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?
Develop monitoring objectives

- 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 choose 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: Identify monitoring goals and objectives
2: Design monitoring program
3: Collect data
4: Manage data
5: Interpret and analyze data
6: Report results
7: Review results and revise design as needed

Understand climatic and other effects on salmon
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

Develop 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

Design
Monitoring
Program
STRIDe Approach to Designing a Monitoring Program

- **Spatial design**: how we select what spatial units to monitor within the spatial domain
- **Temporal design**: how we select what temporal units to monitor within the temporal domain
- **Response design**: what measurements we make, how we take them & how we calculate metrics on spatial-temporal units based on the measurements
- **Inference Design**: 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

• 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

• 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

• 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

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## Surveys over Time: Panel Designs

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Inference Design for Indicators

• 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
Change Detection


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)

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?)
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.
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)

\[ \text{var}(\text{slope}) = \sum \frac{(X_i - \overline{X})^2}{N_s} \]

\[ \frac{\sigma_s^2}{N_s} + \sigma_y^2 + \frac{\sigma_r^2}{N_v} \]

\(X_i = \text{Year} ; \quad N_s = \text{Number of sites in region} ; \quad N_v = \text{Number of within-year revisits} \)

\[ \text{var}(\hat{\beta}_{\text{DESIGN}_1}) = \frac{\sigma_{\text{YEAR}}^2 + \frac{\sigma_{\text{RESIDUAL}}^2}{s}}{\sum (j - \bar{j})^2}. \]

\[ \text{var}(\hat{\beta}_{\text{DESIGN}_1}) = \frac{\sigma_{\text{YEAR}}^2 + \frac{\sigma_{\text{RESIDUAL}}^2}{s}}{\sum (j - \bar{j})^2} + \frac{\sigma_B^2}{s}. \]
A - Design comparisons, one slope
C - Year comparisons, one slope

YEAR VARIANCE = 0.000

YEAR VARIANCE = 0.050
D - Trend comparisons, one slope

TREND = 0.03

TREND = 0.02

TREND = 0.01
G - Slope variance comparisons, many slopes

SLOPE VARIANCE = 0.00 & 0.01

SLOPE VARIANCE = 0.025 & 0.05
What about some real world examples?
Habitat Variables

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

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

<table>
<thead>
<tr>
<th>Habitat Attribute</th>
<th>MA</th>
<th>Slope</th>
<th>P-Value</th>
<th>Intercept</th>
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<td>Instream Wood</td>
<td>NC</td>
<td>-0.066 (0.02)</td>
<td>0.004</td>
<td>3.12 (0.20)</td>
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<tr>
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<td>MC</td>
<td>0.024 (0.02)</td>
<td>0.265</td>
<td>2.55 (0.21)</td>
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<tr>
<td></td>
<td>MS</td>
<td>-0.025 (0.02)</td>
<td>0.272</td>
<td>2.56 (0.22)</td>
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<tr>
<td></td>
<td>UMP</td>
<td>-0.021 (0.02)</td>
<td>0.338</td>
<td>2.43 (0.21)</td>
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<tr>
<td></td>
<td>SC</td>
<td>-0.012 (0.02)</td>
<td>0.492</td>
<td>2.07 (0.18)</td>
</tr>
</tbody>
</table>
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 tree log10( PCTSNDOR )

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

Multiple Imputation Esti
1-NC

Site Slope log10( PCTSNDOR)
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](http://www.epa.gov/nheerl/arm)**
  - Developed under Tony Olsen’s guidance

- **[www.salmonmonitoringadvisor.org](http://www.salmonmonitoringadvisor.org)**
  - Developed under funding from the Moore Foundation, Randall Peterman PI; moving to PNAMP umbrella

- **[www.monitoringmethods.org](http://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 $\tau_0, \tau_1, \ldots, \tau_k$

• Our target response $\tau_0$ is only available on Panel 0. For all other panels, treat $\tau_0$ as a missing observation

• Use multiple imputation to capture the trend information from panels 1 to $k$
CDF Variance for Multiple Imputation Trend

- Imputation
- Full sample (4 panels)
- Full sample plus imputation
- Annual panel only

Multiple Imputation Estimation

Site Slope log10(ACW)
Imputed Site-specific trend
\[ \text{asin}(\sqrt{\text{PCTGRAVEL}}) \]
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

### RESULTS

<table>
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<tr>
<th>Season</th>
<th>Potential Smolts Produced (Smolts/Km)</th>
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</thead>
<tbody>
<tr>
<td>Winter</td>
<td>1,700</td>
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<tr>
<td>Summer</td>
<td>1,700</td>
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### ODFW HLFM model
- Summer, Winter Parr/km

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<tr>
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<th>Potential Smolts Produced (Smolts/Km)</th>
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<tbody>
<tr>
<td>Winter</td>
<td>1,700</td>
</tr>
<tr>
<td>Summer</td>
<td>1,700</td>
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### HABITAT DATA

<table>
<thead>
<tr>
<th>Wood Type</th>
<th>Length (M)</th>
<th>Habitat Type</th>
<th>Wood Quality</th>
<th>Pool Frequency</th>
<th>Pool Quality</th>
<th>Wood Frequency</th>
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<tbody>
<tr>
<td>SPM</td>
<td>3.8</td>
<td>Backwater Pools L</td>
<td>LMH</td>
<td>100</td>
<td>100</td>
<td>150</td>
</tr>
</tbody>
</table>

### Oregon Coast Coho Trend Sites

- Strata:
  - Lakes
  - Mid-Coast
  - Mid-South Coast
- Populations
- Habitat Trend Sites

### Pool Area

- Summer: 1,400
- Winter: 1,400

### Percent Pools

- Summer: 78%
- Winter: 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

\[ Y_{site_i, pop_j, gcg_k} = B_{0, i, j, k} + B_{1, i, j, k} \cdot year + \varepsilon_{i, j, k} \]

Site-level

\[ B_{0, i, j, k} \sim \text{Normal}(B_{0, j, k}, \sigma_{Site}); \quad B_{1, i, j, k} \sim \text{Normal}(B_{1, j, k}, \kappa_{Site}) \]

Pop-level

\[ B_{0, j, k} \sim \text{Normal}(B_{0, k}, \sigma_{Pop}); \quad B_{1, j, k} \sim \text{Normal}(B_{1, k}, \kappa_{Pop}) \]

GCG-level

\[ B_{0, k} \sim \text{Normal}(B_{0, \text{global}}, \sigma_{GCG}); \quad B_{1, k} \sim \text{Normal}(B_{1, \text{global}}, \kappa_{GCG}) \]

Ownership (as factor)

\[ B_{0, \text{global}} = (1 - \text{owner}) \cdot B_{0, \text{public}} + \text{owner} \cdot B_{0, \text{private}} \]

\[ B_{1, \text{global}} = (1 - \text{owner}) \cdot B_{1, \text{public}} + \text{owner} \cdot B_{1, \text{private}} \]

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

Error

\[ \varepsilon_{i, j, k} \sim \text{Normal}(0, \sigma_{\text{Residual}}) \]
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 $\text{cor(}\text{summer, winter}) = 0.961$

• Channel score
  – Similar model selected, but several differences:
    – Land ownership no longer important
    – $B_0$: 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

\[ Y_{site, wat, sub} = B_{0, i, j, k} + B_{1, i, j, k} \cdot year + \varepsilon_{i, j, k} \]

Site-level

\[ B_{0, i, j, k} \sim Normal(B_{0, j, k}, \sigma_{Site}); \quad B_{1, i, j, k} \sim Normal(B_{1, j, k}, \kappa_{Site}) \]

Watershed-level

\[ B_{0, j, k} \sim Normal(B_{0, k}, \sigma_{wat}); \quad B_{1, j, k} \sim Normal(B_{1, k}, \kappa_{wat}) \]

Subbasin-level

\[ B_{0, k} \sim Normal(B_{0, global}, \sigma_{sub}); \quad B_{1, k} \sim Normal(B_{1, global}, \kappa_{sub}) \]

Factors

\[ B_{0, global} = (1 - \text{zone}) \cdot B_{0, anad} + \text{zone} \cdot B_{0, resident} \]

\[ B_{1, global} = (1 - \text{zone}) \cdot B_{1, anad} + \text{zone} \cdot B_{1, resident} \]

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

Error

\[ \varepsilon_{i, j, k} \sim Normal(0, \sigma_{Residual}) \]
## Summary of models

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<thead>
<tr>
<th></th>
<th>B0-sigma GCG</th>
<th>B0-sigma POP</th>
<th>B0-sigma SITE</th>
<th>B1-sigma GCG</th>
<th>B1-sigma POP</th>
<th>B1-sigma SITE</th>
<th>Owner - B0</th>
<th>Owner - B1</th>
<th>DIC (low = good)</th>
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<tr>
<td><strong>SUMMER PARR</strong></td>
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</table>
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

- Site
- Year
- Site:Year
- Residual
Variance Decomposition for Wenatchee metrics

- Value of the repeat visits in 2009
<table>
<thead>
<tr>
<th>Parameters / Models</th>
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<tr>
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**METRICS (log-transformed) / DIC score (low is good)**

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<th>AvgOfBankfullDepth</th>
<th>StDevOfBankfullDepth</th>
<th>AvgOfWettedWidth</th>
<th>StDevOfWettedWidth</th>
<th>AvgOfThalwegDepth</th>
<th>StDevOfThalwegDepth</th>
<th>TotalWoodCount</th>
<th>TotalWoodVolume</th>
<th>TotalWoodVolume</th>
<th>AvgOfDensiometerReading</th>
<th>PoolCount</th>
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</table>

**BFWidthDepthRatio**

| BFWidthDepthRatio             | 344                | 327                 | 397                | 337                | 299              | 356               | 353               | 370               | 355           | 350           | 340           | 0.1347                 |

**WetWidthDepthRatio**

| WetWidthDepthRatio            | 259                | 234                 | 274                | 290                | 293              | 297               | 278               | 253               | 284           | 280           | 275           | 266                    |

**FC_Total**

| FC_Total                      | 745                | 1064                | 699                | 1056               | 718              | 704               | 742               | 712               | 711           | 729           | 714           | 696                    |

**AvgOfStationEmbeddedness**

| AvgOfStationEmbeddedness      | 712                | 453                 | 310                | 446                | 516              | 538               | 513               | 335               | 274           | 458           | 439           | 368                    |

**PercentFinesLT006mm**

| PercentFinesLT006mm           | 1684               | 1625                | 1537               | 1409               | 1471             | 1497              | 1444              | 1596              | 2084          | 1564          | 1539          | 1626                    |

**PercentFinesLT16mm**

| PercentFinesLT16mm            | 599                | 565                 | 578                | 527                | 542              | 588               | 593               | 558               | 593           | 566           | 573           | 562                    |

**PercentFinesLT16mm**

| PercentFinesLT16mm            | 599                | 565                 | 578                | 527                | 542              | 588               | 593               | 558               | 593           | 566           | 573           | 562                    |

**AvgOfStationEmbeddedness**

| AvgOfStationEmbeddedness      | 712                | 453                 | 310                | 446                | 516              | 538               | 513               | 335               | 274           | 458           | 439           | 368                    |

**PercentFinesLT006mm**

| PercentFinesLT006mm           | 1684               | 1625                | 1537               | 1409               | 1471             | 1497              | 1444              | 1596              | 2084          | 1564          | 1539          | 1626                    |

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**PercentFinesLT16mm**

| PercentFinesLT16mm            | 599                | 565                 | 578                | 527                | 542              | 588               | 593               | 558               | 593           | 566           | 573           | 562                    |
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

- **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
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