Sample surveys and trend detection

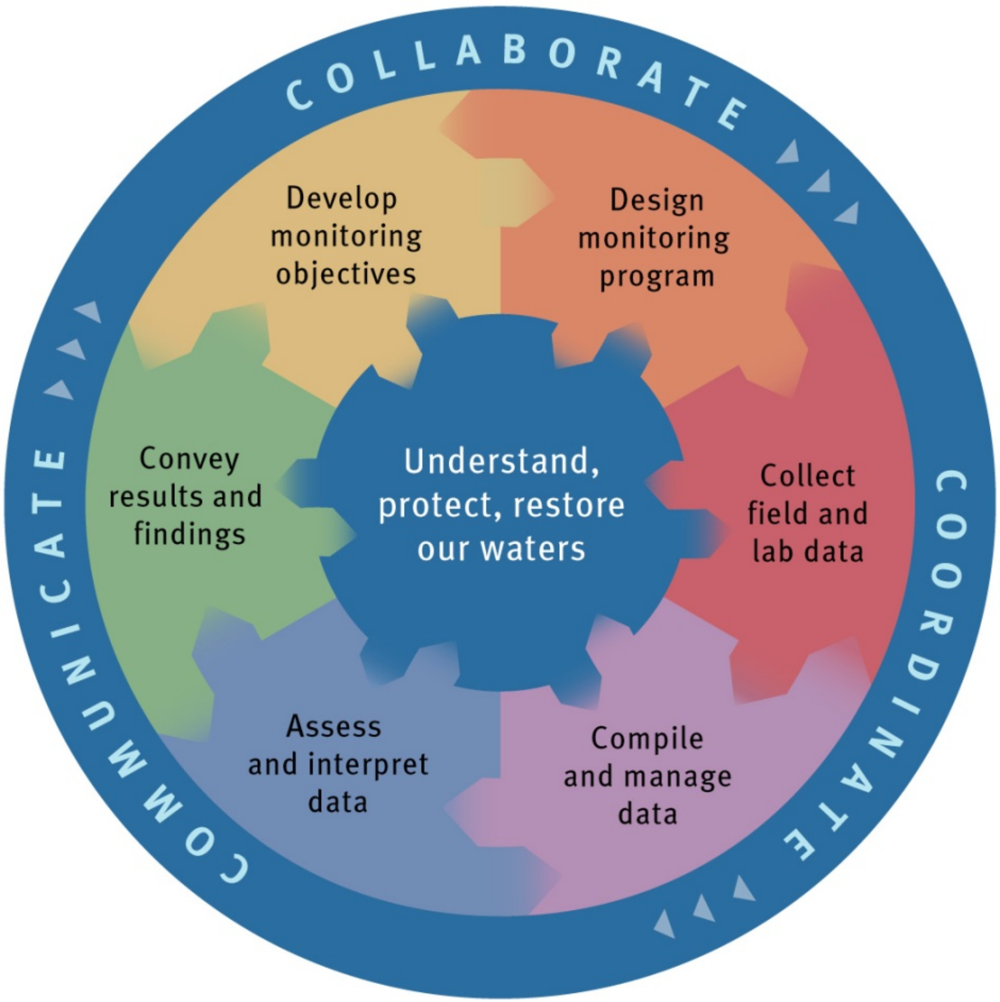
Phil Larsen, PSMFC

Contributions from:
Tony Olsen, USEPA
Don Stevens, OSU
Scott Urquhart, CSU
John Van Sickle, USEPA
Kara Anlauf-Dunn, ODFW
Chris Jordan and colleagues, NOAA

Objectives

- Overview of status and trends monitoring
- Spatial design
- Temporal design
- What do we mean by change or trend detection
- Examples
- A few take home messages

National Water Quality Monitoring Council: Monitoring Framework



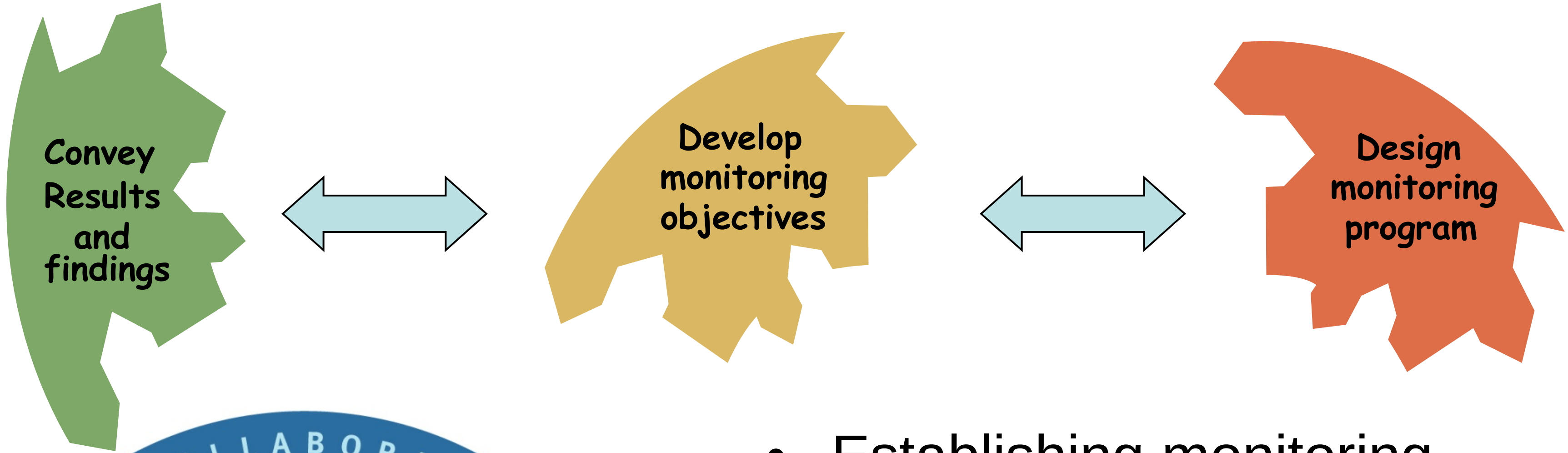
- View as information system
- Monitoring pieces must be designed and implemented to fit together
- Implementing a monitoring framework is an iterative process
- Reference: Water Resources IMPACT, September 2003 issue
- www.epa.gov/nheerl/arm

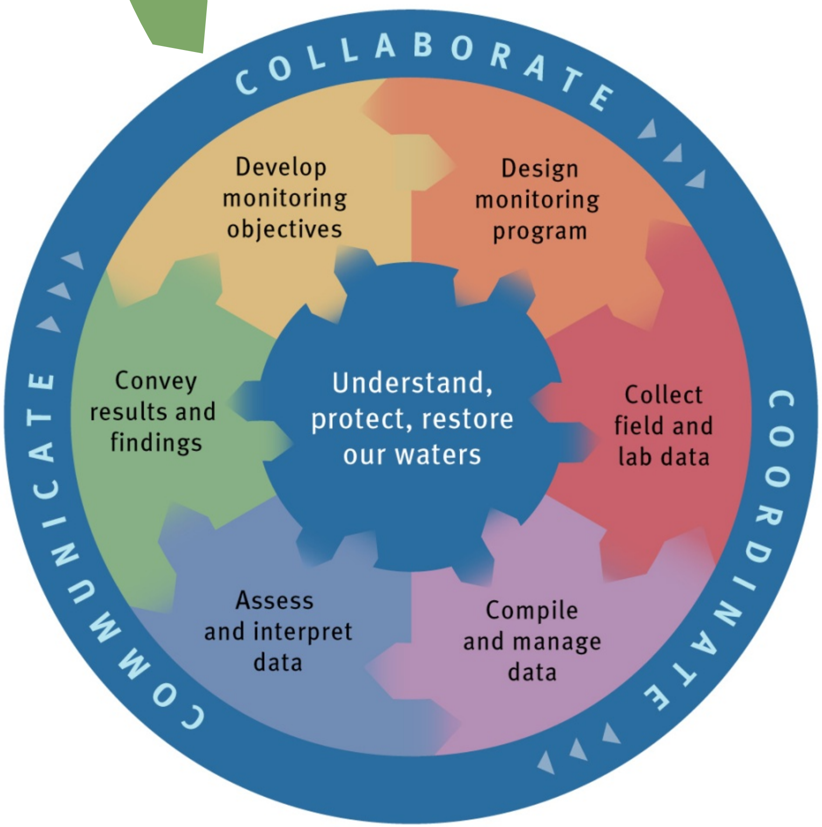
Generic Questions of Interest

- What is the condition of the aquatic resource? (Status)
- Where, how, and why are water quality conditions changing over time? (Trends)
- What factors are causing these problems? (Associations)
- Are management programs working? (Effectiveness)
- Are water quality standards being met? (Compliance)

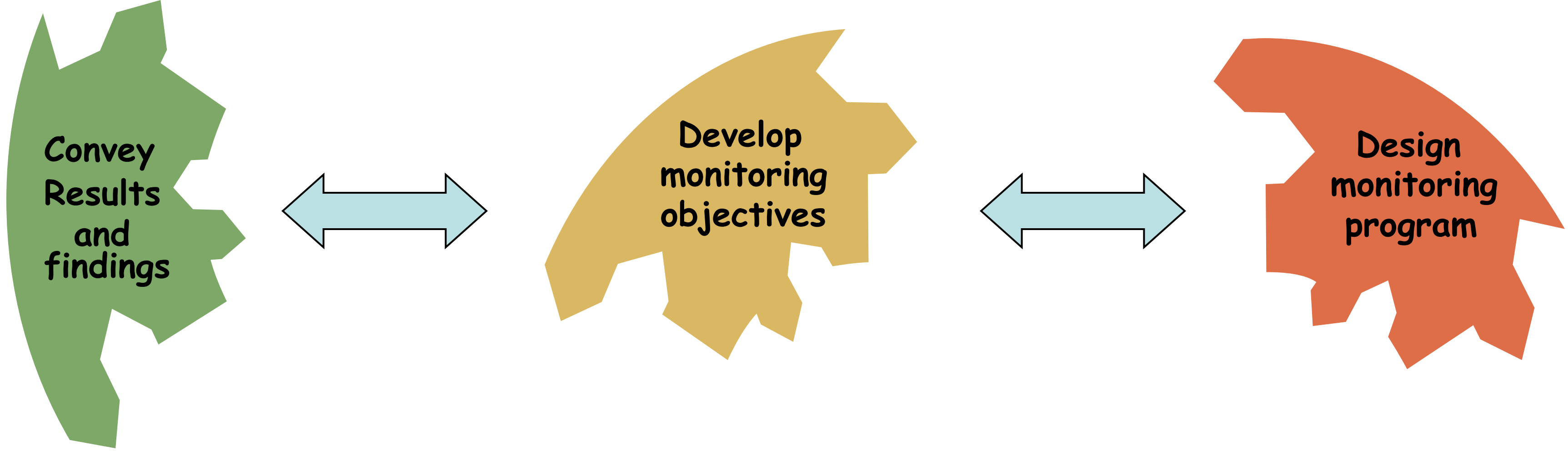
Basin, State, Region, National Scale Questions

- Status
  - Assessment: How many stream miles, number of lakes, or estuarine hectares meet WQS or satisfy aquatic life use based on IBI scores?
  - Condition: What proportion of streams, lakes, and estuaries are in good ecological condition?
- Trends
  - How has the proportion of stream miles, number of lakes, or estuarine hectares meeting WQS or satisfy aquatic life use based on IBI scores changed over time?
  - Has the proportion of streams, lakes, and estuaries in good ecological condition changed between 2000 and 2010?





- Establishing monitoring objectives drives entire monitoring framework process
- Useful to consider reporting of results when defining objectives
- Objectives provide critical information to design step



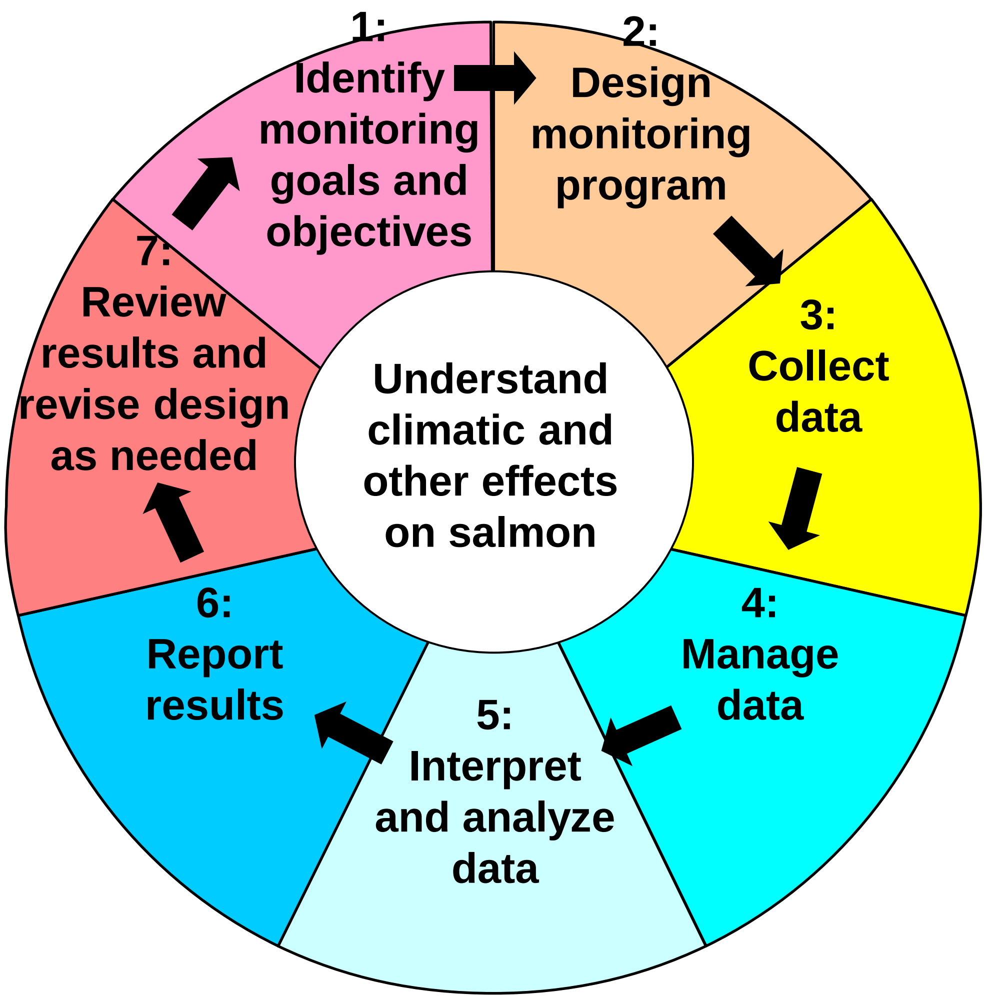
- Kish (1965): “The survey objectives should determine the sample design; but the determination is actually a two-way process…”
- Initially objectives are stated in common sense statements – challenge is to transform them into quantitative questions that can be used to specify the design.
- Statistical survey design perspective leads to
  - Knowing whether a monitoring design can answer the question
  - Knowing when the question is not stated precisely enough to chose a survey design

Monitoring Questions Provide Information Required at Design Step

- Spatial domain & spatial unit
  - Spatial domain is geographic region over which study will be conducted
  - Spatial domain usually consists of a collection of spatial units
- Temporal domain & temporal unit
  - Temporal domain is entire length of time the study will collect data
  - Temporal domain may consist of a collection of temporal units
- Indicators state what will reported and drive what will be measured
- Reporting domain
  - Specific collection of spatial-temporal units in the spatial and temporal domain for which indicator results will be reported.

“Salmon Monitoring Advisor”

www.salmonmonitoringadvisor.org



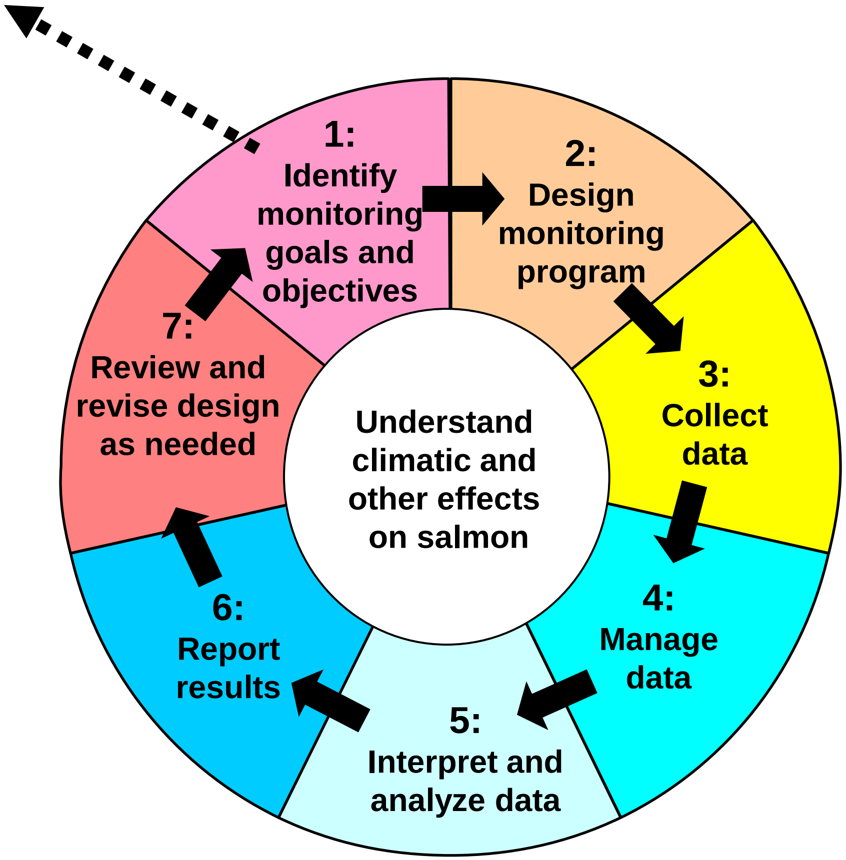
1. Goals and objectives

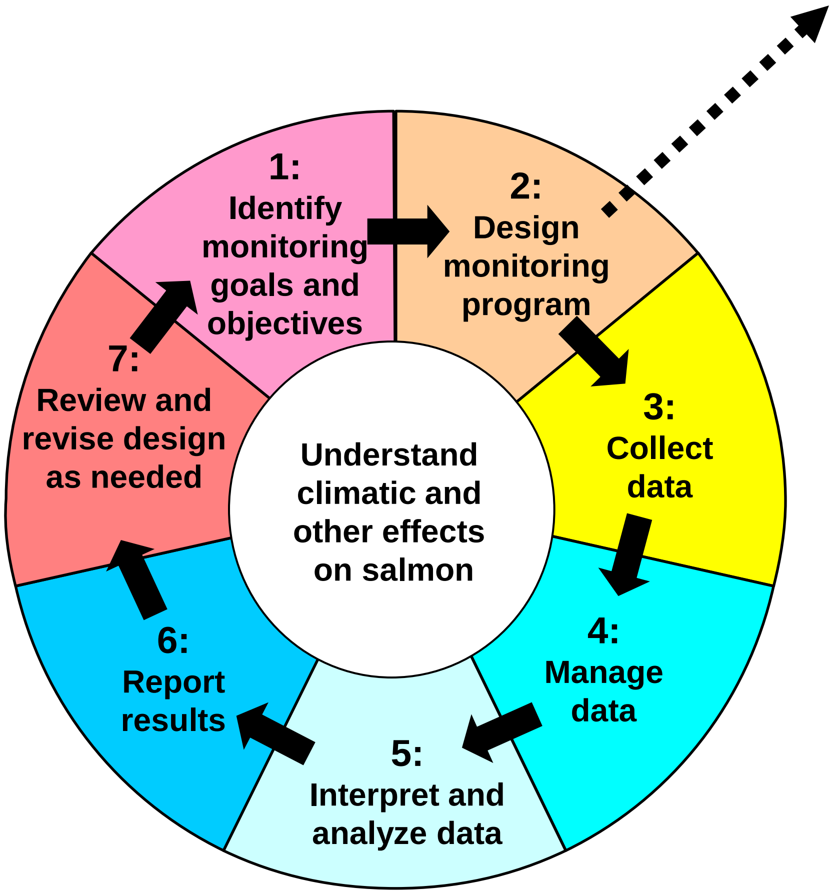
A. Type of questions (e.g., status + trend, or mechanism)

B. Type of indicators
- Abundance
- Productivity
- Diversity

C. Spatial and temporal requirements for the monitoring design

D. Constraints:
- Costs
- Desired precision of results





2. Design monitoring program

The STRIDe approach:

a. Spatial design (where)

b. Temporal design (when)

c. Response design (how)

d. Inference Design (estimates indicators from sampled data)

e. Options for each of these four elements are linked to:
- **Definition with a diagram**
- **Pros and cons**
- **Past examples**
- **Documents**

Developing Monitoring Objectives

Identify Monitoring Objectives

- Monitoring program weakness: Objectives for monitoring are not clearly, precisely stated and understood
- Objectives must be linked to management decisions and reporting requirements
- Objectives determine the monitoring design
  - Usual to have multiple (many) objectives
  - Precise quantitative statements are required
  - Objectives must be prioritized
  - Objectives compete for samples

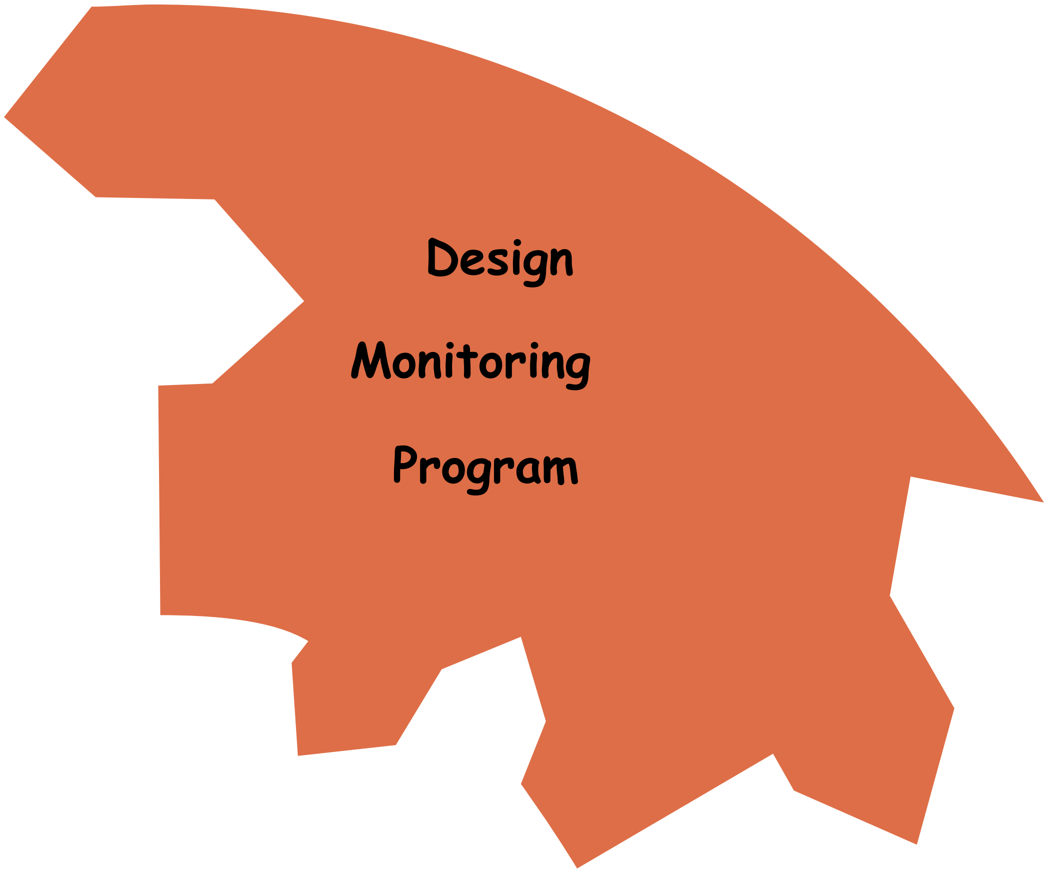
From Questions to Objectives: Stream Example

- What is the overall quality of waters in the state of Yucatan?
- What is the overall quality of streams with flowing water during summer in Yucatan?
- What is the biological quality of streams with flowing water during summer in Yucatan?
- How many km of streams with flowing water during the summer have a benthic macroinvertebrate index (BMI) value greater than 75 within Yucatan?
  - How is BMI determined?
  - What is meant by summer?
  - What is meant by flowing waters?
- What about time?
  - Estimate required every year?
  - Once every 5 years?

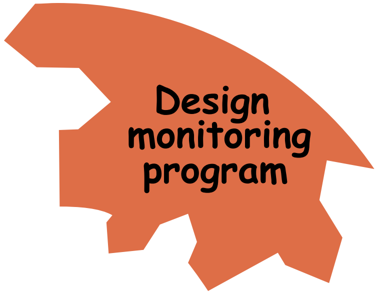
Stream Example: Design Requirements

- Spatial Domain: Yucatan state
- Spatial Unit: All possible locations on streams with flowing water within Yucatan
- Temporal Domain: 2011 to 2020
- Temporal Unit: Year
- Reporting Domains: Yucatan annually
- Indicator: Length (km) of streams with flowing water within Yucatan with BMI less than 45 reported annually
- Metric: BMI value at a stream location determined annually
- Measurement: Benthic macroinvertebrate assemblage determined in summer

STRIDe Approach to Design



STRIDe Approach to Designing a Monitoring Program



- **S**patial design: how we select what spatial units to monitor within the spatial domain
- **T**emporal design: how we select what temporal units to monitor within the temporal domain
- **R**esponse design: what measurements we make, how we take them & how we calculate metrics on spatial-temporal units based on the measurements
- **I**nference **De**sign: how we summarize metrics across spatial-temporal units within a temporal domain to obtain indicator value for a reporting domain

Spatial Domain and Units: Building Blocks for Spatial Design

Design monitoring program

- Spatial domain and its spatial units define the target population
- Target population
  - Requires a clear, precise written definition
    - Must be understandable to users
    - Field crews must be able to determine if a particular site is included
  - More difficult to define than most expect.
  - Includes definition of what the spatial units (elements) are that make up the spatial domain
  - Definition is written and usually not given in terms of a GIS layer

Spatial Design & Representative Sample

- Goal is to obtain a “representative sample” of the target population that can be used to make inferences from the metric values on the sampled spatial units to indicator values for a reporting domain
- Problem: At least 9 definitions for representative sample
  - General acclaim for data
  - Absence of selective forces
  - Miniature of the population
  - Typical or ideal case(s)
  - Coverage of the population
  - Vague term, to be made precise
  - **Representative sampling as a specific sampling method**
  - Representative sampling as permitting good estimation
  - Representative sampling as good enough for a particular purpose.

Types of Statistical Designs

- Experimental designs
  - Random allocation of treatments to spatial units
  - Focus on testing not estimation
- Observational studies
  - Factor space designs (e.g. gradient studies, coverage of population)
  - Opportunistic designs (professional judgment, ease of access)
- Survey designs
  - Census
  - **Probability survey design**
  - Model-based survey design

Basic Spatial Survey Designs

Design monitoring program

- Simple Random Sample
- Systematic Sample
  - Regular grid over an area
  - Regular spacing on linear resource
- Spatially Balanced Sample
  - Combination of simple random and systematic
  - Guarantees all possible samples are distributed across the target population
  - Generalized Random Tessellation Stratified (GRTS) design

Temporal Design

- Temporal designs describe how sampling effort will be allocated across temporal units within the temporal domain
- Monitoring objectives specify temporal objectives
  - Change between two temporal periods
    - Focus on net change
    - Focus on gross change
  - Trend summary (e.g., linear trend as slope)
  - Trend trajectory – require an estimate for study domain for every temporal unit during the temporal domain

Temporal Design: Change

Design monitoring program

- Net change: Has the percent of the streams in good condition in Yucatan changed between 2005 and 2010?
- Gross change: Has the number of stream km in Yucatan that were in good condition in 2005 increased/decreased in 2010?

Temporal Design: Trend

- Trend: What is the linear trend over the last 10 years in the stream km in Yucatan that are in good condition? (i.e. km change/year)
- Trend trajectory: What is the annual pattern of stream km with nitrate concentrations exceeding criteria in streams within Yucatan from 2000 to 2020?
- Trend trajectory at site: What is the annual pattern in nitrate concentration on the Santiam River at its confluence with the Willamette River.

Temporal Design Approaches

- Sample all spatial units selected by a spatial design in every temporal unit (e.g. sample all sites each year)
- Define a revisit pattern for a spatial unit to be sampled across the temporal units
  - May be done systematically
  - May be done randomly

Surveys over Time: Panel Designs

Design monitoring program

		------------------- TIME PERIODS (=YEARS) --------------------												
PANEL	**SIZE**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**…**
DESIGN 1 = = ALWAYS REVISIT = SAME SITES														
1	60	X	X	X	X	X	X	X	X	X	X	X	X	…
DESIGN 2 = NEVER REVISIT = NEW SITES														
1	60	X												
2	60		X											
3	60			X										
4	60				X									
5	60					X								
6	60						X							
7	60							X						
8	60								X					
9	60									X				
10	60										X			
11	60											X		
12	60												X	
⋮	⋮													⋱

Design monitoring program

Surveys over Time: Panel Designs

PANEL	SIZE	------------------- TIME PERIODS (=YEARS) --------------------												
		1	2	3	4	5	6	7	8	9	10	11	12	...
DESIGN 3 = ROTATING PANEL														
-3	12	X												
-2	12	X	X											
-1	12	X	X	X										
0	12	X	X	X	X									
1	12	X	X	X	X	X								
2	12		X	X	X	X	X							
3	12			X	X	X	X	X						
4	12				X	X	X	X	X					
⋮	⋮					⋱	⋱	⋱	⋱	⋱				

Surveys over Time: Panel Designs

PANEL	SIZE	------------------ TIME PERIODS (=YEARS) -------------------												
		1	2	3	4	5	6	7	8	9	10	11	12	...
DESIGN 4 = AUGMENTED SERIALLY ALTERNATING														
1	50	X				X				X				...
2	50		X				X				X			...
3	50			X				X				X		...
4	50				X				X				X	...
COMMON	10	X	X	X	X	X	X	X	X	X	X	X	X	...

Surveys over Time: Panel Designs

Design monitoring program

PANEL	SIZE	------------------- TIME PERIODS (=YEARS) --------------------											
		1	2	3	4	5	6	7	8	9	10	11	12	…
DESIGN 5 = PARTIALLY AUGMENTED SERIALLY ALTERNATING														
1	50	X				X				X				…
2	50		X				X				X			…
3	50			X				X				X		…
4	50				X				X				X	…
5	5	X	X											…
6	5		X	X										…
7	5			X	X									…
8	5				X	X								…
9	5					X	X							…
10	5						X	X						…
11	5							X	X					…
12	5								X	X				…
13	5									X	X			…
14	5										X	X		…
15	5											X	X	…

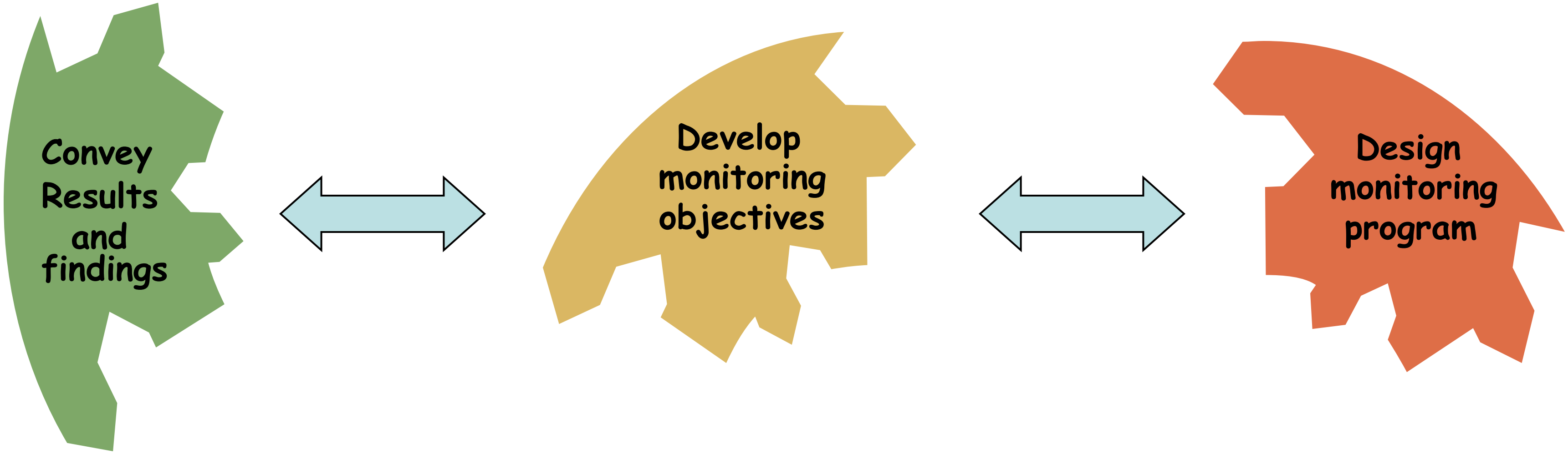
Inference Design for Indicators

Design monitoring program

- Great point to evaluate whether the prior design pieces for monitoring program will meet your objectives
- Indicators are associated with Reporting Domains which may require metric summaries across spatial units and temporal units
- Organized around three types of indicators (or objectives)
  – Status
  – Temporal pattern (change, trend)
  – Spatial pattern (map)

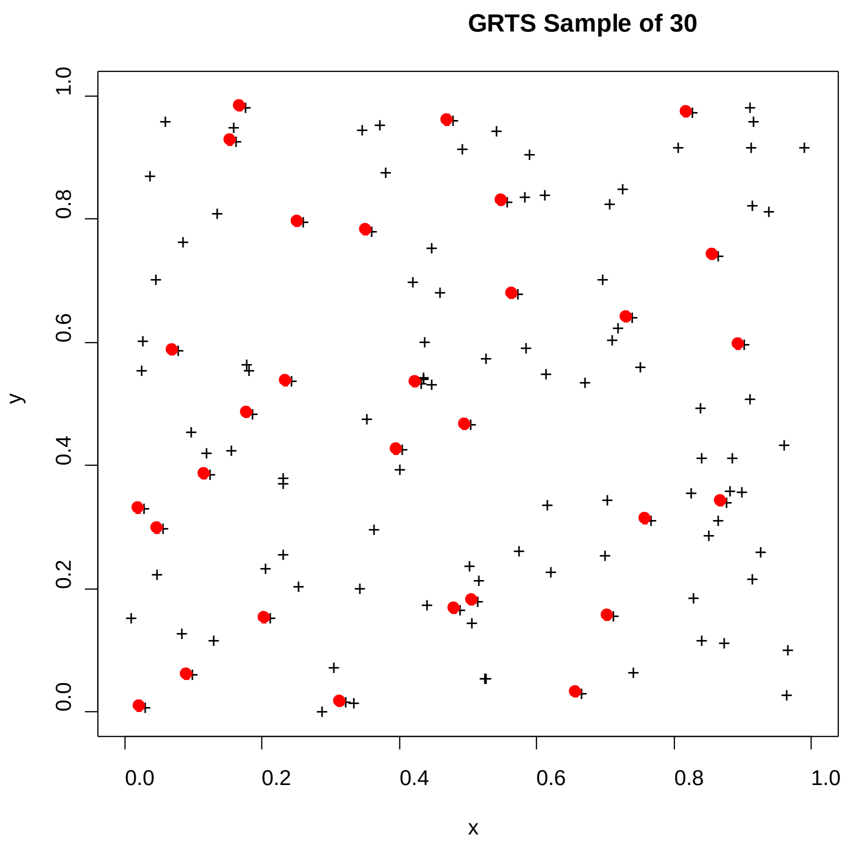
Inference Design: Sample Size

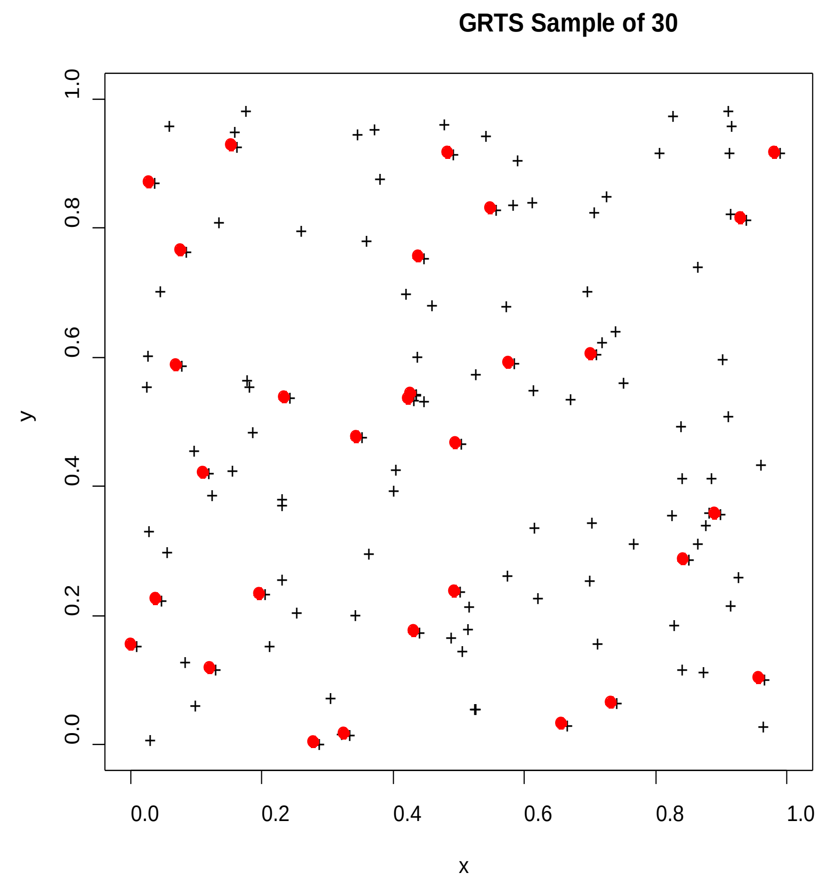
- Statistical quality requirements must be translated into sample size requirements
- Margin of error used to determine sample size
  - For each indicator and reporting domain
  - Based on spatial survey design
  - Requires prior information on variance for each metric
- Change and trend power requirements
  - Impact sample size
  - Selection of spatial-temporal design (i.e., panel structure, survey over time)

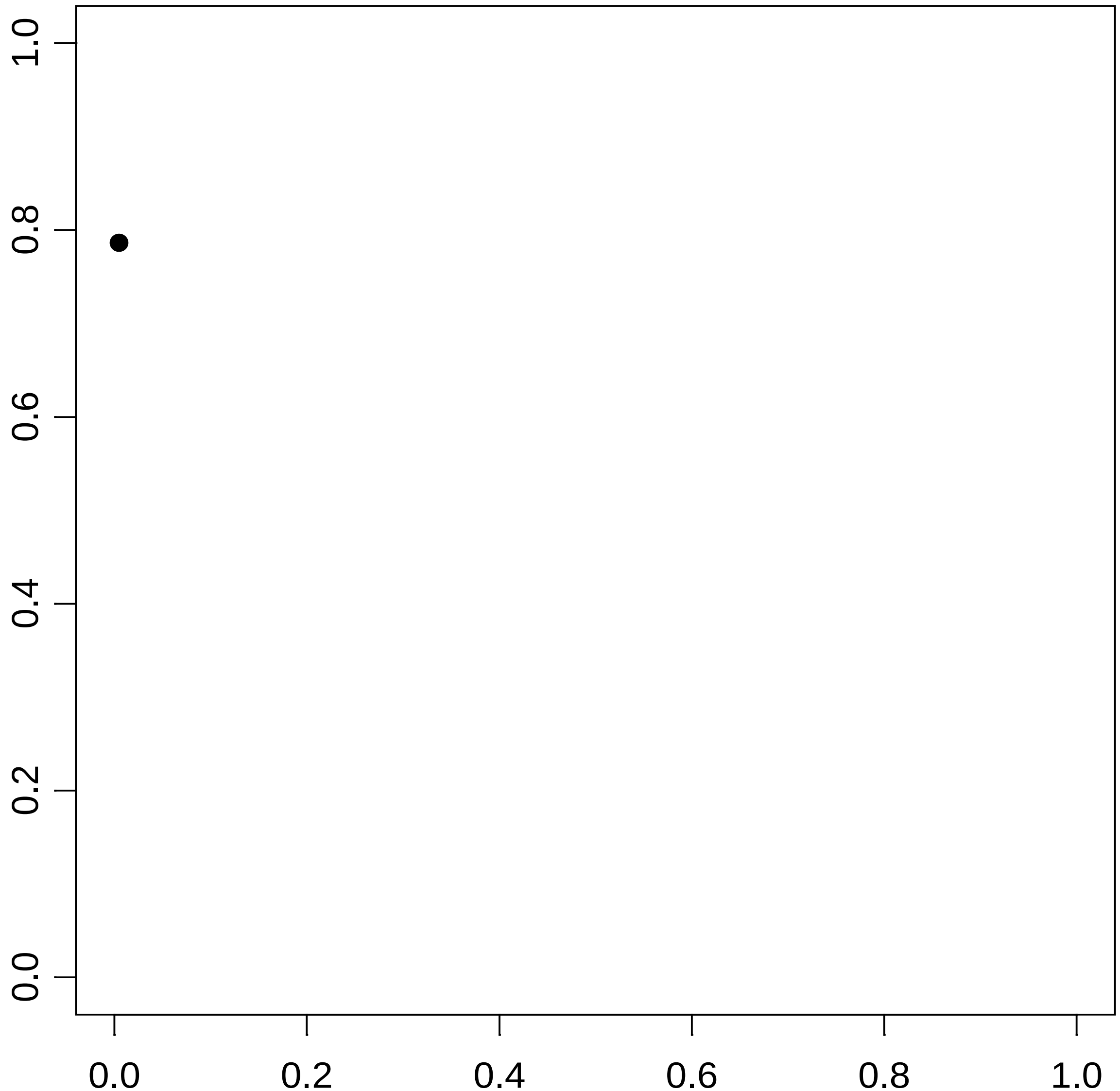


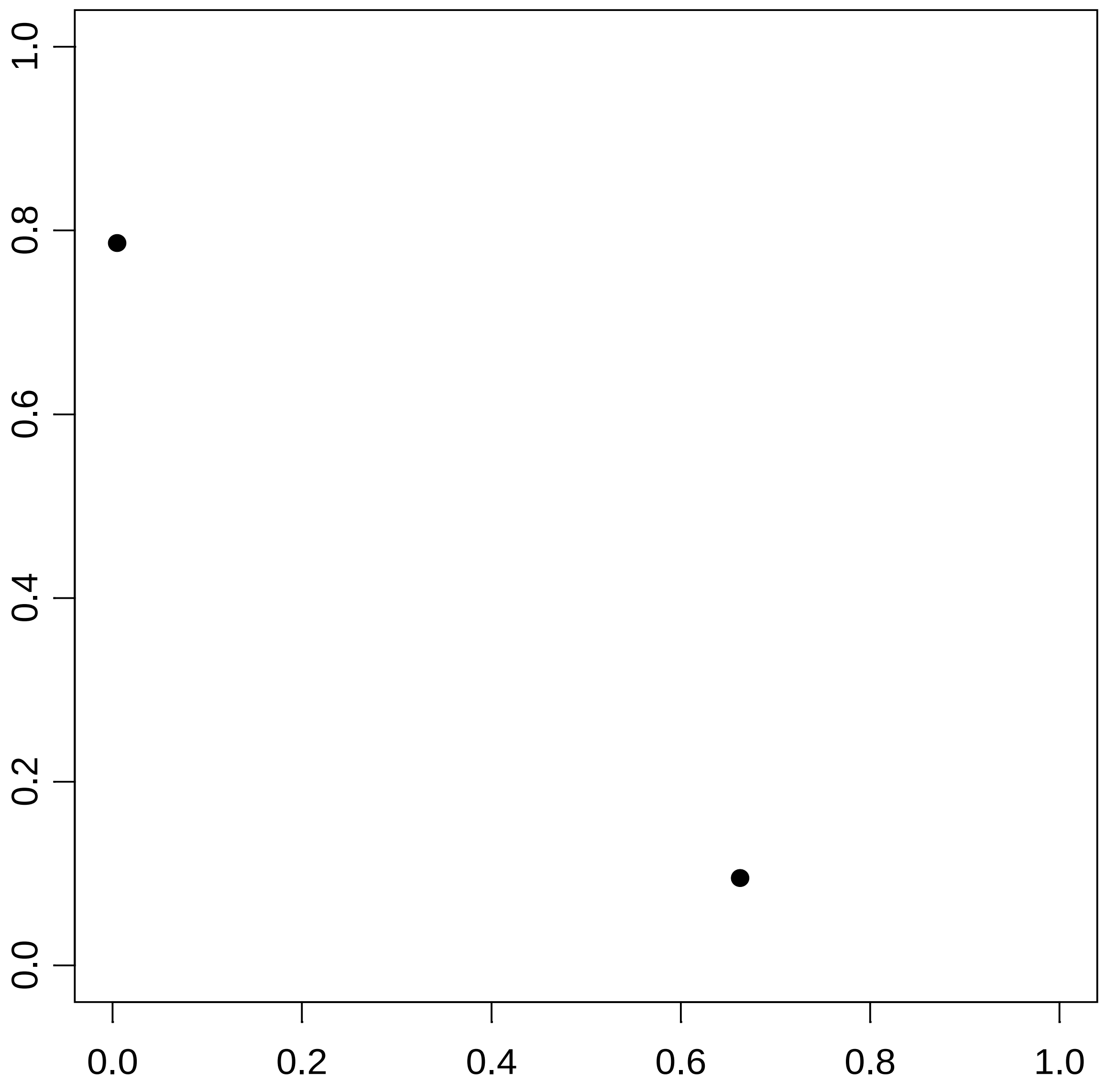
- Monitoring Objectives specify: Spatial domains, Spatial units, Temporal domains, Temporal Units, Reporting domains, Indicators, Statistical Quality
- STRIDe specifies based on monitoring objectives: Spatial design, Temporal design, Response design (including metrics and measurements), and Inference Design (including sample size)

Two GRTS samples: Size 30

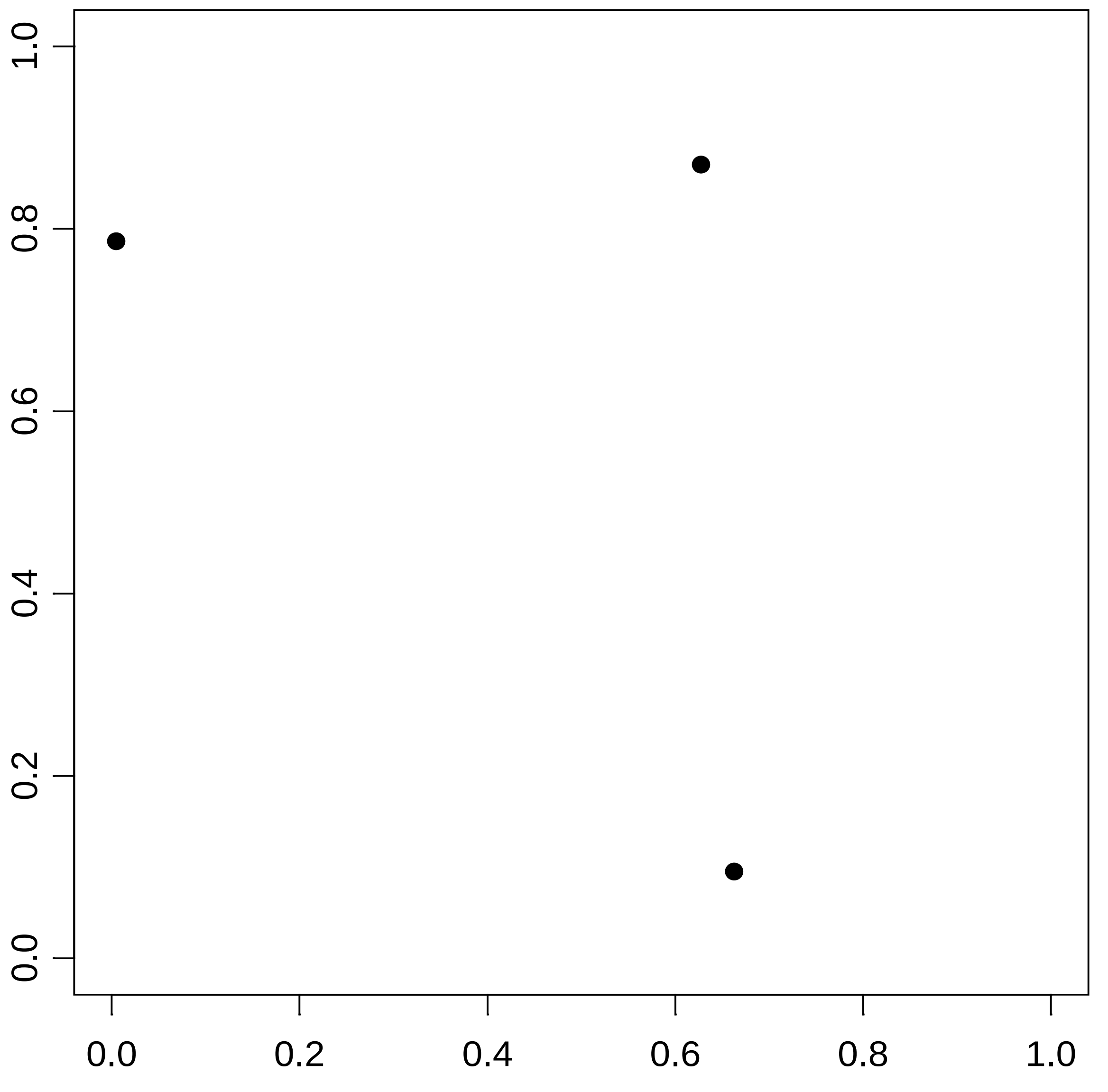


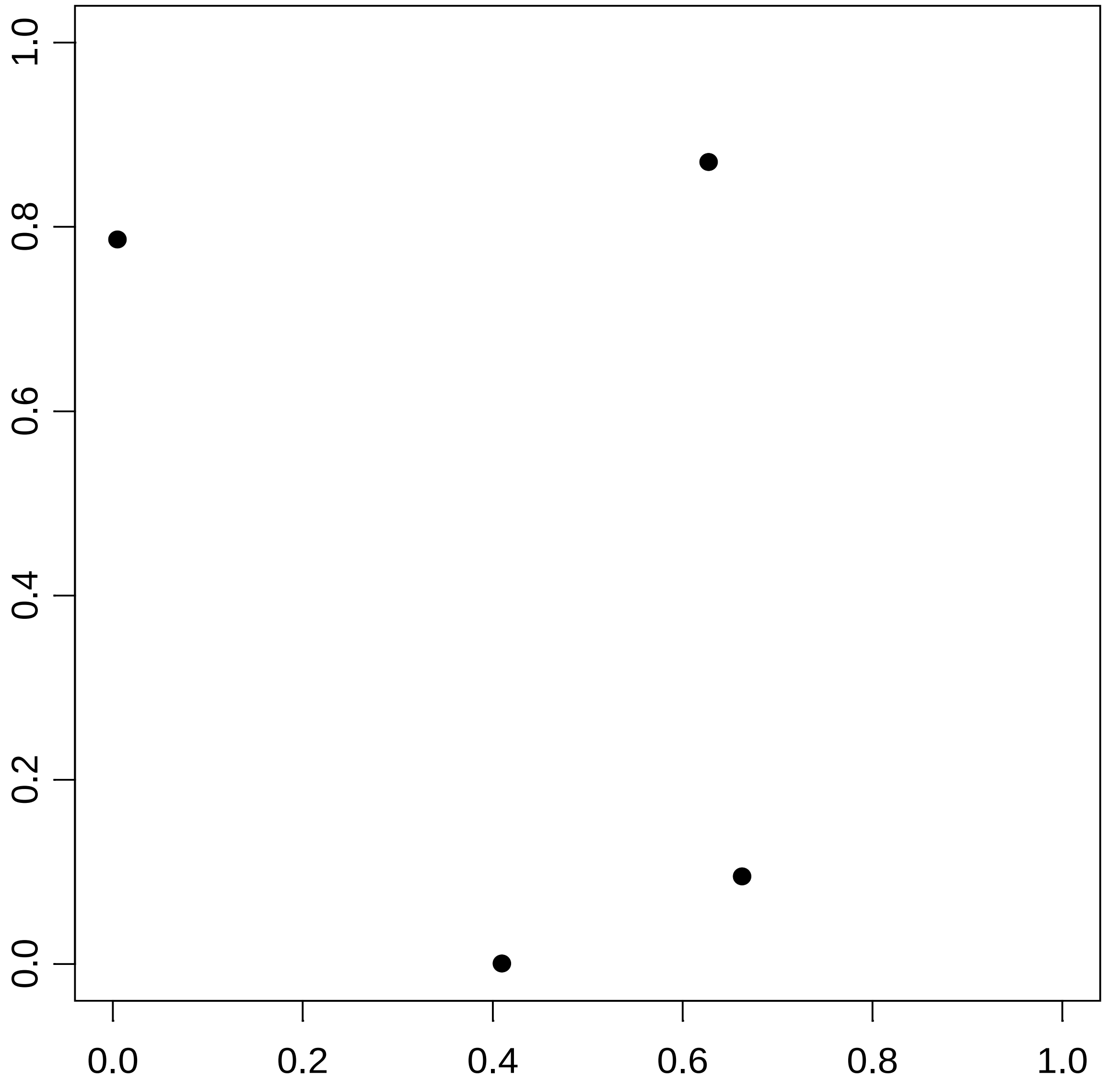



0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0

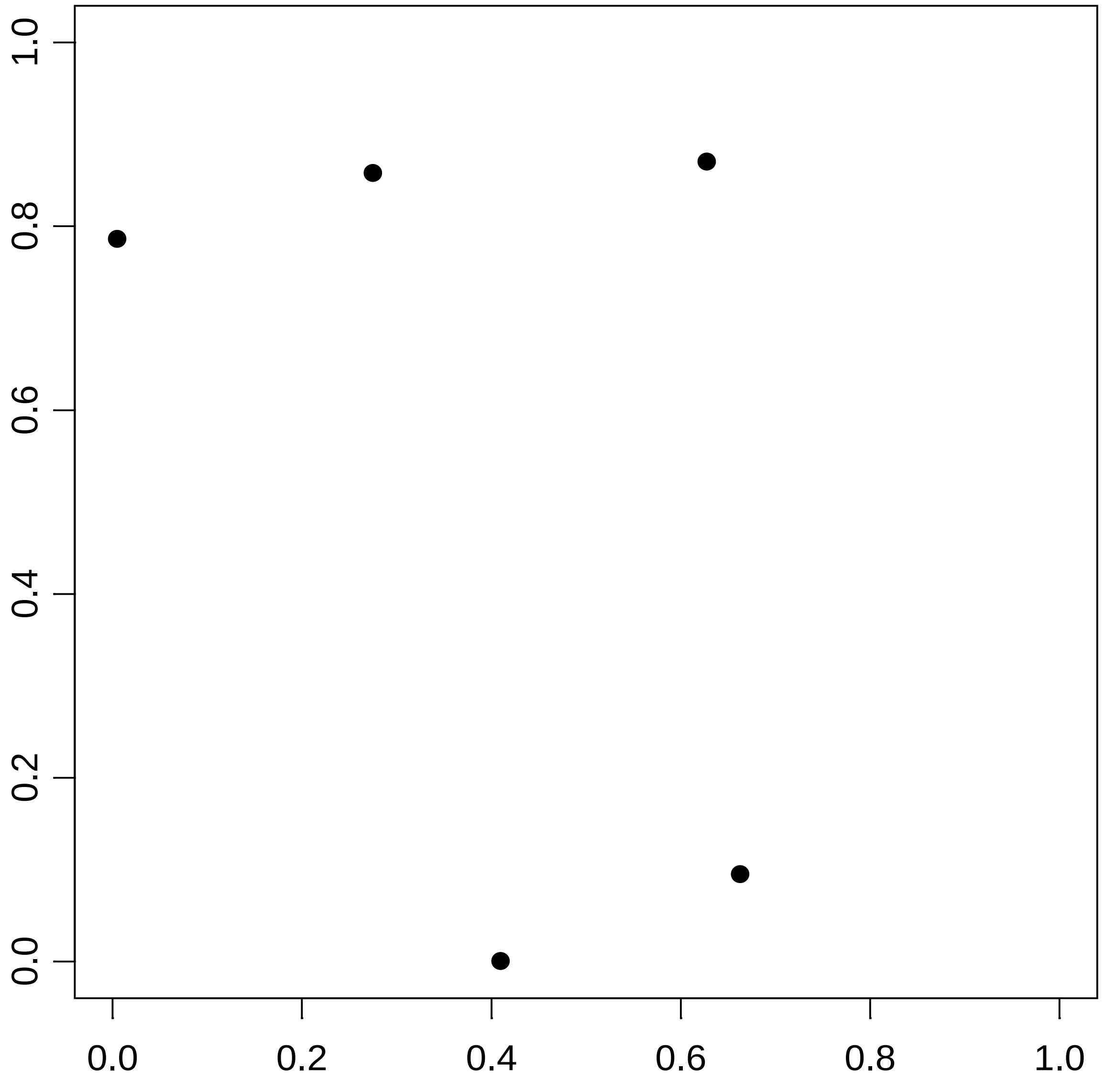


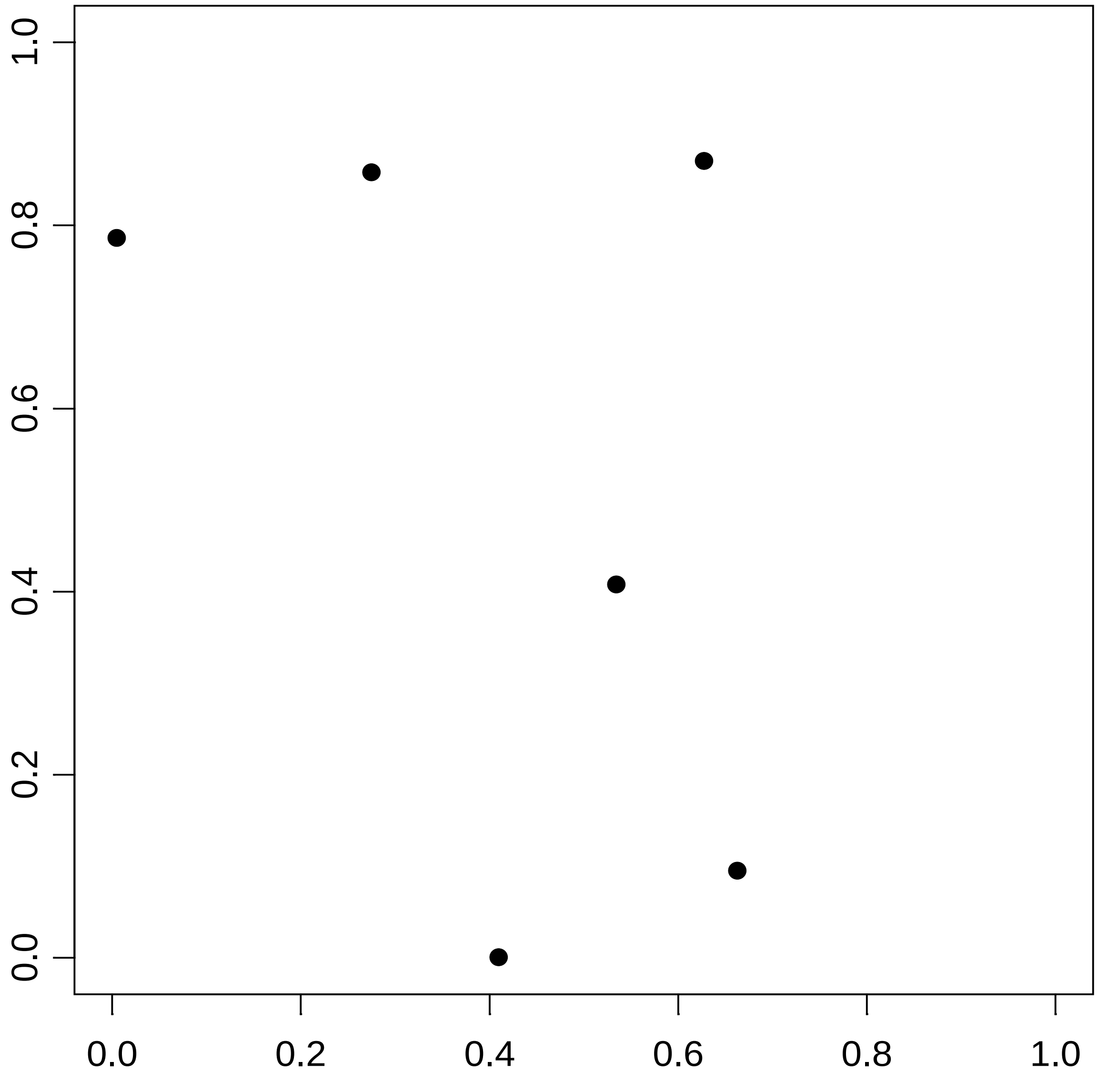
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0

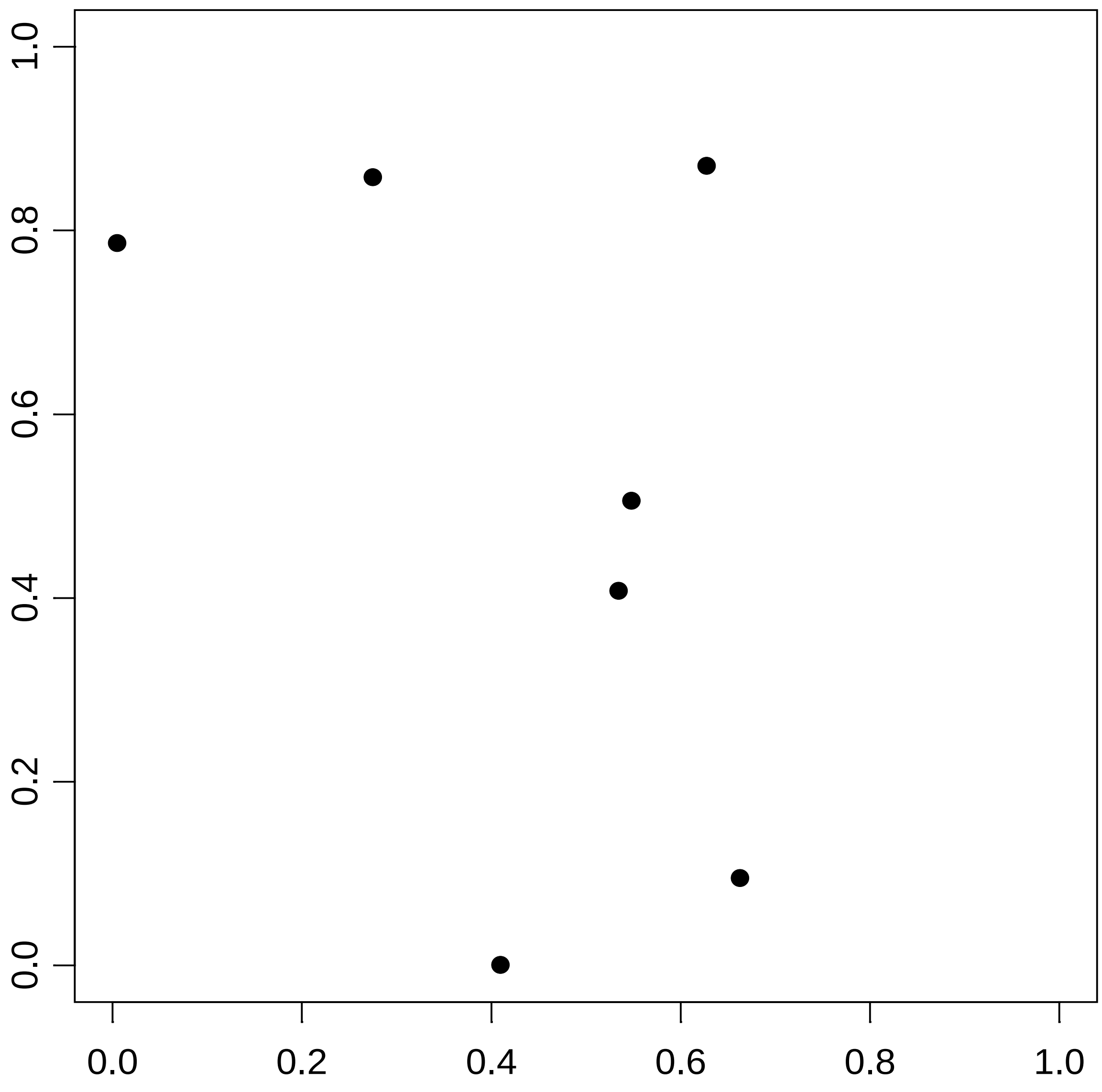

0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0

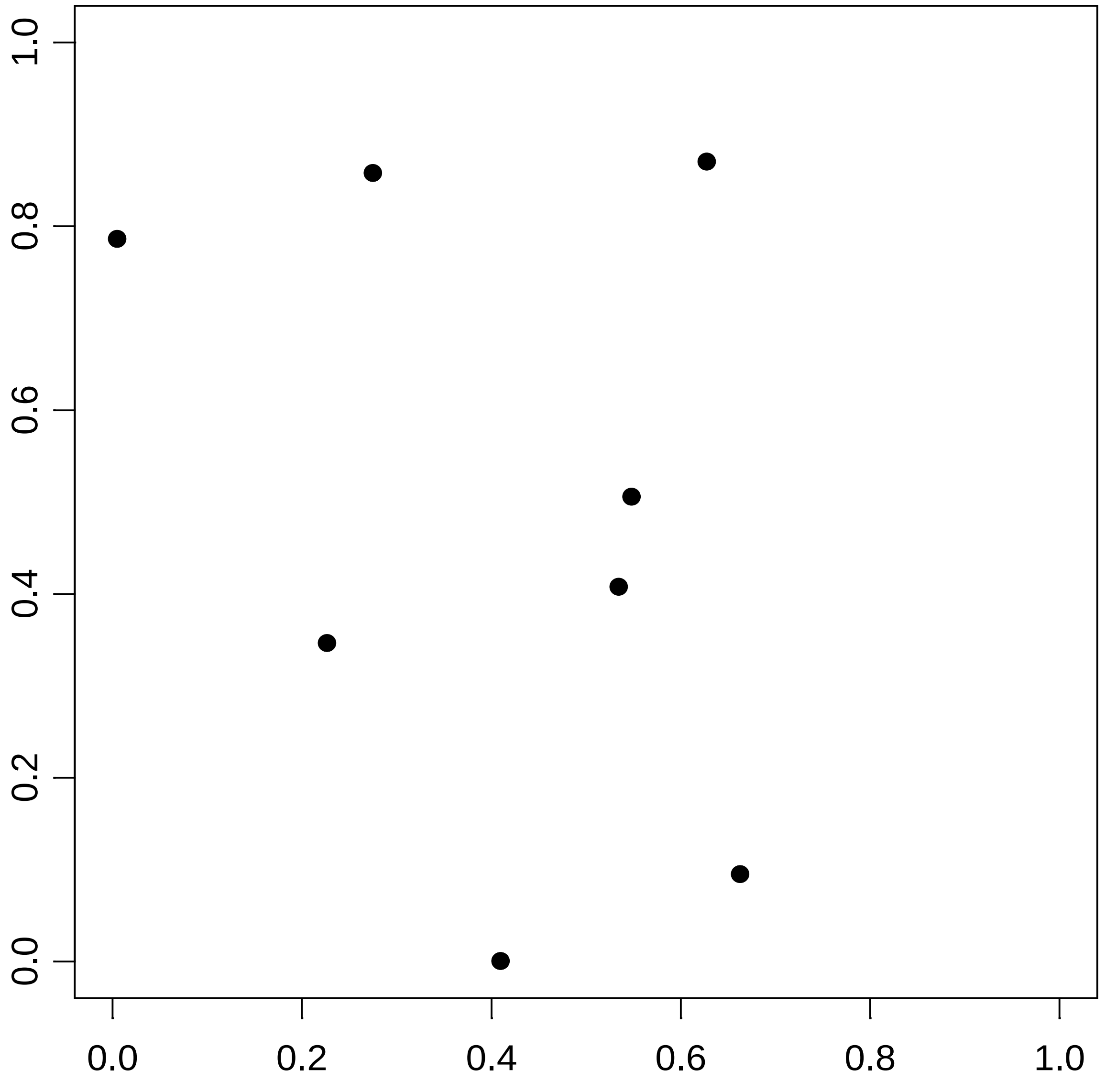


0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0

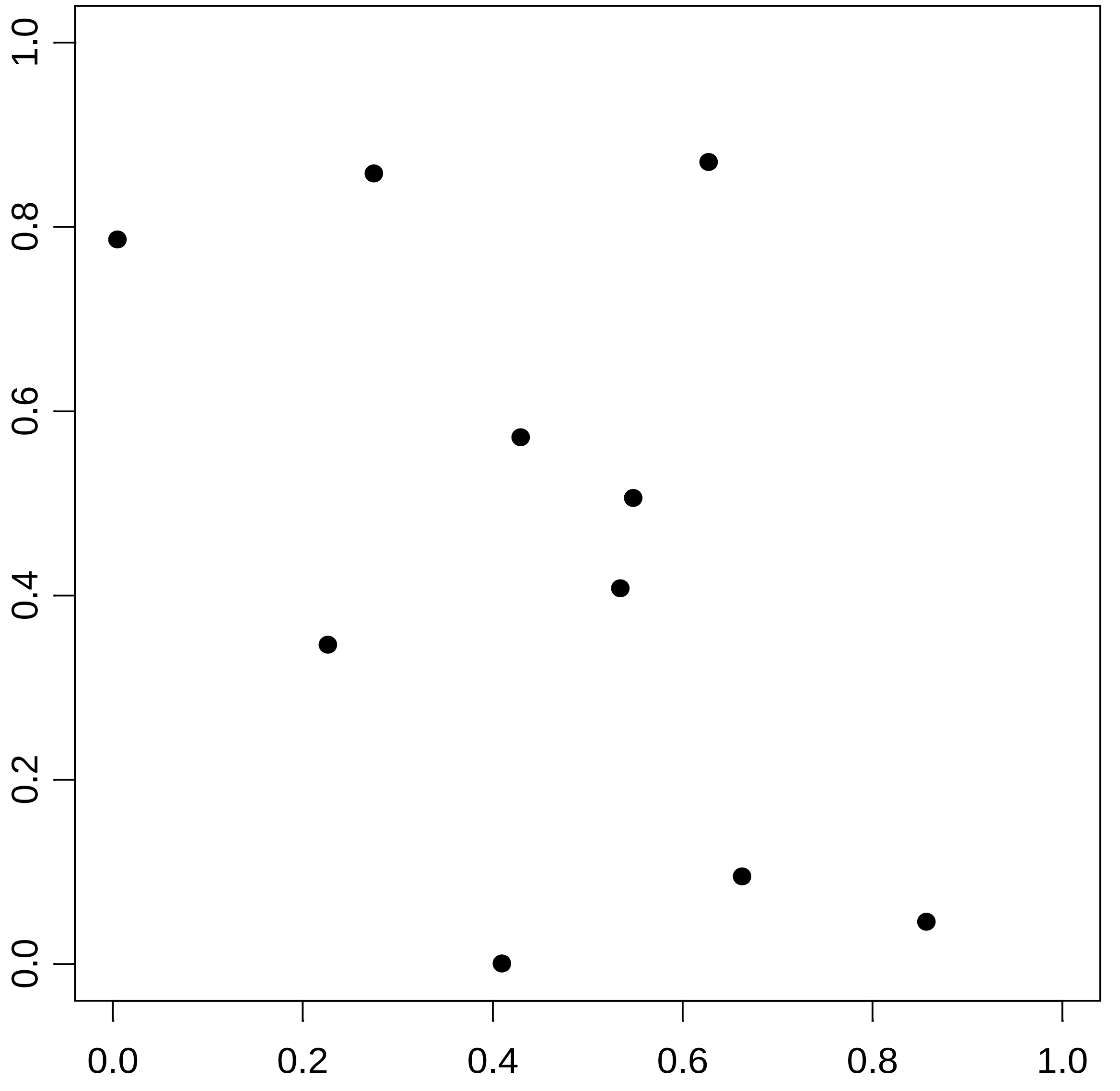

0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0

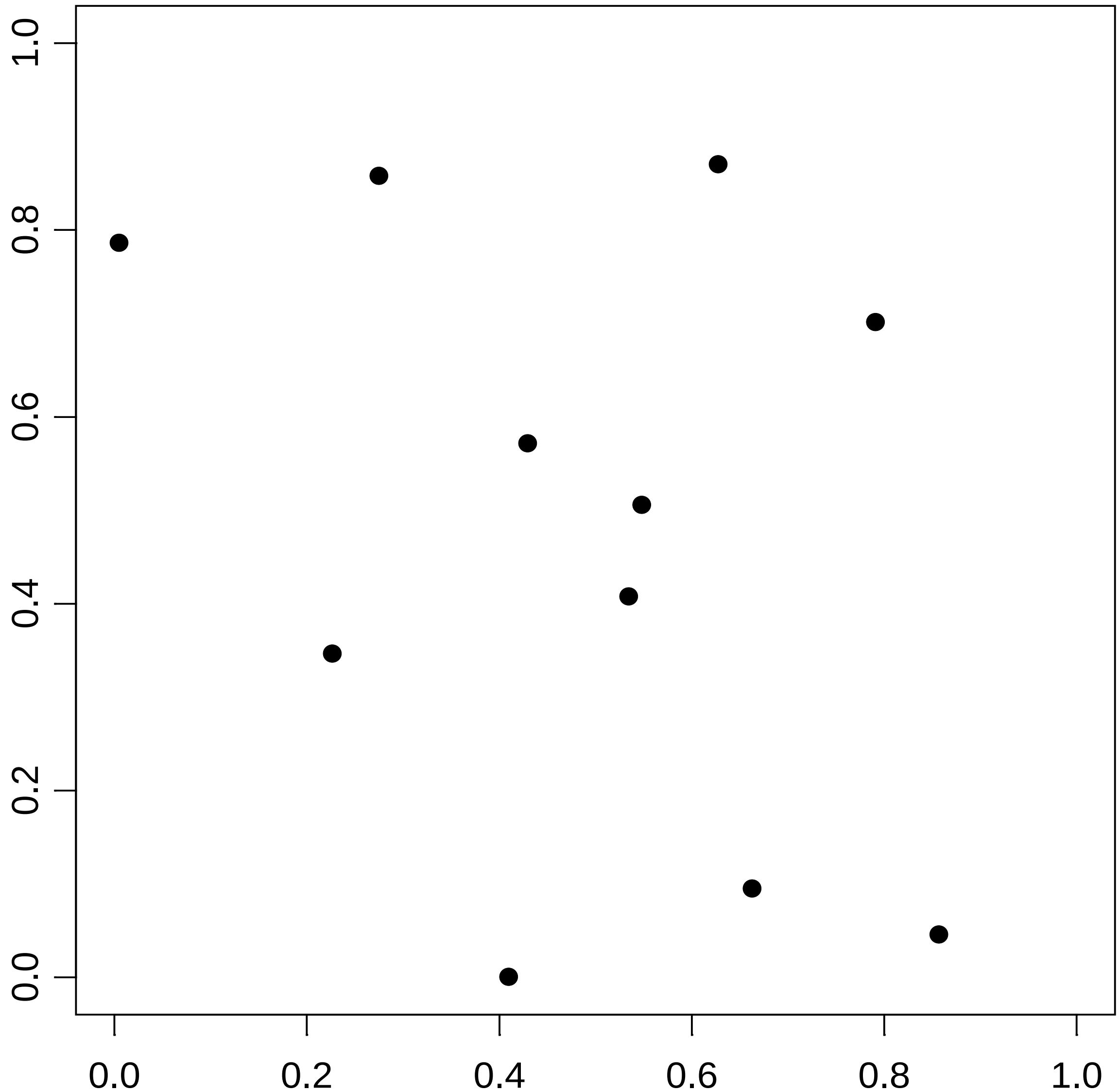

0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0


0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0

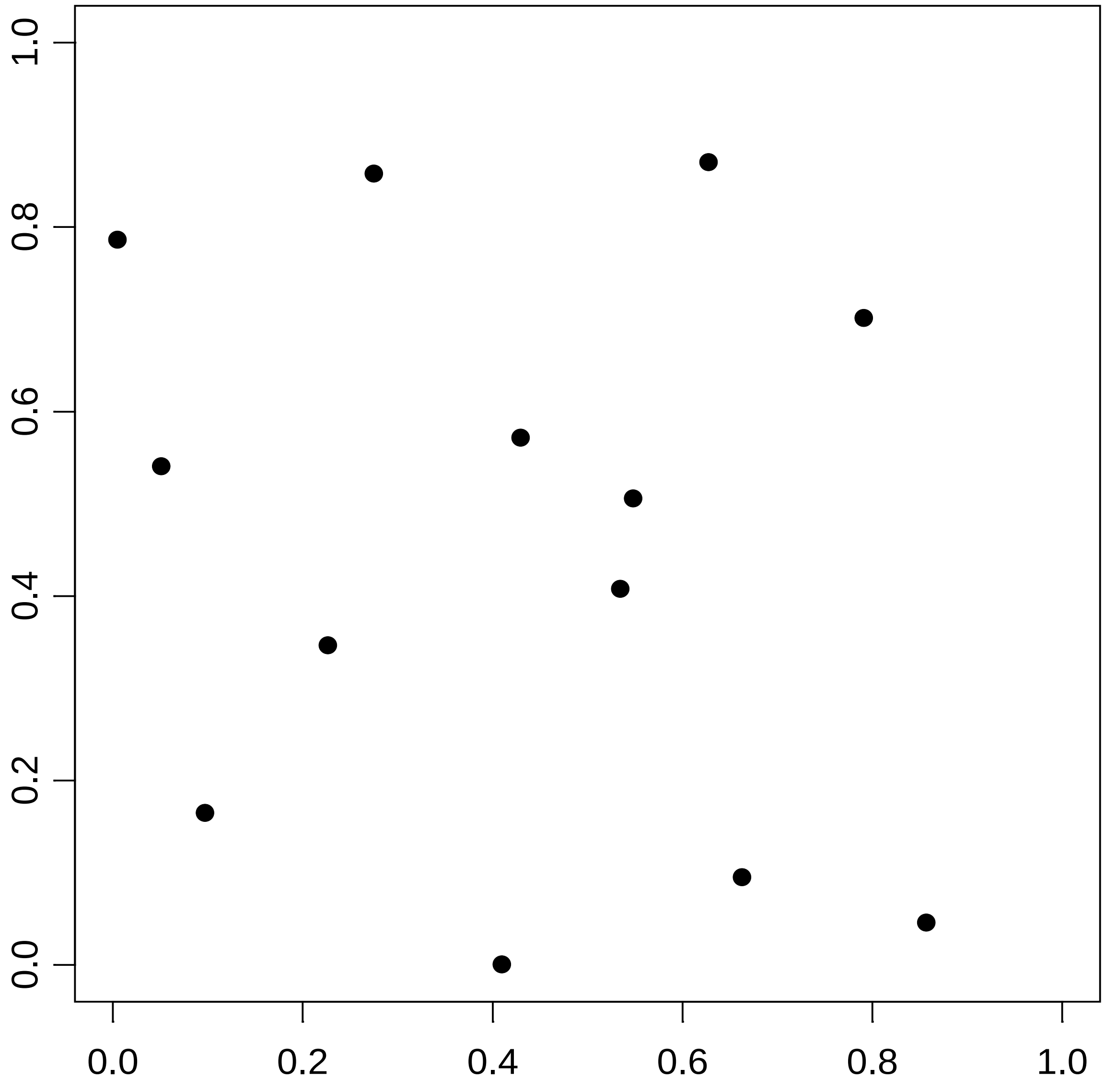


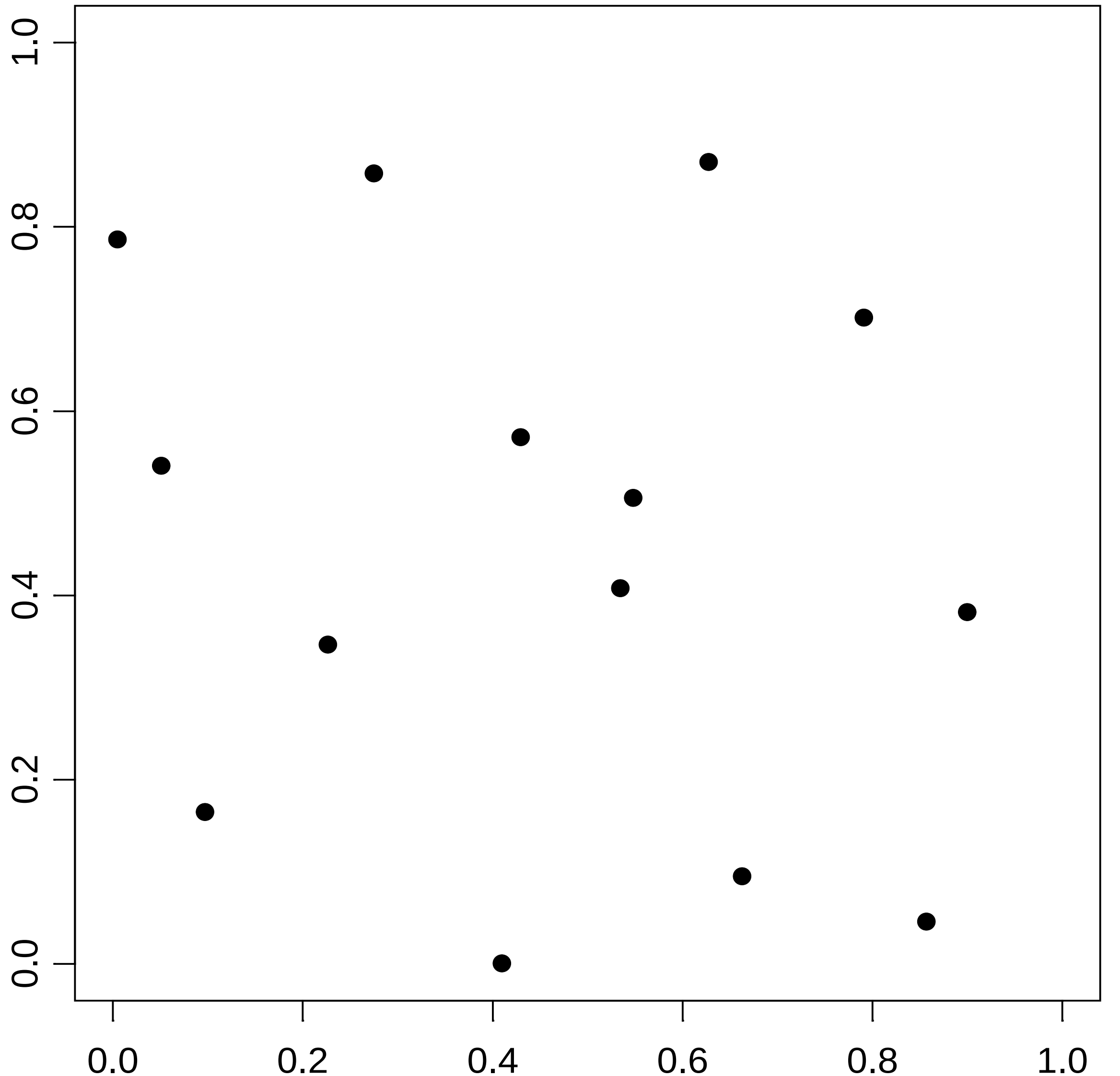
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0

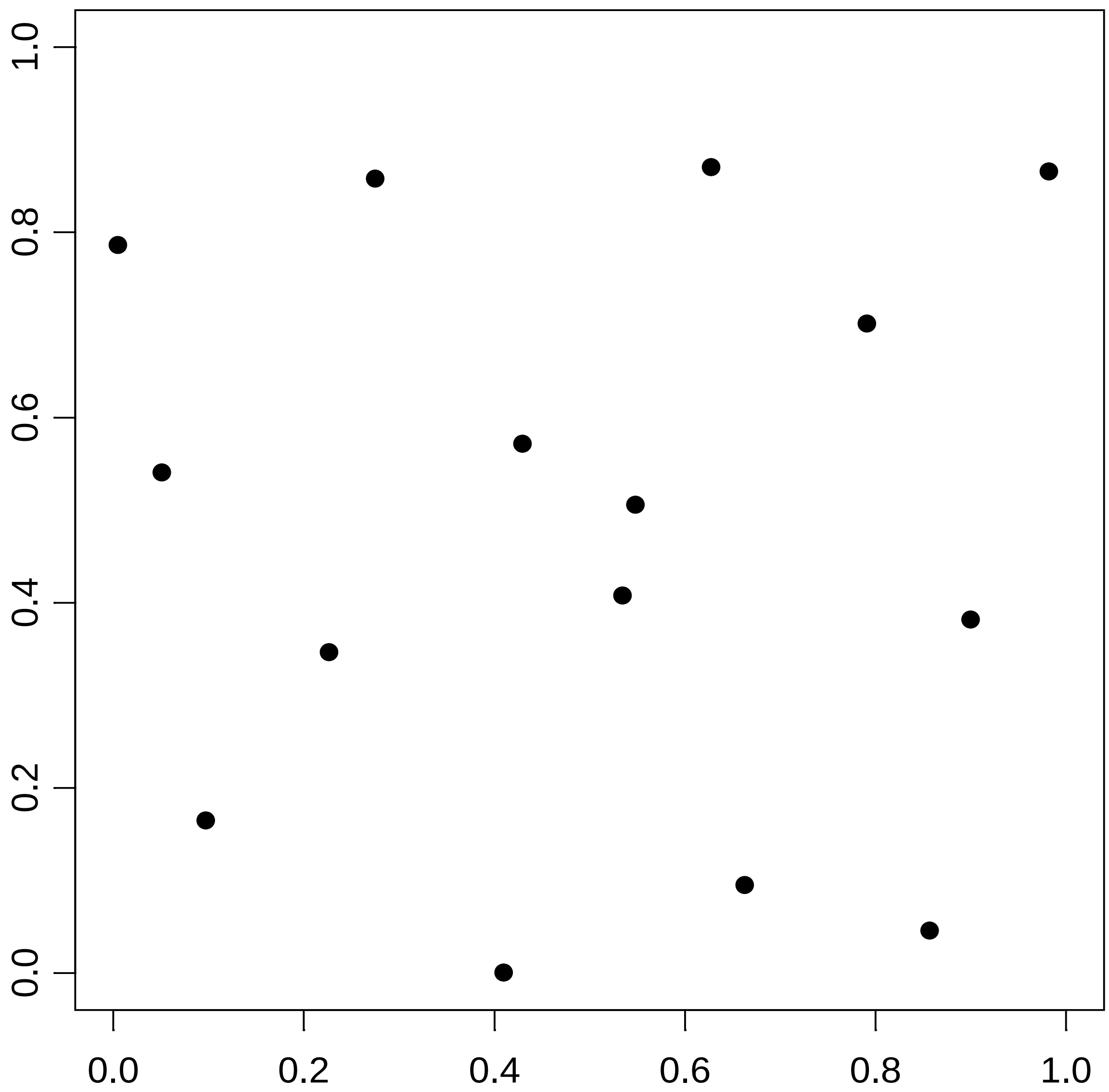

0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0

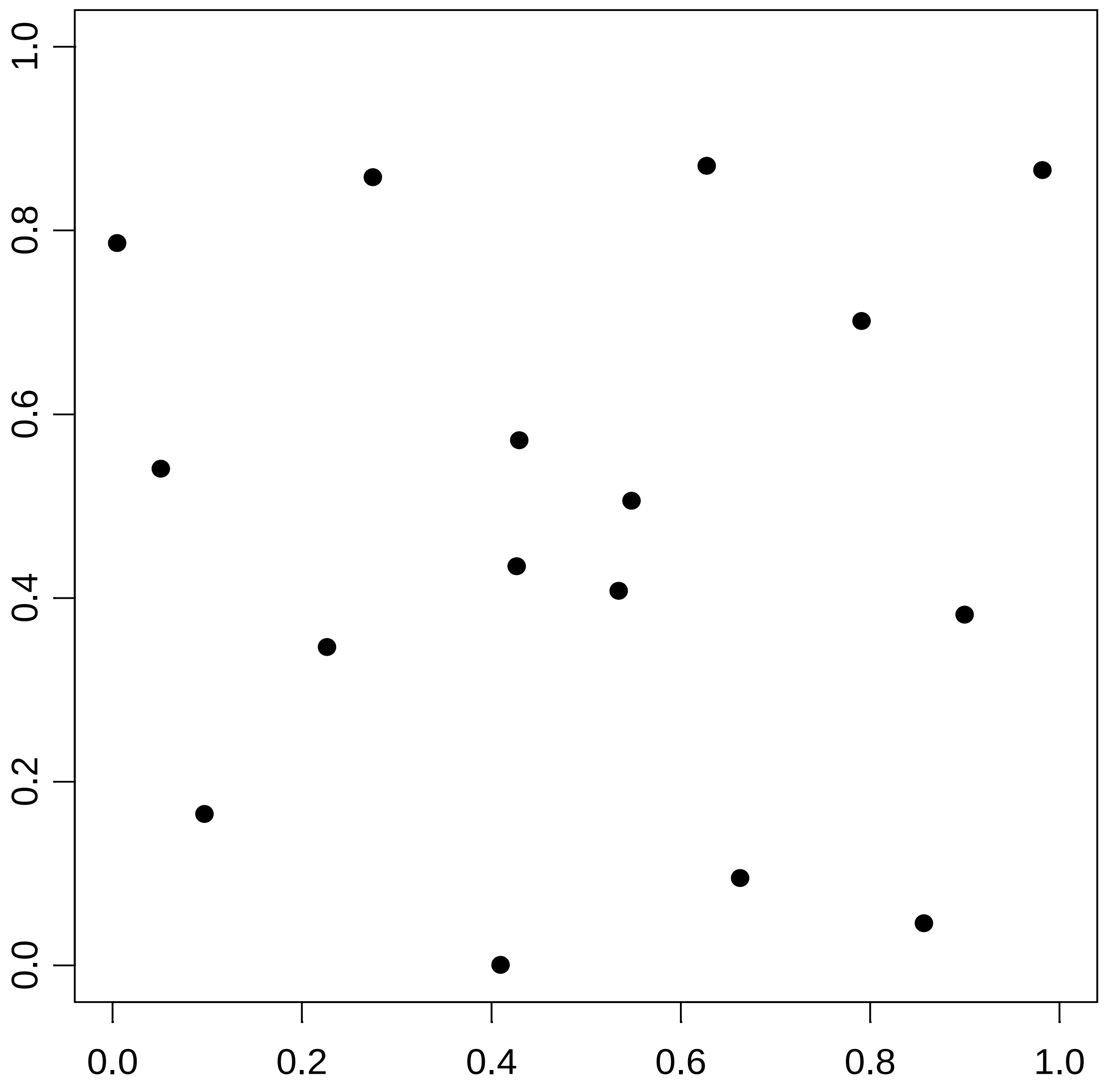


1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0

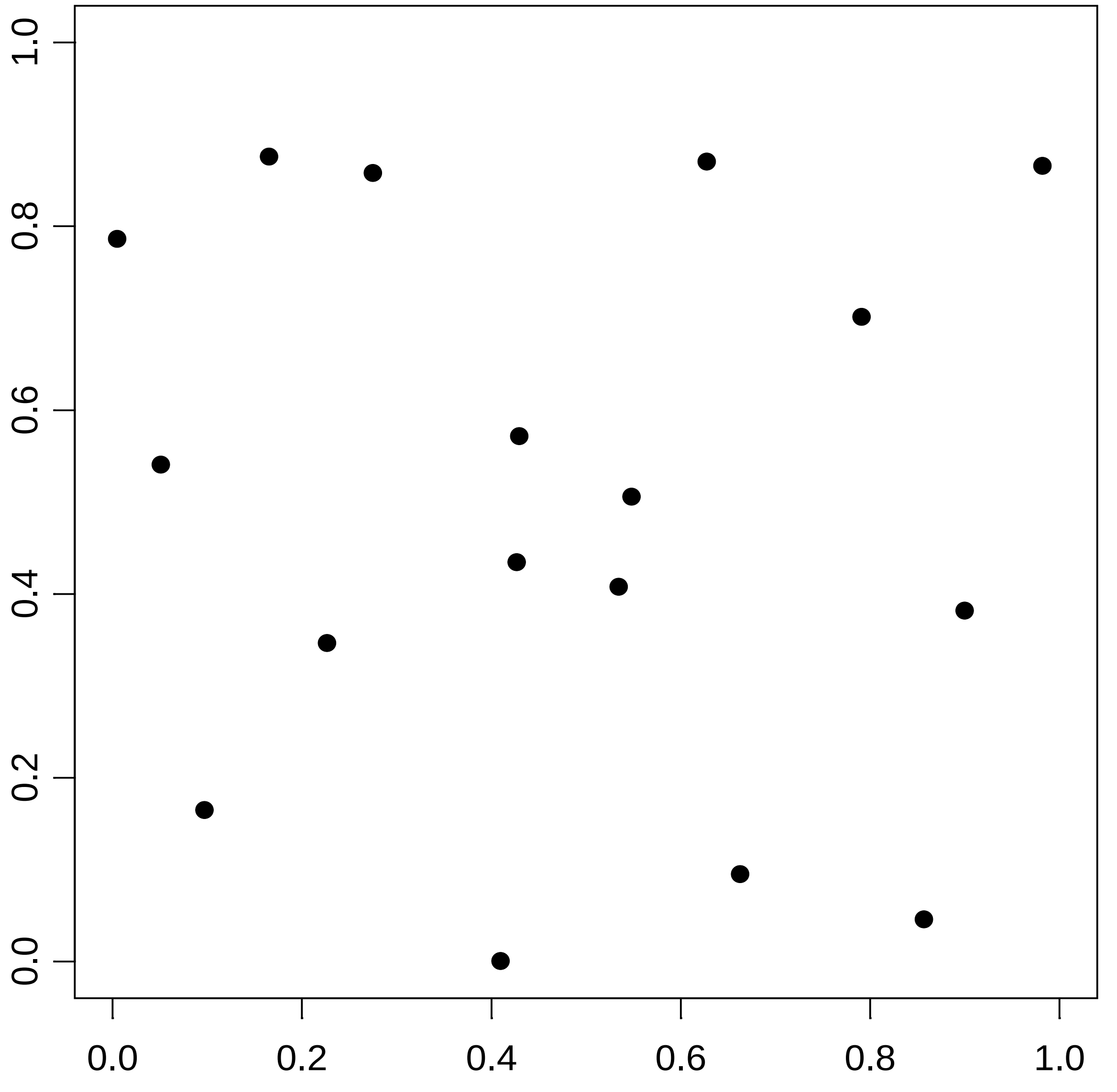

0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0

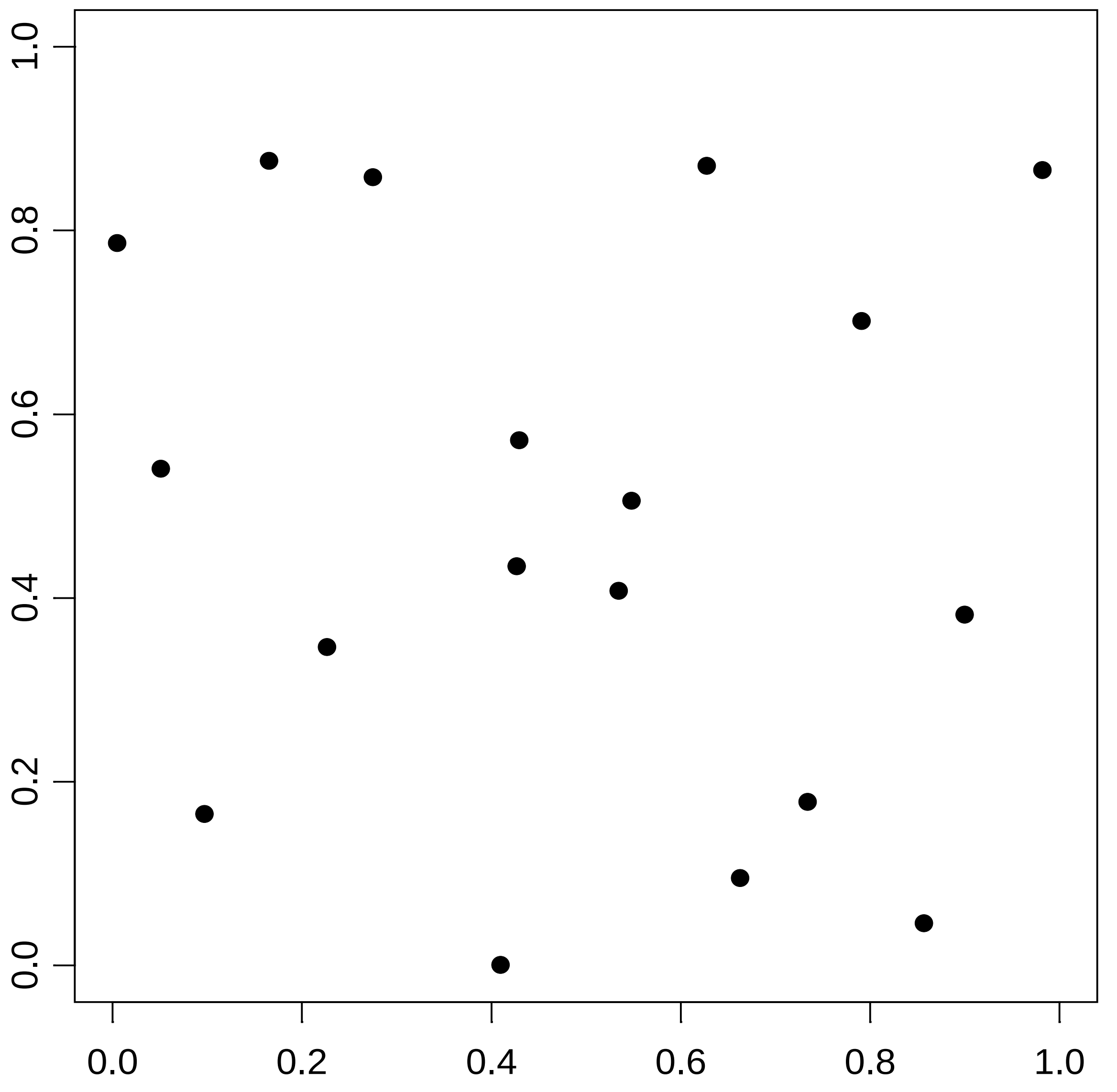

0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0

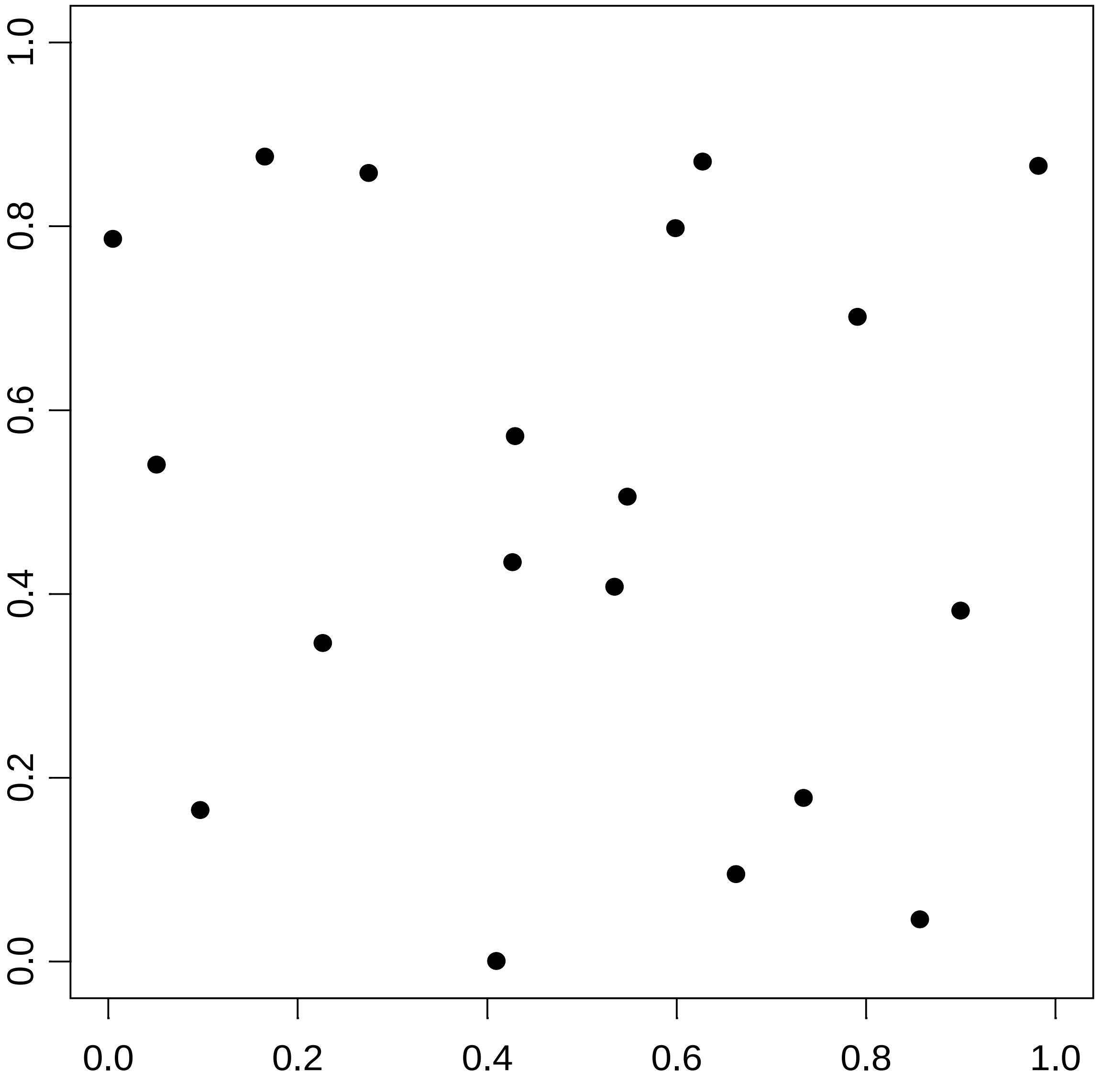

0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0



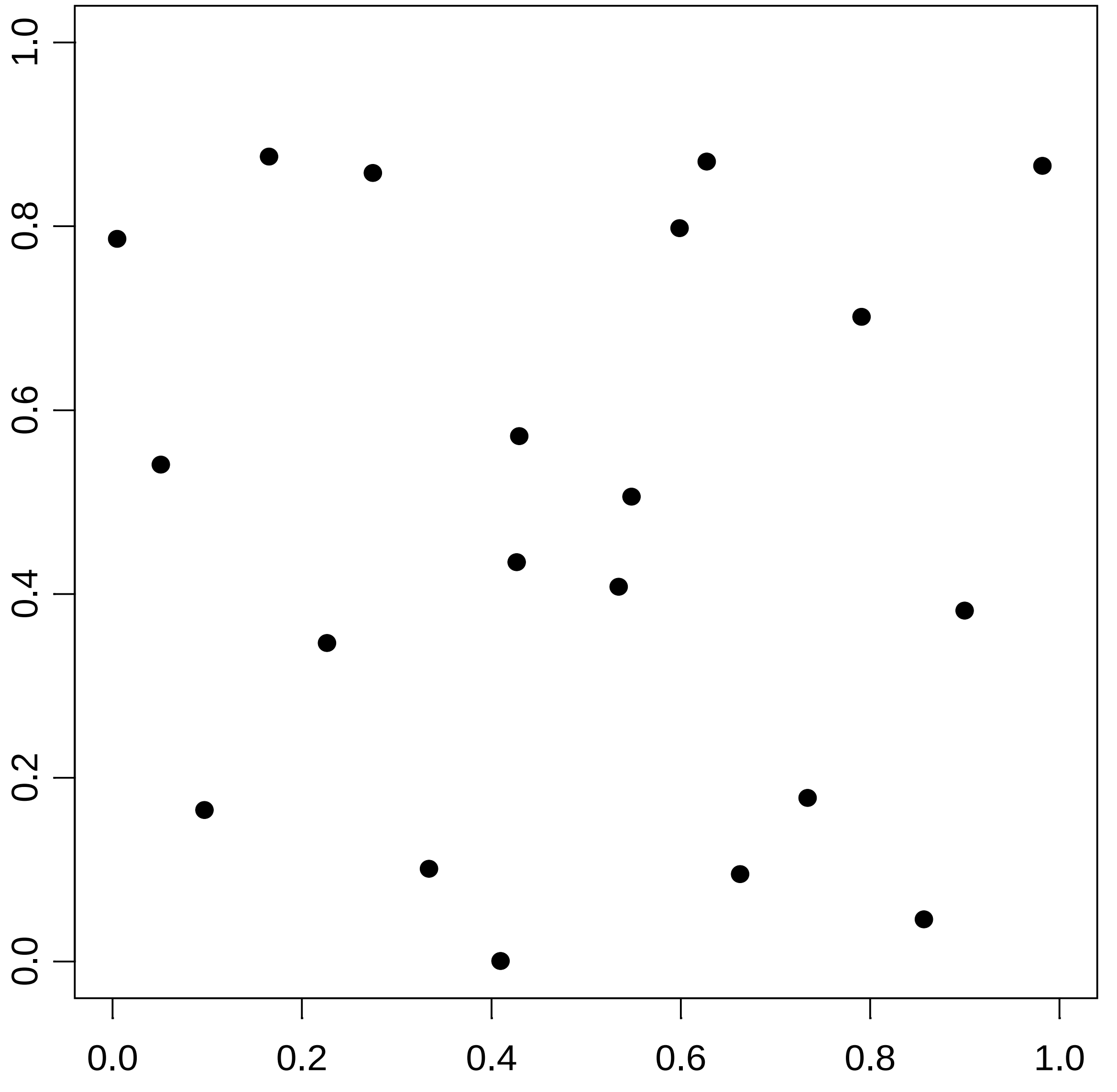
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0


0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0

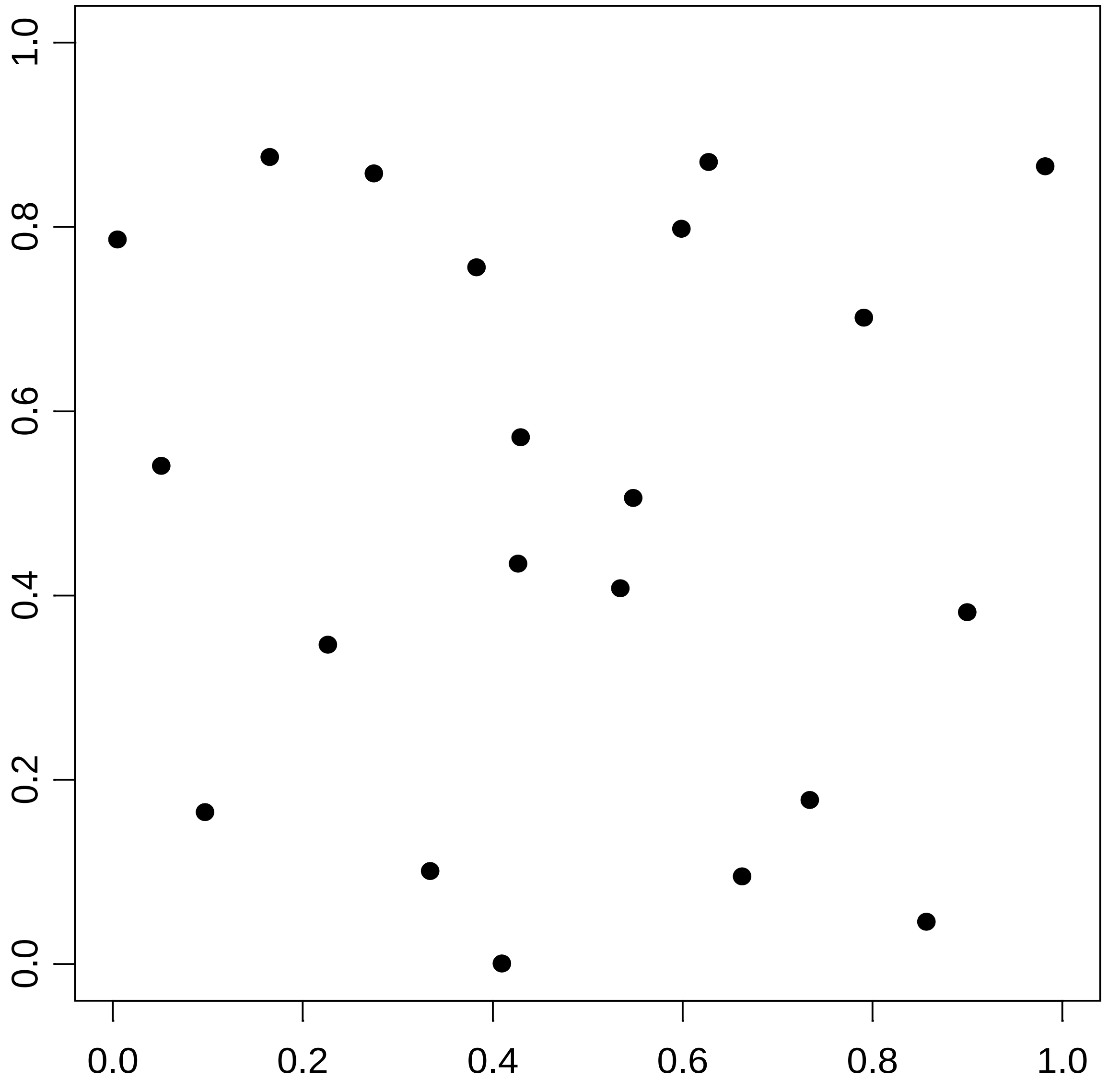

0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0

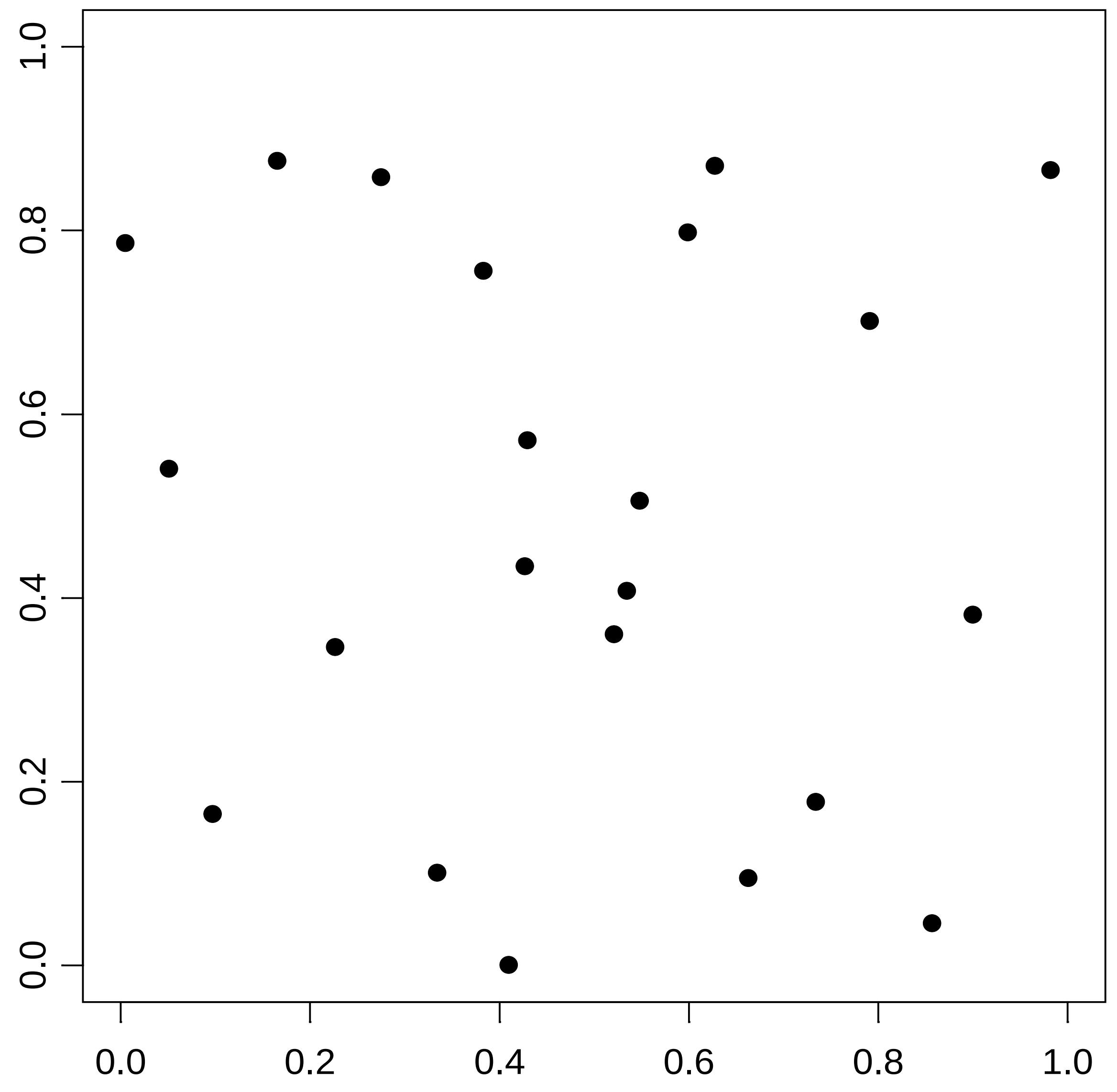


0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0

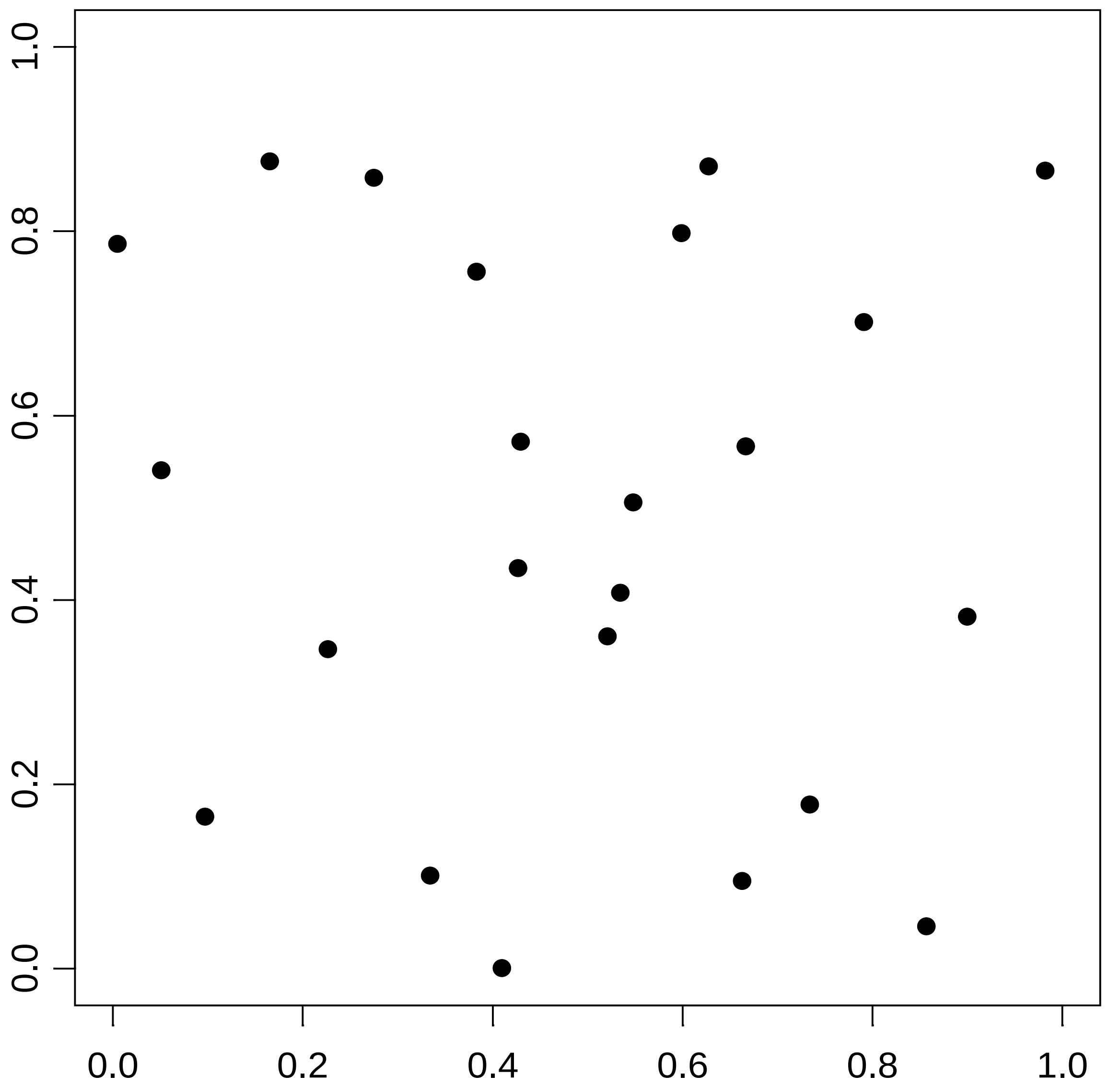


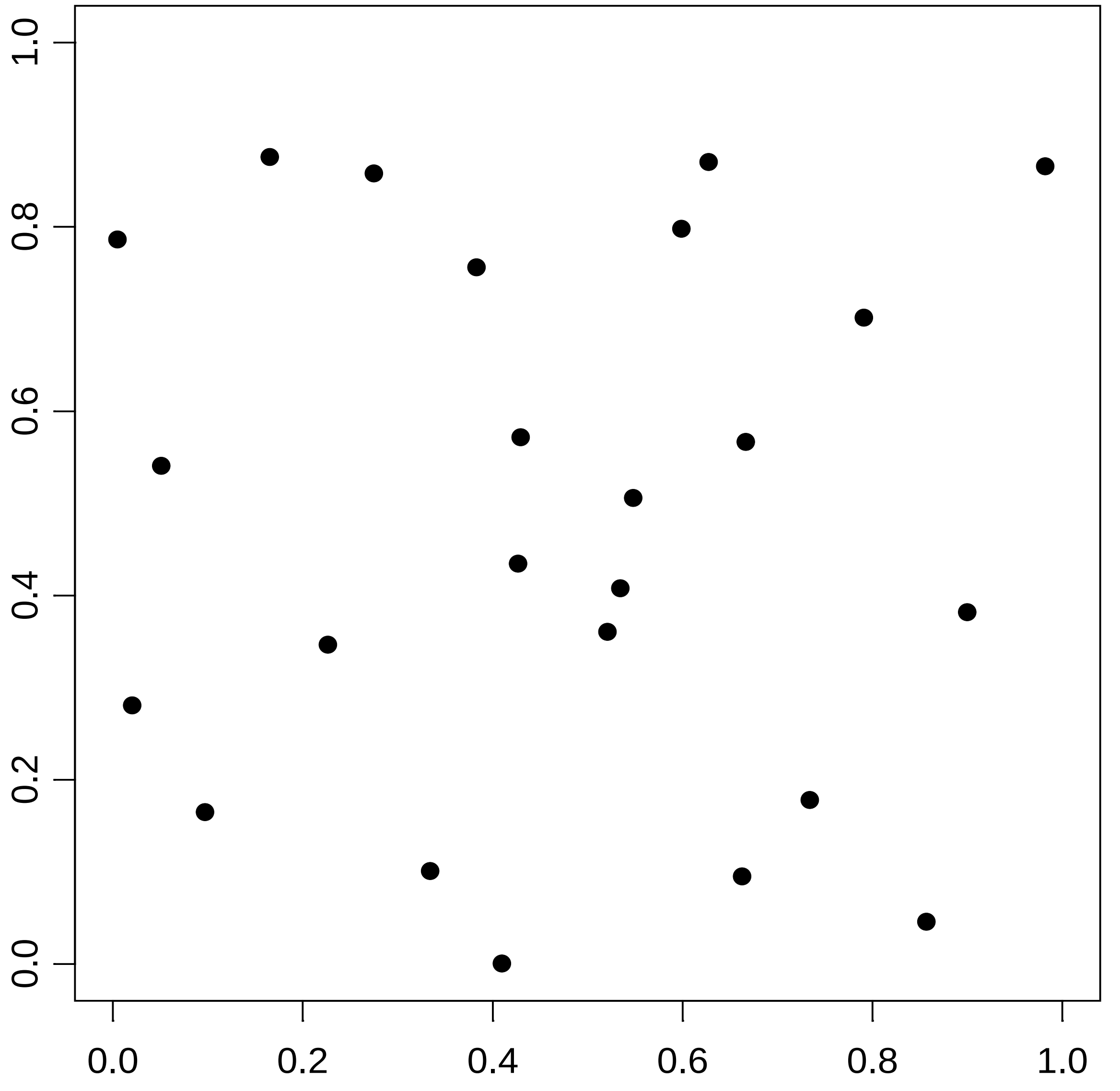
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0


0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0

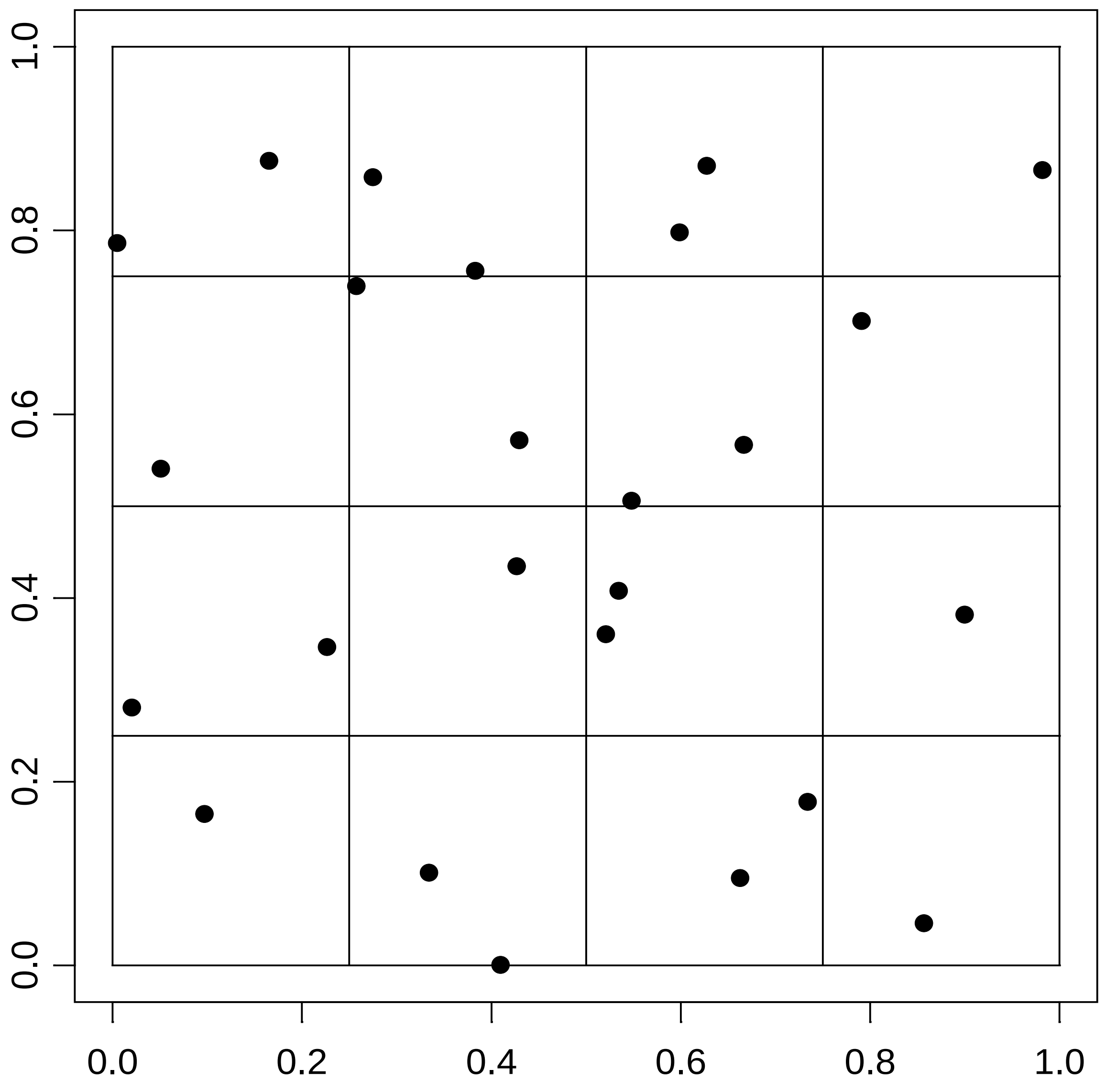


1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0


0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0

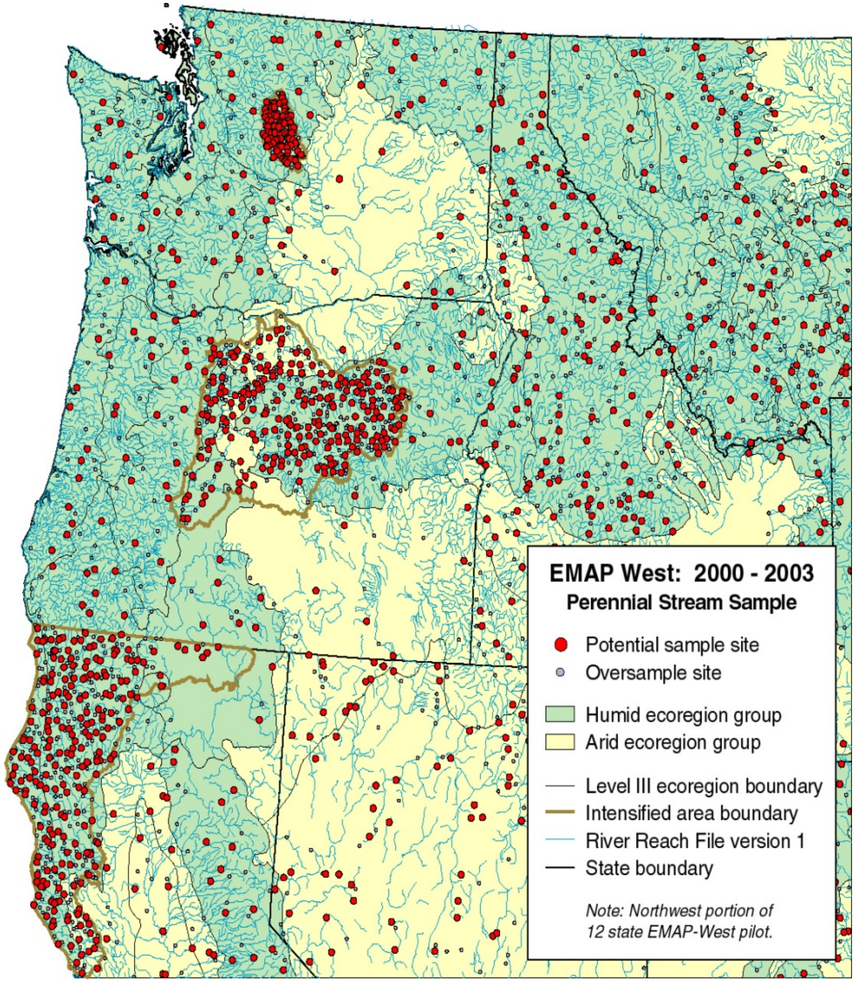


0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0



0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0

Perennial Streams GRTS sample



Change Detection

Estimated Differences between WSA (2000-2004) and NRSA (2008 - 2009)

Nutrient Data

John Van Sickle, ORD

Sarah Lehmann, OWOW

Ellen Tarquinio, OWOW

Objective:

Estimate stream chemistry differences between 2 stream surveys.

-- *WSA (Wadeable Streams Assessment)*

- West (EPA Regions 8, 9, 10): 2000-2003.
- East (Regions 1-7): 2004.

-- *NRSA (National Rivers and Streams Assessment)*, 2008-2009.

Target stream population (defined by WSA):

-- “Wadeable” streams, Strahler order 1 to 5.

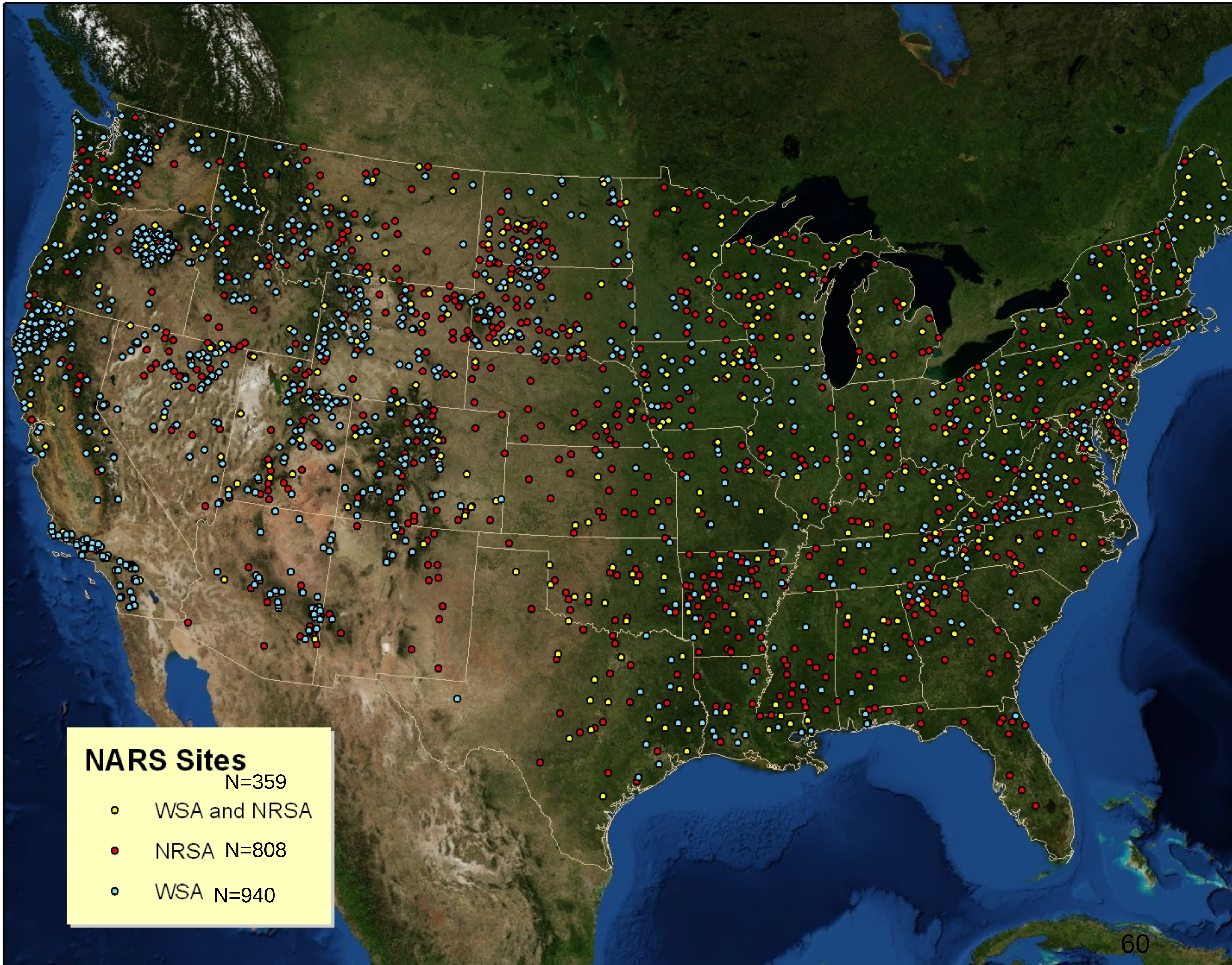
-- Analyze only the “wadeable” subset of NRSA streams.

Major Questions:

-- Are there significant differences?

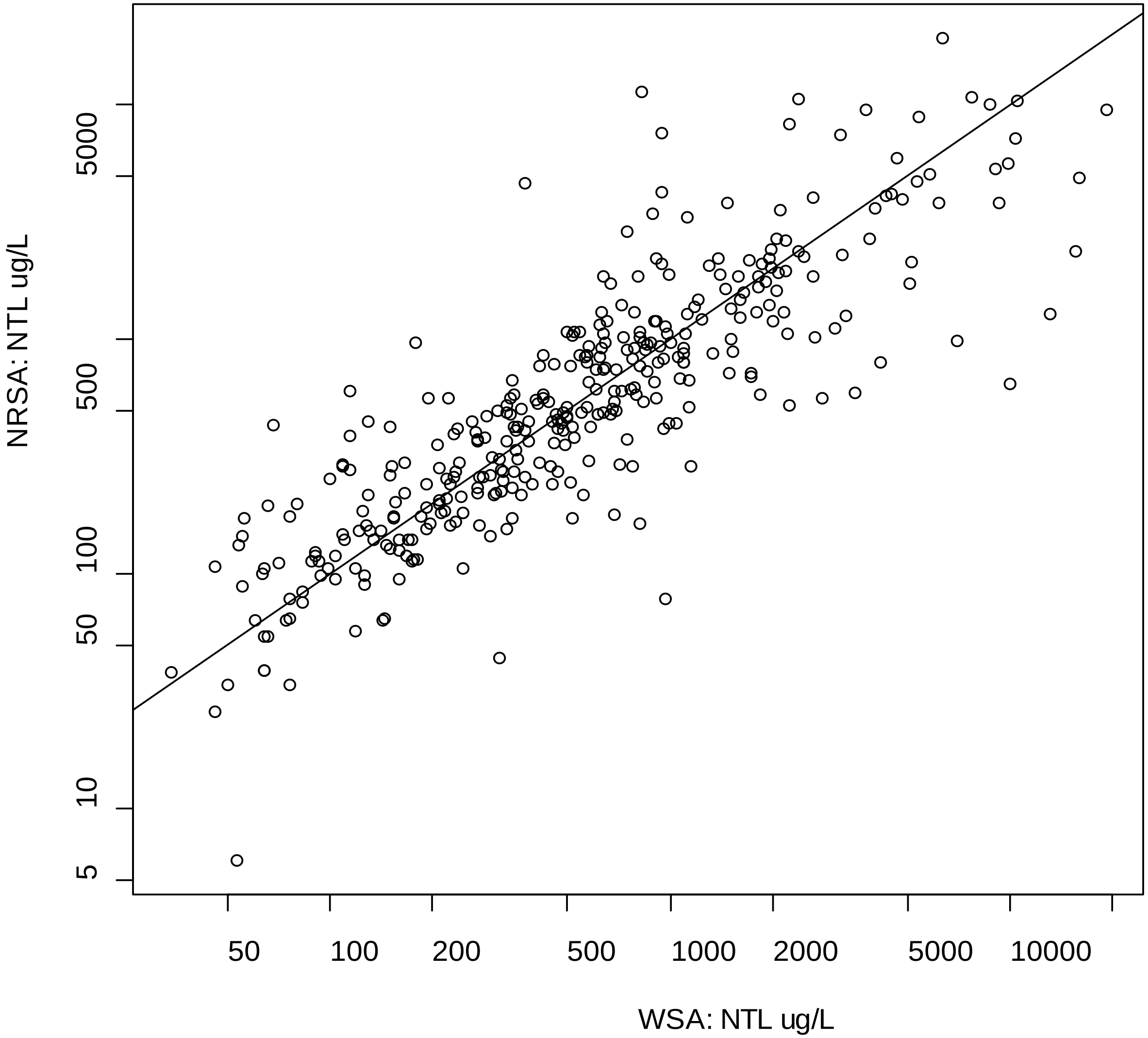
-- If so, then why?

(Human effects? Natural variation? Changes in survey methods?)

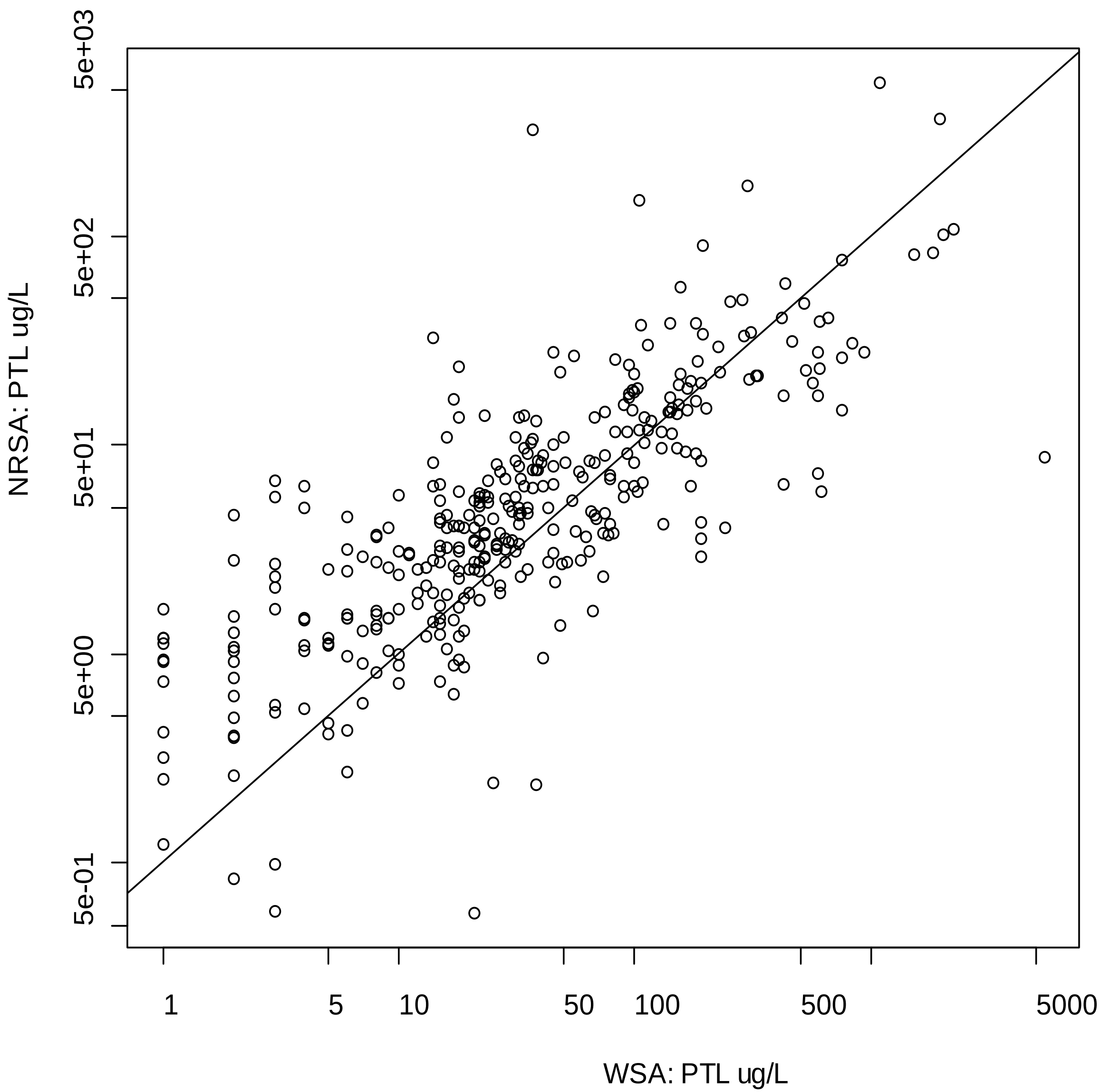

NARS Sites
N=359
WSA and NRSA
NRSA N=808
WSA N=940

Results (1):

Total Nitrogen, sampled at 359 sites, nationwide, by the WSA (x-axis), and then resampled during the NRSA (y-axis). Solid line is 1-1 line.



Total Phosphorus (sampled at 359 sites, nationwide, by the WSA (x-axis), and then resampled during the NRSA (y-axis). Solid line is 1-1 line.



Trend?

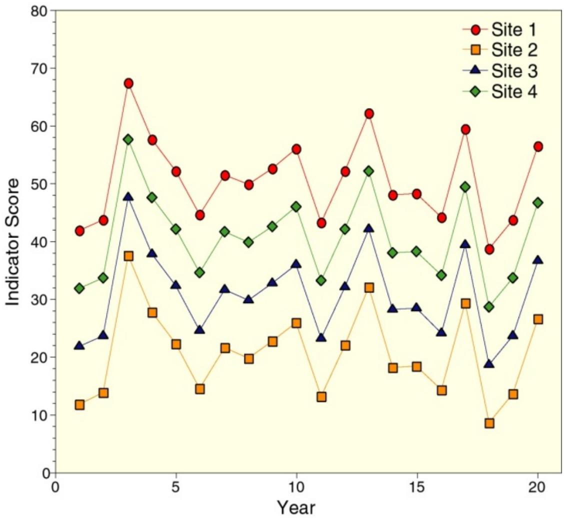
- What do we mean by trend, that is, what response behavior through time would prompt us to claim that "trend is present"
- Almost always think of trend in terms of a single parameter, e.g., trend in mean value
- However, populations can change in many ways that leave some population parameters invariant
  - These changes may be critical to good management decisions

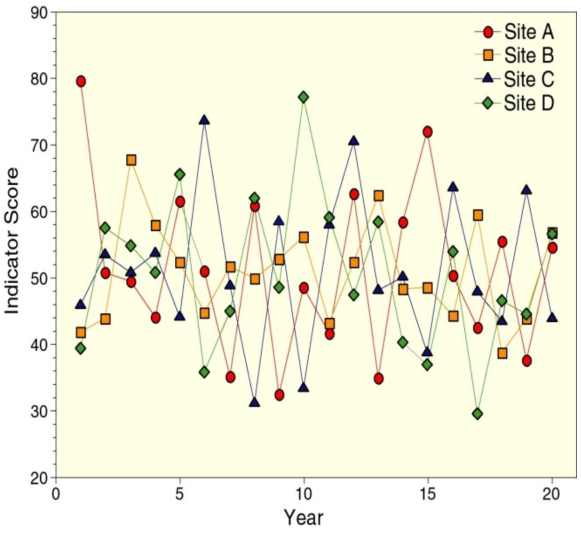
Trend?

- Trend in mean of a population of sites
- Proportion of population violating a critical value
- Population of site specific trends
  - Apply single site trend detection models
  - Generate summary stats: mean, variance of trends, frequency distribution
  - Characterize subpopulations
  - Insight into subpopulation change even if no net change

Hierarchical Decomposition of Variance

- Spatial
  - Site (differences among sites)
- Temporal
  - Coherent or synchronous
  - Interaction
    - Site specific trend
    - Interaction





- Residual
  - Index
    - Seasonal
    - Measurement
      - Crew
      - Protocol

Variance of a trend slope

(New sites each year)

site → σ_s^2; year → σ_y^2; interaction → σ_i^2; residual → σ_r^2

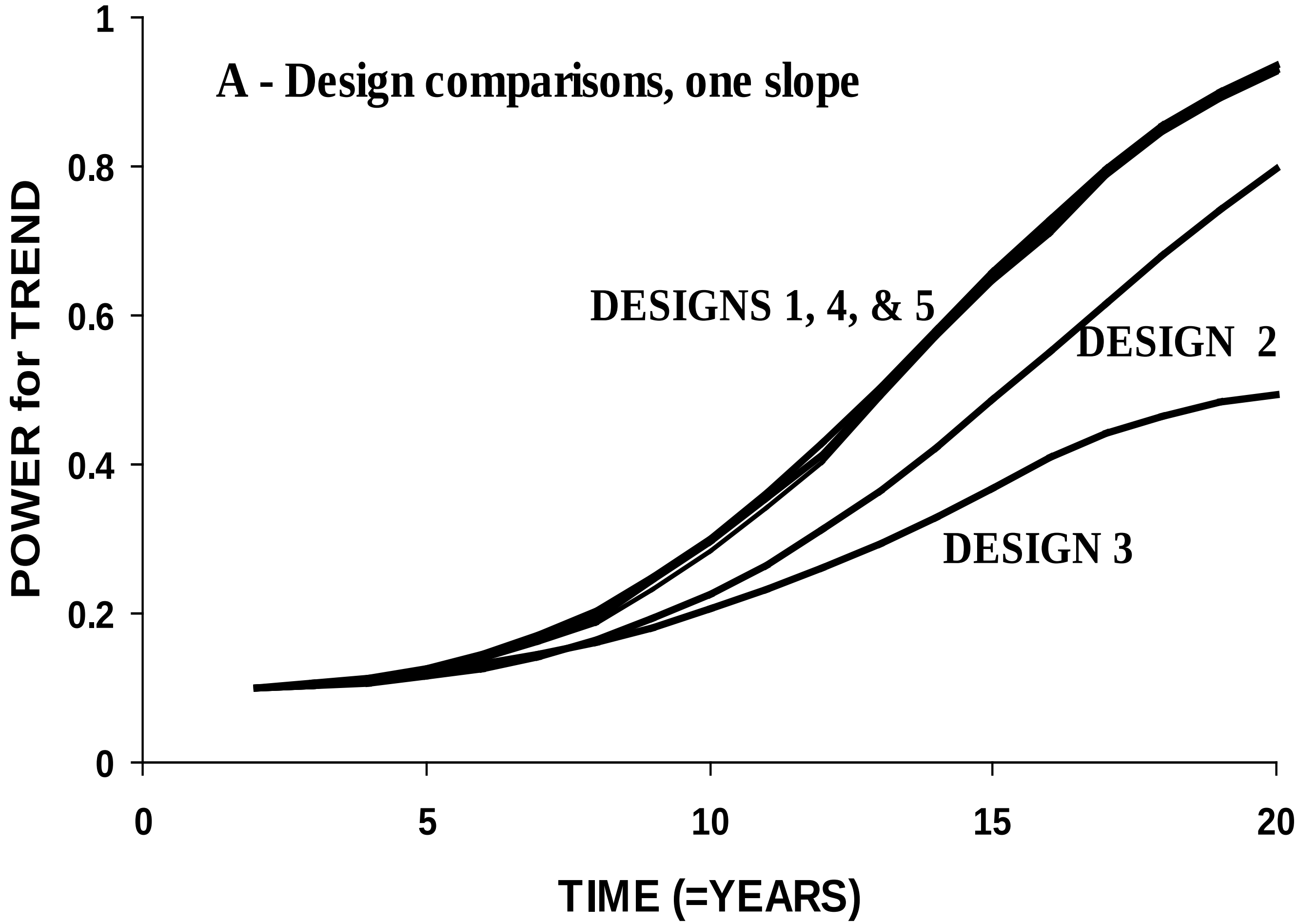
$$\mathrm{var}(slope) = \frac{\dfrac{\sigma_s^2}{N_s} + \sigma_y^2 + \dfrac{\sigma_i^2 + \dfrac{\sigma_r^2}{N_v}}{N_s}}{\sum (X_i - \bar{X})^2}$$

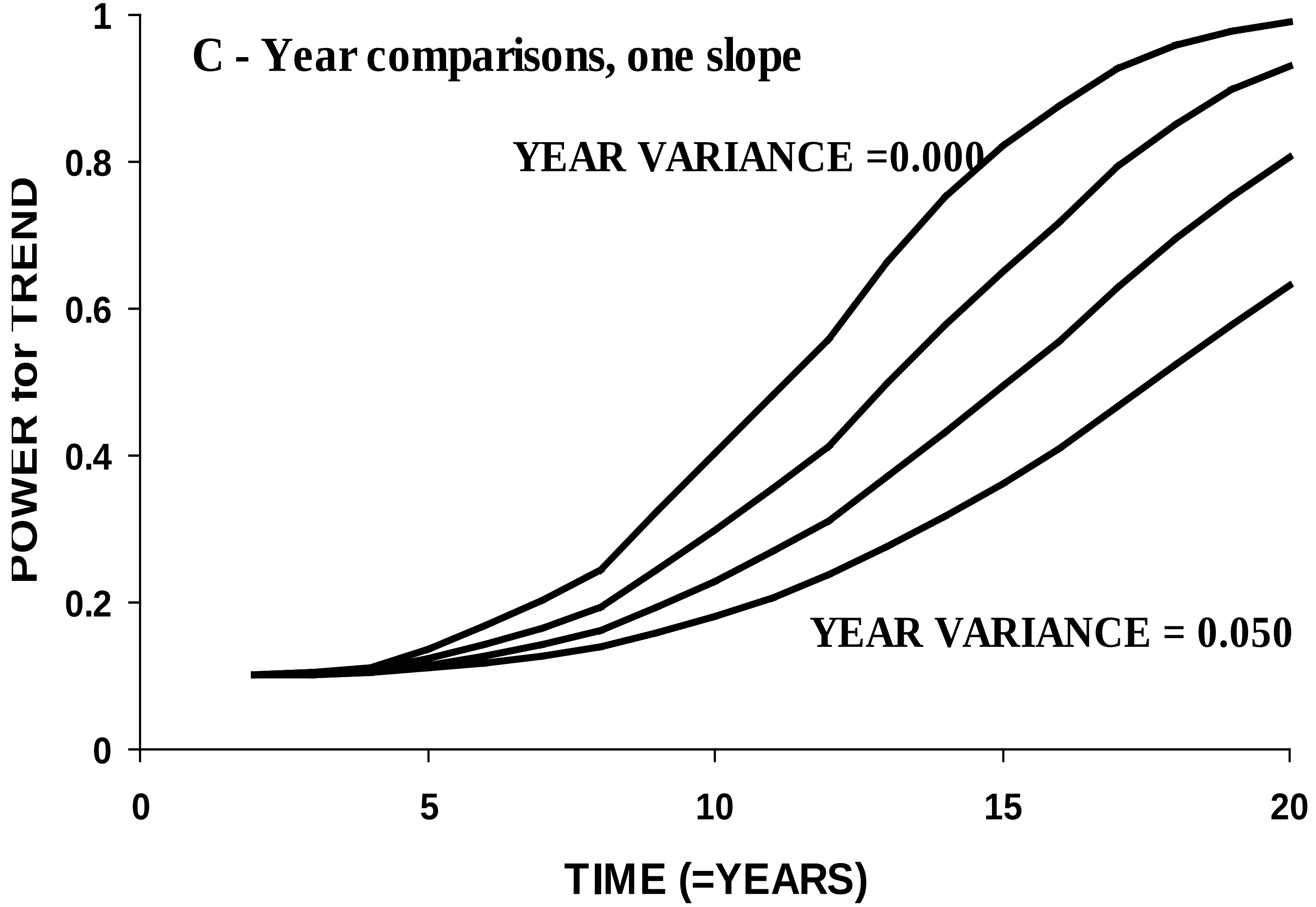
X_i = Year ; **N_s**= Number of sites in region; **N_v**= Number of within-year revisits

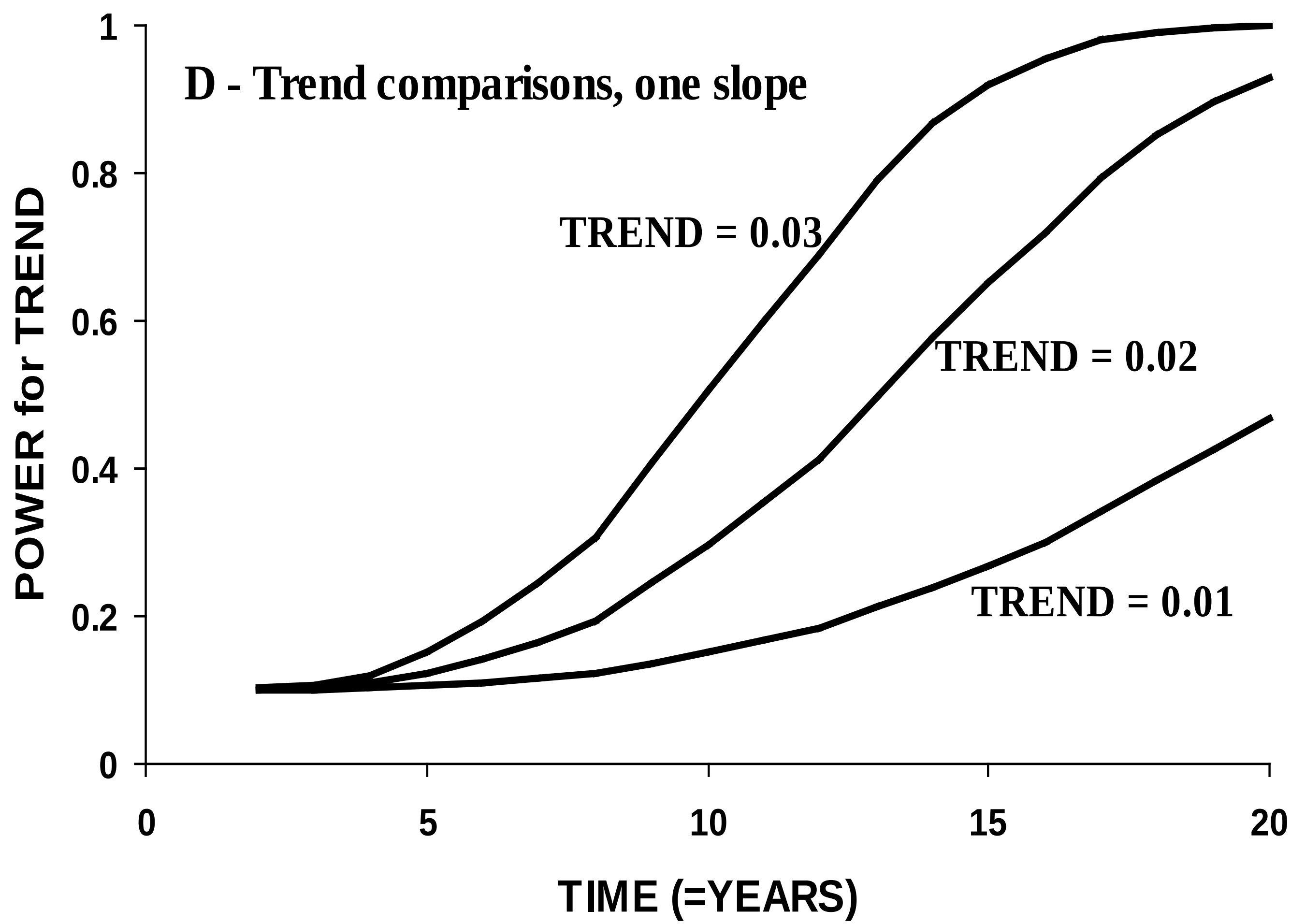
(Urquhart and Kincaid. 1999. J. Ag., Biol., and Env. Statistics 4:404-414)

$$var(\hat{\beta}_{DESIGN\,1}) = \frac{\sigma^2_{YEAR} + \frac{\sigma^2_{RESIDUAL}}{s}}{\sum (j - \bar{j})^2}.$$

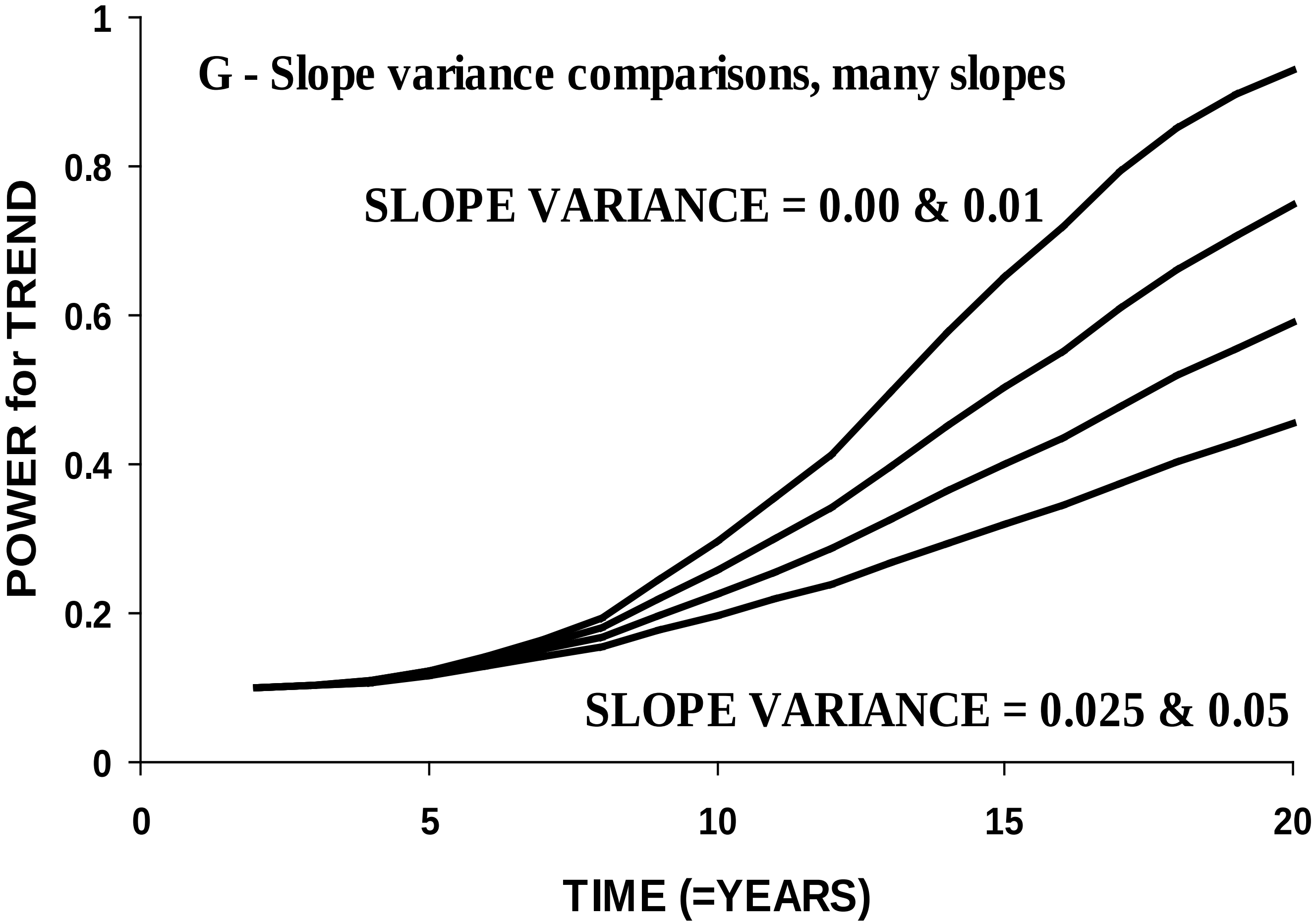
$$var(\hat{\beta}_{DESIGN\,1}) = \frac{\sigma^2_{YEAR} + \frac{\sigma^2_{RESIDUAL}}{s}}{\sum (j - \bar{j})^2} + \frac{\sigma^2_B}{s}.$$


A - Design comparisons, one slope
DESIGNS 1, 4, & 5
DESIGN 2
DESIGN 3
POWER for TREND
TIME (=YEARS)
0
0.2
0.4
0.6
0.8
1
0
5
10
15
20


C - Year comparisons, one slope
YEAR VARIANCE =0.000
YEAR VARIANCE = 0.050
POWER for TREND
TIME (=YEARS)
0
0.2
0.4
0.6
0.8
1
0
5
10
15
20



D - Trend comparisons, one slope
TREND = 0.03
TREND = 0.02
TREND = 0.01
POWER for TREND
TIME (=YEARS)
0
0.2
0.4
0.6
0.8
1
0
5
10
15
20



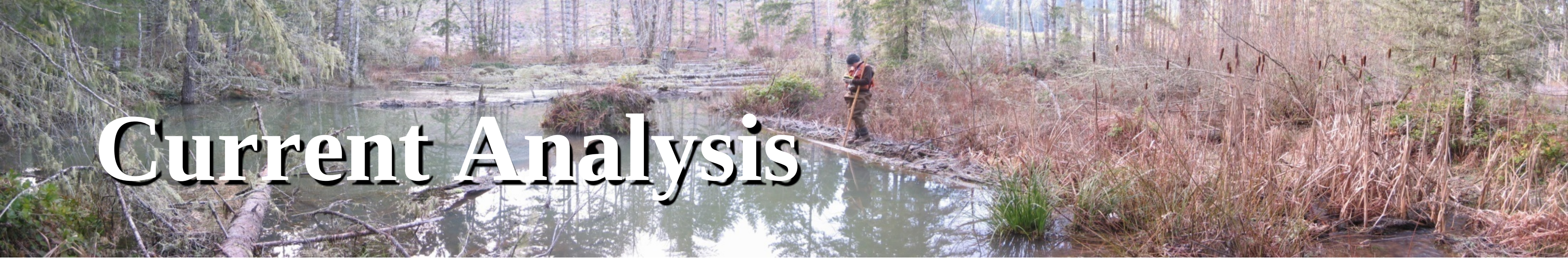
G - Slope variance comparisons, many slopes
SLOPE VARIANCE = 0.00 & 0.01
SLOPE VARIANCE = 0.025 & 0.05
POWER for TREND
TIME (=YEARS)
0
0.2
0.4
0.6
0.8
1
0
5
10
15
20

What about some real world examples?

Habitat Variables

- Active Channel Width
- Pool Habitat
- Wood Volume
- Fine Sediment

Anlauf, et al., 2011. Detection of regional trends in salmon habitat in coastal streams, Oregon. Transactions of the American Fisheries Society, 140:52-66

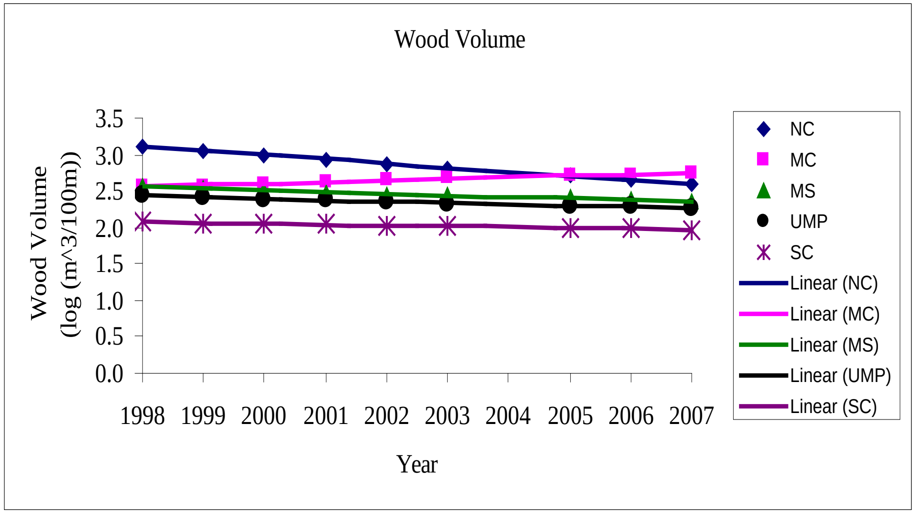


Current Analysis

- Use full data set—985 obs across all monitoring areas
- Able to test differences among monitoring areas
- Fit unequal slopes model—test if slopes are equal to zero
- Test heterogeneous variances
  - Are variances among monitoring areas across years different
  - Used model selection criteria to compare heterogeneous and homogenous variance models
  - Homogenous variance model selected

Results: Wood Volume

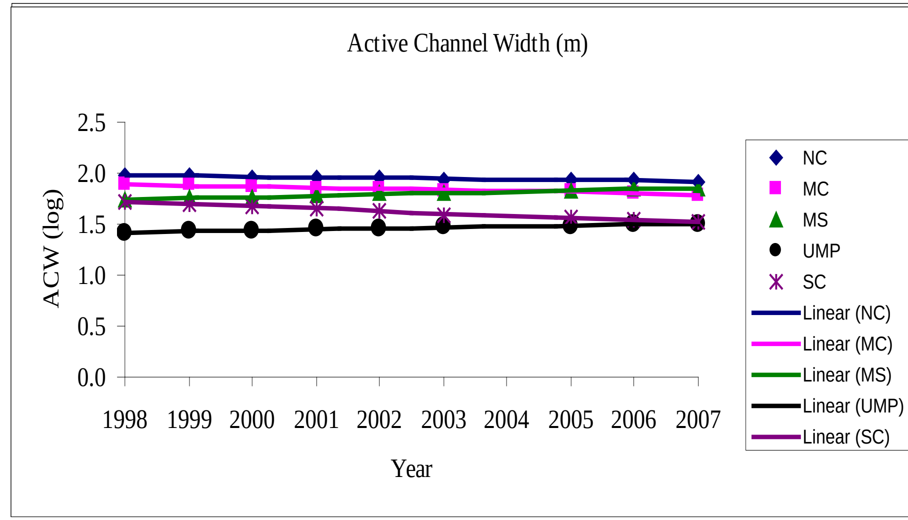
- Slope estimates for wood volume differed from zero
  - Wood Volume: NC
  - 6.6 % decrease each year
- Fit unequal slopes



Habitat Attribute	*MA*	*Slope*	*P-Value*	*Intercept*
Instream Wood	**NC**	**-0.066 (0.02)**	**0.004**	**3.12 (0.20)**
	MC	*0.024 (0.02)*	*0.265*	*2.55 (0.21)*
	MS	*-0.025 (0.02)*	*0.272*	*2.56 (0.22)*
	UMP	*-0.021 (0.02)*	*0.338*	*2.43 (0.21)*
	SC	*-0.012 (0.02)*	*0.492*	*2.07 (0.18)*

Results—Fine sediments & ACW

- Slope estimates for fine sediment and active channel width differed from zero
  - Fine Sediment NC and MS
  - Active Channel Width: SC
- Fit unequal slopes

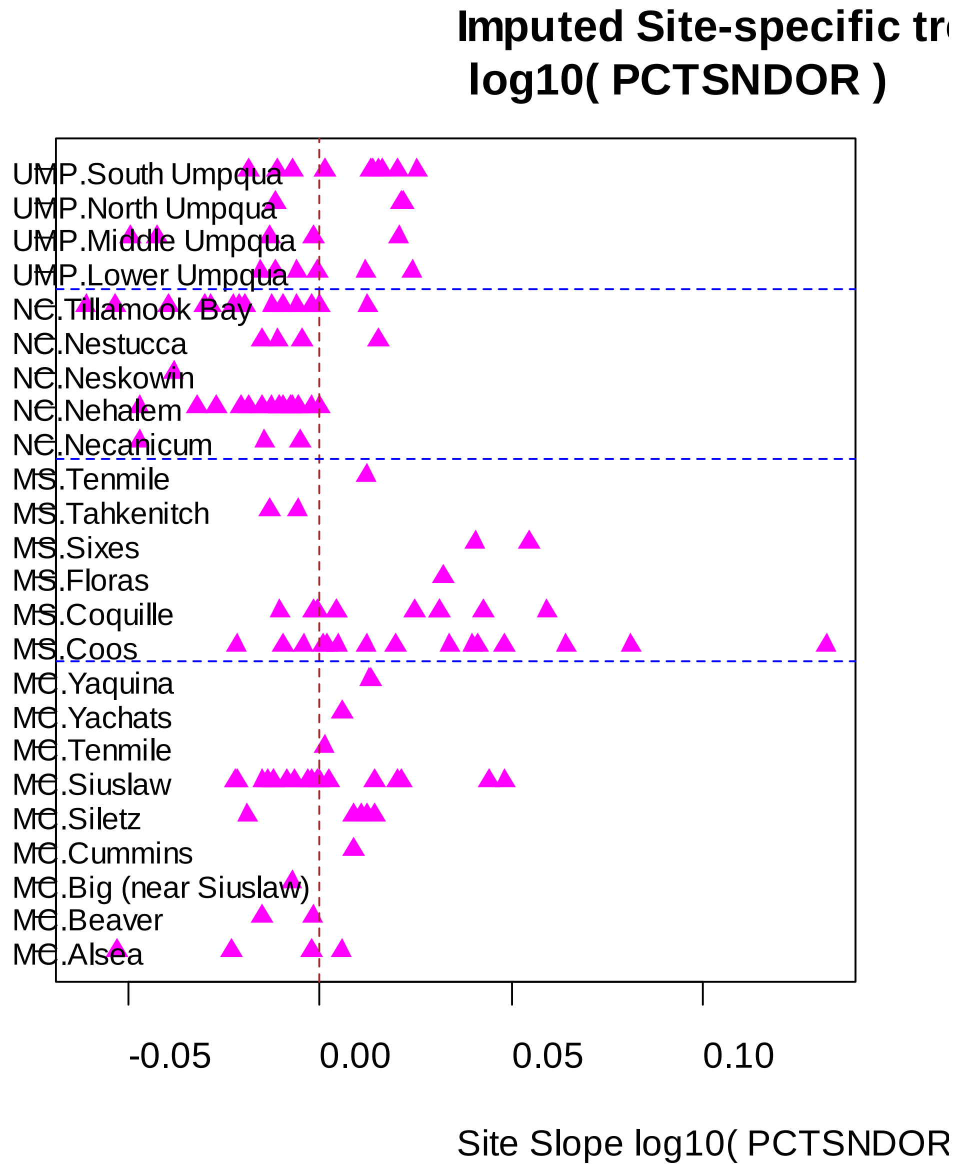


•1.7% decrease in fine sediment in NC

• 1.2% increase in fine sediment in MS

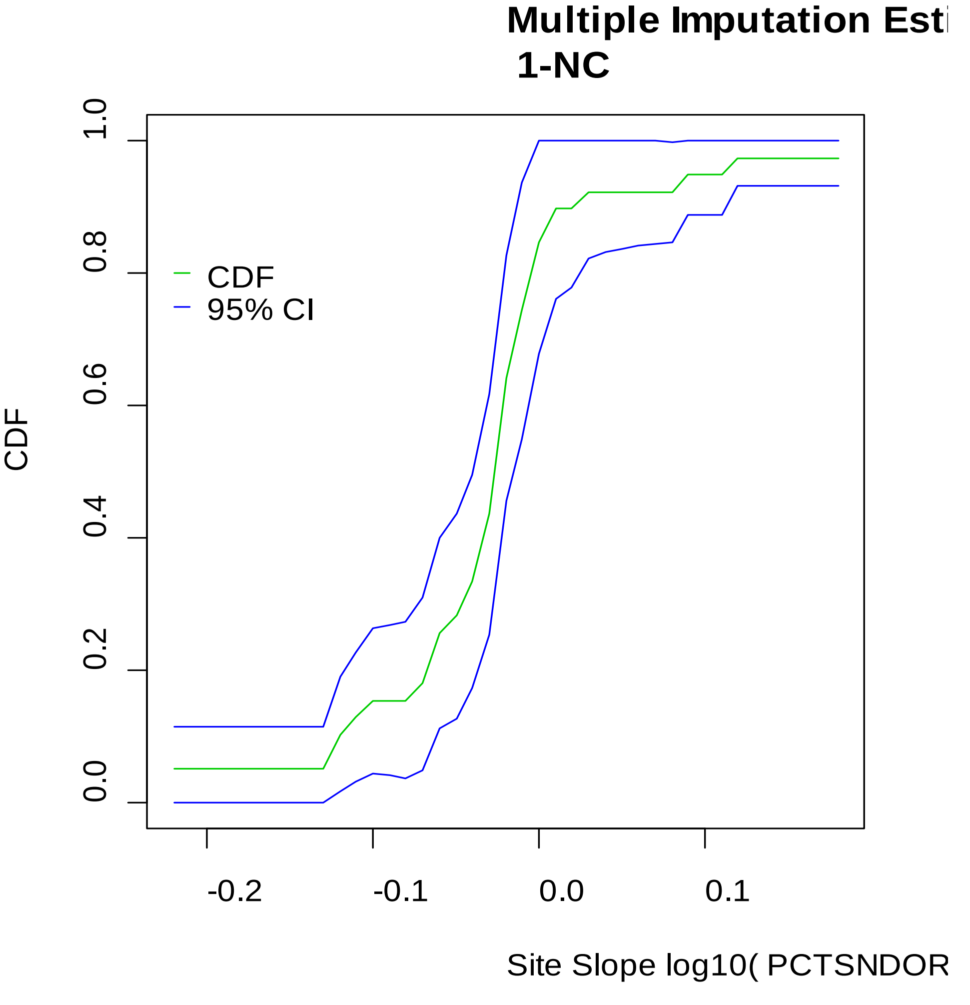
•Across all 9 years

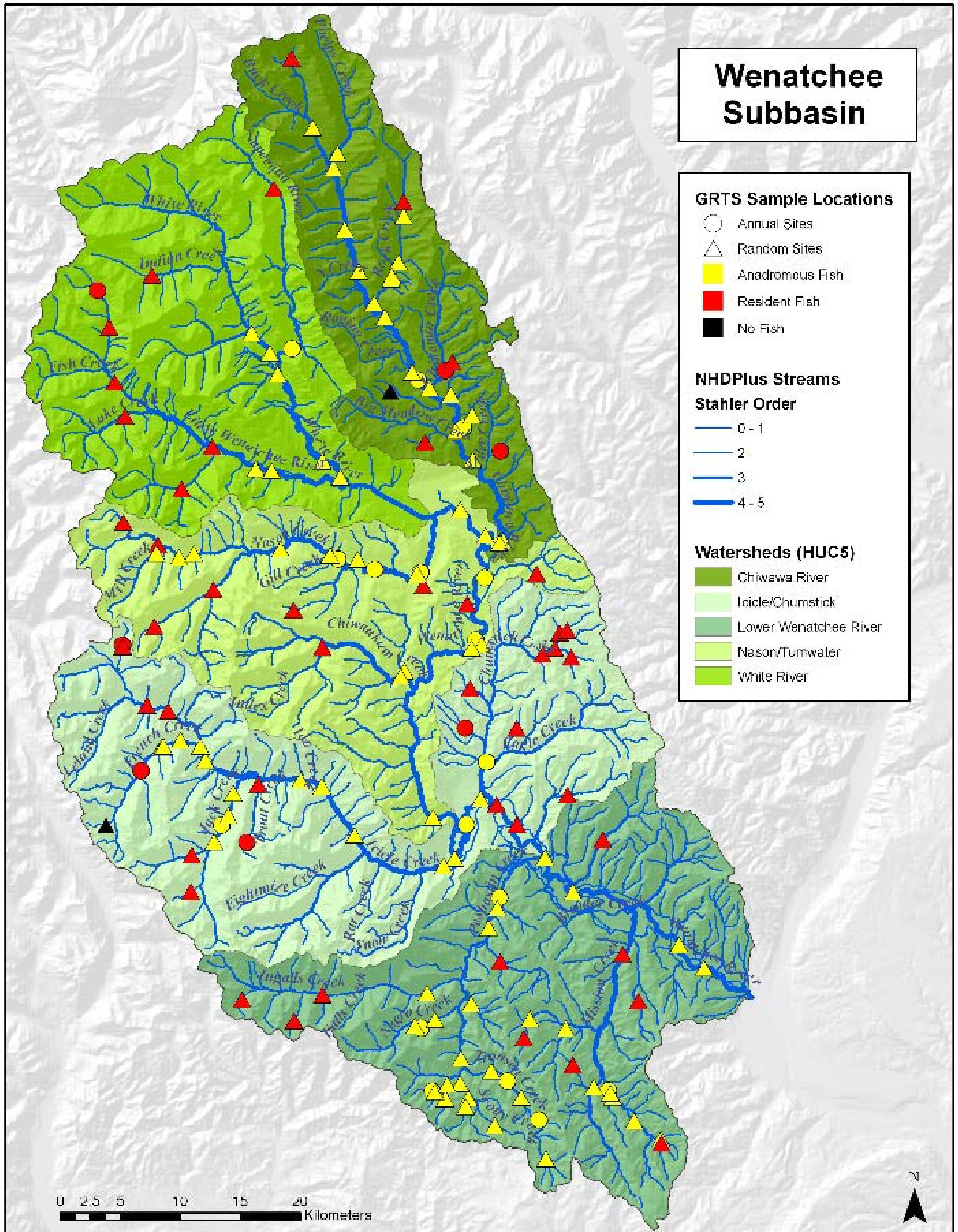
• 2.5% decrease in width in SC each year


Imputed Site-specific tr
log10(PCTSNDOR)
UMP.South Umpqua
UMP.North Umpqua
UMP.Middle Umpqua
UMP.Lower Umpqua
NC.Tillamook Bay
NC.Nestucca
NC.Neskowin
NC.Nehalem
NC.Necanicum
MS.Tenmile
MS.Tahkenitch
MS.Sixes
MS.Floras
MS.Coquille
MS.Coos
MC.Yaquina
MC.Yachats
MC.Tenmile
MC.Siuslaw
MC.Siletz
MC.Cummins
MC.Big (near Siuslaw)
MC.Beaver
MC.Alsea
-0.05
0.00
0.05
0.10
Site Slope log10(PCTSNDOR

PCTSNDOR

	Mean	Lower 95% CI	Upper 95% CI
NC	***-0.033391253***	***-0.059239577***	***-0.007542928***
MC	-0.019860580	-0.042110230	0.002389070
MS	0.028273664	0.004100816	0.052446512
UMP	0.005798923	-0.023670329	0.035268174





Habitat Monitoring
2004 – 2008

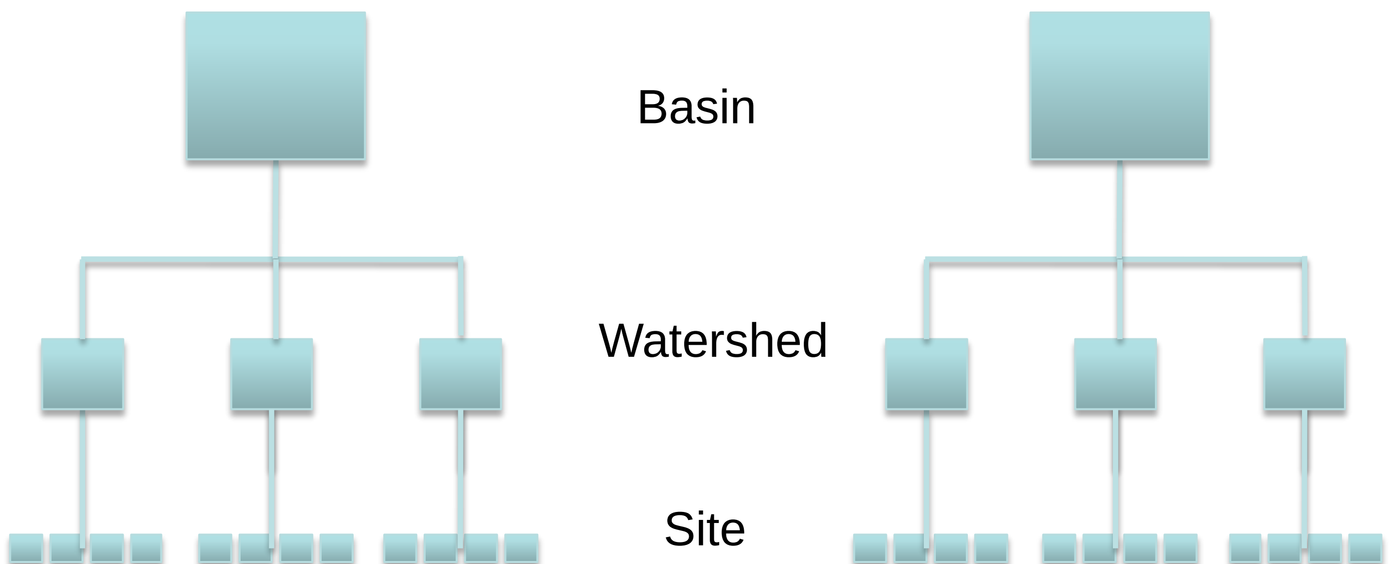
GRTS based survey design
Annual Panel with 25 sites
Random Panel with 25 sites

Response Design
As in Entiat

2009 – 3x Annual Panel for variance decomposition, no random sites

Habitat data are collected hierarchically

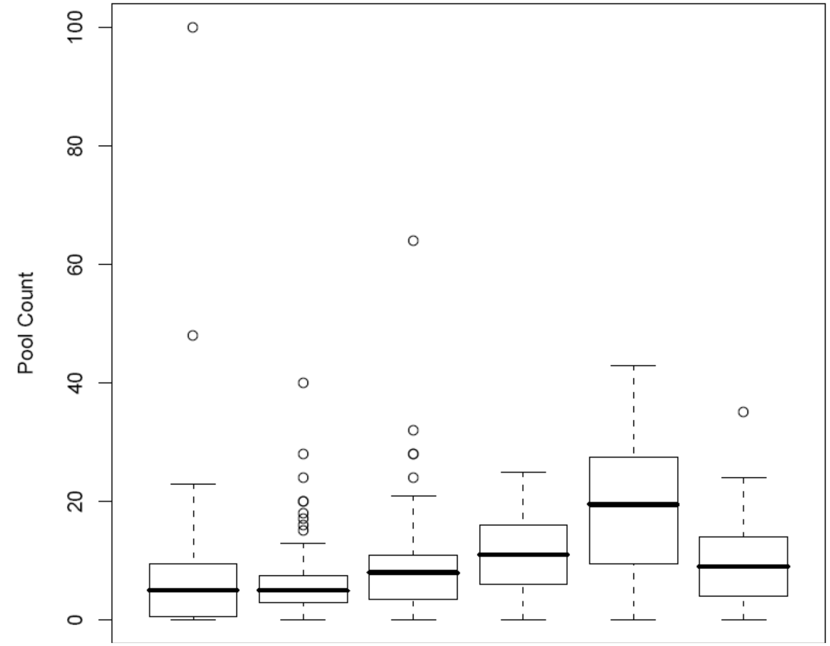
- Both the intercept and trend may be:
  - Constant across all sites/watersheds/subbasins
  - Shared among sites
  - Shared among watersheds
  - Shared among subbasins
  - Affected by factors (anadromous, resident area)

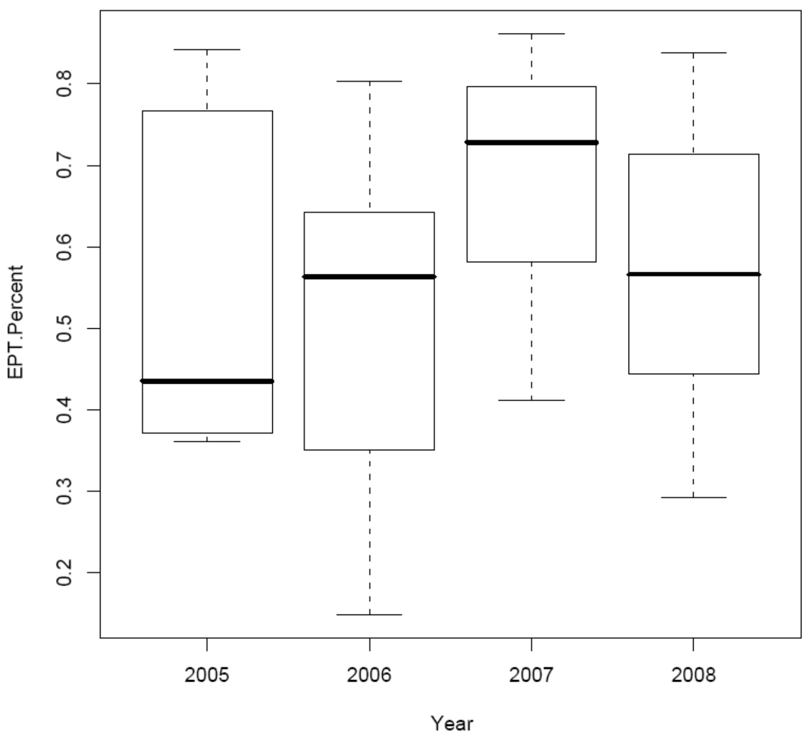


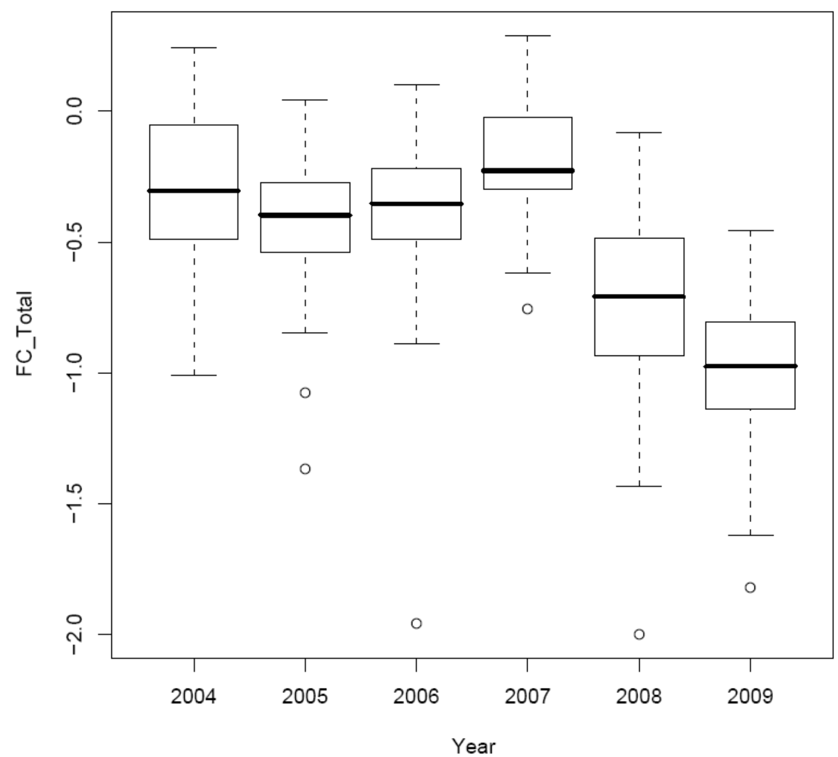
Wenatchee Habitat Status

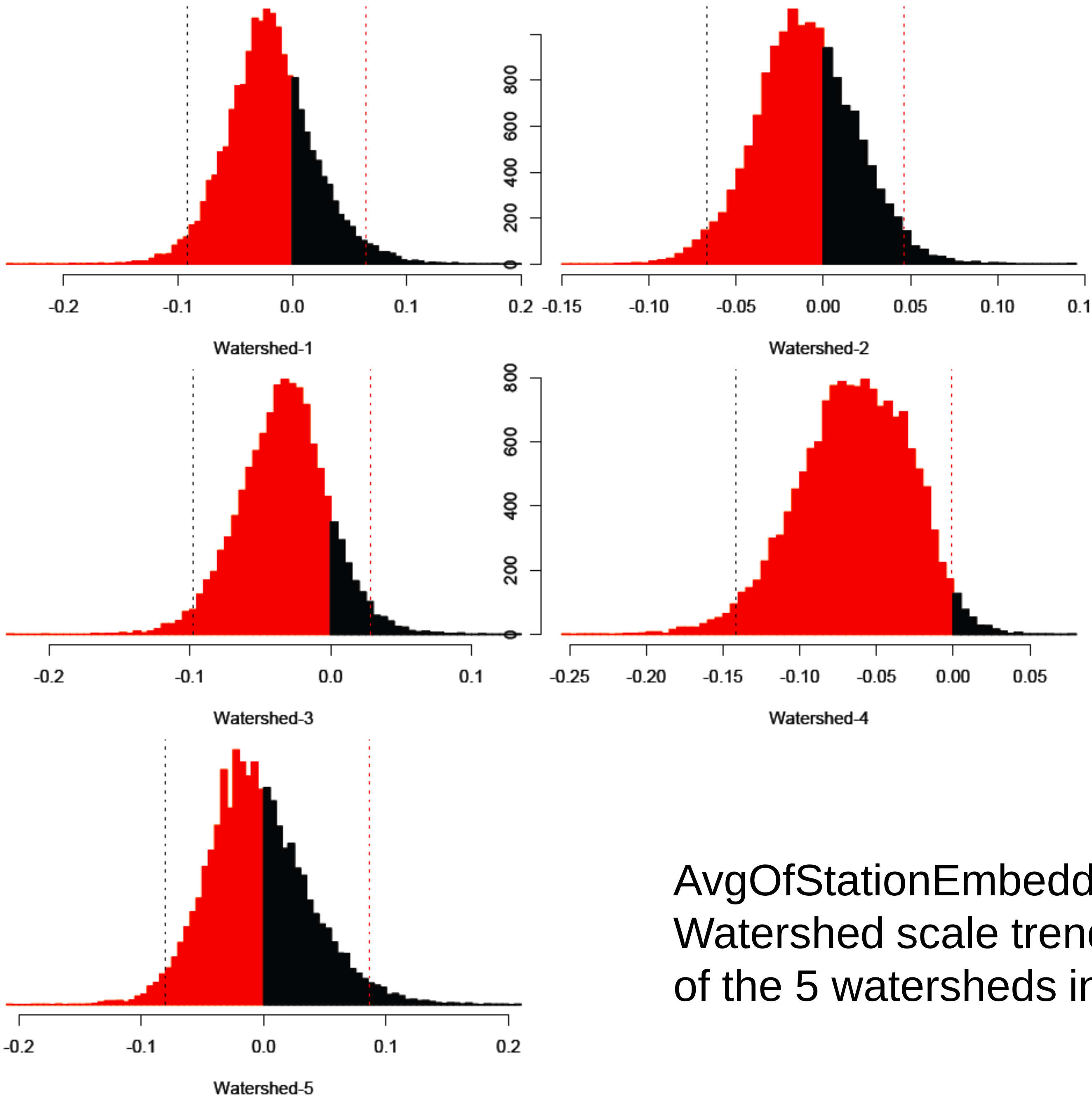
Annual mean/variance

Metric x Year

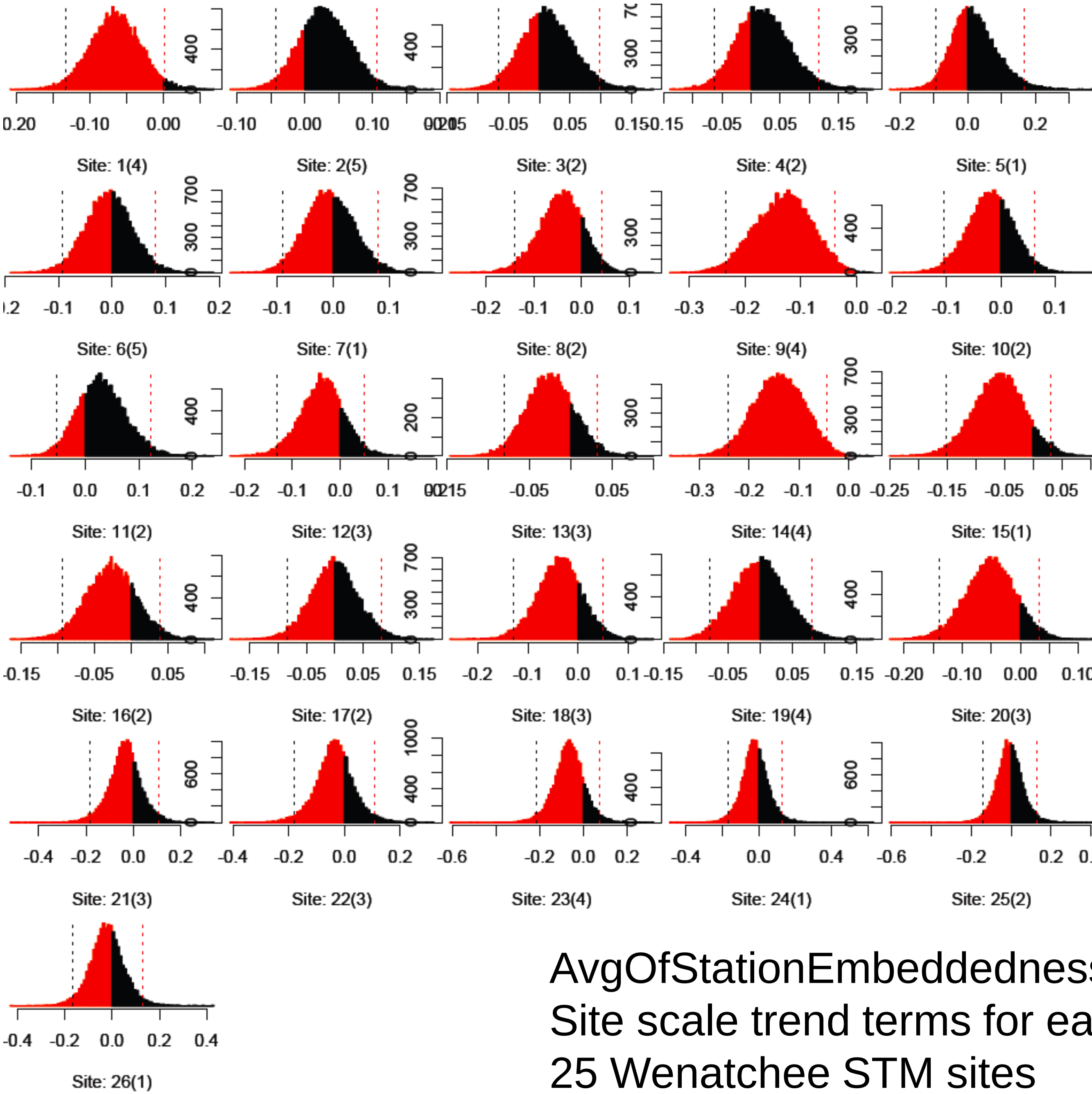






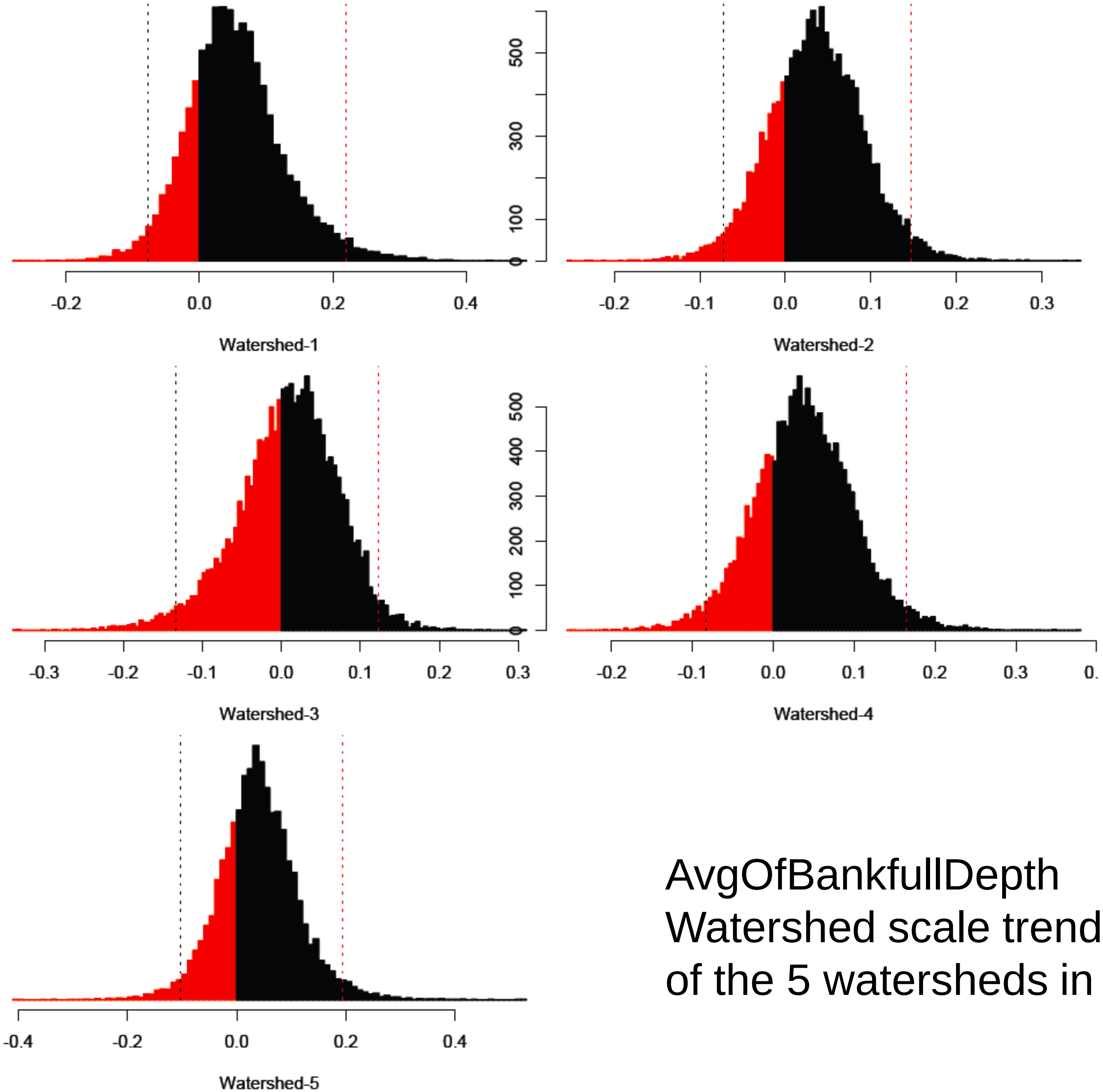


AvgOfStationEmbeddedness
Watershed scale trend terms for each of the 5 watersheds in the Wenatchee

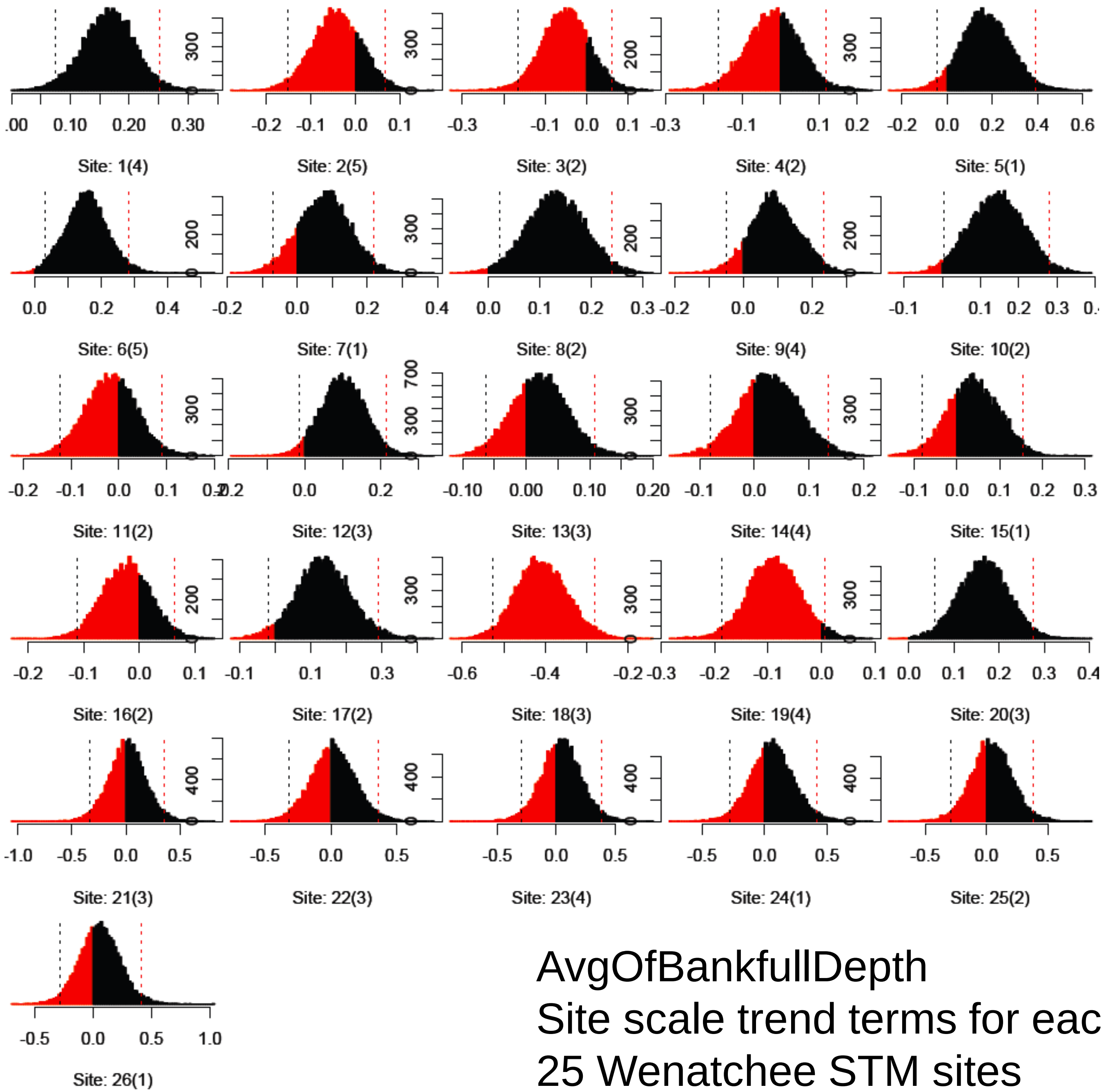


AvgOfStationEmbeddedness

Site scale trend terms for each of the 25 Wenatchee STM sites



AvgOfBankfullDepth
Watershed scale trend terms for each of the 5 watersheds in the Wenatchee



AvgOfBankfullDepth
Site scale trend terms for each of the 25 Wenatchee STM sites

Some Take Home Messages

- STRIDe framework useful framework for organizing survey designs, once explicit objectives have been established
- GRTS based spatial designs are efficient for generating representative spatial samples
- Rotating panel designs are efficient for developing efficient temporal designs to estimate status and trends
- The effect of temporally coherent variance on trend detection is an underappreciated aspect of developing monitoring plans
- A variety of change and trend detection tools are available for evaluating temporal patterns

Websites with details

- www.epa.gov/nheerl/arm
  - Developed under Tony Olsen's guidance
- www.salmonmonitoringadvisor.org
  - Developed under funding from the Moore Foundation, Randall Peterman PI; moving to PNAMP umbrella
- www.monitoringmethods.org
  - Under PNAMP umbrella; primarily covers what we've been calling "response design"; links to salmonmonitoringadvisor for design information

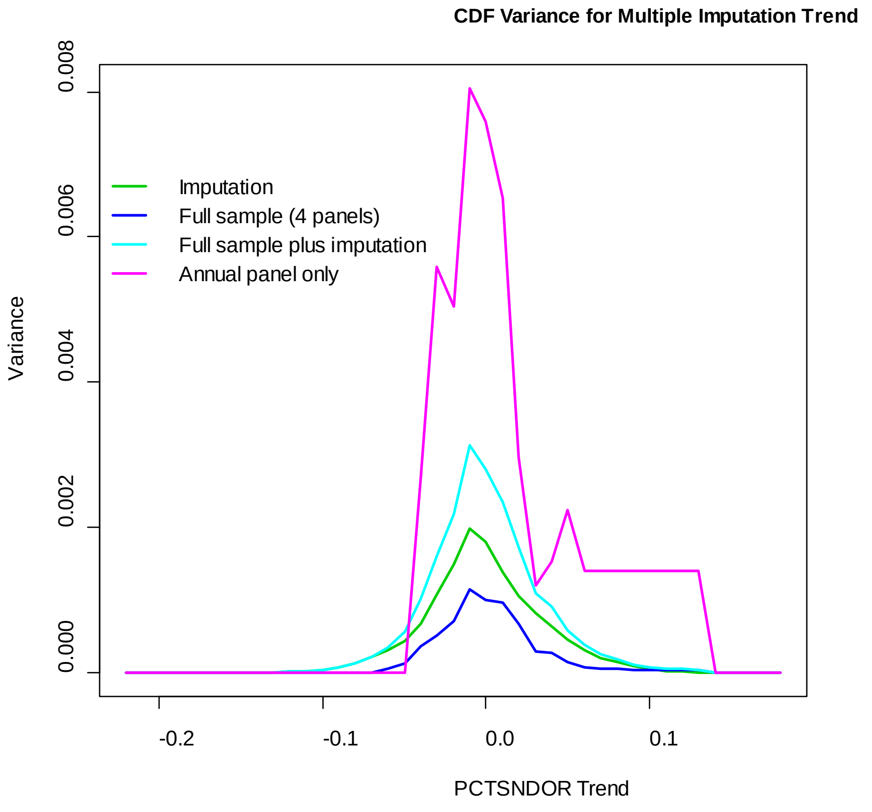
Rotating Panel Trend Analysis

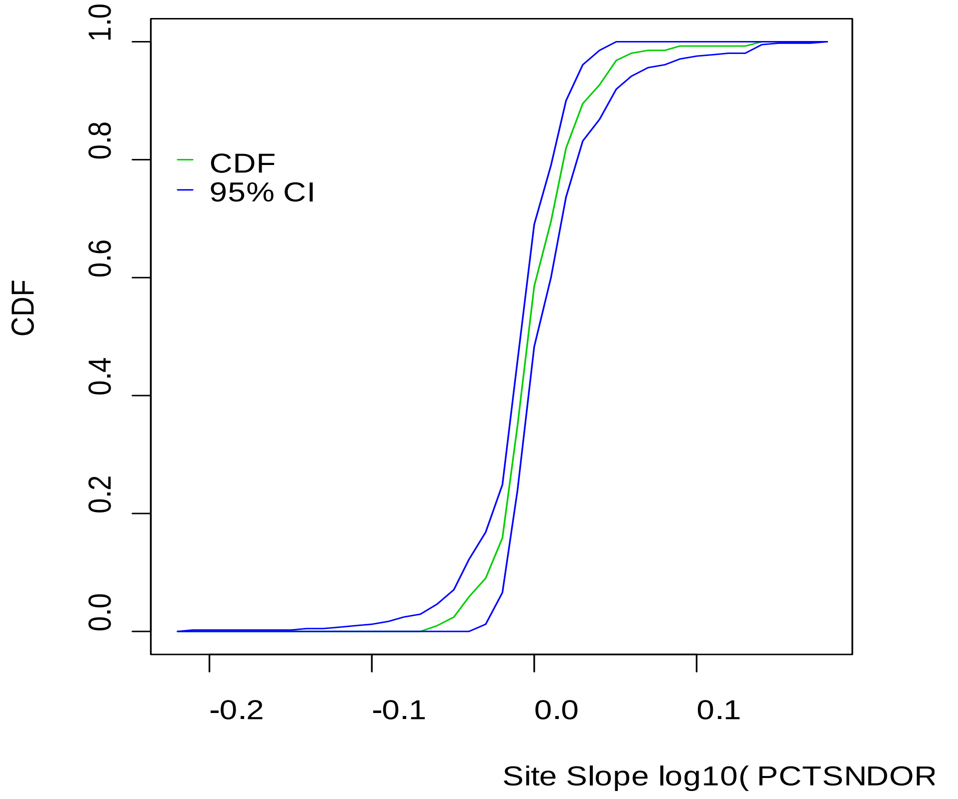
- Consider a rotating panel design with one panel visited every occasion and *k* panels visited once every *k* occasions.
- Each panel defines a visit pattern, so in this design, there are *k+1* visit patterns.
- Label the all-occasion panel as Panel 0, and the remaining panels as Panel 1 through Panel *k*.

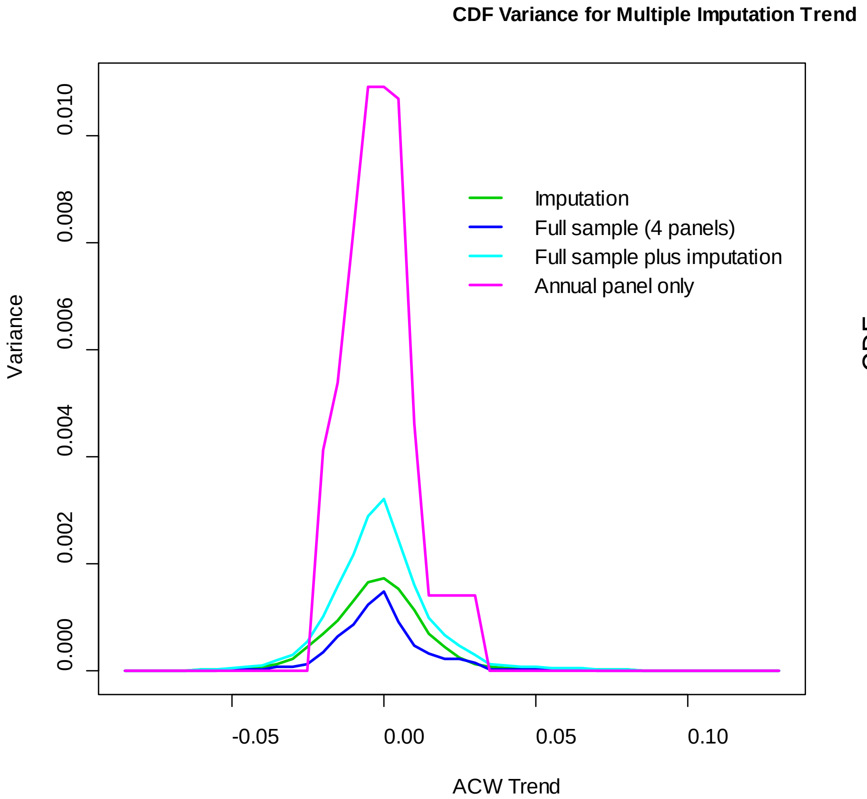
Rotating Panel Trend Analysis

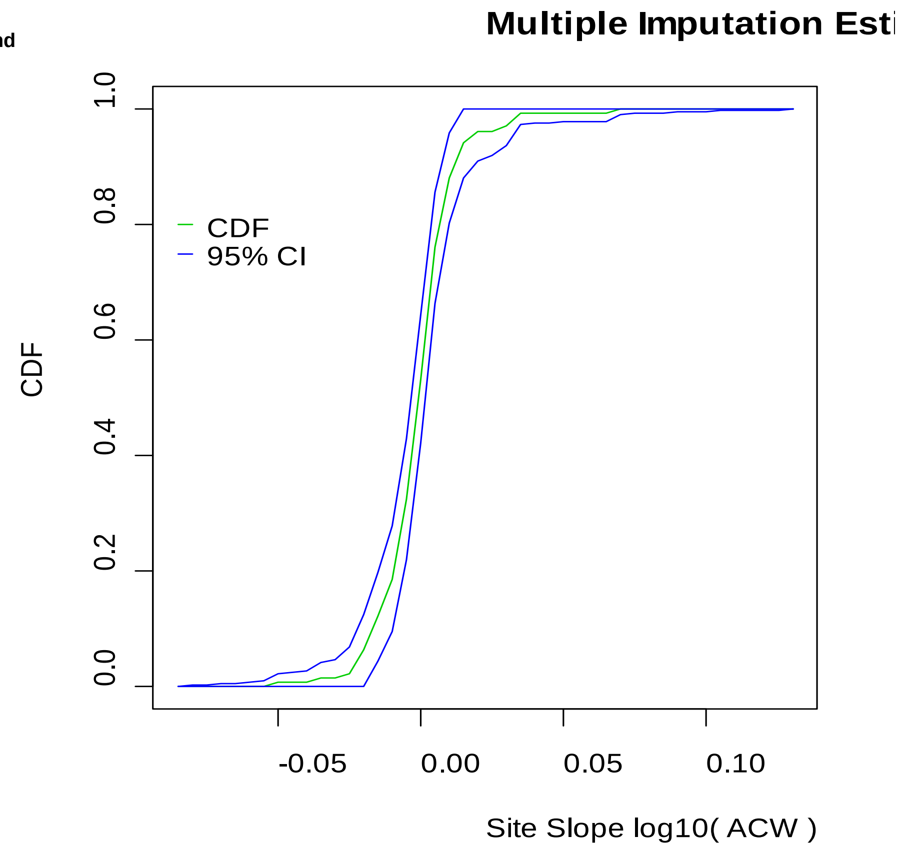
- For each panel (visit pattern) define an associated trend descriptor , say $\tau_{0,}$ τ_1 ,…., τ_k
- Our target response τ_0 is only available on Panel 0. For all other panels, treat τ_0 as a missing observation
- Use multiple imputation to capture the trend information from panels 1 to k

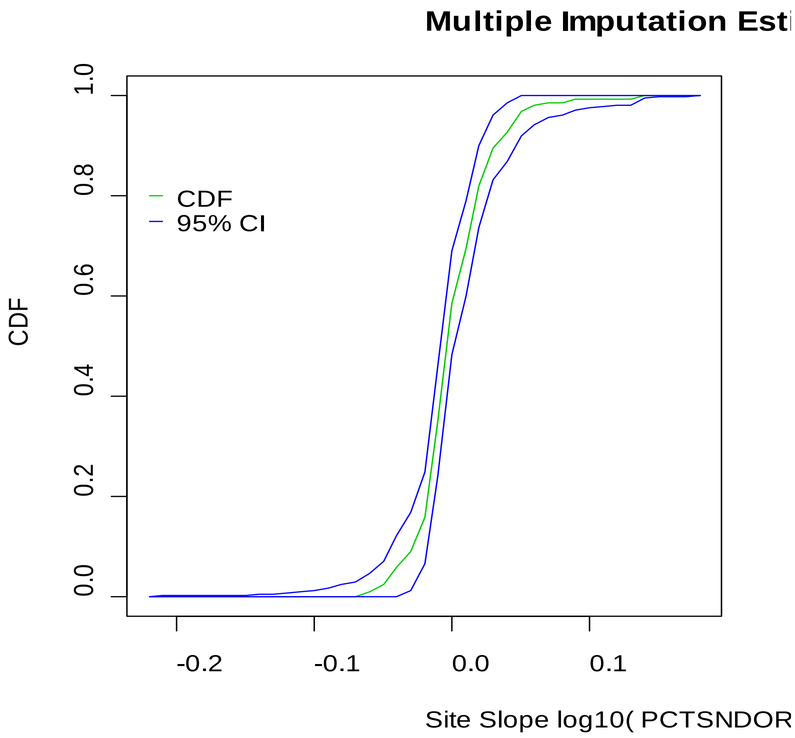
Multiple Imputation Esti

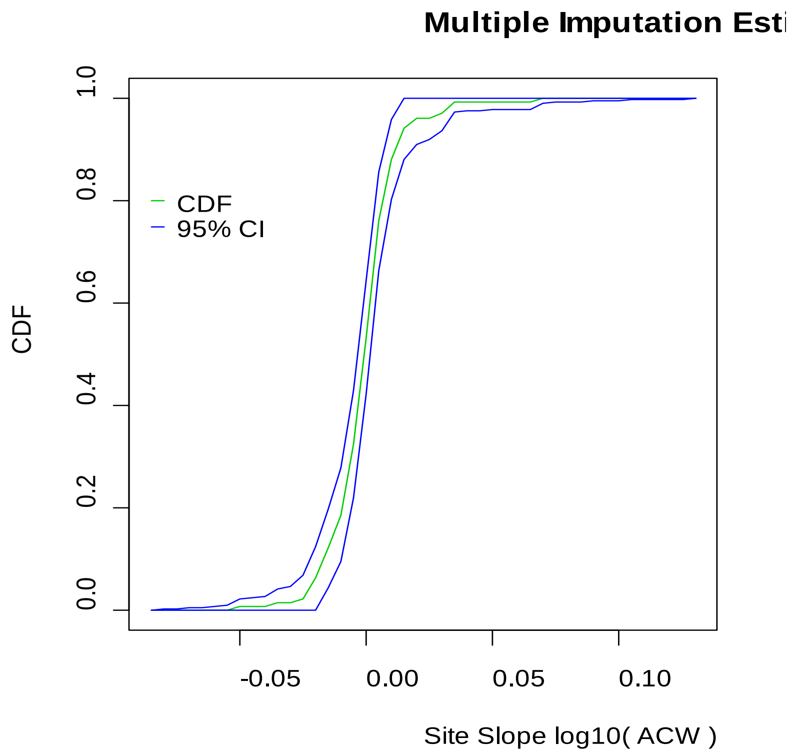


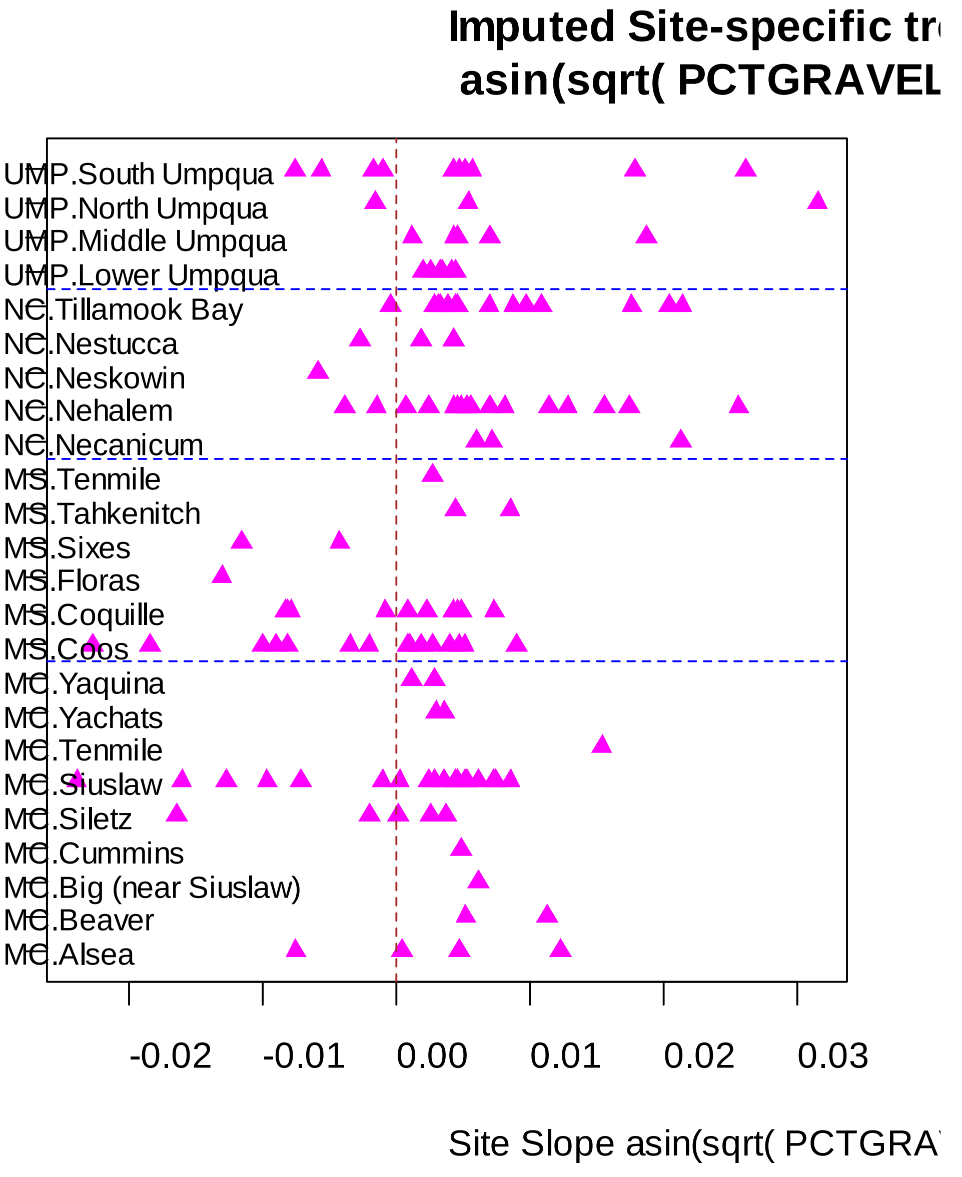



CDF Variance for Multiple Imputation Trend
Variance
0.000
0.002
0.004
0.006
0.008
0.010
Imputation
Full sample (4 panels)
Full sample plus imputation
Annual panel only
-0.05
0.00
0.05
0.10
ACW Trend

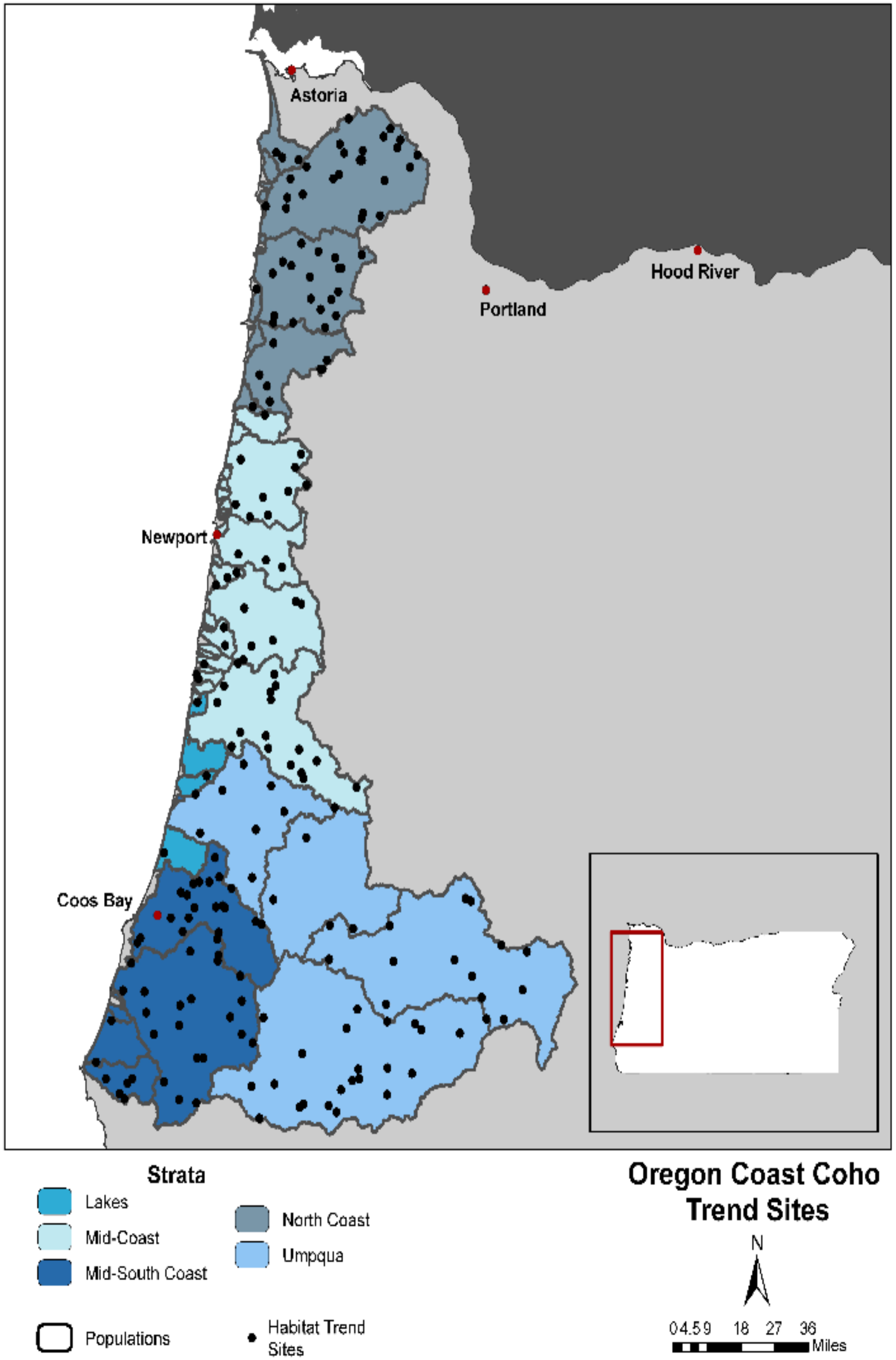

Multiple Imputation Esti
CDF
0.0
0.2
0.4
0.6
0.8
1.0
CDF
95% CI
-0.05
0.00
0.05
0.10
Site Slope log10(ACW)


Multiple Imputation Esti
CDF
95% CI
CDF
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.1
0.0
0.1
Site Slope log10(PCTSNDOR


Multiple Imputation Esti
CDF
95% CI
CDF
1.0
0.8
0.6
0.4
0.2
0.0
-0.05
0.00
0.05
0.10
Site Slope log10(ACW)



Imputed Site-specific tr
asin(sqrt(PCTGRAVEL
UMP.South Umpqua
UMP.North Umpqua
UMP.Middle Umpqua
UMP.Lower Umpqua
NC.Tillamook Bay
NC.Nestucca
NC.Neskowin
NC.Nehalem
NC.Necanicum
MS.Tenmile
MS.Tahkenitch
MS.Sixes
MS.Floras
MS.Coquille
MS.Coos
MC.Yaquina
MC.Yachats
MC.Tenmile
MC.Siuslaw
MC.Siletz
MC.Cummins
MC.Big (near Siuslaw)
MC.Beaver
MC.Alsea
-0.02
-0.01
0.00
0.01
0.02
0.03
Site Slope asin(sqrt(PCTGRA

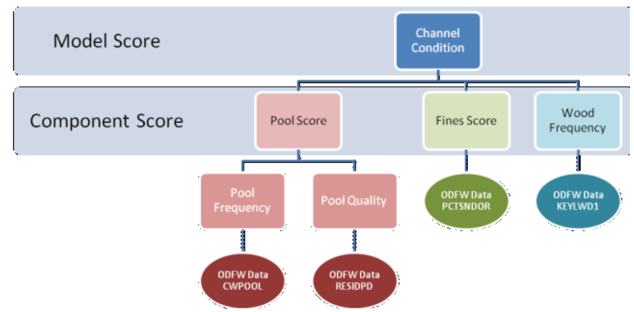


ODFW stream habitat monitoring

- 1998 - 2008 trend sites
- Physical habitat metrics

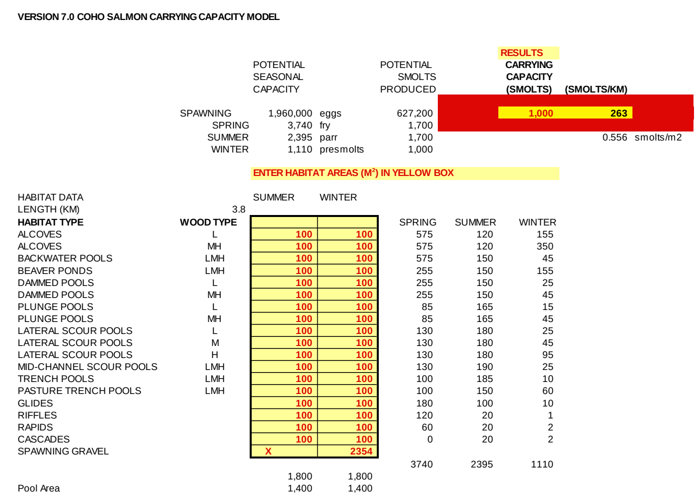
USFS AREMP Watershed Complexity DSM

- Channel Score



ODFW HLFM model

- Summer, Winter Parr/km



VERSION 7.0 COHO SALMON CARRYING CAPACITY MODEL

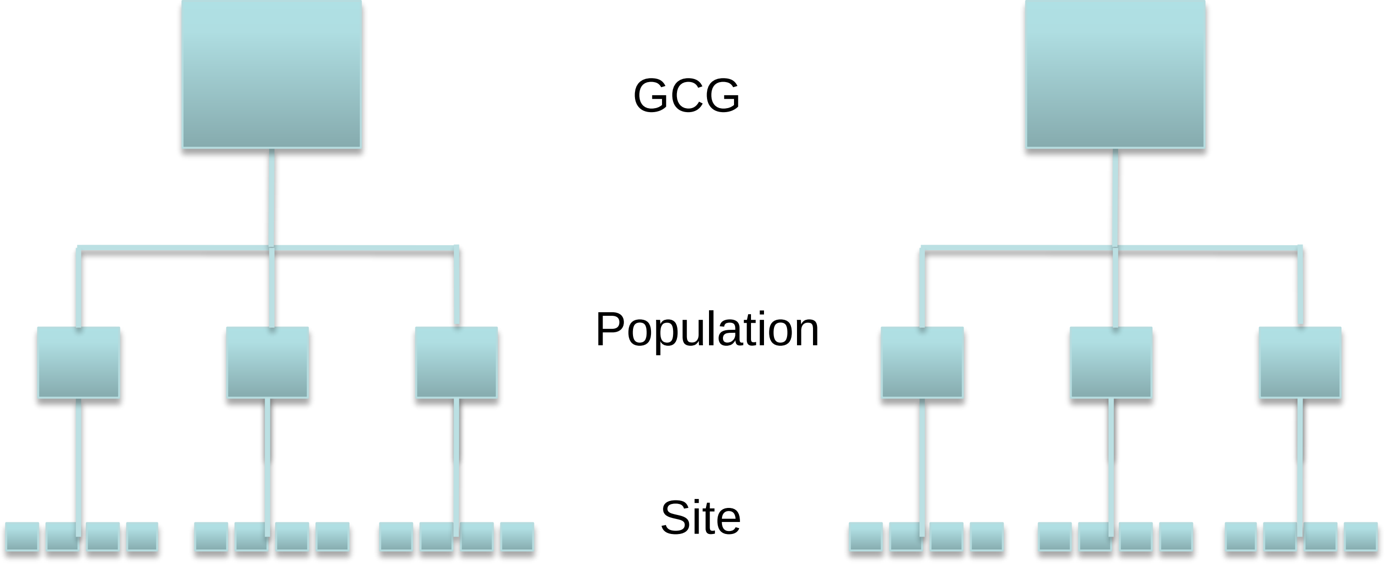
	POTENTIAL SEASONAL CAPACITY		POTENTIAL SMOLTS PRODUCED	RESULTS CARRYING CAPACITY (SMOLTS)	(SMOLTS/KM)	
SPAWNING	1,960,000	eggs	627,200	1,000	263	
SPRING	3,740	fry	1,700			
SUMMER	2,395	parr	1,700		0.556	smolts/m2
WINTER	1,110	presmolts	1,000			

ENTER HABITAT AREAS (M^2) IN YELLOW BOX

HABITAT DATA		SUMMER	WINTER			
LENGTH (KM)	3.8					
HABITAT TYPE	**WOOD TYPE**			SPRING	SUMMER	WINTER
ALCOVES	L	100	100	575	120	155
ALCOVES	MH	100	100	575	120	350
BACKWATER POOLS	LMH	100	100	575	150	45
BEAVER PONDS	LMH	100	100	255	150	155
DAMMED POOLS	L	100	100	255	150	25
DAMMED POOLS	MH	100	100	255	150	45
PLUNGE POOLS	L	100	100	85	165	15
PLUNGE POOLS	MH	100	100	85	165	45
LATERAL SCOUR POOLS	L	100	100	130	180	25
LATERAL SCOUR POOLS	M	100	100	130	180	45
LATERAL SCOUR POOLS	H	100	100	130	180	95
MID-CHANNEL SCOUR POOLS	LMH	100	100	130	190	25
TRENCH POOLS	LMH	100	100	100	185	10
PASTURE TRENCH POOLS	LMH	100	100	100	150	60
GLIDES		100	100	180	100	10
RIFFLES		100	100	120	20	1
RAPIDS		100	100	60	20	2
CASCADES		100	100	0	20	2
SPAWNING GRAVEL		X	2354			
				3740	2395	1110
		1,800	1,800			
Pool Area		1,400	1,400			
Percent Pools		78%	78%			

Complexity data are collected hierarchically

- Both the intercept and trend may be:
  - Constant across all sites/populations/GCGs
  - Shared among sites
  - Shared among populations
  - Shared among GCGs
  - Affected by land ownership (public, private)



The full hierarchical model

Regression $$Y_{site_i,\ pop_j,\ gcg_k} = B0_{i,j,k} + B1_{i,j,k} \cdot year + \varepsilon_{i,j,k}$$

Site-level $$B0_{i,j,k} \sim Normal(B0_{j,k}, \sigma_{Site}); \quad B1_{i,j,k} \sim Normal(B1_{j,k}, \kappa_{Site})$$

Pop-level $$B0_{j,k} \sim Normal(B0_{k}, \sigma_{Pop}); \quad B1_{j,k} \sim Normal(B1_{k}, \kappa_{Pop})$$

GCG-level $$B0_{k} \sim Normal(B0_{global}, \sigma_{GCG}); \quad B1_{k} \sim Normal(B1_{global}, \kappa_{GCG})$$

Ownership (as factor)

$$B0_{global} = (1 - owner) \cdot B0_{public} + owner \cdot B0_{private}$$

$$B1_{global} = (1 - owner) \cdot B1_{public} + owner \cdot B1_{private}$$

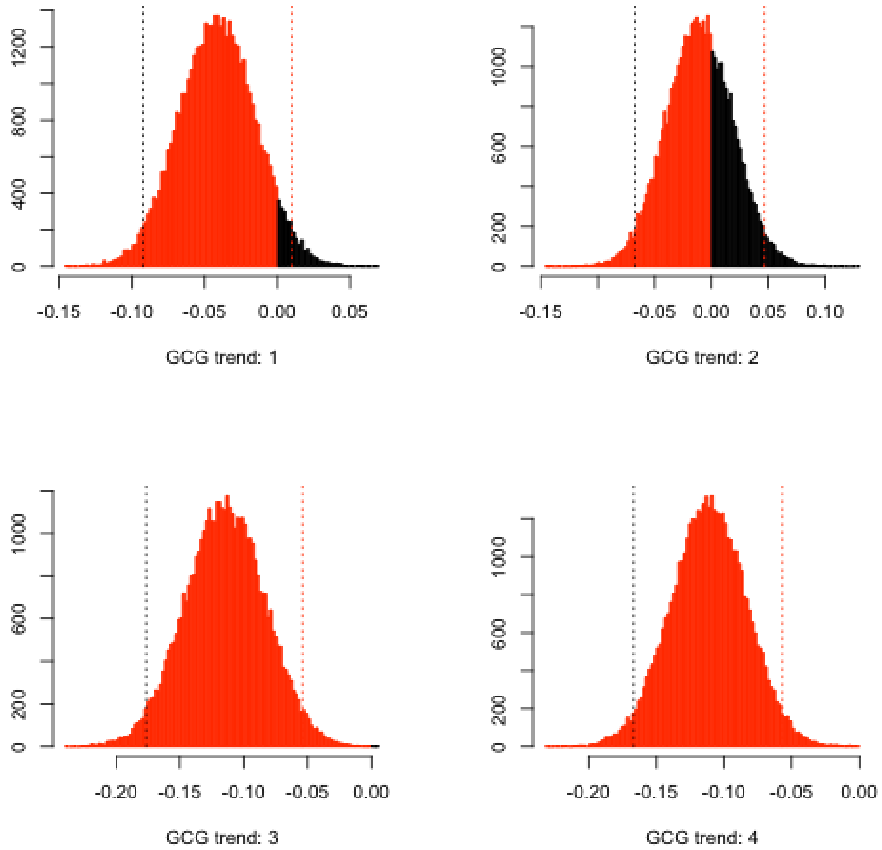
$$owner = \begin{cases} 1 & \text{Private} \\ 0 & \text{Public} \end{cases}$$

Error $$\varepsilon_{i,j,k} \sim Normal(0,\ \sigma_{\text{Residual}})$$

Results: Summer Parr

- B0
  - Each site has a unique intercept (1998)
  - Because of similarities between sites within populations, these site-level complexities are distributed around population-level complexities
  - Population-level complexity is sufficiently different such that they are not clustered by GCG
- B1
  - All sites within a population, and all populations within a GCG are similar enough such that there are only 4 trends (specific to each GCG)
- Ownership
  - The trend in complexity on public land is more negative on private land

Trends



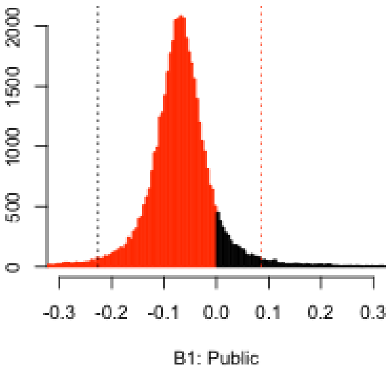
These are distributions for the GCG trends on public land. Trends on private land will be shifted.

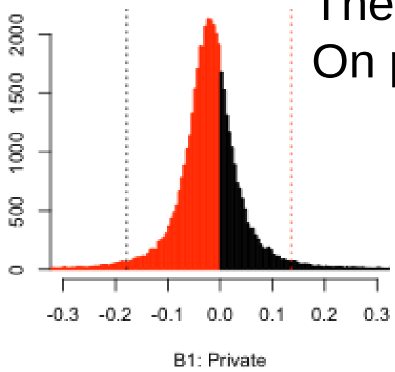
Population / site-level variation in the trend is not supported, suggesting that trends are affected by large-scale patterns

Histograms represent 60000 posterior draws

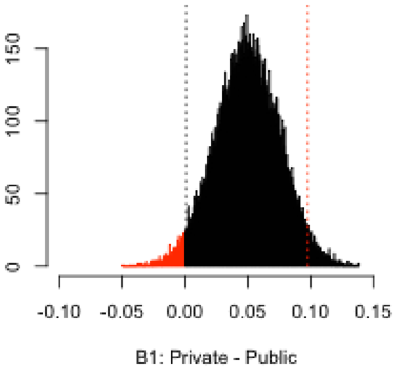
- -red regions are < 0
- -black regions are > 0
- -dashed lines are 95% probability intervals

Effect of ownership on trends



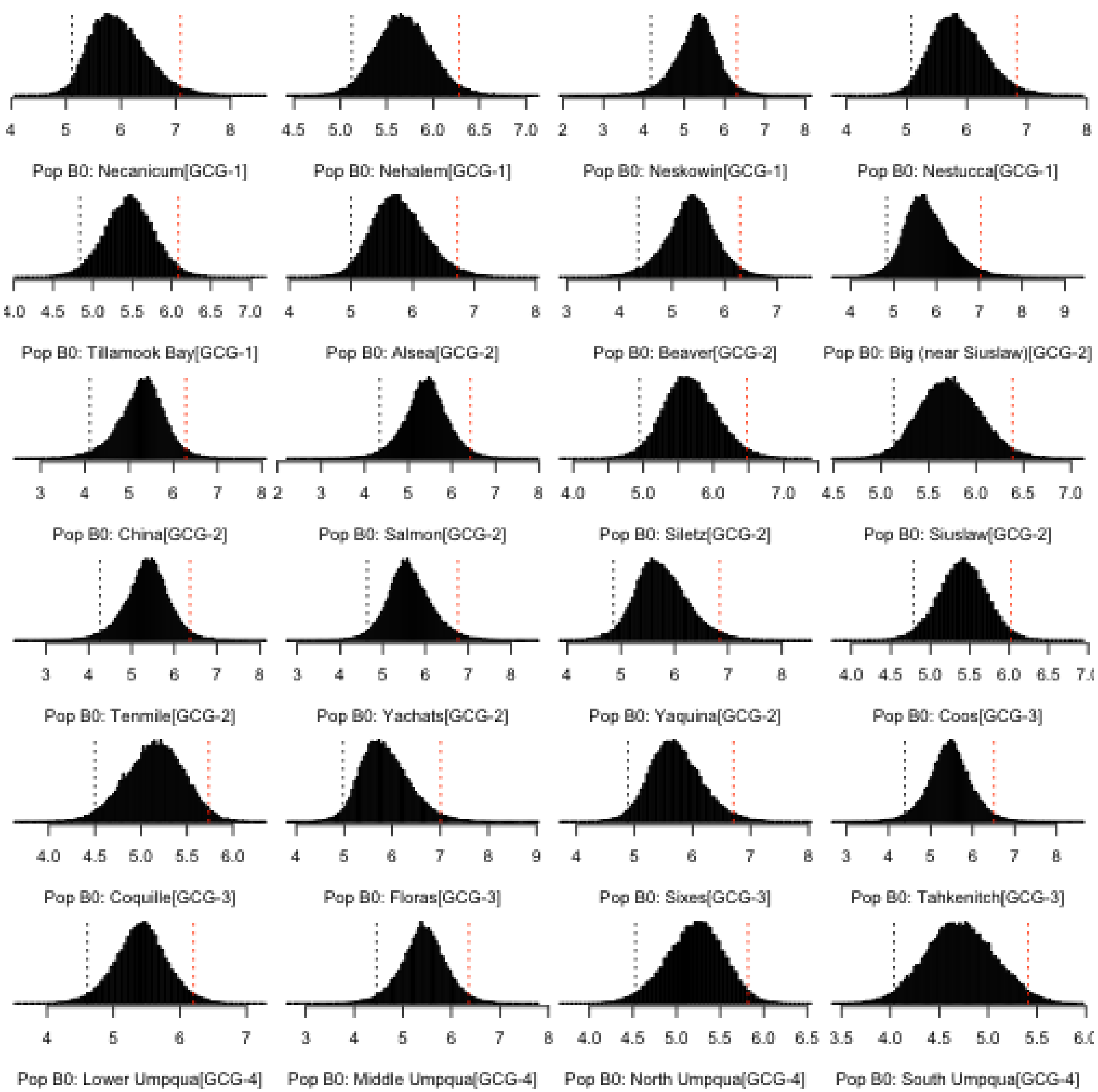


These first 2 plots represent the mean trend
On public and private land, across all GCGs



This third plot represents the difference in the trends as a derived parameter (private – public).
Pr(diff > 0) = 97.79%

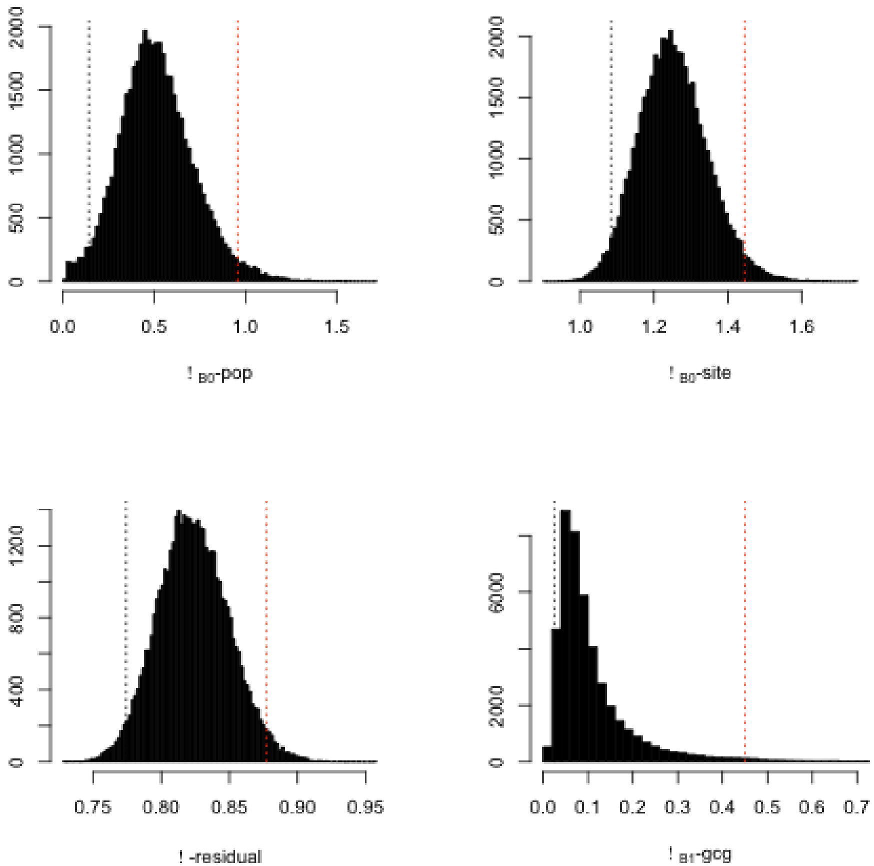
Population level means (B0)



Within a GCG, populations are different enough so that they aren't clustered

The B0s for all sites within a population are normally distributed around the respective population B0

Variance parameters



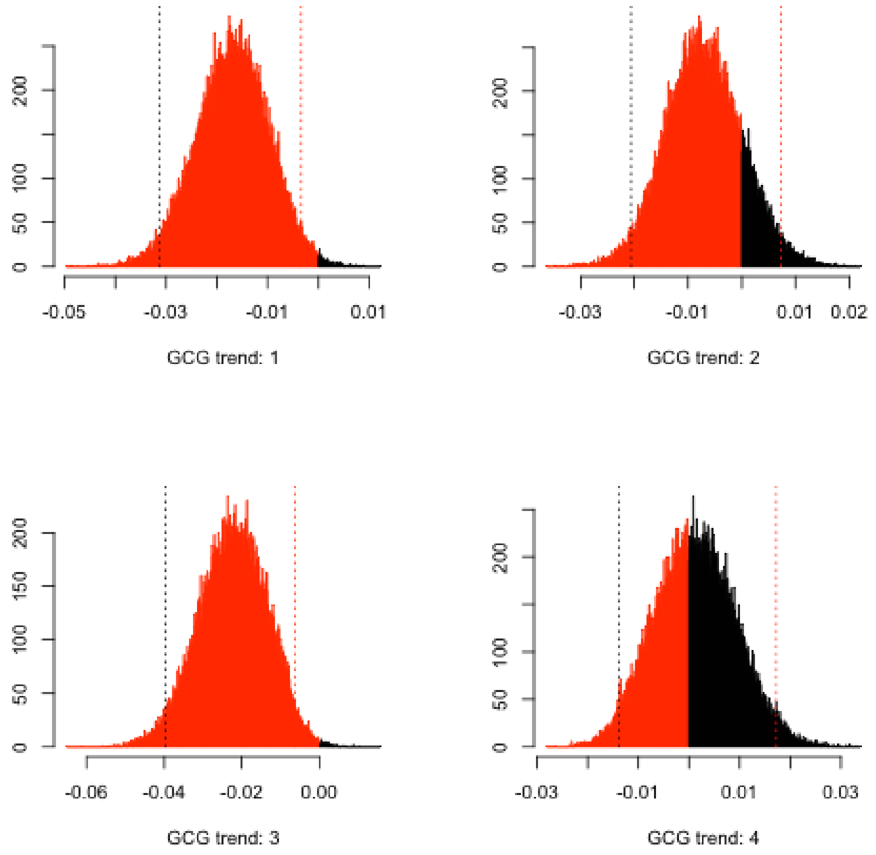
These first two parameters are the variability in mean complexity (B0) between populations and sites: the variation among sites within a population is greater than the variation across populations.

These plots represent the residual variance and the variability among trends across GCGs.

Other Complexity Metrics

- Winter parr
  - Identical best model chosen to summer parr
  - Identical parameter estimates
  - Not surprising, given cor(summer, winter) = 0.961
- Channel score
  - Similar model selected, but several differences:
  - Land ownership no longer important
  - B0: in addition to random effects at the Site and Population level, random effects included at the GCG level

GCG Trend: channel score



Compared to the parr indices:
GCG 1-2 are slightly more negative
GCG 4 is centered ~ 0, instead of being 100% negative

Three questions to address:

- Which levels of variation are important?
  - Each site has unique features (slope, beaver dam, etc), so we expect a priori that good models will let B0 to be site-specific
- Are factors such as Anadromous v. Resident zone important in either the intercept (B0) or trend (B1) in habitat metrics across sites?
- Do the range of habitat metrics support similar models?

The full hierarchical model

Regression

$$Y_{site_i,\ wat_j,\ sub_k} = B0_{i,j,k} + B1_{i,j,k} \cdot year + \varepsilon_{i,j,k}$$

Site-level

$$B0_{i,j,k} \sim Normal(B0_{j,k}, \sigma_{Site}); \quad B1_{i,j,k} \sim Normal(B1_{j,k}, \kappa_{Site})$$

Watershed-level

$$B0_{j,k} \sim Normal(B0_k, \sigma_{wat}); \quad B1_{j,k} \sim Normal(B1_k, \kappa_{wat})$$

Subbasin-level

$$B0_k \sim Normal(B0_{global}, \sigma_{sub}); \quad B1_k \sim Normal(B1_{global}, \kappa_{sub})$$

Factors

$$B0_{global} = (1 - zone) \cdot B0_{anad} + zone \cdot B0_{resident}$$

$$B1_{global} = (1 - zone) \cdot B1_{anad} + zone \cdot B1_{resident}$$

$$zone = \begin{cases} 1 & \text{Resident} \\ 0 & \text{Anadromous} \end{cases}$$

Error

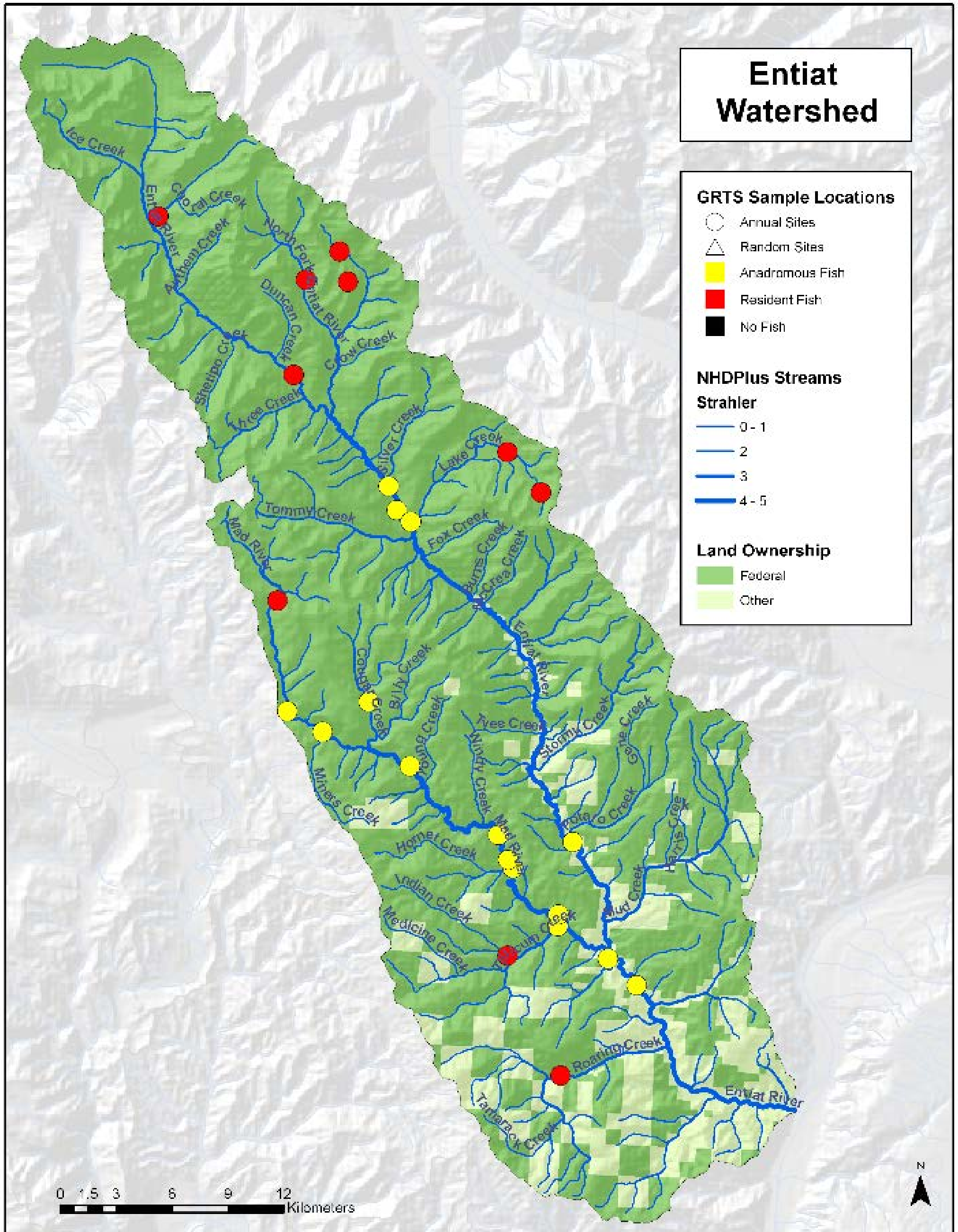
$$\varepsilon_{i,j,k} \sim Normal(0,\ \sigma_{\text{Residual}})$$

Summary of models

SUMMER PARR																
B0-sigma GCG	x											x		x		x
B0-sigma POP	x	x									x	x	x	x	x	x
B0-sigma SITE	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
B1-sigma GCG	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
B1-sigma POP	x	x	x	x	x	x									x	x
B1-sigma SITE	x	x	x	x	x											
Owner - B0	x	x	x		x	x	x	x								
Owner - B1	x	x	x	x		x	x			x	x	x				
DIC (low = good)	1899	1905	1897	1905	1901	1717	1710	1709	1709	1710	**1708**	1712	1712	1709	1714	1717
WINTER PARR																
B0-sigma GCG	x											x		x		x
B0-sigma POP	x	x									x	x	x	x	x	x
B0-sigma SITE	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
B1-sigma GCG	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
B1-sigma POP	x	x	x	x	x	x									x	x
B1-sigma SITE	x	x	x	x	x											
Owner - B0	x	x	x		x	x	x	x								
Owner - B1	x	x	x	x		x	x			x	x	x				
DIC (low = good)	1278	1277	1287	1304	1288	1146	1137	1141	1139	1137	**1137**	1138	1138	1138.6	1148	1150
CHANNEL SCORE																
B0-sigma GCG	x											x		x		x
B0-sigma POP	x	x									x	x	x	x	x	x
B0-sigma SITE	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
B1-sigma GCG	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
B1-sigma POP	x	x	x	x	x	x									x	x
B1-sigma SITE	x	x	x	x	x											
Owner - B0	x	x	x		x	x	x	x								
Owner - B1	x	x	x	x		x	x			x	x	x				
DIC (low = good)	343	374	354	353	359	265	266	264	261	265	261	257	258	**255**	259	255

Summary of results

- Which levels of variation are important?
  - B1: The trends are affected by large scale processes: different across GCG units, but the same within GCGs B0: Complexity is affected by multiple spatial scales. Populations and sites are unique; sites within a population are more similar to sites from the same population than sites from neighboring populations
- How does ownership affect mean complexity / trends?
  - For the parr indices, ownership affects the trend across all GCG units. Public land has a more negative trend than private land.
- Are the three complexity metrics similar?
  - Summer / winter parr indices produce identical results
  - Channel score supports 1 more layer of variation in B0, and ownership has no impact on the trend



Habitat Monitoring

2005 – 2009

GRTS based survey design

Annual Panel with 25 sites

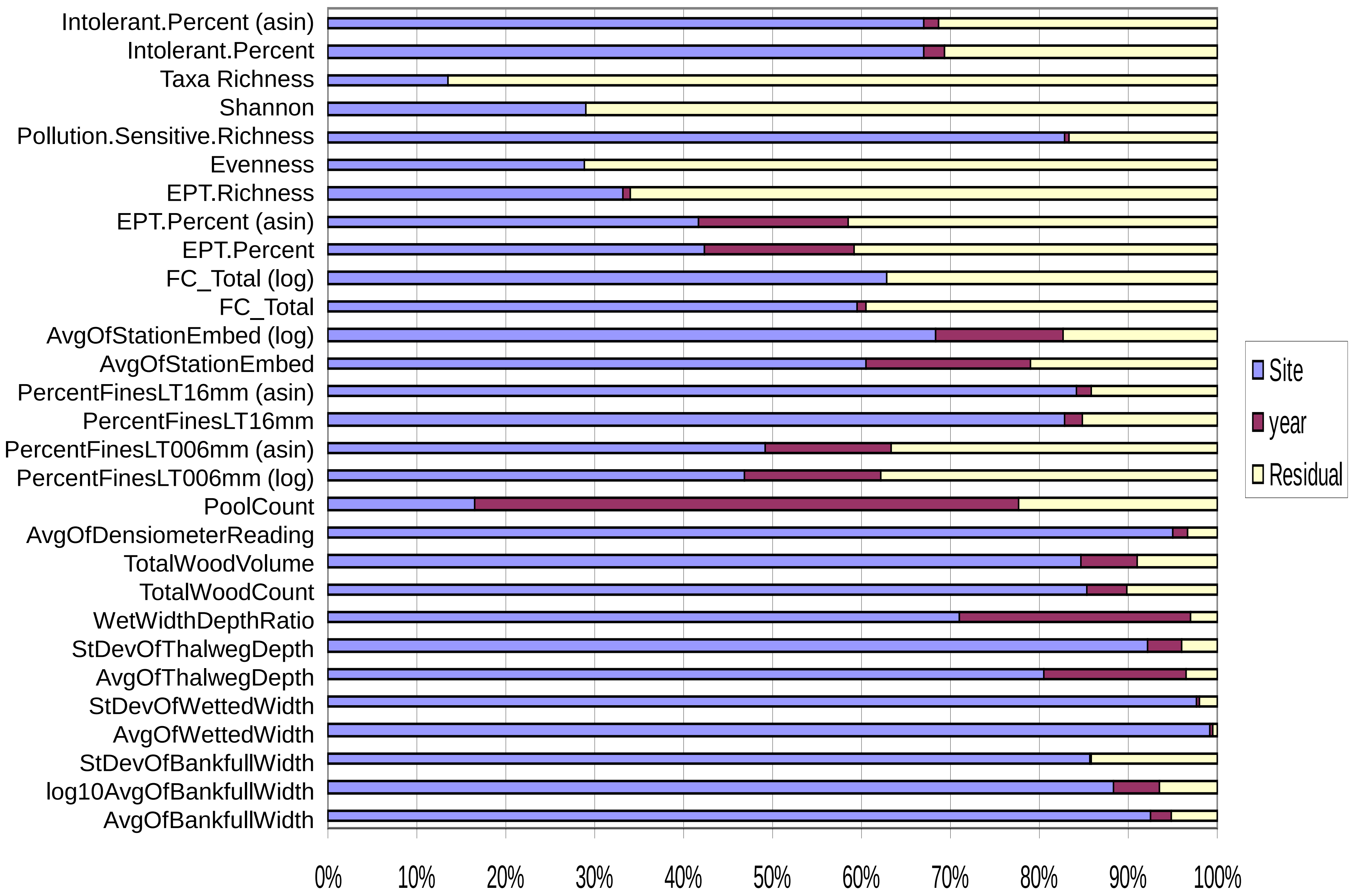
Response Design

EMAP based

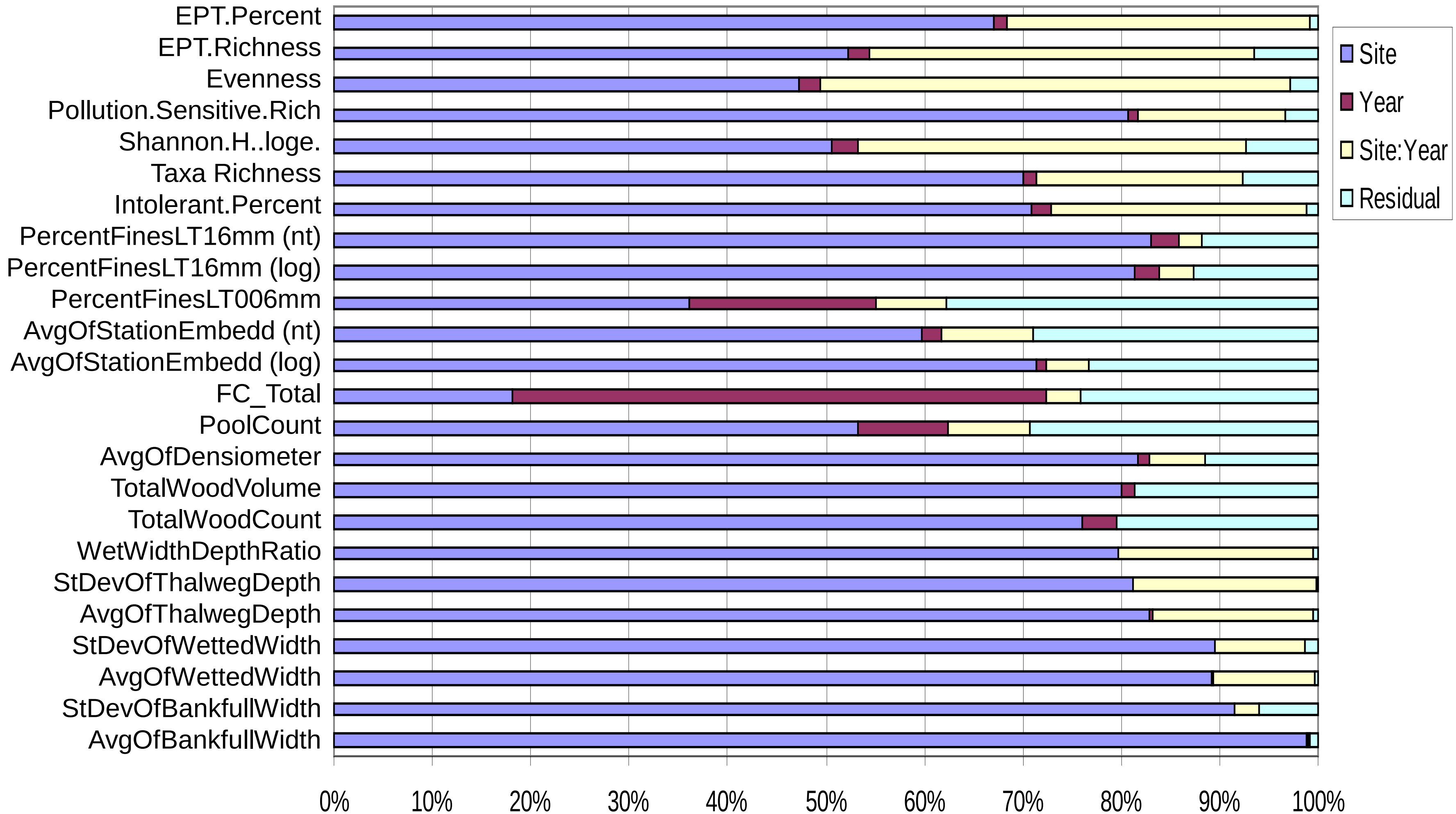
Metrics:

- AvgOfBankfullWidth
- AvgOfBankfullDepth
- AvgOfWettedWidth
- AvgOffThalwegDepths
- BFWidthDepthRatio
- WetWidthDepthRatio
- LW >30cm x >6m
- LW >30cm x 3-6m
- LW >30cm x 1-3m
- LW 10-15cm x >6m
- LW 10-15cm x 3-6m
- LW 10-15cm x 1-3m
- LW 15-30cm x >6m
- LW 15-30cm x 3-6m
- LW 15-30cm x 1-3m
- TotalWoodCount
- AvgOfDensiometerReading
- PoolCount
- FC_ArtificialStructures
- FC_Boulders
- FC_Brush_Woody Debris
- FC_Bryophytes
- FC_FilamentousAlgae
- FC_LargeWoodyDebris
- FC_LiveTreesRoots
- FC_Macrophytes
- FC_OverhangingVeg
- FC_UndercutBanks
- FC_WoodyDebris
- AvgOfStationEmbeddedness
- PercentFinesLT006mm
- PercentFinesLT16mm
- Benthic Macro-invertebrates

Variance Decomposition for Entiat metrics (2005-2008)

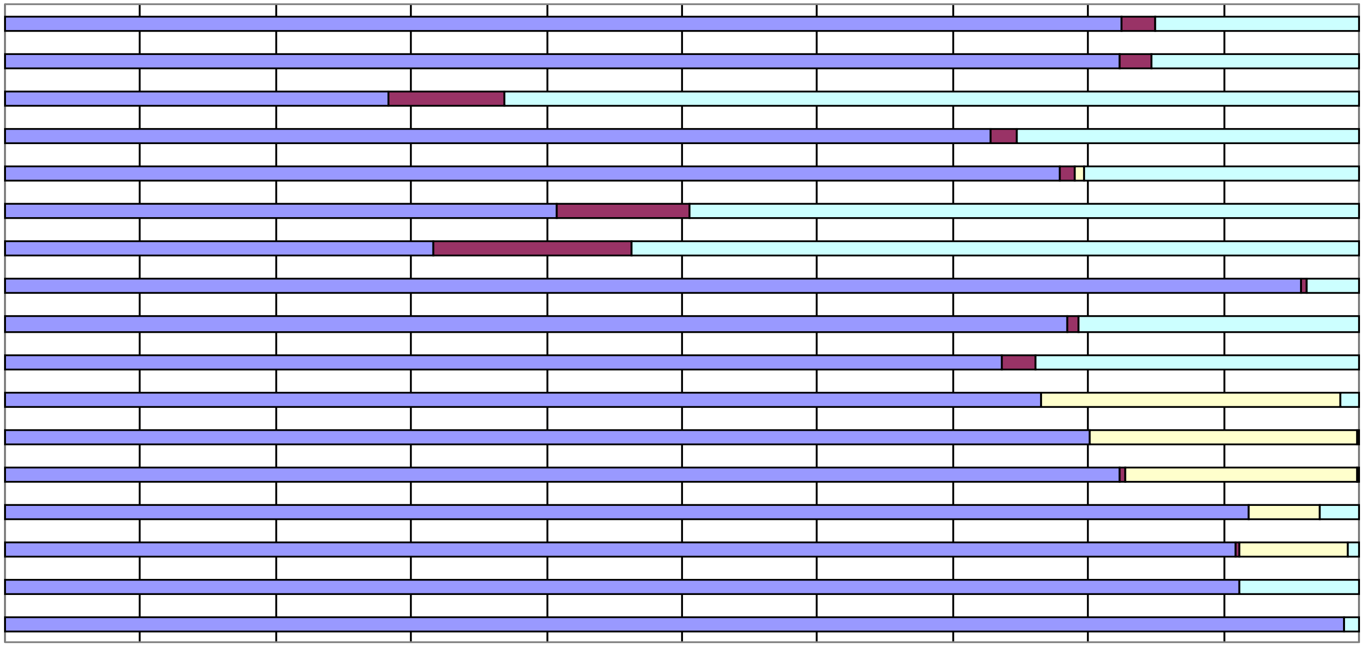


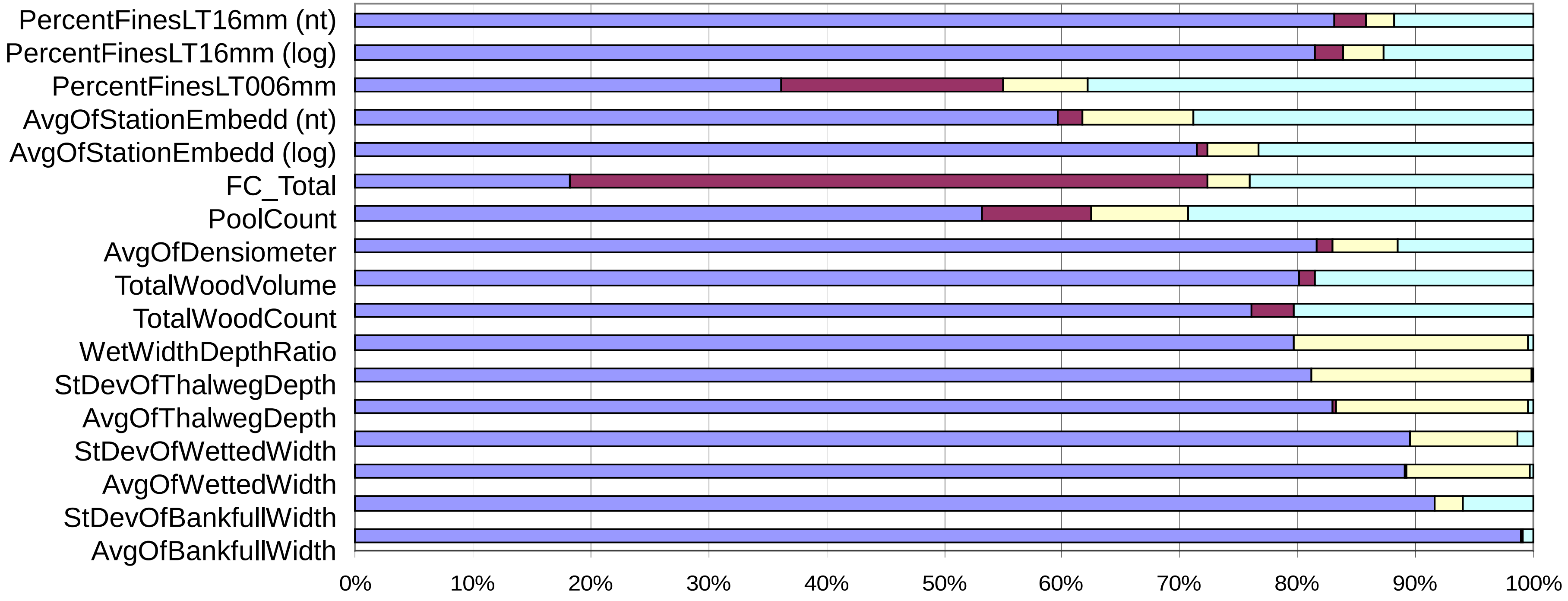
Variance Decomposition for Wenatchee metrics (2004-2009) -including all repeat visits



Variance Decomposition for Wenatchee metrics

-Value of the repeat visits in 2009





Model selection table

-Parameters involved in selected models, DIC scores

Parameters / Models	4	10	13	16	17	18	19	20	22	25	27	29	31	
Watershed variation (B0)			X		X	X	X			X	X	X	X	
Site variation (B0)			X					X	X	X	X	X	X	
Watershed variation (B1)	X		X		X	X	X	X	X		X			
Site variation (B1)	X		X		X	X	X	X	X	X				
Resident / anadromous (B0)	X	X				X					X			
Resident / anadromous (B1)	X	X			X			X				X		
trend estimate (best model)	0	0	0											
METRICS (log-transformed) / DIC score (low is good)														trend estimate
AvgOfBankfullWidth	239	236	285	268	239	255	226	60	204	181	-195	150	148	0.0058
StDevOfBankfullWidth	644	596	457	614	626	627	609	561	606	574	589	664	628	-0.0156
AvgOfBankfullDepth	376	473	477	420	375	396	404	492	434	430	466	450	512	0.0414
StDevOfBankfullDepth	571	687	474	660	534	570	538	472	485	484	499	484	517	-0.0120
AvgOfWettedWidth	269	275	298	261	296	250	266	310	291	262	273	266	265	0.1347
StDevOfWettedWidth	483	512	514	506	560	502	545	521	508	519	528	537	513	0.0755
AvgOfThalwegDepth	369	389	351	341	372	374	376	374	336	362	356	351	377	0.1146
StDevOfThalwegDepth	112	124	111	143	128	78	138	113	103	114	138	142	91	0.2199
BFWidthDepthRatio	344	327	397	337	344	337	299	356	353	370	355	350	340	-0.0038
WetWidthDepthRatio	259	234	274	290	293	297	278	253	284	280	275	279	262	0.0562
TotalWoodCount	809	781	727	777	880	750	813	796	753	736	765	774	713	-0.0273
TotalWoodVolume	925	805	903	786	1057	872	950	825	883	729	1021	787	655	-0.0347
AvgOfDensiometerReading	573	557	427	590	505	494	537	404	439	368	391	365	351	-0.0202
PoolCount	1496	1420	1537	1409	1471	1497	1444	1596	2084	1564	1539	1514	1626	0.5754
FC_Total	745	1064	699	1056	718	704	742	712	711	729	714	696	746	-0.3454
AvgOfStationEmbeddedness	712	453	310	446	516	538	513	335	274	458	472	384	605	-0.0271
PercentFinesLT006mm	1684	1625	2093	1659	2728	1962	2599	1508	1716	1957	1486	1071	1812	1.0475
PercentFinesLT16mm	599	565	578	527	542	588	593	558	593	566	573	562	534	0.0281

Monitoring Program Weaknesses

- Monitoring results are not directly tied to management decision making
- Results are not timely nor communicated to key audiences
- Objectives for monitoring are not clearly, precisely stated and understood
- Monitoring measurement protocols, survey design, and statistical analysis become scientifically out-of-date

Why aren't Basic Designs Sufficient in Many Cases?

- Monitoring objectives may include requirements that basic designs can't address efficiently
  - Estimates for particular Reporting Domains requires greater sampling effort
  - Administrative restrictions and operational costs
- Ecological resource occurrence in study region makes basic designs inefficient
  - Resource is known to be restricted to particular habitats

Stratification: Reasons to Use

- Administrative or operational convenience
  - Regions or states need to be operationally independent
- Particular portions of the target population require different survey designs
  - Design for extensive wetlands (Everglades) may be different from prairie pothole wetlands
- Increase precision by constructing strata that are homogeneous
- Reporting domains identified require additional samples to meet margin of error requirements

More complex Survey Designs

- Unequal probability sample
  - Alternative to stratification
  - Requires auxiliary information
- Spatial strata random sample
  - Don't have a list frame
  - Alternative way to spatially balance sample
- Cluster sample
  - Can decrease field operation costs
- Multiple-stage or multi-phase sample
  - Way to decrease cost of sample frame construction
- Adaptive Sampling

Stratification and Unequal Probability Selection

Design monitoring program

- Stratification: reasons
  - Based on auxiliary information
  - Allocate sample to subpopulations
  - Improve precision of results
  - Guarantees exact sample sizes
  - Operational/administrative efficiency
  - Different subpopulations require different survey designs
- Unequal weighting
  - Based on auxiliary information
  - Allocate sample to subpopulations
  - Improve precision of results
  - Only guarantees expected sample size

Inference Design: Status

- Each spatial survey design is linked with a design-based statistical analysis appropriate for that design
  - Stratified design uses a stratified statistical analysis
  - Unequal probability design uses an unequal probability statistical analysis
- Design-based analyses are based on the Horwitz-Thompson theorem for probability survey designs
- Statistical sampling books provide required information

Inference Design: Change

- Estimating change between two periods depends on the temporal design
- Revisiting same spatial units in both temporal periods
  - Have paired data so procedures used to take advantage of pairing
  - Analysis may be based on differences for continuous data
  - Analysis may be based on two-way tables for categorical data
  - Can estimate gross change
- No revisits of same spatial units in both temporal periods
  - Can only estimate net change
  - Analyses based on differences between indicator values for two periods.

Inference Design: Trend

- Requires temporal design that covers multiple temporal units
- Simple approach is trends in status estimated for each temporal unit
- More complex analyses incorporate spatial-temporal design structure by using metric values on all spatial-temporal units sampled
  - Typically rely on statistical linear model analyses
  - Example: VanLeeuwen, D.M., L.W. Murray and N.S. Urquhart 1996. A mixed model with both fixed and random trend components across time. Journal of Agricultural, Biological and Environmental Statistics 1:435-453

Inference Design: Spatial Pattern

- Model-based approaches are required
- Geostatistics (Kriging) when resource is an area
- Geostatistics when resource is a linear network (new methodology)
- Spatial prediction models incorporating auxiliary information
  - Generalized linear models
  - CART: classification and regression trees
  - Random forests