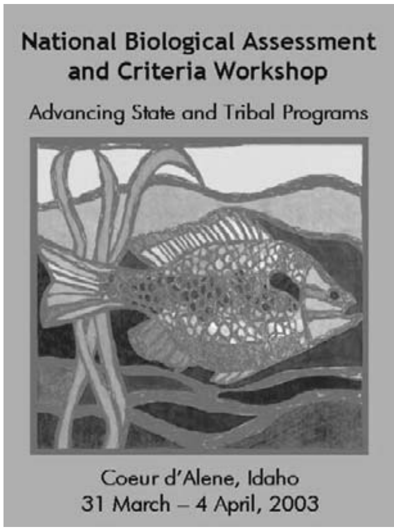
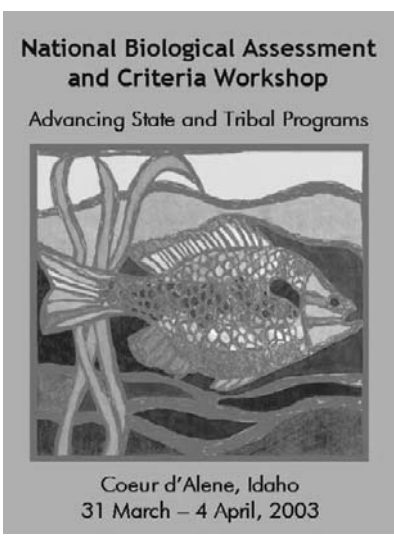


LAKES 101

LAKE BIOLOGICAL ASSESSMENTS AND CRITERIA

Course Presenters
Chris Faulkner, Jeroen Gerritsen, Paul Garrison, Tyler Baker, Jim Hulbert, Neil Kamman

Other Contributors
Linda Bacon, Karen Blocksom, Bob Carlson, Don Charles, Don Dycus, Bob Hall, Gary Hickman, Jim Kurtenbach, Peter Nolan



LAKES 101

Introduction

Presented by

Jeroen Gerritsen, Tetra Tech, Inc.

EPA

Lake and Reservoir Bioassessment and Biocriteria

Technical Guidance Document

Why lakes?

- Recreation
- Water supply
- Lakefront property
- Intrinsic ecological values

Why are lakes different?

- Bottom of watershed – receiving waters
- Physical consequences of standing water
  - Retention time – much more sensitive to nutrients, organic pollution
  - Currents
  - Stratification – limited atmospheric exchange
  - Sedimentation
- Biological characteristics
  - Plankton (zoo & phyto)
  - Vegetation (submerged & emergent)

Lake stresses

- Cultural eutrophication (nutrients)
- Physical
- Acidification
- Toxic contamination
- Exotic species

Lake Biological Assessment

• Saprobic index	1920’s-50’s
• The Phosphorus controversy	1960’s
• Vollenweider model	1966
• Algal indexes	1950’s-60’s
• Clean Water Act	1972
• Trophic State Index	1977
• Paleolimnology for acid dep	1980’s
• Macroinvertebrate lake indexes (Ohio, Sweden, TVA)	Early 90’s
• EPA Lake bioassessment guidance	1998

Process

- Define the resource
- Preliminary classification
- Identify reference criteria and sites
- Select assemblages
- Sample reference and stressed lakes
- Final classification
- Estimate response of attributes and indicators to stressor gradient
- Develop and test indexes

Define the resource

- What is a lake/reservoir?
- Which ones do we care about?
- e.g.:
  - Mean depth > 1 m
  - Open (unvegetated) water > 0.25 ha
  - Hydraulic residence time > 14 days

Classification

- Region (ecoregion, physiographic)
- Size (area, depth)
- Water quality (natural)
  - Alkalinity, pH
  - Color
- Hydrology (retention, stratification)
- Lake origin (natural, impoundment)

Reference condition

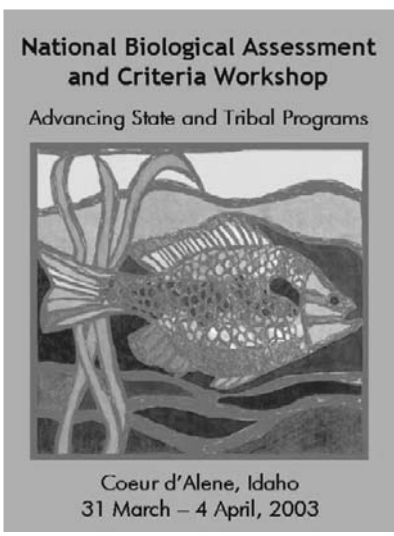
- Definition
- Sampling/modeling
- Characterization

Issues: reference criteria

- Trophic state is **not** an *a priori* indicator (naturally eutrophic lakes exist), but cultural eutrophication is widespread in agricultural areas.
- Reservoirs: what is the desired condition of an artificial system?

Biological indicators for lakes

- Trophic state (chlorophyll, Secchi)
- Sedimented diatoms
- Phytoplankton
- Zooplankton
- Benthic macroinvertebrates
- Fish
- Submerged macrophytes
- Emergent vegetation



LAKES 101

Defining Reference Conditions with Sediment Cores

Presented by

Paul Garrison
Wisconsin Department of Natural Resources

Wisconsin Department of Natural Resources

Wisconsin Department of Natural Resources
FISHERIES and AQUATIC SCIENCES RESEARCH

WHY TAKE SEDIMENT CORES?

- Lack of long-term data.
- Lack of suitable reference conditions.
- How has the water quality of my lake changed?

HOW DO YOU COLLECT SEDIMENT CORES?

Gravity Corer

Piston Corer

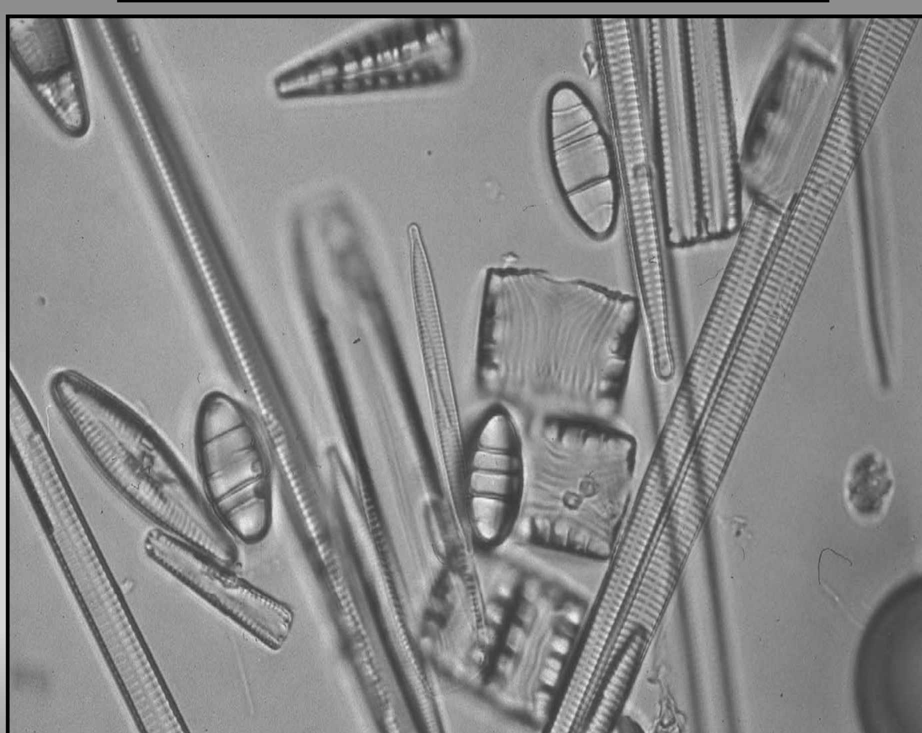
CORE COLLECTION

- Where do you collect a core?
  - Generally in deep area of the lake or reservoir where the bottom is broad and flat
- When do you collect a core?
  - Can be done any time of the year when access is best

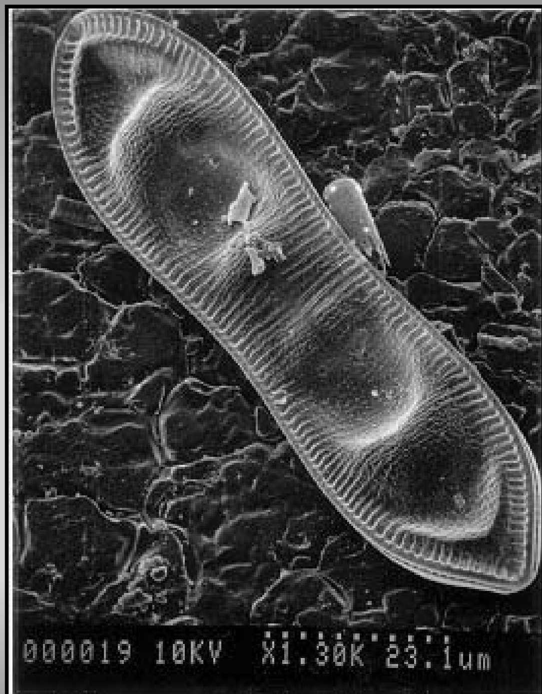
WHAT TYPE OF CORE?

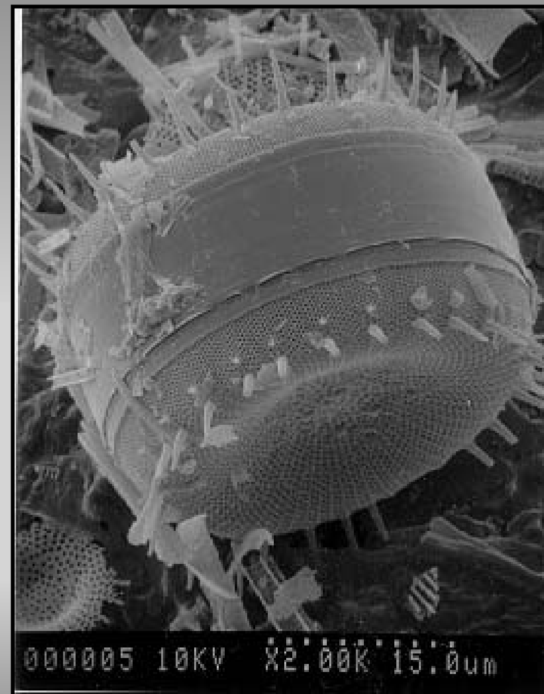
- Full Core
  - Core depth should be deep enough so it includes time period prior to impact.
  - Complete core is sectioned and archived
  - Provides much more information about overall trends and specifics regarding timing of changes
- Top/Bottom Core
  - Only surface sample and pre-impact depth is kept.
  - Depth of bottom sample estimated from other cores in region, stratigraphic marker, e.g. color change, change in texture.
  - Much less expensive and provides a snapshot of changes

WHAT ARE DIATOMS?



DIATOMS





WHY USE DIATOMS?

- QUANTITATIVE & QUALITATIVE
  - Changes in nutrients
  - Changes in pH
  - Changes in macrophytes
- TECHNIQUES
  - Multivariate statistics
    - Weighted averaging

COMMON DIATOM SPECIES

REFERENCE

- *Cyclotella michiganiana*
- *C. atomus*
- *C. comensis*
- *Aulacoseira ambigua*
- *A. subarctica*

IMPACTED

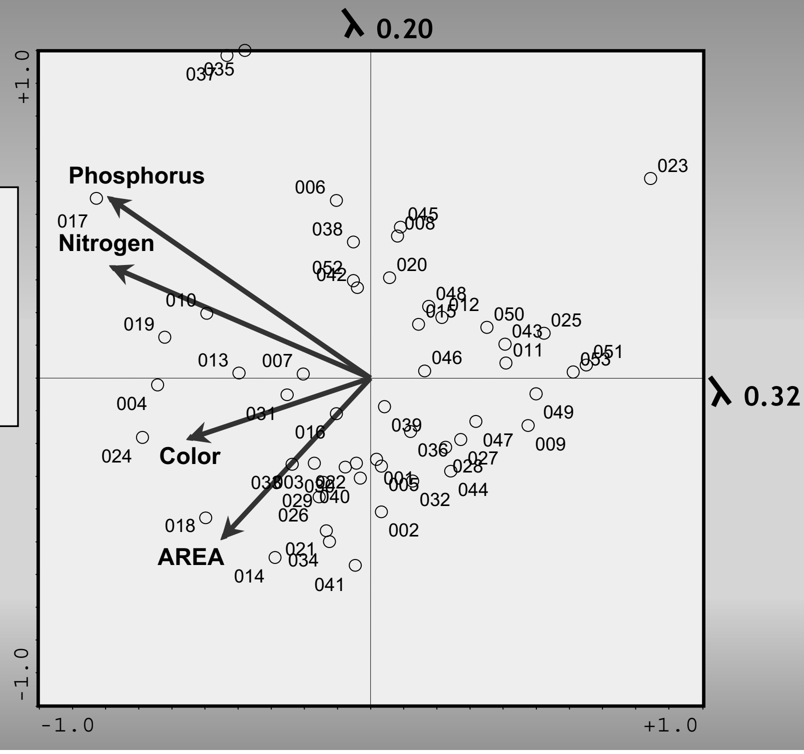
- *Stephanodiscus medius*
- *S. hantzschii*
- *S. parvus*
- *S. minutulus*
- *Aulacoseira ambigua*
- *A. granulata*
- *A. italica*
- *Cyclostephanos dubius*
- *C. invisitatus*
- *Fragilaria crotonensis*
- *Asterionella formosa*

Statistical Analyses

- Canonical Correspondence Analysis (CCA)
  - Determine variables that can be reliably inferred
- Weighted Averaging
  - Infer historical levels
    - Phosphorus, pH, chloride, etc

Canonical Correspondence Analysis

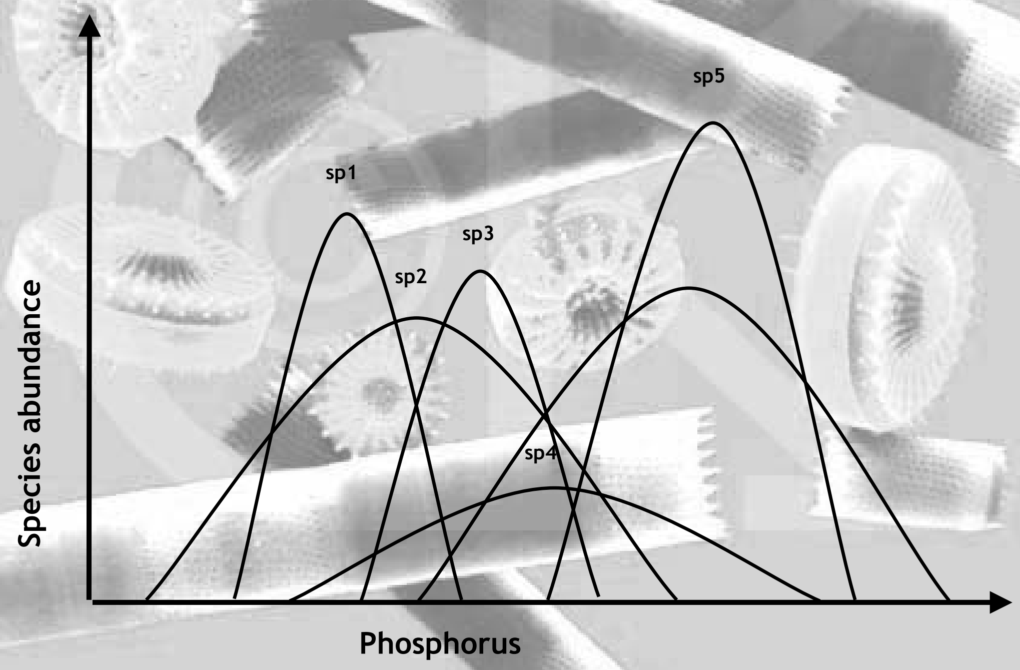
	P value
Phosphorus	0.005
Area	0.010
Nitrogen	0.010
Color	0.030

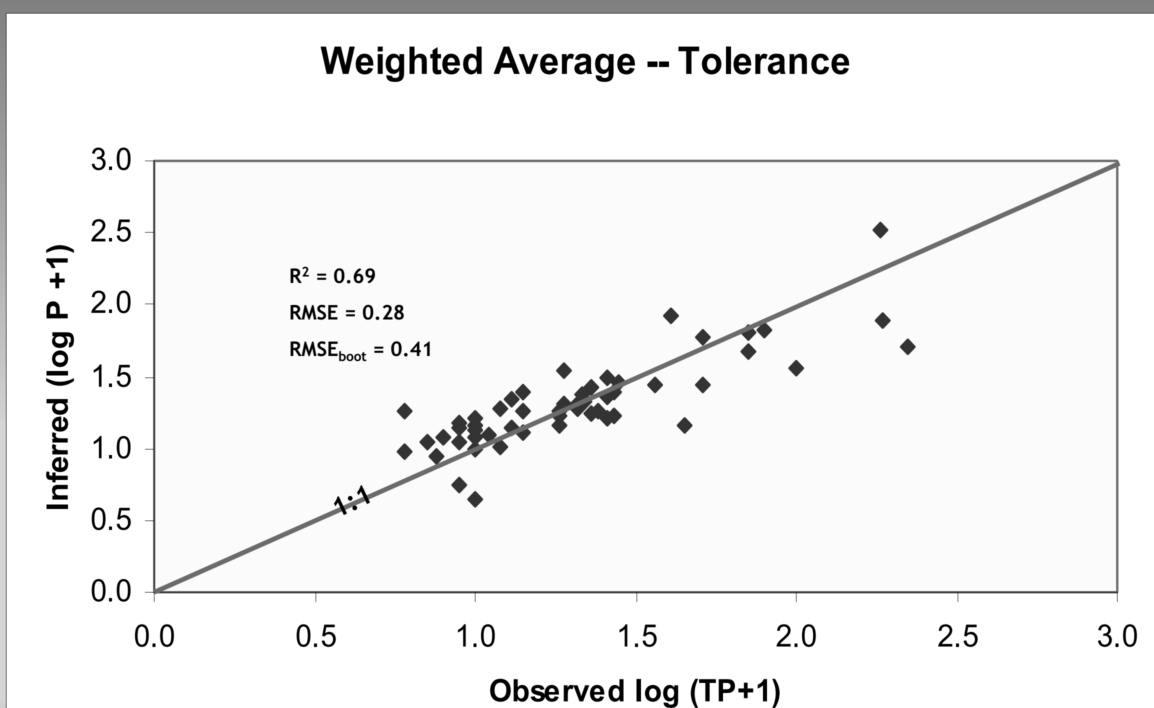


WEIGHTED AVERAGING

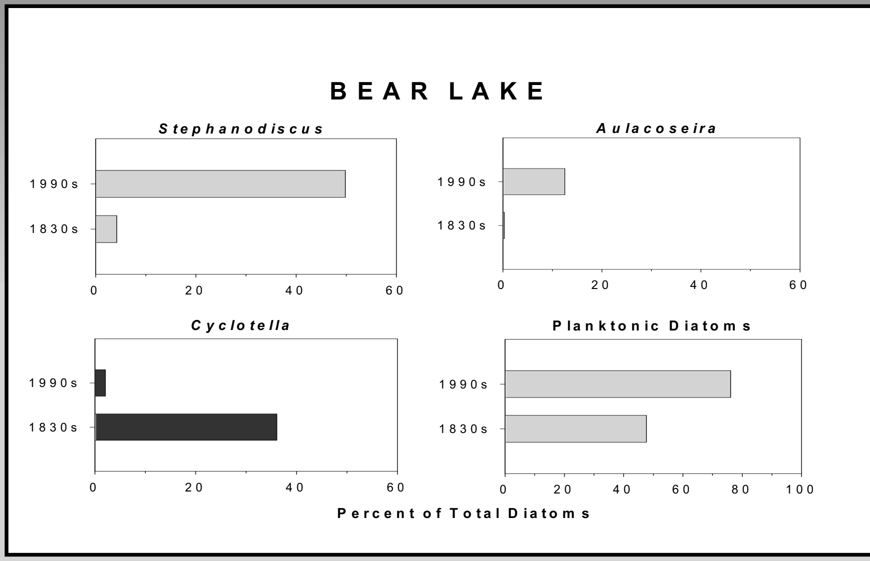
- Statistical model that allows the use of diatoms to estimate historical levels of variables of interest, e.g., P, pH, Cl, ANC, DOC
- Usually done with program WACALIB

WEIGHTED AVERAGING



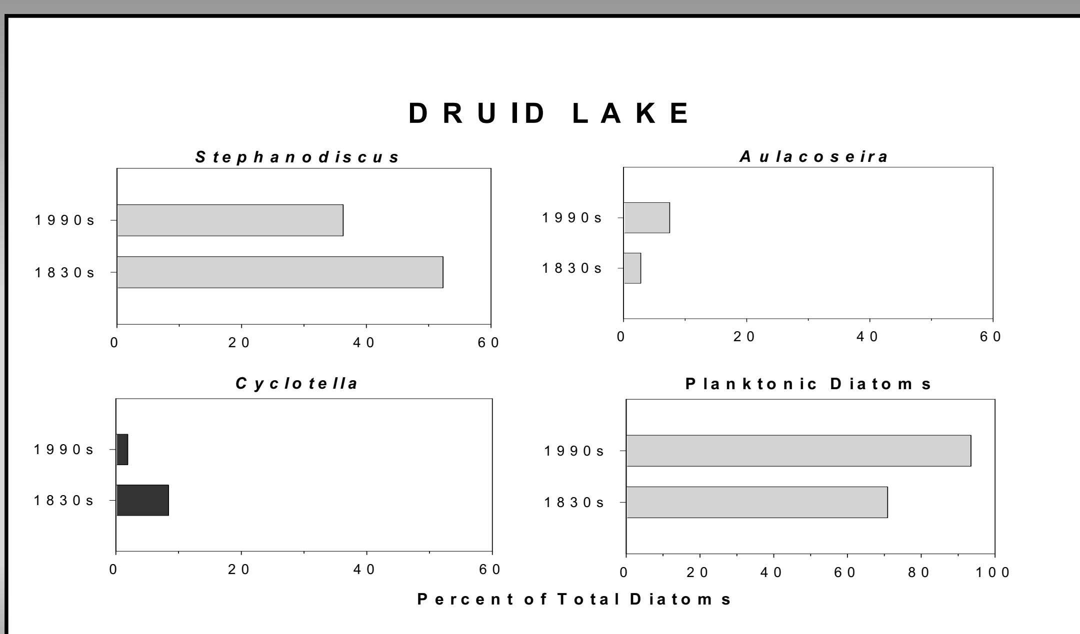


CASE STUDIES
Phosphorus

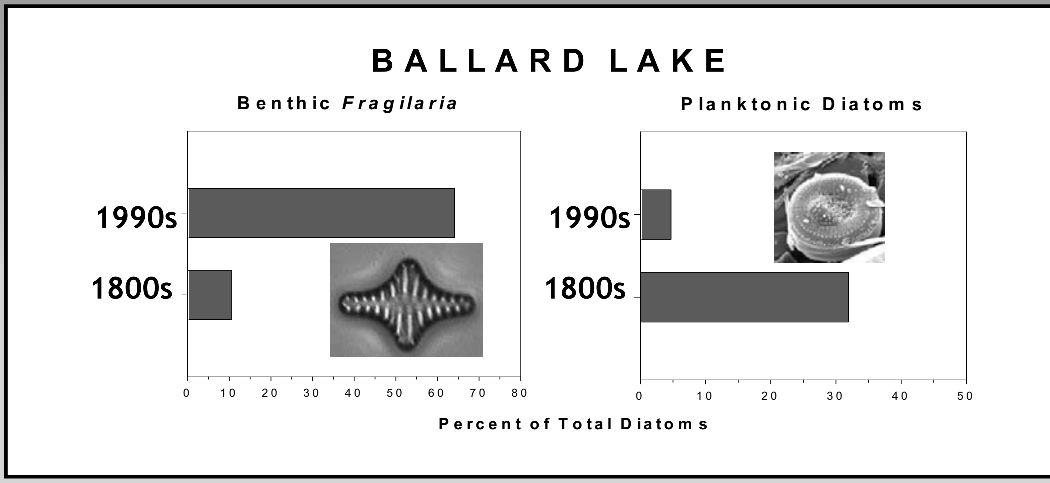


Increase of high phosphorus diatoms (green); P increase of 25 µg L^{-1}

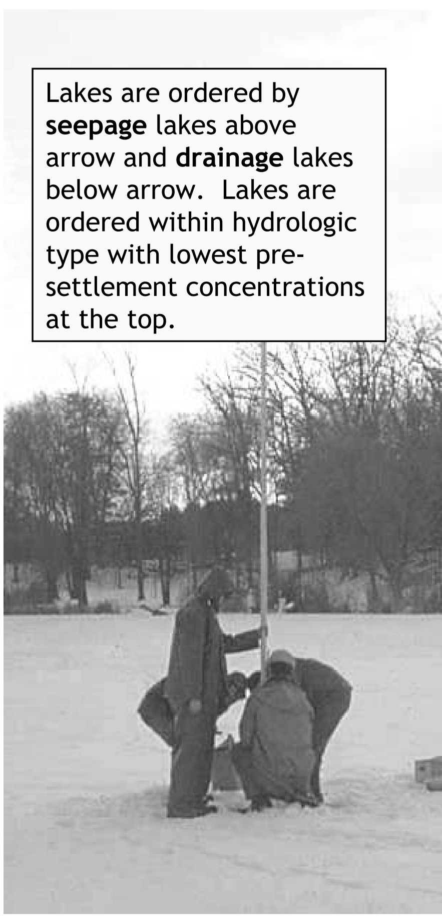
CASE STUDIES
Naturally Eutrophic Lake



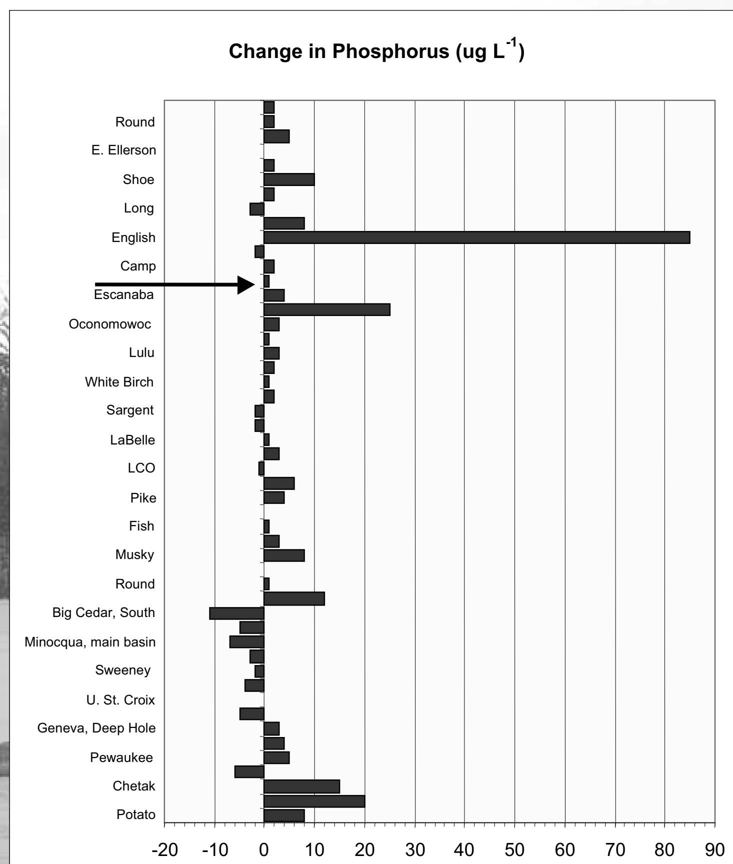
CASE STUDIES
Macrophytes & P

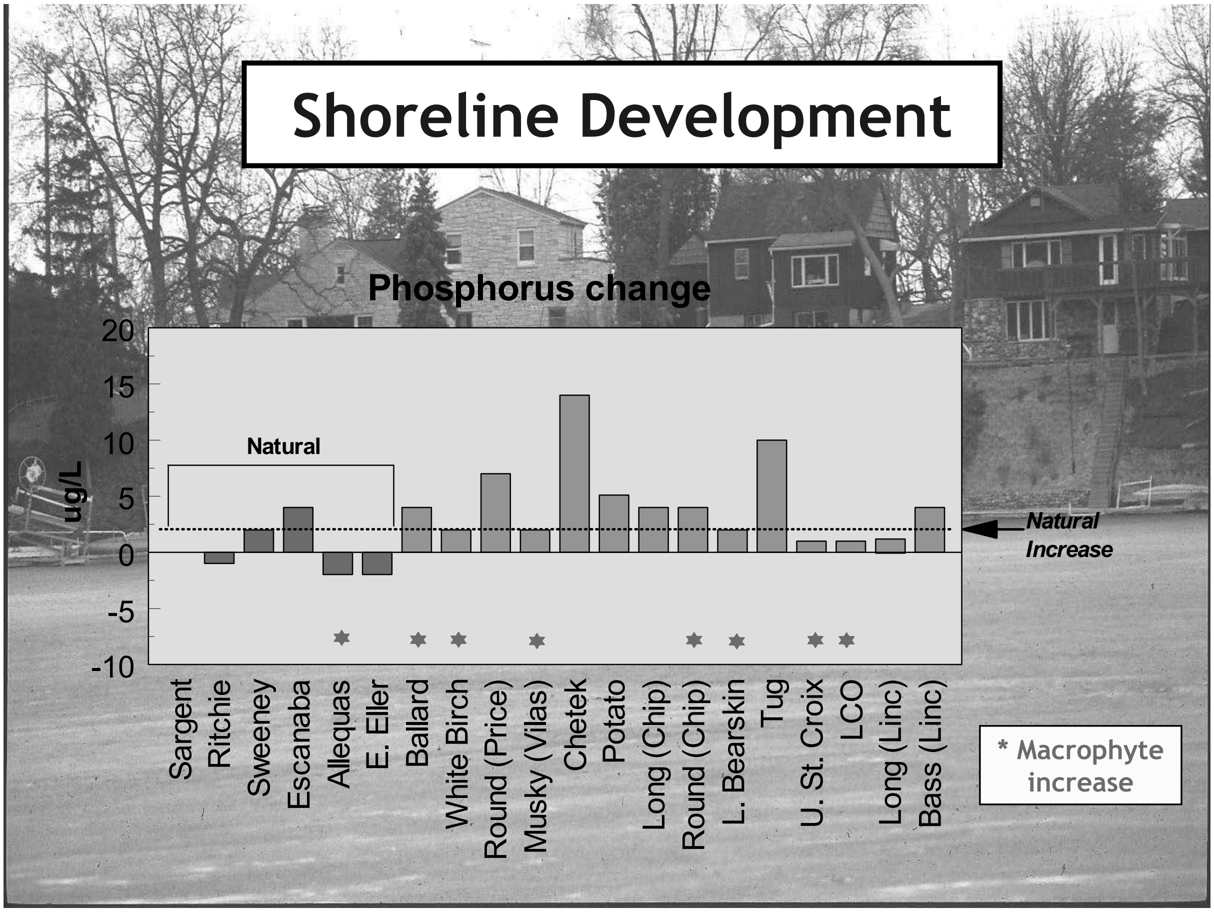


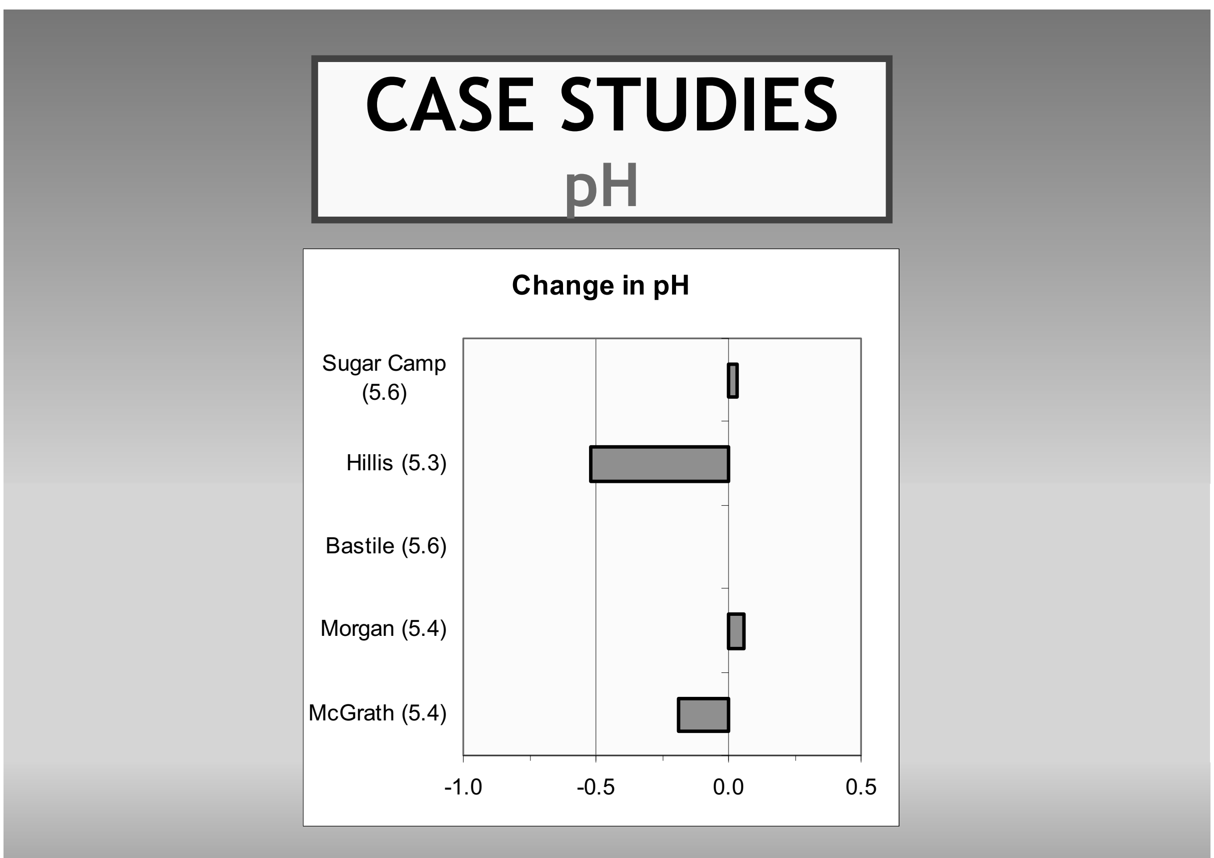
More macrophytes and phosphorus increase of 1 µg L^{-1}



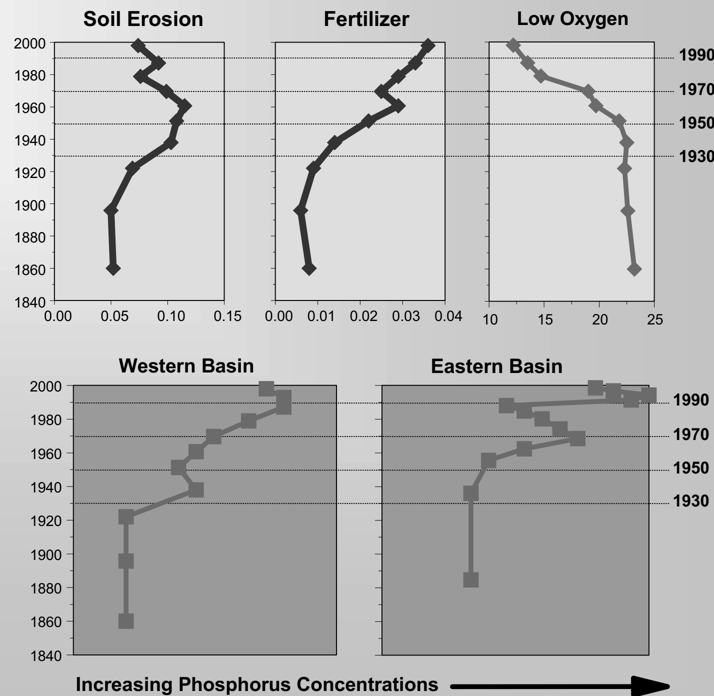
Lakes are ordered by **seepage** lakes above arrow and **drainage** lakes below arrow. Lakes are ordered within hydrologic type with lowest pre-settlement concentrations at the top.




Shoreline Development
Phosphorus change
ug/L
20
15
10
5
0
-5
-10
Natural
Natural Increase
Sargent
Ritchie
Sweeney
Escanaba
Allequas
E. Eller
Ballard
White Birch
Round (Price)
Musky (Vilas)
Chetek
Potato
Long (Chip)
Round (Chip)
L. Bearskin
Tug
U. St. Croix
LCO
Long (Linc)
Bass (Linc)
* Macrophyte increase

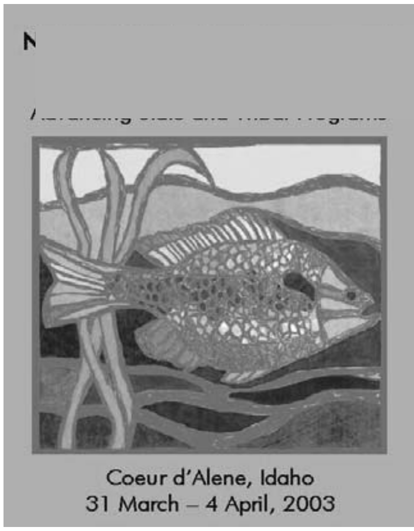

CASE STUDIES
pH
Change in pH
Sugar Camp (5.6)
Hillis (5.3)
Bastile (5.6)
Morgan (5.4)
McGrath (5.4)
-1.0
-0.5
0.0
0.5

HISTORY IN THE MUCKING



STRENGTHS AND WEAKNESSES OF TOP/BOTTOM SAMPLING

- **STRENGTHS**
  - –Relatively inexpensive
  - –Many lakes can be examined in a short time
- **WEAKNESSES**
  - –Requires fair degree of taxonomic knowledge
  - –Bottom samples may not be representative of typical pre-impact conditions, e.g. drought
  - –Some important diatoms taxa have wide range of environmental optima, especially in shallow lakes

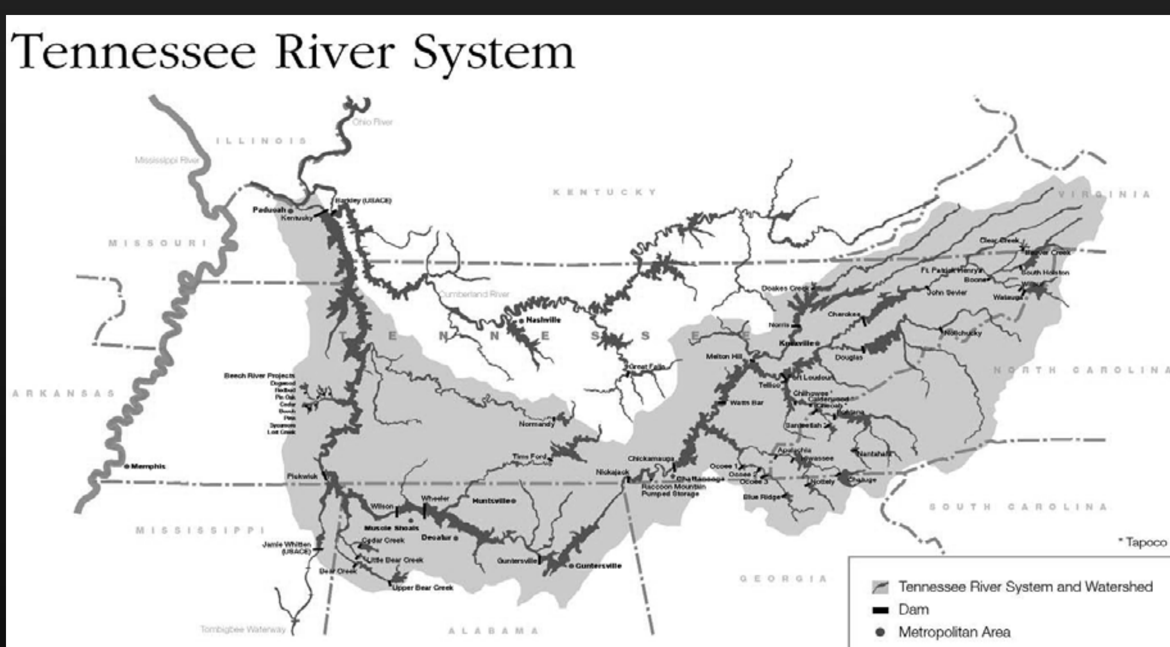


LAKES 101

Reservoir Biological Assessment and Criteria: TVA Methods and Experiences

Presented by

Tyler Baker, Tennessee Valley Authority (TVA)



Why Is TVA Involved in Water Quality Monitoring?

- TVA's focus for its monitoring program is aimed at:
  - Stewardship responsibilities
  - Operating the reservoir system
  - Responding to stakeholders
- TVA has no regulatory authority related to water quality monitoring.
- TVA monitoring is not aimed at use attainment per sec'.

Presentation Outline – Reservoir Ecological Health

I. Monitoring Design Considerations

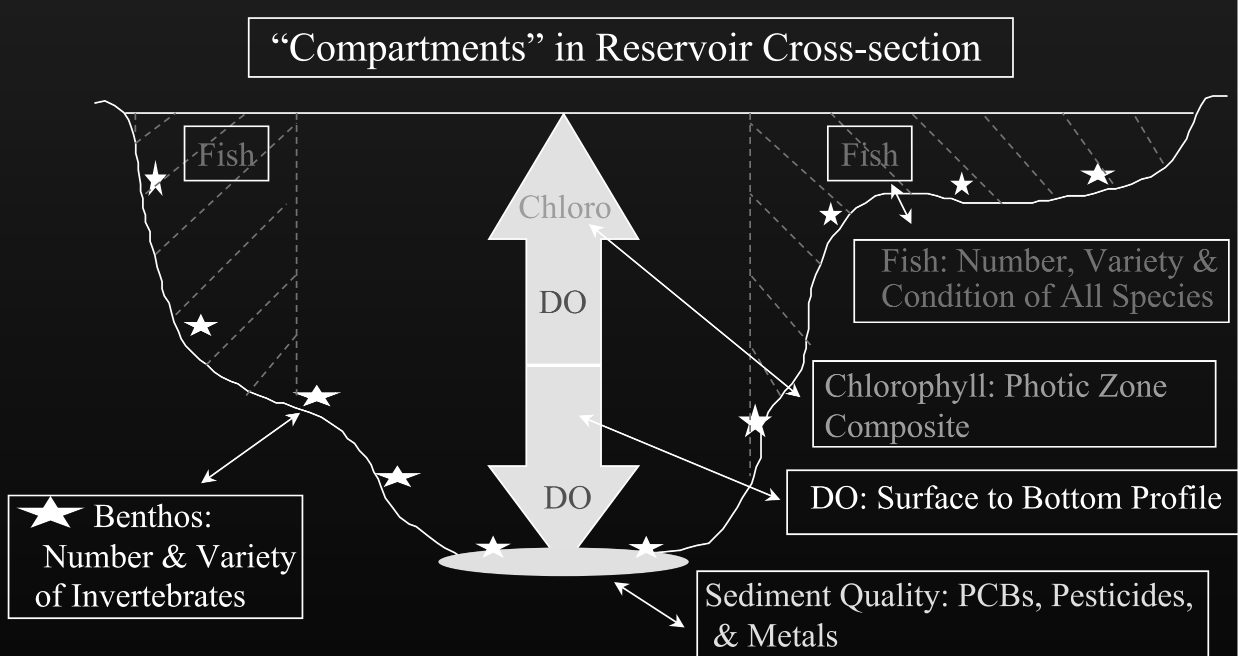
II. Data Evaluation Considerations

III. TVA Reservoir Ecological Health Rating Methods

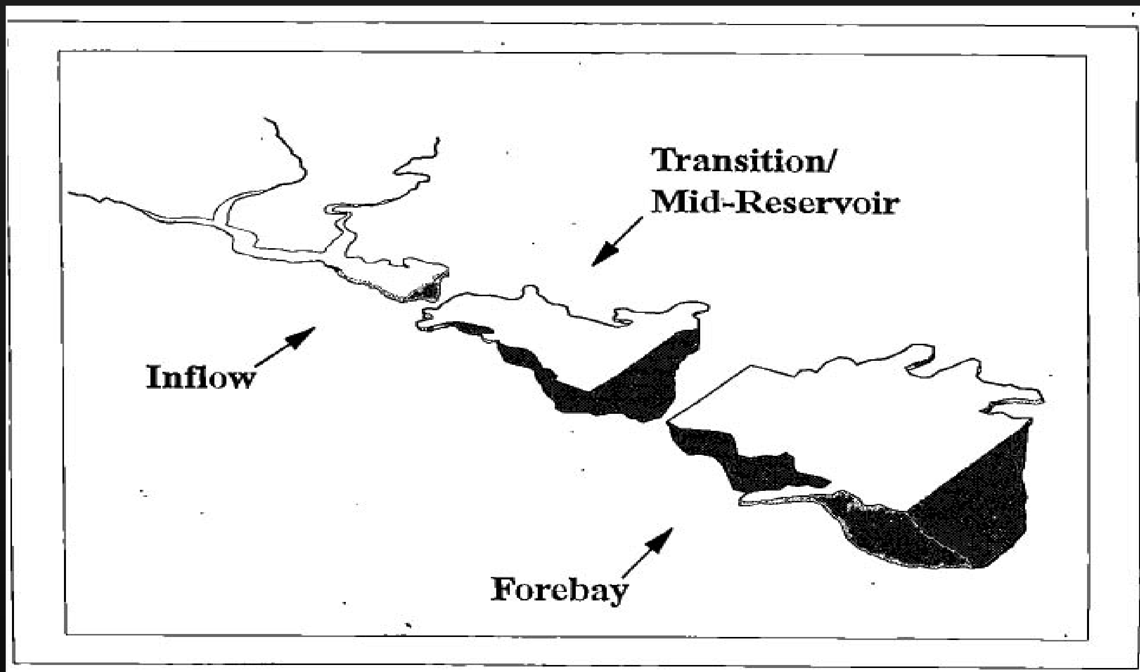
A. Monitoring Design – Selection of Indicators and Sampling Frequency

- Dissolved oxygen: Monthly (April – October)
- Trophic status (chlorophyll/nutrients): Monthly (April – October)
- Sediment quality: Annually (summer)
- Benthic macroinvertebrate community: Annually (fall)
- Fish assemblage: Annually (fall)

Ecological Indicators & Reservoir "Compartments"



B. Monitoring Design - Sample Locations



II. Data Evaluation Considerations

- Is the reservoir in good condition; must have reference or yardstick for comparison.
- Standard approaches used to determine reference conditions for streams are not appropriate for reservoirs.
  - Reservoirs lack natural reference sites.
  - Reservoirs have had little opportunity to evolve an adaptive community.
  - Not enough information available to model all indicators used in reservoir monitoring.

A. Data Evaluation – Reservoir Classification

(Important Considerations: size, gradient/depth, ecoregion, reservoir management objective, etc.)

- **Tennessee Valley Reservoirs**
  - **Run-of-the-River (Short Retention Time & Little Drawdown)**
    - Kentucky
    - Pickwick
    - Wilson
    - Wheeler
    - Guntersville
    - Nickajack
    - Chickamauga
    - Watts Bar
    - Melton Hill
    - Fort Loudoun
    - Tellico
  - **Tributary Reservoirs (Long Retention Time & Substantial Winter Drawdown)**
    - **Interior Plateau Ecoregion**
      - Bear Creek
      - Cedar Creek
      - Little Bear Cr.
      - Normandy
      - Beech
      - Tims Ford
    - **Ridge & Valley Ecoregion**
      - Cherokee
      - Ft. Pat. Henry
      - Boone
      - South Holston
      - Norris
      - Douglas
    - **Blue Ridge Ecoregion**
      - Fontana
      - Apalachia
      - Hiwassee
      - Chatuge
      - Nottely
      - Blue Ridge
      - Parksville
      - Watuaga

B. Data Evaluation – A Fundamental Question To Be Answered

Should reservoir ecological health evaluations be based on:

- Ideal conditions, or
- The best conditions attainable/observed given the environmental and operational characteristics of the dam/reservoir?

Data Evaluation – TVA Response to The Fundamental Question

- Ideal Condition (Regardless of Reservoir Class)
  - DO
  - Sediment Quality
- Best Expected/Attainable Condition
  - Benthos
  - Fish Assemblage
- Combination of the Two Approaches
  - Trophic Status (Chlorophyll)

III. TVA Reservoir Ecological Health Rating Methods

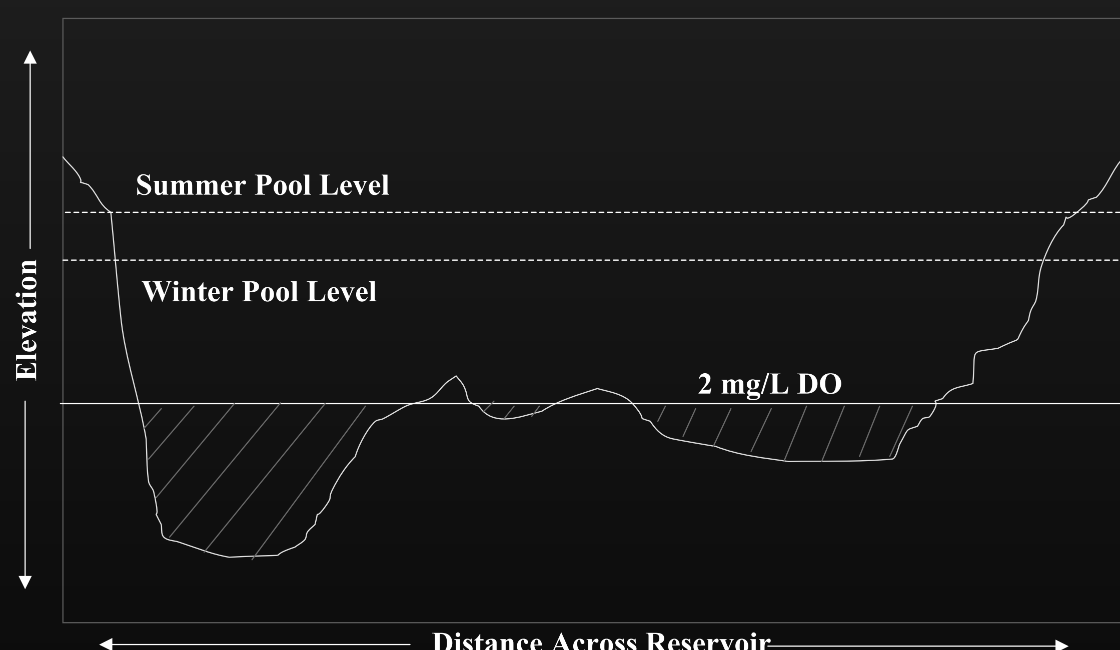
Results for each indicator at each site are given a rating from 1 (poor) - 5 (good);

- Ratings from all sites within a reservoir are then summed;
- That sum is then divided by the maximum possible sum for the reservoir to provide a single overall score which is expressed as a %.
- Scores generally range from the low 40s (poor) to high 80s (good).

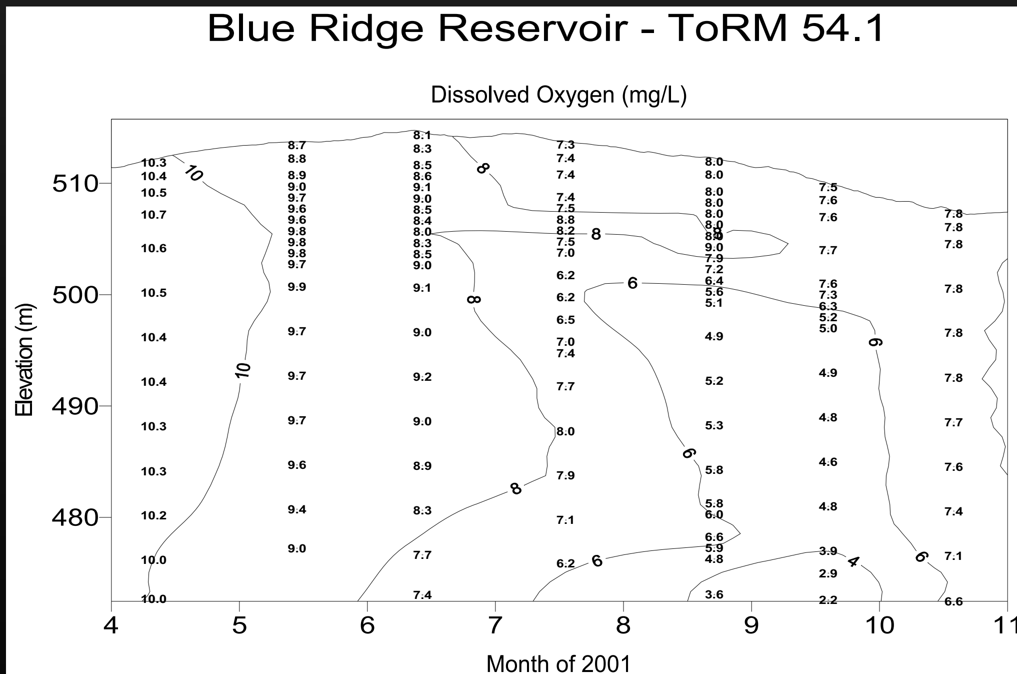
A. TVA Reservoir Ecological Health Rating Methods - DO

- The rating criteria represent a multidimensional approach.
  - Water column DO
  - Bottom DO
- A DO concentration $\leq$2.0 mg/L is the critical value.

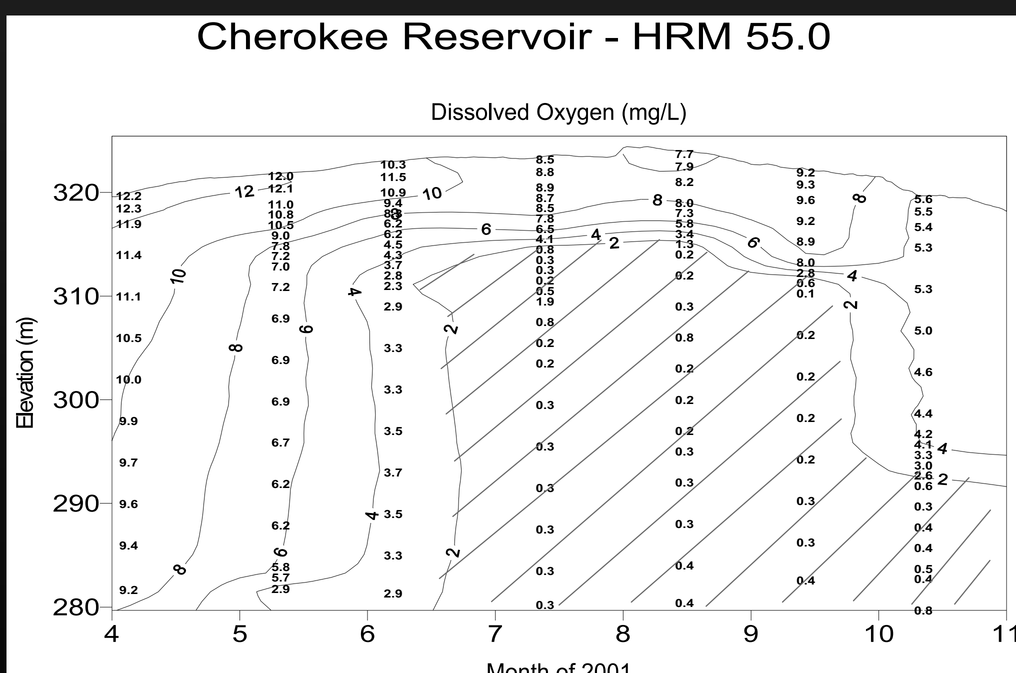
Reservoir Cross-sectional Area Showing the Area with DO Less Than 2.0 mg/L



Example of a Reservoir with a Good DO Rating



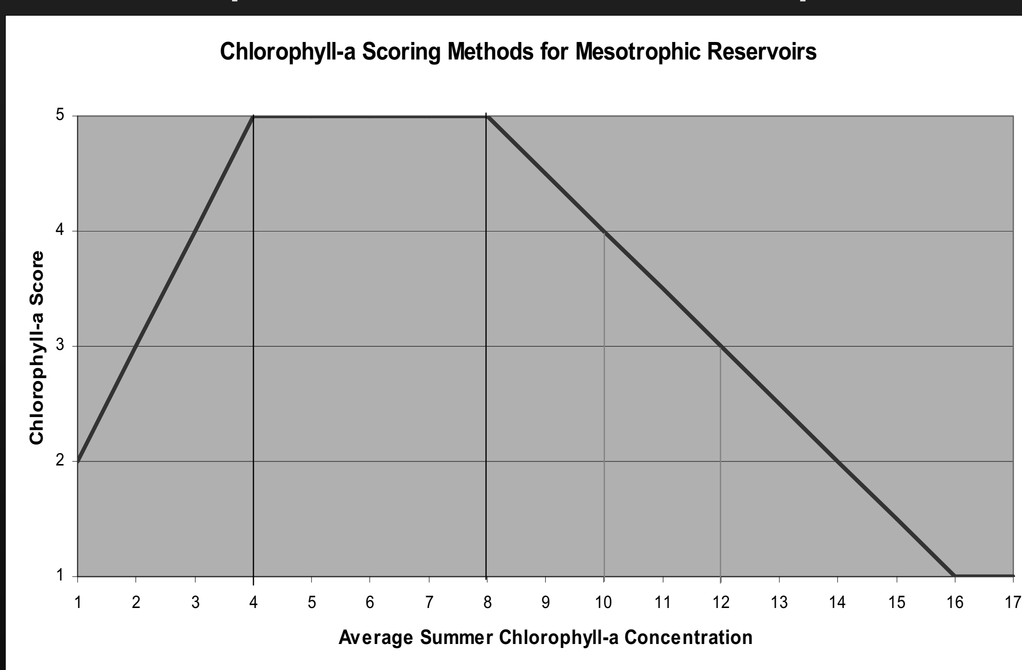
Example of a Reservoir with a Poor DO Rating



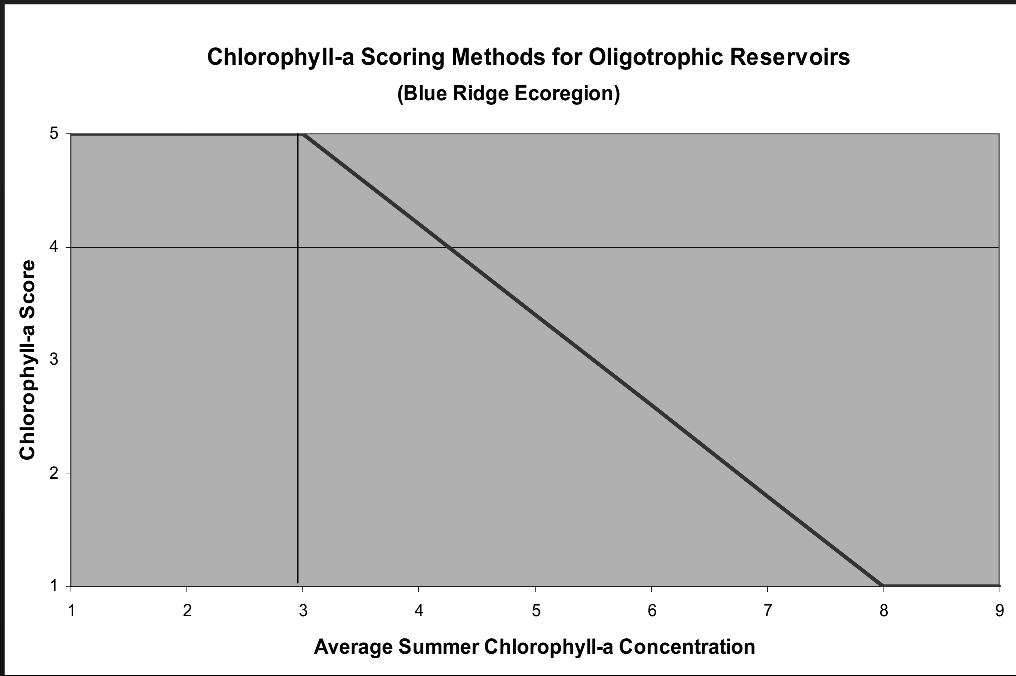
B. TVA Reservoir Ecological Health Rating Methods – Trophic Status

- Scoring criteria were developed separately for each of the two classes of reservoirs.
  - Reservoirs expected to be mesotrophic
  - Reservoirs expected to be oligotrophic
- Ratings are developed based on seasonal average concentrations compared to a sliding scale.

Trophic Status Rating for Reservoirs Expected to be Mesotrophic



Trophic Status Rating for Reservoirs Expected to be Oligotrophic



C. TVA Reservoir Ecological Health Rating Methods – Sediment Quality

- Based on chemical analysis for:
  - Metals (compared to sediment guidelines adapted from EPA Region 5 [EPA, 1977]).
  - Pesticides and PCBs (compared to laboratory detection limits)
- Rating developed as follows:
  - No analyte exceeding - highest rating= 2.5
  - One or two exceeding - medium rating= 1.5
  - Three or more exceeding - lowest rating= 0.5

D. TVA Reservoir Ecological Health Rating Methods – Benthos

- Based on 7 metrics or characteristics.
- Scoring criteria for each metric based on the trisection of data from TVA reservoirs.
- Criteria vary by reservoir class, ecoregion, and zone.
- Score is the total of these metrics (from 7 – 35).
- Scores converted to rating from 1 – 5.

Metrics Used to Evaluate Benthic Macroinvertebrate Results

Metric	R-O-R Res.	Trib Res.
Taxa Richness	X	X
EPT Taxa	X	
Long-lived Taxa	X	
Non-Chiron. / Oligo. Density	X	X
Percent Oligochaetes	X	X
Dominance	X	X
Zero Samples	X	X
Non-Chiron. / Oligo. Taxa		X
Chironomid Density		X

E. TVA Reservoir Ecological Health Rating Methods – Fish Assemblage

- Based on 12 metrics or characteristics.
- Scoring criteria for each metric is based on the trisection of data from TVA reservoirs.
- Criteria vary by reservoir class, ecoregion, and zone.
- Score is the total of these metrics (from 12 – 60).
- Scores converted to rating from 1 – 5.

Metrics Used to Evaluate Fish Assemblage Results

Species Richness and Composition Metrics

1. Total number of species
2. Number of centrarchid species
3. Number of benthic invertivore species
4. Number of intolerant species
5. Number of top carnivore species
6. Percent tolerant individuals (excluding Young-of-Year)
7. Percent non-native species
8. Percent dominance by one species

Trophic Composition Metrics

9. Percent individuals as omnivores
10. Percent individuals as top carnivores

Abundance Metrics

11. Average number per run

Fish Health Metrics

12. Percent individuals with anomalies

Reservoir Ecological Health Scoring Process

Dissolved Oxygen (A)

Chlorophyll (B)

Sediment Quality (C)

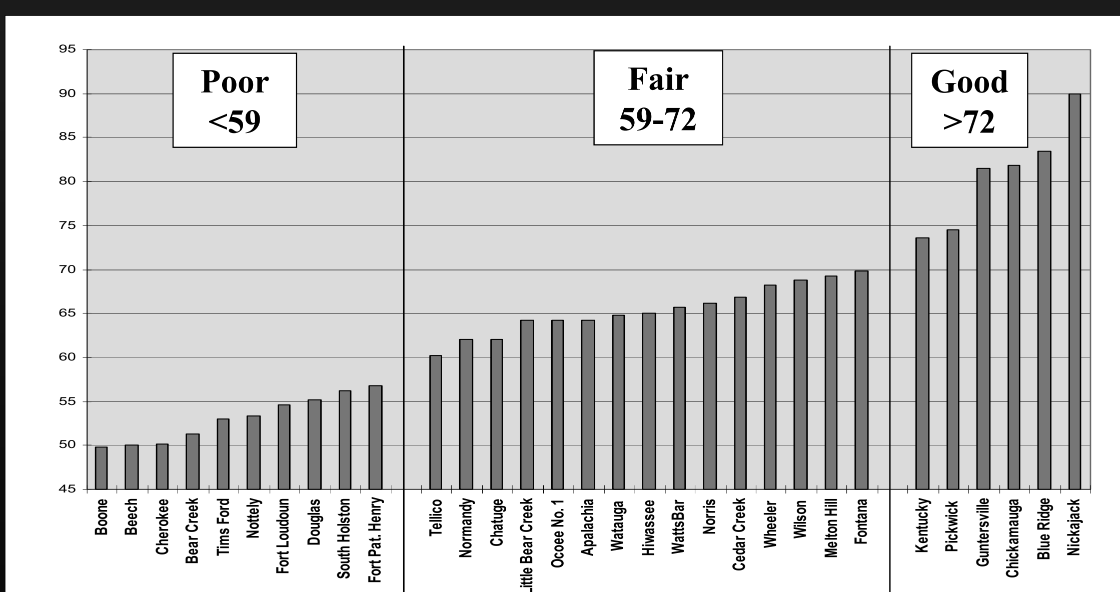
$$\text{Reservoir Health Score} = \frac{\Sigma_i (A + B + C + D + E)_i}{\Sigma_i (A_{max} + B_{max} + C_{max} + D_{max} + E_{max})_i}$$

where i = location 1, 2,...

Benthic Macroinvertebrates (D)

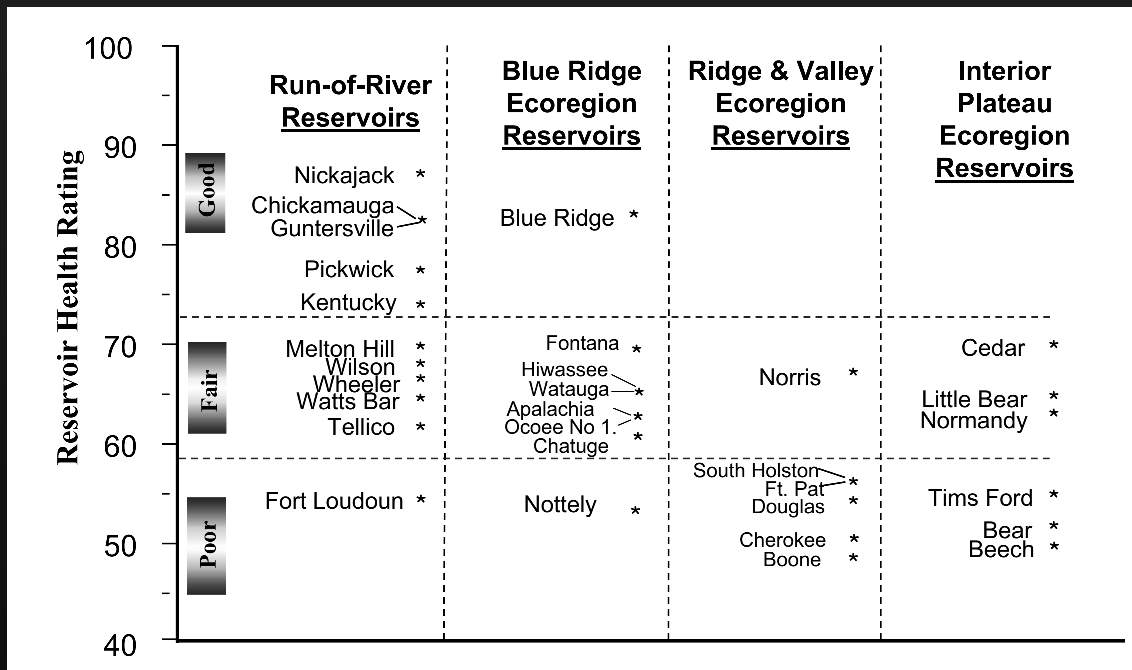
Fish Assemblage (E)

Average Reservoir Scores (1994-2001)

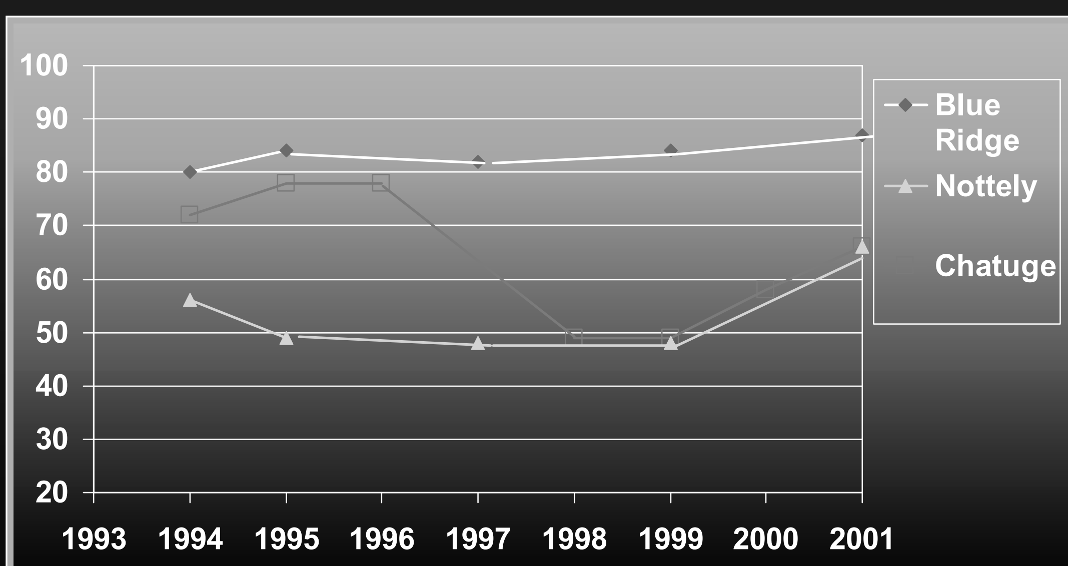


Reservoir Ecological Health

Long-Term Average Reservoir Ecological Health Scores



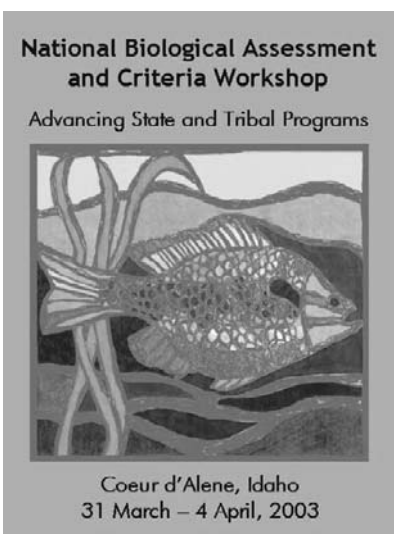
Long-Term Ecological Health Scores for Three Reservoirs



Most Notable Trend Is Increase In Chlorophyll

Type of Reservoir	Decreasing Trend (Negative Slope)	No Trend (Flat Slope)	Increasing Trend (Positive Slope)
Run-of-the-river	1 site	3 sites	20 sites (10 sites significant α= 0.05)
Tributary Reservoirs	0	4 sites	30 sites (16 sites significant α= 0.05)
Total	1 site	7 sites	50 sites (26 sites significant α= 0.05)

Regressions: Concentration vs Time (1990-2001)
Total of 59 locations



LAKES 101

Florida Lake Biocriteria and Bioassessment Development

Presented by

Jim Hulbert & Dana Denson, Florida Department of Environmental Protection
Jeroen Gerritsen, Tetra Tech, Inc.

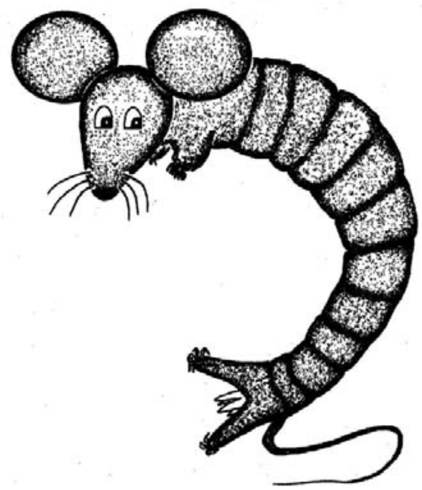
FLORIDA'S BIOCRITERIA/ BIOASSESSMENT HISTORY

- Macroinvertebrate program started in 1948
- Single metric indices:
  - Beck's Biotic Index in 1950; changed to Florida Index in 1980's
  - Shannon Index into Florida Administrative Code in late 1980's
- Primarily Risk Assessment for organic pollution/DO (wastewater effluents)
- Problems with single metric indices
- Risk Assessment became for NPS (nutrients) in 1990's
- Bioassessment and Biocriteria documents developed, following EPA's recommended procedures: **SCI in 1996; LCI in 2000**

Silver Glen Spring, Ocala National Forest

- Many remain for days; most with no sanitary facilities.

- >1000 powerboats anchored in spring run at times.



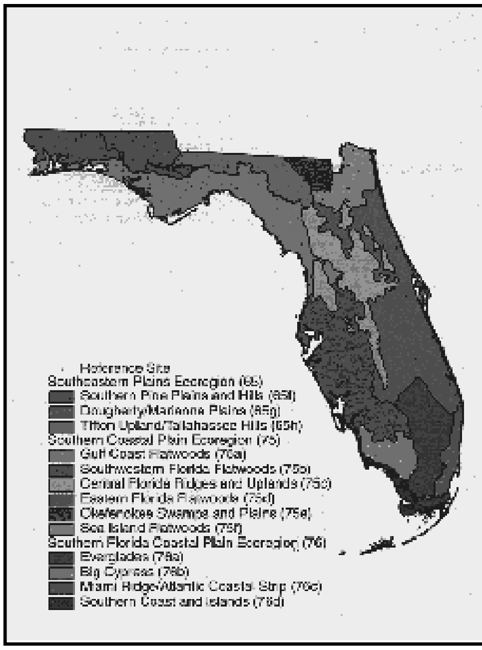
Midgie Mouse

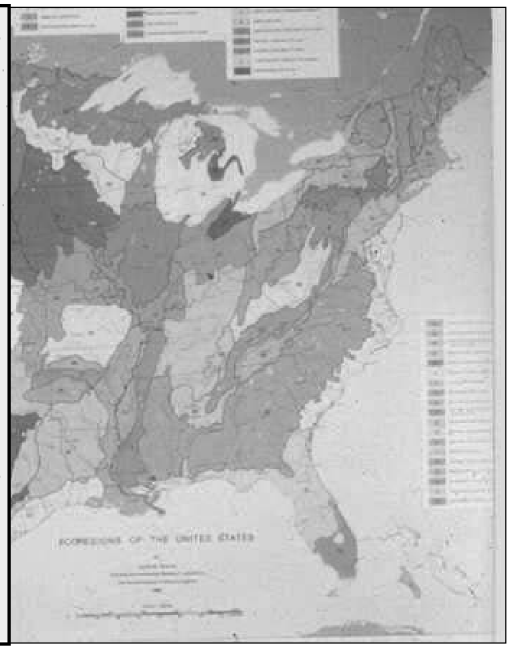
BIOLOGICAL INTEGRITY

Biological integrity is the ability of an aquatic ecosystem to support and maintain a balanced community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitats within a region.

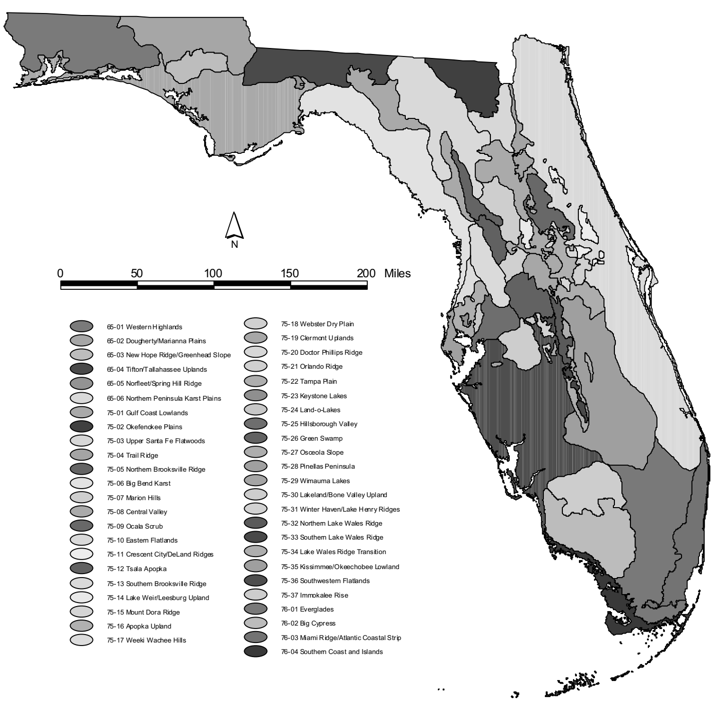
(Karr and Dudley 1981)

Level IV Sub-ecoregions   Level III Ecoregions





Level IV Sub-Ecoregions for Lakes



Establishing Reference Sites and Conditions

Determine sources of effect (NPS, sedimentation, turbidity, human or agricultural activity, proximity of roads)

Evaluate vegetation (shoreline, complexity, age, extent, quality)

Evaluate biological health of candidate sites

Paleolimnology

Local expert consensus

Review historical data

Conduct aerial and ground reconnaissance

Lake Campbell clear, acid

Big Blue Lake clear, acid

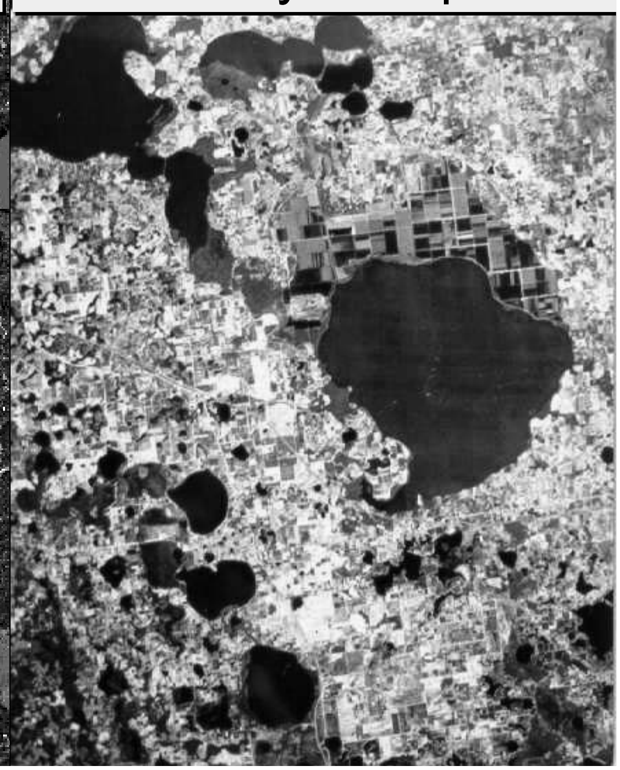
Lake Louisa
colored, acid

Lake Formation

Lake Seminary
(best available)
clear, acid

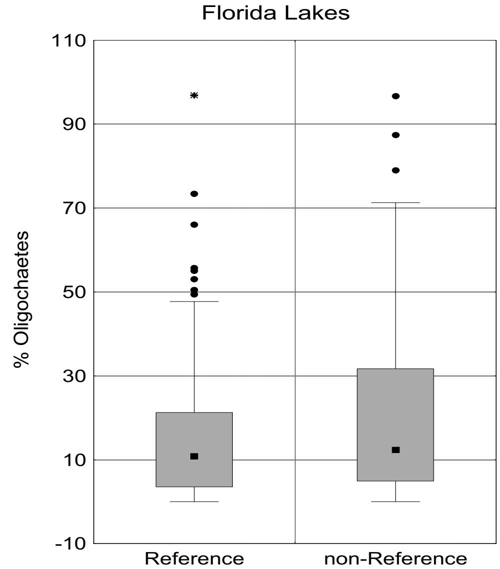
Lake Tsala Apopka
naturally eutrophic

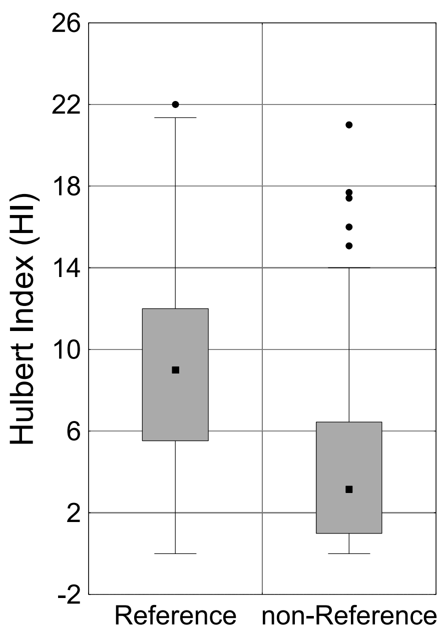
Lake Apopka
culturally eutrophic

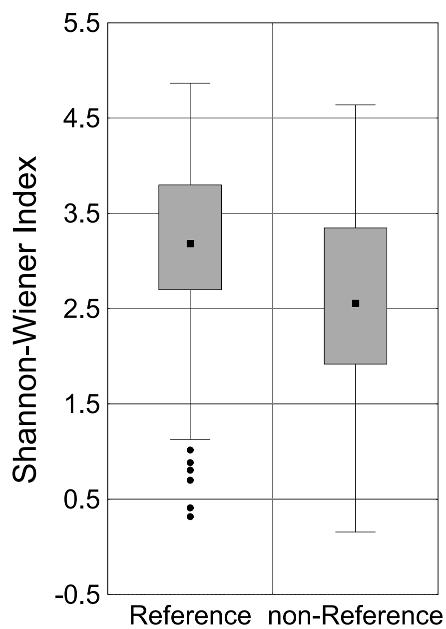


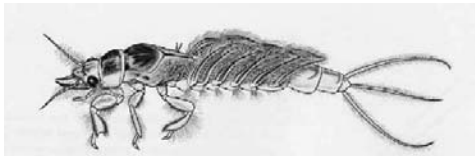
Development of Invertebrate Index

- Examine responsiveness of 33 metrics
  - compare reference and non-reference lakes
  - by lake type
- Select responsive, not overly redundant metrics for multimetric index



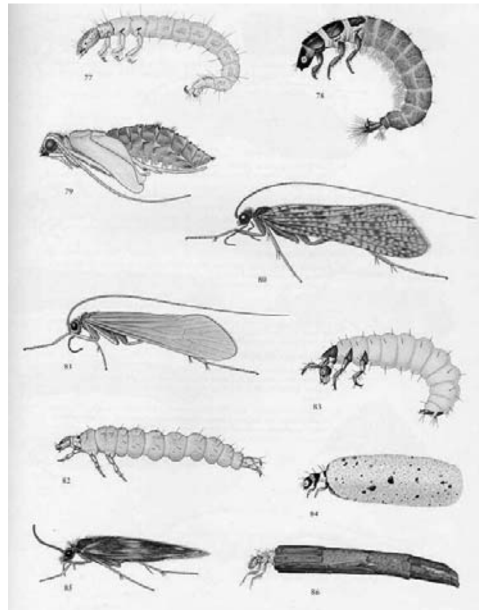




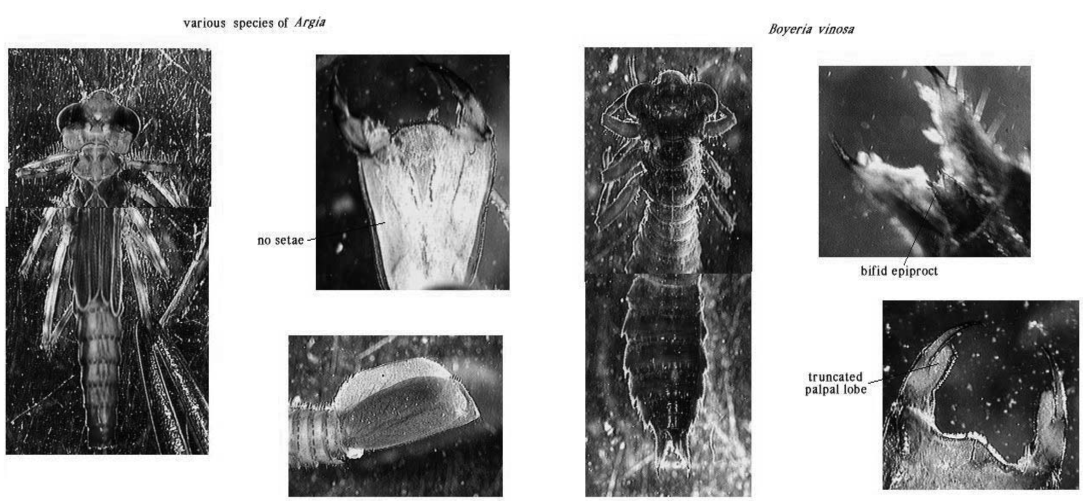


FW macroinvertebrate indicators

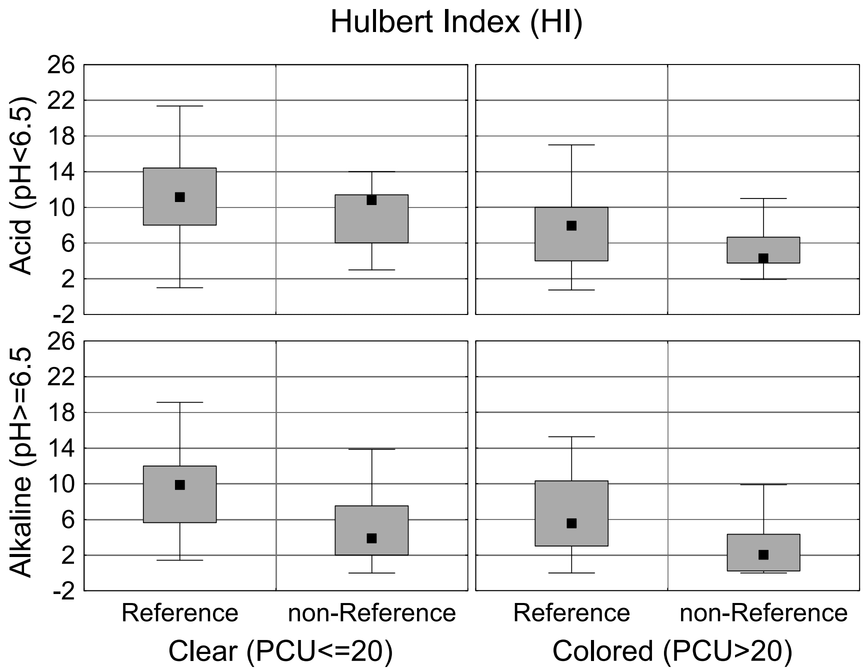
- “EPT” - larval mayflies, stoneflies, and caddisflies
  - occur mainly in clean and flowing streams
  - adult stages very short-lived
  - stoneflies chiefly in Panhandle area
  - well known to fly fishermen



Dragonflies and Damselflies (Odonata)

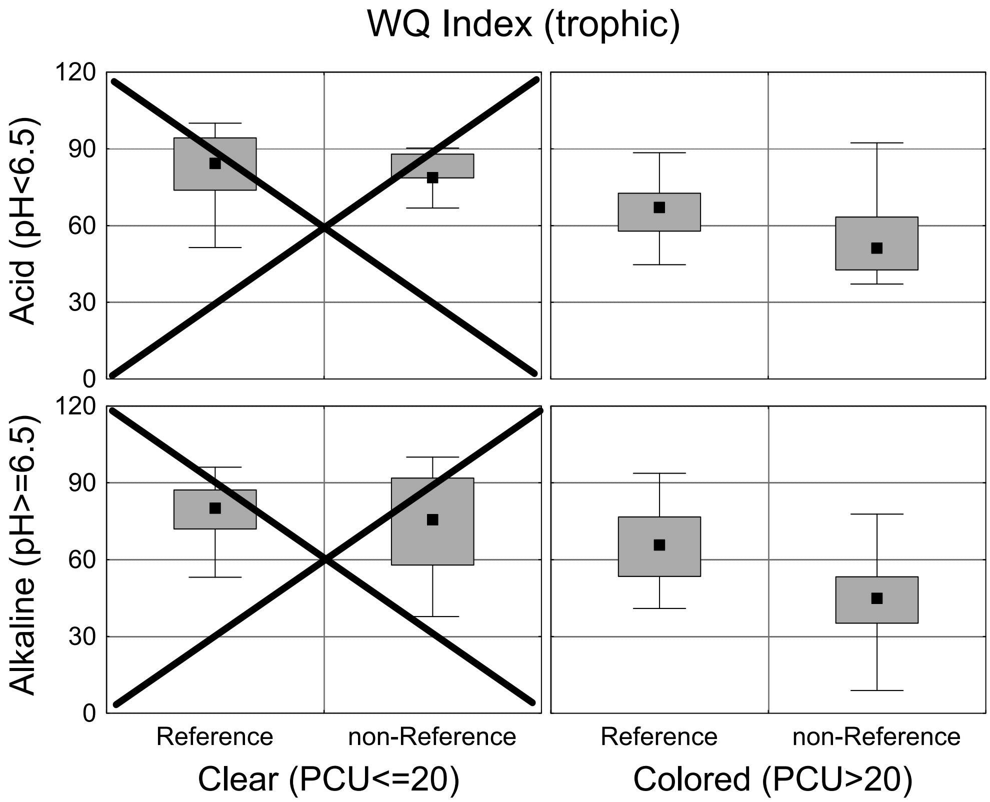


Response varies among lake types



5 practical lake classes

- Acid clear
  - Southeastern Plains (65)
  - Southern Coastal Plain (75)
- Acid colored
- Alkaline clear
- Alkaline colored

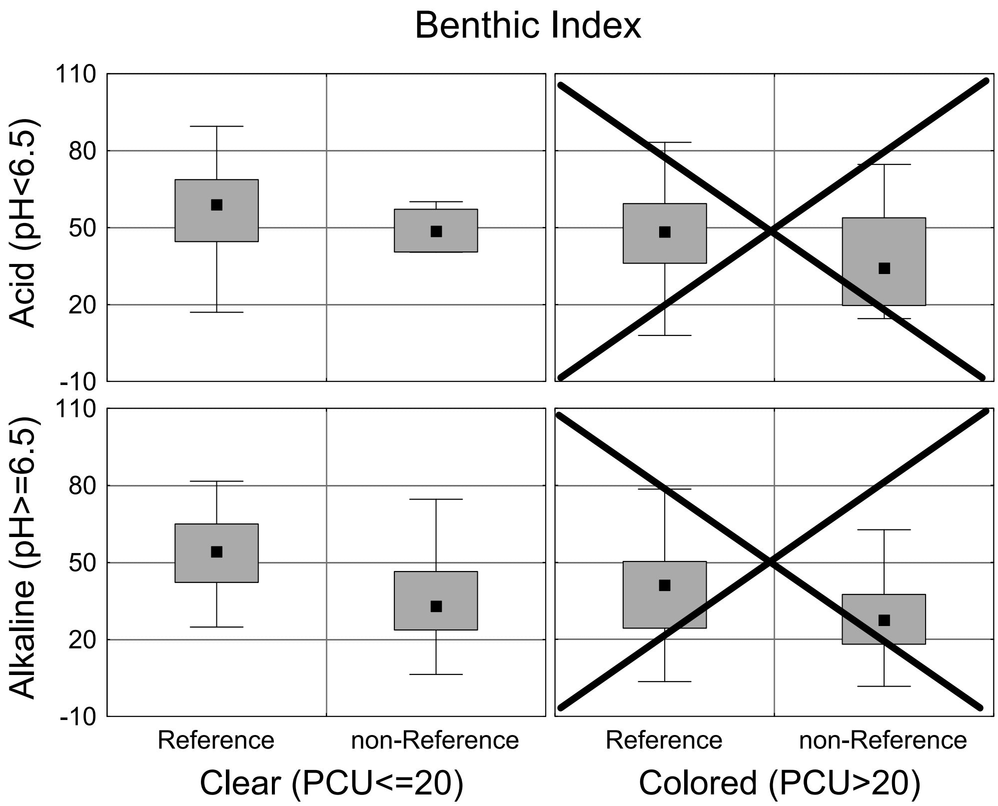


Benthic Lake Index

Invertebrate index of 6 metrics:

- **Total taxa**
- **EOT taxa (mayflies, dragonflies, caddisflies)**
- **Hulbert tolerance index (HI; macroinvertebrate part)**
- **Shannon-Wiener diversity**
- **% EOT**
- **% Diptera**

Works best in clear lakes (<60 PCU)



Conclusions

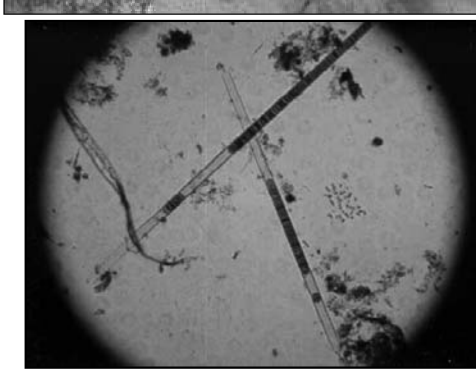
- No single index (among 5) was able to consistently discriminate reference from stressed lakes. Use of two indexes will allow assessment throughout Florida

  - benthic macroinvertebrate index for uncolored lakes (color ≤ 20 PCU)

  - Trophic index for colored lakes (color > 20 PCU)

- Benthic macroinvertebrate assemblage associated with color and transparency

  - highly colored lakes have depauperate benthic fauna tolerant to low DO, organic muck



Conclusions

- Throughout Florida, the lake index is associated with trophic state.
- Lake index and trophic state are associated with urban or agricultural land use in 2 types:
  - Acid, clear lakes of region 65 (Panhandle uplands)
  - Alkaline, colored lakes throughout

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Recommendations

- Adoption of 2 LCIs
  - macroinvertebrate LCI for clear lakes (< 80 PCU?)
  - trophic LCI for colored lakes (> 20 PCU)
- Further calibration and testing of benthic LCI in acid-clear lakes, especially stressed or altered lakes
- Examination of 20-80 PCU “intermediate” color range
- Use LCIs as primary response variable for nutrient criteria development

Floristic Quality Index Development

- Compile list of all taxa sampled
- Floristic quality response form
    - Species list
    - Coefficient of Conservation scoring criteria
- Compile and calculate “Coefficient of Conservation” (C of C)
- Calculate the “Floristic Quality Index”

Floristic Quality Index

“Simple Mean” Coefficient of Conservation

Avg C of C = ($\sum$ C of C_{ijk})

where *j* is the sampling unit, *i* is each species at unit *j* and *k* is the weighting factor

Coefficient of Conservatism Scoring Criteria

(modified from Fennessy et al. 1996)

0	Alien and invasive native taxa
1.0 - 3	Tolerant taxa
3.1 - 6	Ubiquitous taxa
6.1 - 9	Intolerant (sensitive) taxa
9.1 - 10	Taxa that exhibit high degrees of fidelity to a narrow set of ecological conditions.

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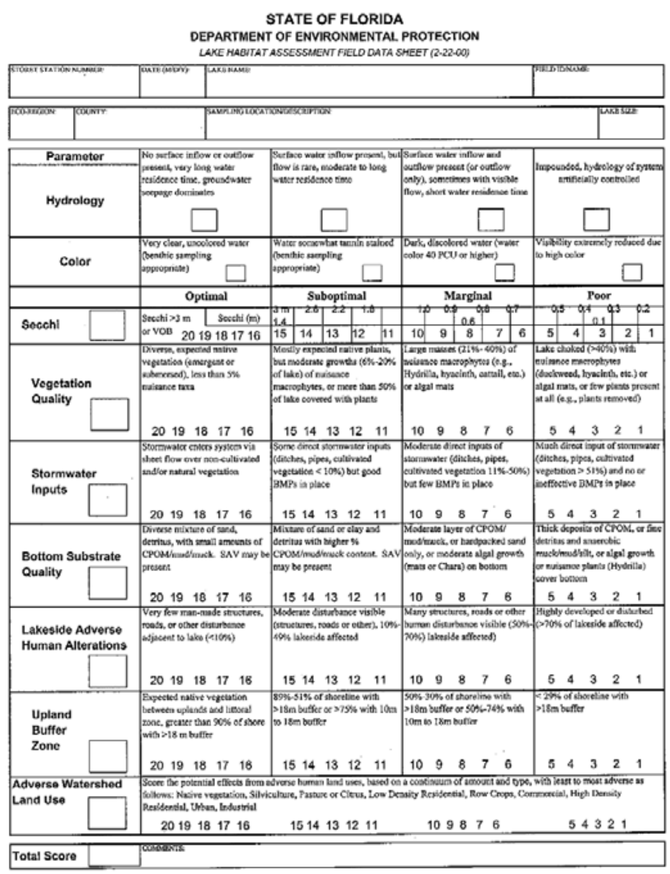
Habitat Assessment

Field observations by trained biologist.

Accompanies biological sampling.

If habitat is impaired, biota will be adversely affected, despite presence of good water quality.



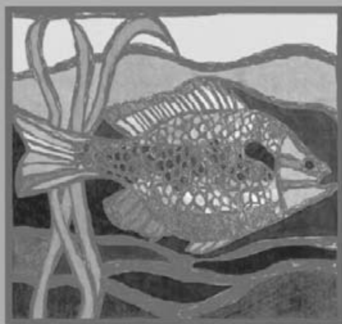
STATE OF FLORIDA
DEPARTMENT OF ENVIRONMENTAL PROTECTION
LAKE HABITAT ASSESSMENT FIELD DATA SHEET (2-22-00)

STORET STATION NUMBER:	DATE (M/D/Y):	LAKE NAME:	FIELD ID/NAME:
ECO-REGION:	COUNTY:	SAMPLING LOCATION/DESCRIPTION:	LAKE SIZE:

Parameter				
Hydrology	No surface inflow or outflow present, very long water residence time, groundwater seepage dominates	Surface water inflow present, but flow is rare, moderate to long water residence time	Surface water inflow and outflow present (or outflow only), sometimes with visible flow, short water residence time	Impounded, hydrology of system artificially controlled
Color	Very clear, uncolored water (benthic sampling appropriate)	Water somewhat tannin stained (benthic sampling appropriate)	Dark, discolored water (water color 40 PCU or higher)	Visibility extremely reduced due to high color
	Optimal	**Suboptimal**	**Marginal**	**Poor**
Secchi	Secchi >3 m or VOB; Secchi (m) 20 19 18 17 16	3 m 2.6 2.2 1.8 1.4; 15 14 13 12 11	1.0 0.9 0.8 0.7 0.6; 10 9 8 7 6	0.5 0.4 0.3 0.2 0.1; 5 4 3 2 1
Vegetation Quality	Diverse, expected native vegetation (emergent or submersed), less than 5% nuisance taxa 20 19 18 17 16	Mostly expected native plants, but moderate growths (6%-20% of lake) of nuisance macrophytes, or more than 50% of lake covered with plants 15 14 13 12 11	Large masses (21%-40%) of nuisance macrophytes (e.g., Hydrilla, hyacinth, cattail, etc.) or algal mats 10 9 8 7 6	Lake choked (>40%) with nuisance macrophytes (duckweed, hyacinth, etc.) or algal mats, or few plants present at all (e.g., plants removed) 5 4 3 2 1
Stormwater Inputs	Stormwater enters system via sheet flow over non-cultivated and/or natural vegetation 20 19 18 17 16	Some direct stormwater inputs (ditches, pipes, cultivated vegetation < 10%) but good BMPs in place 15 14 13 12 11	Moderate direct inputs of stormwater (ditches, pipes, cultivated vegetation 11%-50%) but few BMPs in place 10 9 8 7 6	Much direct input of stormwater (ditches, pipes, cultivated vegetation > 51%) and no or ineffective BMP's in place 5 4 3 2 1
Bottom Substrate Quality	Diverse mixture of sand, detritus, with small amounts of CPOM/mud/muck. SAV may be present 20 19 18 17 16	Mixture of sand or clay and detritus with higher % CPOM/mud/muck content. SAV may be present 15 14 13 12 11	Moderate layer of CPOM/ mud/muck, or hardpacked sand only, or moderate algal growth (mats or Chara) on bottom 10 9 8 7 6	Thick deposits of CPOM, or fine detritus and anaerobic muck/mud/silt, or algal growth or nuisance plants (Hydrilla) cover bottom 5 4 3 2 1
Lakeside Adverse Human Alterations	Very few man-made structures, roads, or other disturbance adjacent to lake (<10%) 20 19 18 17 16	Moderate disturbance visible (structures, roads or other), 10%-49% lakeside affected 15 14 13 12 11	Many structures, roads or other human disturbance visible (50%-70%) lakeside affected) 10 9 8 7 6	Highly developed or disturbed (>70% of lakeside affected) 5 4 3 2 1
Upland Buffer Zone	Expected native vegetation between uplands and littoral zone, greater than 90% of shore with >18 m buffer 20 19 18 17 16	89%-51% of shoreline with >18m buffer or >75% with 10m to 18m buffer 15 14 13 12 11	50%-30% of shoreline with >18m buffer or 50%-74% with 10m to 18m buffer 10 9 8 7 6	< 29% of shoreline with >18m buffer 5 4 3 2 1
Adverse Watershed Land Use	Score the potential effects from adverse human land uses, based on a continuum of amount and type, with least to most adverse as follows: Native vegetation, Silviculture, Pasture or Citrus, Low Density Residential, Row Crops, Commercial, High Density Residential, Urban, Industrial 20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
Total Score	COMMENTS:			

National Biological Assessment and Criteria Workshop

Advancing State and Tribal Programs



Coeur d'Alene, Idaho
31 March – 4 April, 2003

LAKES 101

Biocriteria Development for Lakes: Merging multimetric & multivariate approaches to develop trial biocriteria for phytoplankton and macroinvertebrates in lakes

Presented by

Neil Kamman, Vermont Department of Environmental Conservation

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Outline

- Need and approach
- Incorporating probability-based statistics into multimetric assessments
- Assemblages evaluated, and description of database
- Results - phytoplankton
- Results - macroinvertebrates

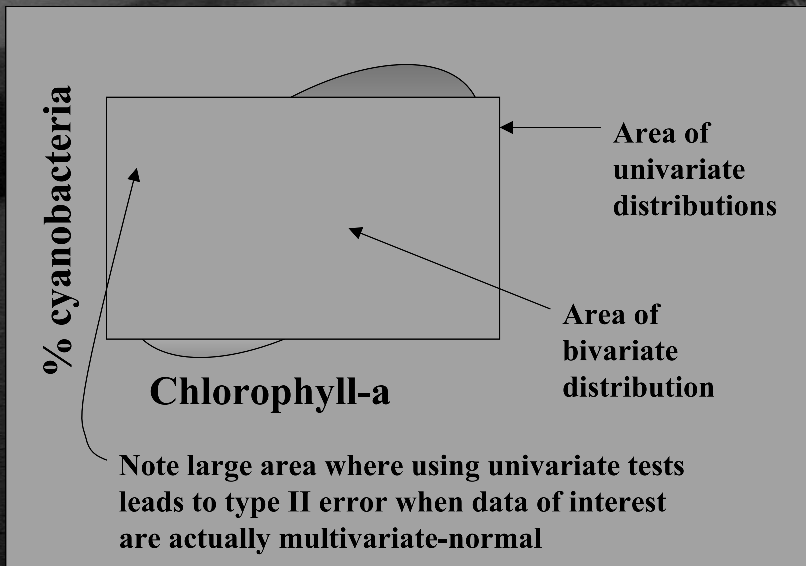
Need and approach

- VT’s 2000 WQS revision established regulator requirement for quantitative biocriteria for use in assessment and listing.
- VT uses the standard reference-based multimetric approach, but it is...
- Validated using probability-based statistics.

Incorporating probability-based statistics into multimetric assessments

- Multivariate methods
- Commonly used techniques like T-tests and ANOVA, but mathematically extended to multiple metrics
- Address simultaneous joint variation in multiple metrics
- Controls for experiment-wise error

Controlling experiment-wise error using multivariate-normal data



Assemblages evaluated, and description of database

- 40+ lakes
- Assessed for trophic parameters (S.D., cha), phytoplankton, macrophytes, bugs.
- Lakes range widely in alkalinity, size, depth, trophic status, and level of disturbance.
- Large number of candidate metrics produced from VTDEC biomonitoring database - also several ‘new’ metrics developed for lakes

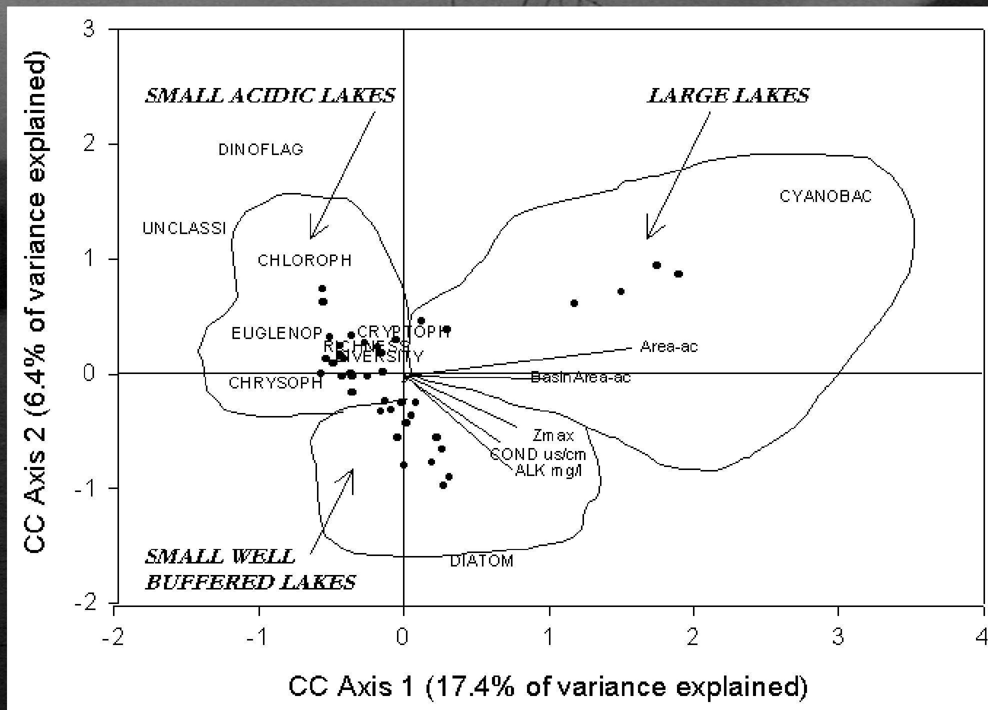
Multivariate methods used in this project

- Canonical Correspondence Analysis (CCA)
- Multivariate ANOVA (MANOVA)
- Discriminant Function Analysis (DFA)

Classification approach

- Use CCA to infer the existence of lake classes, which appear to be influenced by environmental variables
- Use DFA to generate algorithms permitting calculation of a lake’s membership to a group
- Verify that biometrics actually vary w/ classes

Classification Approach - CCA

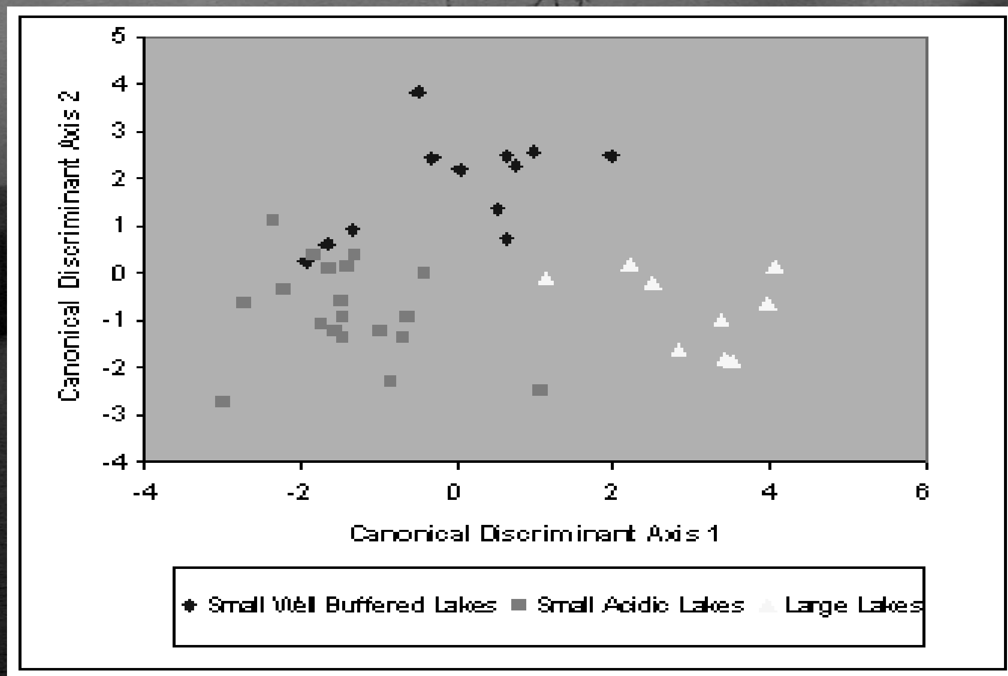


Discriminant function analysis

Create equations based on:

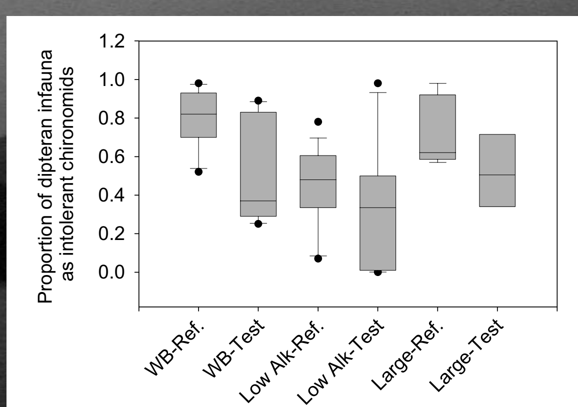
- Lake Area (ac)
- Basin area (ac)
- Basin/Lake Area Ratio
- Maximum depth (m)
- Alkalinity (mg/l)
- Conductivity (*u*S/cm)

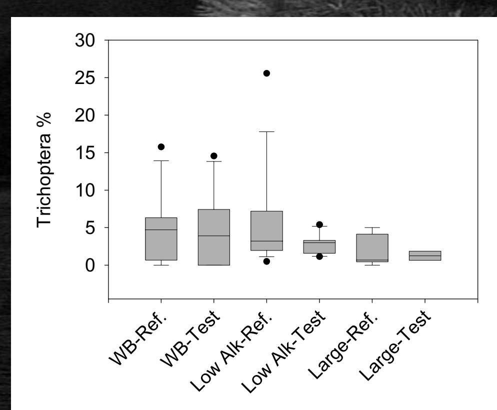
Discriminant function analysis



p=0.001 Overall error rate 15%

Metric selection / scoring procedure





Index development followed standard procedures. The above figures pertain to macroinvertebrates and are for illustrative purposes.

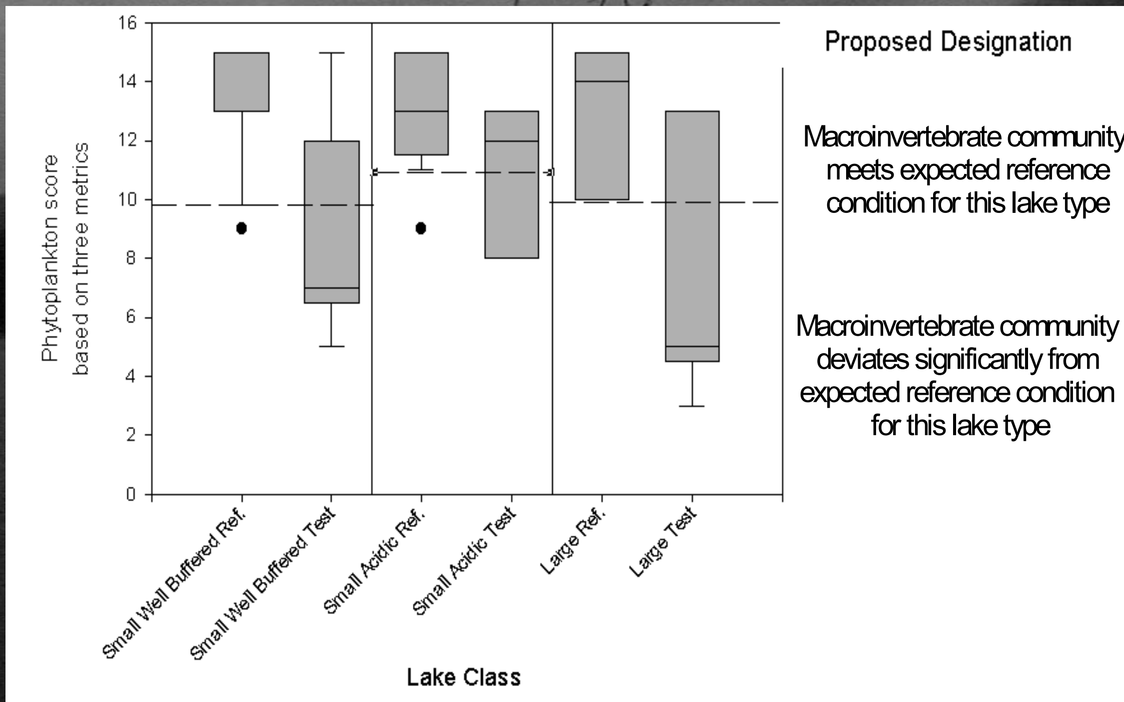
Metrics selected

- Total density, % *Aphanizomenon spp., Anabaena spp., Microcystis spp.* by volume +
- for Small, Well Buffered Lakes:
  - % chrysophytes by density
- for Small, Acidic Lakes:
  - % cryptophytes by volume
- for Large Lakes:
  - % diatoms by density

Verification of selected metrics using manova

- Use MANOVA to test that the variation observed across classes and between reference and test lakes is statistically significant
- Results:
  - No sig. variation attributable to interaction
    - $p=0.806$
  - Sig. variation attributable to lake class
    - $p<0.001$
  - Sig. variation attributable to reference status
    - $p=0.022$

Box plots of final phytoplankton scores



Macroinvertebrates

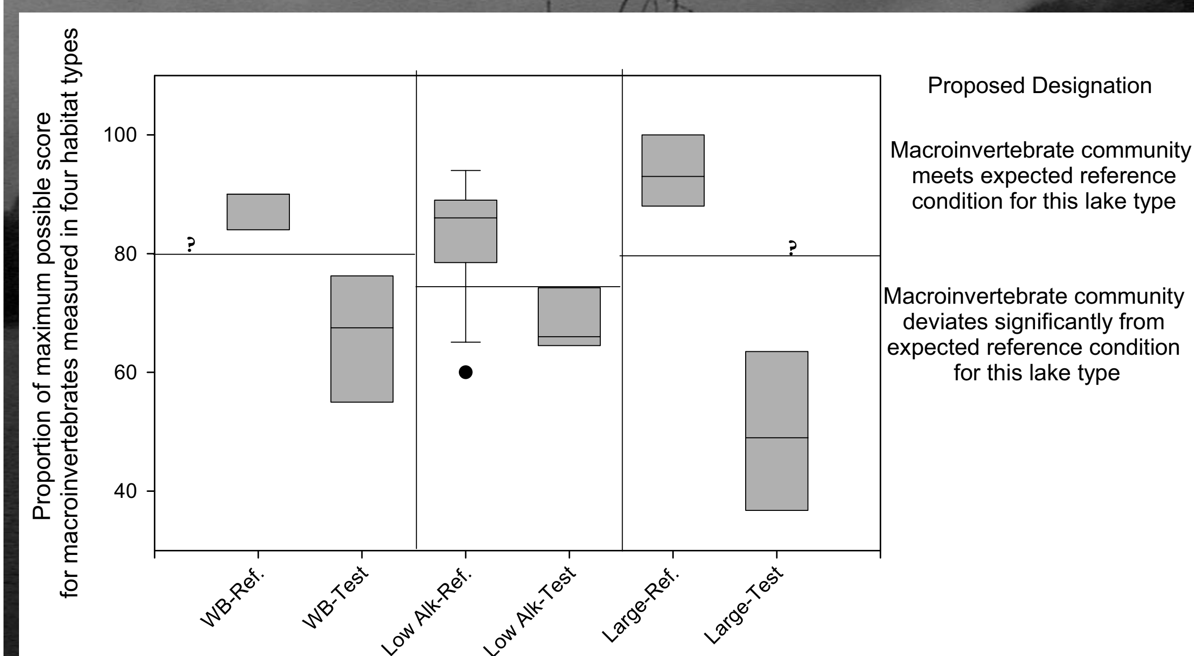
- Five habitats assessed
  - rocky littoral (kick net),
  - muddy littoral (kick net),
  - littoral macrophytes (sweep net),
  - sublittoral (Ekman grab),
  - profundal (Ekman grab).
- Classification derived using the phytoplankton metrics was re-verified for macroinvertebrates and retained.
- Index development again followed standard procedures, and was then verified using MANOVA.

Macroinvertebrate metric summary -

	Lake class		
Habitat	Small low-alkalinity	Small well buffered	Large
Rocky littoral	2	1	4
Muddy littoral	0	2	2
Macrophyte	2	2	2
Sublittoral	2	3	3
p for MANOVA	0.009	0.04	0.026

- For each lake class, between 6 and 11 metrics comprise the macroinvertebrate index.
- Structural and functional aspects

Box plots of final macroinvertebrate scores



What about the profundal zone??

- Reference, test, and impaired lakes all showed wide ranges in dipteran community structure (richness and diversity).
- Some reference lakes were devoid of profundal community.
- Some impaired lakes had maximum richness/diversity values (intermediate disturbance).
- Mostly unusable data for the purpose of generating lake biocriteria based on these data.

Macroinvertebrates – Impairment types

- Flow regulation - depression in rocky-littoral metrics, and in macrophyte-bed community metrics.
- Eutrophication – alterations to the dipteran and crustacaea-mollusca communities.
- Cumulative impact – several lakes show alterations which are most appropriately pinned to ‘cumulative stresses.’
- Acidity – signal of acidification effects in low alkalinity lakes is present, albeit weak.

Summary:

- VT's bioassessment system is comprised of:
  - Classification scheme
    - error-quantified
    - equations to allocate lakes to a class
  - Phytoplankton
    - 5 metrics
    - vary by lake type
  - Macroinvertebrate Index
    - 6-11 metrics
    - vary by lake type

- **MACROINVERTEBRATE METRIC LISTS**

Metric selection / scoring procedure

- Untransformed data
- Box plots to visualize distributions
- Correlation matrix (non-parametric) to weed out redundant metrics
- Calculation of interquartile coefficients
- Retain metrics explaining greatest separation between classes and providing largest discrimination of reference vs. impaired status

Macroinvertebrates - Well buffered lakes

- Eight metrics
- RL: COTE/COTE+remaining dipterans
- ML: VT Hilsenhoff BI, taxa richness
- MAC: % tanytarsus, chironomid richness
- SL: % in top 3 dominant communities, % collector filt., % dipterans as intolerant chironomids
- Model indicates significant separation between reference and test/imp. lake scores:
  – Wilks’ • •= 0.278, F = 4.54, p=0.04

Macroinvertebrates - Low alkalinity lakes

- Six metrics
- RL: %crustacaea-mollusca, % dipterans as intolerant chironomids
- ML:none
- MAC: crustacaea-mollusca R, taxa richness
- SL: % tanytarsus, % dipterans as intolerant chironomids
- Model indicates significant separation between reference and test/imp. lake scores:
  - Wilks' • •= 0.237, F = 11.77, p=0.009

Macroinvertebrates - Large lakes

- Eleven metrics
- RL: % top dominant taxa, % ephemoptera, % coll. gath., % crustacaea-mollusca
- ML: VT Hilsenhoff BI, % chironomids
- MAC:taxa richness, chironomid R
- SL: % coll. filt., chironomid R, % dipterans as intolerant chironomids
- Model indicates significant separation between reference and test/imp. lake scores:
  - Wilks' • •= 0.121, F = 9.36, p = 0.026