Update of Statistical Framework for the Onondaga Lake Ambient Monitoring Program

prepared for

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by

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Table of Contents

1.0 Introduction

The Onondaga Lake Ambient Monitoring Program (AMP) was designed to provide information supporting future decisions on wastewater and watershed management (Onondaga County, 1998). These decisions will be based in part upon measured responses in the Lake, its tributaries, and Seneca River as specific point and non-point source control measures are implemented over the 2000-2010 period. Decisions will also rely upon comparisons of monitored conditions with water quality standards, indices of ecosystem health, and other management goals. Specific hypotheses have been formulated to track the progress of the program, guide data collection, and guide statistical analysis. Those hypotheses are summarized in Table 1; details are listed in Appendix A. The AMP design and station locations for 2007 are summarized in Table 2 and Figure 1, respectively.

Previous reports (Walker, 1998; 1999; 2000a; 2002ab) describe a statistical framework (AMPSF) with the following functions:

- Identifying and quantifying sources of variability in the data;
- Evaluating precision of yearly summary statistics, expressed as relative standard errors, RSE = standard error / mean);
- Evaluating power for detecting long-term trends, expressed as likelihood of detecting hypothetical trends or step changes of specific magnitudes;
- Refining monitoring program designs;
- Developing methods for testing hypotheses regarding trends or compliance.

The framework uses a statistical model that expresses precision and power with a common set of numerical indices. It supplements statistical analyses of each dataset in the AMP yearly monitoring reports. The best analytical approach to support biological and limnological interpretation of the data varies with monitored component and metric.

The AMPSF has been implemented in two phases. One series of reports (Phase I, Walker 1999; 2002a) focused on water quality components (nutrients, chlorophyll-a, transparency, & bacteria). A second series (Phase II, Walker 2000a, 2002b) focused on biological components (phytoplankton, macrophytes, macroinvertebrates, fish). These reports evaluated sampling designs using variance component models calibrated to recent and historical data from Onondaga Lake, other regional lakes, and the general literature. Variance component models provide explicit estimates of statistical precision and power as they relate to natural variability in the system, precision of the monitoring program, and to monitoring design parameters, including temporal frequency (seasonal, annual), spatial frequency, and replication. Compared with previous AMPSF updates, substantially more site-specific data are now available for model calibration and hypothesis testing.

In previous reports, the precision of yearly summary statistics was evaluated in relation to the pre-specified AMP goal (RSE < 20%). Precision was estimated based upon on estimates of variability derived from the literature and limited site-specific data. Results generally indicated that predicted RSE values were well below the 20% criterion for most water quality components and qualitative indices of the biological communities (those reflecting species composition or diversity). In many cases, RSE values exceeded the 20% criterion for indices reflecting relative abundance of biological components (Catch per Unit Effort (CPUE) for fish populations, macrophyte biomass, phytoplankton biomass, chlorophyll-a, bacteria). The relatively low precision primarily reflected high inherent variability of the biological communities, as opposed to factors that could be practically addressed by increasing spatial or temporal monitoring frequency. Lower precision in annual means can decrease statistical power for detecting trends and assessing long-term compliance with numeric standards or goals. Those effects are not necessarily large, however, because power is often controlled primarily by random year-to-year variability, as opposed to the uncertainty in the measured yearly means.

Sensitivity analyses provided a basis for recommending specific adjustments in sampling frequency or replication to improve cost-effectiveness of the monitoring program. Several recommendations were subsequently implemented, including doubling sampling frequencies for lake chlorophyll-a and bacteria (from biweekly to weekly), adult fish (from biennial to annual), juvenile fish (from 2 to 3 sites per stratum and from 3 to 1 replicate per site). Another recommendation was to place an increased emphasis on tracking biological components using indicators of community composition, such as species richness (number of species) and diversity, which can be measured with greater precision, as compared with measurements of abundance or relative abundance (e.g., fish Catch Per Unit Effort (CPUE)). That recommendation was consistent with the consensus of the AMP Biological Workgroup, which advises the OCDWEP on the analysis and interpretation of the biological data. A final recommendation was to develop a set of hypotheses regarding long-term improvement in the Lake to be tested with the monitoring data.

This report updates both the water quality (Phase I) and biological (Phase II) portions of the AMPSF using data collected between 1999 and 2005 (EcoLogic et al, 2006). Previous reports focused on precision and power as bases for refining the monitoring program designs. Given that the 1999-2005 period represents more than half of the AMP duration, substantial changes in the monitoring plan are neither practical nor desirable at this point, given the importance of providing consistent datasets for tracking long-term changes. Topics for this report include:

1) Update precision and power estimates based upon 1999-2005 data

2) Development of a framework for testing the management hypotheses in Table 1 using the cumulative AMP datasets.

3) Exploratory analysis of the data to identify statistical issues that are relevant to interpreting the data and testing the management hypotheses

4) Topics for consideration by the Onondaga Lake Technical Advisory Committee (OLTAC):
   a) Potential minor adjustments to the monitoring program to fill gaps and increase precision
   b) Refinement of metrics, hypotheses, & statistical methods
   c) Future data analysis

Although the water quality and phytoplankton datasets have much longer periods of record, this report focuses on data collected between 2000-2005, when all of the biological and water quality components of the monitoring program were underway. Some datasets begin in 1999. This allows comparison of the precision, power, and trend analysis results for a common period.

The following section describes basic statistical concepts related to precision, power, and hypothesis testing. Subsequent sections describe the analytical approach and results for each water quality and biological component. Each component is expressed in one or more metrics (e.g., mean concentration, frequency of occurrence, relative abundance, diversity, macroinvertebrate index, etc.), as identified in the list of hypotheses and metrics (Table 1, Appendix A). Final sections contain a discussion of results, conclusions, and recommendations.

2.0 Statistical Concepts

This section summarizes relevant statistical concepts and basic conclusions with respect to statistical methodology to support general data interpretation in AMP annual reports and formal hypothesis testing.

2.1 Variance Components

Previous AMPSF reports describe the statistical models used to evaluate precision and power under the AMPSF . Variance components generally fall into two major categories:

1) Within-Year Variations
   a) Spatial (depth, lake region, station)
   b) Seasonal (fixed patterns from year to year)
   c) Random temporal (background)
   d) Random sampling/analytical errors

2) Among-Year Variations
   a) Long-term trend or step change in the mean reflecting anthropogenic factors and/or natural phenomena that vary over long time scales
   b) Covariation with specific management measures implemented during the monitoring period
   c) Covariation with independent factors that are causally connected (e.g., flow, rainfall, temperature)

d) Random variations of unspecified origin (e.g., climatologic, ecologic)

The specific components vary with dataset, depending on the monitoring plan. Analyses of Variance (ANOVA's) provide estimates variance components, from which estimates of precision and power are derived.

It is not practical or necessary to estimate all of the variance components in testing management hypotheses regarding long-term improvement (Component 1). Trend analyses (as presented in the AMP yearly reports on a 10-year basis) typically boil down to comparison of a hypothetical trend (2a) with a composite "error" term that reflects all of the remaining variance components, i.e. a comparison of a hypothetical "signal" to observed "noise".

Filtering out noise components is obviously desirable for detecting signals. Filtering methods for a given data set typically include:

1) Remove seasonal variance by
   a) averaging the data over the year (or monitoring season)
   b) testing hypotheses separately by season
   c) using a statistical method that explicitly accounts for seasonality (e.g., Seasonal Kendall (SK) Test, Helsel & Hirsch, 1992).

2) Remove spatial variance by
   a) averaging the data over representative sites
   b) averaging the data over depths
   c) testing hypotheses separately by site or region (e.g. lake stratum)
   d) using a statistical method that explicitly accounts for spatial variations (e.g., analysis of covariance)

3) Reduce among-year variance by adjusting the yearly time series for covariance with independent hydrologic or climatologic factors.

With spatial and seasonal variations removed, variance components are condensed into the following categories for the purposes of evaluating precision and power:

A. Random within-year variations (spatial, temporal, or replicate)
B. Random among-year variance
C. Long-term trend

ANOVA's are used to estimate each component for variables with yearly time series. To facilitate comparisons across metrics, variance components are expressed as coefficients of variation (standard deviation / mean). Components B and C cannot be reliably estimated from existing datasets for variables that are sampled at two or five year intervals (macroinvertebrates, macrophytes). Component A provides a basis for estimating precision, as described below.

Variance component estimates are most accurate when the data are normally distributed. Modest deviations from normal distribution can be tolerated in the within-year variance term when estimating precision and testing hypotheses using parametric procedures. (Helsel & Hirsch, 1992; Ward & Loftis, 1990; Snedocor & Cochran, 1989). Generally, the impact of skewed distributions typically encountered in water quality and biological datasets is to inflate error bars and weaken hypotheses tests (increase risk of Type II error) but not impact the risk of Type I error (false trends). The actual "p" values will be over-estimated and therefore decrease the chance that the null hypothesis will be rejected when a trend actually exists in the data. As a consequence, the outcomes of the hypothesis test tend to be conservative when the distribution is skewed. The log or square root transformation can be used to reduce skewness and increase power, but is not necessary when a nonparametric procedure (SK test) is used for trend analysis.

Since covariance with independent factors (3 above) is not removed in the existing framework, it is implicitly included in the random year-to-year variance term (B). That has the effect of limiting power for detecting trends. Especially for variables that are directly correlated with nutrient loads, removing covariance with hydrologic or climatologic variables could increase power and facilitate interpretation of observed year-to-year variations (Helsel & Hisrch, 1992; Walker, 1999b, 2000b). For example, removing the effects of random year-to-year variations in precipitation would be important for tracking long-term trends in watershed runoff potentially related to anthropogenic factors (Figure 2). As phosphorus loads from Metro are reduced, interpreting year-to-year variations in nonpoint phosphorus loads and lake responses will become increasingly important. It is recommended that this topic be further explored in future AMPSF updates.

2.2 Precision

The Relative Standard Error (RSE) is used as an indicator of precision in the yearly-mean (or seasonal-mean) values and is computed with the following formula:

$$\text{RSE} = [\text{ Random Within-Year Variance / Number of Samples}]^{.5} / \text{Mean}$$

In estimating the precision of annual means, it is important that the data be reduced so that the within-year term is randomly distributed. If seasonal variations are not removed prior to the computation, the RSE will be over-estimated (i.e., the true precision will be better than indicated). In some cases, the analysis is performed separately for different seasons (e.g. adult fish).

2.3 Power

As depicted in Figure 3, power reflects the likelihood of rejecting the null hypothesis when a trend actually exists in the data. Power can be expressed in statistical jargon as

"1 - β", where β = risk of Type II Error (false negative in hypothesis test). Power depends on the following factors:

1. Uncertainty in measured yearly means, as reflected by the RSE.
2. Random year-to-year variations
3. Magnitude of the trend or change in the long-term mean
4. Duration of the dataset
5. The "significance level" selected to test hypotheses (α = maximum risk of Type I error or false positive)
6. Statistical method used to test hypotheses

These relationships are summarized in Figure 3. In the analysis below, power is evaluated for a one-tailed null hypothesis (no improvement) and significance level α = 0.1. A ten-year monitoring period is assumed with one, two, or five-year intervals, depending on the AMP design for each metric (Table 1).

Power is expressed in the following terms:

1. Probability of detecting hypothetical trends of a specific magnitudes. The analyses are based on a hypothetical increase of 20% in the long-term mean over a 10-year period, based upon a comparison of data from years 1-5 with data from years 6-10 using a t-test or analogous non-parametric procedure. Higher values for this statistic would indicate greater power.

2. Change in the long-term mean detectable with 90% confidence. For example, a value of 28% indicates that there is more than a 90% chance of detecting a change greater than 28% (i.e. rejecting the null hypotheses). Lower values for this statistic would indicate greater power.

Sensitivity of the above metrics to monitoring intensity, as reflected by 2-fold variations in the number of random samples per year (replicates, dates, or transects), is also evaluated. This sensitivity provides a basis for evaluating the impacts and cost-effectiveness of potential changes monitoring plan.

2.4 Hypotheses Testing

In testing hypotheses regarding improvement in the waterbody, we start by assuming that conditions are not improving (i.e., "null hypothesis, Figure 3) and then estimate the probability that our assumption is wrong. That probability is reflected in the "p" value generated when a statistical method is applied to a given dataset. The null hypothesis is "1-tailed" because we are asking whether there is positive trend or improvement, as opposed to whether the trend is significantly different from zero (positive or negative) (Snedecor & Cochran, 1989). The null hypothesis is rejected if the p value is below a pre-specified "significance level" (α). Significance levels of 0.1 and 0.05 have been routinely used in trend analyses of AMP data (Ecologic et al., 2006). Optimizing the monitoring plan and using appropriate statistical methods maximizes the power of the hypothesis test, i.e. reduces the probability of a "Type II" error, as defined in Figure 3.

Formal statistical hypothesis testing (leading to a "p" value) is a supplement to reasoned limnological interpretation of the data, as presented in the AMP yearly reports. The "p" value is only one factor to be considered in forming conclusions. The "p" value is only an estimate (because of limitations in the data and statistical methodology) and the outcome of the hypothesis test depends on the chosen significance level (α = .1, .05 etc), which is somewhat subjective. If conclusions with respect to compliance or trend are not readily apparent in a simple plot of the data, then it is doubtful that a low "p" value with statistical significance will have much management significance. These limitations should be conveyed in the presentation of statistical results in yearly reports.

Testing for trends alone does not address all of the hypotheses listed in Table 1 and Appendix A. The hypotheses are of three types:

1) That standards or goals have been achieved.

2) That conditions are improving.

3) That improvement is caused by (or at least correlated with) implementation of management measures (Metro improvement, CSO control, etc)

Figures 4 contains exhibits from the 2005 AMP report (EcoLogic et al., 2006) which effectively convey each of the three hypothesis types. The top panel shows declining trends in phosphorus load and lake P concentration. The bottom panel shows declining trends in ammonia load and lake ammonia concentration.

Figures 5 and 6 expand on this concept by showing Metro phosphorus and ammonia concentrations along with separate time series for AMP water quality, phytoplankton, and transparency metrics that have explicit numerical goals or standards. These convey extent of goal attainment, improvement, and correlation with loads. Refinement of this type of presentation as a concise summary of progress is recommended for potential inclusion in future AMP reports.

3.0 Methods

Data reduction and analysis involved the following steps:

1. Compile the data into a collection of tables, each representing a specific monitoring program (e.g., pelagic water quality, near-shore water quality, phytoplankton, macrophytes, macroinvertebrates, juvenile fish, adult fish). The columns of each table include sample identifiers (site, date, etc), measurements (concentration, counts by specie, etc), and metrics computed from the

measurements (exceedance frequency, CPUE, diversity, richness). Each row represents a different sample. Given myriad structures of the source datasets, more than 50% of the project effort was devoted to this task.

2. Identify specific time series to be analyzed in each table. Each time series represents a specific metric, site (or collection of sites), and, in some cases, season, as they relate to the AMP hypotheses.

3. Adapt time-series analysis software previously developed for the AMP Long-Term Water Quality Database (Walker, 2004) for general application to both biological and water quality data. The database interface has been generalized to accommodate the unique features of each data table (Figure 7). The analytical capabilities of the program (statistical summary, outlier detection, trend analysis, diagnostic graphics) have been expanded to support Analysis of Variance (ANOVA), estimation of precision/power, additional diagnostics, and additional trend analysis methods (linear and step-trend regressions).

4. Use ANOVA's to estimate within-year (seasonal, random) and among-year (random, trend) variance components.

5. Evaluate precision (RSE) and power (probability of detecting trends) based upon the monitoring frequencies and variance components.

6. Evaluate the sensitivity of power to 2-fold increases/decreases in sampling intensity (number of samples per year, replicates, or transects per stratum).

Data from some programs (zooplankton, fish nests, fish larvae, macroalgae, angler surveys) have not been analyzed because they are too limited and/or provide supplementary data that are not used directly in testing AMP hypotheses. Results are summarized in the following sections.

4.0 Results

Table 3 summarizes the ANOVA structure for each dataset. Table 4 summarizes variance components, precision, power, and sensitivity to sampling intensity. Variance components are the averages of values estimated for each stratum or station. Precision and power estimates pertain to annual mean values for a given station or stratum. Values from this table are plotted in Figure 8. Results for individual datasets are discussed in subsequent sections

Figure 8 shows the precision of yearly means, variance components of yearly-mean time series, and power metrics. Precision (RSE) is compared with the AMP objective (RSE < 20%). Consistent with results of previous analyses (Walker, 2002ab), RSE values exceed 20% for metrics with high inherent variability (adult & gamefish CPUE, Plant biomass, phytoplankton biomass, and bacteria). Variance components of yearly means include measurement error (reflecting precision of yearly means), trend, and random year-to-year variations.

As explained in Section 2, power for detecting trends is controlled by the sum of the error and random components. Power metrics are shown in Figure 8 for three levels of sampling intensity (N = number of samples per year) relative to the existing design (N/2, N, and 2 x N). Sensitivity to sampling intensity depends on the size of the error variance component relative to the background year-to-year variations, as shown in the top panel of Figure 8. Sensitivity tends to be higher for the biological variables, as compared with water quality variables, which are monitored more frequently.

The following sections describe data-reduction procedures and results specific to each dataset. These also include suggestions for analysis and summary of data in AMP annual reports.

4.1 Water Quality

Specific AMP water quality metrics include:

- Summer Total P, June-August, 1 meter depth, [Goal < 20 ppb]
- Frequency of Nitrite-N Concentrations >100 ppb, all seasons & depths [Standard= 0%]
- Frequency of Free Ammonia Concentrations > NYSDEC & EPA Criteria (Temperature & pH dependent) [Standard = 0%]

Free ammonia levels have been consistently below the standard since 2004. Total ammonia is used here as a surrogate for free ammonia. Although AMP hypotheses refer specifically to total phosphorus, ammonia, nitrite, and total nitrogen in both the UML and LWL samples provides a basis for tracking the overall response of the nutrient cycle to reductions in ammonia and total P loads.

Data from three locations have been analyzed: South Deep Upper Mixed Layer (UML, 0-3 meters), South Deep Lower Water Level (LWL, 12-18 m), and Outlet (12 ft or 3.7 m). Lake samples collected at intermediate depths have been excluded because they are strongly influenced by variations in thermocline depth and are therefore more variable than the upper or lower layer samples. While seasonal variations in the LWL are large as a consequence of vertical stratification, LWL samples provide a useful signal for tracking overall response of the lake nutrient cycles to reduction in external loads (Appendix 7, Figure A7-7, EcoLogic et al., 2006). Year-to-year variations in the LWL are likely to be buffered by nutrient storage and recycling from the surface sediments. Those processes would have less immediate effect on the UML and outlet samples, which are more likely to be influenced by random year-to-year variations in hydrology.

Outlet samples collected at 12 ft depth are considered to be more representative of flow leaving the lake, as compared with those collected at 2 ft, which are influenced by occasional backflow from the Seneca River. Precision and trends at the Outlet and South Deep UML sites are similar. The responses of ammonia and total phosphorus concentrations at the Outlet were similar to those observed in the UML (Figure 5). This indicates that outlet data can be used as a supplementary metric for tracking long-term trends in the UML.

Figures 9-11 show yearly means, monthly means, and trends within each month for each variable over the 1999-2005 period for the UML, LWL, and Outlet stations, respectively. Both means and apparent trends in nutrient species vary with season. For example, trends in LWL Total P samples, UML/Outlet ammonia, and UML/Outlet nitrate are more pronounced in the spring months. While the Seasonal Kendall (SK) test accounts for seasonal variations in means, it assumes that trends are similar in each month. The SK test is weakened but not invalidated under these circumstances. Gilbert(1987) suggests that trends can be tested separately by season in these situations. To avoid biasing the results, formal testing of AMP hypotheses should be based upon seasons that are explicitly defined in the AMP metrics. Those definitions should be clarified where appropriate based upon OLTAC review. Regardless of the seasons explicitly specified in the AMP metrics, it would be useful to include seasonal variations in trends as supplementary diagnostic information in the AMP yearly reports. AMP database software currently used for trend analysis (Walker, 2004) can be modified to provide appropriate output formats.

A more complicated statistical procedure (e.g., bootstrap, Efron & Tibshirani, 1998) would be needed to estimate the precision of integrated dissolved oxygen metrics (volume-days of anoxia, cold- and cool-water fish habit). These metrics involve considerable (interpolation, volume-weighting) of dissolved oxygen and temperature profile data. Further testing and refinement of those procedures is recommended in order to establish formal protocols. Future updates of the AMPSF could include assessments of precision and power based upon refined datasets and computation procedures.

4.2 Phytoplankton, Chlorophyll-a, and Transparency

Although collected under different programs, these variables are analyzed together because each is a direct or indirect measure of algal growth in the pelagic zone (i.e. trophic state indicators), control of which is a primary management objective. Relevant hypotheses are that nutrient load reductions will result in lower phytoplankton biomass, reduced importance of cyanobacteria (bluegreen algae), lower chlorophyll-a concentrations, and improved water clarity, all measured at the South Deep station.

Designated AMP metrics(*) and related ones are listed below:

- Total Phytoplankton Biomass (ppb)
- Percent Bluegreen Biomass* [Target < 10%]
- Bluegreen Biomass (ppb)

- UML/Epilimnetic Chlorophyll-a Concentration (ppb)*
- Photic Zone Chlorophyll-a Concentration (ppb)*
- Frequency of Chl-a Concentrations > 15 ppb * [Target < 15%]
- Frequency of Chl-a Concentrations > 30 ppb * [Target < 10%]
- Secchi Depth (m)
- Frequency of Secchi Depth < 1.5 meters * [Target = 0%]
- Frequency of Secchi Depth < 1.2 meters [Target = 0%]

While bloom frequencies and transparency metrics are based upon the June-August recreational season defined by NYSDEC (June-August), data from May-October are analyzed to provide broader estimates of precision and trends.

Phytoplankton were sampled biweekly between April and October between 2000-2005. Winter samples were also collected occasionally. Sampling and enumeration methods varied prior to 2000. Sample frequency was biweekly at South Deep and quarterly at North Deep. Various vertical sampling procedures were used (discrete grabs, 2000-2001, epilimnetic composites 2000-2002, photic zone composites in 2001-2003, and UML composites in 2003-2005). The analysis is based on a composite of the epilimnetic and UML data, which reflect essentially the same sampling procedures.

Chlorophyll-a was sampled weekly. To assess sensitivity to sampling method, two chlorophyll-a time series have been analyzed: one consisting of photic zone samples (1999-2005) and the other a composite of the epilimnetic(1999-2003) and UML (2004-2005) samples. Photic zone samples collected for the entire period have been used to compute bloom frequencies (percent of samples > 15 and >30 ppb).

Zooplankton are not considered here. While zooplankton can vary significantly from year to year and have major impacts on phytoplankton, there is no reason to expect they would "respond" to the management measures and there are no numerical indices that would reflect a desirable or undesirable condition. Although there is no "goal", the precision of the zooplankton measurements is of interest because the data are useful for interpreting variations in the phytoplankton and fish communities. As reflected in the error bars in Figures 3-4 and 3-5 (EcoLogic et al., 2006), precision appears to be sufficient for quantifying significant year-to-year variations in the zooplankton community over the 2000-2005 period.

Figure 12 shows yearly means, monthly means, and trends within each month for phytoplankton metrics. Both means and trends tend to vary with month for each metric. Decreasing trends are indicated in mid to late summer when maximum biomass and chlorophyll-a concentrations are typically observed. In the extreme case, total phytoplankton biomass trends are increasing in Spring and Fall but decreasing in Summer. Conversely, increasing trends in transparency are apparent only in August. Applying the Seasonal Kendall test to the data from the entire growing season would mask these patterns. As discussed above for the nutrient data, it would be useful to summarize seasonal variations in trends as supplementary diagnostic information in the AMP yearly reports.

Figure 13 compares photic zone and epilimnetic/UML composite samples for total biomass, bluegreen biomass, percent bluegreens, and chlorophyll-a. The null hypothesis (no difference between stations) is tested using a paired t-test of log-transformed values. Results indicate that the photic zone samples have slightly higher concentrations of total biomass (16% +- 9%, p = 0.07) and chlorophyll-a 11% +- 2%, p <.01), but no differences in bluegreen biomass or percentage. Further analysis indicates that there are no significant differences between sample types when the data are restricted to the July-August period of peak algal biomass. Bloom frequency metrics based on the slightly-higher photic zone data provide a more conservative assessment.

While AMP metrics are explicitly based on data from the South Deep station, differences between North (sampled quarterly) and South stations are of potential interest for modeling and data interpretation. Figure 14 compares biomass, chlorophyll-a, and transparency data collected at the North and South stations. The null hypothesis (no difference between stations) is tested using a paired t-test of log-transformed values. No significant differences are identified.

As shown in Figure 5, year-to-year variations in transparency and phytoplankton metrics are correlated with variations in Metro phosphorus loads over the 2000-2005 period. As shown in Figure 15, year-to-year variations in transparency are also correlated with zooplankton size. Significant trends in individual phytoplankton taxa also occurred over this period (Figure 16). As discussed in Section 2, covariance with independent factors can have a large impact on year-to-year variations and make it difficult to detect long-term trends, particularly over relatively short periods. Power for detecting trends in phytoplankton and transparency could be potentially improved by adjusting the time series to account for these relationships. Mechanistic (QEA, 2007) or empirical (Appendix 7, EcoLogic et al, 2006) models essentially provide this function and can therefore be used for interpreting year-to-year variations in the data, as well as for forecasting.

4.3 Near-Shore Transparency & Bacteria

The near-shore monitoring network includes eight stations distributed around the lake shoreline (Figure 1). These track regional variations in fecal coliforms, E-coli, transparency, and turbidity in areas adjacent to recreational areas along the northeastern and adjacent to wastewater and urban runoff discharges along the southern shore. AMP metrics include:

- Frequency of Fecal Coliform Counts < 200 cfu/100 ml [Standard = 0%]
- Frequency of Ecoli Counts < 126 cfu/100ml [Standard = 0%]
- Frequency of Secchi Depths < 1.2 m (4 feet) [Goal < 10%]

These apply to the recreational season (June-August), as specified in NYSDEC criteria.

Table 5 contains an inventory of near-shore data collected under two programs between 1999 and 2005. One program involved regular weekly sampling. Sampling frequency was apparently monthly at 3 sites (Metro, Ley Creek, Harbor Brook) prior to 2002. Sampling at one site (Bloody Brook) was initiated in 2002. The remaining five sites were monitored weekly over the entire 1999-2005 period. The South Deep station was sampled simultaneously with the shoreline sites. A second program involved daily sampling during and following storm events between 1999 and 2003. Storm event monitoring was resumed in 2006. Some of the sampling events were collected under both programs.

Statistical analysis of data from the near-shore monitoring program is complicated by the mixture of data from two programs, apparent correlations between bacteria counts and antecedent storm events, and high inherent variability in the bacteria counts. In addition, potential problems with the classification of some samples in the water quality database were identified in compiling the data for analysis. Refinement of the database, analysis of the data in relation to antecedent storm events, and refinement of precision and power estimates are recommended for future AMPSF updates.

Consistent with previous estimates (Walker, 2002ab), RSE values for geometric mean bacteria counts were generally above the 20% criterion (Table 4, Figure 8). Analysis of geometric means is complicated by values above or below detection limits. These limits have been assigned to the samples in evaluating precision of the geometric means derived from log-transformed data. It is likely that actual RSE values are greater than those indicated in Table 4, particularly at sites with relatively low detection frequencies.

The NYSDEC bacteria standards are actually expressed in terms of monthly geometric means. Frequencies based upon individual samples provide a conservative assessment of compliance. It is recommended that frequencies be expressed both ways in future AMP reports. It also seems appropriate to include near-shore results in the summary compliance table for the Lake (Table 3-3, EcoLogic et al., 2006), which currently contains only the South Deep results. Yearly time series charts showing compliance rates and confidence intervals for transparency and bacteria metrics at each site (e.g., Figure 6) are recommended as a supplement to the maps displaying the spatial distribution of values for individual years. Given the difficulties in estimating the geometric mean when results are above or below detection limits, detection frequencies (percent > 5 cfu/100 ml) would be useful as a supplementary metrics.

Given the expression of the AMP bacteria and transparency metrics, the precision of the yearly compliance frequencies is more relevant than the precision of the geometric means. Values above or below detection limits would generally not impact frequency metrics. Future refinements to the AMPSF could include refinement of precision estimates for frequency metrics, which are typically based upon the binomial distribution (Snedocor & Cochran(1989), Gilbert(1987)). The same recommendation applies to other

AMP metrics that are expressed in terms of frequencies (transparency, bloom frequency, nitrite).

4.4 Littoral Macrophytes and Algae

Littoral-zone macrophytes and algae were sampled once per year in 2000 and 2005. The sampling design involved 20 fixed transects (4 per stratum). Random subplots were sampled along each transect from the shoreline out to about 6 meters of water depth. Samples were collected at depths greater than 6 meters in some instances, but have not been included in the analysis for consistency with the remaining data. There was an average of 102 subplots per transect for plant coverage and 7 subplots for macrophyte biomass. This design supports evaluation of precision and differences between 2 sampling events at each site and spatial variations across strata and transects. Given two years of data, trends, random year-to-year variations, and seasonal variations cannot be resolved. Power estimates (Table 4 and Figure 8) assume that random year-to-year variation (CV = 0.2) is similar to that assumed in the previous AMSF report (Walker, 2002b).

Specific AMP metrics include macrophyte species, coverage, biomass, and maximum depth of growth. Figures 17 and 18 show average macrophyte coverage and biomass vs. distance from shoreline, computed from individual transects averaged in 5-meter increments. A substantial increase in coverage between the two years is evident. This increase is consistent with the general increasing trend evident in annual aerial photographs. While biomass was sampled less frequently, differences between years are also indicated, with the exception of stratum 2, where biomass levels were relatively low in both years.

While sub-plots were selected randomly along each transect, results are correlated with distance from shoreline and thus the individual subplots cannot be considered random for the purpose of estimating the precision of the transect-mean values. Accordingly, the transect mean has been treated as the fundamental sampling unit. The precision of the stratum means is estimated based upon variance across transect means. Figure 19 shows means and standard errors by stratum and year. It is apparent from the size of the error bars that precision is sufficient to capture the dominant spatial and temporal variance components.

Variations in transect means do not capture community changes that may be different in near-shore vs. off-shore regions. That type of information is more readily conveyed in Figures 17 and 18. For example, the apparent increase in Stratum 2 macrophyte cover between 100 and 220 meters offshore (Figure 17) is not reflected in the transect mean values (Figure 19). Transect data could be subdivided into near-shore vs. off-shore regions to capture this type of variation.

Consistent with previous results (Walker, 2002ab), macrophyte biomass estimates are less precise than percent cover estimates (RSE = 0.99 vs. 0.37, Table 4). This reflects lower sampling frequency and higher inherent variability in the biomass data. Given the low precision, biomass data are less useful for tracking long-term variations in the littoral macrophyte and algae communities. The data were collected primarily to obtain general estimates of mean values to support potential future modeling efforts, as opposed to tracking trends.

Precision has also been estimated for littoral algae data are collected under the same program (Table 4), although there are no explicit AMP metrics. The RSE for stratum-mean algae coverage is 0.55, as compared with 0.37 for macrophyte coverage. Visual measurements of shoreline macro-algae have also been collected under a different program since 2004 (Figure 2-31, EcoLogic et al., 2006). Analysis of these data is recommended in future AMP updates.

4.5 Littoral Macroinvertebrates

Lake macroinvertebrates were sampled once per year in 1999, 2000, and 2005 at 5 sites (one per lake stratum) with 18-36 replicates per site. This design potentially supports evaluating temporal differences between 2 sampling events at each site and spatial variations across sites.

AMP hypotheses refer specifically to species richness, NYSDEC Index, Hilsenhoff Biotic Index (HBI), and percent oligochaetes. Precision estimates are summarized in Table 4. Figure 20 shows mean values as a function of lake stratum and year.

It is unlikely that the replicates represent random samples because they were spatially clustered horizontally and vertically around each site. The effective number of independent samples is likely to be substantially lower than the total number of samples. While the RSE estimates are low (0.06 to 0.09, Table 4), it is likely that they are underestimated A more detailed statistical model would be needed to estimate the effective number of samples and evaluate precision. Based upon Figure 20, precision appears sufficient to capture variations among sites and years, even if the actual standard errors are substantially larger than those shown.

4.6 Tributary Macroinvertebrates

Tributary macroinvertebrates were sampled once per year during 3 years (2000,2002, 2004) at 3-4 sites with four replicate samples in each creek influenced by Combined Sewer Overflows. This design supports evaluating temporal variations among 3 years and spatial variations across sites. Tributary macroinvertebrates are not explicitly mentioned in AMP hypotheses, but are included in the AMP metrics.

Precision estimates are summarized in Table 4. Figure 21 shows mean values as a function of site and year. Precision (RSE = 0.18 to 0.32) appears to be sufficient to measure spatial and year-to-year variations.

4.7 Littoral Juvenile Fish

Juvenile fish populations were sampled in the littoral zone biweekly at 15 sites (3 in each stratum). Three replicate samples were collected in 2000 and single samples in 2001-2005. The second and third replicate samples in 2000 have been excluded from the analysis for consistency with the other years. Samples were generally collected over a few days in each event. For purposes of statistical analysis, these have been clustered into discrete rounds (6 - 8 per year between May and October).

As indicated in the sample inventory (Table 6), relatively few fish were counted in the May, June, and October sampling events. No samples were collected in October 2000-2001 and in May of 2004-2005. In order to reduce the impact of the strong seasonal variance component and to provide a dataset with at least one sampling round in each month and year, the statistical analysis is based the July-September samples only.

Metrics considered include species richness (number of species) total CPUE, bass CPUE, and Shannon/Weaver diversity index. The bass CPUE is included because of its recreational significance and because reproduction of bass is cited as a basis for the macrophyte metrics (Appendix A).

Based upon previous (Walker,2002b), precision and power are expected to be relatively low for fish CPUE metrics. Site-mean RSE values are between 0.6 and 0.8 for total and bass CPUE and between 0.15 and 0.20 for richness and diversity.

Yearly time series are shown in Figure 22. Despite the relatively low precision of bass CPUE, significant increasing trends are indicated in 4 out of 5 strata and for the Lake as a whole. The magnitude of the trends (averaging ~50 % per year) increases the probability of trend detection. This is consistent with concepts discussed in Section 2 and illustrated in Figure 3. The same pattern is observed in the adult fish bass CPUE data discussed below.

4.8 Littoral Adult Fish

Adult fish populations in the littoral zone were sampled by electrofishing once in the spring and fall of each year between 2000 and 2005. An additional fall survey was conducted in October 2000 but excluded from the analysis for consistency with data from other years. Samples were collected along 24 fixed transects distributed around the shoreline and further classified into 5 strata (Figure 1). Gamefish were counted along all 24 transects and all fish were counted along 12 transects in each sampling event.

Given the size and importance of this dataset, it has been analyzed in greater detail, as compared with other AMP biological datasets. AMP hypotheses refer to gamefish species richness and pollution intolerance. Pollution intolerance is expressed as 100 percent minus the percent of species classified 'Tolerant' or 'Moderately Tolerant', as identified in the sample inventory (Table 7). Other metrics include CPUE (catch per unit effort) and Shannon-Weaver diversity index. Each metric has been evaluated for subsets of the total fish population (total, non-clupeid, gamefish). In addition, CPUE has been evaluated separately for clupeid and bass species.

Adult fish counts are summarized by species and year in Table 7. Table 8 provides an inventory of direct and estimated counts by year. The former reflect fish that were actually captured and counted on board the electofishing boat. The latter reflect fish that were observed but not captured, typically because of their large numbers. Clupeids tend to occur in large schools and were frequently estimated (90% of total counts for alewife and 86% for gizzard shad). Appreciable percentages of other major species were also estimated (white perch (51%), yellow perch (30%), pumpkinseed (19%)).

As indicated in Table 8, the percentage of estimated counts for non-clupeid species increased dramatically between 2000-2002 (<5%) and 2003-2005 (40-70%). This reflects a change in protocol, rather than a change in the population of non-clupeid fish (pers. com., D. Snyder, OCDWEP). The percentage of clupeids counted varied randomly from 46% to 91% over the years. Following assumptions in the AMP monitoring report (EcoLogic et al., 2006), estimated counts for non-clupeid species are ignored in this analysis. Consideration should be given to potential future uses for the estimated counts.

Previous analyses (Walker, 2002b; EcoLogic et al., 2006) have shown that occasional spikes in estimated clupeid counts occurring when large schools are encountered can have large impacts on total fish CPUE and other metrics. This reflects extraordinarily high estimates (>3,000), relative to maximum direct counts of 242 and 134 for clupeids and non-clupeid species, respectively, in any single transect. To reduce the impacts of these data on the analysis, clupeid counts have been restricted to a maximum value of 250 in any transect before computing adult fish metrics. In addition, separate analyses have been performed for clupeids and non-clupeids. This adjustment impacts only CPUE and, to less extent, diversity for total fish, but does not impact the gamefish indices which are more important AMP metrics.

Stratum means and standard errors have been computed from individual transect results. Richness and diversity indices have been computed for transects with at least two collected fish. The remaining transects have been treated as missing values, which accounted for 5% of the gamefish transects and 0% of the total fish transects. RSE values for individual strata are 0.25-0.27 for CPUE indices and 0.09-0.12 for richness and diversity indices (Table 4).

Alternative transformations (linear, square root, and logarithmic) have been tested to reduce skewness in the adult fish CPUE data. Transformation does not appear to significantly impact the general distribution of variance components and conclusions regarding presence/absence of trends in the fish metrics. Results are based upon square root transformations, which are typically recommended for counts (Snedocor & Cochran, 1989; Green, 1987). As shown in Figure 23, the distributions of square-root transformed values tend to have less skewness, as compared with those of the un-transformed (positively skewed) or log-transformed (negatively skewed) values. Means computed from transformed values are less sensitive to occasional spikes in the fish counts and expected to have better precision, as compared with means computed from the untransformed data. Means and standard errors computed from the square-root transformed data can be translated back to linear scales using the formulas listed in Figure 23.

Measurements of species richness and diversity depend to some extent on the total number of fish collected and are influenced by averaging procedure (Walker, 2002b). The richness metric analyzed here reflects the average number of species per transect or essentially the number of species identified per unit effort (analogous to the abundance metric, catch per unit effort or CPUE).

Pooling of samples is another important consideration in developing datasets for statistical analysis, especially for richness and diversity metrics (Walker, 2002b). Pooling involves combining counts from individual samples across spatial dimensions (depths, sites, transects, strata, whole-lake) and/or temporal dimensions (dates, months, seasons) prior to computing metrics (CPUE, richness, diversity) and testing for trends. Sensitivity analyses using AMP datasets indicate that pooling impacts both the magnitude and precision of richness and diversity indices, but does not impact CPUE.

If we start with two barrels (transects) of fish collected randomly, we can compute the number of species (richness) in each barrel and then average the results. If combine the two barrels into one big barrel (stratum) and then compute richness, the single result will on the average be higher than the average of the mean values computed from the individual barrels. Further pooling of the samples across the whole lake will produce yet a higher richness value. Pooling does not impact CPUE because the total number of fish does not change when we combine the two barrels.

The effects of pooling (transect, stratum, lake) on lakewide gamefish trends in Spring and Fall are shown in Figure 24. While pooling by stratum or lake increases the richness values, it does not influence conclusions regarding the presence or absence of trends in each season.

The benefit of pooling samples is that precision increases with the total number of fish per pooled sample. The downside of pooling samples is that the number of pooled samples decreases dramatically. If samples are pooled across all strata and seasons, we end up with only one sample per year. Precision cannot be estimated, although trend analyses is still possible (Figure 24). When the samples are pooled across the entire lake, richness can be very sensitive to single fish caught in a given season or year, as indicated in Table 7. For example, a single yellow bullhead caught in the spring of 2005 accounts for 25% of the increase in gamefish richness between 2000 and 2005 (Figure 24) when the samples are pooled across all transects before computing richness. Analysis of individual transects or pooled stratum values are less sensitive to individual fish and provide a basis for estimating precision.

Yearly time series of adult fish metrics for each stratum and season are shown in Figure 25 (CPUE) and Figure 26 (other metrics). Increasing trends are indicated for CPUE (total, clupeid, bass), gamefish richness, and gamefish diversity in some strata and seasons. Clupeid trends (reflecting increases in alewife, EcoLogic et al, 2006) largely account for the apparent increasing trends in total fish CPUE and small decreasing trends in total fish diversity. Trends in total fish CPUE and diversity are not evident when clupeids are excluded. Increasing trends in bass CPUE and gamefish indices (diversity, richness) are focused in the southern strata (2,3,4) in the spring. This pattern of trend variation with season is discussed above for nutrients and phytoplankton and further indicates that important trends could be obscured if analyses are based on lakewide and/or annual means only.

Based upon the above results, it is recommended that the adult fish data be analyzed separately by stratum and season. Means and standard errors can computed from the results for individual transects within each stratum. To indicate sensitivity to averaging method, richness and diversity indices can also be reported for samples pooled across transects within each stratum and season. Results can also be reported for regional and/or yearly means, but with recognition that averaging may obscure important trends and/or spatial patterns.

5.0 Conclusions & Recommendations

Conclusions and recommendations pertaining to specific datasets are discussed in previous sections. Those of a more general nature are summarized below:

1) AMP hypotheses have three dimensions: (a) attainment of goals or standards, (b) long-term improvement, and (c) correlation with management measures. The presence or absence of "trends" in the data is of no consequence if the goals have been attained or if there is a strong correlation with management measures that have not been fully implemented.

2) Analysis and presentation of data in a manner that expresses each of the above components is important in testing AMP hypotheses (e.g., Figures 5 and 6). While useful, testing for long-term trends alone tells only part of the story and is not sufficient for tracking progress.

3) For metrics with specific numeric goals or standards, time series charts showing goal attainment/compliance frequencies can be shown in addition to tabulating results for the current year in AMP reports.

4) Power for detecting trends in AMP metrics is controlled by year-to-year variance, which can be separated into three components:

   a) Uncertainty in the yearly mean values
   b) Random year-to-year variability
   c) Covariation with causally-linked factors (nutrient loading, hydrology, climate).

   As evaluated under the AMPSF, the first component is directly related to sampling frequency and is generally the least important. The third component is very important for some metrics (nutrient, phytoplankton) which are strongly correlated with recent variations in Metro nutrient loadings. Direct consideration of the third component will increase power for detecting trends in the future. For example, adjusting for variations in runoff/'rainfall is likely to be important for tracking improvements in nutrients and phytoplankton as the lake nutrient budget is increasing controlled by nonpoint sources, as opposed to Metro discharges.

5) Magnitudes and/or signs of apparent trends may vary with lake region and/or season (e.g., nutrients in spring, phytoplankton in late summer, adult gamefish in spring). Important patterns can be obscured by averaging across strata and/or seasons. On the other hand, averaging increases precision and power for variables that do not exhibit seasonal/spatial variations in trend. It is recommended that data be analyzed and presented both ways (by season/stratum as well as lakewide/annual average) in AMP reports. Strata can be combined regionally (north, south) to increase precision.

6) While formal hypothesis tests should be based upon seasons defined in the AMP hypotheses, diagnostic charts similar to those shown in Figures 9-12 provide important diagnostic information and can be presented in AMP reports as supplementary information, where appropriate.

7) Management hypotheses should be clearly defined with respect to seasonal averaging period, based upon limnological and/or regulatory concepts. For example, the definition of "summer" is critical for nutrient and phytoplankton data. The June-August definition of summer specified in the NYSDEC guidelines is based upon recreational use patterns and does not in general provide the most powerful test for trends in phytoplankton and nutrients. In particular, conditions in June typically reflect a transition from spring to summer and are not representative of July thru early September, when nuisance algal blooms are more likely to occur. Inclusion of June in the trend analysis increases variability in the seasonal-average time series and decreases power for detecting trends.

8) It is recommended that future refinements to the AMP statistical framework include:

   a) Development of procedures to account for correlations with external factors (loading, rainfall, etc.) in testing for trends.

b) Refinement of methods for estimating the precision of frequency statistics that are used to track progress with respect to numeric goals or standards.
c) Development of concise graphical and tabular formats for summarizing results of hypotheses tests applied to each metric for potential inclusion in annual AMP reports.
d) Analysis of near-shore data in relation to antecedent storm events.

9) QA/QC procedures for both water quality and biological databases should include testing for systematic errors (sample identification, etc), as well as statistical outliers. Improvements in software and procedures for updating the databases would decrease the risk of such errors.

10) Further refinement of time-series analysis software presenting part of the AMP long-term water quality database is recommended to support future data analysis, outlier detection, and hypothesis testing. Adaptation and integration of the software with the AMP biological database under development is also recommended.

6.0 References

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List of Tables

Table 1 AMP Design for Biological Parameters For Sample Year 2007*

Category	Years	Season	Seasonal Freq	Dates / Year	Method	Depths	Lake Strata	Sites / Stratum	Samples /Site	Total Samp. /Yr	Metrics	Methodology	Notes
Pelagic Larvae	yearly	May -Aug	biweekly	8	miller sampler double oblique tows, day	0-5 m integral	2 Basins (N/S)	4	1	4 reps x 2 sites x 8 dates = 64	#/m^3	NYSDEC Percid Sampling Manual (1994)	
Littoral Juvenile Fish	yearly	June-Oct	every 3 weeks	8	seine	-	5	3	1	15 sites x 8 dates = 120	c/e, l/w	NYSDEC Centrarchids Sampling Manual (1989)	
Adult Total Fish, Littoral	yearly	Spring & Fall	twice	2	electrofish	< 2 m	5	varies	1	12 sections x 2 seasons = 24	c/e, l/w, PSD, RSD, etc	NYSDEC Centrarchids Sampling Manual (1989)	Trap net data 1987-present
Adult Gamefish, Littoral	yearly	Spring & Fall	twice	2	electrofish	< 2 m	5	varies	1	24 sections x 2 seasons = 48	c/e, l/w, PSD, RSD, etc	NYSDEC Centrarchids Sampling Manual (1989)	Trap net data 1987-present
Adult Fish, Profundal	yearly	Spring & Fall	twice	2	gill nets	4-5 m	5	1	1	5 sites x 2 seas = 10	c/e, l/w	NYSDEC Percid Sampling Manual (1994)	
Fish Nests	yearly	June	once	1	visual counts, by species	bottom	5	varies	1	Count 24 Sections Once	count	Arrigo. (1998)	
Phytoplankton	yearly	April-Oct	biweekly /monthly	~18 South, 3 North	tube	UML & photic zone compos.	2 (N/S)	1	1	18 South	count, biovolume	Ed Mills	Season varies can be Jan-Dec
Zooplankton	yearly	April-Oct	biweekly	~18	net tow	UML & 15 m	2 (N/S)	Lake S + N (4X)	1	2 depths x 18 dates = 72 (South)	count, biovolume	Ed Mills	Season varies can be Jan-Dec
Macrophyte Biomass	every 5 years	August	once	1	harvest	littoral zone	5	~ 4 Trans	~6.4	125 / Lake	g/m2,	Ecologic	
Macrophyte Cover	every 5 years	August	once	1	observation	littoral zone	5	~ 4 Trans	~95	1900 subplots / Lake	% cover, spec ies richness	Ecologic	
Littoral Macroinvert.	every 5 years	June	once	1	dredge	3	5	1	18	5 sites x 18 reps = 90	counts, indices	NYSDEC/ Ecologic	
Tributary Macroinvert	every 2 years	July	once	1	kick	1	n/a	10	4	10 sites x 4 reps = 40	counts, indices	NYSDEC / Ecologic	

* Designs varied somewhat in previous years, as reflected in the previous statistical framework reports and in the cumulative datasets analyzed in this report.

Table 2 Summary of AMP Lake Management Hypotheses

Variable	Hypothesis	Type of Hypothesis				Data Used for Assessment
		SPDES	Stds / Guid	Trend / Change	Correl v Load	
Ammonia-N	Improvements at Metro enables the County to meet Phase 3 effluent limits (or as modified by TMDL) for ammonia N	*				Outfall 001 effluent concentrations, calculated for summer and winter (seasonal limits apply)
Ammonia-N	Reduced ammonia load results in compliance with ambient water quality standards and federal criteria for ammonia in Onondaga Lake		*	*	*	South Deep station Biweekly monitoring, discrete samples collected @ 3-m intervals, plus temperature and pH
Nitrite-N	Achievement of Phase 3 effluent limits for ammonia results in compliance with the NYS ambient water quality standard for nitrite (warm water fish community)		*	*	*	UML, LWL composite samples, biweekly @ South Deep
Phosphorus	Improvements at Metro will enable the County to meet final effluent limits (as modified by TMDL)	*				Outfall 001 effluent concentrations
Phosphorus	Reduced phosphorus load from Metro reduces concentration of phosphorus in Onondaga Lake		*	*	*	South Deep station Biweekly monitoring TP, SRP and TDP, discrete samples collected @ 3-m intervals
Phosphorus	Reduced phosphorus load from Metro brings the lake into compliance with guidance value (or site-specific guidance value)		*	*	*	TP at South Deep, 1-m depth (weekly measurements, June –Sept)
Dissolved Oxygen	Improvements at Metro enable the County to meet Phase 3 effluent limits (or as modified by TMDL) for BOD	*				Outfall 001 effluent concentrations
Dissolved Oxygen	Improvements at Metro and related load reductions bring the lake into compliance with AWQS for DO during fall mixing.		*	*	*	Weekly or biweekly measurements through water column and high-frequency measurements at buoy
Dissolved Oxygen	Improvements at Metro reduce the volume-days of anoxia.			*	*	Weekly or biweekly measurements through water column and high-frequency measurements at buoy
Dissolved Oxygen	Improvements at Metro reduce the areal hypolimnetic oxygen depletion rate.			*	*	Weekly or biweekly measurements through water column and high-frequency measurements at buoy
Indicator bacteria	CSO remedial measures reduce the loading of fecal coliform bacteria entering the lake through Onondaga Creek, Ley Creek, and Harbor Brook during high flow conditions.	*		*		Storm event data: baseline and post-improvement rating curves for fecal coliform bacteria (load as a function of total precipitation, and total storm flow)
Indicator bacteria	Implementation of Stage 1 and 2 improvements to the wastewater collection and treatment system (including CSO projects) will reduce concentration of indicator organisms in Onondaga Lake	*	*	*	*	Indicator bacteria abundance at nearshore stations during summer and following storms. Annual average concentration at South Deep, 0m depth
Chlorophyll-*a*	Metro improvements and related nutrient load reductions result in lower chlorophyll concentrations in the lake.			*	*	Weekly or Biweekly measurements @ South Deep, photic zone and UML
Chlorophyll-*a*	Freq Chl-a > 15, > 30					
Secchi Disk	Metro improvements and related nutrient load reductions result in improved water clarity (as measured by Secchi disk transparency)			*	*	Weekly or Biweekly measurements at South Deep and nearshore stations.
Phytoplankton	Metro improvements and related nutrient load reductions result in lower biomass of phytoplankton in Onondaga Lake			*	*	Biweekly samples of UML phytoplankton community, numbers, size and identifications (PhycoTech)
Phytoplankton	Metro improvements and related nutrient load reductions result in reduced importance of cyanobacteria to the lake's phytoplankton biomass			*	*	Biweekly composite samples of UML phytoplankton abundance, biomass, and ID (PhycoTech)

Monitoring Parameter	Hypothesis	Type of Hypothesis				Data Used for Assessment
		SPDES	Stds / Guid	Trend / Change	Correl v Load	
Zooplankton	Metro improvements and related nutrient load reductions reduce the biomass of zooplankton in Onondaga Lake			*	*	Biweekly composite samples of UML and tow (0-15 m), zooplankton abundance, size, biomass, ID (Cornell)
Zooplankton	Metro improvements and related nutrient load reductions (and DO improvements) increase the abundance of zooplankton deeper in the water column			*	*	Biweekly composite samples of UML and tow (0-12 m), zooplankton abundance, size, biomass, ID (Cornell)
Macroalgae	Metro improvements and related nutrient load reductions result in reduced areal coverage of macroalgae in nearshore areas			*	*	Weekly surveys during recreational period (June –Sept) at eight nearshore stations. Percent cover, biomass, and frequency of occurrence. Surveys: 2000, 2005, 2010
Macrophytes	Metro improvements and related nutrient load reductions result in increased areal coverage of macrophytes in littoral zone			*	*	Percent cover, biomass, frequency of occurrence, and maximum depth of growth. Surveys: 2000, 2005, 2010 plus annual aerial photos (surface area containing macrophytes (acres))
Macrophytes	Metro improvements and related load reductions result in increased number of macrophyte species in Onondaga Lake			*	*	Macrophyte species richness Detailed surveys: 2000, 2005, 2010
Littoral macro	Implementation of load reductions at Metro and CSO remediation will increase species richness of littoral benthic macroinvertebrates			*	*	Littoral macroinvertebrate species richness. Detailed surveys: 2000, 2005, 2010
Littoral macro	Implementation of load reductions at Metro and CSO remediation will increase the relative abundance of benthic macroinvertebrates that are not chironomids or oligochaetes			*	*	Littoral macroinvertebrate dominance, percent oligochaetes. Detailed surveys: 2000, 2005, 2010
Littoral macro	Implementation of load reductions at Metro and CSO remediation will improve the NYSDEC Biological Assessment Profile as			*	*	NYSDEC calculated index Detailed surveys: 1999,2000, 2005, 2010
Littoral macro	Implementation of load reductions at Metro and CSO remediation will improve the littoral macroinvertebrate HBI as compared to				*	Hilsenhoff Biotic Index (HBI) Detailed surveys: 2000, 2005, 2010
Fish	Implementation of load reductions at Metro and CSO remediation will increase the number of fish species present in Onondaga Lake			*	*	Annual program Species richness, electrofishing, gill nets
Fish	Implementation of load reductions at Metro and CSO remediation will increase the number of fish species that are sensitive to			*	*	Annual program: (Electrofishing) Pollution tolerance index (Whittier and Hughes 1998)
Fish	Implementation of load reductions at Metro and CSO remediation will increase the number of fish species reproducing in Onondaga Lake			*	*	Annual program Nesting survey Larval tows Littoral YOY seines
Fish	Implementation of load reductions at Metro and CSO remediation will improve the lake's IBI .			*	*	Annual program Electrofishing

Table 3 ANOVA Structure for Each Dataset

Program	Yearly Statistic	Sampling Unit	Samples within Unit	Years	Average Number of Samples/Yr*	
Adult Total Fish	Spring / Fall Mean	Stratum	Transect	6	5	Transects / Stratum / Yr
Adult Game Fish	Spring / Fall Mean	Stratum	Transect	6	10	Transects / Stratum / Yr
Juvenile Fish	July - September Mean	Stratum	Tri-Weekly at 3 Sites	6	12	3 Sites x 4 Dates / Stratum / Yr
Macrophytes	August	Stratum	Transect	2	4	Transects / Stratum / Yr
Lake Macroinvert	August	Stratum	Replicate	3	30	Replicates / Stratum / Yr
Trib MacroInvert	August	Creek / Site	Replicate	3	4	Replicates / Site / Yr
Phytoplankton	May-October Mean	South Deep	Dates - Biweekly	7	11	Dates / Year
Chlorophyll-a	May-October Mean	South Deep	Dates - Weekly	7	24	Dates / Year
Near-Shore	June - August Mean	Station	Dates - Weekly	7	11	Dates / Year
Water Quality	May- October Mean	South Deep (UML, LWL)	Dates - Biweekly	7	14	Dates / Year

* Average number of samples per sampling unit per year; sampling unit defined in column 4; samples within unit in column 5

Table 4 Summary of Precision & Power Estimates for Stratum or Station Yearly Means

				Total			Coefficient of Variation						Precis.	Power	Prob of Detecting 20% Change			Detectable Change (%)		
Dataset	Variable	Years	N / Yr	Samples	Median	Mean	Total	Yr-Total	Yr-Trend	Yr-Rand	Season	Sample	RSE	CV	N	N / 2	N x 2	N	N / 2	N x 2
Adult Fish	CPUE_BASS	6	9.6	58	20.12	26.38	0.93	0.49	0.25	0.20	0.00	0.92	0.37	0.36	0.46	0.36	0.58	0.36	0.46	0.29
	CPUE_GAME	6	9.6	58	85.92	112.47	0.88	0.28	0.00	0.02	0.24	0.75	0.28	0.24	0.69	0.49	0.89	0.24	0.34	0.17
	CPUE_ALLFISH	6	4.8	29	337.24	367.27	0.54	0.28	0.13	0.06	0.13	0.50	0.25	0.24	0.71	0.51	0.89	0.23	0.32	0.17
	RICH_GAME	6	9.2	55	5.00	4.66	0.35	0.13	0.05	0.05	0.12	0.34	0.12	0.12	0.98	0.90	1.00	0.12	0.16	0.09
	RICH_ALLFISH	6	4.8	29	9.40	9.22	0.25	0.12	0.00	0.04	0.04	0.25	0.11	0.12	0.99	0.91	1.00	0.12	0.16	0.09
	DIV_ALLFISH	6	4.8	29	1.62	1.61	0.21	0.11	0.03	0.06	0.02	0.20	0.09	0.11	0.99	0.96	1.00	0.11	0.14	0.09
	DIV_GAME	6	8.9	54	1.25	1.21	0.27	0.12	0.04	0.07	0.08	0.27	0.09	0.11	0.99	0.96	1.00	0.11	0.14	0.09
Juvenile Fish	CPUE	6	12.3	74	15.80	64.33	2.65	1.09	0.03	0.78	0.53	1.31	0.76	0.87	0.21	0.20	0.22	0.85	0.93	0.81
	CPUE_BASS	6	12.3	74	2.60	9.58	1.81	1.06	0.65	0.56	0.24	1.22	0.63	0.65	0.26	0.24	0.28	0.64	0.73	0.59
	RICHNESS	6	6.8	41	2.60	2.80	0.34	0.16	0.00	0.06	0.04	0.38	0.15	0.16	0.93	0.77	0.99	0.15	0.21	0.12
	DIVERSITY	6	6.8	41	0.60	0.58	0.49	0.25	0.00	0.14	0.10	0.52	0.20	0.24	0.69	0.53	0.81	0.24	0.31	0.20
Macrophytes	P_COVER%	2	4.0	8	0.19	0.21	0.83	0.42	0.00	0.20	0.14*	0.73	0.37	0.42	0.40	0.30	0.52	0.41	0.54	0.32
	P_SPECIES	2	4.0	8	0.86	0.98	0.69	0.34	0.00	0.20	0.12*	0.54	0.27	0.34	0.50	0.38	0.61	0.33	0.42	0.27
	P_BIOMASS	2	4.0	8	33.59	47.58	1.31	1.01	0.00	0.20	0.53*	5.04	0.99	2.53	0.13	0.12	0.15	2.48	3.50	1.76
	A_COVER%	2	4.0	8	0.09	0.13	1.25	0.58	0.00	0.20	0.56*	1.09	0.55	0.58	0.29	0.23	0.38	0.57	0.78	0.43
Lake Macroinv	S_DEC	3	29.6	89	3.58	3.61	0.44	0.14	0.03	0.10		0.49	0.09	0.13	0.97	0.92	0.99	0.13	0.16	0.12
	S_HBI	3	29.9	90	4.02	4.23	0.47	0.30	0.15	0.25		0.39	0.07	0.26	0.64	0.62	0.65	0.26	0.27	0.26
	% OLIG	3	29.5	89	0.63	0.61	0.41	0.31	0.08	0.30		0.32	0.06	0.30	0.56	0.55	0.56	0.30	0.30	0.29
Trib Macroinv	S_DEC	3	3.8	11	3.68	3.79	0.35	0.26	0.18	0.05		0.34	0.18	0.18	0.87	0.68	0.97	0.18	0.24	0.13
	S_HBI	3	3.8	11	4.21	4.23	0.46	0.35	0.19	0.04		0.56	0.29	0.29	0.59	0.41	0.80	0.28	0.40	0.20
	% OLIG	3	3.8	11	0.38	0.39	0.77	0.71	0.48	0.41		0.63	0.32	0.53	0.32	0.28	0.35	0.52	0.61	0.46
Phytoplankton	TOTAL_BM	7	10.7	64	1922.08	2903.99	1.00	0.58	0.00	0.47	0.33	1.51	0.34	0.66	0.26	0.22	0.30	0.64	0.79	0.56
	BLUEGR%	7	10.7	64	0.07	0.16	1.42	0.49	0.08	0.25	0.78	1.34	0.41	0.48	0.35	0.27	0.44	0.47	0.62	0.37
	CHLA_UML	7	24.4	171	17.62	21.45	0.75	0.22	0.00	0.13	0.36	1.00	0.17	0.24	0.70	0.54	0.83	0.24	0.31	0.19
	CHLA_PHO	7	24.3	170	18.45	24.09	0.77	0.20	0.00	0.10	0.48	1.05	0.18	0.23	0.72	0.53	0.87	0.23	0.31	0.17
	SECCHI	7	21.0	147	1.70	2.02	0.61	0.13	0.05	0.06	0.14	0.50	0.10	0.12	0.98	0.91	1.00	0.12	0.16	0.10
Near-Shore	SECCHI	7	11.1	75	1.44	1.54	0.35	0.16	0.01	0.12	0.18	0.34	0.10	0.16	0.92	0.85	0.96	0.16	0.18	0.14
	FCOLI	7	11.0	75	10.25	66.69	2.64	0.40	0.05	0.12	0.06	2.25	0.38	0.69	0.25	0.20	0.34	0.67	0.95	0.48
	ECOLI	7	9.5	64	11.38	58.32	2.47	0.41	0.03	0.10	0.09	2.24	0.39	0.73	0.24	0.19	0.32	0.72	1.01	0.51
WQ_UML	TP	7	13.9	97	0.06	0.07	0.63	0.24	0.00	0.22	0.40	0.35	0.09	0.24	0.70	0.65	0.72	0.24	0.25	0.23
	TN	7	14.6	102	1.45	1.75	0.54	0.37	0.28	0.23	0.32	0.30	0.08	0.24	0.70	0.67	0.72	0.24	0.25	0.23
	NH3N	7	14.9	104	0.27	0.47	1.02	0.76	0.58	0.45	0.90	0.93	0.21	0.51	0.33	0.30	0.35	0.50	0.55	0.47
	NO2N	7	14.6	102	0.09	0.09	0.41	0.22	0.14	0.14	0.18	0.36	0.09	0.17	0.90	0.83	0.93	0.16	0.19	0.15
WQ_LWL	TP	7	13.9	97	0.28	0.29	0.56	0.41	0.25	0.31	0.75	0.44	0.11	0.33	0.51	0.47	0.52	0.33	0.35	0.31
	TN	7	14.6	102	3.90	4.20	0.46	0.43	0.34	0.26	0.28	0.30	0.08	0.27	0.63	0.61	0.64	0.26	0.27	0.26
	NH3N	7	14.7	103	1.65	1.82	0.54	0.54	0.43	0.30	0.37	0.41	0.10	0.32	0.52	0.49	0.54	0.32	0.33	0.31
	NO2N	7	14.6	102	0.06	0.09	0.86	0.57	0.00	0.52	0.50	1.07	0.23	0.59	0.29	0.26	0.30	0.58	0.64	0.55

Table 5 Inventory of Near-Shore Fecal Coliform Data

June-August - Routine / "Dry"?

Year	MAPLE	WIL	LKPK	BLBRK	9MILE	LEY	HARB	METRO	SOUTH
1999	13	13	13		12	3	3	3	13
2000	14	14	14		14	3	3	3	14
2001	12	12	12	4	12	4	5	4	13
2002	12	12	12	12	12	12	12	12	13
2003	13	13	13	13	13	13	13	13	13
2004	13	14	14	14	14	13	14	14	14
2005	13	13	13	13	13	13	13	13	13

June-August - Storm Event ?

Year	MAPLE	WIL	LKPK	BLBRK	9MILE	LEY	HARB	METRO	SOUTH
1999	3	3	3		3	3	2	3	
2000	3	3	3		3	3	3	3	
2001	3	3	3	3	3	3	3	3	
2002	3	3	3	3	3	3	3	3	3
2003	20	20	20	20	20	20	20	20	20
2004									
2005									

Percent of June-August Samples with 3-Day Antecedent Rain > 0.5 inches

Year	MAPLE	WIL	LKPK	BLBRK	9MILE	LEY	HARB	METRO	SOUTH
1999	0	0	0		0	0	0	0	0
2000	18	18	18		18	0	0	0	21
2001	20	20	20	29	20	29	38	29	15
2002	20	20	20	20	20	20	20	20	19
2003	30	30	30	30	30	30	30	30	30
2004	46	43	43	43	43	46	43	43	43
2005	23	23	23	23	23	23	23	23	23

Shaded Areas = missing data or sampling frequencies different from normal protocol (weekly)

No storm-event sampling conducted in 2004-2005

Table 6 Inventory of Juvenile Fish Data

Fish Counts by Specie

Common Name	2000*	2001	2002	2003	2004	2005	Total
Banded killifish	4	5	27	56	5	49	146
Bluegill	0	13	21	0	29	15	78
Bluntnose minnow	0	0	0	4	0	0	4
Brook Silverside	45	24	10	0	0	0	79
Carp	1	0	28	76	58	30	193
Emerald shiner	0	4	0	0	0	0	4
Gizzard shad	1790	1559	2	321	178	2	3852
Golden shiner	1	0	0	11	0	2	14
Largemouth bass	30	248	261	182	618	1529	2868
Lepomis sp.	591	5150	2719	4942	1419	2715	17536
Pumpkinseed	0	43	13	0	3	272	331
Smallmouth bass	78	193	56	82	140	361	910
White perch	30	34	2	10	3	0	79
Yellow perch	28	329	2	0	0	12	371
Johnny darter	0	0	1	0	0	0	1
White sucker	0	11	1	0	0	0	12
Tesselated darter	0	0	0	0	0	2	2
Logperch	7	3	0	0	0	0	10
Longnose gar	0	0	0	0	1	0	1
Rock bass	0	0	0	0	0	6	6
Brown bullhead	0	2	1	3	0	18	24
Channel catfish	0	0	1	0	0	0	1
Total	2605	7618	3145	5687	2454	5013	26522

Fish Counts by Month

Month	2000*	2001	2002	2003	2004	2005	Total
5	37	0	1	0	0	0	38
6	0	0	0	0	0	18	18
7	15	0	366	251	787	1107	2526
8	2366	6389	1711	2918	500	594	14478
9	187	1229	599	2274	647	3072	8008
10	0	0	468	244	520	222	1454
Total	2605	7618	3145	5687	2454	5013	26522

Fish Counts by Measurement Method

Year	2000	2001	2002	2003	2004	2005	Total
Catch Estimated **	0	0	0	1260	0	0	1260
Catch Counted	3770	5639	1852	3078	1278	2724	18341
Individuals Counted	1699	1979	1294	1349	1176	2289	9786
Total	5469	7618	3146	5687	2454	5013	29387
Total Counted	5469	7618	3146	4427	2454	5013	28127

Samples Collected by Month

Month	2000*	2001	2002	2003	2004	2005	Total
5	30	0	15	30	0	0	75
6	15	0	15	15	0	4	49
7	18	0	26	27	30	27	128
8	27	30	19	19	14	19	128
9	15	29	15	15	15	26	115
10	0	0	15	15	30	15	75
Total	105	59	105	121	89	91	570

Sampling Rounds by Month

Month	2000	2001	2002	2003	2004	2005	Total
5	2		1	2			5
6	1		1	1			3
7	1		2	2	2	2	9
8	2	2	1	1	1	1	8
9	1	2	1	1	1	2	8
10			1	1	2	1	5
Total	7	4	7	8	6	6	38
July-Sept	4	4	4	4	4	5	25

Samples Collected by Stratum

Stratum	2000*	2001	2002	2003	2004	2005	Total
Str 1	21	12	21	24	18	19	115
Str 2	21	11	21	24	18	18	113
Str 3	21	12	21	25	17	18	114
Str 4	21	12	21	24	18	18	114
Str 5	21	12	21	24	18	18	114
Total	105	59	105	121	89	91	570

Data from OLMP fish database, Life Stage = Y

* Replicate samples 2 and 3 in 2000 excluded from analysis (reps. not collected in 2001-2005)

** The estimated catch in 2001 reflects a single sample of Leopomis spp.
While unique, that sample been included in the analysis because there were several other records records with direct counts in the 500-1000 range.

Table 7 Inventory of Adult Fish Data

All Seasons

Common Name	2000	2001	2002	2003	2004	2005
Clupeids						
Alewife		5	11	156	1416	681
Gizzard shad*	361	232	406	113	27	245
Total Fish	361	237	417	269	1443	926
Non-Game Fish						
Banded killifish	1			1	1	
Brook Silverside			3			
Carp*	220	324	170		48	122
Freshwater drum	14	13	6	7	30	13
Golden shiner*	4		2	3	6	6
Greater Redhorse	0					1
Logperch	2		1	1	1	0
Longnose gar*	3	1	3		3	6
Northern hog sucker	2		1			
Rudd*						1
Shorthead redhorse*	11	29	9	14	13	5
White perch*	306	196	221	339	368	230
White sucker*	132	153	71	91	96	102
Total Fish	695	716	487	456	566	486
Total Species	10	6	10	7	9	9
Shannon-Weaver	1.28	1.26	1.25	0.77	1.13	1.31
Gamefish						
Black crappie*	5		1	2	1	
Bluegill*	226	276	445	584	252	47
Bowfin*	6	1	9	6	20	7
Brown bullhead*	17	30	24	21	45	89
Brown trout	1				1	2
Bullhead (species unk	0		1			
Channel catfish*	31	13	16	9	25	7
Largemouth bass*	135	77	252	170	208	209
Lepomis sp.				1		
Northern pike	1	2	2	2	1	2
Pumpkinseed*	116	229	356	451	402	305
Rainbow trout			1			
Rock bass	6		7	2	4	9
Smallmouth bass	47	158	98	97	88	112
Tiger muskellunge		1			1	2
Walleye*	27	16	9	8	1	7
Yellow bullhead*					1	1
Yellow perch*	212	215	151	189	225	205
Total Fish	830	1018	1372	1542	1275	1004
Total Species	13	11	14	13	15	14
Shannon-Weaver	1.87	1.75	1.70	1.57	1.78	1.81

* Pollution Tolerant or Moderately Tolerant

Table 8 Inventory of Counted & Estimated Adult Fish

	2000	2001	2002	2003	2004	2005
Fish Counted						
Clupeid	361	237	417	269	1443	926
Non Game	695	716	487	456	566	486
Game	830	1018	1372	1542	1275	1004
Total	1886	1971	2276	2267	3284	2416
Fish Estimated						
Clupeid	1500	200	4200	1540	13862	8070
Non Game *	6	0	17	311	1167	635
Game *	0	0	65	1434	1616	999
Total	1506	200	4282	3285	16645	9704

* Excluded from analysis in AMP Yearly & AMPSF Reports

List of Figures

Figure 1 Maps of Lake Strata & Stations

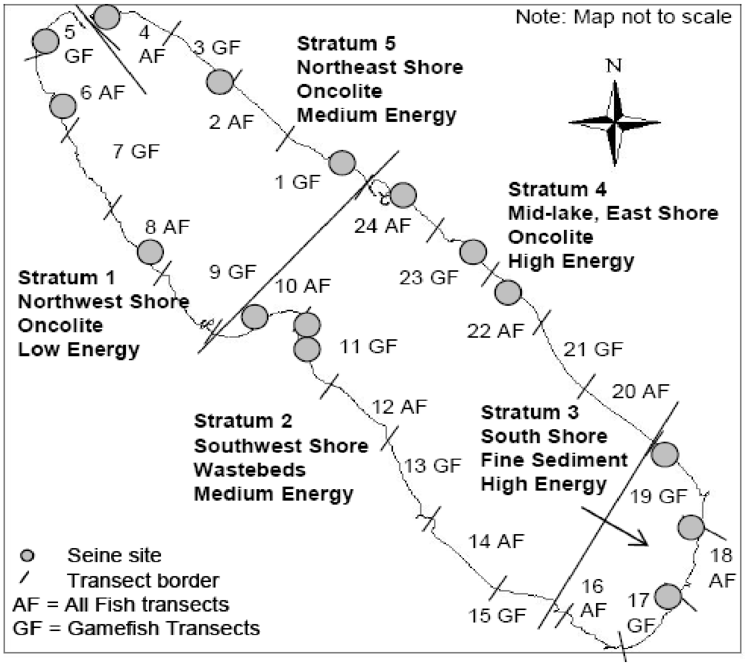


Figure A8-1. Location and description of strata, boat electrofishing transects, and seining sites in Onondaga Lake.

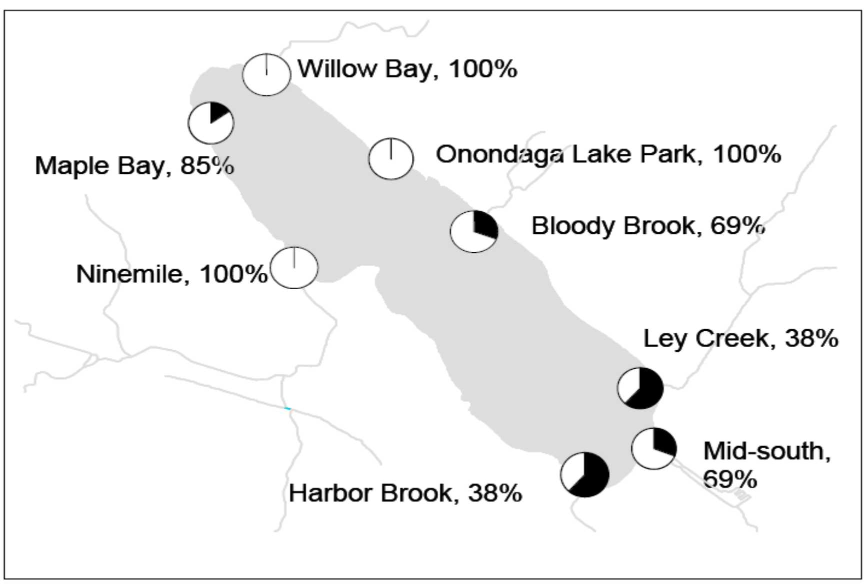
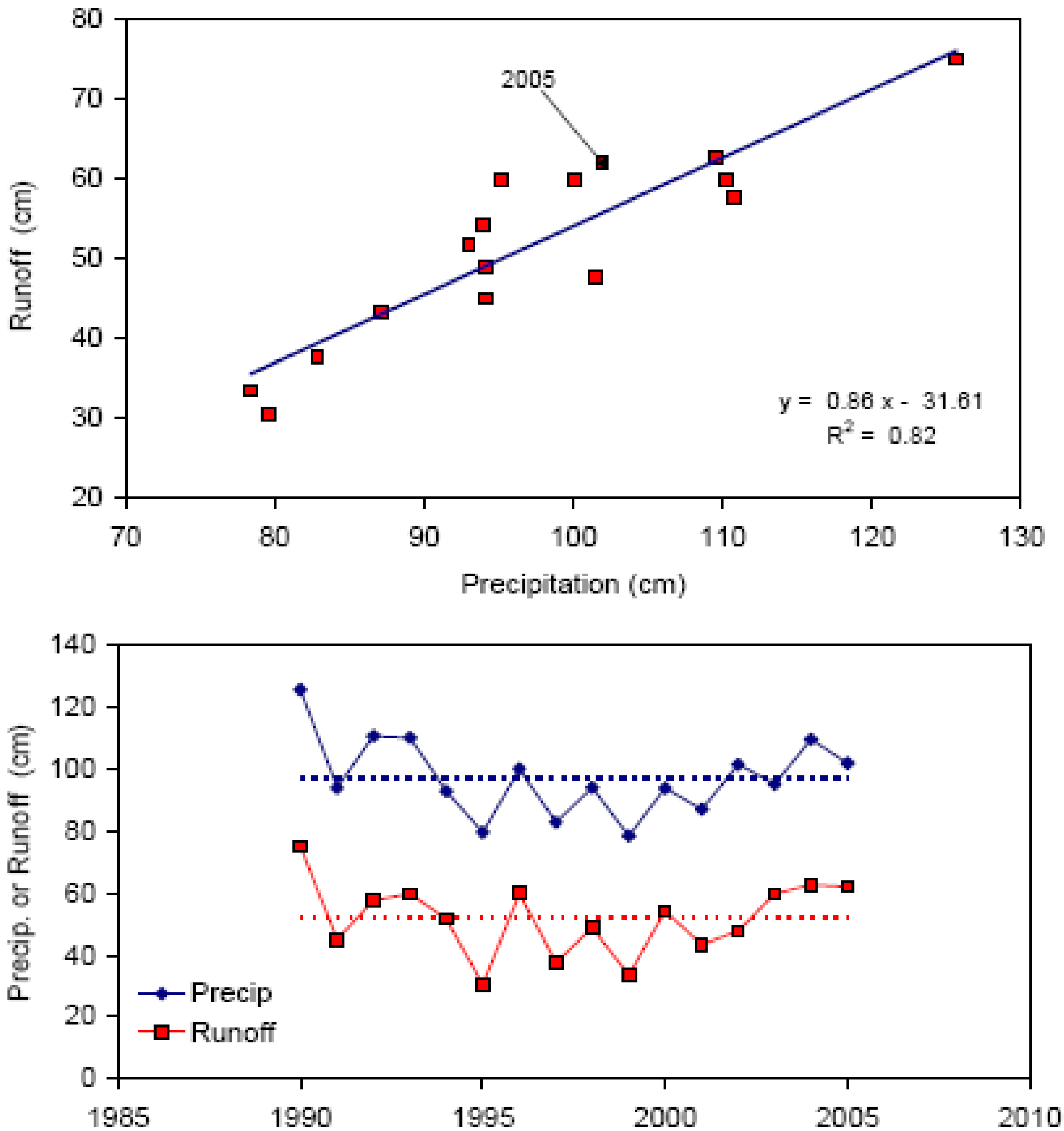


Figure 2-24. Nearshore water clarity conditions in 2005. Percent shown in figure indicates compliance with swimming safety guidance value (1.2 m). Shaded area of pie charts indicates percent of samples where Secchi depth was below guidance value.

from AMP 2005 Monitoring Report (Ecologic et al, 2006).

Figure 2 Annual Watershed Runoff vs. Precipitation



From AMP 2005 Report (Ecologic et al., 2006)

Precipitation measured at Hancock Airport

Figure 3 Structure of Hypothesis Tests

Null Hypothesis (H_o): No Improvement (1-Tailed)

Outcome of Hypothesis Test:

	Reality	
Test Outcome	No Trend	Trend
H_o Accepted	Correct	Type II Error prob. = β
H_o Rejected	Type I Error max prob. = α	Correct

"Significance Level" = α, Pre-Selected

Maximum (β) = 1 - α

Power = Probability of Detecting Trend = 1 - β

= Function ("Trend Number" , α)

$$\text{Trend Number} \sim \frac{\text{Size of Trend x (Years of Monitoring)}^{1.5}}{\text{Std Dev of Yearly Means}}$$

Figure 4 Lake Responses to Reductions in Phosphorus & Ammonia Loads

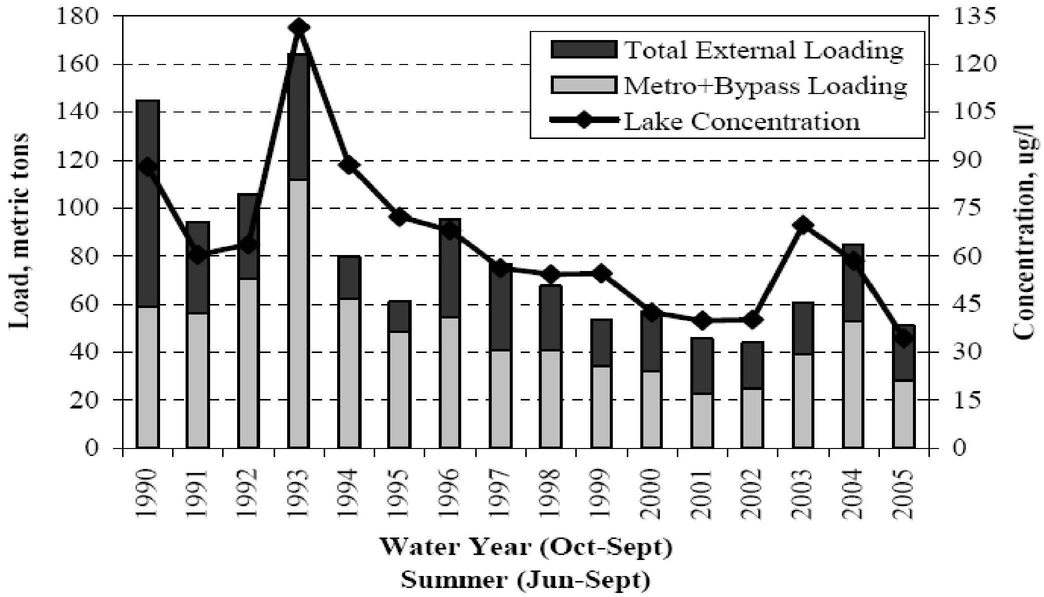


Figure 2-14. Total Phosphorus: Water Year (October to September) external loading and Metro (Outfalls 001 and 002) loading to the lake, compared with South Deep summer (June-September) daily average concentrations for depths 0 to 6 meters. Onondaga Lake, 1990-2005.

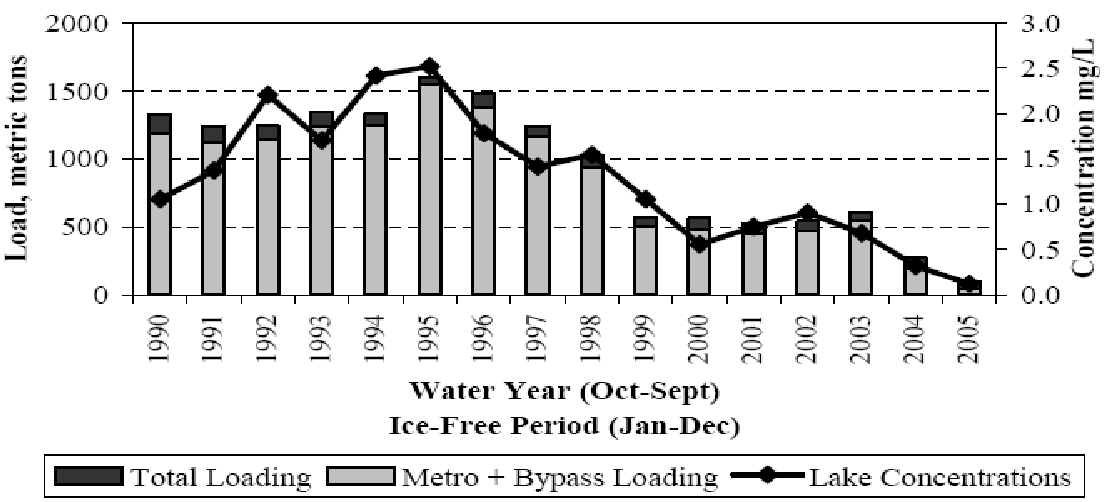
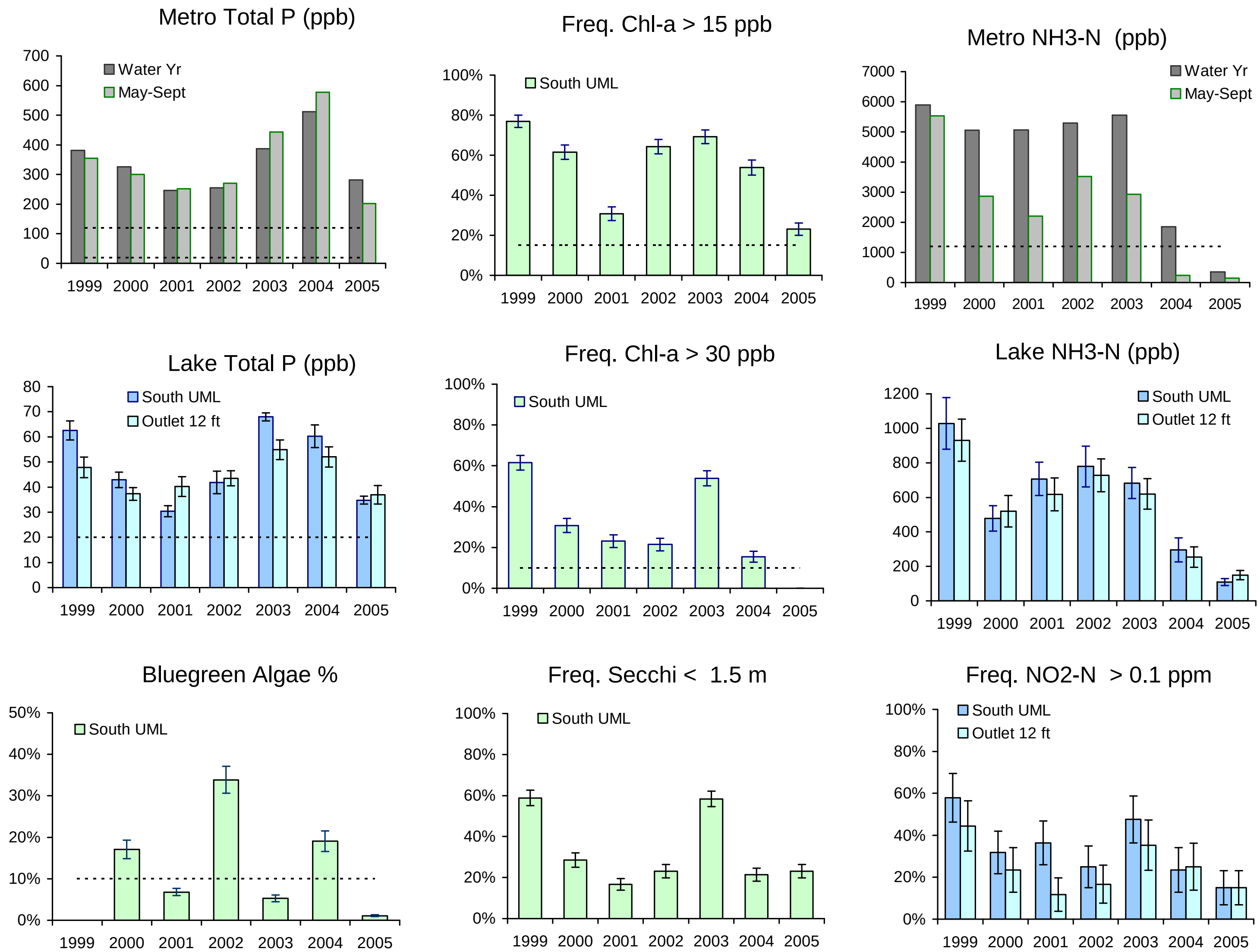


Figure 2-27. Water year (October to September) external ammonia load and average annual (January to December, ice-free period) concentrations of ammonia in Onondaga Lake. For example, loading for the period 10/2004 to 09/2005 is paired with concentration for 2005. Lake concentrations are the annual average of sample date averages of discrete samples collected at meter depths 0, 3, and 6. External ammonia loading obtained from historic_loads.xls.

From AMP 2005 Monitoring Report (Ecologic et al, 2006)

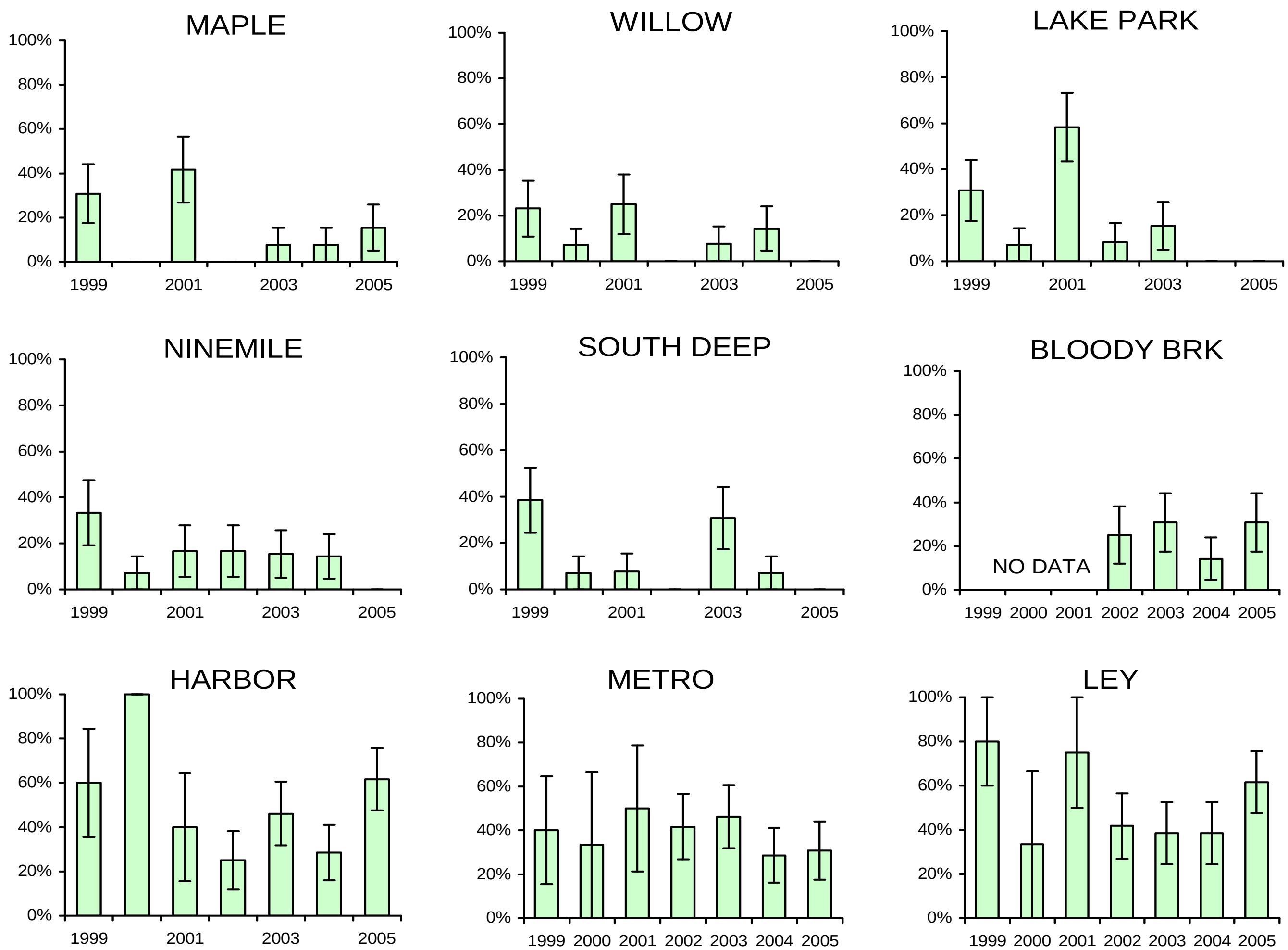
Figure 5 Metro Discharge Concentrations & AMP Lake Water Quality Metrics



Seasons: June-Aug for Phosphorus, Chlorophyll-a, & Secchi; April-Nov for NH3 & NO2 Bars = approximate standard errors

Dashed lines = lake goal or future discharge limit (Metro); lake goals for Secchi & NO2-N Frequencies = 0%

Figure 6 Compliance Frequencies for Transparency

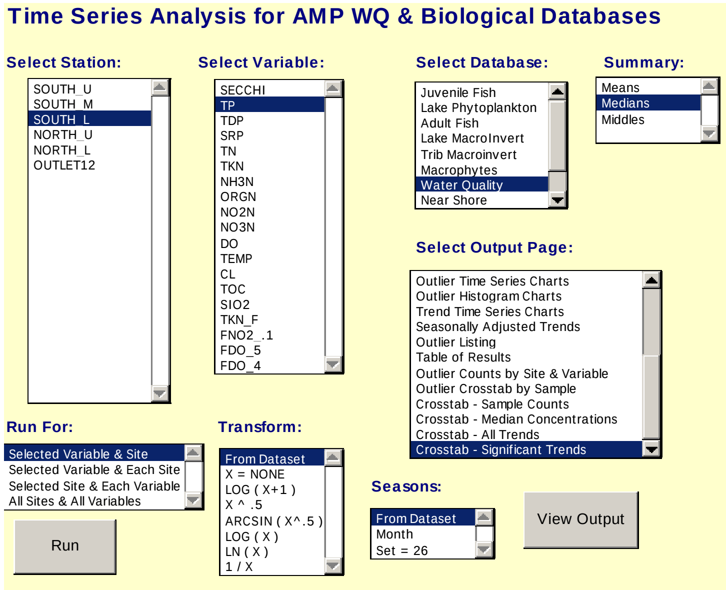


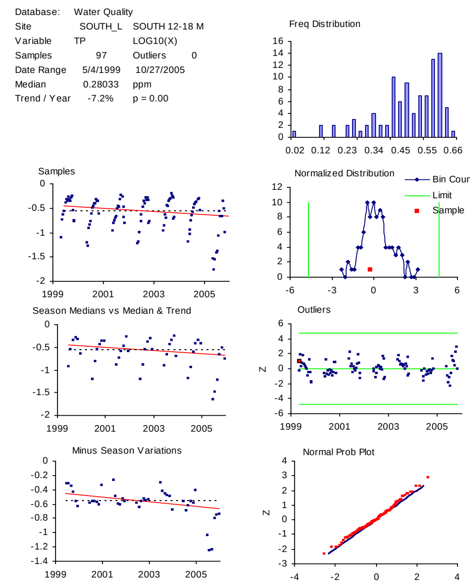
Frequency of Secchi Depths < 1.2 m (4 feet), June-August samples.; Stations locations shown in Figure 1.

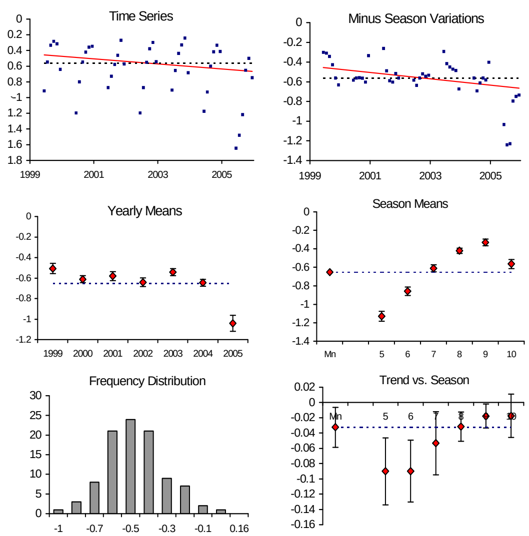
Data from routine weekly monitoring program are included; data from storm event program are excluded.

Yearly frequencies +/- 1 standard error (approximate estimates).

Figure 7 AMPSF Analytical Software & Sample Output







Water Quality	Site: SOUTH_L	SOUTH 12-18 M	Group by: Season
Variable: TP	ppm		Transf: LOG10(X)

		Variance Components			
Samples	97	Source	CV	p 2T	Signif
Season	6	Total	0.915		
Years	7	Cells	0.926		
Missing%	0%	Season	0.753	**0.00**	**
N / Cell	2.3	Yr_Total	0.406	**0.00**	**
N / Seas	16.2	Yr_Trend	0.250	0.08	**
N / Yr	13.9	Yr_Rand	0.310	0.00	**
Regress R2	0.50	Error	0.327		
Step R2	0.22				

Statistics	Data	Transf	Filtered	Anova
Count	97	97	97	42
Median	0.28	-0.55	-0.57	-0.56
Mean	0.29	-0.63	-0.55	-0.65
Std Dev	0.16	0.34	0.17	0.34
Skewness	0.14	-1.12	0.28	-1.14

Null Hypothesis Tails = 1 , Alpha = 0.1

Method	p 1 T	Slope	SE	Signif
1- SK 1	**0.00**	**-7.2%**	**2.4%**	**
1- SK 2	**0.05**	**-7.2%**	**2.4%**	**
2- Lin Reg	**0.04**	**-12.6%**	**5.6%**	**
3- Step Reg	0.14	-30.5%	25.4%	
4- Difference	**0.00**	**-29.4%**	**8.4%**	**

1 - Monotonic Trend (Seasonal Kendall, Versions 1 & 2)
2 - Linear Trend (Regres 3 Step Change after 2002
4 - Difference (Period 1 Mean vs Period 2 Mean)

Precision & Power - vs. Samples / Yr

Design	N	N / 2	N x 2
Sampl/Yr	13.9	6.9	27.7
CV_W	0.44	0.44	0.44
CV_Y	0.31	0.31	0.31
CV_YT	0.33	0.35	0.32

Precision - Relative Std Error of Mean %

Yearly Mn	0.11	0.16	0.08
Long-Term	0.12	0.13	0.12
Period Mn	0.04	0.06	0.03

Prob. of Detecting Trends with 10 yrs of data

Change %	N	N / 2	N x 2
10%	0.26	0.25	0.27
20%	0.51	0.47	0.52
30%	0.75	0.71	0.77
50%	0.97	0.96	0.98
100%	1.00	1.00	1.00

Change Detectable with 90% Confidence

Incre %	32.6%	34.8%	31.5%

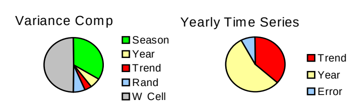
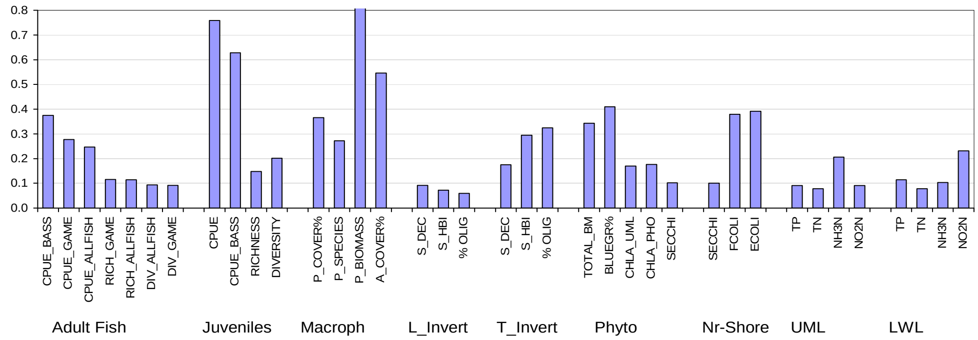
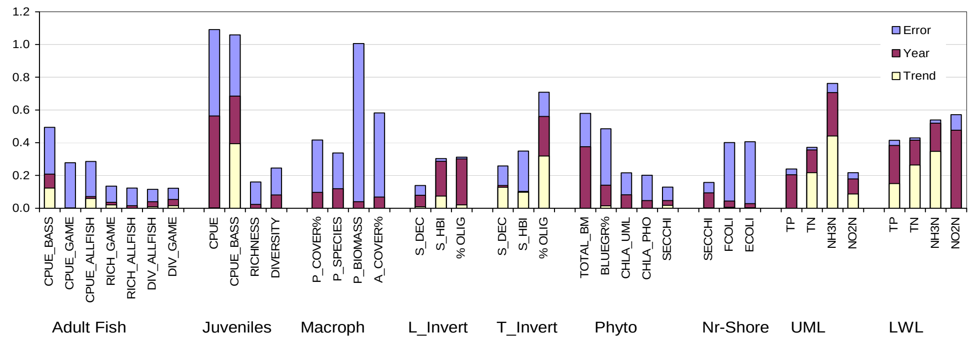


Figure 8 Precision & Power Estimates for Stratum / Station Means

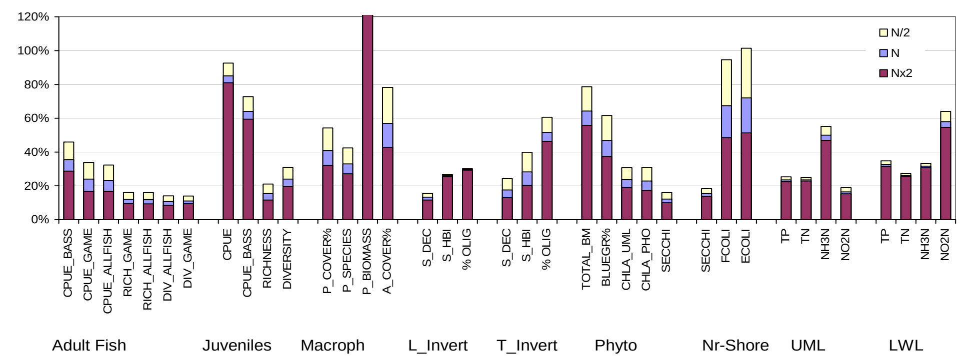
Relative Standard Error of Yearly Mean



Variance Components of Yearly Mean Time Series



Change Detectable with 90% Confidence vs. Samples/Yr



Probability of Detecting a 20% Change vs. Samples/Yr

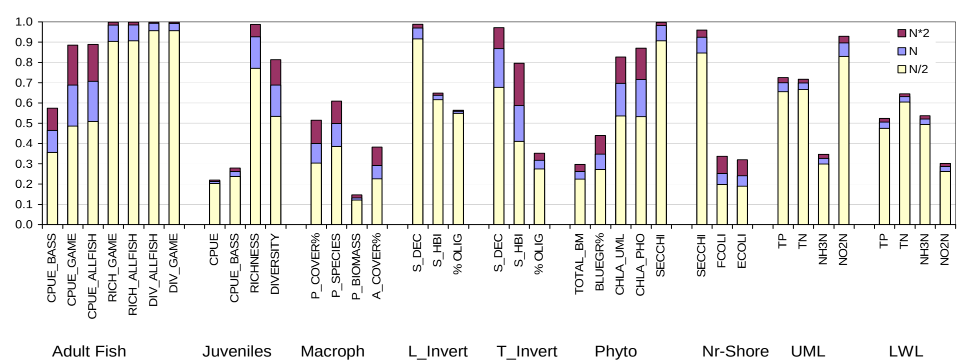
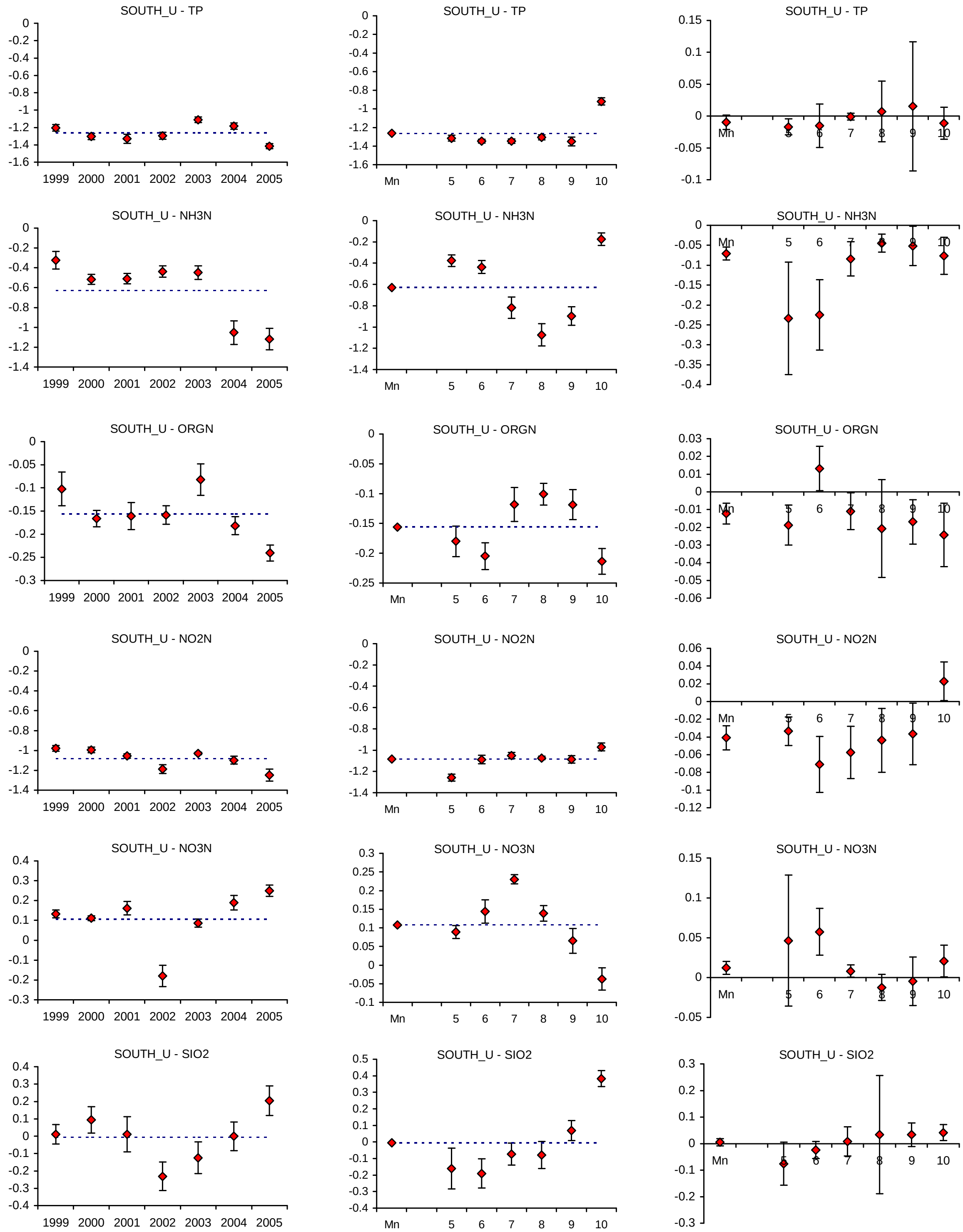


Figure 9 Yearly & Seasonal Variations in Nutrient Concentrations
South Deep Upper Mixed Layer (0 - 3 m)

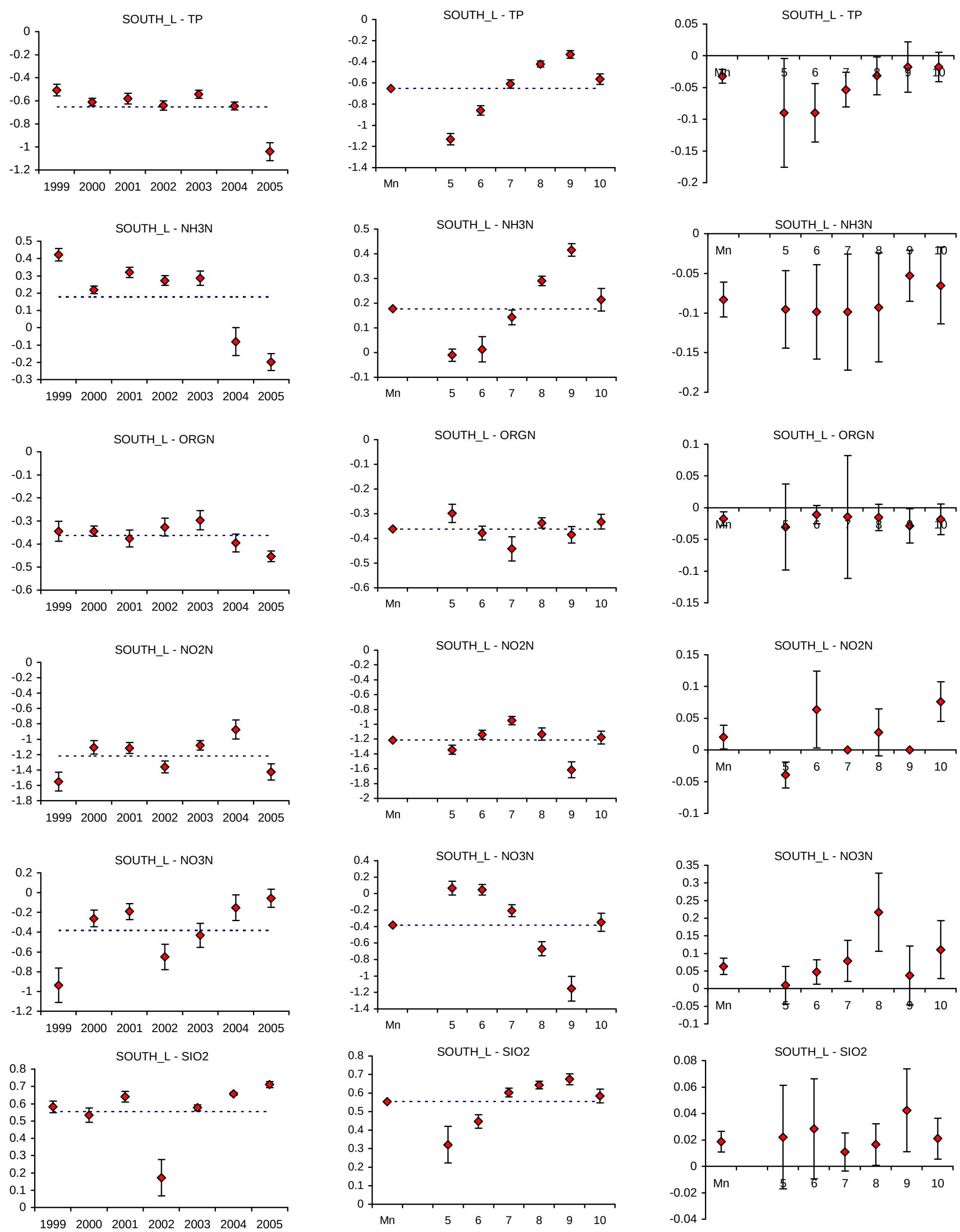
Yearly Means Monthly Means Monthly Trends



Yearly & Monthly Means +/- 1 Standard Error; Trend = Kendall/Tau Slope +/- 1 Standard Error; South Deep Station
Units ppm, Log10 Transformed

Figure 10 Yearly & Seasonal Variations in Nutrient Concentrations
South Deep Lower Water Layer (12 - 18 m)

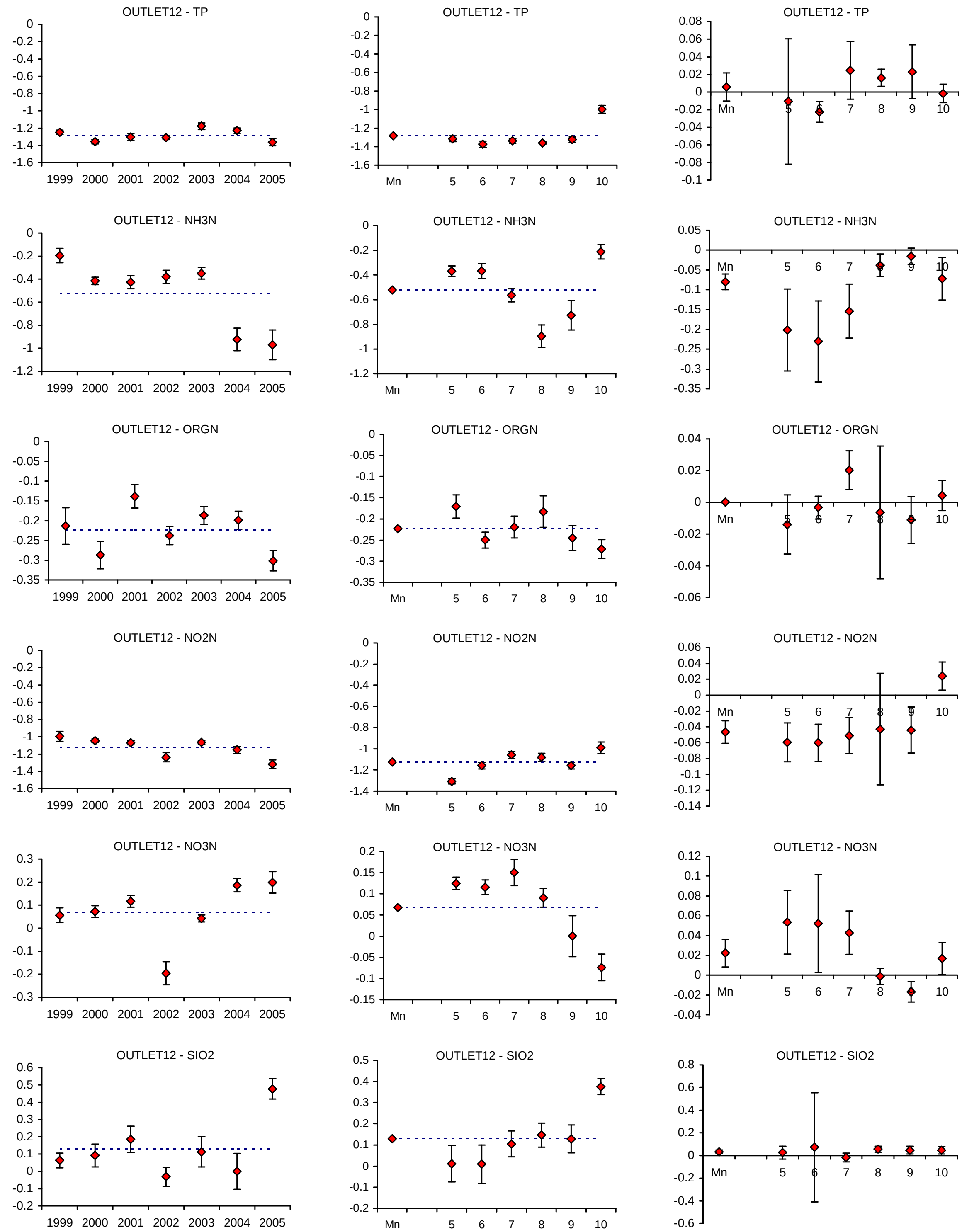
Yearly Means Monthly Means Monthly Trends



Yearly & Monthly Means +/- 1 Standard Error; Trend = Kendall/Tau Slope +/- 1 Standard Error; South Deep Station
Units ppm, Log10 Transformed

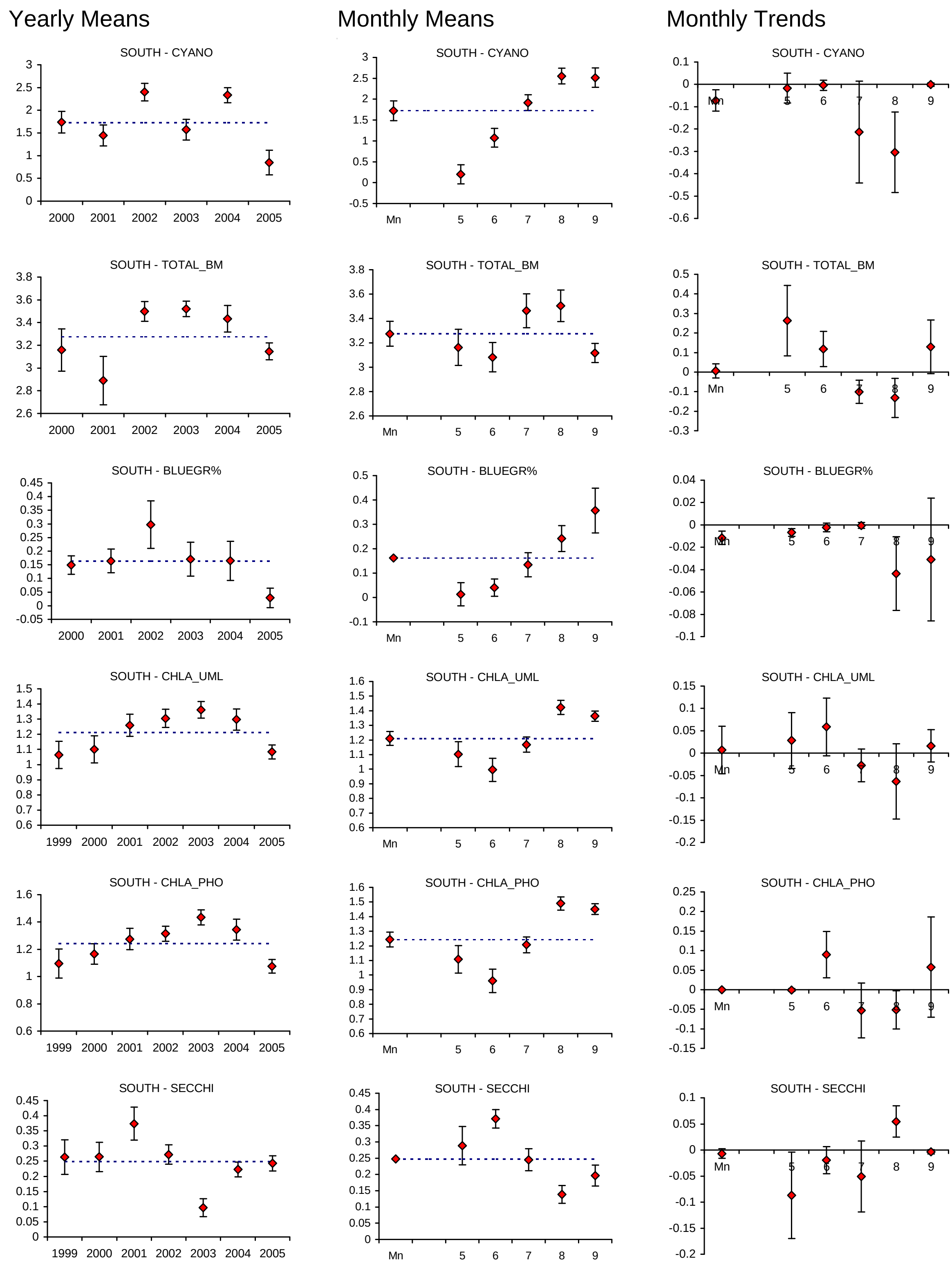
Figure 11 Yearly & Seasonal Variations in Nutrient Concentrations
Outlet at 12 Feet

Yearly Means Monthly Means Monthly Trends



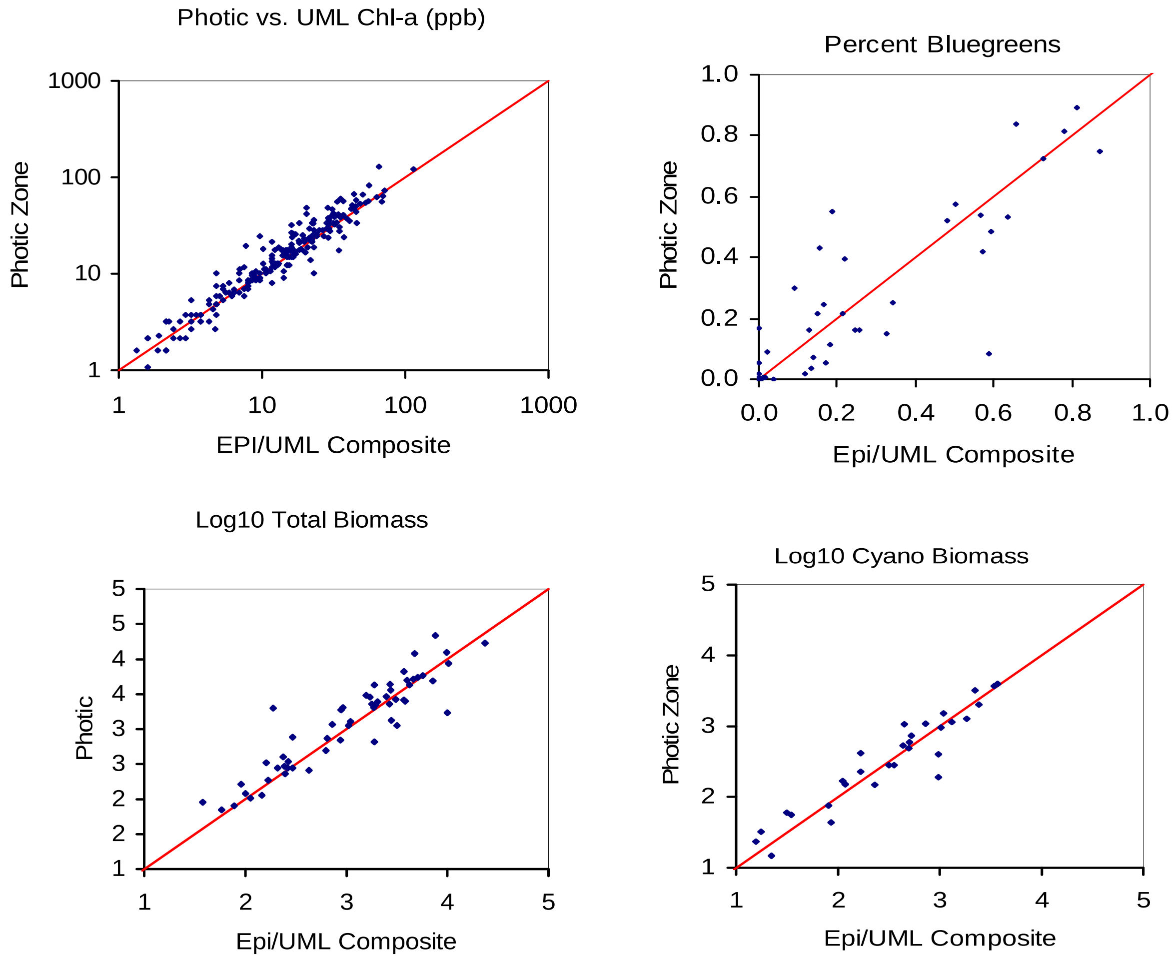
Yearly & Monthly Means +/- 1 Standard Error; Trend = Kendall/Tau Slope +/- 1 Standard Error; South Deep Station
Units ppm, Log10 Transformed

Figure 12 Yearly & Seasonal Variations in Phytoplankton Metrics



Yearly & Monthly Means +/- 1 Standard Error; Trend = Kendall/Tau Slope +/- 1 Standard Error; South Deep Station
Units ppb, Log10 Transformed: Cyanobacter, Total Biomass, Chlorophyll-a (Photic Zone), Chlorophyll-a (Upper Mixed Layer / Epilimnetic), Secchi Depth (m)
Blue Green Biomass as Percent of Total

Figure 13 UML/Epilimnetic vs. Photic Zone Phytoplankton Metrics

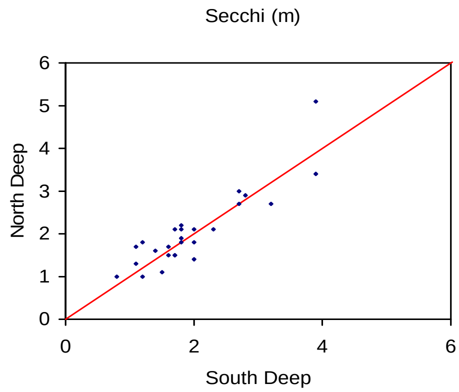


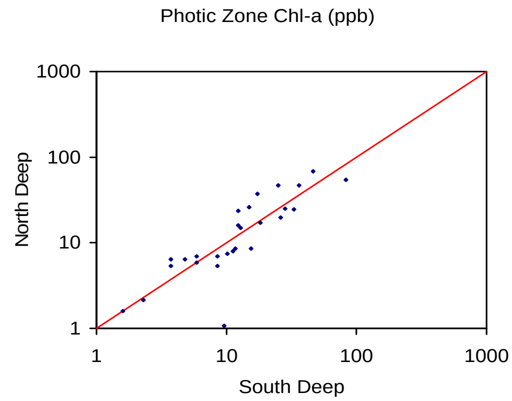
Red Line: Y = X, Symbols: Measured Paired by Date, South Deep Station

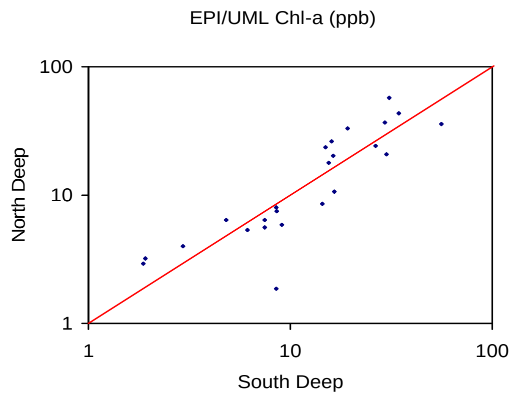
Paired T-Test Results (1999 -2005)

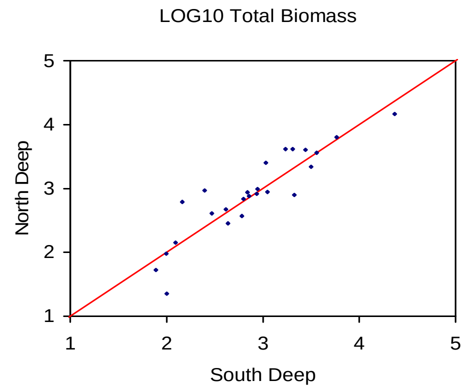
Variable	Chl-a	Total BM	Cyano BM	% Cyano
Count	220	57	57	57
Percent Diff. (P - E)	10.5%	15.8%	-6.0%	-0.3%
Standard Error	2.2%	8.5%	13.6%	3.6%
p	0.00	0.07	0.66	0.93

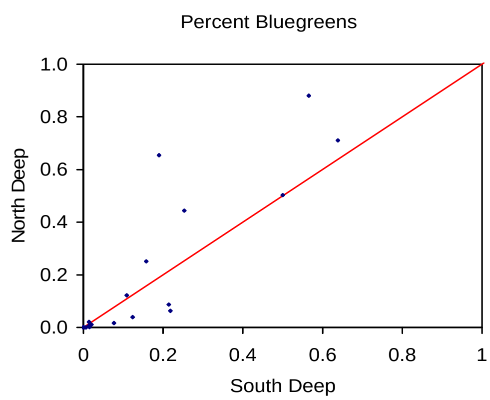
Figure 14 South Deep vs. North Deep Phytoplankton Metrics

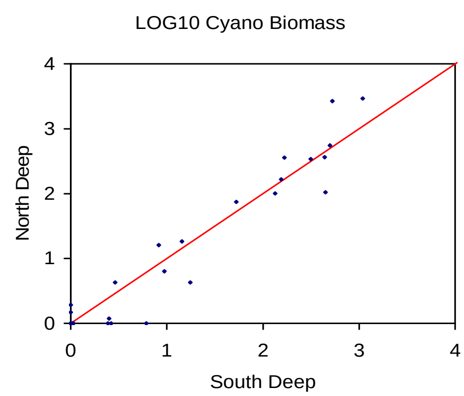










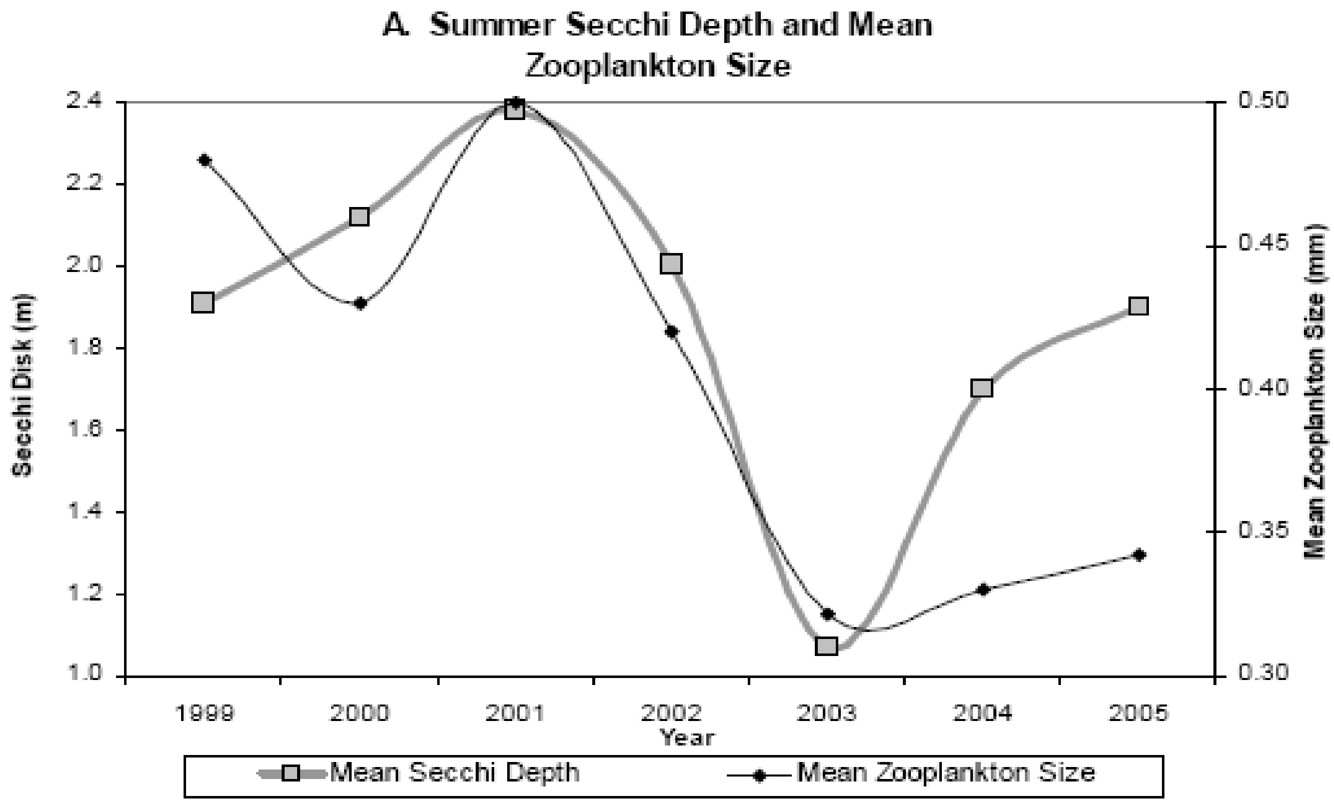


Line : Y=X, Symbols = Measurements paired by date.

Paired T-Test Results (1999 -2005)

Variable	Secchi	Chl-a	Chl-a	Total BM	Cyano BM	% Cyano
Sample Type	EP/UML	Photic	EP/UML	EP/UML	EP/UML	EP/UML
Count	26	24	27	25	25	25
Percent Difference (N - S)	3.3%	0.5%	2.5%	7.5%	-7.4%	6.6%
Standard Error	4.0%	9.9%	11.2%	13.5%	15.4%	6.1%
p	0.42	0.96	0.83	0.58	0.63	0.29

Figure 15 Correlation between Secchi Depth & Zooplankton Size



AMP 2005 Monitoring Report (Ecologic et al., 2006)

Figure 16 Trends in Phytoplankton Taxa

Seasonally Adjusted Time Series

Dataset: Lake Phytoplankton Site: SOUTH Lake South

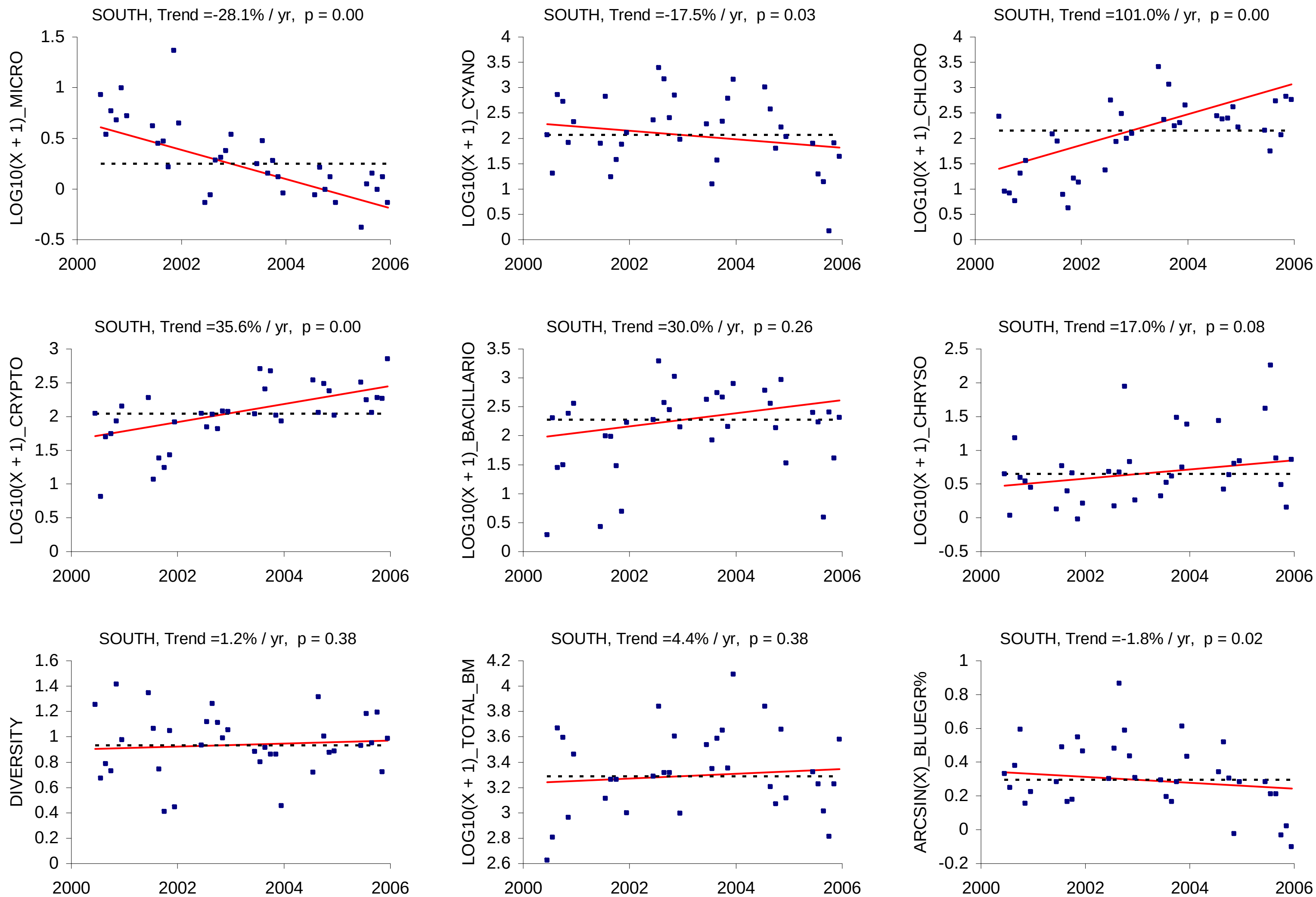
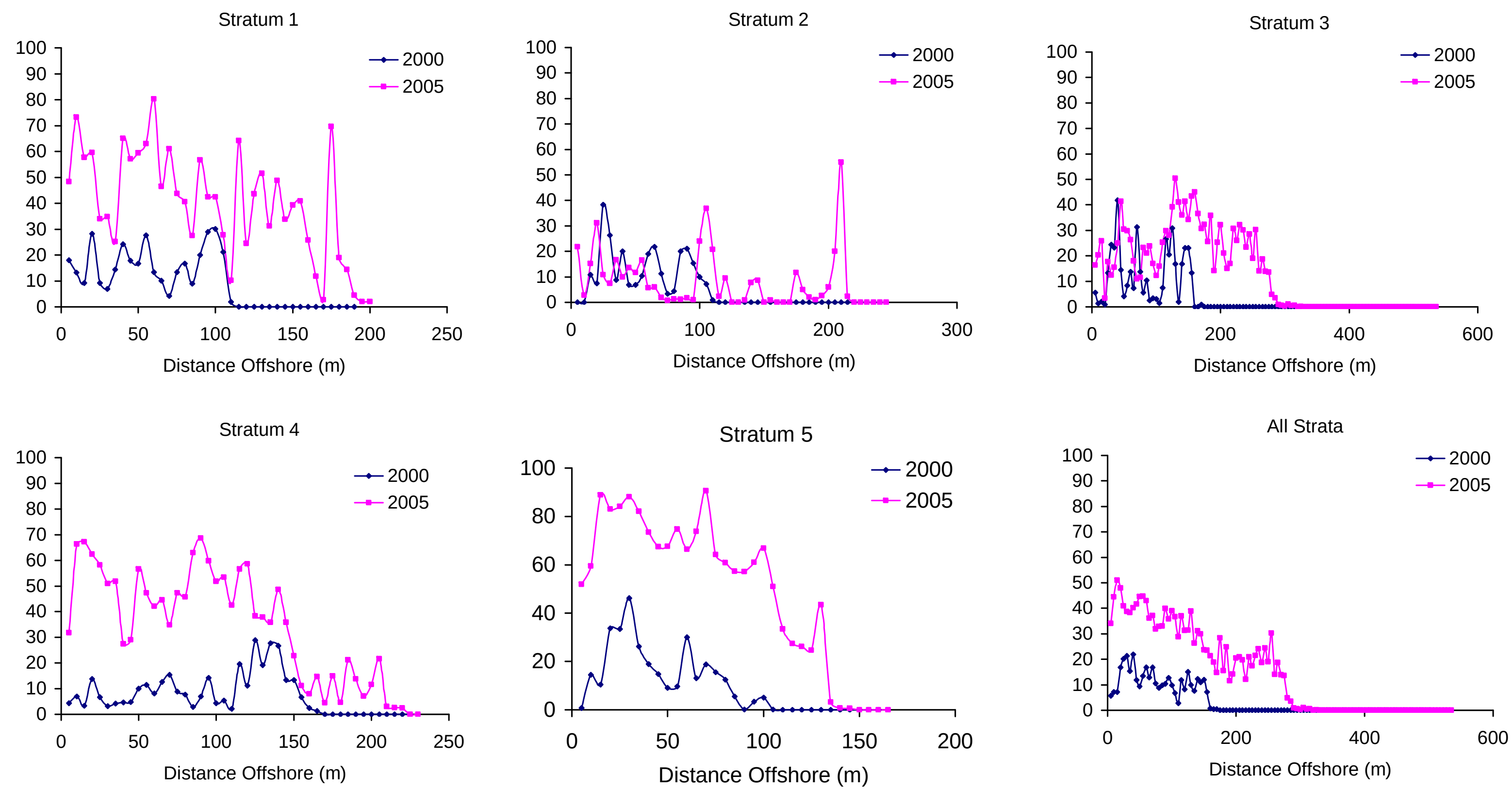
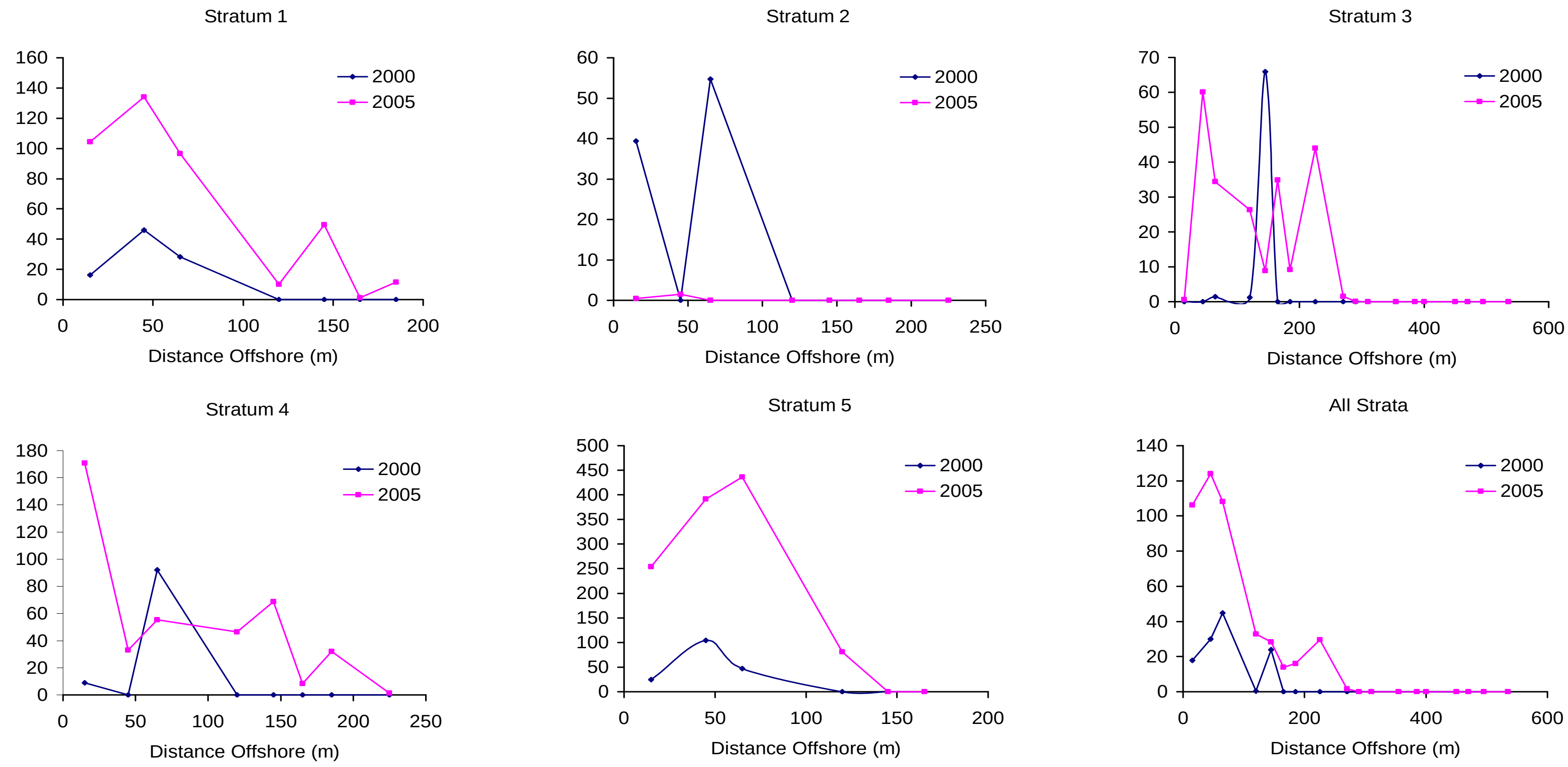


Figure 17 Macrophyte Percent Cover vs. Distance from Shore



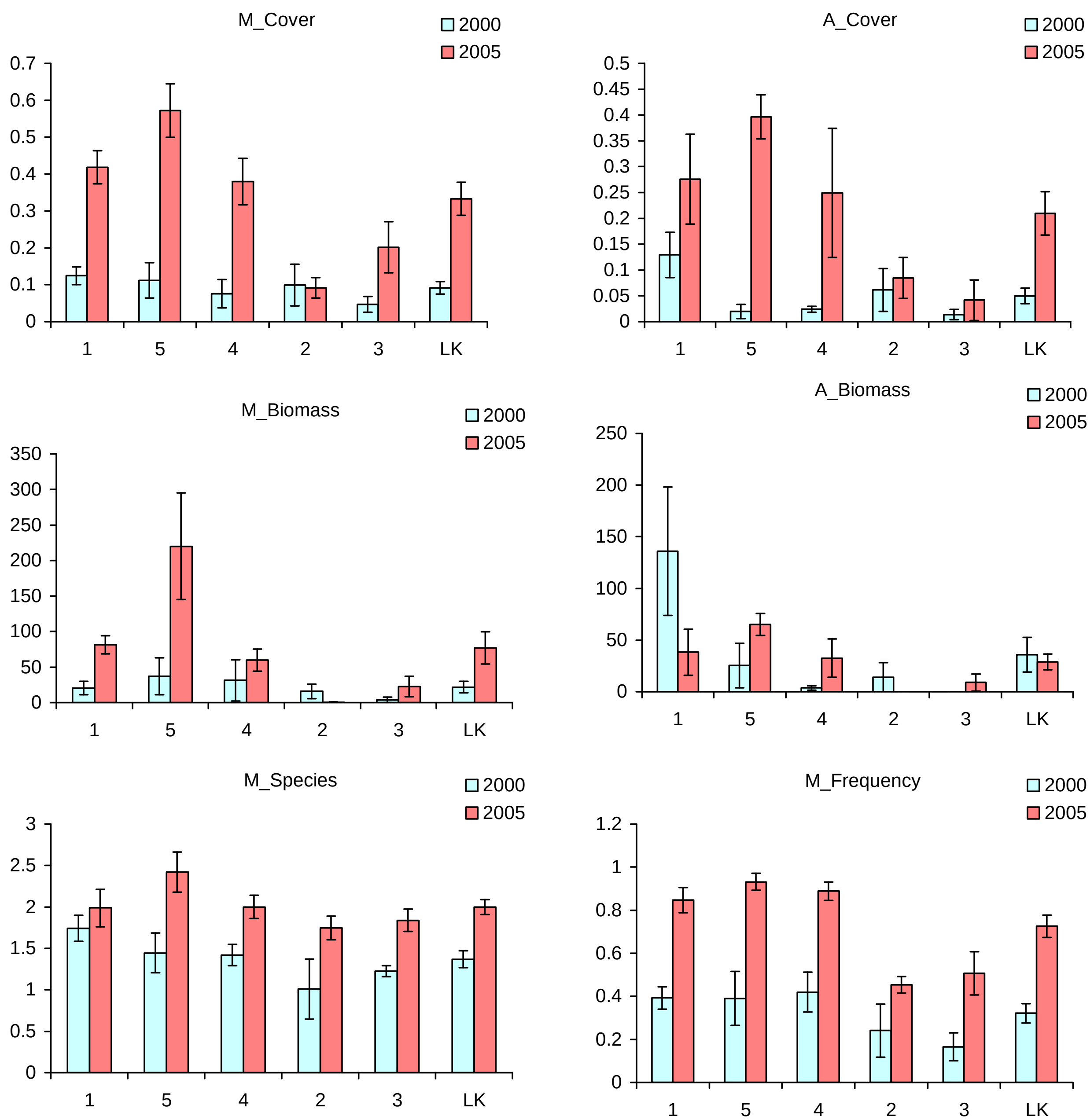
Suplot data averaged in 5 meter increments

Figure 18 Macrophyte Biomass vs. Distance from Shore



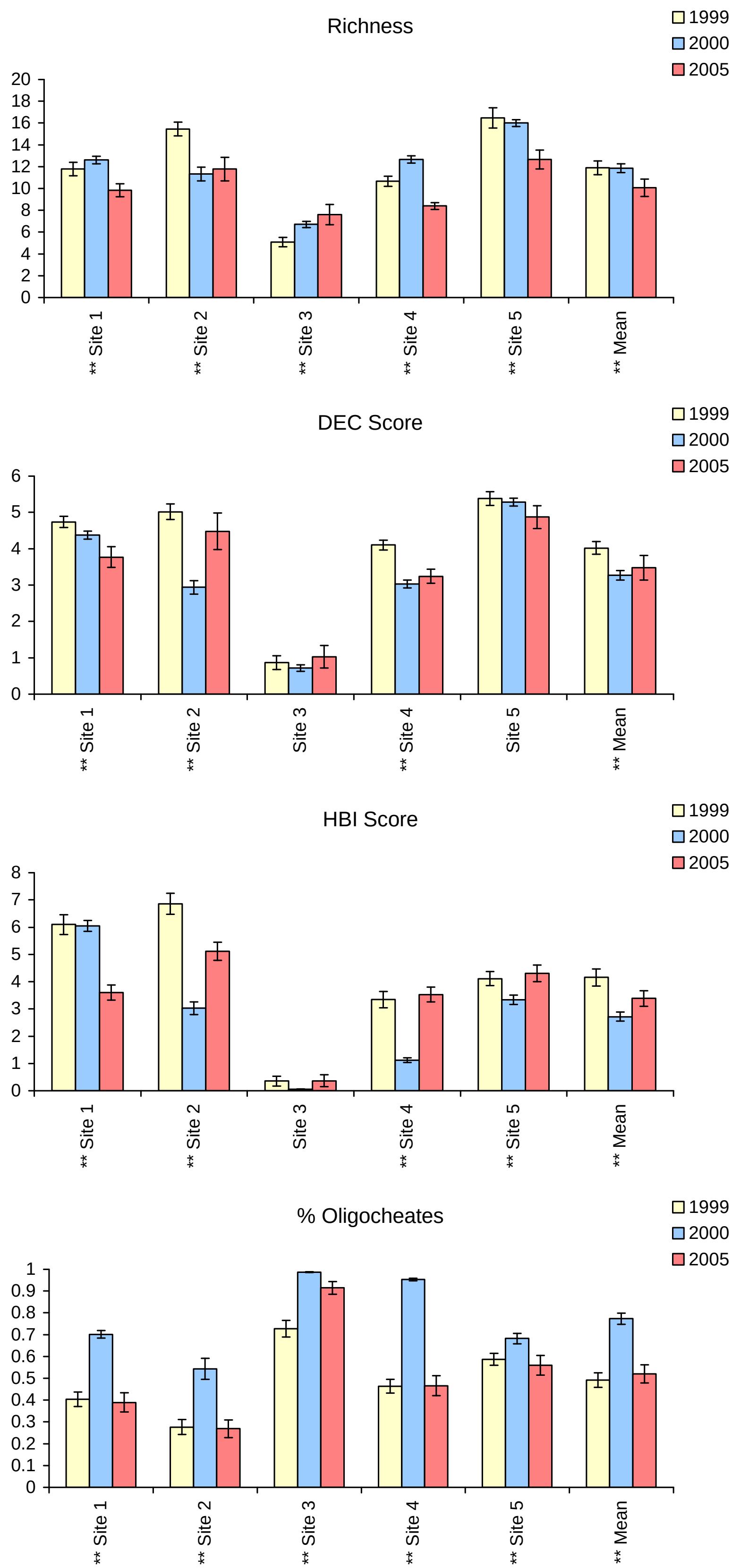
Suplot data averaged in 5 meter increments; Units = grams/m2

Figure 19 Spatial & Temporal Variations in Littoral Macrophyte & Algae



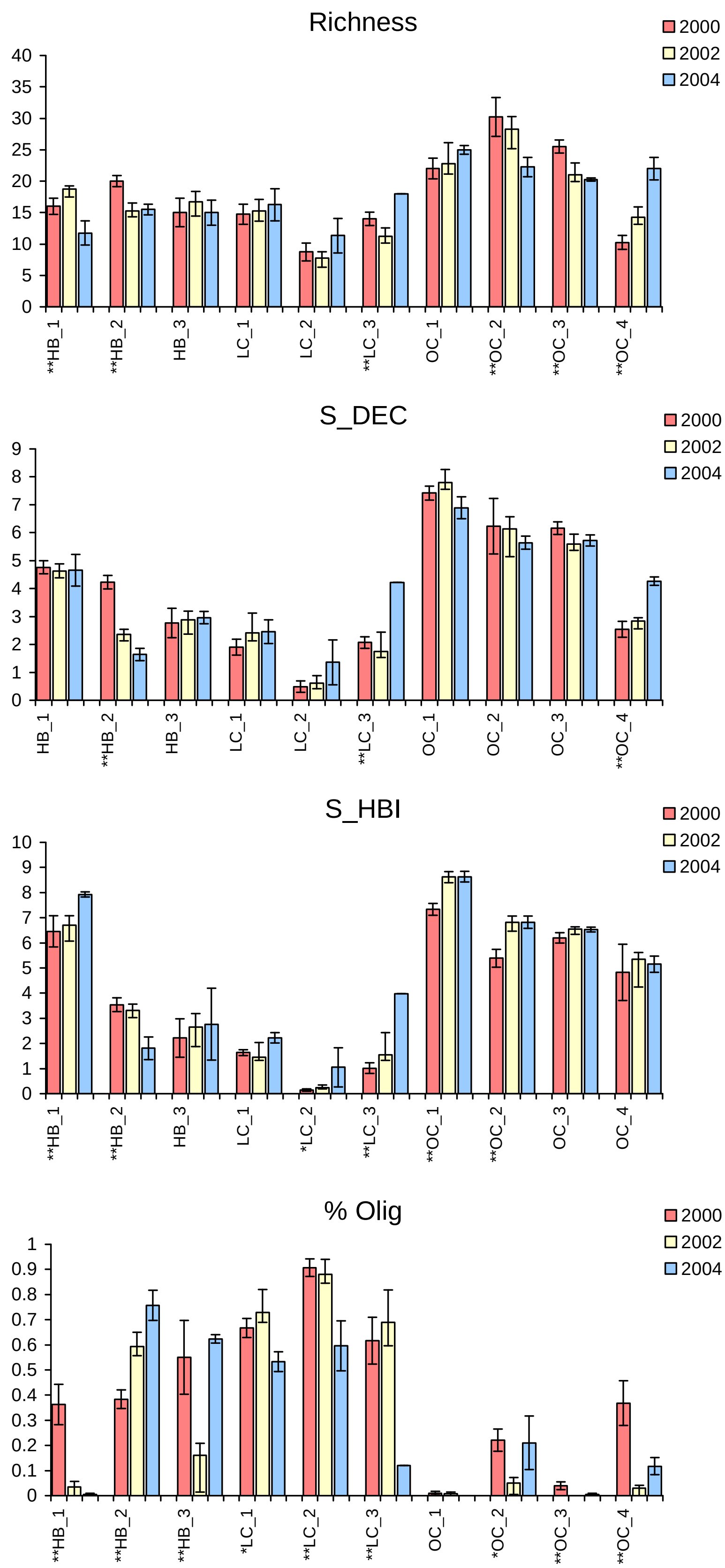
M = Macrophytes, A = Algae
Means & Standard Errors Across Transects, X-Axis = Lake Stratum

Figure 20 Spatial & Temporal Variations in Lake Macroinvertebrates



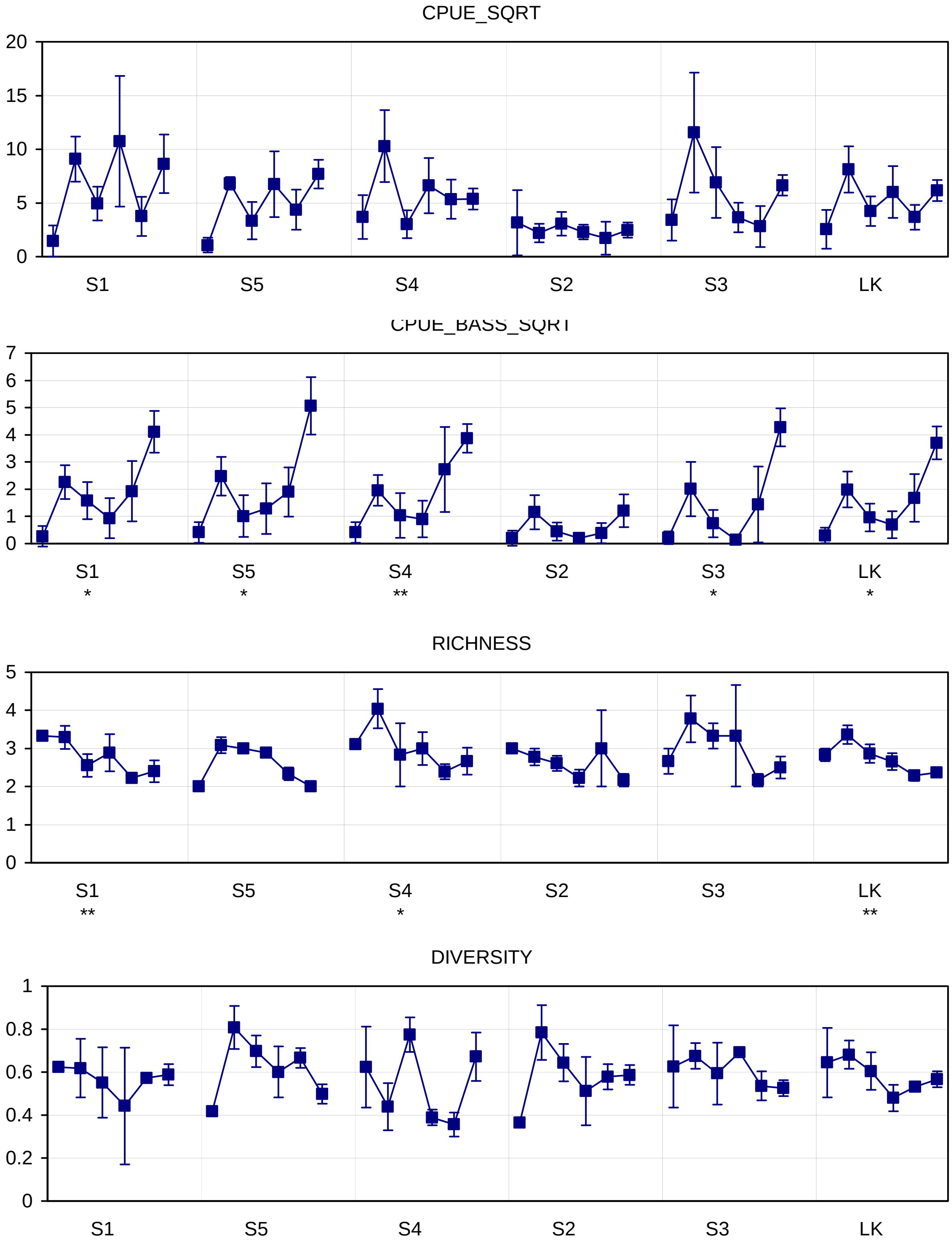
Symbols = Lake Stratum
*,** Differences among years significant at p<.10 & p<.05 (One-Way ANOVA)

Figure 21 Spatial & Temporal Variations in Tributary Macroinvertebrates



Symbols = Creek_Site
*,** Differences among years significant at p<.10 & p<.05 (One-Way ANOVA)

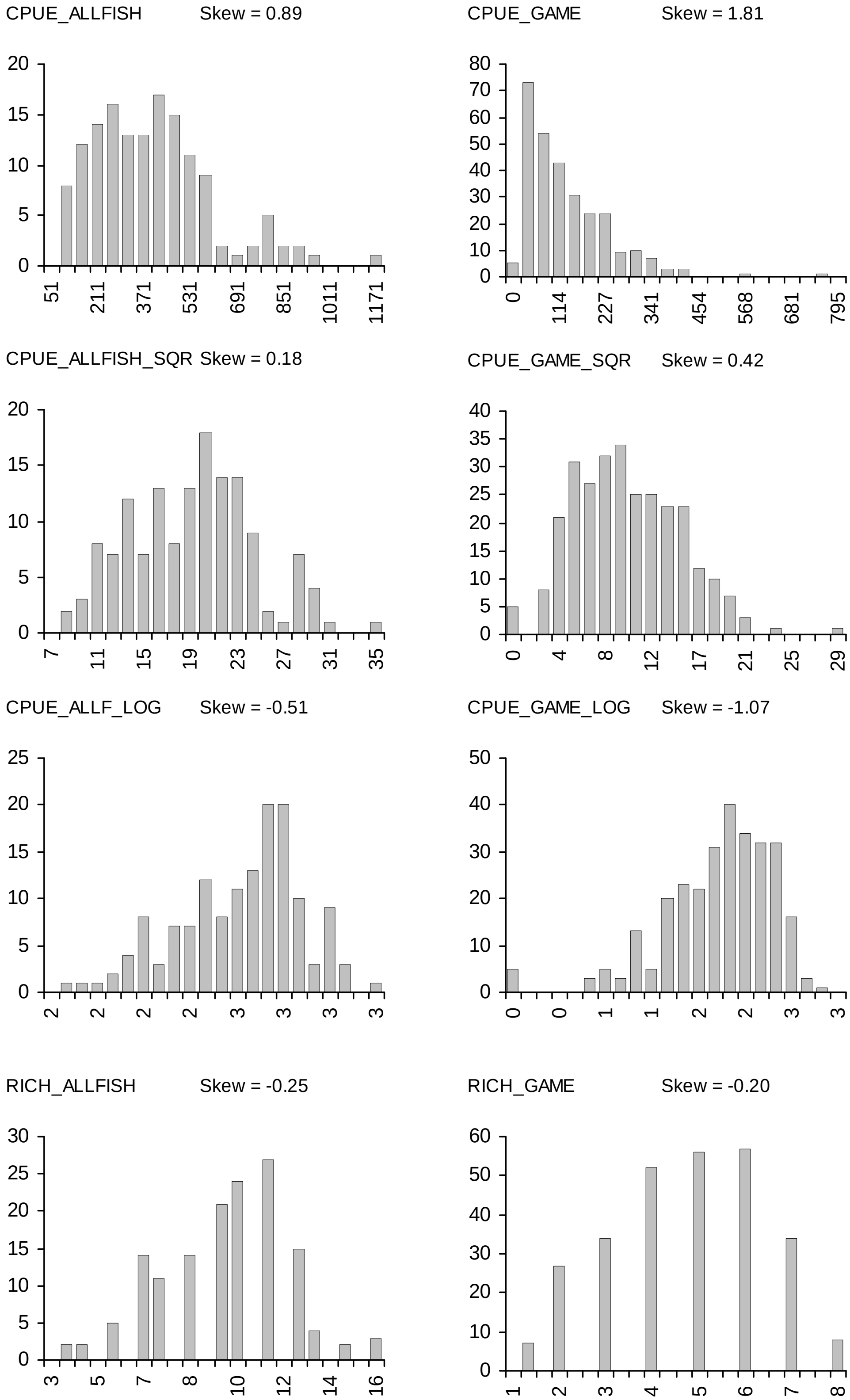
Figure 22 Spatial & Temporal Variations in Littoral Juvenile Fish



July-September Samples; Means and standard errors across replicates

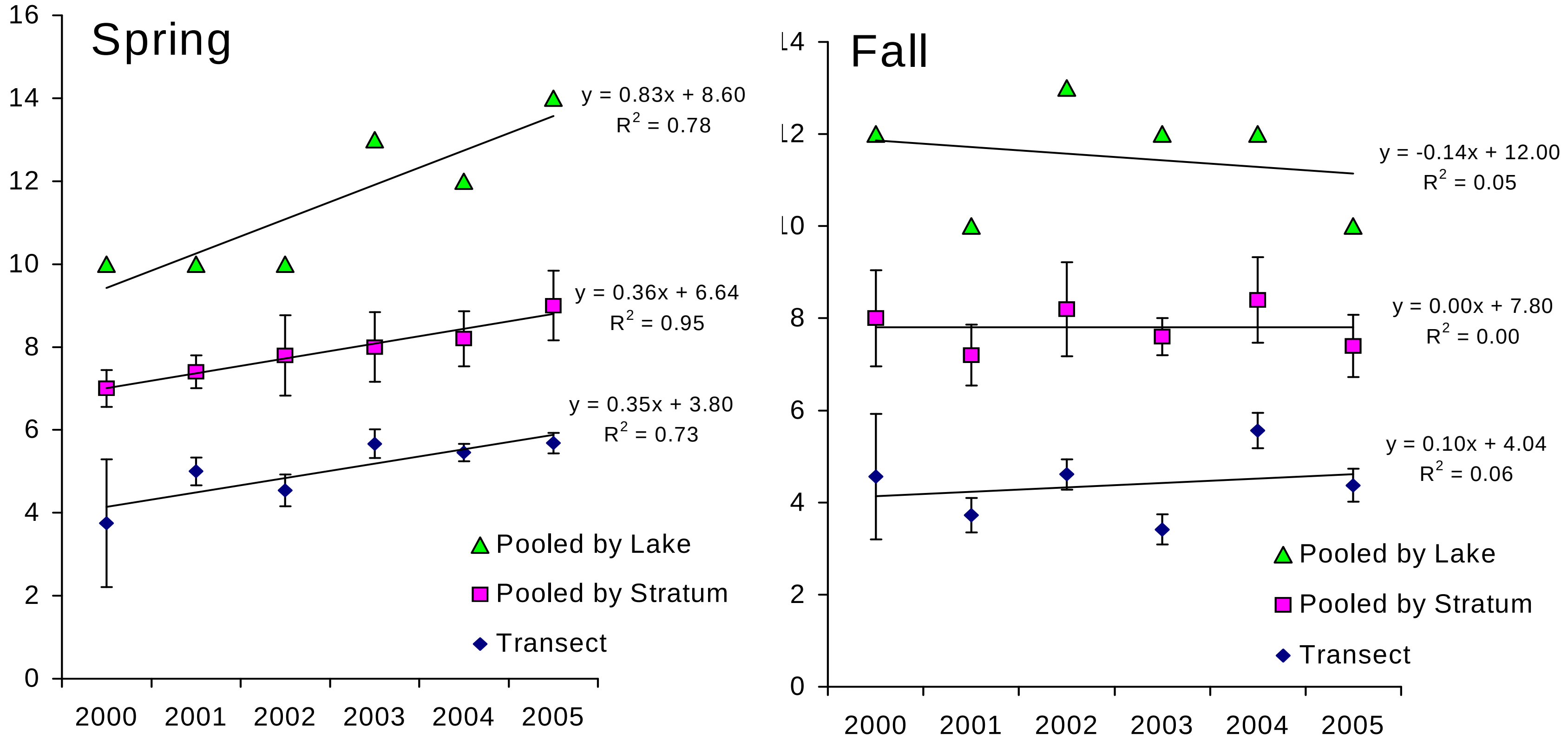
*,** Linear trend significant at p<.10 or p<.05, 1-tailed test

Figure 23 Frequency Distributions of Adult Fish Metrics



Results for each Transect, Season, & Year (2000-2005)

Figure 24 Trends in Gamefish Richness vs. Season & Sample Pooling Method



Pooled by Lake All samples combined in each year and season (1 pooled sample per season/yr)

Pooled by Stratum Samples pooled across transects within each stratum (5 pooled samples per season/yr)

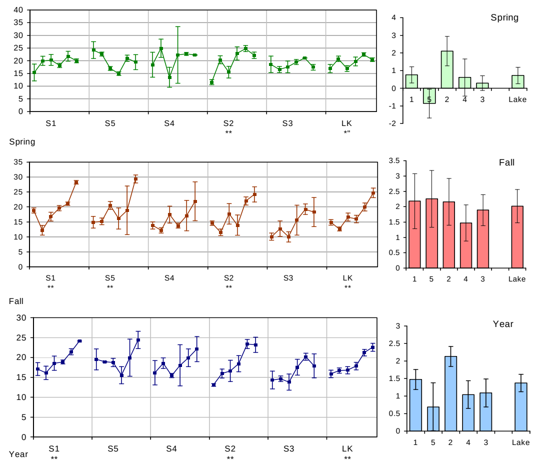
Transects Individual transect samples (24 pooles samples per season/yr)

Lines are linear regressions. All spring regressions are significant ($p < .05$). None of the fall regression are significant.

Figure 25 Trends in Adult Fish CPUE

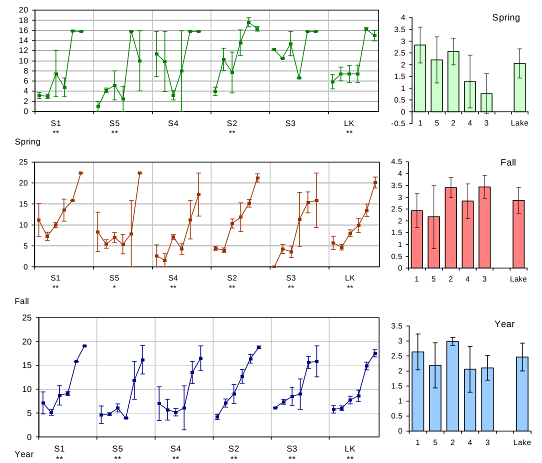
Total Fish CPUE - Square Roots

Yearly time series, significant trends (* p<.10, **p<.05, 1-tailed) Trend Slopes



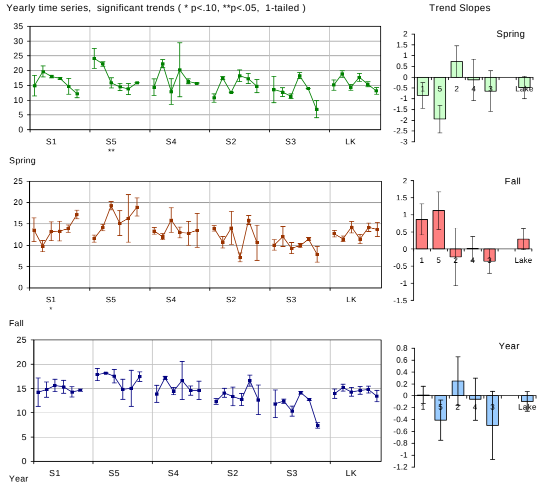
Clupeid CPUE - Square Roots

Yearly time series, significant trends (* p<.10, **p<.05, 1-tailed) Trend Slopes



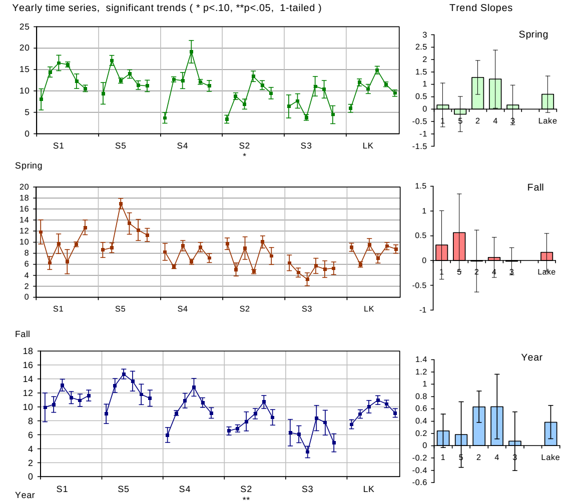
Non-Clupeid Fish CPUE - Square Roots

Yearly time series, significant trends (* p<.10, **p<.05, 1-tailed) Trend Slopes



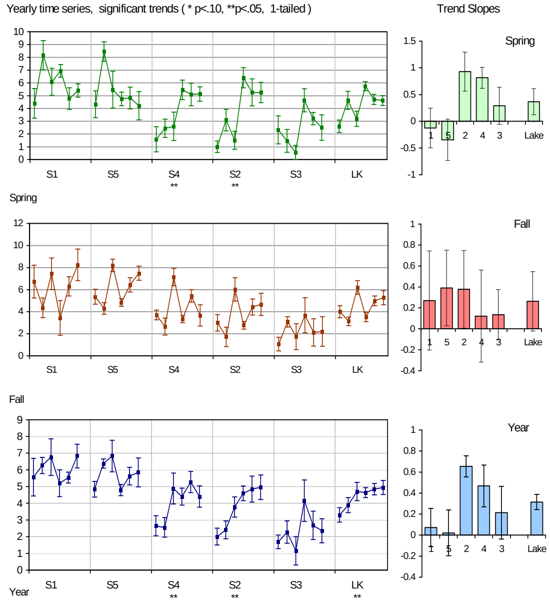
Gamefish CPUE - Square Roots

Yearly time series, significant trends (* p<.10, **p<.05, 1-tailed) Trend Slopes



Bass CPUE - Square Roots

Yearly time series, significant trends (* p<.10, **p<.05, 1-tailed) Trend Slopes

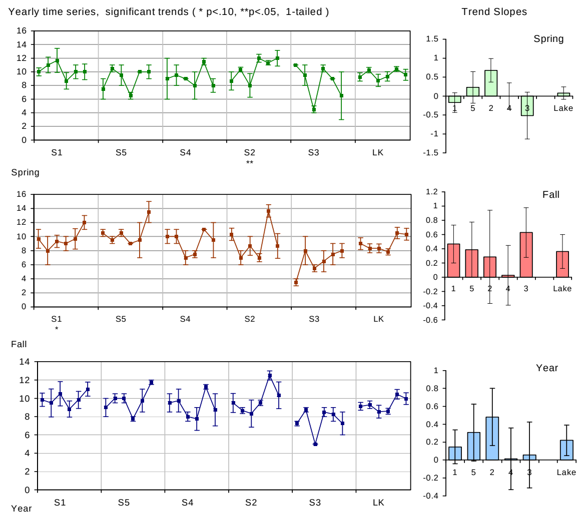


Strata Ordered North to South

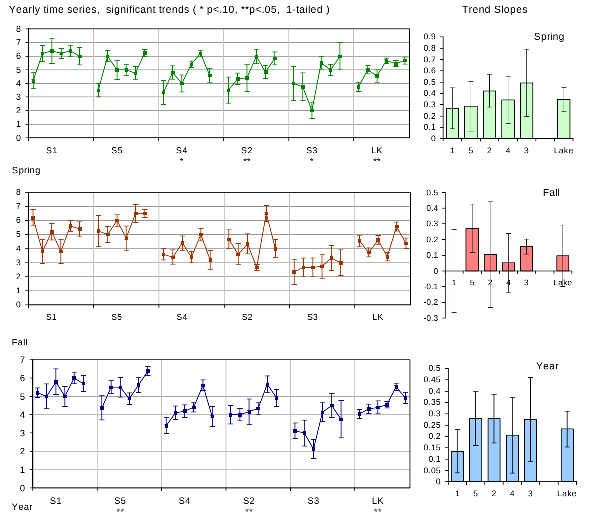
Left	Means by Stratum & Year +/- 1 Standard Error
Right	Trend Slopes +/- 1 Standard Error (Linear Regression)
Top	Spring
Middle	Fall
Bottom	Year

Figure 26 Trends in Adult Fish Richness & Diversity Indices

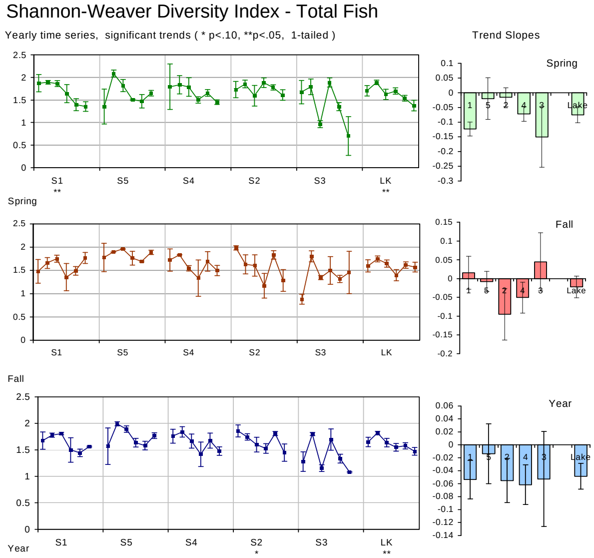
Total Fish Richness (Number of Species per Transect)



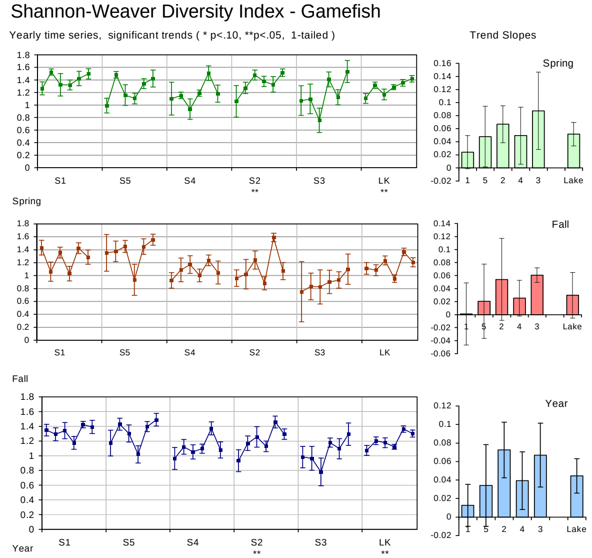
Gamefish Richness (Number of Species per Transect)



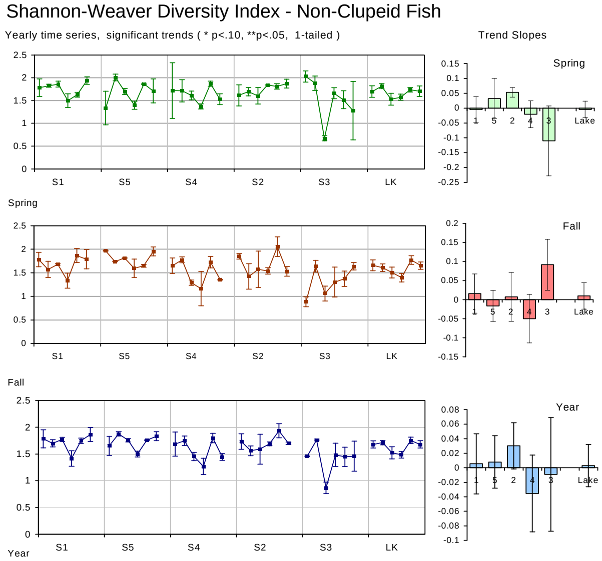
Shannon-Weaver Diversity Index - Total Fish



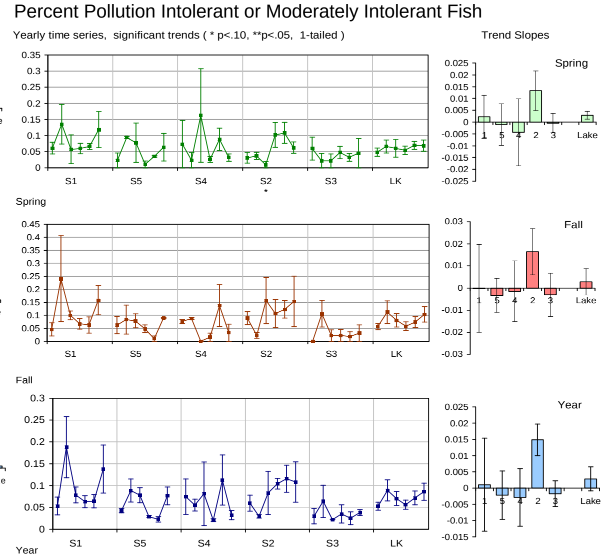
Shannon-Weaver Diversity Index - Gamefish



Shannon-Weaver Diversity Index - Non-Clupeid Fish



Percent Pollution Intolerant or Moderately Intolerant Fish



Appendix A

AMP Hypotheses

EcoLogic et al., 2006

Table 1-4. Summary of hypotheses underlying the AMP.

Monitoring Parameter	Hypothesis	Type of Hypothesis: Compliance with SPDES[1] permit	Type of Hypothesis: Compliance with AWQS[2] or guidance value	Type of Hypothesis: Significant Trend or Shift In Monitoring Data	Data Used for Assessment (*for assessment tools, see Tables 3-11 to 3-22)*
Ammonia-N	Improvements at Metro enable the County to meet Stage III effluent limits (or as modified by TMDL) for ammonia N	*			Outfall 001 effluent concentrations, calculated for summer and winter (seasonal limits apply)
	Reduced ammonia load results in compliance with ambient water quality standards and federal criteria for ammonia in Onondaga Lake		*	*	South Deep station Biweekly monitoring, discrete samples collected at 3-m intervals, plus temperature and pH
Nitrite-N	Achievement of Stage III effluent limits for ammonia results in compliance with the NYS ambient water quality standard for nitrite (warm water fish community)		*	*	UML, LWL[3] composite samples, biweekly at South Deep

[1] SPDES = State Pollution Discharge Elimination System
[2] AWQS = Ambient Water Quality Standards
[3] UML = Upper Mixed Layer (generally 0 to 6 meters); LWL = Lower Water Layer (generally 9 to 18 meters)

Table 1-4. Summary of hypotheses underlying the AMP (continued).

Monitoring Parameter	Hypothesis	Type of Hypothesis			Data Used for Assessment (*for assessment tools, see Tables 3-11 to 3-22)*
		Compliance with SPDES[1] permit	Compliance with AWQS[2] or guidance value	Significant Trend or Shift In Monitoring Data	
Phosphorus	Improvements at Metro will enable the County to meet final effluent limits (as modified by TMDL)	*			Outfall 001 effluent concentrations
	Reduced phosphorus load from Metro reduces concentration of phosphorus in Onondaga Lake		*	*	South Deep station Biweekly monitoring TP, SRP and TDP, discrete samples collected at 3-m intervals
	Reduced phosphorus load from all sources brings the lake into compliance with guidance value (or site-specific guidance value)		*	*	TP at South Deep, 1-m depth (biweekly measurements, June –Sept)

Table 1-4. Summary of hypotheses underlying the AMP (continued).

Monitoring Parameter	Hypothesis	Type of Hypothesis: Compliance with SPDES[1] permit	Type of Hypothesis: Compliance with AWQS[2] or guidance value	Type of Hypothesis: Significant Trend or Shift In Monitoring Data	Data Used for Assessment (*for assessment tools, see Tables 3-11 to 3-22)*
Dissolved Oxygen	Improvements at Metro enable the County to meet Stage III effluent limits (or as modified by TMDL) for BOD	*			Outfall 001 effluent concentrations
	Improvements at Metro and related load reductions bring the lake into compliance with AWQS for DO during fall mixing.		*	*	Weekly or biweekly measurements through water column and high-frequency measurements at buoy at South Deep station
	Improvements at Metro reduce the volume-days of anoxia.			*	Weekly or biweekly measurements through water column and high-frequency measurements at buoy at South Deep station
	Improvements at Metro reduce the areal hypolimnetic oxygen depletion rate.			*	Weekly or biweekly measurements through water column and high-frequency measurements at buoy at South Deep station

Table 1-4. Summary of hypotheses underlying the AMP (continued).

Monitoring Parameter	**Hypothesis**	**Type of Hypothesis**			**Data Used for Assessment** (*for assessment tools, see Tables 3-11 to 3-22)*
		Compliance with SPDES[1] permit	**Compliance with AWQS[2] or guidance value**	**Significant Trend or Shift In Monitoring Data**	
Indicator bacteria	CSO remedial measures reduce the loading of fecal coliform bacteria entering the lake through Onondaga Creek, Ley Creek, and Harbor Brook during high flow conditions.	*		*	Storm event data: baseline and post-improvement rating curves for fecal coliform bacteria (load as a function of total precipitation, and total storm flow)
	Implementation of Stage 1 and 2 improvements to the wastewater collection and treatment system (including CSO projects) will reduce concentration of indicator organisms in Onondaga Lake	*	*	*	Indicator bacteria abundance at nearshore stations during summer and following storms. Annual average concentration at South Deep, 0m depth
Chlorophyll-*a*	Metro improvements and related nutrient load reductions result in lower chlorophyll concentrations in the lake.			*	Weekly or biweekly measurements at South Deep, photic zone and UML

Table 1-4. Summary of hypotheses underlying the AMP (continued).

Monitoring Parameter	**Hypothesis**	**Type of Hypothesis**			**Data Used for Assessment** (*for assessment tools, see Tables 3-11 to 3-22)*
		Compliance with SPDES[1] permit	**Compliance with AWQS[2] or guidance value**	**Significant Trend or Shift In Monitoring Data**	
Zooplankton community	Metro improvements and related nutrient load reductions reduce the biomass of zooplankton in Onondaga Lake			*	Biweekly composite samples of UML and tow (0-15 m), zooplankton abundance, size, biomass, ID (Cornell Biological Field Station)
	Metro improvements and related nutrient load reductions (and DO improvements) increase the abundance of zooplankton deeper in the water column			*	Biweekly composite samples of UML and tow (0-12 m), zooplankton abundance, size, biomass, ID (Cornell Biological Field Station)
Macroalgae	Metro improvements and related nutrient load reductions result in reduced areal coverage of macroalgae in nearshore areas of Onondaga Lake			*	Weekly surveys during recreational period (June –Sept) at eight nearshore stations.

Table 1-4. Summary of hypotheses underlying the AMP (continued).

Monitoring Parameter	Hypothesis	Type of Hypothesis: Compliance with SPDES[1] permit	Compliance with AWQS[2] or guidance value	Significant Trend or Shift In Monitoring Data	Data Used for Assessment (*for assessment tools, see Tables 3-11 to 3-22)*
Secchi disk transparency	Metro improvements and related nutrient load reductions result in improved water clarity (as measured by Secchi disk transparency) in Onondaga Lake			*	Weekly or biweekly measurements at South Deep and nearshore stations
Phytoplankton community	Metro improvements and related nutrient load reductions result in lower biomass of phytoplankton in Onondaga Lake			*	Biweekly samples of UML phytoplankton community, numbers, size and identifications (PhycoTech)
	Metro improvements and related nutrient load reductions result in reduced importance of cyanobacteria to the Lake's phytoplankton community (measured by percent of total biomass)			*	Biweekly composite samples of UML phytoplankton abundance, biomass, and ID (PhycoTech)

Table 1-4. Summary of hypotheses underlying the AMP (continued).

Monitoring Parameter	Hypothesis	Type of Hypothesis: Compliance with SPDES[1] permit	Compliance with AWQS[2] or guidance value	Significant Trend or Shift In Monitoring Data	Data Used for Assessment (*for assessment tools, see Tables 3-11 to 3-22)*
Macrophytes	Metro improvements and related nutrient load reductions result in increased areal coverage of macrophytes in littoral zone of Onondaga Lake			*	Percent cover, biomass, and maximum depth of growth. Surveys: 2000, 2005, 2010 plus annual aerial photos (% cover)
	Metro improvements and related load reductions result in increased number of macrophyte species in Onondaga Lake			*	Macrophyte species richness Detailed surveys: 2000, 2005, 2010

Table 1-4. Summary of hypotheses underlying the AMP (continued).

Monitoring Parameter	Hypothesis	Type of Hypothesis: Compliance with SPDES[1] permit	Compliance with AWQS[2] or guidance value	Significant Trend or Shift In Monitoring Data	Data Used for Assessment (*for assessment tools, see Tables 3-11 to 3-22)*
Littoral macroinvertebrates Note: effects may be in strata 2,3 and 4 (see Appendix 8 Figure A8-1 for strata locations)	Implementation of load reductions at Metro and CSO remediation will increase species richness of littoral benthic macroinvertebrates			*	Littoral macroinvertebrate species richness. Detailed surveys: 2000, 2005, 2010
	Implementation of load reductions at Metro and CSO remediation will increase the relative abundance of benthic macroinvertebrates that are not chironomids or oligochaetes			*	Littoral macroinvertebrate dominance, percent oligochaetes. Detailed surveys: 2000, 2005, 2010
	Implementation of load reductions at Metro and CSO remediation will improve the NYSDEC Biological Assessment Profile as compared to baseline conditions.			*	NYSDEC calculated index Detailed surveys: 2000, 2005, 2010
	Implementation of load reductions at Metro and CSO remediation will improve the littoral macroinvertebrate HBI as compared to baseline conditions (indicating increased importance of pollution-sensitive organisms in the macroinvertebrate community)			*	Hilsenhoff Biotic Index (HBI) Detailed surveys: 2000, 2005, 2010

Table 1-4. Summary of hypotheses underlying the AMP (continued).

Monitoring Parameter	Hypothesis	Type of Hypothesis: Compliance with SPDES[1] permit	Compliance with AWQS[2] or guidance value	Significant Trend or Shift In Monitoring Data	Data Used for Assessment (*for assessment tools, see Tables 3-11 to 3-22)*
Fish community	Implementation of load reductions at Metro and CSO remediation will increase the number of fish species present in Onondaga Lake			*	Annual monitoring program Species richness, electrofishing, gill nets,
	Implementation of load reductions at Metro and CSO remediation will increase the number of fish species that are sensitive to pollution present in Onondaga Lake			*	Annual monitoring program: Electrofishing Pollution tolerance index (Whittier and Hughes 1998)
	Implementation of load reductions at Metro and CSO remediation will increase the number of fish species reproducing in Onondaga Lake			*	Annual monitoring program Nesting survey Larval tows Larval light traps Littoral seines
	Implementation of load reductions at Metro and CSO remediation will improve the lake's Index of Biotic Integrity (IBI). Effects may be in strata 2,3, and 4 (see Appendix 8 Figure A8-1 for strata locations)			*	Annual monitoring program Electrofishing

Table 1-4. Summary of hypotheses underlying the AMP (continued).

Monitoring Parameter	**Hypothesis**	**Type of Hypothesis**			**Data Used for Assessment** (*for assessment tools, see Tables 3-11 to 3-22)*
		Compliance with SPDES[1] permit	**Compliance with AWQS[2] or guidance value**	**Significant Trend or Shift In Monitoring Data**	
Fish community (continued)	Implementation of load reductions at Metro and CSO remediation will increase the habitat available for the coolwater fish community			*	Fish space metrics: dissolved oxygen and temperature profiles at South Deep station

Note: The potential impact of zebra mussels on the lake water quality will be assessed using the Onondaga Lake Water Quality Model under development by QEA, LLC for Onondaga County. While zebra mussels are not part of the ACJ-required monitoring program for the lake, their proliferation has the potential to affect water clarity and habitat for primary producers, as well as alter the cycling of energy and nutrients.