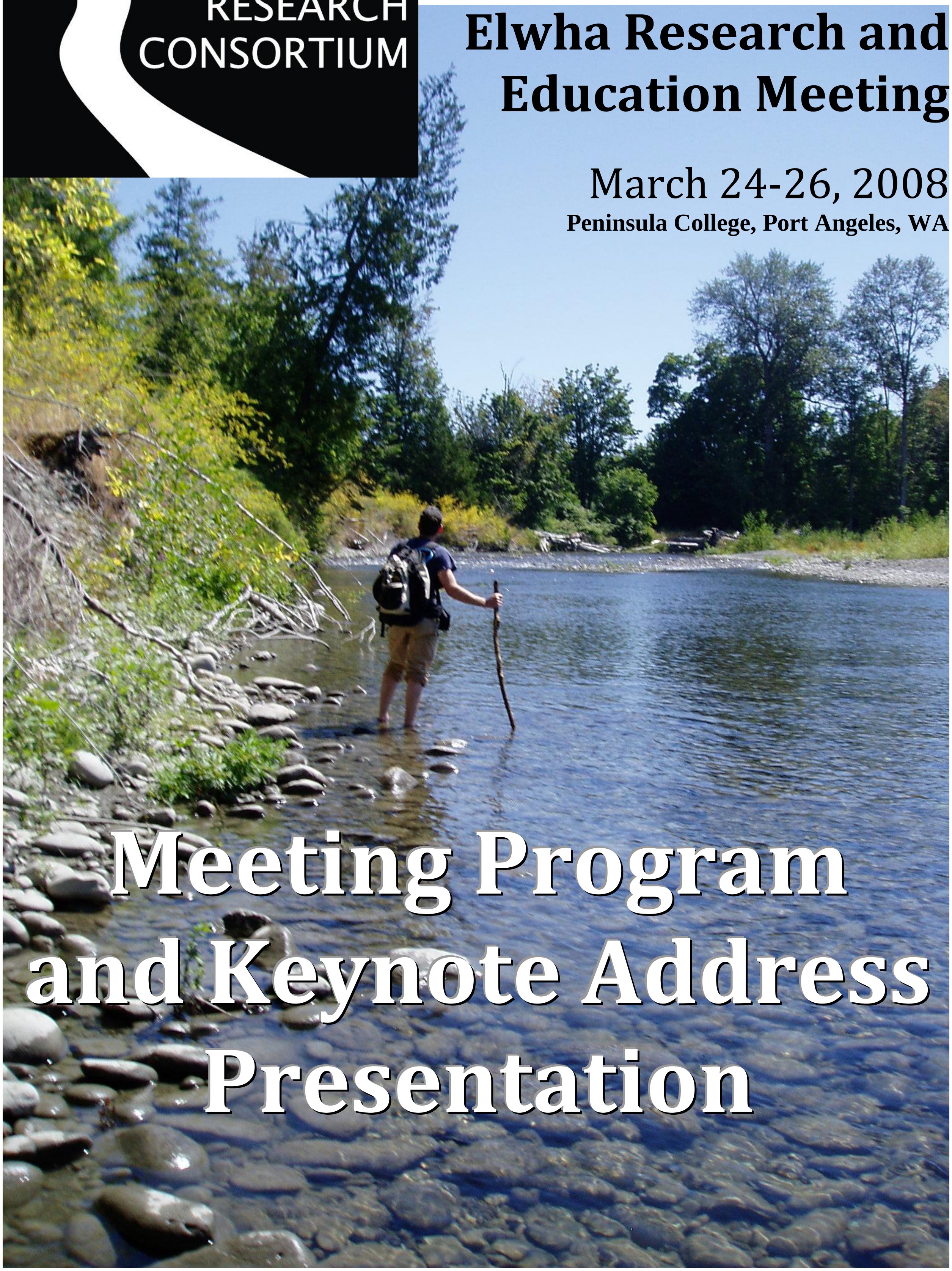
ELWHA RESEARCH CONSORTIUM

Fifth Annual Elwha Research and Education Meeting

March 24-26, 2008

Peninsula College, Port Angeles, WA



Meeting Program and Keynote Address Presentation

Fifth Annual Elwha Research and Education Meeting
March 24-26, 2008

Tuesday, March 25

Peninsula College Science and Technology Building, Room M125

800 Continental breakfast

830 Welcome
Bill Eaton, PC

830 Status Report on the Elwha River Restoration Project
Brian Winter, OLYM

900 Session I

(900) Keynote Address: Detecting Change in a Variable World—Val Cullinan, PNL

Conceptual models are a planning tool used to apply scientific understanding to the development of measurement endpoints for damage assessment, monitoring programs, and adaptive management strategies associated with protecting, restoring, and managing natural resources. They provide a graphical display that relates working hypotheses of the linkage between stressors and effects that acknowledge a variable spatial and temporal system. Conceptual models can also be used to help design the field research and provide a structure for the integration of results. Studies that are intended to evaluate environmental impacts and restoration require the estimation of the spatial extent and magnitude of change; in this talk, I will discuss the effect of different design strategies and methods of data integration on the resolution of change detection and the implied inference of causation. Finally, the incorporation of the spatial variability of measurements of concern measured at multiple scales and across a gradient allows the development of hypotheses of the functional response between stressors and effects that can be used to update the conceptual model and be applied under similar impact scenarios.

(945) NASA Applications for Elwha Research—Jeff Ward, PNL

1000 Break

1020 Session II

(1020) Use of Radiotelemetry, Electrofishing, and Snorkeling to Determine Movements, Growth, and Relative Abundance of Elwha River Salmonids in Olympic National Park—Sam Brenkman, OLYM

(1040) Elwha River Fish Restoration Plan and the Bull Trout Rescue Plan: Ensuring the Objectives of the Elwha Act are Achieved—Pat Crain, OLYM, Sam Brenkman, OLYM, and Larry Ward, LEKT

(1100) Genetic Inventory of Anadromous Pacific Salmonids of the Elwha River Prior to Dam Removal—Gary Winans, NOAA

(1120) North Olympic Watershed Science Education: Bringing Science to Life for Teachers and Students—Darek Staab, OPI

(1135) The Elwha Science Education Project: a confluence of traditional knowledge and the geosciences—Lindsey Schromen-Wawrin, OPI, and Brenda Lovik, LEKT

~1200 Lunch, Longhouse

100 Session III

(100) Beyond the Elwha: Large Dam Removals Nationwide—Amy Kober, American Rivers

(115) Elwha Restoration Stories: Views and Voices—Ryan Hilperts, UVic

(130) Nearshore Fish Responses to Sediment Changes After Elwha River Dam Removal: Results of 2006-2007 Monitoring Efforts—Anna Kagley, NOAA, Kurt Fresh, NOAA, Larry Ward, LEKT, and Joshua Chamberlin, UW

(150) Preliminary Findings on Habitat Function and Salmon Use of the Elwha Nearshore with an Eye to Ecological Implications of Long Term Sediment Starvation to Nearshore Habitat Function—Anne Shaffer, WDFW

(210) Elwha River Inventory and Survey—Bill Pietsch, UW, and Jerry Freilich, OLYM

230 Break

250 Session IV

(250) Response of Riparian Wildlife Communities to Restoration of Anadromous Fish in the Elwha River Ecosystem—Kurt Jenkins, USGS, Nate Chelgren, USGS, Kim Sager-Fradkin, LEKT, Patti Happe, OLYM, Mike Adams, USGS, Steve Perakis, USGS, and Robert Knapp, Western Washington University

(310) Predicting Spread of Invasive Exotic Plants on De-watered Reservoirs—Andrea Woodward, USGS, Joshua Smith,OLYM, Steve Acker, OLYM, and Christian Torgersen, USGS

(325) Preliminary Evidence for The Use of Microbial and Nutrient Data As Indicators of Habitat Change Within the Elwha River —Bill Eaton, PC

(345) Dynamiting Dams and Exploding American Myths about Nature: The Elwha Dam Decommission Plan—Enrique Lanz Oca, CUNY

Over →

400 Break-out groups (second floor on south side in adjacent labs; each seats 24)

- Wildlife, Room M213
- Fish and Aquatic Ecology, Room M215
- Vegetation, Soils, and Sediment, Room M217

500-600 Poster Session and hors d'oeuvres (second floor atrium, north end)

Wednesday, March 26

830-1230 **Introduction to Bayesian Statistics**—Lorraine Read, TerraStat Consulting Group (Fee: $50, register through Peninsula College at 452-9277 using course code N850)

This workshop will provide an introduction to Bayesian statistics, contrasted with the more commonly utilized frequentist approach to statistical probabilities. You will learn about prior and posterior probabilities; how prior information (or non-information) can be incorporated into your analysis, and how to describe these priors quantitatively; as well as the utility of Bayesian Decision Analysis in managing natural resources. Examples and exercises will be provided showing a Bayesian approach to hypothesis testing and statistical modeling. Pre-reqs: prior knowledge/experience in frequentist statistics (e.g., ANOVA, etc.) and use of Excel for quantitative assessment in natural resource science or management. Room M134

830-930 **Grant Development for NEH College Faculty Workshop**—Kate Reavey, Peninsula College

A group of humanities educators is interested in developing a grant proposal to the National Endowment for the Humanities' *We the People* program. We wish to develop a one-week residence-based workshop for community college educators that uses the Elwha watershed and associated historic sites to address central themes and issues in American history, government, literature, art history, and other related subjects in the humanities. Location will be the Second Floor Lounge, South Side of the Sci/Tech Building (M)

Special thanks for making this meeting possible go to Nikki Brown and the staff of Peninsula College Support Services, Karen Siefer, Joy and the staff of Joy's Bistro, and the students of Peninsula College and WWU-Huxley College on the Peninsula

Partial funding was provided by the National Science Foundation

Detecting Change in a Variable World

Valerie Cullinan

Battelle

U.S. Department of Energy
Pacific Northwest National Laboratory

Event/Purpose

- Removal of two dams on the Elwha River
- Restore the Elwha River ecosystem and its native anadromous fisheries

"Dam removals are increasingly viewed as a means of restoring riverine ecosystems. … If the trajectories of ecosystem effects after dam removal are beneficial here, they could be applied in other similar cases." (ERC 2006 Annual Report)

Process

- Dam removal to occur over a two year time period starting in 2012
- Reservoirs behind each dam will be drained
- Dam structures notched to allow a pulsing of sediment
- Work window excludes periods of high flow, fish migration, and spawning (five months per year)
- Estimated time to flush 17.7 million cubic yards of sediment: 1 yr with a 100-year flood, 3 yrs under high flows, and 5 yrs under low flows

Goals of Research Efforts

- Collect information that can be used to minimize extent, magnitude, and time period associated with impacts and maximize the realization of benefits for future dam removal operations (Applied)
- Quantify and understand functional relationships between observed changes (Basic)
- Provide educational opportunities for students and public

Outline

- Define terms
- Conceptual model
- Factors useful in deciding between correlation and causation
- Design of field experiments
- Spatial and temporal variability
- Integrating results

Defining Terms

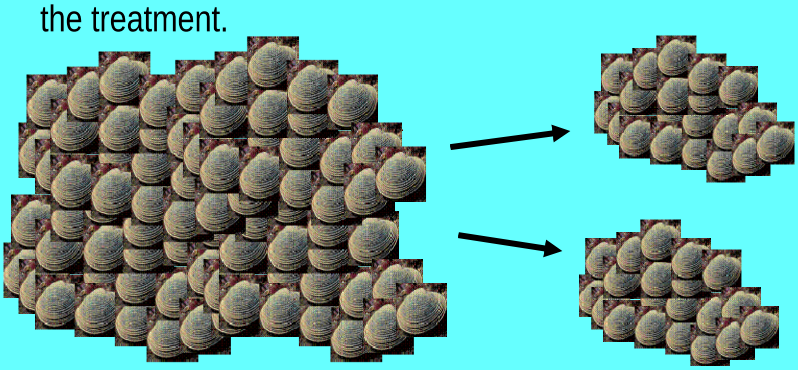
- Impact - the force of one thing on another; implicitly evokes a requirement to provide evidence of cause and effect
- Restore - to bring back to a former or original state
- Change - to make a shift from one state to another
- Effect - a statistically or biologically significant difference in a measurement relative to a reference, gradient, or prior time point

Defining Terms

- Cause - 1) efficient cause: the source of the primary change or stability (Aristotle); 2) treatments in an experiment; 3) a stressor that occurs at an intensity, duration, and frequency of exposure that results in a detectable change.
- Degrees of separation - the number of steps or connections between people, places, or events
- Causal Inference – a statement about the causal effect on a population response relative to another cause (the difference in mean responses); requires the randomization and replication of causes on units of the population.

Causal Inference

- The statistical solution to making a causal inference is to assume that each unit is a sample from a population for which we can estimate a mean response from both the control and the treatment.



Population of Butter Clams

Impact Assessments

- Instead of making a definitive causal inference, impact assessments attempt to provide **evidence from multiple angles** to increase the certainty about cause and effect.
- A causal relationship is said to exist whenever evidence indicates that certain environmental factors increases the **probability of the occurrence** of injury and when a reduction in one or more of these factors decreases the frequency of that injury.

Why is all of this important?

- As the degrees of separation in time and space between the events of dam removal and sampling increase, the ability to assign probable cause to observed changes becomes more difficult.
- The intent is not to just record change, but to determine what parameters and how (functionally) they influence the magnitude and extent of change.

What we are up against

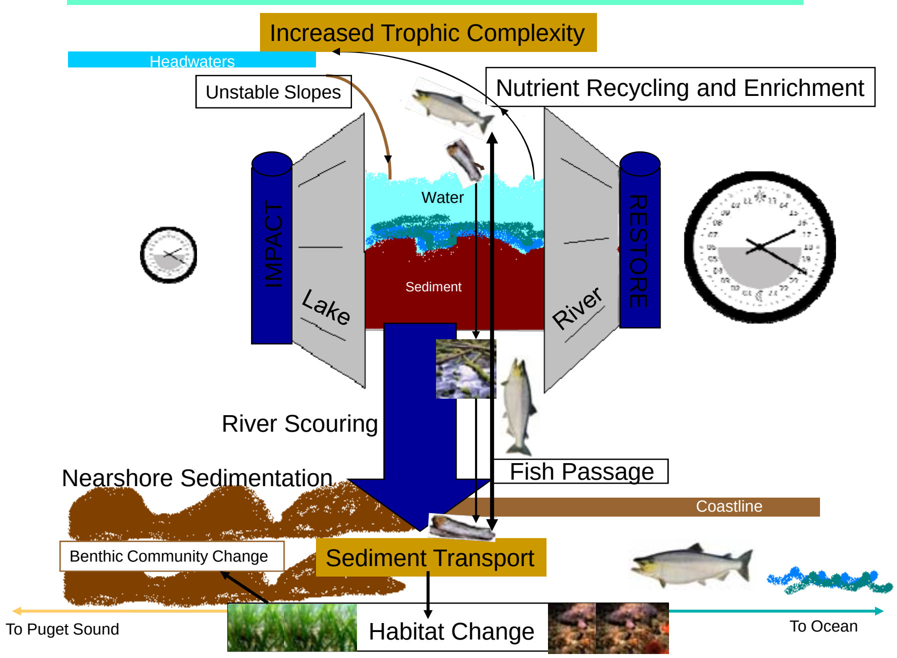
- A variety of confounded stressors, natural and anthropogenic
- Complexity of the systems including compensatory mechanisms, time-lags of response, alternate strategies within food webs
- Multiple pathways for stressors to disrupt function
- Interdependencies among events, organisms, spatial components
- High levels of spatial and temporal variability

Sources of Variability

Stressors and the Conceptual Model

- Conceptual models are a series of qualitative working hypotheses that depict mechanisms or pathways between stressors and effects.
- Stressors were defined as cause #3: the environmental factors that occur at an intensity, duration, and frequency that result in a detectable change (in the integrity of ecosystems).
- A lack of connectivity removes the stressor from being considered a potential cause.

Conceptual Model: Effects of Elwha Dam Removal



Benefits of the Conceptual Model

- Organize scientific understanding of the major associations between stressors and natural systems
- Build consensus on the associated potential effects
- Prioritize biological attributes or indicators of the ecological response
- Identify lacking information and uncertainties
- Prioritize needs and identify measurement endpoints
- Define scale and type of sampling strategy

How to Prioritize

- A critical element in the determination of the target population is the ecological significance of the response.
- Should focus on those most likely to be affected given the fate and transport mechanisms of the stressors.
- Selection and definition should specify the spatial and temporal boundaries for sampling and limitations to inference.

Seven criteria for aiding in evaluating the strength of the causal relationship between the stressor and the effect (Adams 2003)

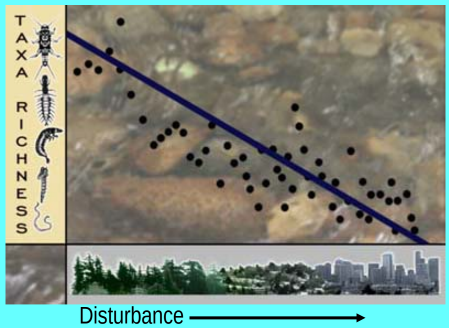
1. Strength of Association – There is a strong relationship between the stressor and the effect. A large portion of individuals in the population are affected in the exposed area compared to a reference area.
2. Consistency of Association – The association between a particular stressor or stressors and an effect on the population has been observed by other investigators in similar studies at other times and places.

Seven criteria continued

3. Specificity of Association – The effect is diagnostic of exposure. Evaluate whether the effect could be due to a different stressor or if the stressor could produce another type of effect on the population.
4. Time order or temporality – The effect occurs only after exposure to the stressor or the effect decreases when the cause is decreased or removed.

Seven criteria continued

5. Biological Gradient – There is a dose-response relationship either spatially or temporally between the stressor and the effect. The probability of an effect on the population is a function of magnitude of exposure.



Seven criteria continued

6. Experimental Evidence – Valid experimental studies (laboratory, mesocosms) support the proposed cause-effect relationship.
7. Biological Plausibility – There is a credible or reasonable biological and/or toxicological basis for the proposed mechanism linking the proposed stressor and biological effect

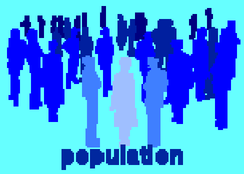
Environmental Sampling to Meet Objectives

- The objective of **descriptive sampling** is to estimate attributes (distributional characteristics) of selected variables.   Need to define population of interest.

Statistic

Sample Variance

Parameter



Population Variance

Environmental Sampling to Meet Objectives

- The objective of **analytical sampling** is to determine whether there are differences between population attributes and why such differences exist.

Environmental Sampling to Meet Objectives

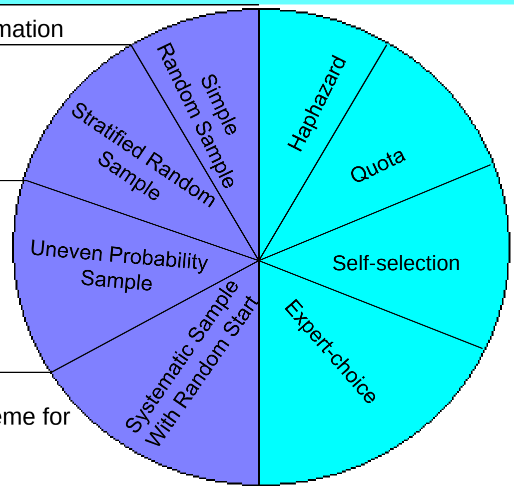
Probability based sample | Non-probability based sample

Little or no information

Not efficient if interested in the pattern of impact

Provides greatest flexibility, but must use weighting scheme in analysis

Most efficient scheme for mapping

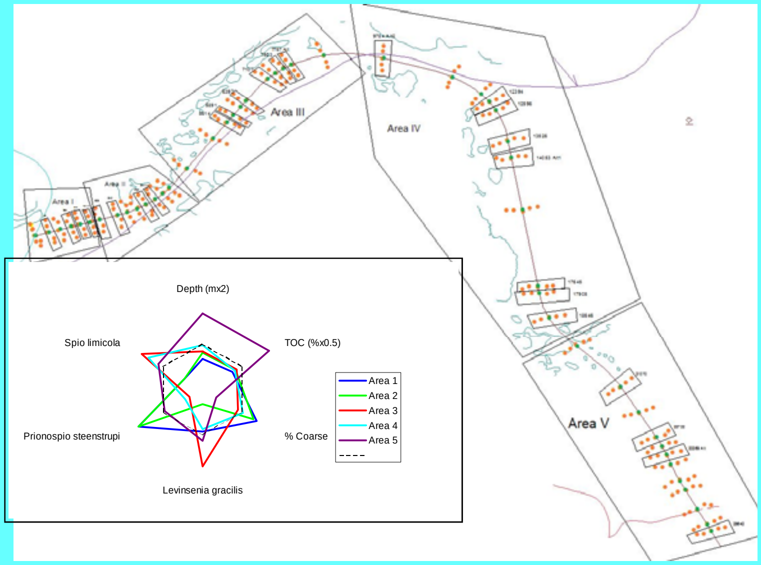


Biased, cannot be used to make inferences to the target population.

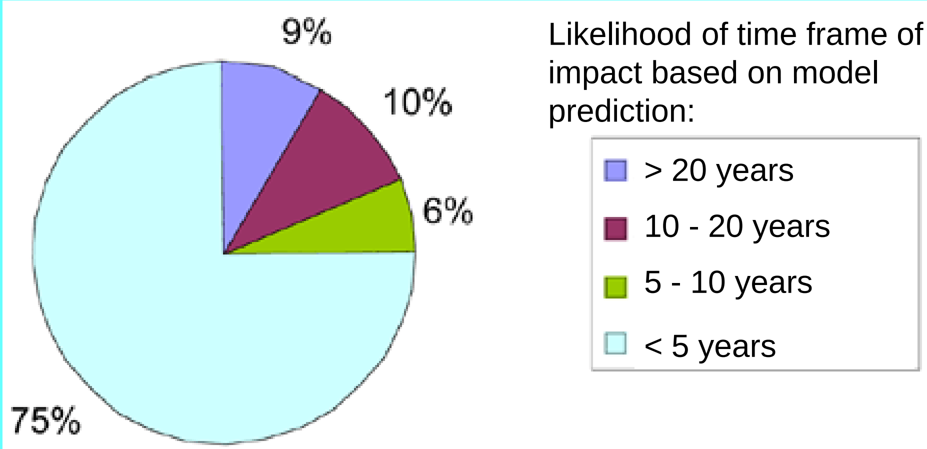
Environmental Sampling to Meet Objectives

Type	Description	Advantage	Disadvantage
Simple Random Sample	Each unit has the same probability of selection	Simple to conduct and analyze; No information	Samples often clumped
Stratified Random Sample	SRS within strata defined as more homogenous blocking of units	Smaller variance within strata; better spatial coverage than SRS; most efficient for estimating population attributes	Requires information, not efficient when interest is the pattern of characteristics or response
Uneven Probability Sample	Probability of selection is based on a known attribute such as the biological or economic significance, size, or location	Allows for the greatest flexibility in designing to meet objectives; conducted at the population level or within strata	A weighted statistical analysis must be conducted with the weights defined as a function of the unequal probabilities of selection
Systematic Sample with Random Start	Type of UPS; selecting the first unit based on SRS and selecting all remaining units at constant intervals based on distance, time, order, or a grid system; can use new random start for each strata	Easy and less costly to conduct in the field and provides a practical way of achieving evenly distributed samples while minimizing serial correlation; samples proportional to size in population; most efficient sampling scheme for mapping	Rare types may be under sampled; variance is overestimated; avoided when the target population displays periodicity associated with the same process being used to select samples

Environmental Sampling to Meet Objectives



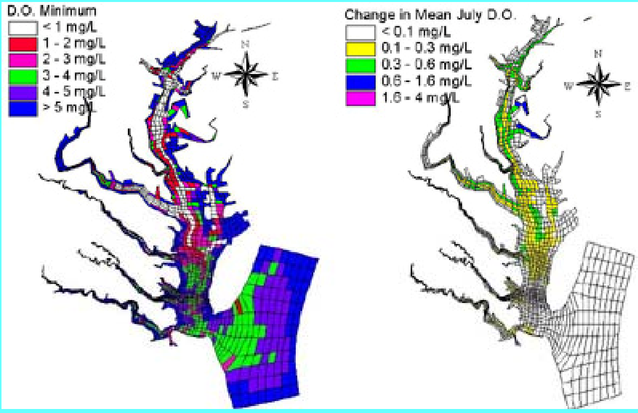
Uneven Probability Sampling



Likelihood of time frame of impact based on model prediction:

Environmental Sampling to Meet Objectives

- A GIS database with all of the available information can be used to develop a **sampling frame** (grid or point data which identifies all units in the target population) to aid in the sample selection process.

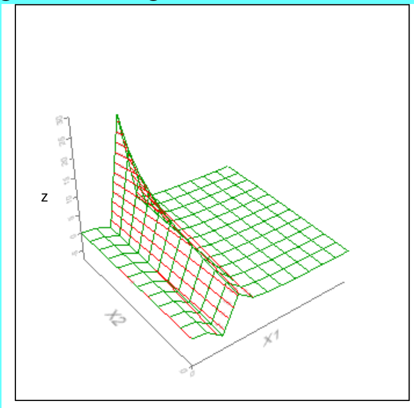


Environmental Sampling to Meet Objectives

- **Sampling for pattern** implies that the major interest is the pattern of dispersal (sediment) or impacts in space and time.
- **Sampling for modeling** implies that the major interest is in estimation of model parameters and model validation.
- Rarely does one sampling scheme meet both objectives.

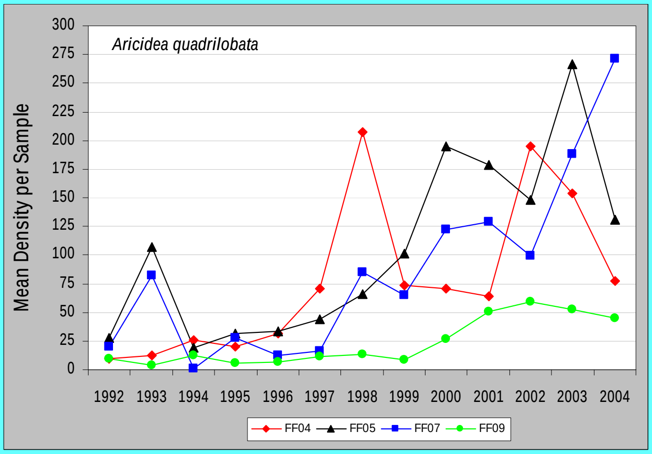
Environmental Sampling to Meet Objectives

- **Sampling for pattern** is better suited to systematic probability sampling to estimate responses located at nodes of a grid for a given level of resolution.



Spatial and Temporal Pattern and Resolution

- Mean density per 0.04-m^2 samples of a benthic worm common in four stations from Massachusetts Bay (Maciolek et al. 2005)

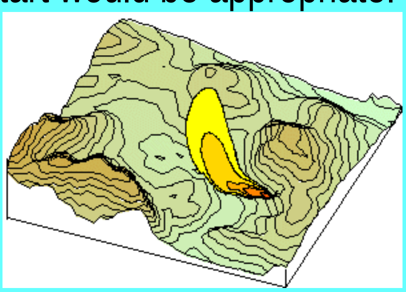


Spatial and Temporal Pattern and Resolution

- **Spatial pattern** is the composition and distribution of the target population across space which can be mapped on a plane in both latitude and longitude coordinates.
- The resolution of a sampling scheme in space is defined by the minimum distance between observations.
- The relationship between the variance in observations as a function of the distance between sampling locations is hypothesized to reflect processes at increasingly greater scales (local competition to regional geologic and climatic processes).

Spatial and Temporal Pattern and Resolution

- The sampling strategy employed for estimating a **spatial pattern** should reflect the scale appropriate for the intended inference.
- A map with estimated contours may be the desired outcome for which case a systematic sample with a random start would be appropriate.



Spatial and Temporal Pattern and Resolution

- **Temporal pattern** is the composition and distribution of the target population through time.
- Rarely do we have the luxury of a long time series of observations on the target population to evaluate changes in mean response or variance.
- Spatial variability can not be used to estimate temporal variation.
- Multi-year studies with samples collected during important seasonal fluctuations, for example the recruitment season for biological populations, is necessary to evaluate long term impacts or recovery.

Spatial and Temporal Pattern and Resolution

- For **temporal pattern**, if the intent is to determine the average value (status) over all sampling time points or if sampling is destructive, then a new sample of units is drawn each time period.
- The mean for the most recent time point can be estimated with either strategy.
- If the trend over time is desired, then often a single sample is revisited.

Spatial and Temporal Pattern and Resolution

- **Rotational sampling** balances goals (status vs. trends) by replacing a fixed fraction of the sampling sites each year with a new selection of units.
- A blending of both schemes is often the most cost effective.
- Overtime, if only fixed sites are sampled, annual estimate to the population mean become less and less representative.
- The precision and estimates of status are then improved over time as subsequent years of data are used to update site-specific estimates.

Limitations on Inference

- It is often not possible to narrowly define the objectives of a study.
- However, once the population and measurements, sampling frame, sampling strategy, and sample allocation has been determined, the scope of the study and any inferences that can be made are defined.

Types of Data

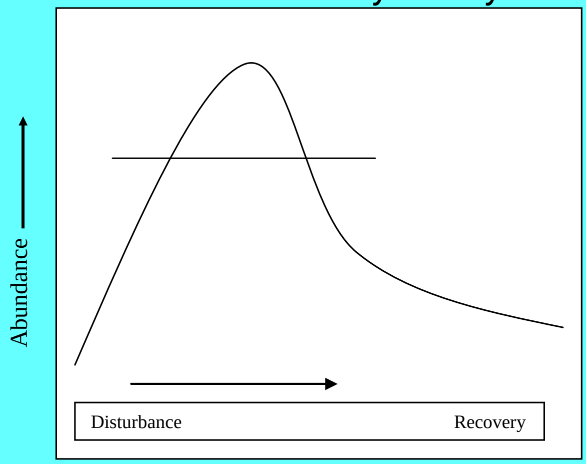
- Physical characteristics (hydrodynamic forces and direction, climatic condition, and landscape texture)
- Habitat characteristics (substrate, salinity, tidal influence, DO, redox potential discontinuity depth)
- Chemical characteristics in sediment and the water column (TOC, Metals, Organics)
- Biological characteristics (flora, fauna, population and community)
- Tissue chemistry and Bioaccumulation
- Toxicity and data
- Pathology and Behavior

Characteristics of Different Variables

- Scale of influence (genetic, cellular, organisms, local habitats, regional, global)
- State of nature, physical limitations (equilibrium, speciation, chemical attraction)
- Mobility through space (chemical transfer, disease, reproduction, trophic transfer)
- Influence on other variables
- Structure and function

What can be combined?

- Total abundance – why or why not?



Guidelines for Combining Variables

- Combination of variables should be appropriate for the scope and need of the specific question being asked
- Variables combined should be more similar in specific characteristics and should increase correlations with other variables
- Variables should be from similar sources, have similar structure, have similar behavior, and should co-vary
- Evaluate the information lost
- External influences should not confound differences between variables (e.g., local changes in redox potential and availability of metals)
- Averaging across space should make sense.

Weight of Evidence Approach

Step 1) Define the environmental component to be protected

Step 2) Develop lines of evidence and measurements to evaluate the component

Step 3) Assess the use and utility of measurements

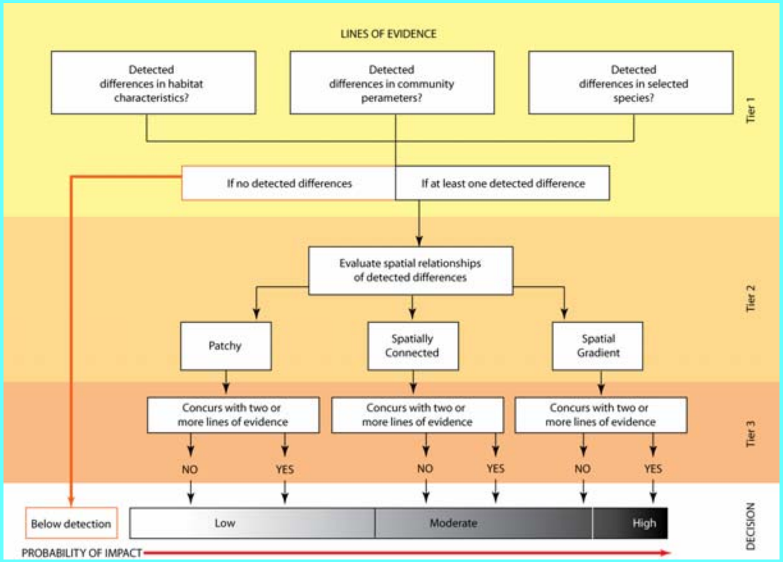
Step 4) Develop decision rules to relate the magnitude of the observed response to the expected environmental impact

Step 5) Evaluate results and integrate decisions with use and utility using a weighted mean

Assessing Use and Utility (from Menzies et al., 1996)

- Strength of Association between the Measurement Endpoint and Assessment Endpoint. The extent to which the measurement endpoint is representative of, correlated with, or applicable to the assessment endpoint.
- Stressor-specificity. The extent to which the measurement endpoint is associated with the specific stressor of concern.
- Availability of an Objective Measure for Judging Environmental Harm. The ability to judge results of the study against well-accepted standards, criteria, or objective measures.
- Quantitative. The degree to which numbers can be used to describe the magnitude of response of the measurement endpoint to the stressor.
- Site-specificity. The extent to which data, media, species, environmental conditions, and other factors reflect the site of interest.
- Quality of Data and Overall Study. The degree to which data quality objectives and other recognized characteristics of high quality studies are met.
- Sensitivity of the Measurement Endpoint for Detecting Changes. The ability to detect a response in the measurement endpoint.
- Spatial Representativeness. The degree of compatibility between the study area, location of measurements or samples, locations of stressors, and locations of ecological receptors and their points of exposure.
- Temporal Representativeness. The temporal compatibility between the measurement endpoint and the period during which effects of concern would occur.
- Correlation of Stressor to Response. The degree to which a correlation is observed between levels of response, and the strength of that correlation.
- Use of a Standard Method. The extent to which the study follows specific protocols recommended by a scientific authority for conducting the method correctly.

Tiered approach to determining the level of the probability of an impact to the structure and function of the benthic community following an impact



Evaluate Contours of Magnitude and Extent of Change Over Time

Time

Impacts	Benefits
Limited movement of coarse-grained sediment; woody debris; marine nutrients	
Scour river bed Cut banks/ erosion Alter river channel Log dams/ flooding Raise river bed	Increase distribution of cobbles, gravel, sand; organic matter Nurishment of flood plain
Sedimentation of nearshore Habitat and benthic community change	Reduce river temperature, disease Marine nutrients moved up stream and into uplands Increase fishery/ food-web complexity
	Expansion of eelgrass beds Shift in flora and fuana within esturary Build up of spit/ beaches

The End

References

- Adams, S.M. 2003. Establishing causality between environmental stressors and effects on aquatic ecosystems. *Human and Ecological Risk Assessment,* Vol. 9, No.1, pp. 17-35.
- Maciolek, N.J., R.J. Diaz, D.T. Dahlen, B. Hecker, I.P. Williams, and C. Hunt. 2005. 2004 Outfall Benthic Monitoring Report. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2005-15. 134 pages plus appendices.
- Menzie, C., M.H. Henning, J. Cura, K. Finkelstein, J. Gentile, J. Maughan, D. Mitchell, S. Petron, B. Potocki, S. Svirsky and P. Tyler. 1996. "Special Report of the Massachusetts Weight-of-Evidence Workgroup: A Weight-of-Evidence Approach to Evaluating Ecological Risks." *Human and Ecological Risk Assessment,* Vol. 2, No.2, pp. 277-304.

Added notes on Monitoring Design

Ellis Joanne, I. and Schneider, David C. 1996. Evaluation of a gradient sampling design for environmental impact assessment. Environmental Monitoring and assessment 48:157-172.

- The authors compared the sensitivity of a gradient design to randomized sampling within an impact and control area using data from an oil platform. They found the gradient design to be more sensitive. Further, they found that reference site selection is often too arbitrary (far enough away that it is unaffected by the disturbance and yet close enough that the areas are compatible). They stated that the gradient design removes the problem of selecting a reference site.

- The authors also made a case suggesting that the gradient design and results are easy to interpret and present to the public. *The spatial scale of an impact is an important question in policy formulation…such questions are more directly addressed with a graph of gradients than with an ANOVA table.*

Added notes on Monitoring Design

Ellis, J.I., Schneider, D.C., and Thrush, S.F. 2000. Detecting anthropogenic disturbance in an environment with multiple gradients of physical disturbance, Manukau Harbour, New Zealand. Hydrobiologia 440:379-391.

- The authors warn that the presence of large physical gradients (i.e., salinity, grain size) can confound the ability to detect the disturbance with a simple gradient design. Separation of the relative effects of these two factors if not accounted for in the design are difficult.

Parker, K.R. and Wiens, J.A. 2005. Assessing recovery following environmental accidents: environmental variation, ecological assumptions, and strategies. Ecological Applications 15:2037-2051.

- This paper defines different types of equilibrium (steady-state, spatial equilibrium, and dynamic equilibrium) and evaluates the meaning and ability through statistical design of determining recovery under each type. They state that inference about recovery is strengthened when an observed significant difference following impact is reduced and becomes no longer detectable through time, thus, providing a rationale for the strength of a multiyear study.

Added notes on Monitoring Design

Parker, K.R. and Wiens, J.A. 2005. continued

- The authors remind the reader that the null hypothesis of no impact is not "accepted", and can only be rejected. Thus, conclusions about recovery should be decided in the context of Type II errors. The impact of this statement is even more important considering the low numbers of field replicates and high variability generally observed. When the null hypothesis in not rejected, we must determine the power of the test and assess the level of change that has occurred. To further protect against falsely declaring recovery, a high alpha-level (0.2) can be used.
- The authors provide some design-related benefits and disadvantages. Random sampling during a multiyear study allows inference to both the reference and proposed impact area. Further, pre-impact relationships (spatial correlation and variation) between the two areas can be determined. Finally, they state that there is no single "best" study design or statistical analysis that will fit all situations. The scale of the impact is usually well-defined, whereas scales of interdependencies among biological resources and their environments and of natural dynamics are generally unknown, at least with any degree of precision.

Added notes on Monitoring Design

Skalski, J.R., Coats, D.A., and Fukuyama, A.K. 2001. Criteria for oil spill recovery: a case study of the intertidal community of Prince William Sound, Alaska, following the Exxon Valdez oil spill. Environmental Management 28:9-18.

- The authors demonstrate alternative statistical endpoints to identify recovery. Differences in population or community levels between control and impacted sites are not a consideration in assessing recovery, only the relative patterns of the temporal trends are of interest … after sufficient time, profiles of control and impacted sites will begin to track or parallel each other as impacted sites begin responding solely to the same regional climatic changes or oceanographic condition as the reference sites. The authors state that there is no reason to expect mean population levels at a control and impacted site to be the same even in the absence of the impact. Because site differences cannot be randomized over treatment level (impacted or not), recovery assessments based on the direct comparison of means are statistically indefensible.

- Repeated observations on the same locations are correlated through time and can not be considered independent. These dependent data violate the assumption of independence necessary for most classical univariate statistical methods. Multivariate repeated measures and profile analysis can be used to test for impact and recovery.

Added notes on Monitoring Design

Stewart-Oaten, A. and Bence, J.R. 2001. Temporal and spatial variation in environmental impact assessment. Ecological Monographs 71:305-339.

- The authors state in their introduction that impacts associated with an alteration will produce at least some local effects. They go on to say that there will be sites near enough to the alteration site to experience similar large-scale natural fluctuations in seasons, weather, current movements, etc., but distant enough to be little affected by the alteration. Thus, they have implicitly set the stage for a gradient of responses across distance from the alteration site within a given time frame. However, the purpose of their paper is to contrast two t-test/interval-based approaches to estimating the effect of the impact, Intervention Analysis (the comparison of a before and after alteration time series of responses) and Impact vs. Reverence sites (IVRS) analysis. The authors include the Before-After, Control-Impact (BACI) design as a two time-point Intervention Analysis where the variable of interest is the difference in the response between sites (Impact-Control) at each time-point. The variance for testing is calculated from before and after differences from several control and impact sites. Alternatively, the IVRS analysis compares the differences between time-points (After-Before) at each location (Figure 1). In both analyses, the intent is to estimate the mean effect of the impact on variable A which could represent the abundance of a given species or the number of species.

Time	Impact Site	Control Site	Difference	Source of Variation	BACI Test
Before = t1	AI_{t1}	AC_{t1}	AI_{t1} - AC_{t1}	Spatial	Before Difference =
After = t2	AI_{t2}	AC_{t2}	AI_{t2} - AC_{t2}	Spatial + Impact	After Difference
Difference	AI_{t2} - AI_{t1}	AC_{t2} - AC_{t1}			
Source of Variation	Time + Impact	Time			
IVRS Test	Control Difference =	Impact Difference			

Figure 1. Comparison of the BACI and the IVRS analysis for variable A

Added notes on Monitoring Design

Stewart-Oaten, A. and Bence, J.R. 2001. continued

- The null hypothesis for the BACI design is that the difference in location plus impact is equal to the difference in location only. The error for testing is achieved by having many time-points before and after the impact or multiple control sites. Whereas the null hypothesis for the IVRS design is that the change across time at the impact site is equal to the change across time at the reference site. The error for testing is obtained by having many reference sites. The effect of time alone can add a substantial amount of variability that has the potential to swamp the effect of the impact. Likewise, if the spatial variability between the impact and control site is too large, it can also swamp the effect of the impact.
- The paper discusses problems associated with an unknown spatial extent of the impact, autocorrelation in space or time, and the lack of consistency in spatial variation through time. The paper also discusses variance for testing based on temporal variation, spatial variation, and sampling error and the associated assumptions. Their discussion of spatial variability is limited to its application for testing the before and after differences. There is only one mention of evaluating the gradient associated with distance from the impact site.