Environmental Study Designs

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- Minnow Environmental Inc.

Overview

1. What is the goal of environmental studies?
2. What is meaningful variation vs. noise?
3. Flowchart for environmental study designs?

Roger H. Green (1979). Sampling design and statistical methods for environmental biologists.

Bowman and Somers (2005). Considerations when using the Reference Condition Approach for Bioassessment of Freshwater Ecosystems. Water Quality Research Journal of Canada. pp347-360

What is the goal of environmental studies?

- Ultimate goal: Evaluate the effects of *environmental factors* on species in a biological community

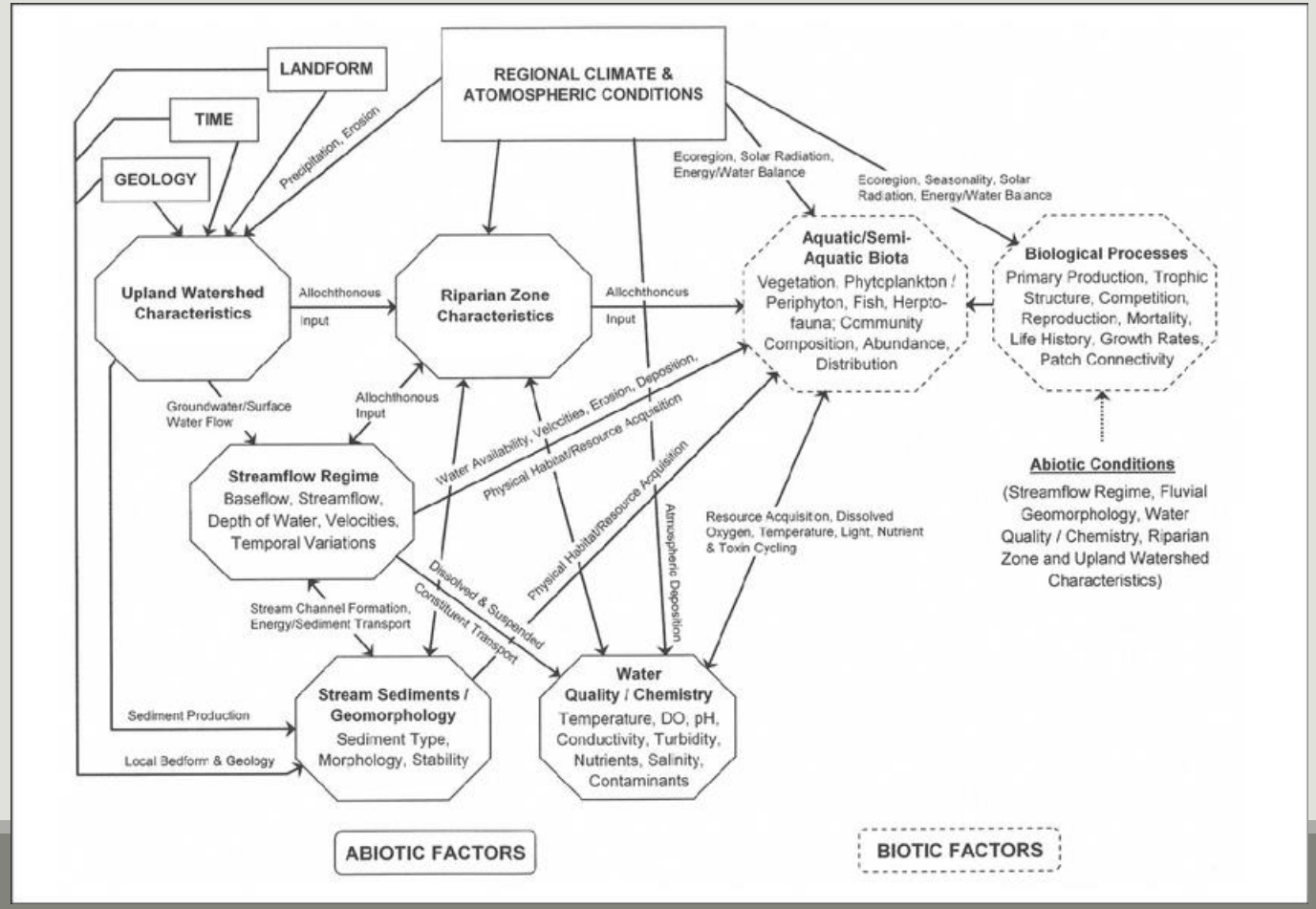
What is the goal of environmental studies?

- Proximate Goal: Design a sampling program to obtain *data* for analysis by some statistical method, to test whether there is in fact evidence of an effect on the biota, and to describe efficiently any demonstrated effects

  - Design a sampling program to obtain *data*
  - Analysis by some statistical method
  - Test whether there is in fact evidence of an effect
  - Describe efficiently any demonstrated effects

What is meaningful variation vs. noise?

- Biological systems are inherently complex



Modified from Scott et al. (2005)

Scott, M. L., A. M. D. Brasher, E. Reynolds, A. Caires, and M. E. Miller. 2005. The structure and functioning of riparian and aquatic ecosystems of the Colorado Plateau – conceptual models to inform monitoring. U.S. Department of the Interior, U.S. Geological Survey, Fort Collins, CO

4 Examples:

1. Early warning of environmental deterioration at the site of a new effluent source by monitoring to detect changes in species composition
2. Determine the impact, if any, of existing point-source pollution by assessing the spatial patterns of species composition in adjacent areas
3. Classify a series of habitats on the basis of their environments and biotas to assignment to different management zones
4. Determine whether a community has changed over time, given a series of annual species lists

Table 1.1 Sampling and analysis properties for four environmental studies objectives

Objective	
Spatial biological pattern	
Natural environment spatial pattern	
Pollutant	
Distribution of samples in space	
Temporal biological change	
Natural environmental temporal change	
Distribution of samples over time	

Table 1.1 Sampling and analysis properties for four environmental studies objectives

Objective	I Warning of Environmental Deterioration
Spatial biological pattern	
Natural environment spatial pattern	
Pollutant	
Distribution of samples in space	Experimental and control station, each with replication
Temporal biological change	
Natural environmental temporal change	
Distribution of samples over time	

Table 1.1 Sampling and analysis properties for four environmental studies objectives

Objective	I Warning of Environmental Deterioration
Spatial biological pattern	
Natural environment spatial pattern	
Pollutant	
Distribution of samples in space	Experimental and control station, each with replication
Temporal biological change	
Natural environmental temporal change	
Distribution of samples over time	Equal intervals, to continue indefinitely

Table 1.1 Sampling and analysis properties for four environmental studies objectives

Objective	I Warning of Environmental Deterioration
Spatial biological pattern	
Natural environment spatial pattern	Noise
Pollutant	To be detected
Distribution of samples in space	Experimental and control station, each with replication
Temporal biological change	
Natural environmental temporal change	Noise
Distribution of samples over time	Equal intervals, to continue indefinitely

Table 1.1 Sampling and analysis properties for four environmental studies objectives

Objective	I Warning of Environmental Deterioration
Spatial biological pattern	Noise
Natural environment spatial pattern	Noise
Pollutant	To be detected
Distribution of samples in space	Experimental and control station, each with replication
Temporal biological change	Information
Natural environmental temporal change	Noise
Distribution of samples over time	Equal intervals, to continue indefinitely

Table 1.1 Sampling and analysis properties for four environmental studies objectives

Objective	2 Pattern and Point-Source Pollution
Spatial biological pattern	
Natural environment spatial pattern	
Pollutant	Exists
Distribution of samples in space	
Temporal biological change	
Natural environmental temporal change	
Distribution of samples over time	

Table 1.1 Sampling and analysis properties for four environmental studies objectives

Objective	2 Pattern and Point-Source Pollution
Spatial biological pattern	
Natural environment spatial pattern	
Pollutant	Exists
Distribution of samples in space	
Temporal biological change	
Natural environmental temporal change	
Distribution of samples over time	

Table 1.1 Sampling and analysis properties for four environmental studies objectives

Objective	2 Pattern and Point-Source Pollution
Spatial biological pattern	
Natural environment spatial pattern	
Pollutant	Exists
Distribution of samples in space	Many stations on a grid, each with replication
Temporal biological change	
Natural environmental temporal change	
Distribution of samples over time	At least two different times

Table 1.1 Sampling and analysis properties for four environmental studies objectives

Objective	2 Pattern and Point-Source Pollution
Spatial biological pattern	Information
Natural environment spatial pattern	Noise
Pollutant	Exists
Distribution of samples in space	Many stations on a grid, each with replication
Temporal biological change	Noise
Natural environmental temporal change	Noise
Distribution of samples over time	At least two different times

Table 1.1 Sampling and analysis properties for four environmental studies objectives

Objective	3 Habitat Classification
Spatial biological pattern	
Natural environment spatial pattern	
Pollutant	May exist along with other environmental factors
Distribution of samples in space	
Temporal biological change	
Natural environmental temporal change	
Distribution of samples over time	

Table 1.1 Sampling and analysis properties for four environmental studies objectives

Objective	3 Habitat Classification
Spatial biological pattern	Information
Natural environment spatial pattern	Information
Pollutant	May exist along with other environmental factors
Distribution of samples in space	In different habitats, preferably with replication
Temporal biological change	Noise
Natural environmental temporal change	Noise
Distribution of samples over time	Preferably two different times

Table 1.1 Sampling and analysis properties for four environmental studies objectives

Objective	4 Community Change from Species Lists
Spatial biological pattern	
Natural environment spatial pattern	
Pollutant	
Distribution of samples in space	
Temporal biological change	
Natural environmental temporal change	
Distribution of samples over time	

Table 1.1 Sampling and analysis properties for four environmental studies objectives

Objective	4 Community Change from Species Lists
Spatial biological pattern	Not relevant
Natural environment spatial pattern	Not relevant
Pollutant	Perhaps relevant to subsequent evaluation
Distribution of samples in space	Not relevant
Temporal biological change	Information
Natural environmental temporal change	Information
Distribution of samples over time	Long series, preferably at equal intervals

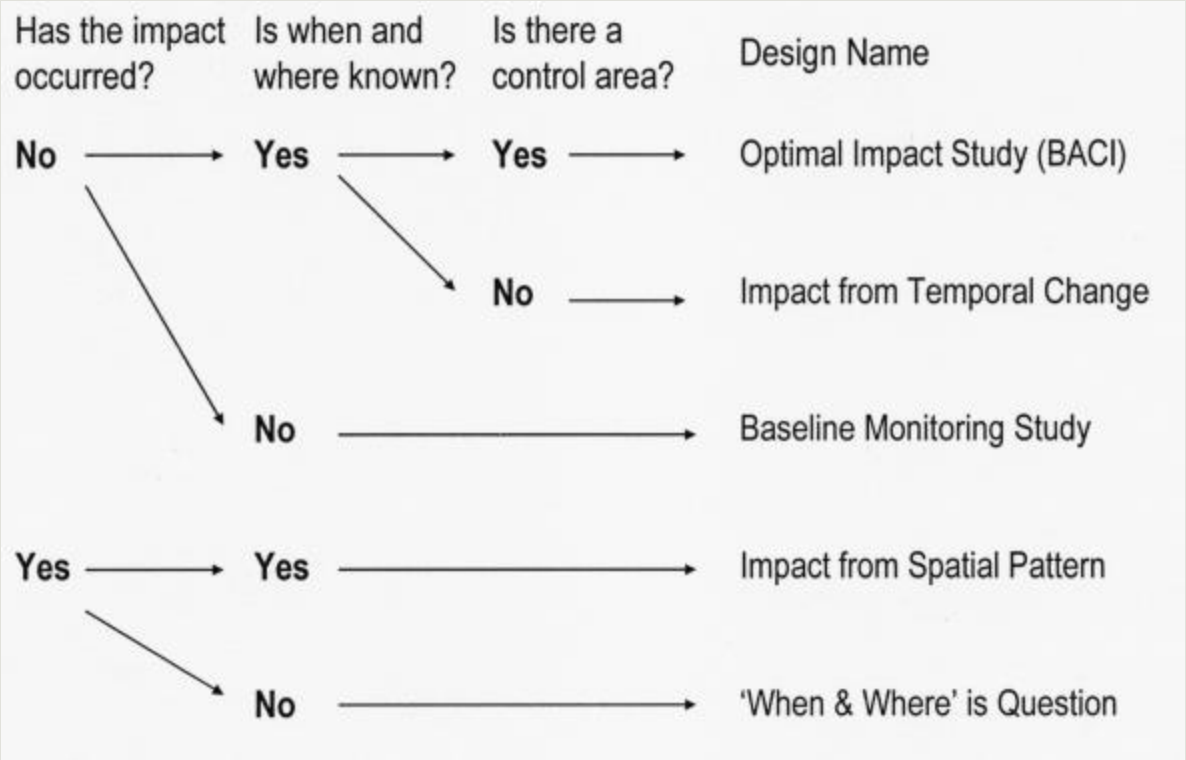
Table 1.1 Sampling and analysis properties for four environmental studies objectives

Objective	1 Warning of Environmental Deterioration	2 Pattern and Point-Source Pollution	3 Habitat Classification	4 Community Change from Species Lists
Spatial biological pattern	Noise	Information	Information	Not relevant
Natural environment spatial pattern	Noise	Noise	Information	Not relevant
Pollutant	To be detected	Exists	May exist along with other environmental factors	Perhaps relevant to subsequent evaluation
Distribution of samples in space	Experimental and control station, each with replication	Many stations on a grid, each with replication	In different habitats, preferably with replication	Not relevant
Temporal biological change	Information	Noise	Noise	Information
Natural environmental temporal change	Noise	Noise	Noise	Information
Distribution of samples over time	Equal intervals, to continue indefinitely	At least two different times	Preferably two different times	Long series, preferably at equal intervals

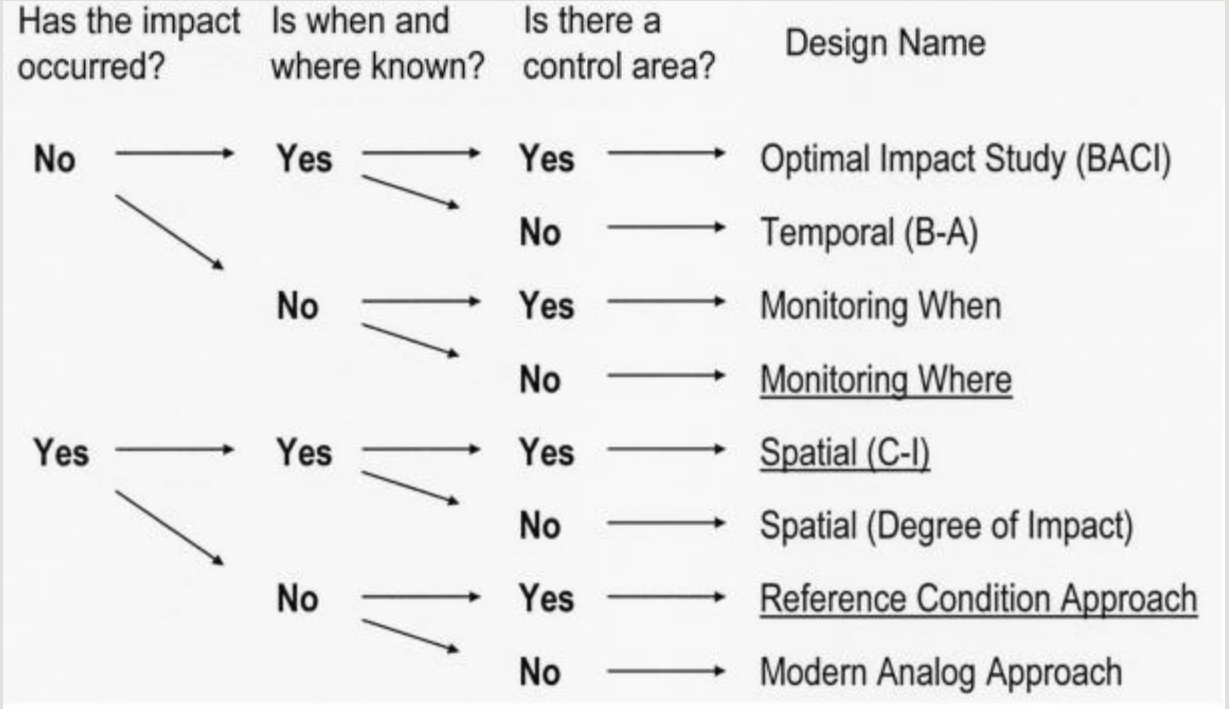
Flowchart for environmental study designs

1. Has an impact occurred?
2. Is when and where known?
3. Is there a control Area?

Flowchart for environmental study designs

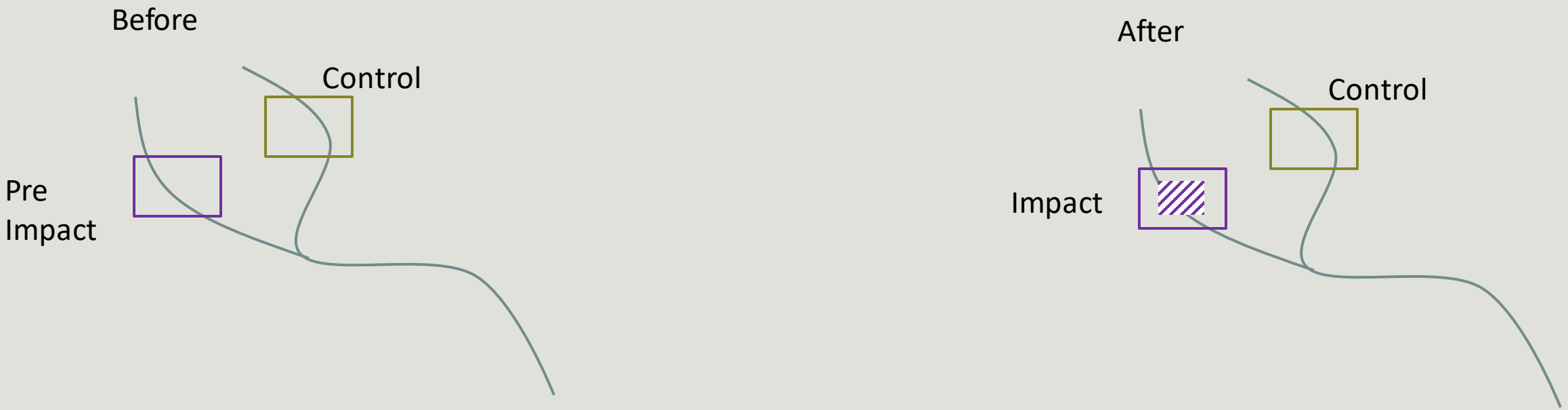


Flowchart for environmental study designs

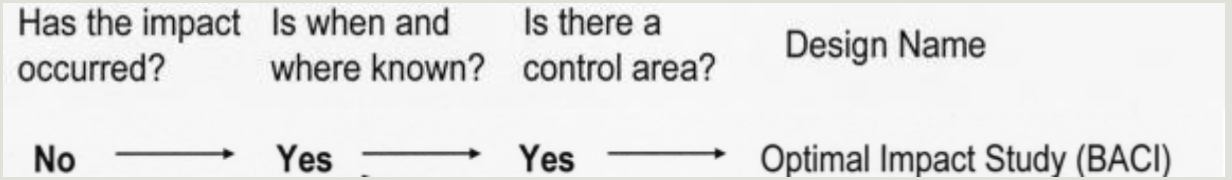


Flowchart for environmental study designs

Has the impact occurred?	Is when and where known?	Is there a control area?	Design Name
No →	**Yes** →	**Yes** →	Optimal Impact Study (BACI)



Flowchart for environmental study designs



Statistical Method:

- ANOVA (lm/glm):
  - Y~ Area (CI) + Time(BA) + **Area*Time**

Flowchart for environmental study designs

Has the impact occurred?	Is when and where known?	Is there a control area?	Design Name
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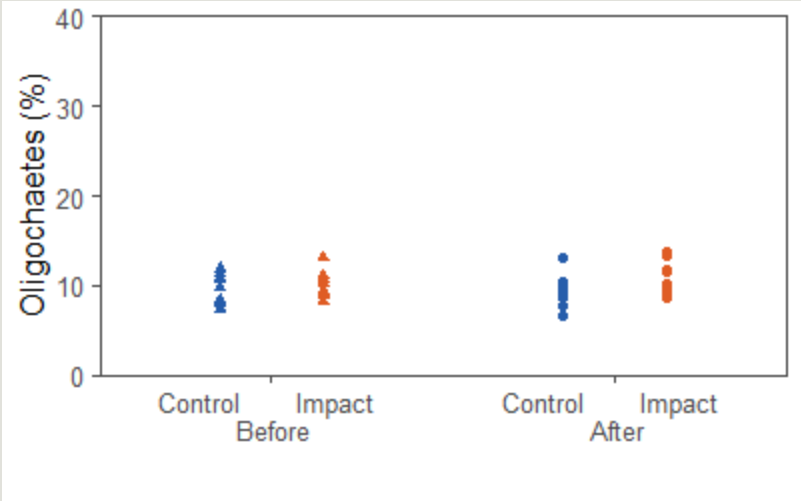
Y~ ~~Area~~ + ~~Time~~ + ~~**Area*Time**~~



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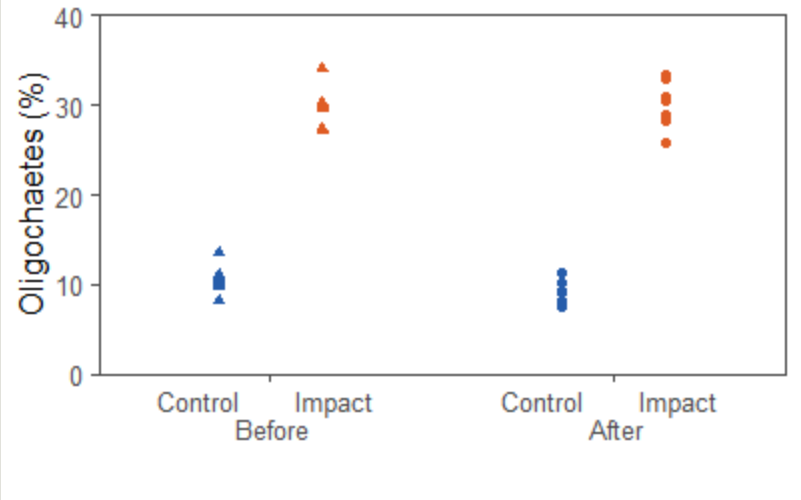
Y~ Area + ~~Time~~ + ~~**Area*Time**~~



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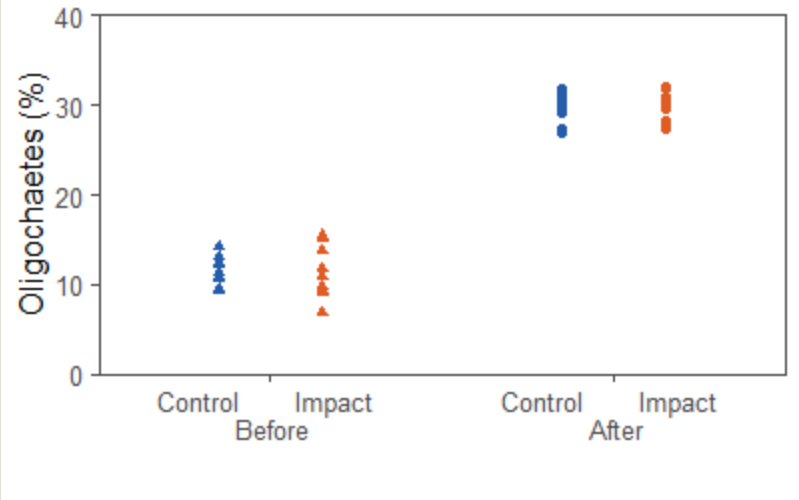

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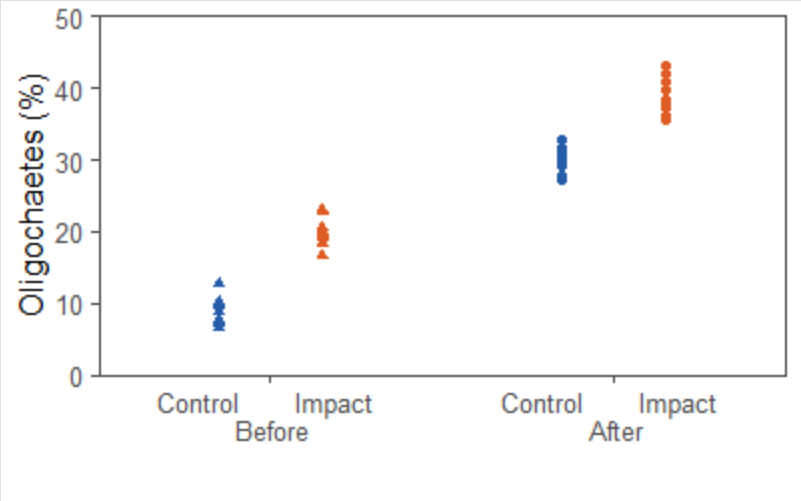
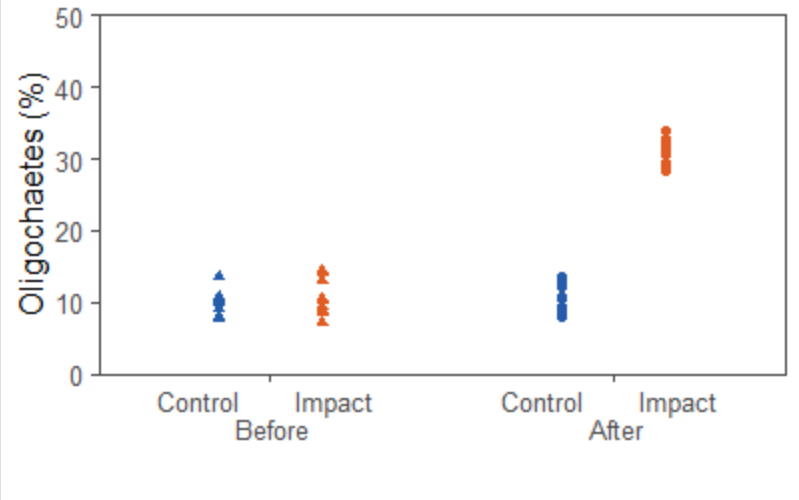
Y~ Area + Time + ~~Area*Time~~



Flowchart for environmental study designs

Has the impact occurred?	Is when and where known?	Is there a control area?	Design Name
No →	**Yes** →	**Yes** →	Optimal Impact Study (BACI)

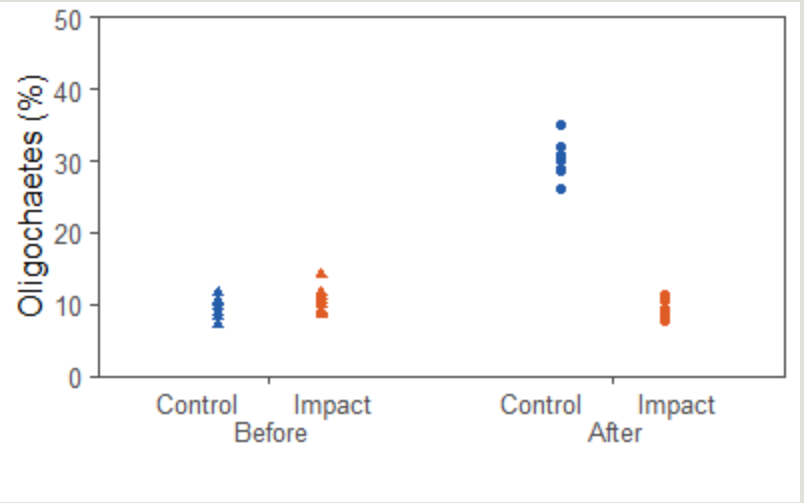
Y~ Area + Time + **Area*Time**

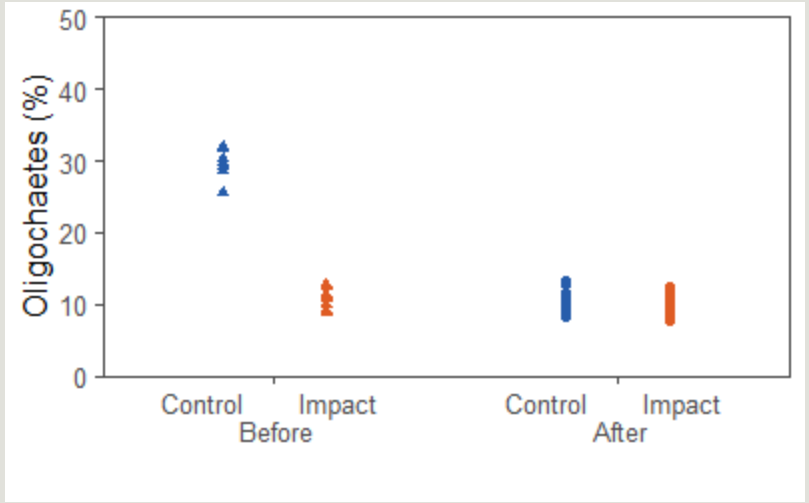


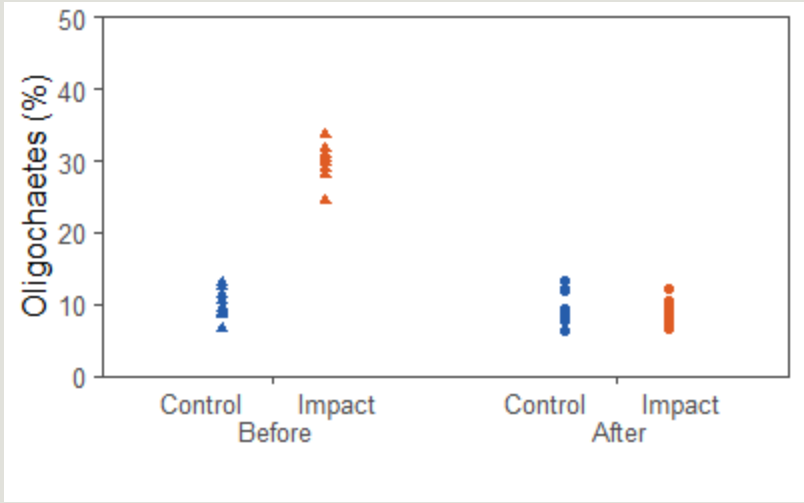
Flowchart for environmental study designs

Has the impact occurred?	Is when and where known?	Is there a control area?	Design Name
No →	**Yes** →	**Yes** →	Optimal Impact Study (BACI)

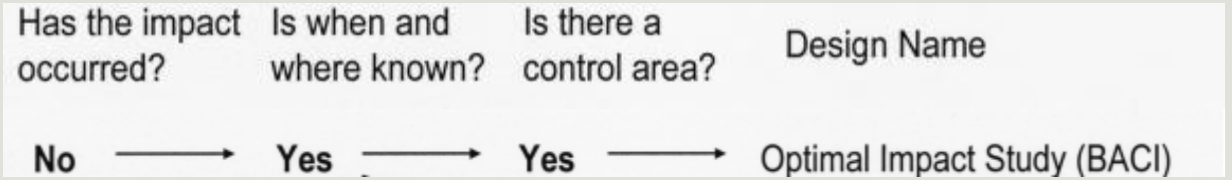
Y~ Area + Time + **Area*Time?**







Flowchart for environmental study designs



- **Pseudoreplication**
- **Additivity**
- **Homogeneity of variance**
- **Confounding factors**
- **Sampling frequency**
- **Sample Independence**
- **Transformations/non-normal sample distributions**

Smith, E. P., Orvos, D. R., & Cairns Jr, J. (1993). Impact assessment using the before-after-control-impact (BACI) model: concerns and comments. *Canadian Journal of Fisheries and Aquatic Sciences*, *50*(3), 627-637.

Stewart-Oaten, A., Murdoch, W. W., & Parker, K. R. (1986). Environmental impact assessment:" Pseudoreplication" in time?. *Ecology*, *67*(4), 929-940.

Hurlbert, S. H. (1984). Pseudoreplication and the design of ecological field experiments. *Ecological monographs*, *54*(2), 187-211.

Many many more…

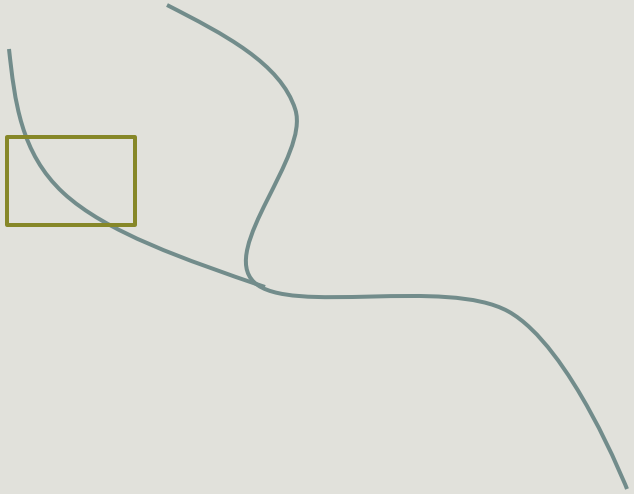
Flowchart for environmental study designs

Has the impact occurred?	Is when and where known?	Is there a control area?	Design Name
No →	Yes		
		No →	Temporal (B-A)

Before

After

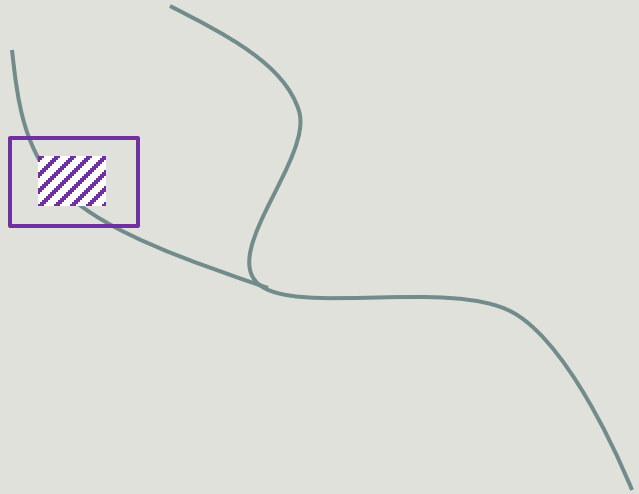
Control



Statistical Method:

- ANOVA:
  - Y~ **Time**

Impact



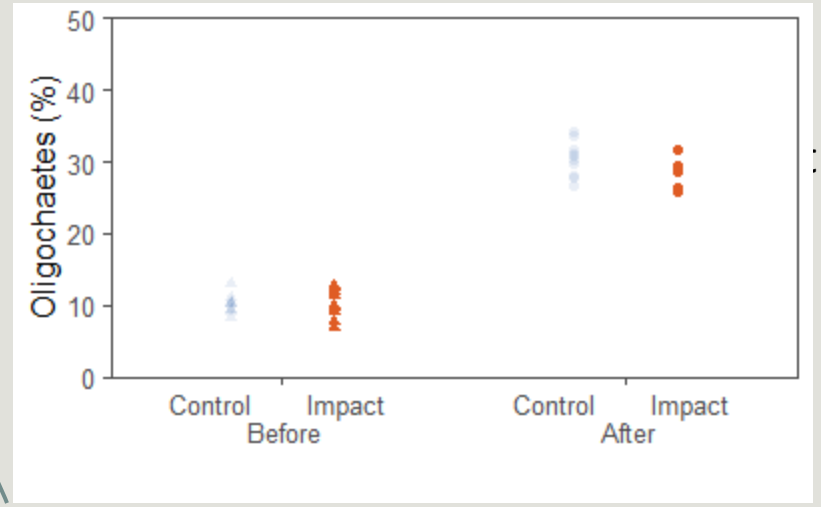
Flowchart for environmental study designs

Has the impact occurred?	Is when and where known?	Is there a control area?	Design Name
No →	Yes →		
		No →	Temporal (B-A)

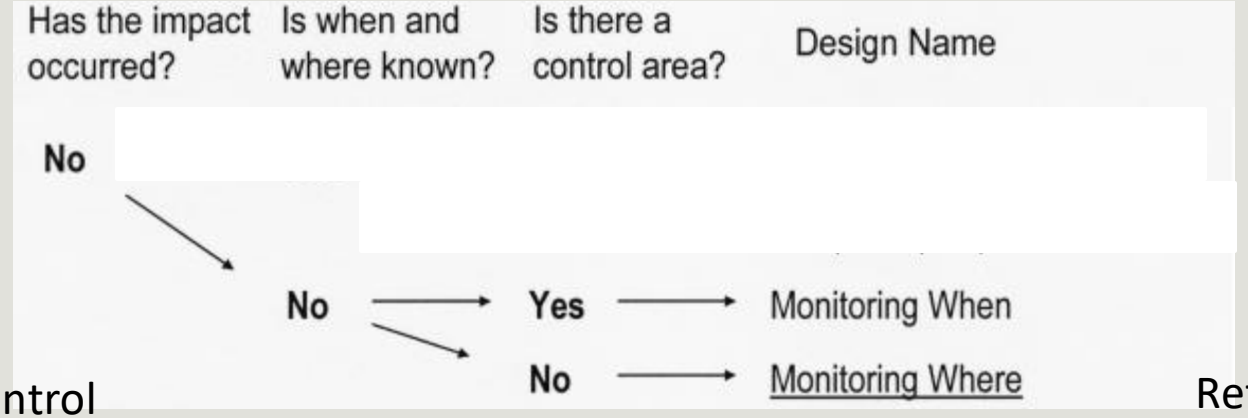
Before

After

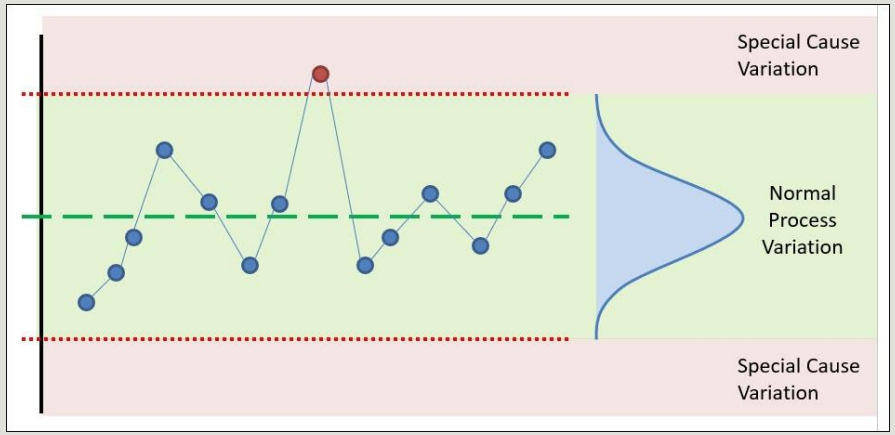
Control



Flowchart for environmental study designs

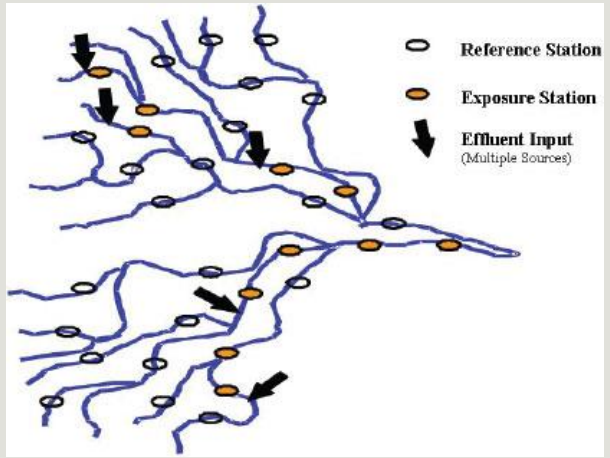


Statistical process control



Arciszewski, T.J., R.R. Hazewinkel, K.R. Munkittrick and B.W. Kilgour. 2018. Developing and applying control charts to detect changes in water chemistry parameters measured in the Athabasca River near the oil sands: A tool for surveillance monitoring. Environmental Toxicology and Chemistry, 37(9)2296–2311.

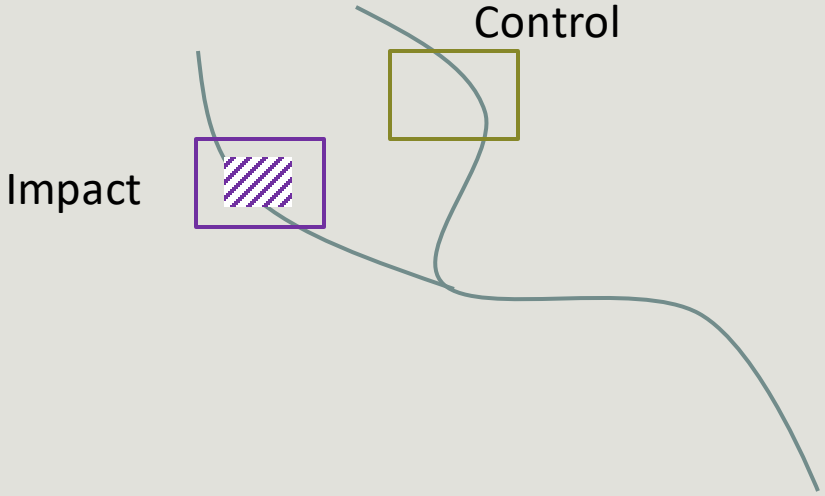
Reference Condition Approach



Bailey, R. C., Kennedy, M. G., Dervish, M. Z., & Taylor, A. R. M. (1998). Biological assessment of freshwater ecosystems using a reference condition approach: comparing predicted and actual benthic invertebrate communities in Yukon streams. *Freshwater Biology*, *39*(4), 765-774.

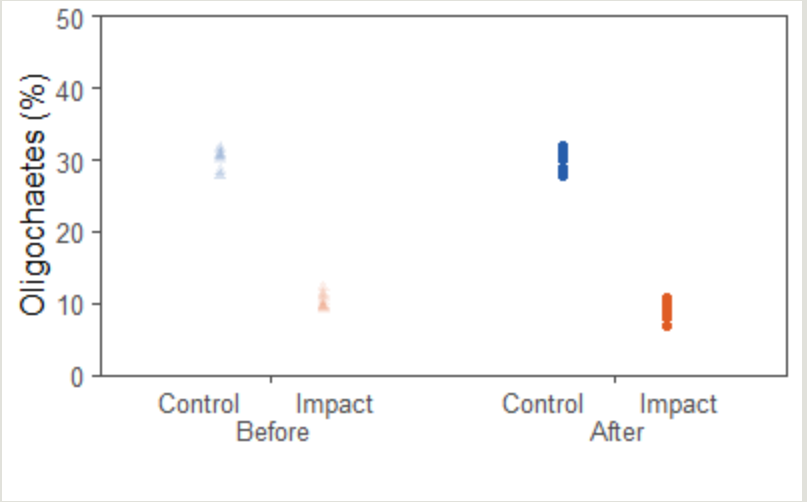
Flowchart for environmental study designs

Has the impact occurred?	Is when and where known?	Is there a control area?	Design Name
Yes →	Yes →	Yes →	Spatial (C-I)



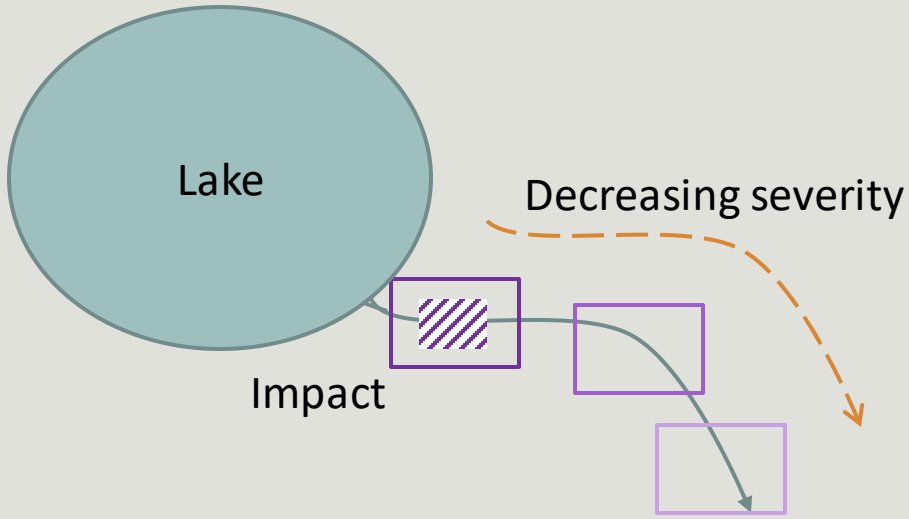
Statistical Method:

- ANOVA:
  - Y~ **Area**



Flowchart for environmental study designs

Has the impact occurred?	Is when and where known?	Is there a control area?	Design Name
Yes →	Yes		
		No →	Spatial (Degree of Impact)

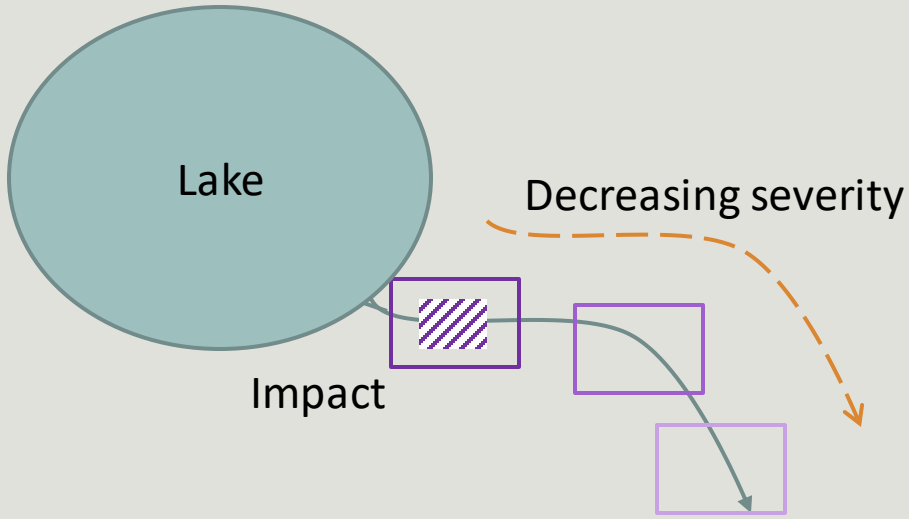


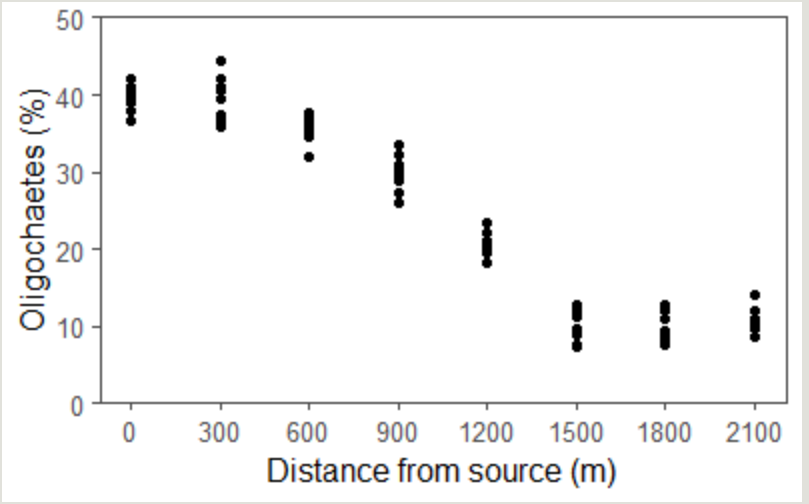
Statistical Method:

- ANOVA/Regression:
  - Y~ **Area**
  - **ANOVA if there are few samples and are equally distant, otherwise consider step-wise regression**

Flowchart for environmental study designs

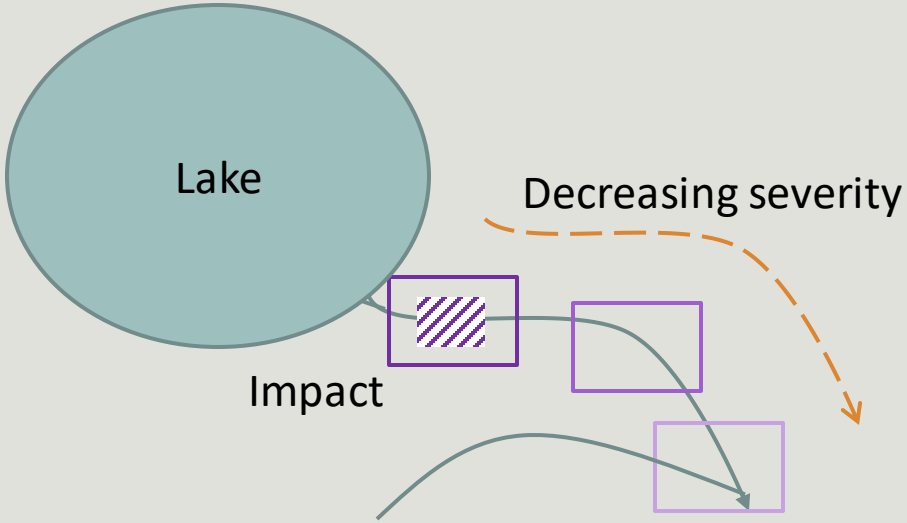
Has the impact occurred?	Is when and where known?	Is there a control area?	Design Name
Yes →	Yes		
		No →	Spatial (Degree of Impact)

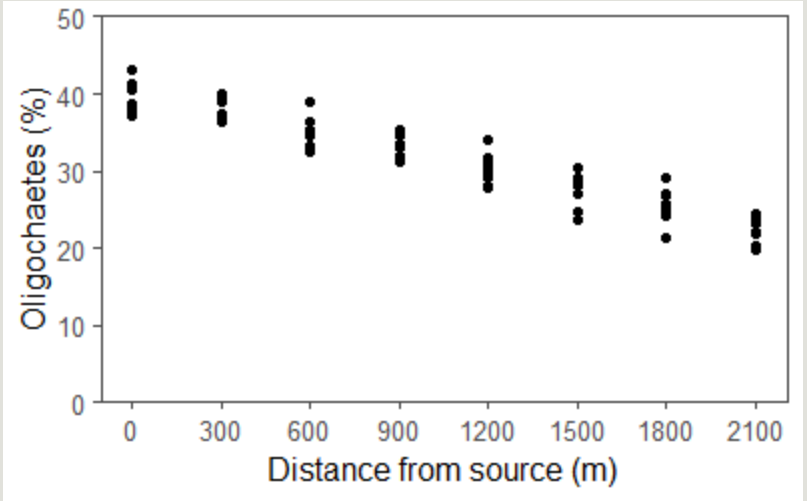




Flowchart for environmental study designs

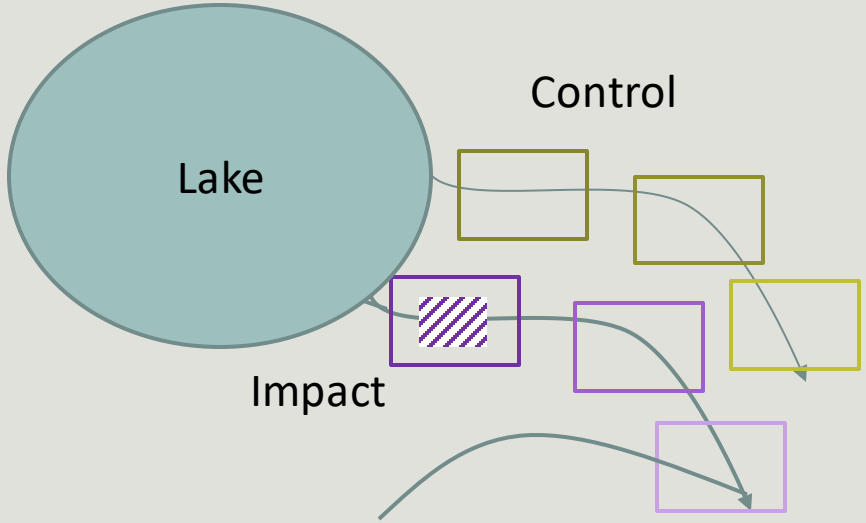
Has the impact occurred?	Is when and where known?	Is there a control area?	Design Name
Yes →	Yes		
		No →	Spatial (Degree of Impact)

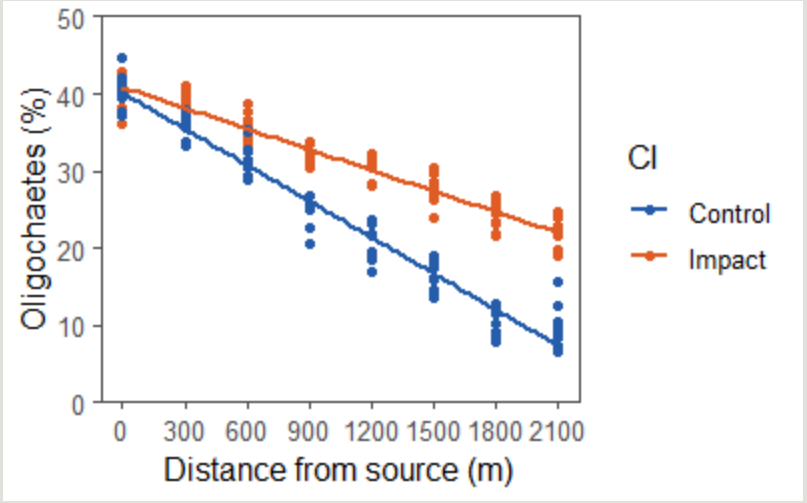




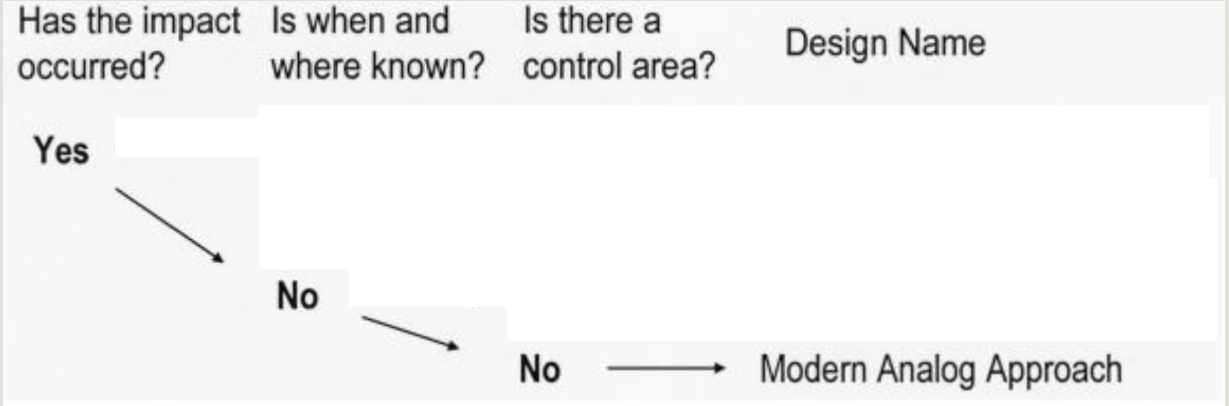
Flowchart for environmental study designs

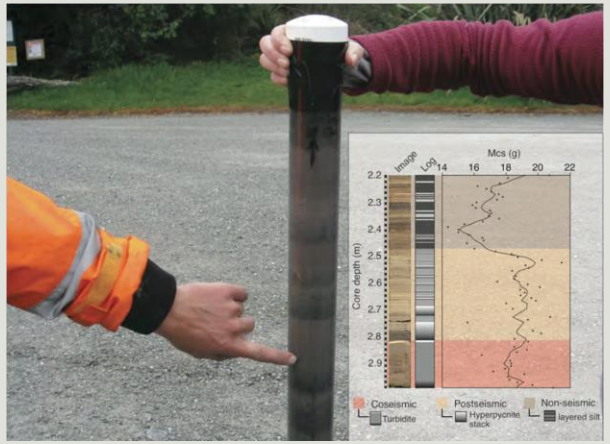
Has the impact occurred?	Is when and where known?	Is there a control area?	Design Name
Yes →	Yes		
		No →	Spatial (Degree of Impact)





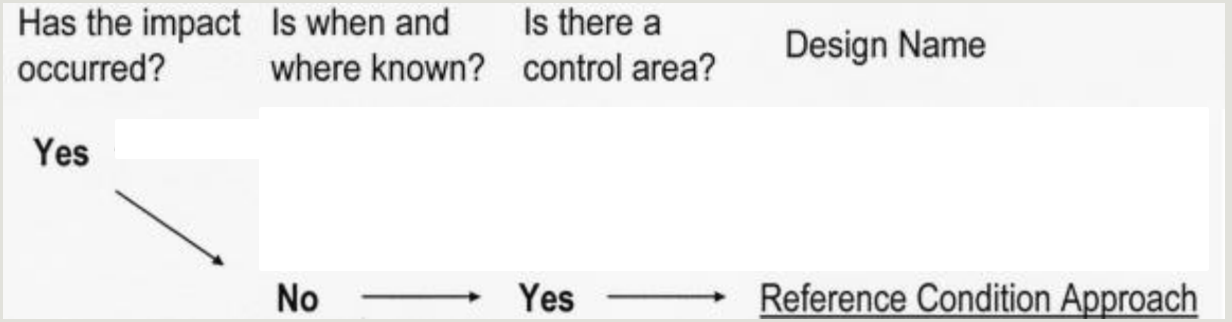
Flowchart for environmental study designs





Kurek, J., Kirk, J. L., Muir, D. C., Wang, X., Evans, M. S., & Smol, J. P. (2013). Legacy of a half century of Athabasca oil sands development recorded by lake ecosystems. *Proceedings of the National Academy of Sciences*, *110*(5), 1761-1766.

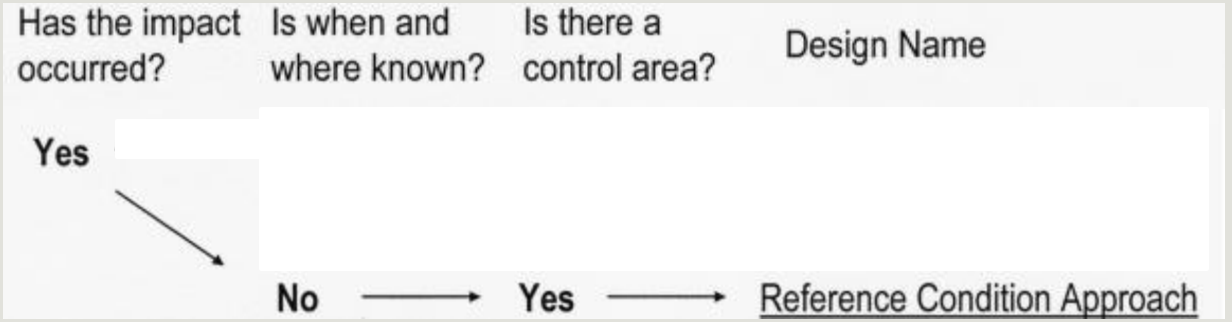
Flowchart for environmental study designs



Compare potentially impacted "Test" sites to a pool of minimally impacted "Refence" Sites.

1. Select Minimally Impacted Reference Sites
2. [Group Reference Sites into Biologically similar types based on abiotic features unrelated to the stressor (i.e. watershed area)]
3. Find a pool of reference sites that best match the test site ecologically
4. Compare the potentially impacted test site to the pool or reference sites

Flowchart for environmental study designs



Best alternative study design (after BACI) because:

- It implicitly accounts for complex interaction that shape biological communities by matching the test site to the most similar reference sites
- It allows for flexible baselines – reference areas can range from being totally undisturbed by human activities to fully built out subdivisions (with top of the line Low Impact developments, buffers and natural heritage features) - depending on the objective to the study
- It provides realistic targets for management/restoration that are appropriate for the habitat conditions present at the site – the target condition already exists on the landscape!
- It can be used temporally and spatially, reference conditions for a site might be itself over the initial 5-10 years of monitoring

Summary

1. Biologically defined objectives should dominate the study design
2. Design a sampling program to obtain *data* for analysis by some statistical method, to test whether there is in fact evidence of an effect on the biota, and to describe efficiently any demonstrated effects
3. Biological-environmental interactions are complex and can result in confounding noise obscuring the signal of an impact
4. BACI is the optimal study design because its powerful and simple
   a) Other methods are less powerful and/or more complex statistically
5. Reference Condition Approach is the best suboptimal study design