Assessing Effectiveness of Green Infrastructure (G.I.) Stormwater BMPs at the Small Watershed Scale

Naomi Detenbeck et al., US EPA ORD
Atlantic Ecology Division, Narragansett, RI

US EPA Green Infrastructure Seminar Series

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Contributors

- EPA ORD/Region 1 RARE project (Ralph Abele, R1)

  - EPA NHEERL: Naomi Detenbeck , Nathan Smucker , Anne Kuhn, Alisa Morrison*, Darin Kopp*
- Green Infrastructure Project 3




  - Delaware River Basin (Maureen Krudner, R2)
    - Naomi Detenbeck, Nathan Smucker ,Jessica Morgan*, Darin Kopp*, Ivan Rubio*
  - Chesapeake Bay Watershed (Kevin Magerr, R3)
    - Naomi Detenbeck, Nathan Smucker , Steve Rego, Suzanne Cox*, Ivan Rubio*, Alisa Morrison*


  - Austin Metropolitan Area, TX (Suzanne Perea, R6)
    - Naomi Detenbeck, Alisa Morrison*, Ivan Rubio*
- Region 3 RARE (Ron Landy, R3)
  - Cooperative Agreement
    - Dale Manty (US EPA/ORD/NCER, P.O.), Gerrit Knaap (Univ of MD, National Center for Smart Growth), Jim Wickham (EPA/ORD/NERL), Matt Nicholson (EPA R3)
  - Interagency Agreement with USGS (EPA Green Infrastructure Add-on)
    - Peter Claggett (USGS-ERG), Matt Nicholson (EPA R3), Naomi Detenbeck (EPA/ORD/NHEERL, P.O.), Jim Wickham (EPA/ORD/NERL), Anne Kuhn (EPA/ORD/NHEERL)

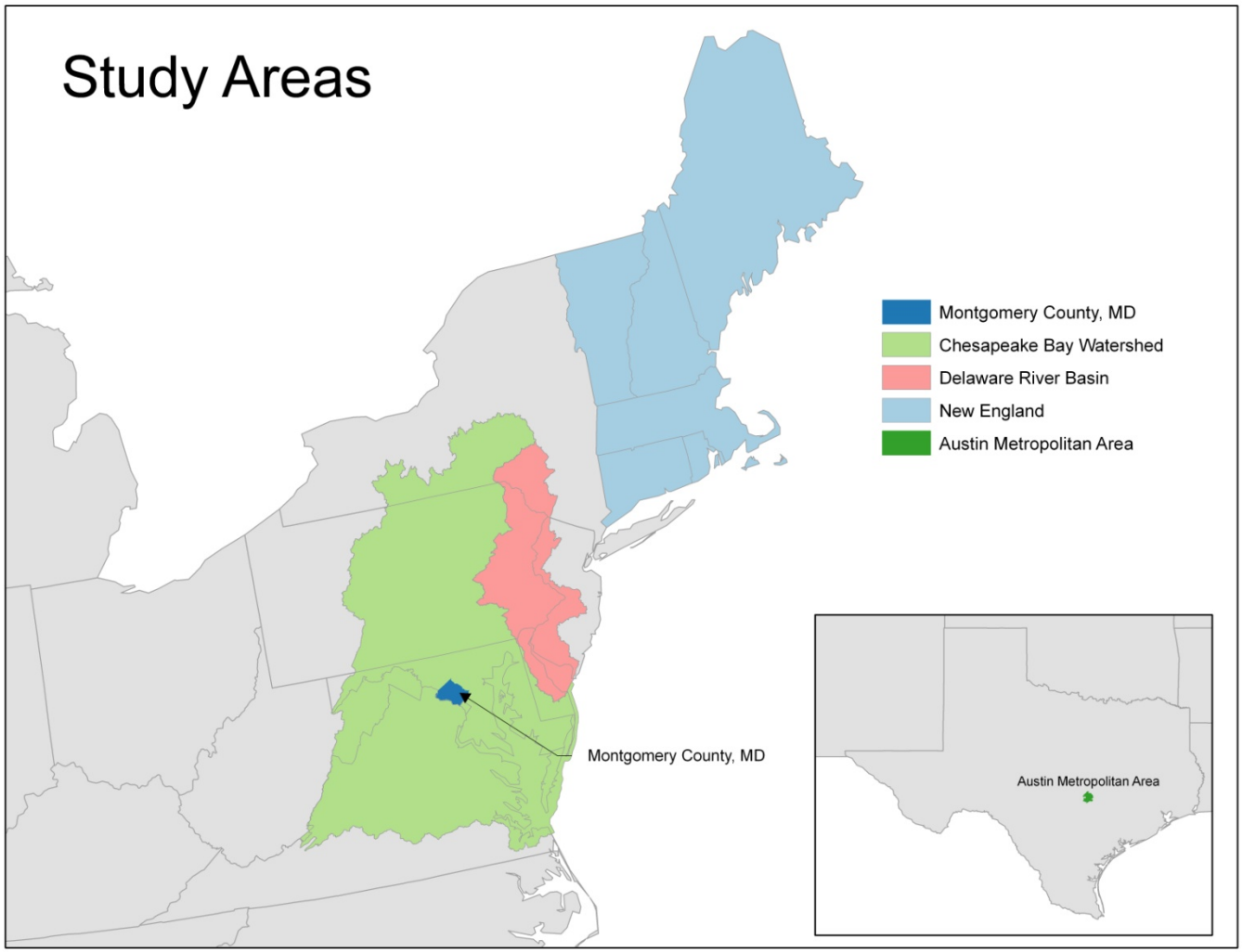
* Student services contractors to EPA

Outline

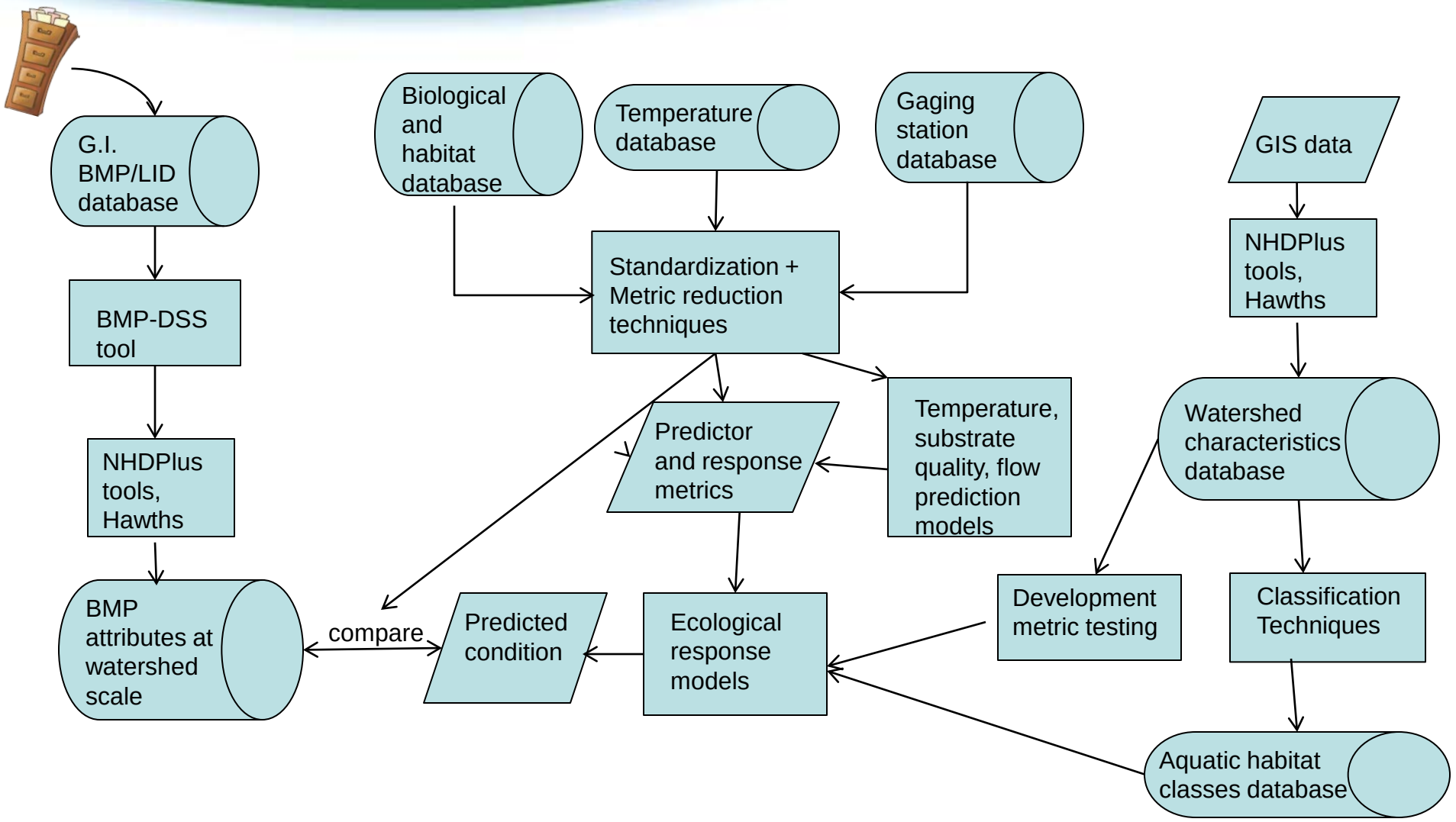
- Goals
- Approaches
- Initial results from Region 1 RARE project
- Remaining brain-teasers
- Coming attractions

Objectives

- Overall: Determine effectiveness of G.I. stormwater BMPs in protecting aquatic life uses
  - Develop urbanization-response relationships for habitat (substrate, bank erosion, temperature regime) and biotic communities (fish, macroinvertebrates, periphyton) in streams
  - Compare condition of watersheds that have green infrastructure BMPs/Low Impact Development (LID) implemented for stormwater with expected condition based on watershed development
    - Historical data
    - New survey of watersheds with GI BMP/LID
  - Diagnose cause of development-related impairments and recovery trajectories for BMP/LID remediations


Study Areas
Montgomery County, MD
Chesapeake Bay Watershed
Delaware River Basin
New England
Austin Metropolitan Area
Montgomery County, MD
Austin Metropolitan Area

General Approach

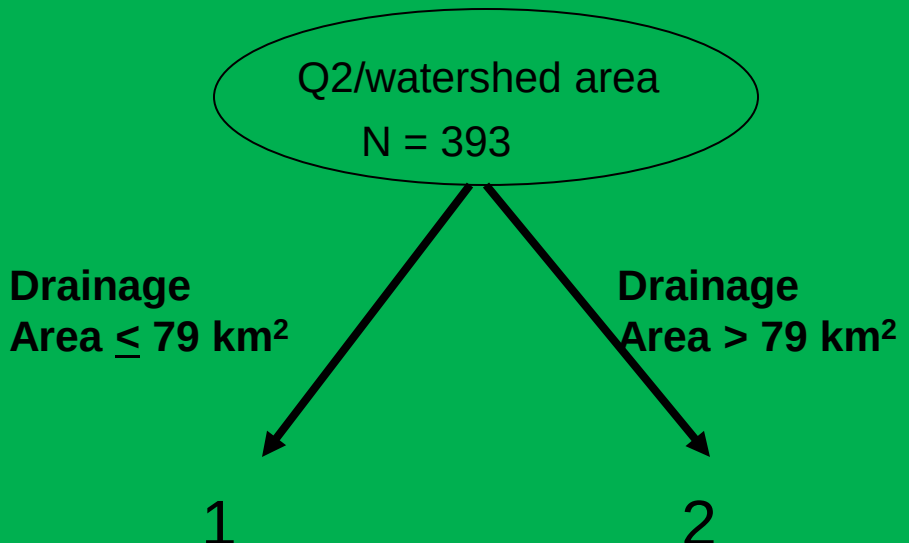


Flow regime classification

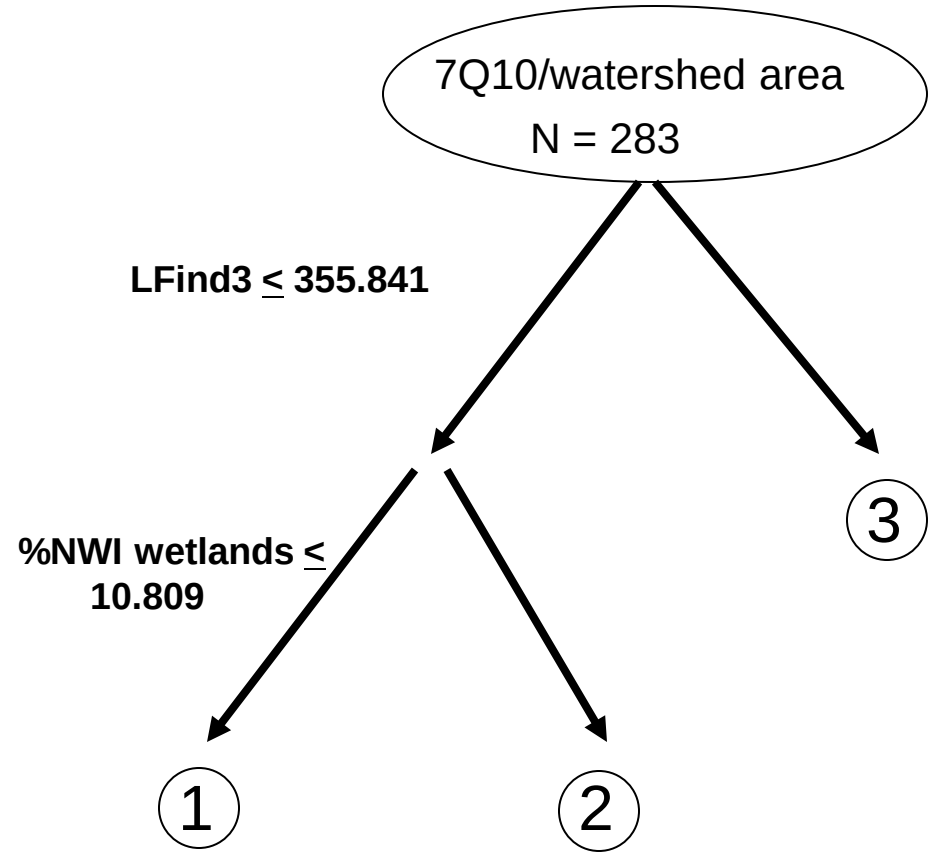
Region 1 basin characteristics related to peak or low flow

- Watershed area
- Main channel length
- Main channel slope
- Lake + pond area (high resolution NHD)
- % wetland area (palustrine emergent + open water classes based on National Wetlands Inventory coverages but not including lake + pond area from high-resolution NHD)
- Percent impervious area
- Percent coarse glacial till, outwash, and stratified drift
- 2-year 24-hour rainfall depth
- % forested (NLCD92 and NLCD01)
- Mean elevation, % area with elevation > 1200 ft
- Annual, spring, and winter precipitation averages (PRISM)
- Annual mean temperature (PRISM)

Bayesian Classification and Regression Tree analysis (BCART)



Which variables discriminate watershed classes with different peak flow prediction equations?



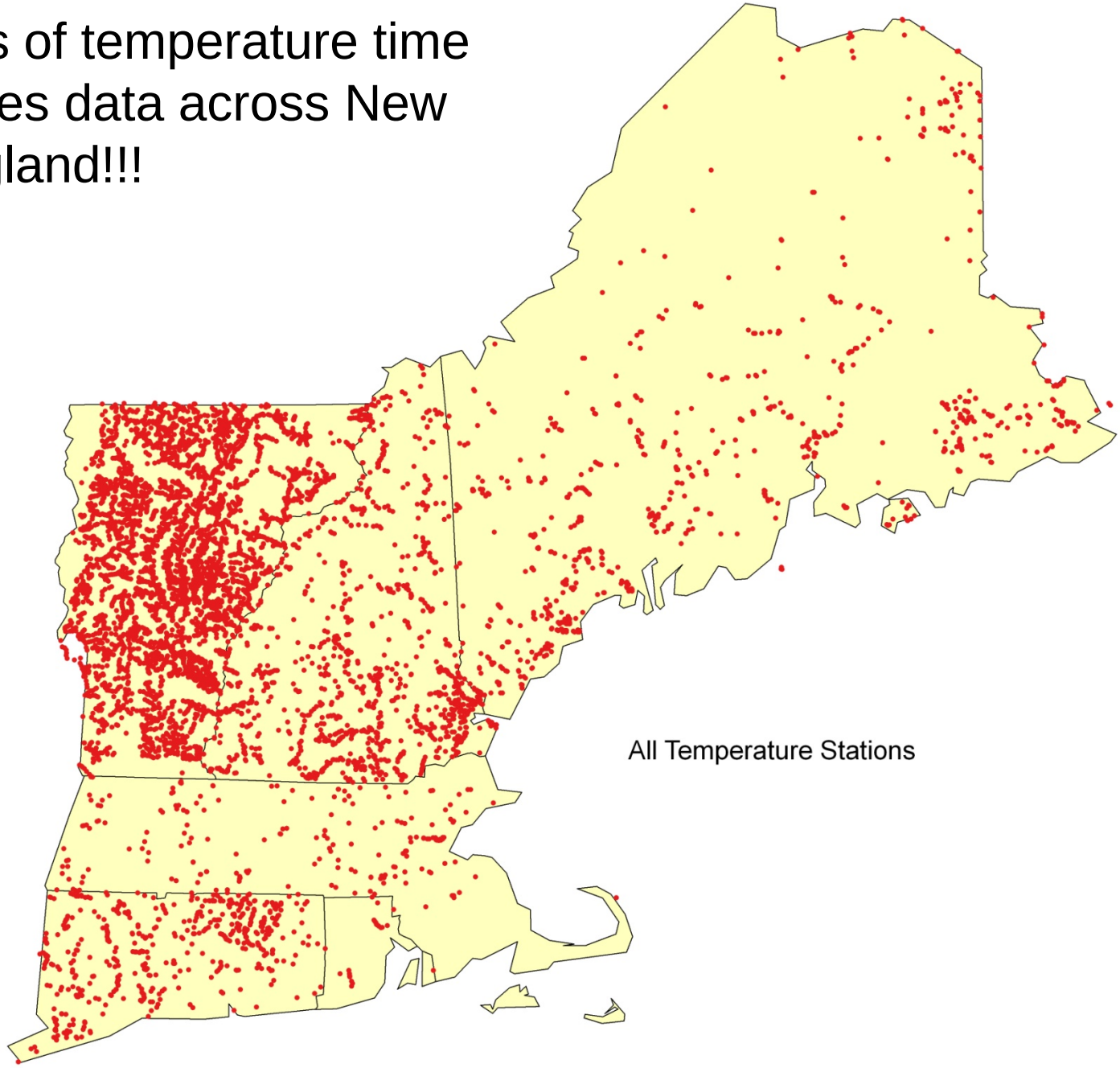
CART

Which variables discriminate watershed subclasses with different low flow levels?

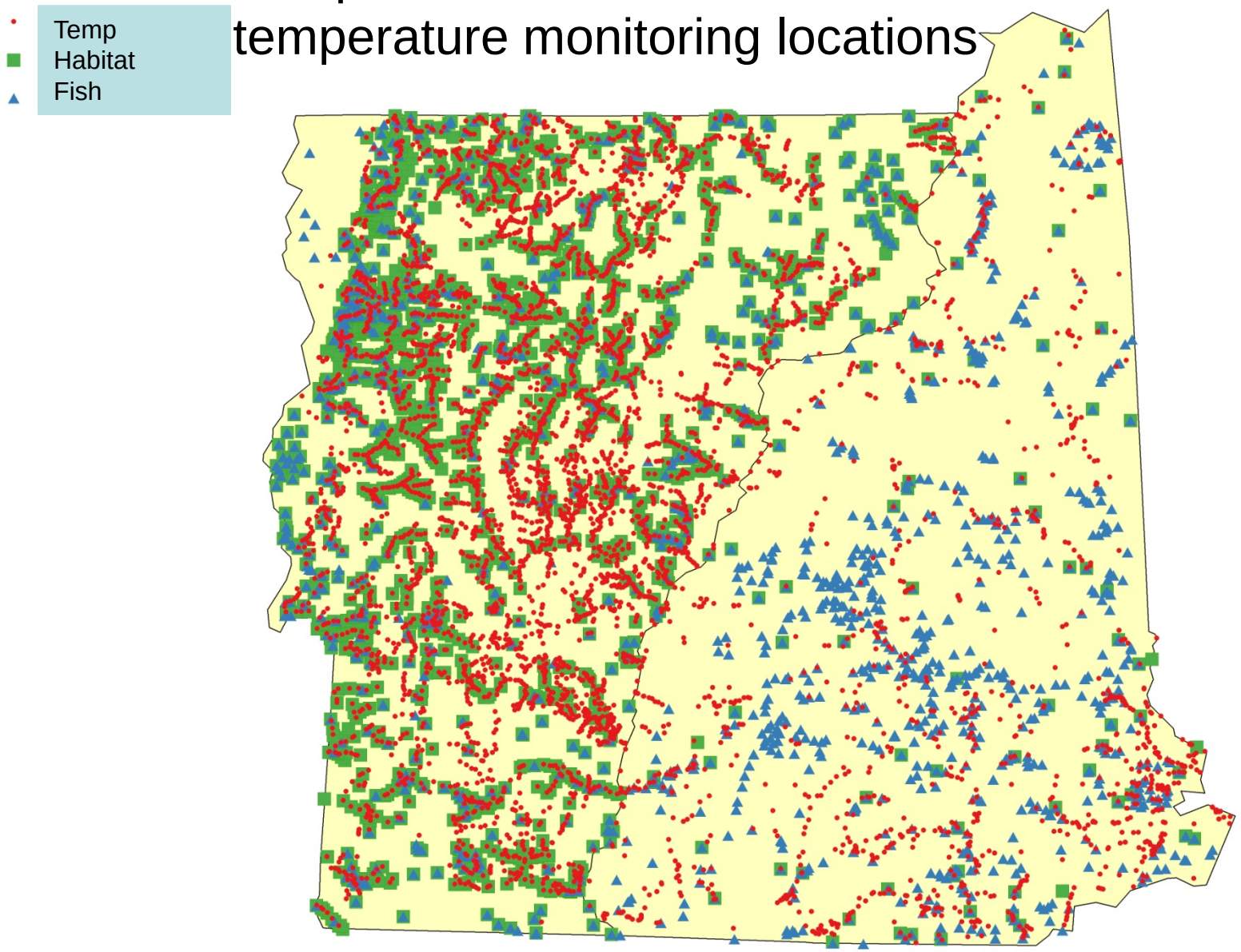
LFind3 = winter prec*ann avg temp / (spring prec*(fr_coarse deposits+0.01))

Predictive Temperature Models

Lots of temperature time series data across New England!!!

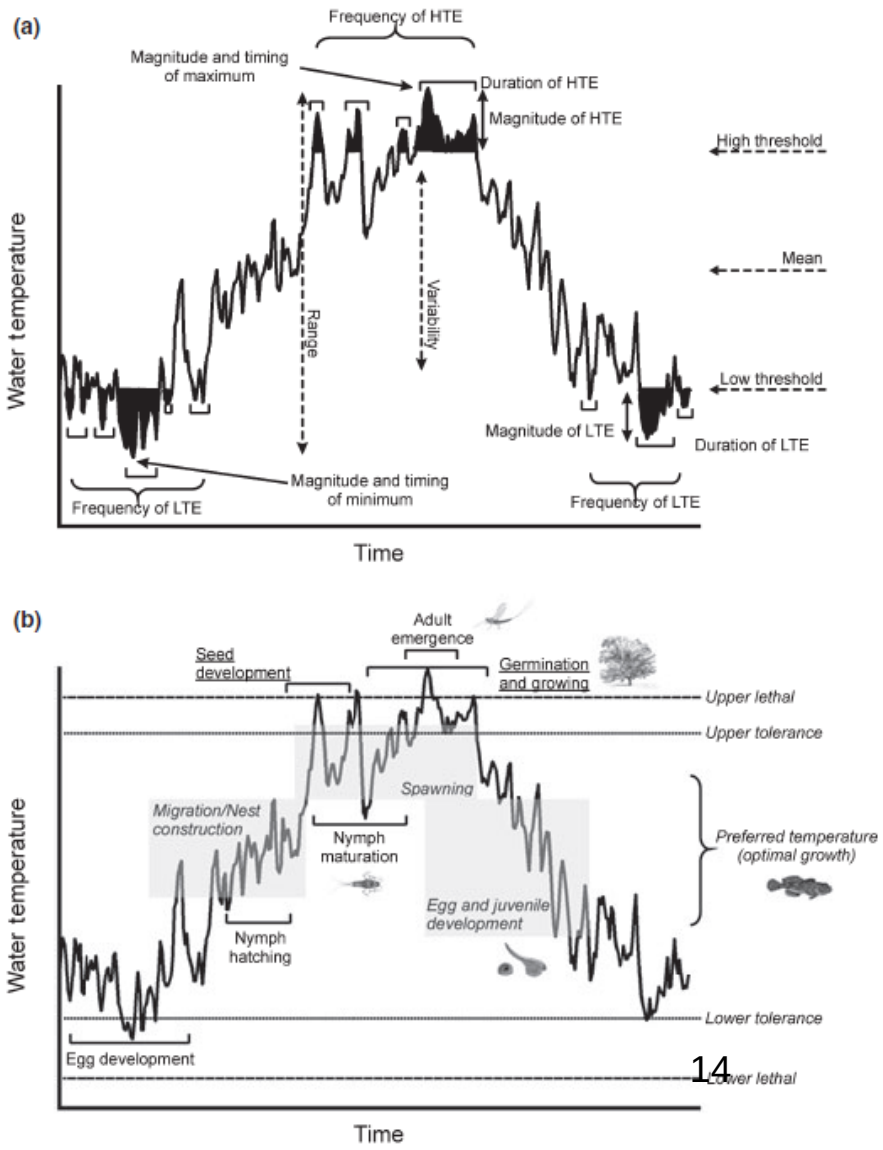


The problem: Limited matches between fish and temperature monitoring locations



Which metrics should we predict?

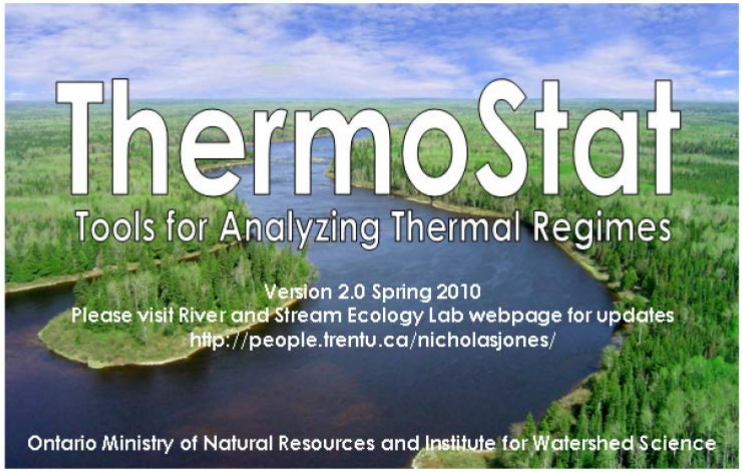
- Possible thermal metrics
  - Maximum/minimum temp
  - Magnitude of high/low temp event
  - Frequency of high/low temp event
  - Duration of high/low temp event
  - Timing
  - …



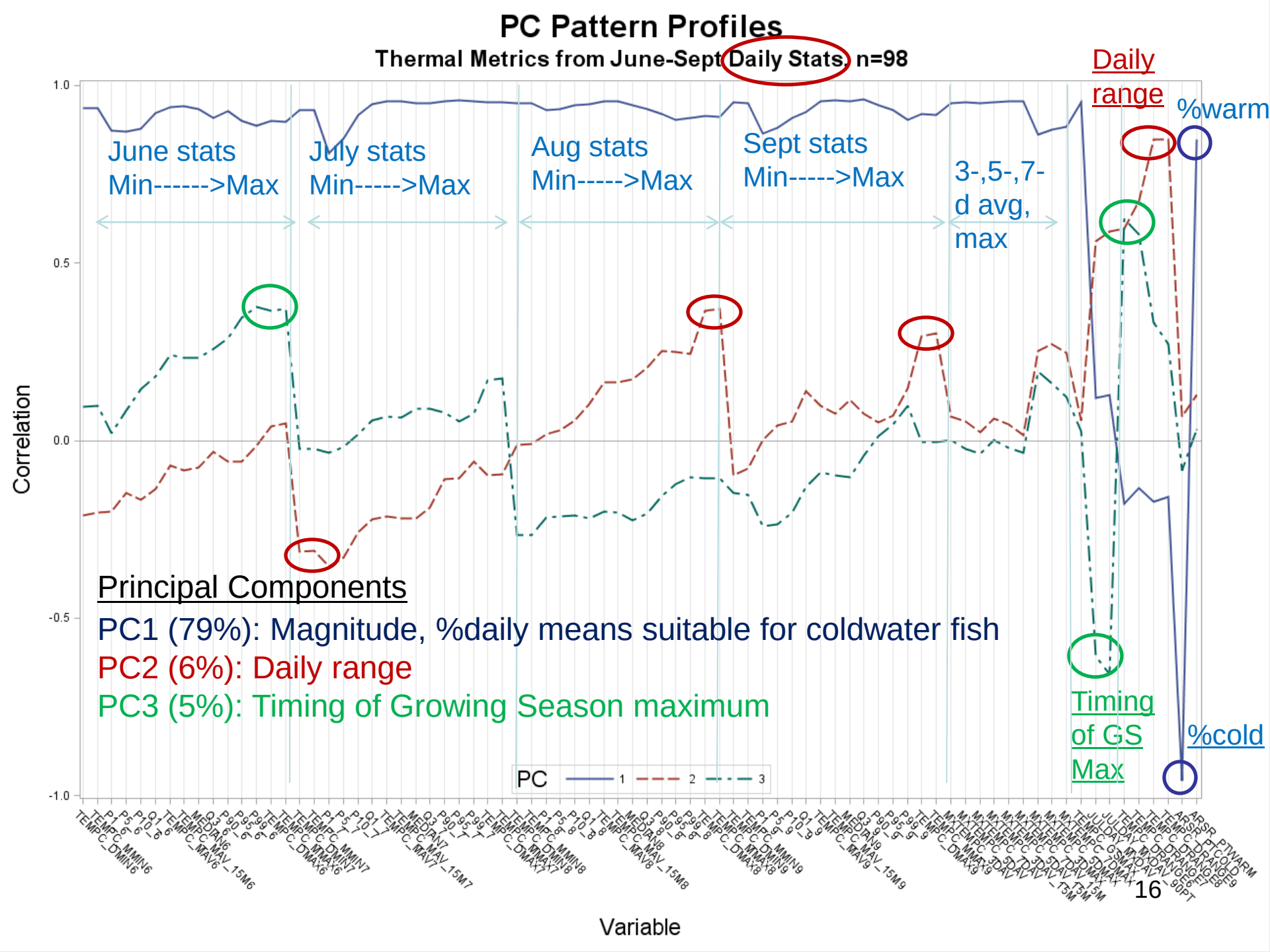
From Olden and Naiman, Freshwater Biology (2010) 55, 86–107

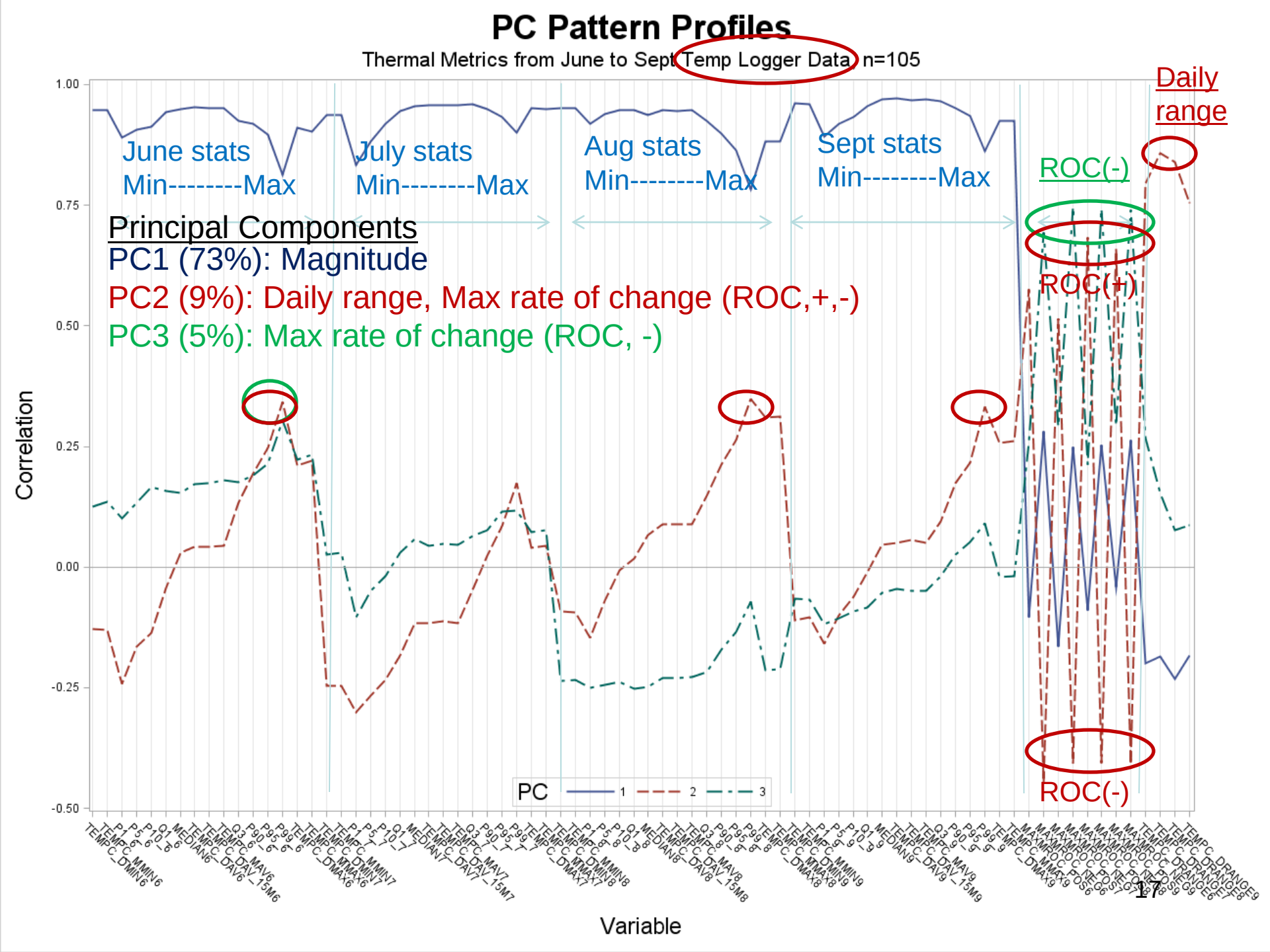
Calculation of thermal metrics

- Change
  - Maximum daily rate of change (ROC, +,
  - Daily range
- Growing season maximum
  - Magnitude
  - Timing
- Monthly duration curves
  - (p1, …median…,p99)
  - 15 min interval time series
  - Daily averages
- Monthly avg, min, max
- Avg and max of 3-, 5-, and 7-day running averages
- % daily averages suitable
  - Coldwater fish species
  - Coolwater fish species
  - Warmwater fish species
- Taxa-specific optima and thresholds



Recoded in SAS for batch processing


PC Pattern Profiles
Thermal Metrics from June-Sept Daily Stats, n=98
Daily range
%warm
June stats Min------>Max
July stats Min----->Max
Aug stats Min----->Max
Sept stats Min----->Max
3-,5-,7-d avg, max
Principal Components
PC1 (79%): Magnitude, %daily means suitable for coldwater fish
PC2 (6%): Daily range
PC3 (5%): Timing of Growing Season maximum
Timing of GS Max
%cold
PC 1 2 3
Correlation
1.0
0.5
0.0
-0.5
-1.0
Variable
16

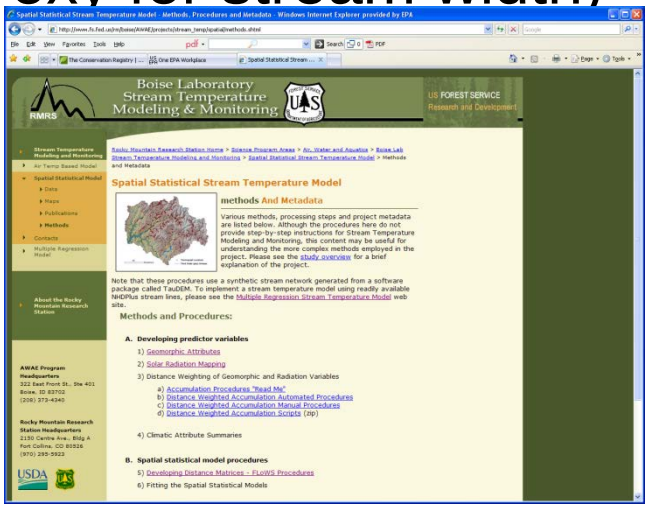

PC Pattern Profiles
Thermal Metrics from June to Sept Temp Logger Data, n=105
Daily range
June stats
Min--------Max
July stats
Min--------Max
Aug stats
Min--------Max
Sept stats
Min--------Max
ROC(-)
ROC(+)
ROC(-)
Principal Components
PC1 (73%): Magnitude
PC2 (9%): Daily range, Max rate of change (ROC,+,-)
PC3 (5%): Max rate of change (ROC, -)
Correlation
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
PC 1 2 3
Variable

Preliminary conclusions

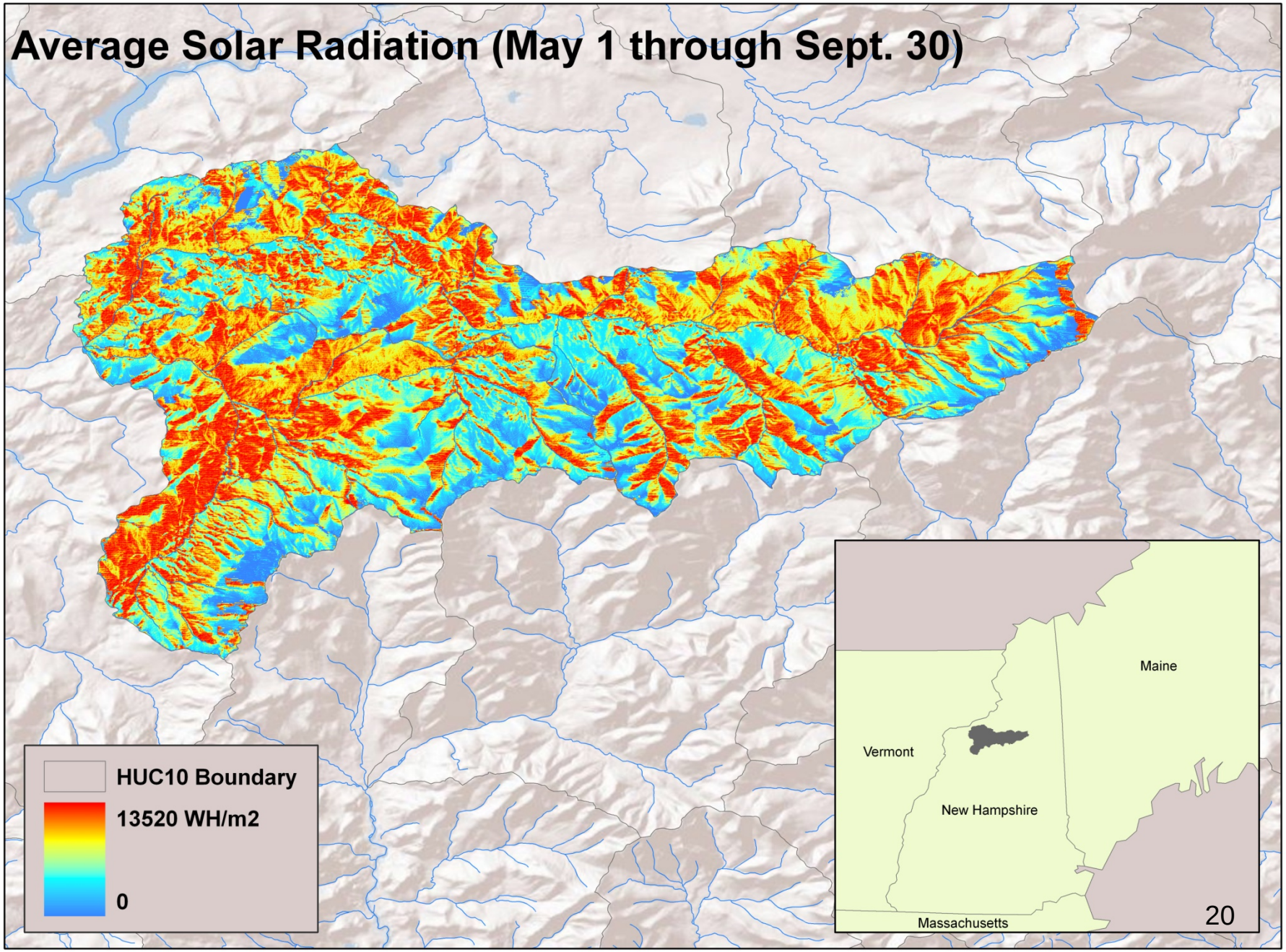
- Metrics to capture greatest variation across thermal regimes
  - Overall magnitude: July or August median
  - Daily range
  - Timing of growing season maximum
  - Max negative rate of change (recovery?)
- Observations limited by inconsistencies in sampling window and logger location but patterns consistent for larger data sets with shorter sampling windows
- Insufficient fish-temperature matches to explore best predictive metrics for fish thermal guilds unless filtering criteria relaxed

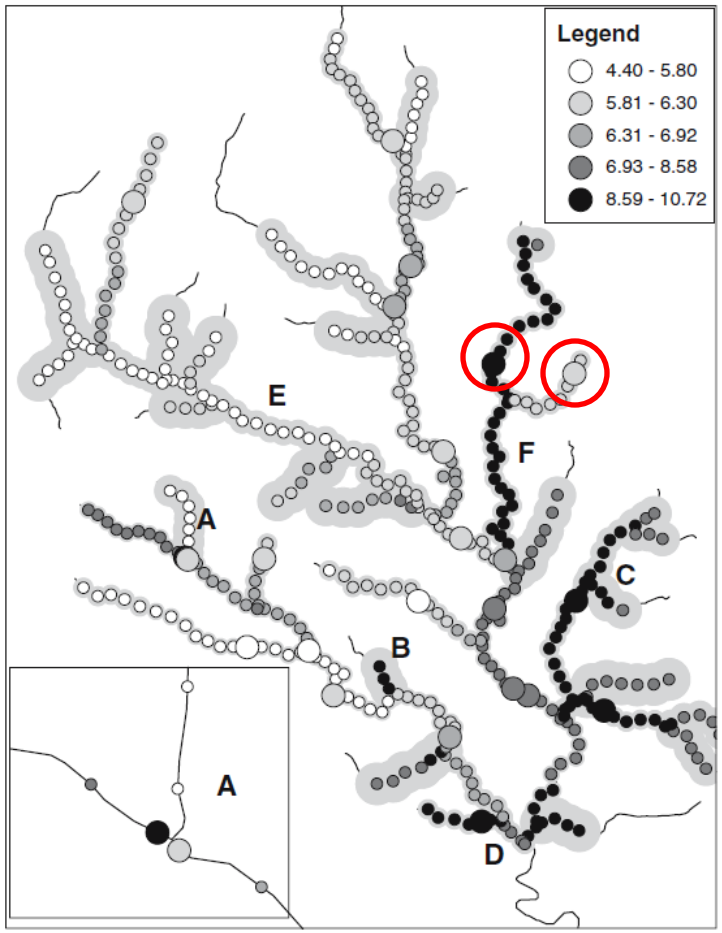
Temperature metric prediction model approach

- Flow-weighted spatial autocorrelation model using stream distance (ver Hoef et al. 2006)
- Potential predictors
  - Watershed area (proxy for stream width)
  - Drainage density
  - Elevation
  - Coarse deposits
  - Channel slope
  - % impervious area
  - Elevation-corrected air temperature
  - Solar radiation proxy (=f(average solar radiation, riparian vegetation type/density, stream width))
  - Stream flow (estimated)



Topographic Shading Component via ArcMap Solar Radiation





A predictive model accounting for spatial autocorrelation using Euclidean (straight-line) distance would assume these points are similar

observed

predicted

Environ Ecol Stat (2006) 13:449–464
DOI 10.1007/s10651-006-0022-8

ORIGINAL ARTICLE

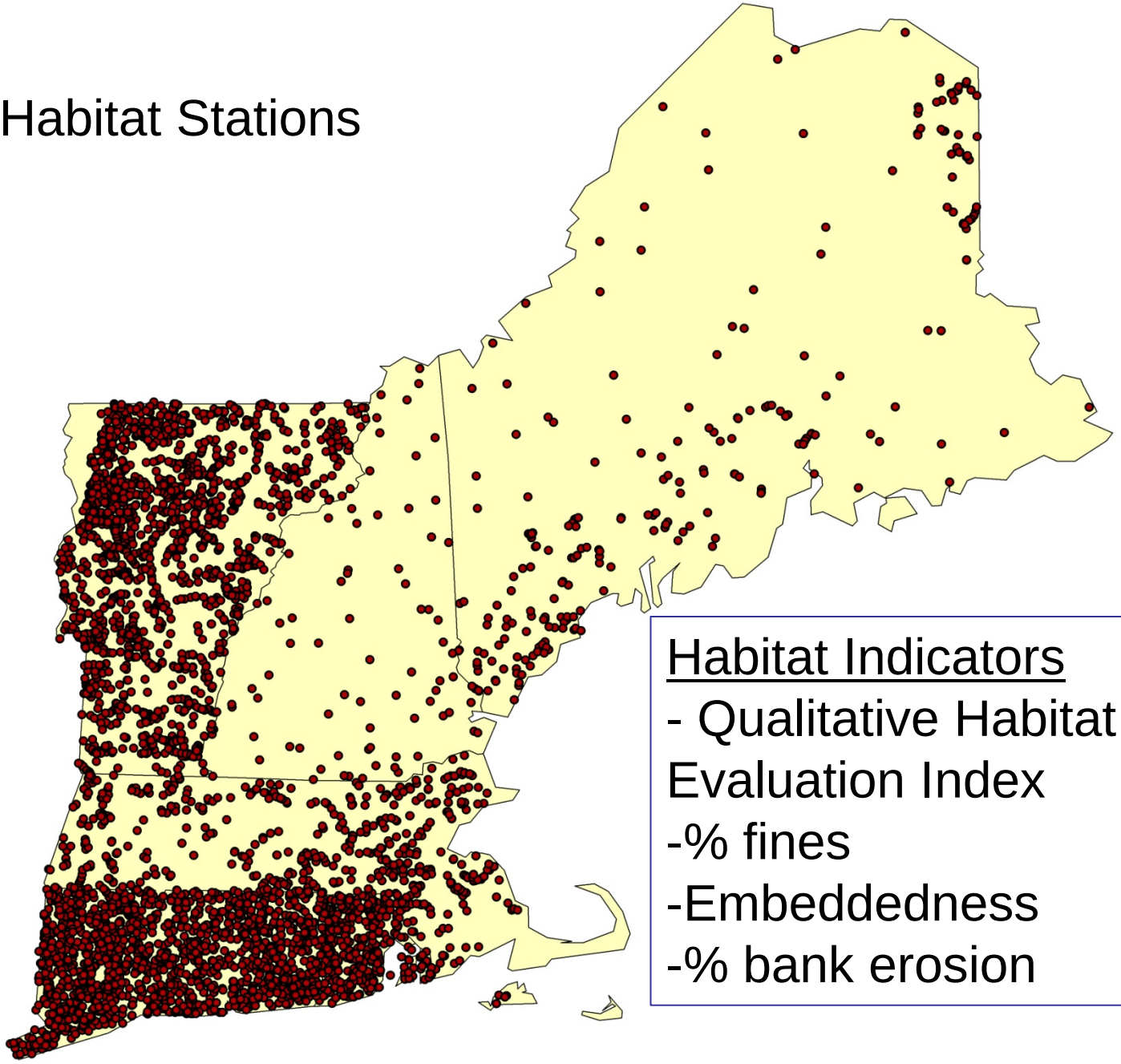
Spatial statistical models that use flow and stream distance

Jay M. Ver Hoef · Erin Peterson · David Theobald

Fig. 6 Predictions for the example data in Fig. 2. The Observed locations are shown with large circles and predicted locations are shown with smaller circles; both are shaded according to their observed or predicted values. The width of the gray shading behind the circles is proportional to the prediction standard errors. Thus, areas with wider shading have less precision

Predictive Habitat Quality Models

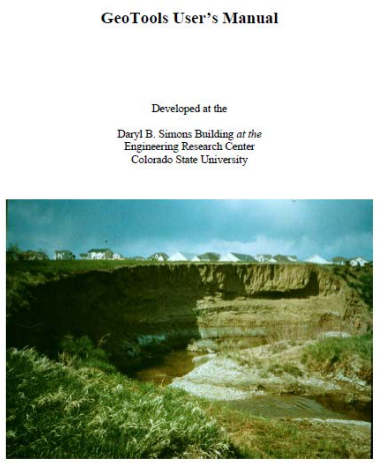
All Habitat Stations



Habitat Indicators
- Qualitative Habitat Evaluation Index
-% fines
-Embeddedness
-% bank erosion

Habitat prediction models

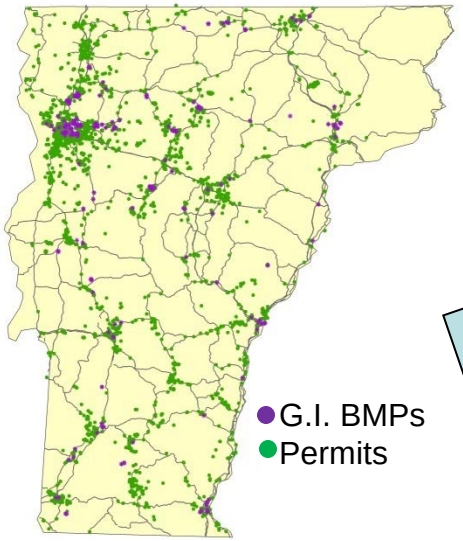
- % bank erosion – previously predicted w simple model of hydrogeomorphic unit, watershed storage (flashiness), % mature forest (natural vegetation)
- % embeddedness
  - Better predicted as function of change in development (construction activity) rather than total development
  - Prediction of loading insufficient
    - Supply vs. transport capacity
    - Comparison of expected travel time for bedload in gravel/cobble versus fine sediment fractions
- Vermont successional channel stage approach



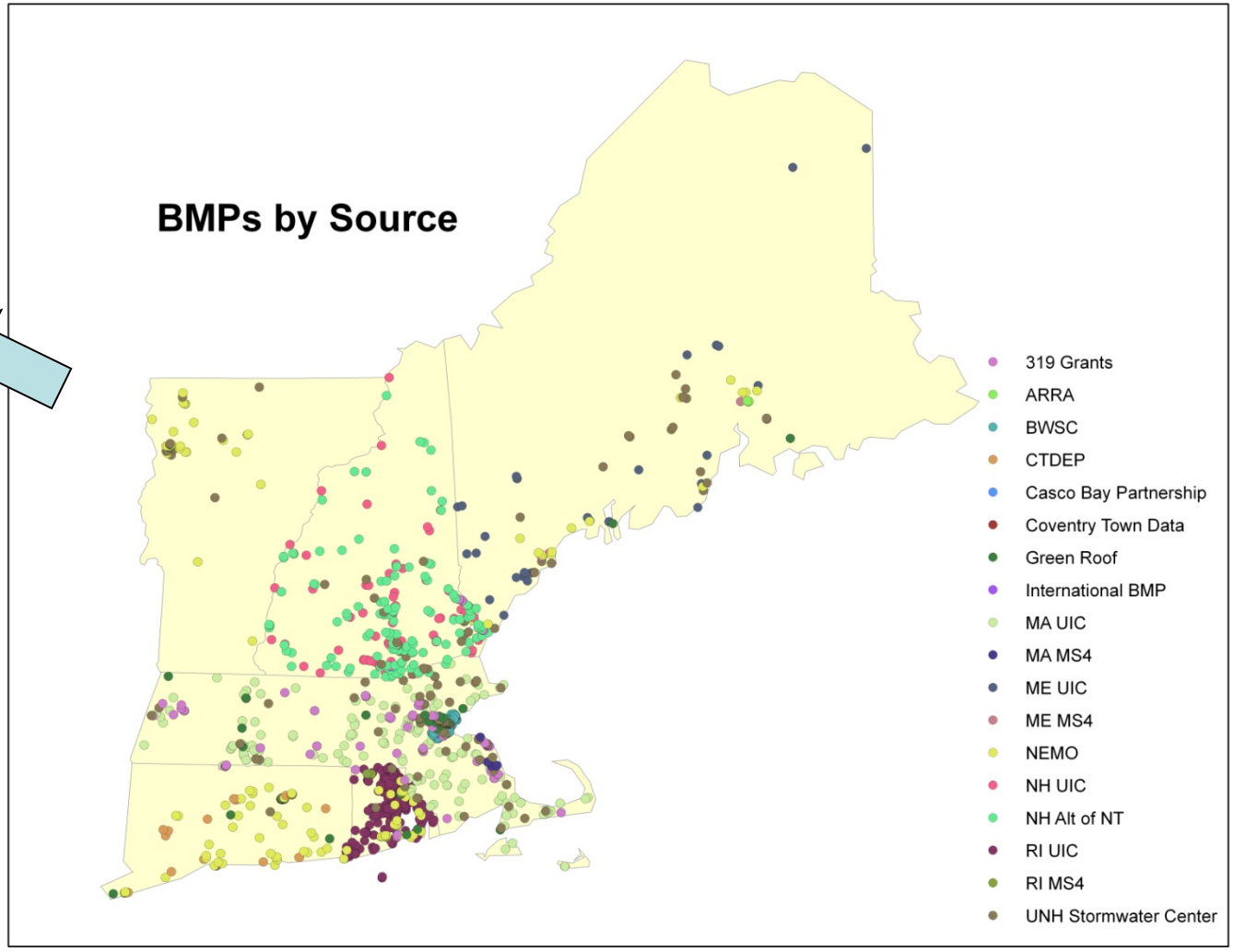
BMP Inventories

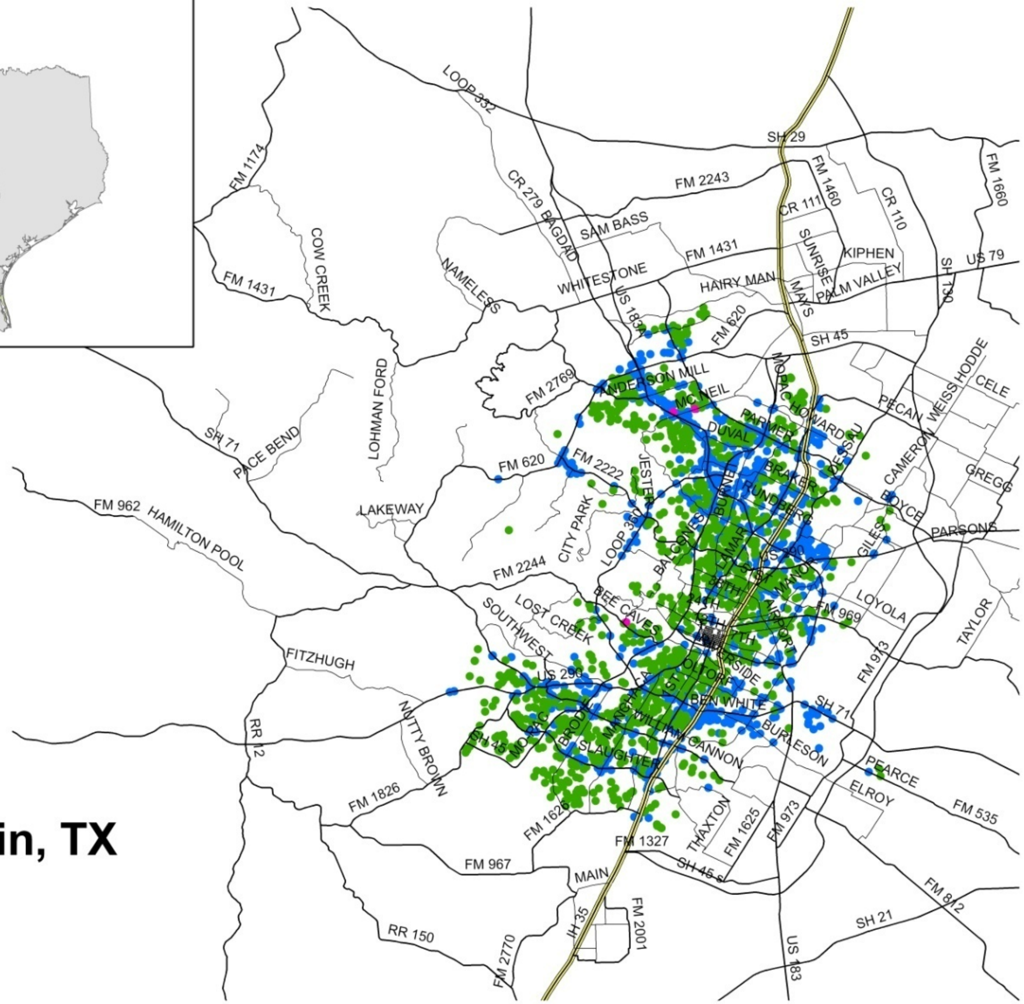
G.I./LID Stormwater BMP Data Sources

- Chesapeake Bay TMDL Tracking Database
- State permit databases (☺) and files (:<)
  - Stormwater permits (VT, DE, MD, PA)
  - Alteration of terrain permits (NH)
  - Wetlands (RI)
  - Underground Injection Control permits (UIC, all states but variable implementation)
  - Construction general stormwater permit NOI forms (NY)
- Municipality BMP databases (e.g., Boston, MA; Austin, TX; Philadelphia, PA, Washington, D.C.)
- NGO Databases (e.g., NEMO, Green Roofs, LEED)
- 319 Projects (GRTS database), ARRA inventories
- MS4 annual reports (minimal info)



VT permit database

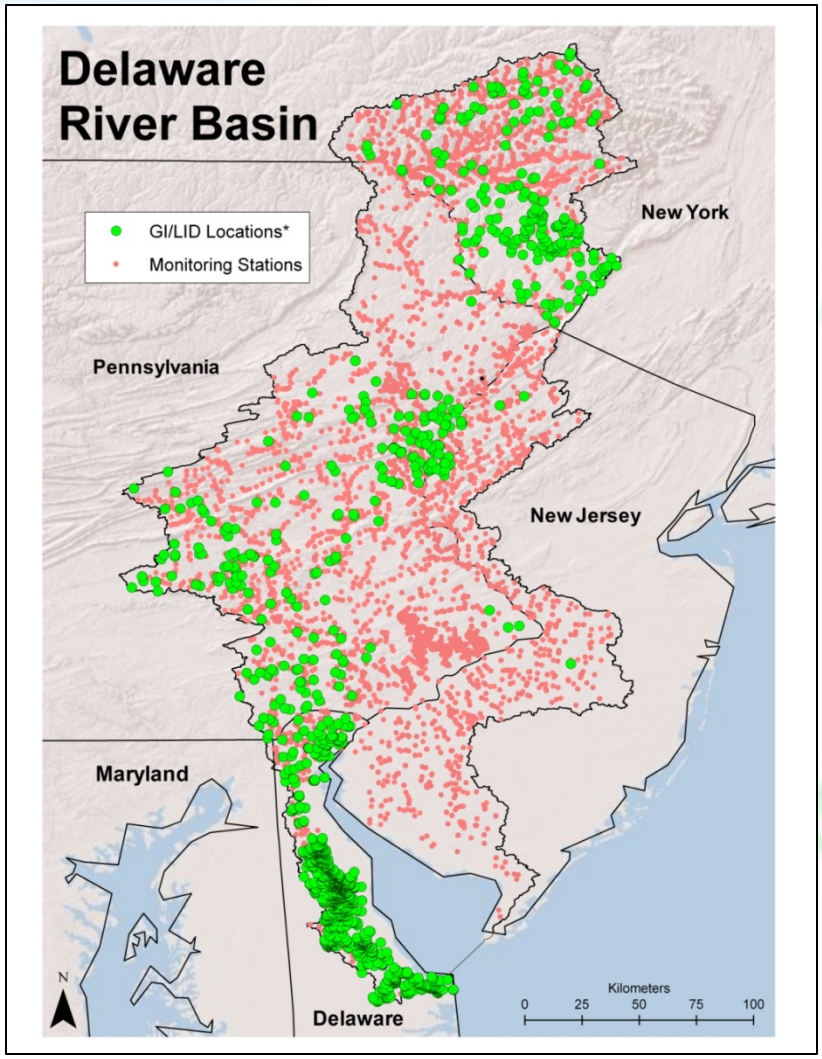




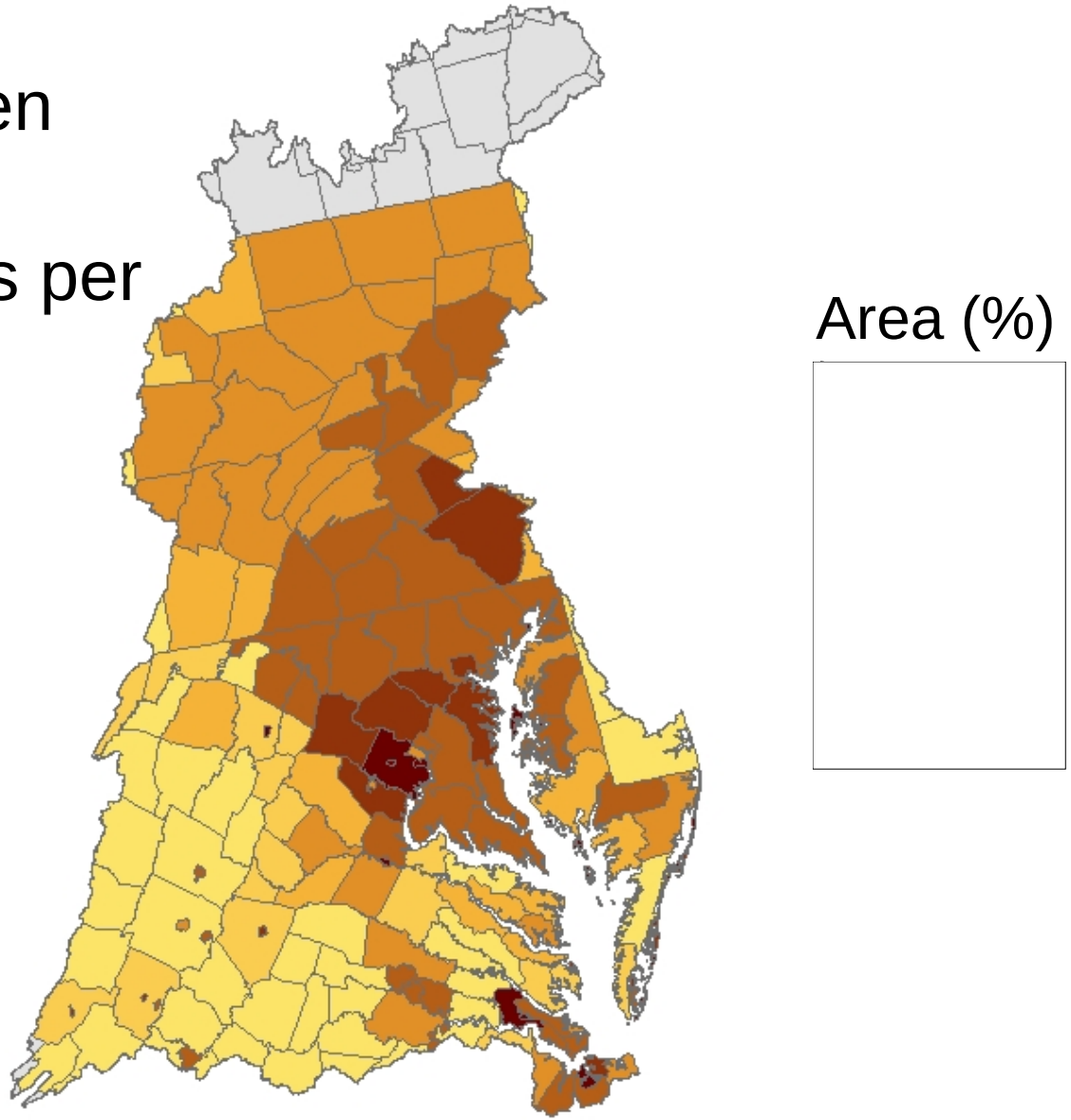
BMPs in Austin, TX

- Austin UIC
- Rain Barrel Rebate Program
- BioInfiltration Systems

Status of Delaware R Basin GI stormwater BMP/LID inventory



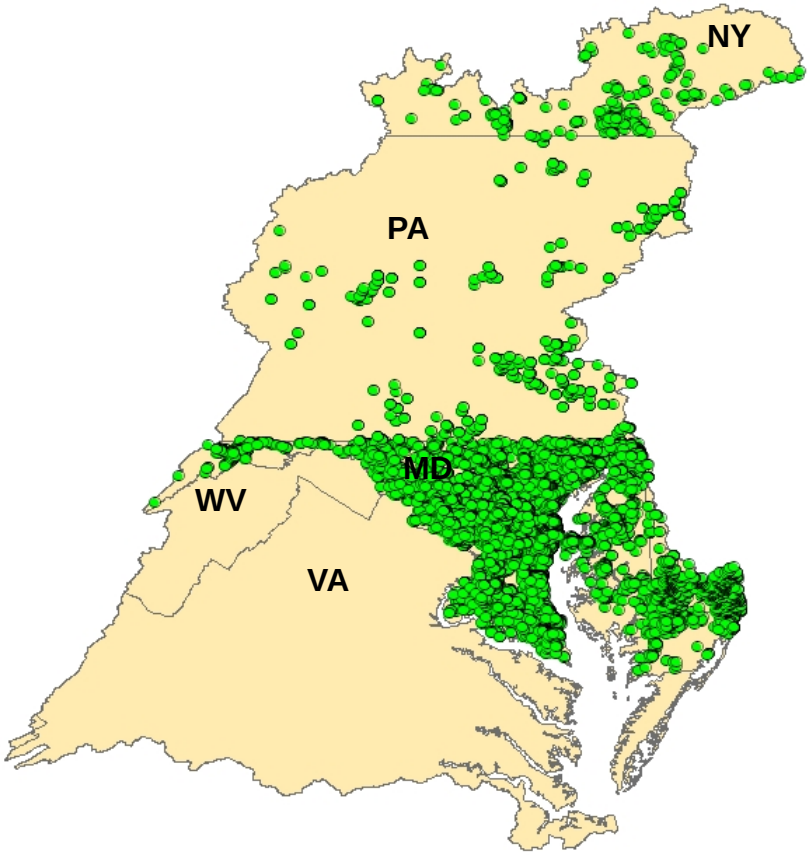
Impervious Area Treated with Green Infrastructure Stormwater BMPs per County Area (%) (NEIEN 2010*)



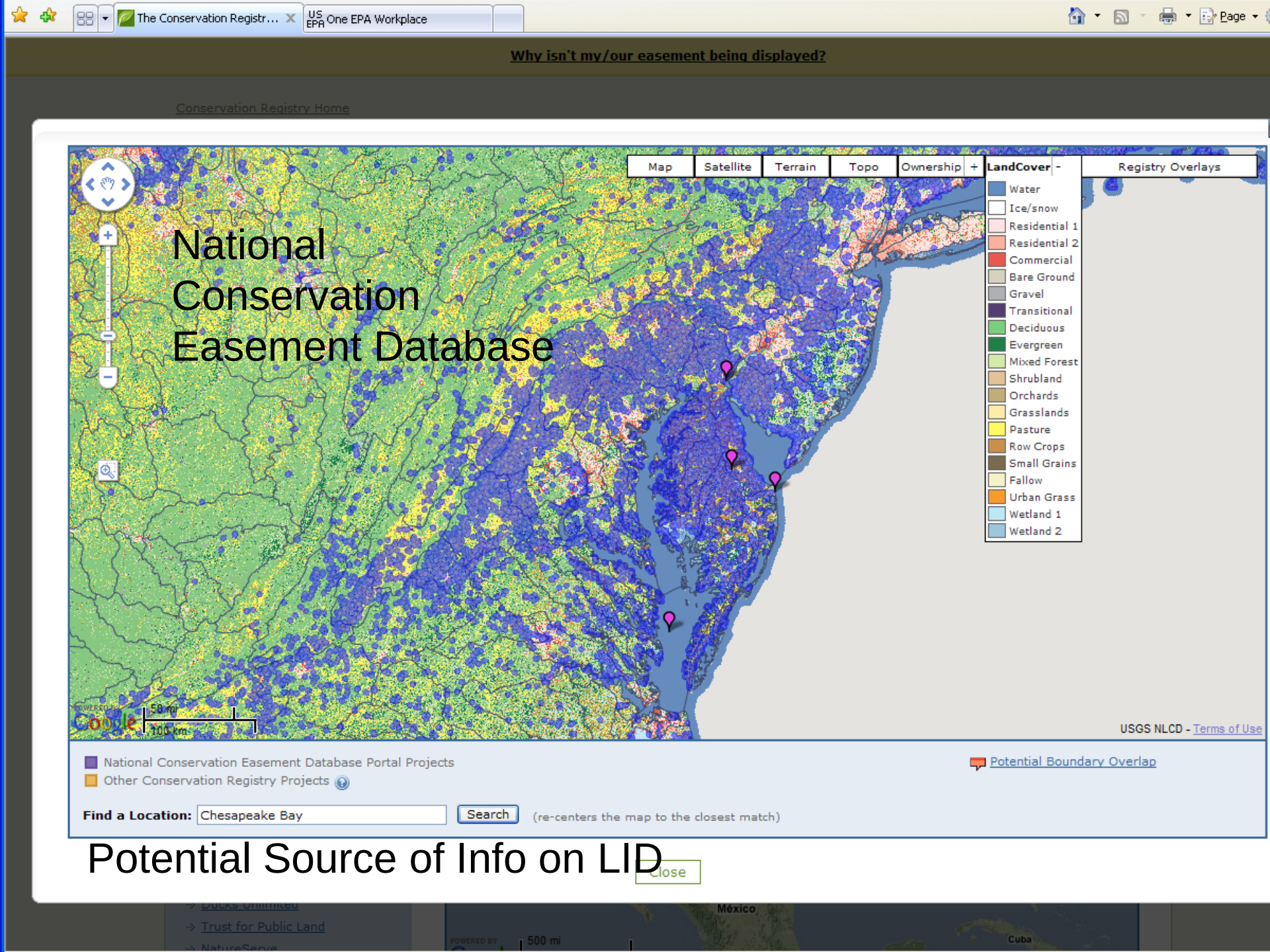
* National Environmental Information Exchange Network Database

DRAFT – for illustration only

Chesapeake Bay Watershed G.I. BMP sites (Inventory still in progress)



- Stormwater BMPs



Potential Source of Info on LID

Basic Information
Municipal MS4s
Construction Activities -Construction General Permit eNOI
Industrial Activities -Multi-Sector General Permit eNOI
Road-Related MS4s
Menu of BMPs
Green Infrastructure
Integrated Municipal Plans
Stormwater Home

Information Collection Request for Proposed Rulemaking

EPA Stormwater Information Collection Request (ICR) Fact Sheet (PDF) (8 pp, 149K) - Provides information about the Stormwater ICR and MS4, NPDES, and Owner/Developer Questionnaires.

MS4 and NPDES Permitting Authority Questionnaires

OMB approved four questionnaire instruments designed to collect information from: regulated MS4s, non-regulated MS4s, Transportation MS4s, and NPDES Permit Authorities.

On August 16, 2010, EPA sent selected recipients a letter which notifies them of their selection and provides a link to obtain an electronic version of the questionnaire. Recipients had 60 days from receipt of the letter to complete and return the questionnaire. EPA distributed the MS4 questionnaires to a statistically-sampled subset of these facilities, sending it to 608 regulated MS4s, 84 regulated Department of Transportation MS4s and 932 federally non-regulated MS4s. The MS4 questionnaires request information on:

- The type of MS4 (e.g., Phase I, traditional, State DOT);
- Stormwater conveyance (including direct discharge) within the MS4 jurisdiction;
- Specific stormwater program components (e.g., outreach, recordkeeping, training) and extent of coverage;
- Extent of new and redevelopment projects and MS4 oversight (e.g. site plan review);
- Current MS4 stormwater management requirements, including specific or numeric long term stormwater discharge standards for new and redevelopment activities;
- Local ordinances, policies, or other regulatory mechanisms that conflict with or encourage long term stormwater retention practices;
- Long term stormwater controls and practices installed, maintained and whethercost and/or performance data are available;
- Current capacity, budget, and funding sources for implementing, enforcing, maintaining and monitoring existing stormwater program; and
- Stormwater capital improvement plans and/or requirements (including retrofit of existing property).

Important Links

- List of MS4 ICR Questionnaire Recipients (PDF) (36 pp, 894KB) This is the most recent version (as of 9-22-10) of the mailing list.
- Final Advance Non-Federally Regulated Municipal Separate Storm Sewer Systems (MS4s) Questionnaire (PDF) (21 pp, 429K)
- Final Advance Regulated Municipal Separate Storm Sewer Systems (MS4s) Questionnaire (PDF) (70 pp, 538K)
- Final Advance Transportation-Related Municipal Separate Storm Sewer Systems (MS4s) Questionnaire (PDF) (51 pp, 899K)
- Webcast on Regulated and Non-regulated MS4s Questionnaires from September 16, 2010.
- Frequently Asked Questions for the Transportation-Related MS4 Questionnaire (PDF) (9 pp, 196KB)
- Clarification on Questions B-1 and B-3 in the Transportation-Related MS4 Questionnaire (PDF) (2 pp, 98KB)

NPDES Permitting Authority Questionnaire

EPA distributef the NPDES Permitting Authority questionnaire to all NPDES permitting authorities. The NPDES questionnaires request information on:

Stormwater Information
Recent Additions
FAQs
Publications
Regulations
Training & Meetings
Links
Contacts
Sign Up For NPDES NEWS

You will need Adobe Reader to view some of the files on this page. Files are best viewed in Internet Explorer and Adobe 8.0 or higher. See EPA's PDF page to learn more.

Watershed selection for BMP assessments

- Inventory green infrastructure BMPs/LID
- Evaluate expected effectiveness
  - % impervious area treated/reduced vs. total % impervious area
  - BMPDSS: % load reductions for TSS, TP by BMP
  - Retention capacity index (Walsh et al. 2009)
    - 0: runoff would reach stream every time rainfall sufficient to generate runoff from impervious surface
    - 1: no change in frequency of runoff events from pre-urban state
- Predict watershed condition w 90% C.I. in absence of BMPs/LID and compare with measured condition

BMP Performance Extrapolation Tool

BMP Performance Extrapolation Tool (BMP-PET) for New England

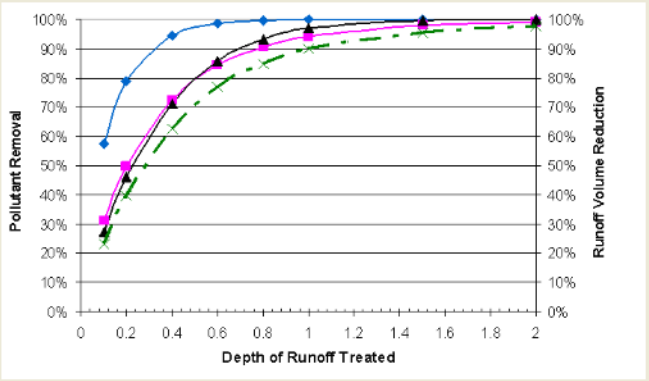
BMP Performance Extrapolation Tool (BMP-PET) for New England

Developed by:
Tetra Tech, Inc.
Fairfax, VA 22030

Developed for:
US Environmental Protection Agency-New England
Boston, MA 02114

March 2010
Version 1.0

TETRA TECH, INC.



Step 1: Select source area
- Commercial
- Industrial
- High Density Residential
- Low Density Residential

Step 2: Select BMP type
- Bio-retention
- Dry pond
- Grass swale
- Gravel wetland
- Infiltration basin-Static method
- Infiltration trench
- Porous pavement

Step 3: Select pollutant
- Total Phosphorous (TP)
- Total Suspend Solids (TSS)
- Total Zinc (Zn)

Step 4: Select infiltration rate (Optional)
- 0.17 in/hr
- 0.27 in/hr
- 0.52 in/hr
- 1.02 in/hr
- 2.41 in/hr

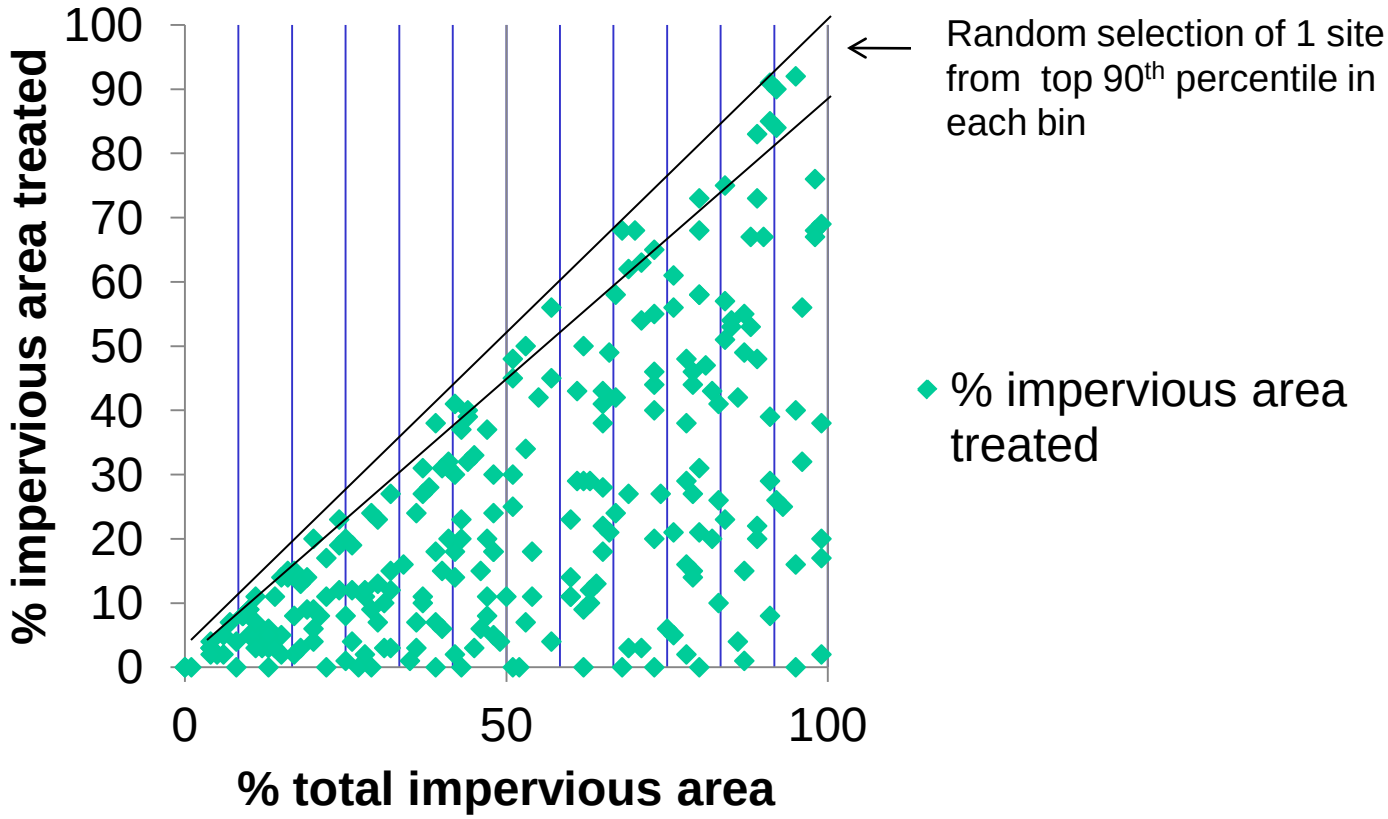
Step 5: Select filter course depth (Optional)
- 12"
- 18"
- 24"

Specify size of BMP (treated depth of runoff): 1 (0-2) inch **OR** Specify target BMP removal efficiency: 0 (0-100) %

Corresponding BMP removal efficiency: 76 % **Corresponding BMP size (depth to be treated):** 0 inch

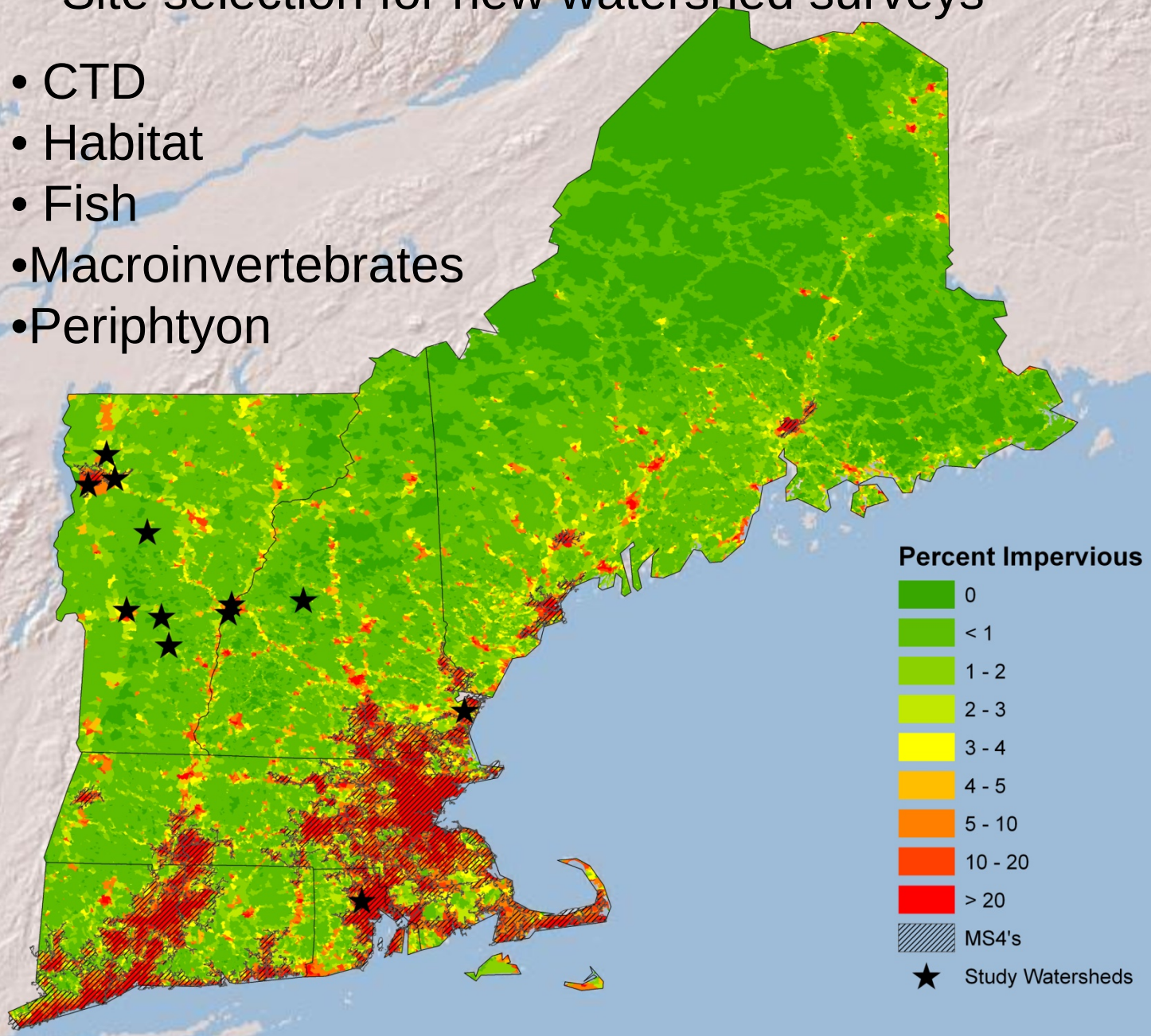
Reset | Extrapolate from curves | Exit

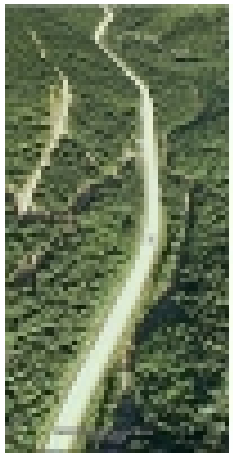
Site selection process for new Region1 watershed surveys

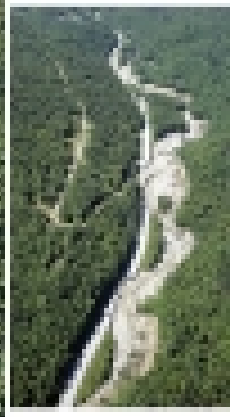


Site selection for new watershed surveys

- CTD
- Habitat
- Fish
- Macroinvertebrates
- Periphtyon





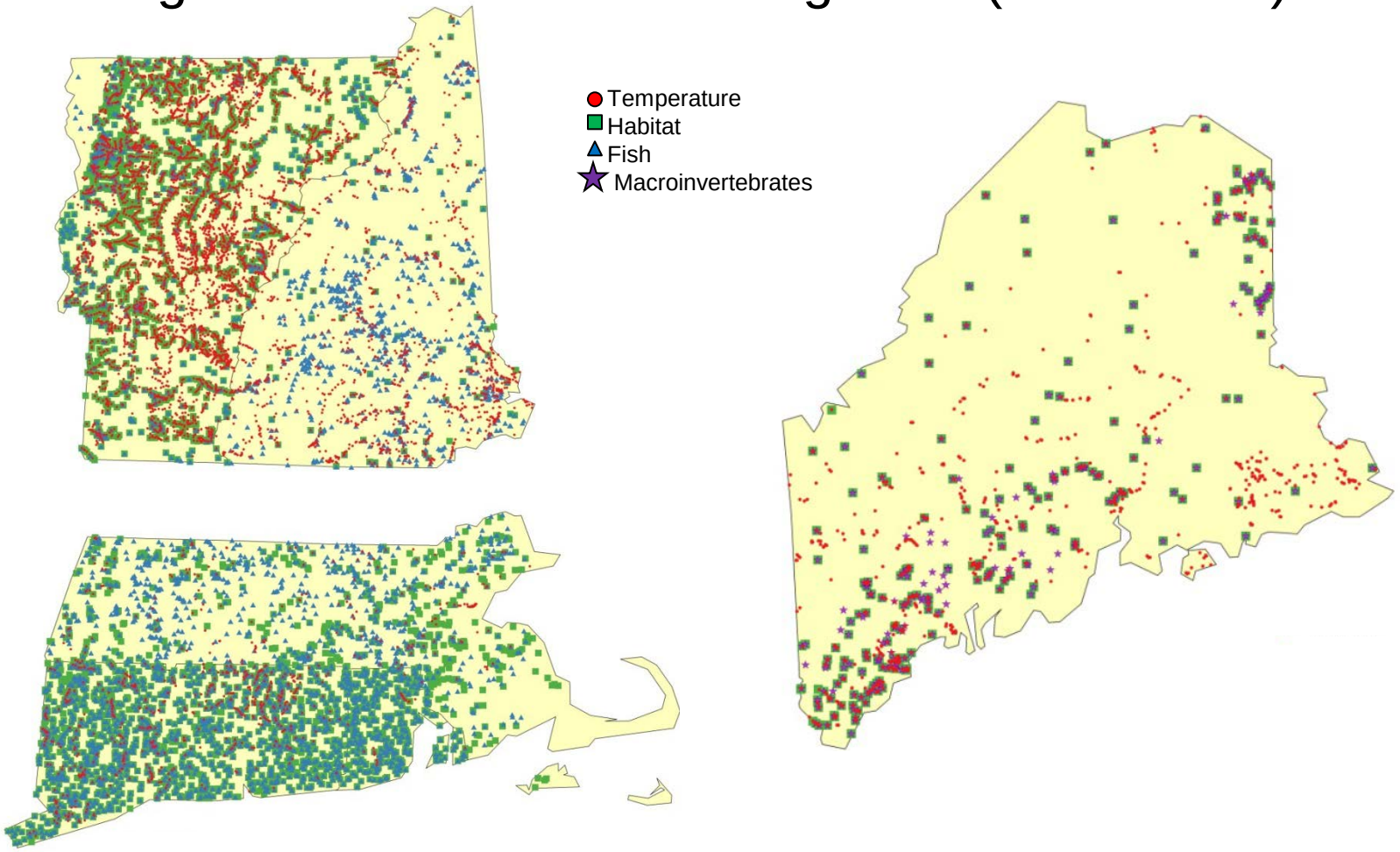


…a temporary change in course following a visit by our friend T.S. Irene…

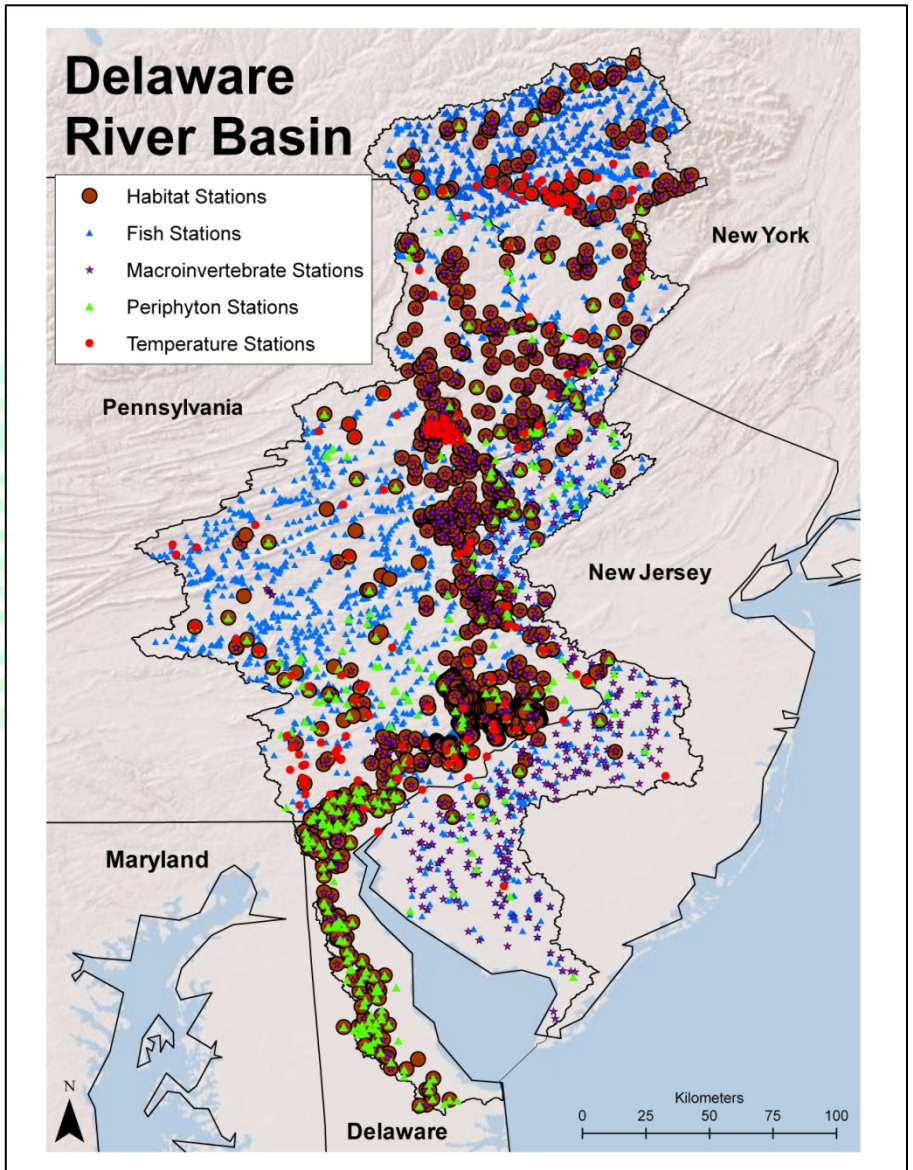
- habitat resampled in 2012
- macroinvertebrate sampling delayed until fall 2012

Biological and Habitat Databases 1986 - 2010

EPA Region 1 Historical Monitoring Data (1986-2010)

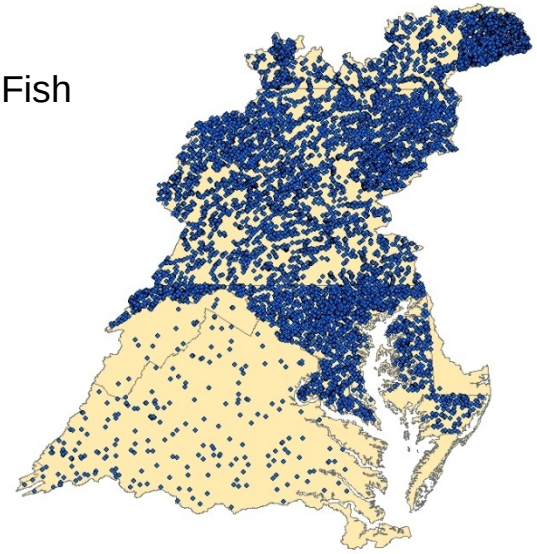


Compilation of Delaware R Basin historic monitoring data (1986-2010)

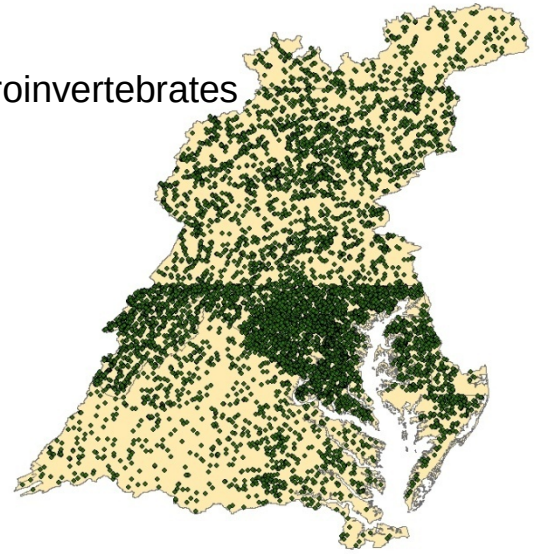


Historical Monitoring Data – Chesapeake Bay Watershed

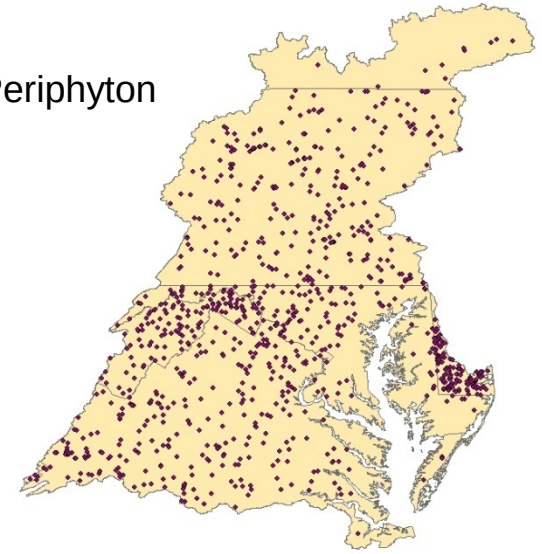
Fish



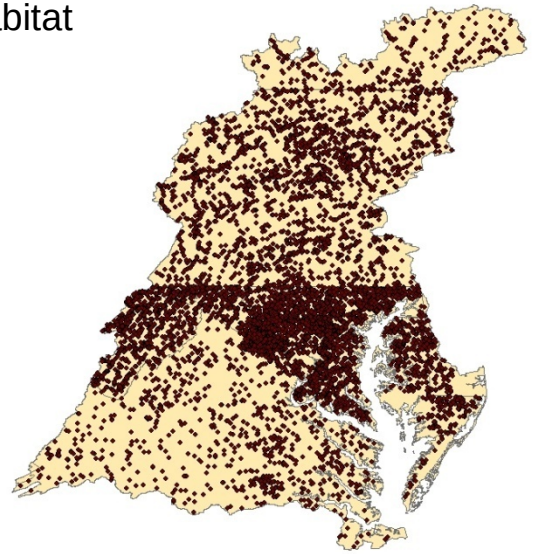
Macroinvertebrates



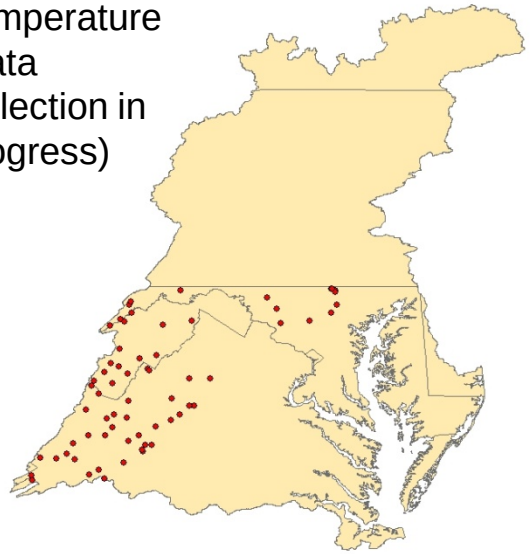
Periphyton



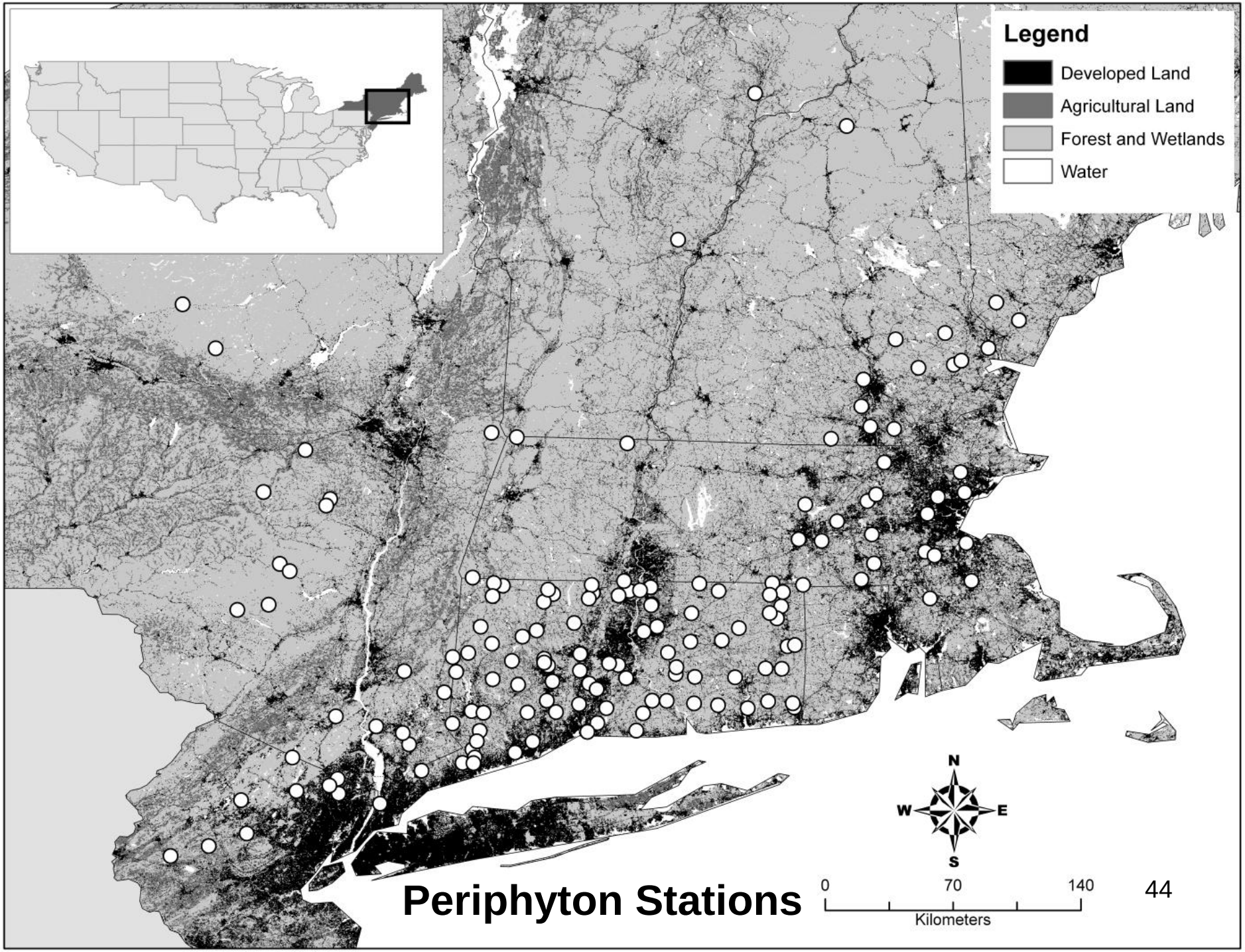
Habitat



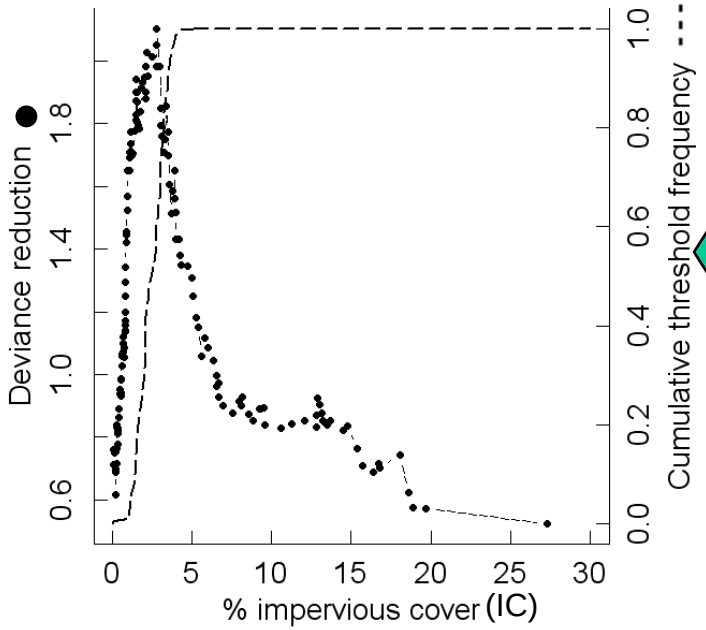
Temperature (data collection in progress)



Ecological Response Modeling

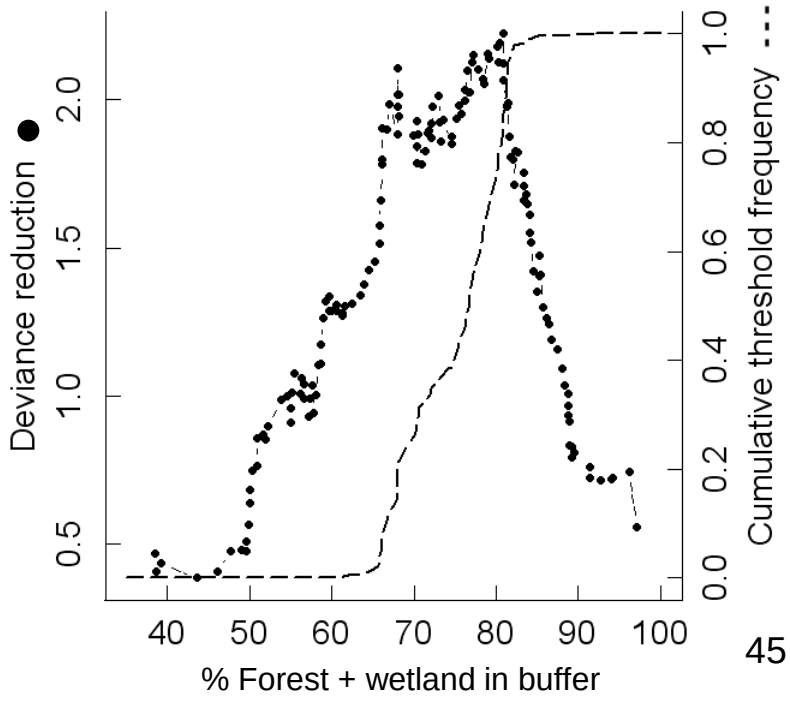

Legend
Developed Land
Agricultural Land
Forest and Wetlands
Water
N
W
E
S
0
70
140
Kilometers
Periphyton Stations
44

Nonparametric Change-point Analysis of Periphyton Community Structure*



Evidence of a threshold response in community structure at 1.2-3.7% IC

Not very convincing of a threshold response between 66-81% forest + wetland in buffer zone, indicating a more gradual change

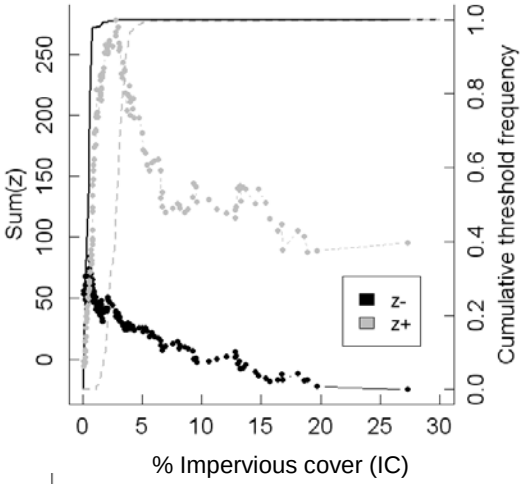


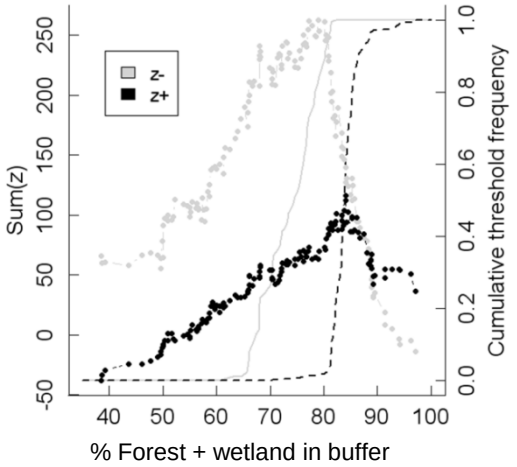
* Based on Bray-Curtis coefficient

RESEARCH & DEVELOPMENT

Building a scientific foundation for sound environmental decisions

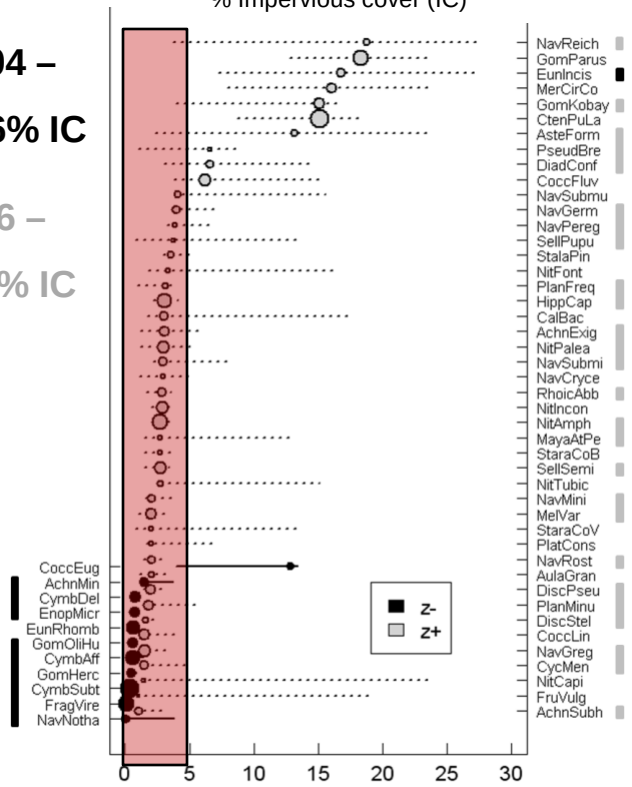
Periphyton Threshold Indicator Taxa ANalysis





0.04 – 0.76% IC

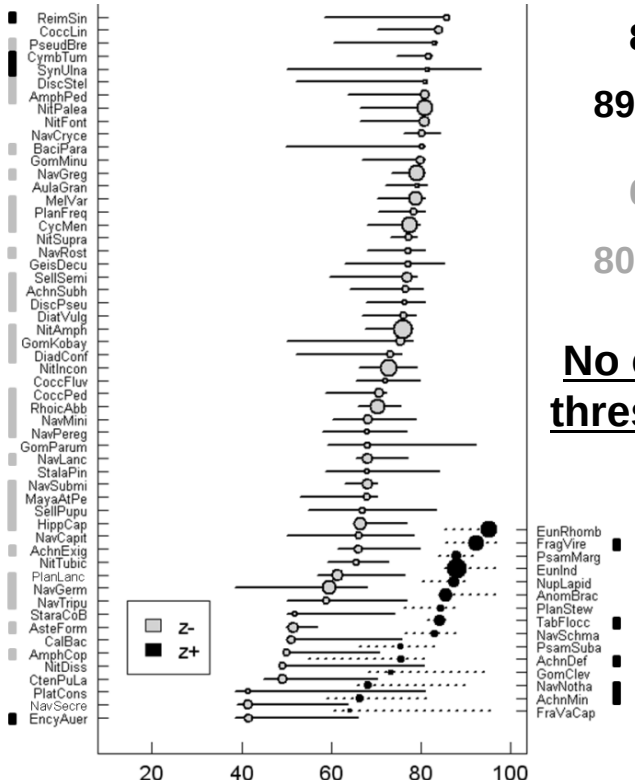
1.6 – 3.9% IC



81 – 89% F/W

66 – 80% F/W

No clear threshold



RESEARCH & DEVELOPMENT

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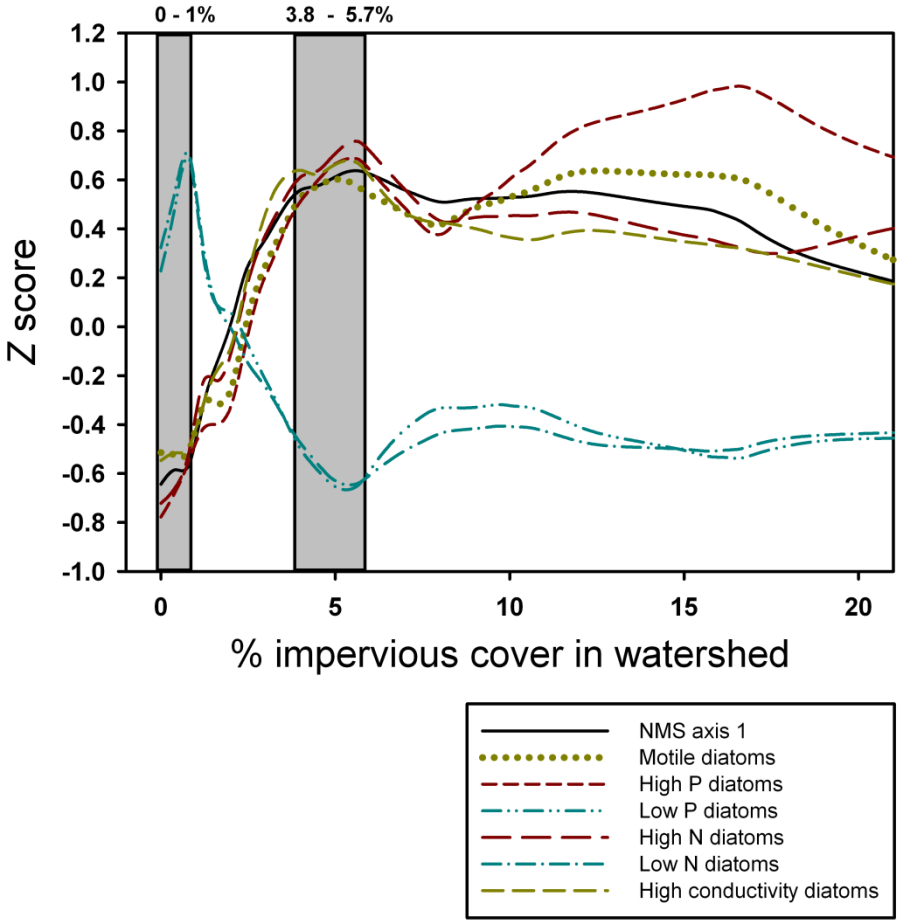
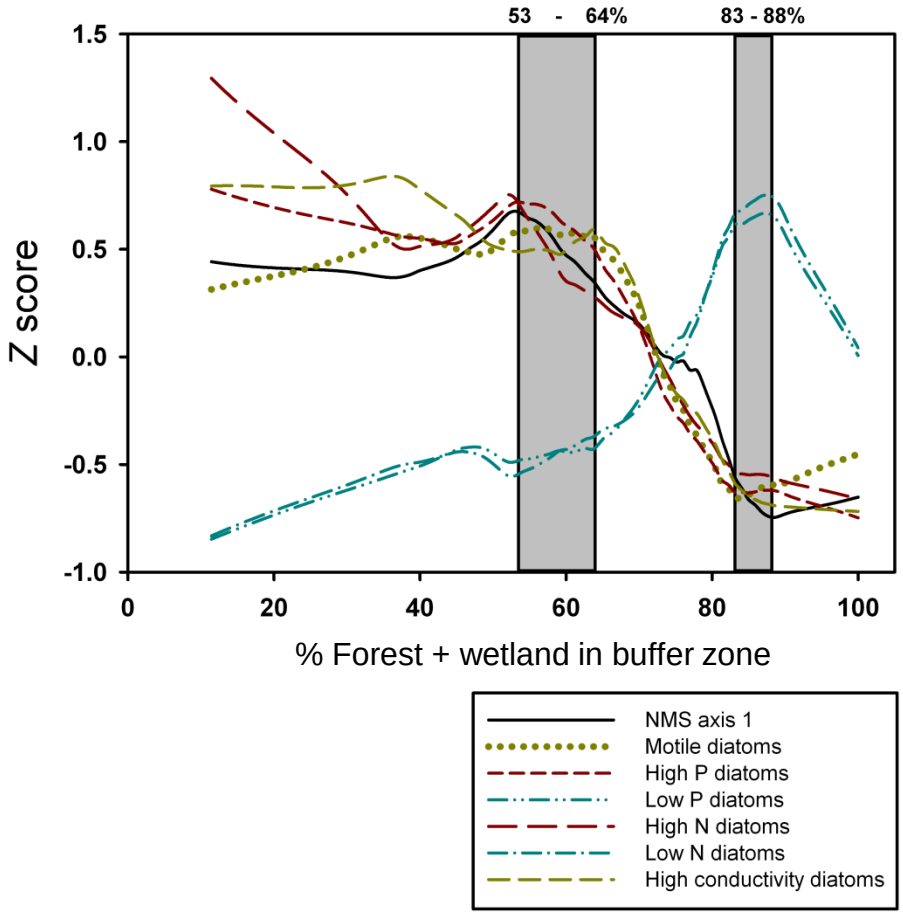
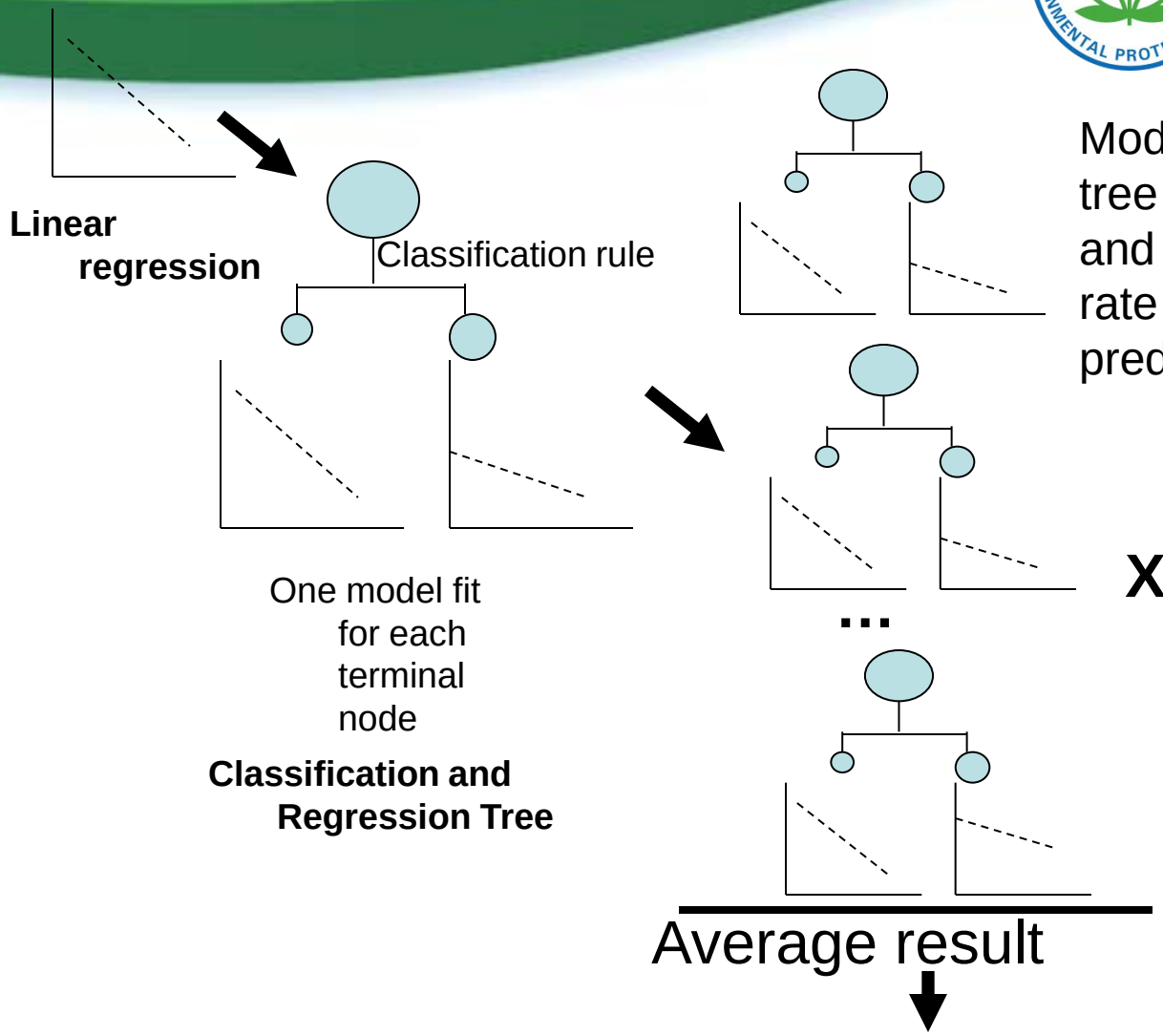
Univariate LOWESS curves





Boosted regression trees



Modify depth of tree (split prob.) and learning rate to optimize prediction

X 10 = 10-fold cross validation (c.v.)

Test predicted vs. observed on withheld 10% of data

CT DEP macroinvertebrates: partial effects plots

fPLECO = fraction Plecoptera
fEPEM = fraction Ephemeroptera
fTRICH = fraction Trichoptera

---

fPRabun = fraction predators
fFCabun = fraction filterer/collectors
fSHabun = fraction shredders
fSCabun = fraction scrapers

---

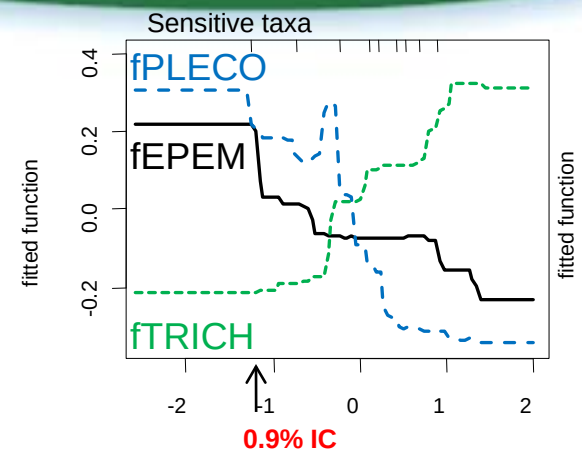
fSW = fraction swimmers

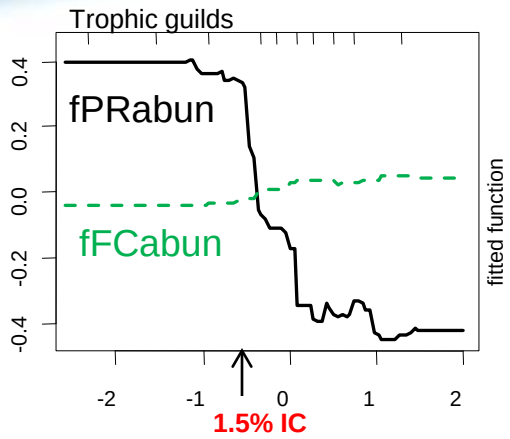
---

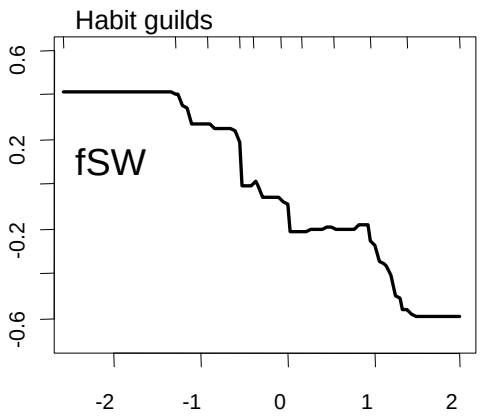
fEPTR = fraction EPT richness

TxAvWMet = taxa-weighted avg heavy metals sensitivity

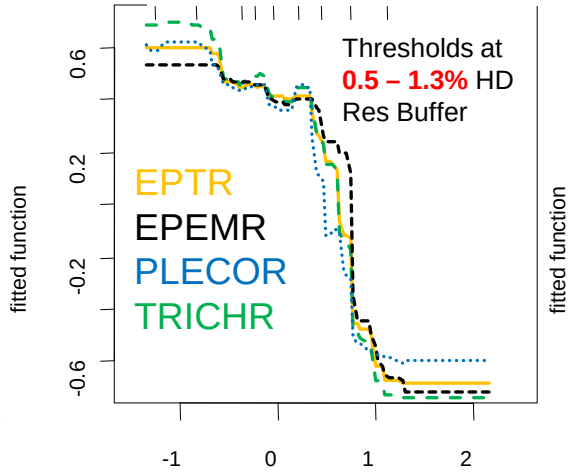
WtAvWMet = abun-weighted avg heavy metals sensitivity

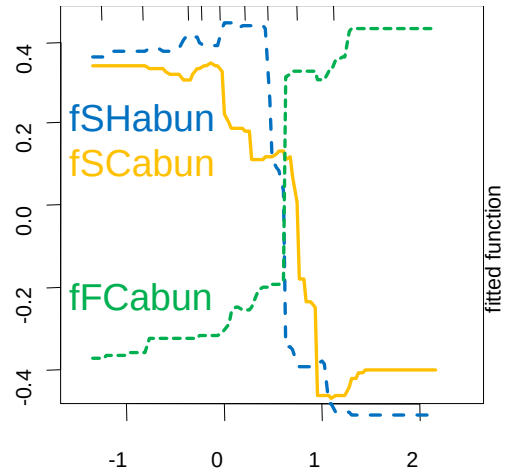


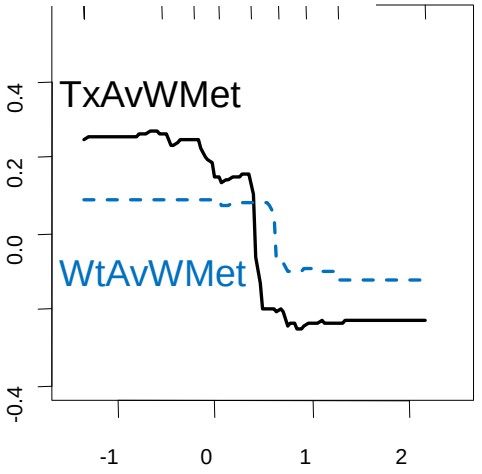




Log_{10}(% watershed impervious cover)







Log_{10}(% high density residential buffer)

Values normalized to z-scores to facilitate comparisons

Macroinvertebrate partial effects plots: buffers

BC = Bray-Curtis coefficient of community disimilarity

CCL = coefficient of community loss

EPTR = EPT richness

EPEMR = Ephemeroptera richness

PLECOR = Plecoptera richness

fPLECO = fraction Plecoptera

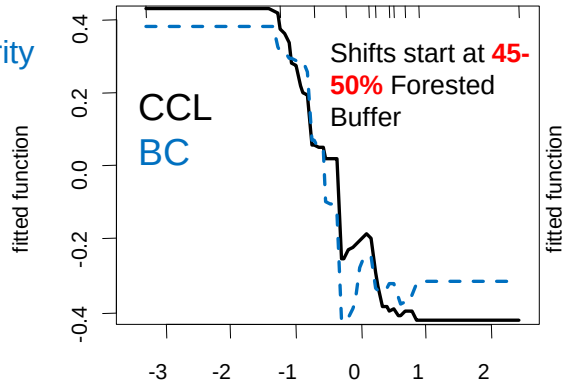
fEPEM = fraction Ephemeroptera

WtAvWMet = abun-weighted avg heavy metals sensitivity

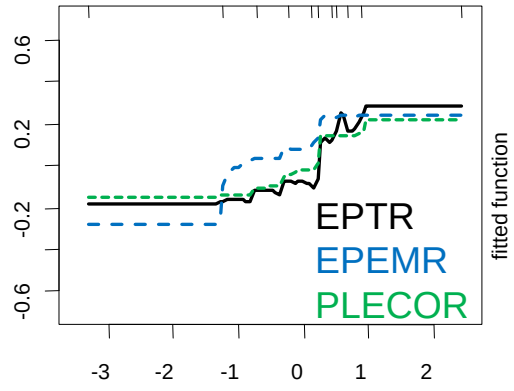
Ftoxtol = fraction toxic-tolerant

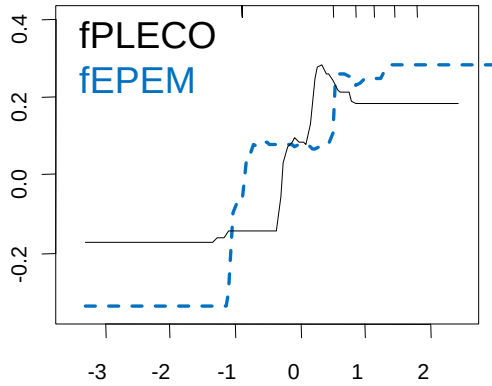
CT DEP

Community composition



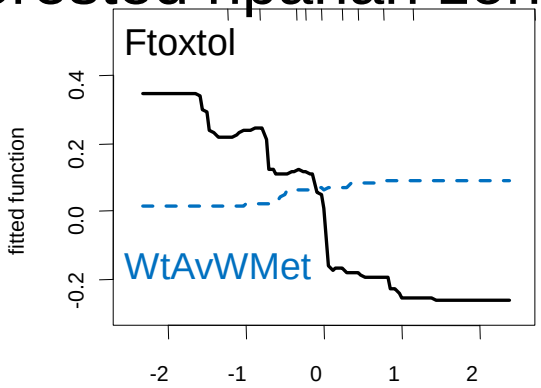
Sensitive taxa





arcsin√(frn forested riparian zone in watershed)

ME DEP



Toxics - sensitive taxa

arcsin√(frn forested riparian zone in local catchment)

Values normalized to z-scores to facilitate comparisons

Preliminary Conclusions

- % high density residential land-cover in riparian zone and % impervious area at watershed scale are best predictors of development impacts (not USGS Urban Intensity Index)
- Strong community-level thresholds for periphyton (incl. nutrient, siltation, conductivity-sensitive guilds) and macroinvertebrates occur at very low levels of % imperviousness, i.e., ~1%-5%
- Macroinvertebrate responses are modified by watershed size, slope class, flow regime
- Vegetated buffers only partially moderate development impacts for both macroinvertebrate and periphyton
  - Forest and wetland cover associated with 13-34% reduction of watershed %IC effects on diatom metrics and community structure as compared to 61-68% reduction in effects of watershed % pasture on motile and high P diatom abundances

Remaining brain-teasers

- Are the extremely low % IC thresholds observed accurate?
  - Low accuracy of %IC measurements for suburban fringe? => starting high resolution image analysis
  - Contribution of urban runoff at low %IC versus septic?
  - Same or different stressors associated with 10% thresholds in literature? Temperature? Conductivity?
- How and why are forested buffers partially effective in urban/suburban/peri-urban settings?
  - Retained functions in spite of WQ function short-circuit? Shading, bank stabilization, groundwater WQ function, refugia for recovery from downstream drift
- Do different GI/LID practices differ in their ability to protect aquatic life uses?
- Given the state of BMP/LID tracking, how can we better inform adaptive watershed management?

Coming attractions…

- Meta-analysis of stormwater BMP and riparian buffer effectiveness (N. Smucker)
- Integrated Watershed Management Decision Support Tool (w GI options) – contract to ABT w Region 1 and stakeholder collaboration
- Smart Growth scenario analysis in collaboration with Region 3, USGS, U-MD Center for Smart Growth, and targeted MD and PA counties

Interim Milestones in Review

- Smucker, N.J., N.E. Detenbeck, and A.C. Morrison. In press. Diatom responses to watershed urbanization and potential moderating effects of near-stream landscape green infrastructure. Freshwater Science.

- Smucker, N.J., M. Becker, N.E. Detenbeck, and A.C. Morrison. In review. Using algal metrics and biomass to evaluate multiple ways of defining concentration based nutrient criteria in streams and their ecological relevance.

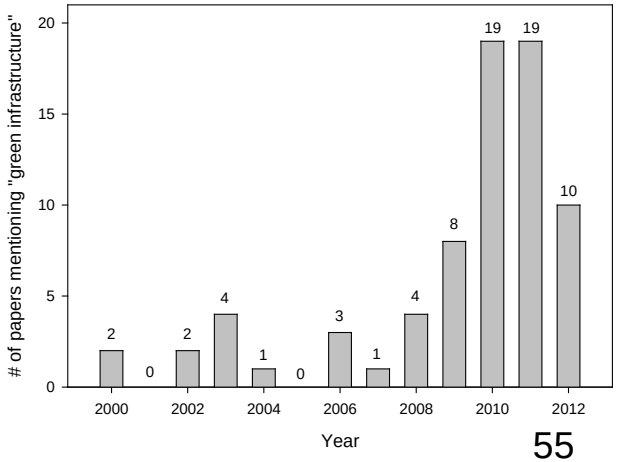
- Detenbeck, N.E., C. Rosiu, L. Hayes, and J. Legros. In revision. Assessment Models for New England Streams Differentiate Cumulative Impacts of Watershed Development and Superfund Sites on Aquatic Life.

Meta-analysis evaluating effectiveness of urban watershed management

- **Goal: Describe general trends by synthesizing results from multiple (often small scale) studies that examined effectiveness of management practices in developed watersheds**
- Search string of terms such as:

  urban, impervious, watershed, management, restoration, conservation river, stream, riparian, buffer, wetland, forest, etc.
- "Green infrastructure"

  not a good search term



Progress

- Ongoing examination of 1000s of abstracts
  - "Efficient" screening of titles, abstracts, **then** methods/results in papers [have to be inclusive… while being exclusive]
- Ecological effects of "built" or "installed" strategies, such as rain barrels, rain gardens, green roofs, etc., were **rarely found** (ties into our other work focused on determining "treated" area using these approaches)
- Much more common to find papers on "reach restoration" in urban catchments (see series of papers in Ecological Applications 9/2011 – failures of treating symptoms and not underlying causes)
- **Most papers** dealt with what could be defined as landscape green infrastructure
  - Riparian restoration or conservation being most common, but some included wetlands or stormwater ponds
- Variety of response variables
  - Most common are **diversity** or some type of **community metric**
  - Less common, but very interesting, are **biomass** or **functional processes**

Progress… and headaches/issues)

- Very few studies are meeting criteria for pooled statistics (effects ratios, regression, etc.)
  - Rare to find studies comparing a control (unrestored or unimpacted stream) to a treatment stream or conditions before to those after
- Synthesizing results when reported as correlations
- The space-time continuum
  - Recovery time, watershed size, scale of measurements (reach length)
- **BUT… stepping back from the trees to see the forest – seeing what (if any) general trends exist**
- Goals and ongoing forces of motivation:
  - Identify and synthesize past data from a variety of sources in a large scale effort to build a stronger scientific foundation in the present to help inform future management decisions, policy, and restoration, which ultimately affect ecosystem integrity
  - Compare effectiveness of preventative actions versus the effectiveness of restorative actions