Design, Implementation and Analysis of Studies to Evaluate Restoration Practices

Restoration

Definition

-The attempt to return an ecosystem to its original, undisturbed state

www.fxbrowne.com

Types of Restoration Methods

-Active

-Passive

Active Restoration- mitigation structures

Large Woody Debris

www.cityoffederalway.com

Deflectors

www.rabuntu.com

Boulder Placement

Restoration Projects

- Large amount of money
  - Monitoring and research to evaluate the project effectiveness:
    - Occurs infrequently
    - Often do not include or are inadequate to quantify Biological response

- Published literature
  - Results are inconclusive/statistically insignificant/ highly variable
  - Poorly stated objectives
  - Most evaluations are reach scale – site specific case studies (not broadly applicable)

↙ Stream and watershed restoration

- Lack of spatial replication
- Inadequate pre and post project monitoring
- Confounding effects of uncontrollable environmental factors

- To create an effective monitoring program requires an understanding of
  - Temporal and spatial scale
  - Nature of both restoration action and response
  - Historic or current conditions

Realization that the evaluation program for stream restoration will differ by project type, region, geomorphology, scale and a variety of other factors

Thus, the best way to create a evaluation program is to treat aquatic restoration projects as experiments

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Use standard rules of experimental design

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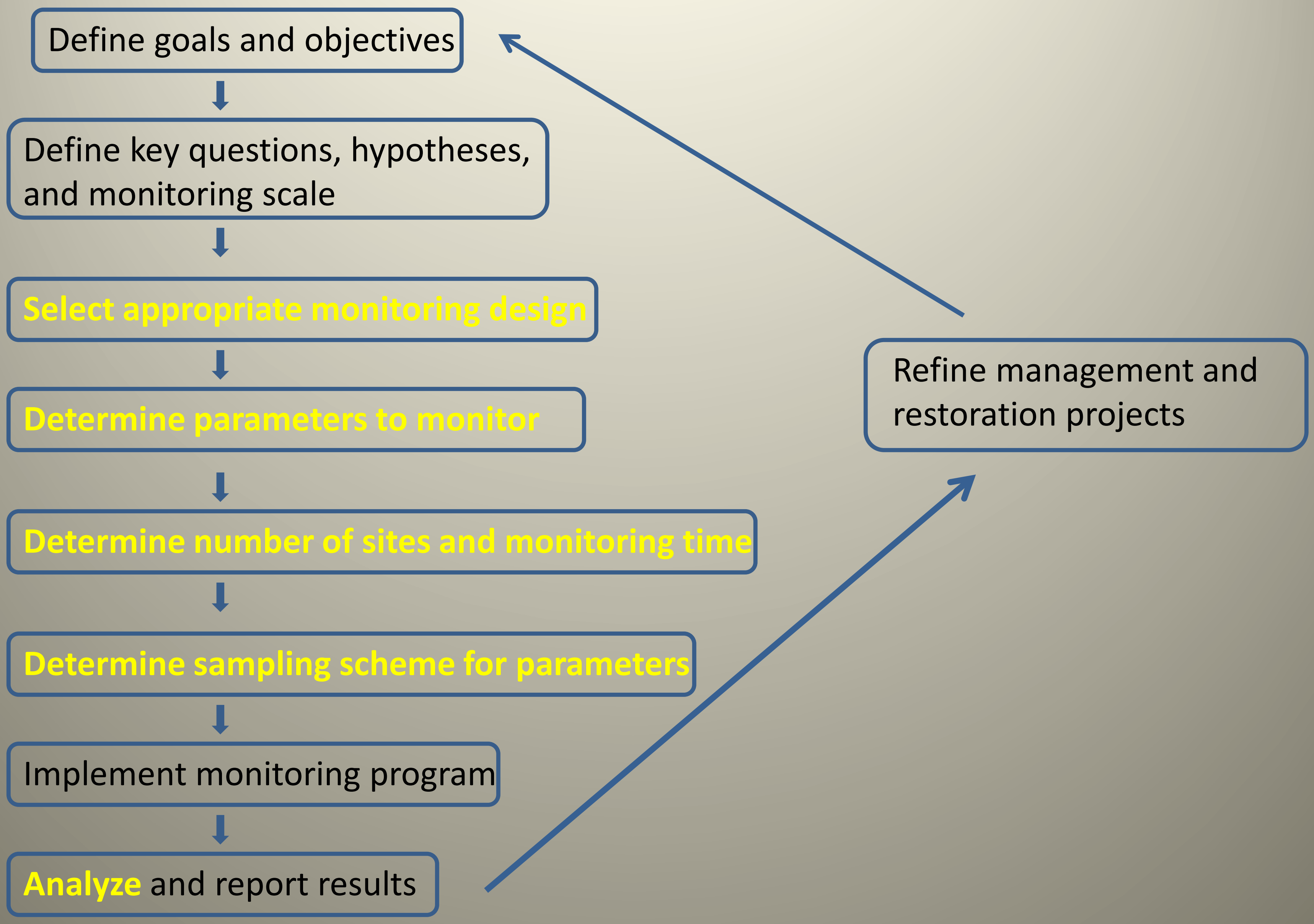
Test Hypotheses (responses)

Physical ┐
Chemical ┘ ├ **Effectiveness monitoring**

Biological → **Validation monitoring**

Steps for monitoring and program evaluation



Defining the General Monitoring Questions

Create specific questions and hypotheses

-differ with projects (specific hypotheses)

↓ refine

Only a few key or overriding questions

1) the spatial scale at which you wish to measure the response

2) Spatial replication or number of projects

Includes – evaluation of single or multiple reach level projects and single watershed or multiple watershed level projects

Questions

• # of projects	Reach/Local	Watershed
Single project	Does the single project affect local habitat condition or biotic abundance	Does the individual project affect watershed conditions or biotic abundance
• # of projects	Reach/Local	Watershed
Multiple project	Do projects of this type affect local habitat condition or biotic abundance	- What are the effects of a suite of different projects on watershed condition and biotic abundance - What is the effect of Projects of type x on on watershed condition and biotic abundance

Artificial riffles in Illinois

To combat the effects of channelization, the Illinois Department of Agriculture installed 30 artificial riffles on 8 creeks between 2000 and 2003.

Project Objectives

- Examine if fish and invertebrate assemblages differ between natural and artificial riffles
- Determine the overall feasibility of this type of habitat restoration

Experimental designs used to evaluate restoration projects

- Post Treatment Designs (Intensive/Extensive)
  - Control-Treatment pairing (within stream)
  - Watershed Comparison (across or within watersheds)
    - Replication spatial or spatially and temporal

- Pre/Post Treatment Design
  - Before-After (BA), before after Control Impact

Others

- Staircase design
- Historical design
- Combined design (meta design)

- Control-Treatment Pairing (CT)
  - Data are collected at some time interval after the remediation has been performed and is collected from treatment site(s) and control site(s) within a stream. Replication occurs in time. Used to monitor individual restoration projects
    - Ex: Artificial riffles

Artificial Riffles

- Watershed Comparisons
  - Data are collected at some time interval after the remediation has been performed and is collected from treatment site(s) and control site(s) within or between watersheds. Replication occurs in time.
    - Ex: Land use changes

Best Management Practices

- Before-After Control (BA)
  - Data are collected both before and after treatment and is generally replicated in time rather than space.
  - Simplest BA – collection of data before and after treatment within a single site, reach, or watershed
  - Used to monitor individual restoration projects
  - Ex: Newbury weirs

Rock Riffles - Newbury Weir

- Before-after Control Impact (BACI)
  - Data are collected both before and after treatment and again is replicated in time, however, now a control site(s) is added and evaluated over the same time period as the treatment site
    - Adding control – allows you to account for environmental variability
    - Allows you to tell treatment effect from natural variability
    - BACI > power than BA (right control)

- Problems:
  - Statistical:
    - Lack of power
    - Autocorrelation of measurement (spacing of replicate sampling)
  - Improper Controls:
    - Need to make sure that pertinent trends in measured parameters are similar between treatment and control sites or will lead to false conclusions

Goal of the Evaluation Design

- Increase the chances of identifying treatment effects from natural variation
  - Can improve your chances by:
    - Increasing Spatial Replication (multiple control sites)
    - Increase Temporal Replication (Long-term sampling)
- Also improve by Spatial replication
  - Paired treatment and controls across the landscape that are monitored for many years
    - Limited resources
    - Logistics
    - Project scale and location

    (dam removal – watershed level)

Which Designs

- # of projects — Reach/Local — Watershed

# of projects	Reach/Local	Watershed
Single project	Does the single project affect local habitat condition or biotic abundance	Does the individual project affect watershed conditions or biotic abundance

- # of projects — Reach/Local — Watershed

# of projects	Reach/Local	Watershed
Multiple project	Do projects of this type affect local habitat condition or biotic abundance	- What are the effects of a suite of different projects on watershed condition and biotic abundance - What is the effect of Projects of type x on on watershed condition and biotic abundance

Can use pre/post or post treatment designs

Controls and Replicates

- Should be as close as possible to an independent replicate of the treatment (similar – land use, geology, hydrology, biology and other features)
- There is a difference
  - **Control** - defined as being identical to the treatment
  - **Replicate** – defined as the ideal or pristine state, with conditions unaltered by human activities, or representing a range of pre-disturbed conditions.
- Allow comparison between restoration area and the conditions before restoration – serve as a covariate to account for natural variation – detect true response to restoration.

Pairing

- When possible pair treatments and controls
  - Help account for some of variability among sites – the measure of interest is the difference between the treatment and controls (analysis –difference between treatment and control)
  - Unpaired comparisons typically focus on whether the average variance or temporal trends differ from those of the treatment and can result in the need for – Larger Sample Sizes

Determining Appropriate Monitoring Parameters

- Should be relevant to:
    - Questions being asked
    - Strongly associated with the restoration activity
    - Ecologically and socially significant
    - Efficient to measure
  - Additionally - Parameters must change in a measurable and appropriate way:
    - In response to treatment
    - Related to resources and concerns
    - Limited variability (natural)
    - Not confounded by temporal and spatial factors

- Appropriate parameters to monitor will differ by types of restoration, as well as hypothesis

Types of Parameters to Measure

- Physical – habitat variable
- Chemical – water chemistry
- Biological – organisms at populations and community level

- Each case should develop a list of which parameters are most important – accounting for proper $ allocation

- Ability of a monitoring program to determine change related to restoration action(s)will depend on:
  - Variability of the parameters of interest
  - Amount of replication across time and space

- Thus, it is important to estimate the sample size (either years, # of sites or both) needed to detect the level of response of interest before initiating a monitoring program.

Sampling Schemes

- Also need to determine method and spatial allocation within site or study area.

Ex. Small Stream – sample entire stream –censes

Large Stream – can not measure everywhere

Optimal Sampling Design:

- Spatial distribution of organism
- Logistics of moving between locations
- Collecting samples or observing the organism

Sampling Designs

- Simple random sample
- Stratified random sampling
- Systematic sampling
- Double sampling
- Line transect
- Capture - recapture

Habitat (Physical) Assessment

- Stream Habitat Assessment Procedure (SHAP)
    - Assessment of 15 habitat metrics
- EPA Visually-Based Habitat Assessment
- 11 Transect Method

Stream Habitat Assessment Procedure Parameters and Values

METRIC	Excellent	Good	Fair	Poor
Substrate and Instream Cover				
Bottom Substrate	16-20	11-15	6-10	1-5
Deposition	10-12	7-9	4-6	1-3
Substrate Stability	13-16	9-12	5-8	1-4
Instream Cover	10-12	7-9	4-6	1-3
Pool Substrate	16-20	11-15	6-10	1-5
Channel Morphology and Hydrology				
Pool Quality	13-16	9-12	5-8	1-4
Pool Variability	13-16	9-12	5-8	1-4
Channel Alteration	7-8	5-6	3-4	1-2
Channel Sinuosity	10-12	7-9	4-6	1-3
Width/Depth Ratio	13-16	9-12	5-8	1-4
Hydrolic Diversity	10-12	7-9	4-6	1-3
Riparian and Bank Features				
Canopy Cover	10-12	7-9	4-6	1-3
Bank Vegetation	13-16	9-12	5-8	1-4
Immediate Land Use	7-8	5-6	3-4	1-2
Flow-Related Refugia	10-12	7-9	4-6	1-3

EPA Visually-Based Habitat Assessment

- Parameters are evaluated and rated on a numerical scale of 0 – 20 (highest for each sample reach).
- Scores increase as habitat quality increase
- Performed in teams of two or more, if possible , to come to a consensus on determination of quality

EPA Parameters

- Epifaunal Substrate/Available Cover
- Embeddedness
- Pool Substrate Characteristics
- Velocity/Depth Combination
- Pool Variability
- Sediment Deposition
- Channel Flow Status
- Channel Alteration
- Frequency of Riffles
- Channel Sinuosity
- Bank Stability
- Bank Vegetation Protection
- Riparian Vegetation Zone Width

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
2.a Embeddedness (high gradient)	Gravel, cobble, and boulder particles are 0-25% surrounded by fine sediment. Layering of cobble provides diversity of niche space.	Gravel, cobble, and boulder particles are 25-50% surrounded by fine sediment.	Gravel, cobble, and boulder particles are 50-75% surrounded by fine sediment.	Gravel, cobble, and boulder particles are more than 75% surrounded by fine sediment.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

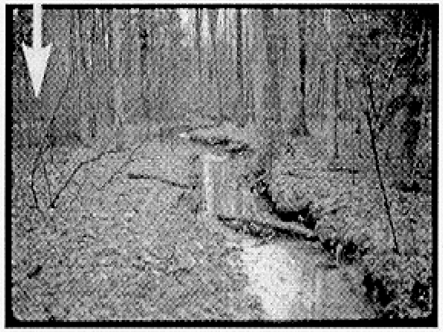
2a. Embeddedness—High Gradient

Optimal Range *(William Taft, MI DNR)*

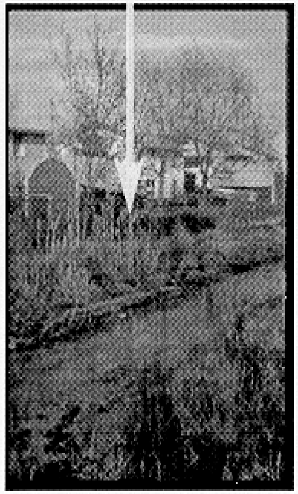
Poor Range *(William Taft, MI DNR)*

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
10. Riparian Vegetative Zone Width (score each bank riparian zone) **(high and low gradient)**	Width of riparian zone >18 meters; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone.	Width of riparian zone 12-18 meters; human activities have impacted zone only minimally.	Width of riparian zone 6-12 meters; human activities have impacted zone a great deal.	Width of riparian zone <6 meters: little or no riparian vegetation due to human activities.
SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0

10b. Riparian Vegetative Zone Width—Low Gradient



Optimal Range
(arrow emphasizing an undisturbed riparian zone)



Poor Range *(MD Save Our Streams)*
(arrow emphasizing lack of riparian zone)

Methods-Physical Habitat Assessment

- Modified IEPA SHAP
- Modified IEPA Transect Method
    - Substrate
    - Mean Depth
    - Mean Velocity

Biotic Assessment

- Periphyton
- **Benthic Macroinvertebrates**
- **Fish**

Macroinvertebrate Assessment

- Rapid bioassessment using benthic invertebrates assemblages has been the most popular set of protocols among the state water resource agencies since 1989.
- Refinement has been made on the original rapid bioassessment procedures
  - Single Habitat Approach: 1 meter Kick net
  - Multihabitat Approach: D-Frame dip net

Single Habitat Sampling Procedures

1. A 100m reach representative of the characteristics of the stream should be selected, mapped and sites sampled marked
2. All riffles and runs are candidates for sampling macroinvertebrate (Cobble)
3. Sampling begins at downstream end and proceeds upstream. Using the 1 m kick net, 2 or 3 kicks are sampled at various velocities in the riffle or series of riffles.
4. Kicks collected from different locations will be combined to obtain a single homogenous sample, preserve in 95% ethanol .

Multihabitat Sampling Approach

1. A 100m reach representative of the characteristics of the stream should be selected, mapped and sites sampled marked
2. Different types of habitat are to be sampled in approximate proportion to their representation of surface area of the total macroinvertebrate habitat in the reach (cobble,snags, vegetated bank, submerged macrophytes, sand/fine sediment)
3. Sampling begins at the downstream end of the reach and proceeds upstream. A total of 20 jabs will be taken over the length of the reach. Jab is forcefully thrusting the net into a productive habitat for a linear distance of 0.5m
4. Jabs collected from different locations will be combined to obtain a single homogenous sample, preserve in 95% ethanol .

Laboratory Processing of Macroinvertebrates

- Subsampling and Sorting

1. Thoroughly rinse sample in 500 micron mesh to remove preservative and fine sediment.
2. Spread sample across a pan marked with a grids approximately 6cm x 6cm
3. Use a random number table to select 4 numbers corresponding to squares within the grid pan, try to obtain a density of 200 organisms $\pm$ 20%
4. Place the sorted organism subsample into a glass vial (70% ethanol); retain rest of sample
5. Identify to the lowest practical level (genus or species)

Category	Metric	Definition	Predicted response to increasing perturbation
Richness measures	Total No. taxa	Measures the overall variety of the macroinvertebrate assemblage	Decrease
	No. EPT taxa	Number of taxa in the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies)	Decrease
	No. Ephemeroptera Taxa	Number of mayfly taxa (usually genus or species level)	Decrease
	No. Plecoptera Taxa	Number of stonefly taxa (usually genus of species level)	Decrease
	No. Trichoptera Taxa	Number of caddisfly taxa (usually genus or species level)	Decrease
Composition measures	% EPT	Percent of the composite of mayfly, stonefly, and caddisfly larvae	Decrease
	% Ephemeroptera	Percent of mayfly nymphs	Decrease
Tolerance/Intolerance measures	No. of Intolerant Taxa	Taxa richness of those organisms considered to be sensitive to perturbation	Decrease
	% Tolerant Organisms	Percent of macrobenthos considered to be tolerant of various types of perturbation	Increase
	% Dominant Taxon	Measures the dominance of the single most abundant taxon. Can be calculated as dominant 2, 3, 4, or 5 taxa.	Increase
Feeding measures	% Filterers	Percent of the macrobenthos that filter FPOM from either the water column or sediment	Variable
	% Grazers and Scrapers	Percent of the macrobenthos that scrape or graze upon periphyton	Decrease
Habit measures	Number of Clinger Taxa	Number of taxa of insects	Decrease
	% Clingers	Percent of insects having fixed retreats or adaptations for attachment to surfaces in flowing water.	Decrease

to increasing perturbation.

Category	Metric	Definition	Predicted response to increasing perturbation	References
Richness measures	No. *Pteronarcys* species	The presence or absence of a long-lived stonefly genus (2-3 year life cycle)	Decrease	Fore et al. 1996
	No. Diptera taxa	Number of "true" fly taxa, which includes midges	Decrease	DeShon 1995
	No. Chironomidae taxa	Number of taxa of chironomid (midge) larvae	Decrease	Hayslip 1993, Barbour et al. 1996b
Composition measures	% Plecoptera	Percent of stonefly nymphs	Decrease	Barbour et al. 1994
	% Trichoptera	Percent of caddisfly larvae	Decrease	DeShon 1995
	% Diptera	Percent of all "true" fly larvae	Increase	Barbour et al. 1996b
	% Chironomidae	Percent of midge larvae	Increase	Barbour et al. 1994
	% Tribe Tanytarsini	Percent of Tanytarisinid midges to total fauna	Decrease	DeShon 1995
	% Other Diptera and noninsects	Composite of those organisms generally considered to be tolerant to a wide range of environmental conditions	Increase	DeShon 1995
	% *Corbicula*	Percent of asiatic clam in the benthic assemblage	Increase	Kerans and Karr 1994
	% Oligochaeta	Percent of aquatic worms	Variable	Kerans and Karr 1994
Tolerance/ Intolerance measures	No. Intol. Snail and Mussel species	Number of species of molluscs generally thought to be pollution intolerant	Decrease	Kerans and Karr 1994
	% Sediment Tolerant organisms	Percent of infaunal macrobenthos tolerant of perturbation	Increase	Fore et al. 1996

Macroinvertebrate Biotic Index (MBI)

- MBI used in Illinois is modified from Hilsenoff (1982)

1. Each Taxon is assigned a pollution tolerance value from 0-11 based on literature and field experience
2. A value of zero is assigned to taxa know to occur in unaltered streams of high water quality
3. A value of 11 is assigned to taxa know to occur in severely polluted or disturbed streams
4. Intermediate values are assigned based on an organism's relative degree of tolerance or intolerance to pollution

Macroinvertebrate Biotic Index (MBI)

Formula:

☞$(n_i\ t_i)/N$

ni is the number of individuals in each taxon

ti is the tolerance value assigned to that taxon

N is the total number of individuals in the sample

MBI values reflect water quality as follows

<5.0	excellent
5.0-6.0	Very good
6.1-7.5	Good/Fair
7.6-10.0	Poor
>10.0	Very Poor

Methods-Benthic Invertebrates

Sugar and Ashmore Creeks sampled from June -September 2005.

Hurricane Creek was not sampled due to draught.

Looked at species richness, diversity, MBI

Fish Assessment

- All fish sampling techniques are generally considered selective to some degree, however, electrofishing has been proven to be the most comprehensive and effective single method for collecting stream fish
  - Boat Electroshocking (nonwadable streams)
  - Backpack electroshocking
  - Electric Seine

Fish Collection Procedure

- Electric Seine

1. Select a representative reach which contains the primary physical habitat characteristics of stream.
2. Both ends of the stream should be blocked with a net
3. Collection should begin at a shallow riffle or other physical barrier at the downstream limit of the sample reach and proceed in an upstream direction and will terminate at the upstream barrier.
4. Fish collected by dipnet are held in the livewell for identification and enumeration
5. All fish collected in the reach must be identified to species. Specimens that can not be identified in the field are preserved in 10% formalin and taken back to lab for identification.

Index of Biotic Integrity

- Proposed by Karr (1981) – assess stream degradation from measurable attributes of the fish assemblage which can be derived from a representative sample.
  - Applicable for Midwestern streams in agricultural areas
  - IBI consisted of 12 attributes in three categories
    - » Species Composition
    - » Trophic composition
    - » Health and Abundance of fish

IBI

- **Species Composition**
  - **Focuses on the overall richness and richness within major taxonomic groups as well as the occurrence of notably tolerant and intolerant groups.**
- **Trophic Composition**
  - **Food habitats of the fish assemblage as categorized by trophic composition which are products of the diversity and productivity of the lower trophic levels in the community**
- **Fish Abundance and Health**
  - **Look at attributes related to fish abundance and health that reflect system productivity and habitat stability**

Index of Biotic Integrity (IBI) Categories and Metrics

Category	Metric	5	3	1
Species Richness and Composition	Total number of fish species			
	Number and identity of darter species			
	Number and identity of sunfish species	Varies with stream size and region		
	Number and identity of sucker species			
	Number and identity of intolerant species			
	Proportion of individuals as green sunfish	<5%	5-20%	>20%
Trophic Composition	Proportion of individuals as omnivores	<20%	20-45%	>45%
	Proportion of individuals as insectivorous cyprinids	>45%	20-45%	<20%
	Proportion of individuals as piscivores (top carnivores)	>5%	1-5%	<1%
Fish Abundance and Condition	Number of individuals in sample	Varies with stream size		
	Proportion of individuals as hybrids	0	0-1%	>1%
	Proportion of individuals with disease, tumors, fin damage, and skeletal anomalies	0	0-1%	>1%

IBI Scoring

- A fish sample is assigned a 1, 3, or 5 points for each of the attributes by comparison to **expectations for a pristine stream** of similar size in the same region (relationship and disturbance).
- IBI Score

1. **51-60: Excellent** - Comparable to best situation without human disturbance
2. **40-50.9: Good** - Good fisheries for game fish; species richness below expectations
3. **31-40.9: Fair** – Bullhead, sunfish and carp predominant; versity/intolerants reduced
4. **21-30.9:Poor** – Fish dominant by omnivorous and tolerant forms; diversity notably reduced
5. **< 21: Very Poor** – Few fish of any species present, no sport fisheries exist

NEW IBI

- -Number of native fish species
- -Number of native minnow species (i.e., Cyprinidae)
- -Number of native sucker species (i.e., Catostomidae)
- -Number of native sunfish species (i.e., Centrarchidae)
- -Number of native benthic invertivore species
- -Number of native intolerant species
- -Proportion of individuals of species that are specialist benthic invertivores
- -Proportion of individuals of species that are generalist feeders
- -Proportion of individuals of species that are lithophilous spawners and not tolerant
- -Proportion of tolerant species

Factors that Effect IBI

1. Assumptions about samples
   - **Representative sample?**
   - **Stream Size (different sample techniques)**
   - **Representative reach**
2. Need knowledge of the structure and function of regional stream fish communities and of species tolerance

Data Collected

Community Metrics

- Species Diversity
- Species Richness
- Similarity Indexes
- IBI

Population Metrics

- Growth rates
- Condition factors
- Length/frequency indices

Methods-Fish

March-June 2005 using an electric seine

September-November 2005 using a backpack shocker.

www.fs.fed.us

Looked at species richness, diversity, IBI

Hurricane Creek was not sampled due to draught.

Data Analysis

- Statistical methods used to analyze that data collected is based on
  - the monitoring design
  - the parameters selected
  - data collected
- Number of common univariate and multivariate statistical approaches that can be used to test hypotheses regarding restoration activities

Dealing with the data collected

- Aggregate scores (combine or group data)
  - Species Diversity
  - SHAP or IBI Scores

    t-test, Anova,
  - Species Richness
  - Similarity Index
- Individual samples
  - Data collected kept as separate samples

Stats:
- Parametric Tests (t-test, ANOVA)

-Regression/ Correlation analysis

-Non Parametric Tests (Man-Whitney test, Wilcox paired rank test, Kruskal-Wallis test)

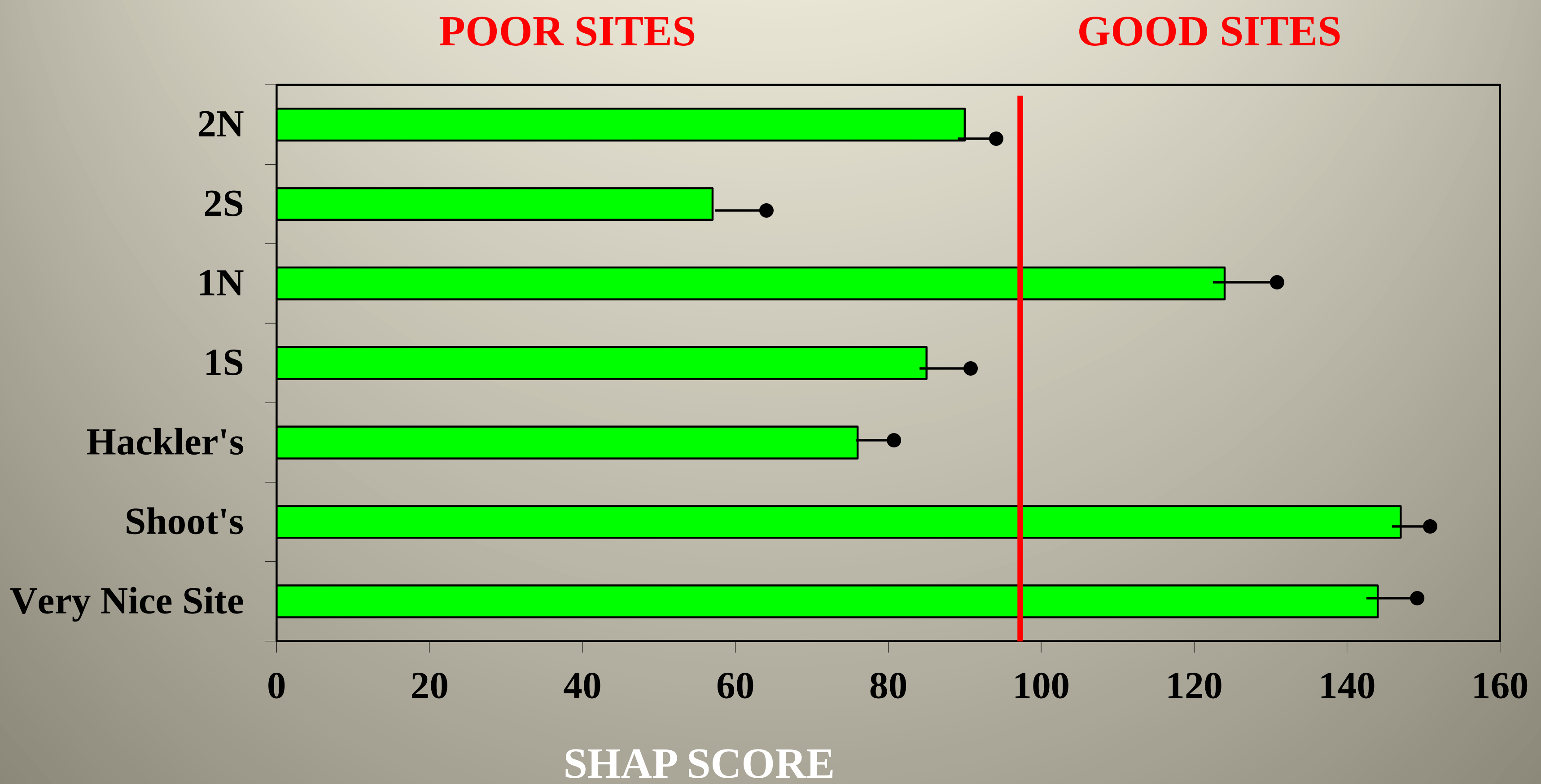
-Multivariate Tests (PCA, Discriminate Analysis Function, MDS –Brey Curtis similarity index)

Other types – Exploratory Data Analysis (graphs, plots, charts) and G.I.S.

MEAN IBI SCORES

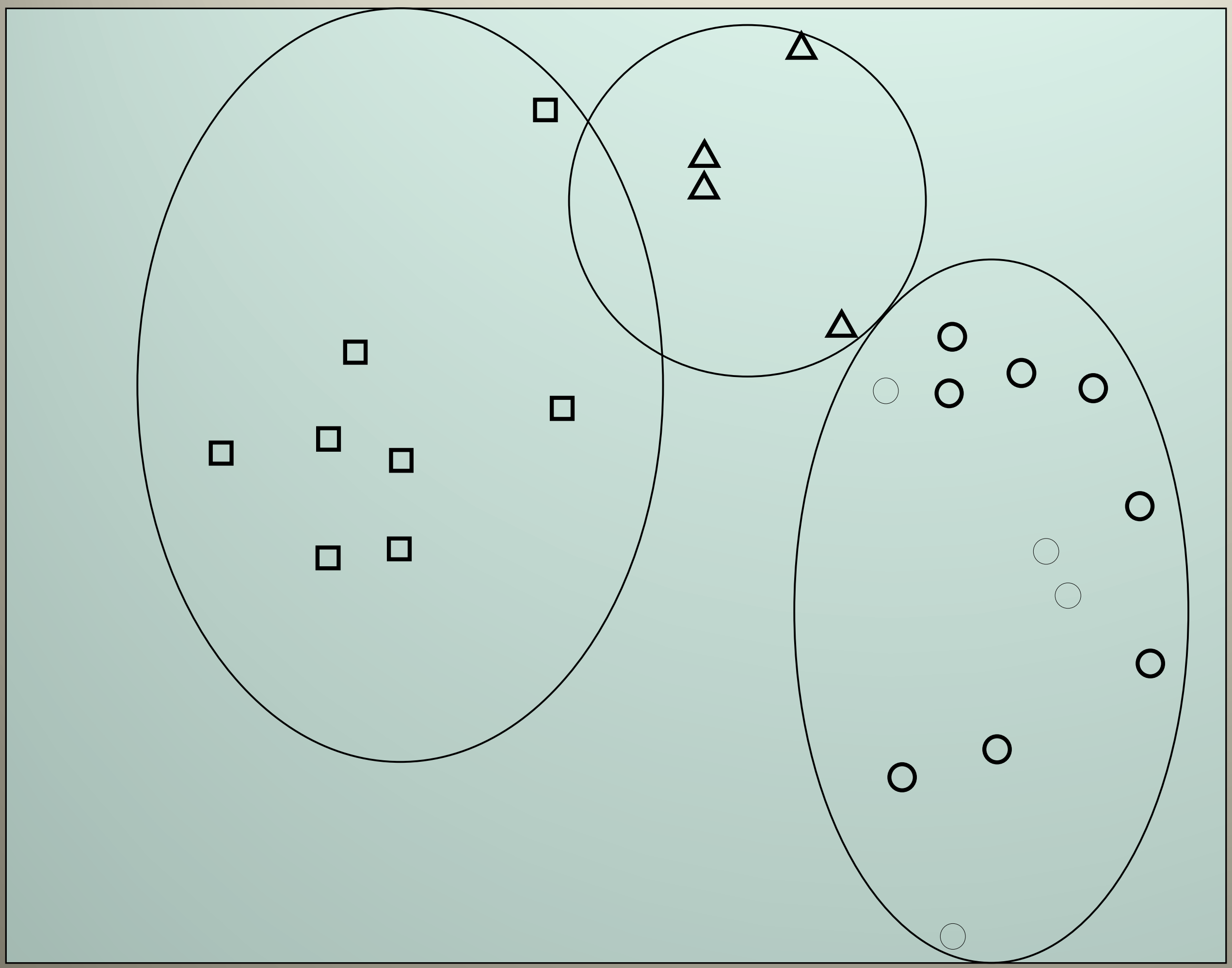
t-test < 0.05

Habitat Analysis



- Significant difference between sites ($p<0.0001$)

Multidimensional Scaling Ordination



STREAM and RIFFLE TYPE

- △ HURRICANE CREEK
- □ SUGAR CREEK
- ○ ASHMORE CREEK

P<0.001

2D Stress: 0.13

Transform: Square root

Resemblance: S17 Bray Curtis Similarity

Steps for monitoring and program evaluation

Define goals and objectives

↓

Define key questions, hypotheses, and monitoring scale

↓

Select appropriate monitoring design

↓

Determine parameters to monitor

↓

Determine number of sites and monitoring time

↓

Determine sampling scheme for parameters

↓

Implement monitoring program

↓

Analyze and report results

→ Refine management and restoration projects

→ Define goals and objectives