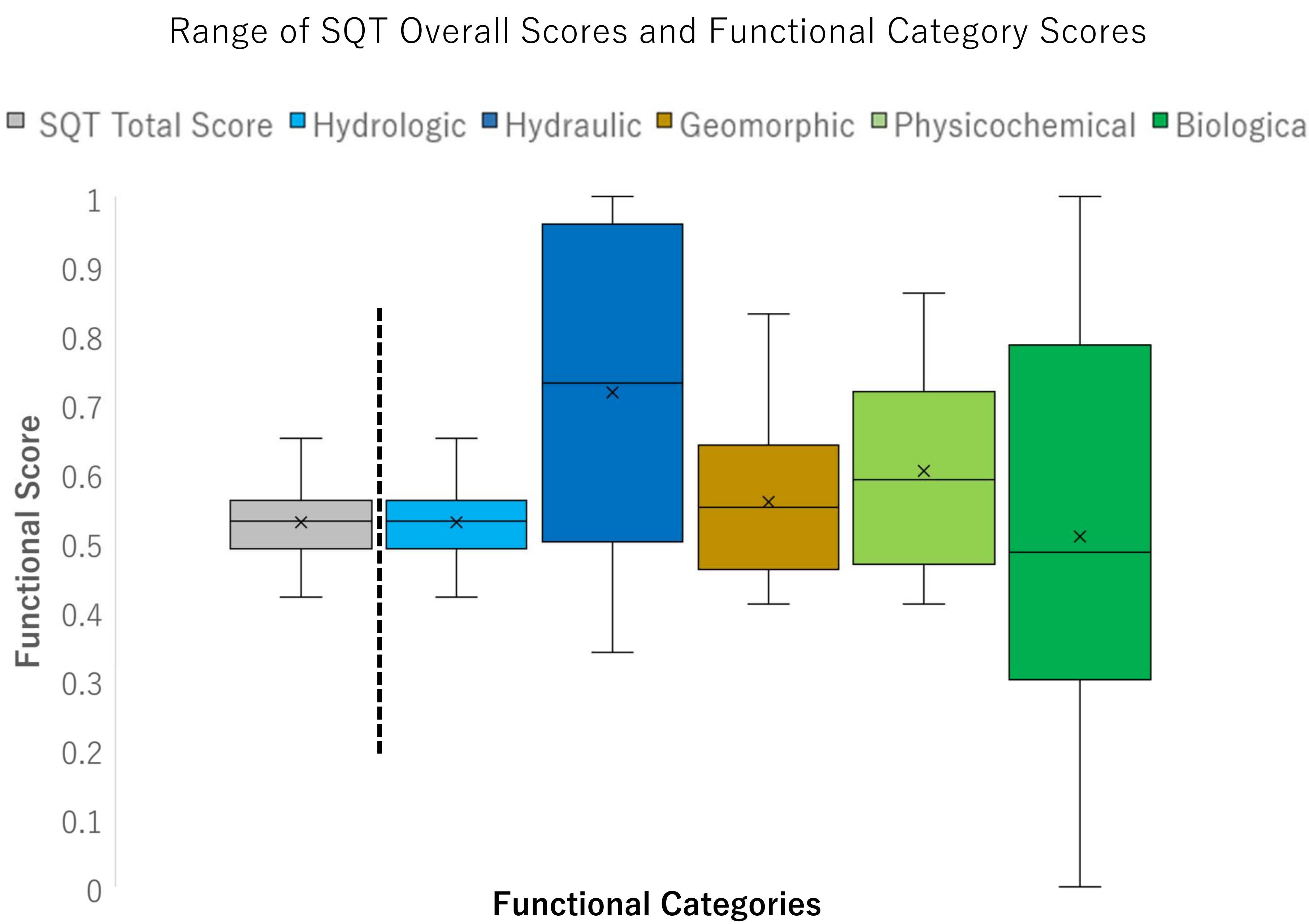








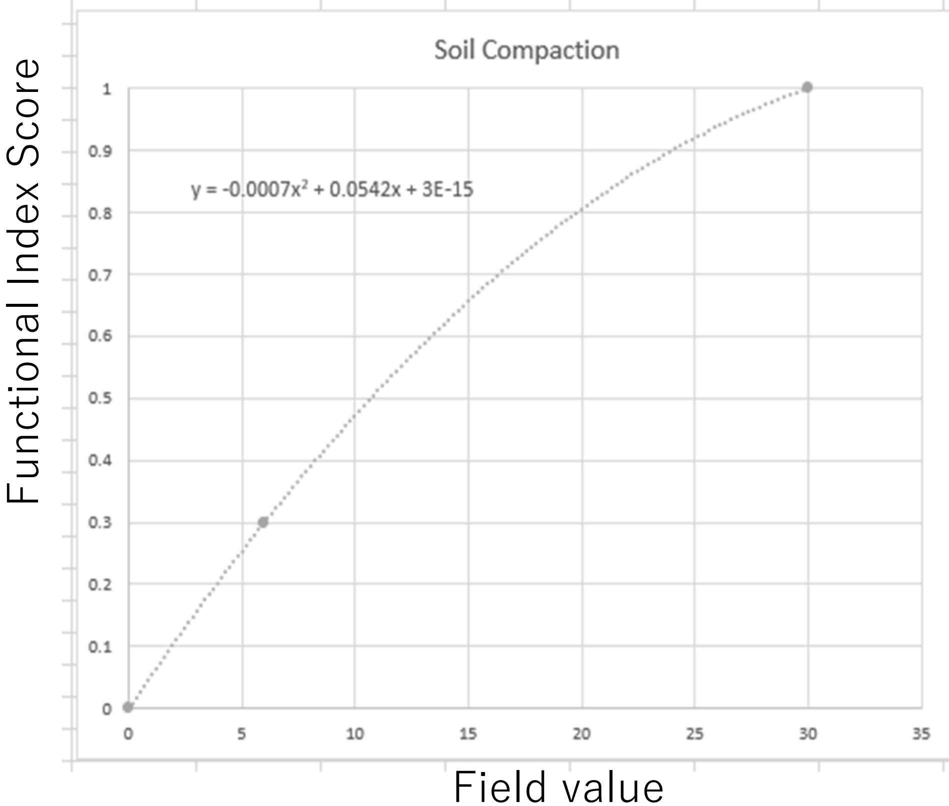
Hydrologic
Hydraulic
Geomorphic
Physicochemical
Biological
Functioning-At-Risk
Functioning
Functional Score Per Category
0.37
0.45
0.46
0.5
0.54
0.57
0.58
0.62
0.63
0.65
0.66
0.72
0.74
UTLR
UTLJ
LAC
MPC
SB
UTSC
UTLW
MOC
UTBDC
FCU
SC
UTMC
FCD
UTPC
UTCC
TC
UTBC
DC
UTVC
Reference Reaches (DMS and DWR; ranked from smallest to greatest Overall Functional Score)

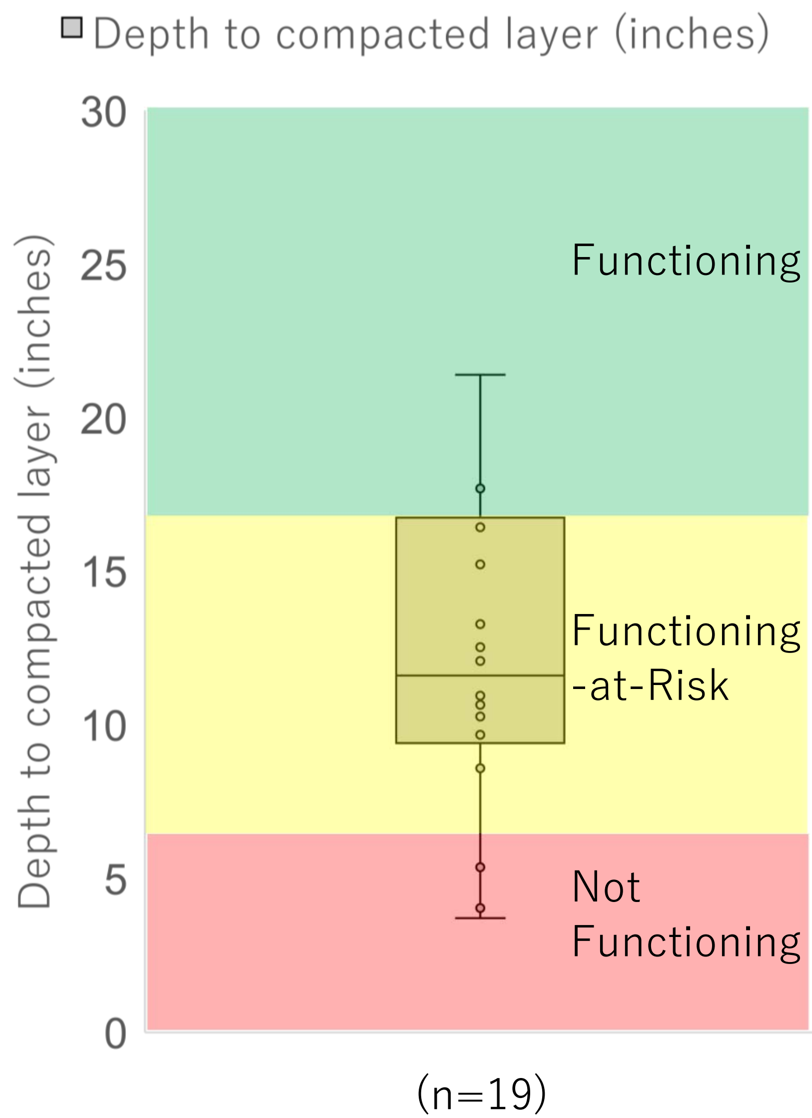

Range of SQT Overall Scores and Functional Category Scores
SQT Total Score
Hydrologic
Hydraulic
Geomorphic
Physicochemical
Biological
Functional Score
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Functional Categories

Soil Compaction

Field Value	0		6			30
Index Value	0	0.29	0.3	0.69	0.7	1

	Coefficients - Y = a * X^2 + b * X + c
a	-0.0007
b	0.0542
c	0

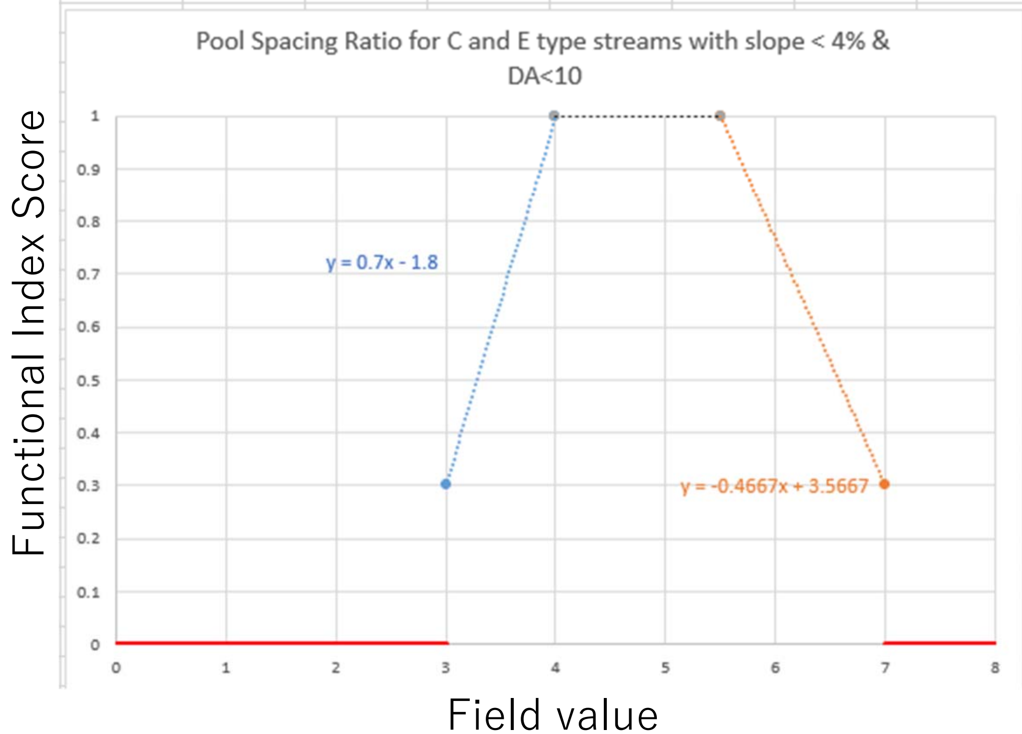


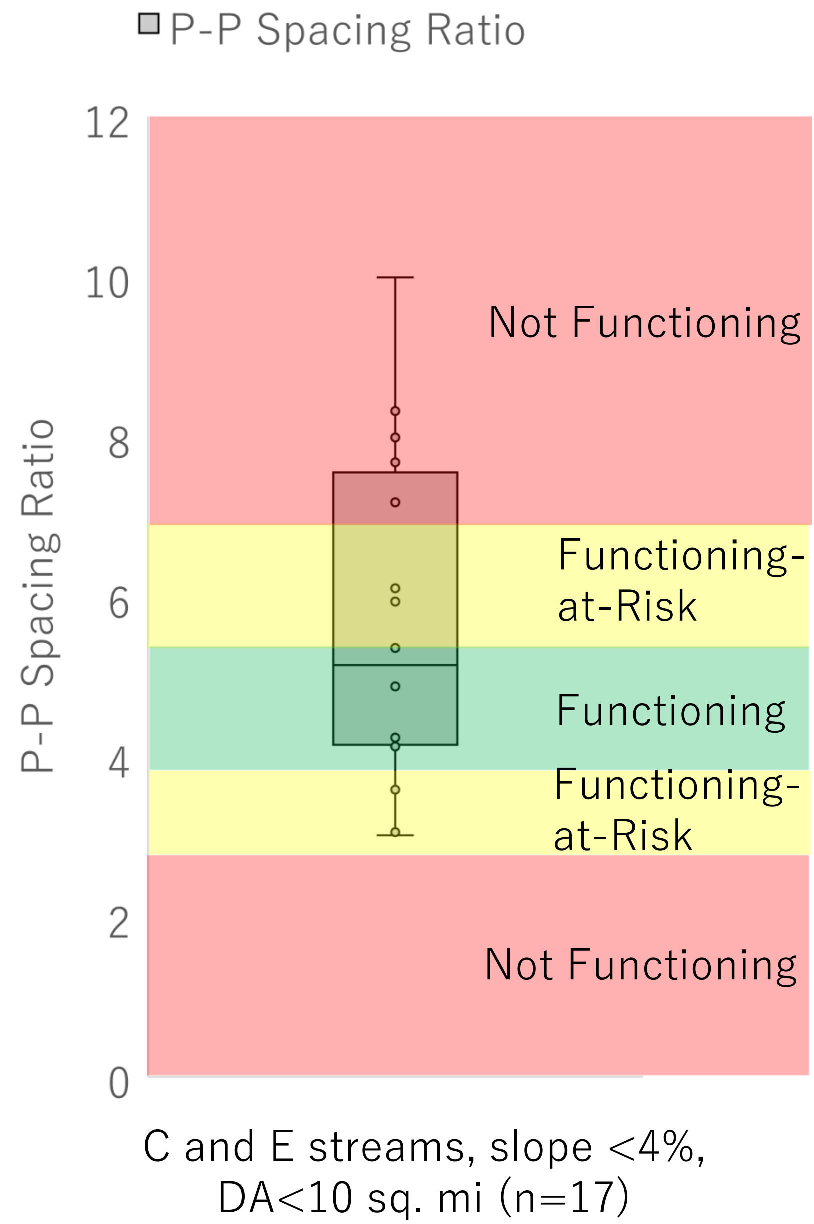


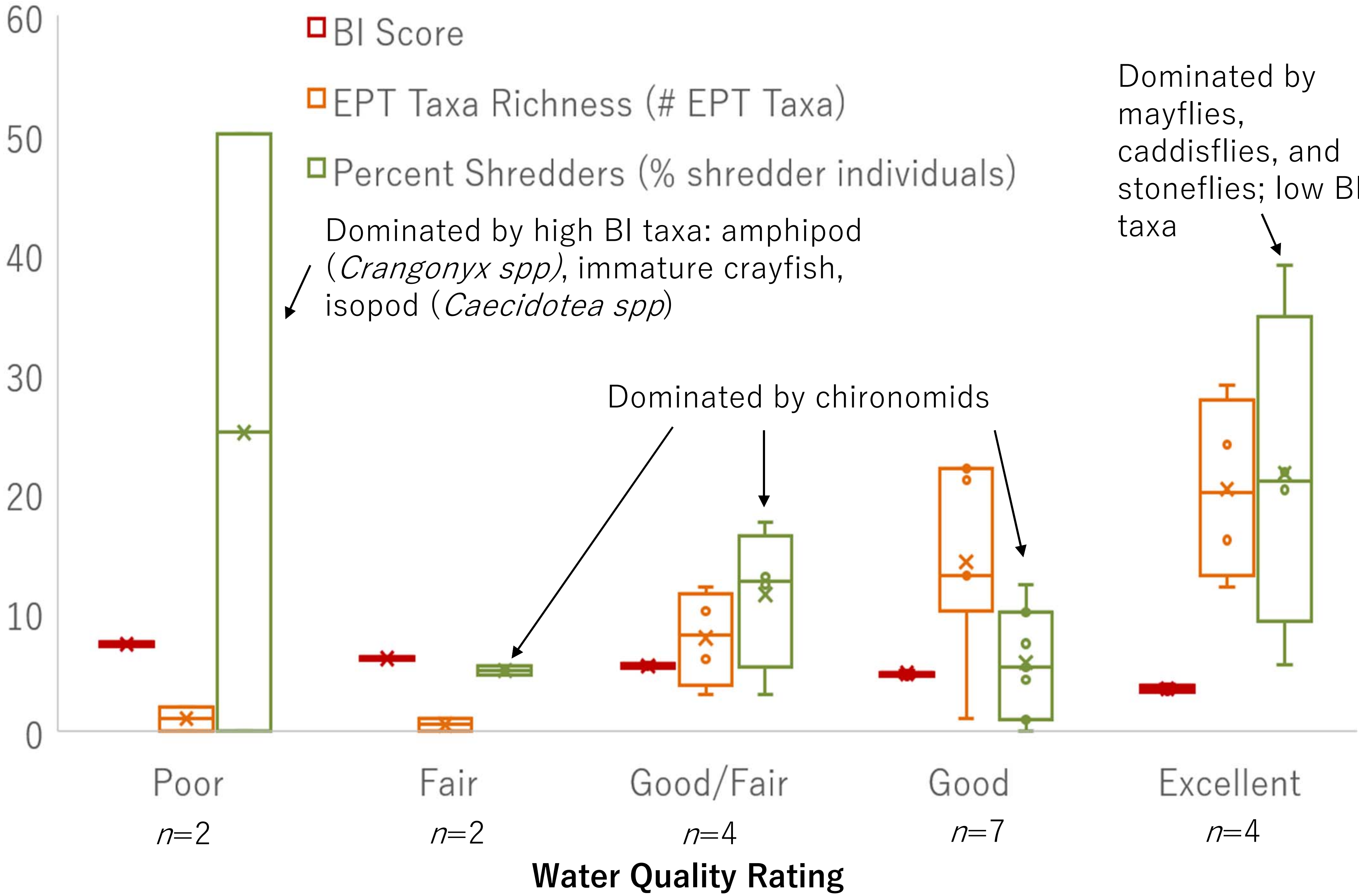
Pool-to-Pool Spacing Ratio (C and E streams)

Field Value			3			4	5.5
			7			5.5	
Index Value	0	0.29	0.3	0.69	0.7	1	1

	Coefficients - Y = a * X + b	
	Field < 4	Field > 5
a	0.7	-0.4667
b	-1.8	3.5667







60
50
40
30
20
10
0
BI Score
EPT Taxa Richness (# EPT Taxa)
Percent Shredders (% shredder individuals)
Dominated by high BI taxa: amphipod (*Crangonyx spp)*, immature crayfish, isopod (*Caecidotea spp*)
Dominated by chironomids
Dominated by mayflies, caddisflies, and stoneflies; low BI taxa
Poor
n=2
Fair
n=2
Good/Fair
n=4
Good
n=7
Excellent
n=4
Water Quality Rating

Next steps

- Evaluate statistical relationships between **landscape** (i.e. hydrologic) and **design** (i.e. hydraulic and geomorphic) variables and **benthic macroinvertebrate community metrics** (i.e. EPT Richness, BI)
- Identify landscape and design **predictor variables** of "good" biological composition
- Develop **significance weights** for SQT variables based on degree to which a variable supports "good" biological composition

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