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Volunteer Lake Monitoring: Testing the Reliability of Data Collected by the Florida LAKEWATCH Program

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ABSTRACT

Canfield, D. E., Jr., C. D. Brown, R. W. Bachmann and M. V. Hoyer. 2002. Volunteer lake monitoring: Testing the reliability of data collected by the Florida LAKEWATCH program. Lake and Reserv. Manage. 18(1):1-9.

Because the use of volunteer samplers is a very cost-effective way to collect large amounts of information on lakes over space and time, we studied the reliability of the protocols used by the Florida LAKEWATCH program. We found that chlorophyll extractions with hot ethanol gave values that were no different from those obtained with the standard method of grinding with acetone. In a comparative study of 125 lakes we found the data collected by volunteers were comparable to those collected by professionals. Mean Secchi disk depth, TP, TN, and chlorophyll values obtained by the citizens were strongly correlated ($r > 0.99$) to the mean values obtained by the professionals. To determine if freezing was a valid means of preserving water samples prior to analysis, we compared estimates of chlorophyll, TP, TN, pH, total alkalinity, and specific conductance obtained from fresh samples with estimates obtained from samples frozen up to 150 days. For most lakes there was little difference in chemical measurements made in samples preserved by freezing for different lengths of time, and various statistical tests indicated that freezing was a valid means of preserving lake water samples prior to analysis. Water quality data produced by volunteer samplers following the LAKEWATCH protocols were just as good as those from samples collected by professional biologists and handled using standard methods of sample preservation. The fact that volunteers can collect credible data means that lake management agencies could amplify their limited budgets by using volunteer monitoring, to sample more lakes and to sample them more frequently.

Key Words: volunteer lake monitoring, sample preservation, frozen water storage.

In the 1970s and 1980s various U.S. management agencies and private groups established innovative programs using volunteers to sample large numbers of lakes on a relatively frequent basis. The University of Florida began the Florida LAKEWATCH program in 1986 with the goal of collecting credible total phosphorus (TP), total nitrogen (TN), chlorophyll and Secchi disk data from a large number of lakes on a monthly basis, and by 1991, the Florida LAKEWATCH was so successful that the Florida Legislature established LAKEWATCH in statute (Florida Statute 240.5329). The Florida Department of Environmental Protection (FLDEP) estimated in 2000 (Jim Hulbert, FLDEP, pers. comm.) that Florida LAKEWATCH over the past 5 years, as a single organization provided the State of Florida more information on lakes (18% of total) than any individual professional agency other than FLDEP (28% of total).

The use of volunteer samplers is a very cost-effective way to collect large amounts of information over space and time and has the added benefit of getting citizens involved in the monitoring of their lakes. However, questions are sometimes raised about the reliability of the data, since professionals do not take the samples and some of the sample preservation techniques do not follow standard procedures. In this paper, we discuss the sampling protocols used by Florida LAKEWATCH and a series of tests that we made to check the reliability of the data.

Our first objective was to determine if there were any differences between the water quality data collected by the Florida LAKEWATCH program and data collected by professional biologists and handled using standard preservation techniques. The second objective was to determine if freezing was an effective method of preserving lake water samples prior to analysis. LAKEWATCH selected freezing as the method of sample preservation for TP and TN be-

cause it provided volunteers with the greatest flexibility in delivering samples to the laboratory for analysis. Freezing lake water samples is simple and does not require the use of hazardous chemicals. Freezing has also been found to be an effective method for the preservation of sea water samples for NO_3^- analysis, as well as lake water samples for TN analyses for up to 90 days of storage (Chapman and Mostert, 1990, Bachmann and Canfield, 1996). We also examined the use of frozen water samples to measure additional variables such as pH, total alkalinity, and specific conductance because the use of freezing as a method of preservation may allow management agencies to develop comprehensive, cost-effective water quality monitoring programs for many lakes.

Methods

Standard LAKEWATCH Procedures

Volunteers in the Florida LAKEWATCH are instructed by professional staff from the University of Florida's Department of Fisheries and Aquatic Sciences on the proper procedures for collecting surface (0.5 m) water quality samples and determining water clarity as measured by a Secchi disk. Volunteers are instructed at their homes during a 4-hr training session, which includes the selection of sampling stations on their lake. After receiving instructions, volunteers sample their lake once each month.

On each sampling date, volunteers use their own boats on their lakes to collect surface water samples from 2 to 6 (depending upon lake size) mid-lake locations. Water samples for nutrients (TP and TN) are collected in 250-mL, acid-cleaned, triple-rinsed Nalgene bottles that are provided by the Department of Fisheries and Aquatic Sciences. Volunteers also measure water clarity at each sampling location with a standard white Secchi disk, and they collect additional surface water at each location in 4-L, tap-water rinsed, plastic milk jugs. Sample bottles are placed in covered coolers in the boat until they are returned to the residence of the volunteer where the 250-mL Nalgene bottles are placed in a freezer. To estimate the concentration of plankton algae at each sampling station, the volunteers obtain a measured volume of lake water from the 4-L milk jugs and filter the water through a Gelman Type A-E glass fiber filter. Filters are folded, blotted dry, wrapped in a larger paper filter and then stored over silica gel desiccant and frozen. Water samples and the glass fiber filters are stored frozen at

the homes of the volunteers for up to three months. All samples are then delivered by the citizens along with the Secchi disk information to the Department of Fisheries and Aquatic Sciences' water quality laboratory or regional collection sites where staff retrieve the frozen samples and Secchi disk information.

TP concentrations ($\mu g \cdot L^{-1}$) are determined using the procedures of Murphy and Riley (1962) with a persulfate digestion (Menzel and Corwin 1965). TN concentrations ($\mu g \cdot L^{-1}$) are determined by oxidizing water samples with persulfate and determining nitrate-nitrogen with second derivative spectroscopy (D'Elia et al. 1977, Simal et al. 1985, Wollin 1987, Crumpton et al. 1992, Bachmann and Canfield 1996). Prior to 1993 chlorophyll concentrations ($\mu g \cdot L^{-1}$) were determined spectrophotometrically following pigment extraction with a tissue grinder using 90% acetone as the extractant. Chlorophyll concentrations were calculated using the trichromatic equation for chlorophyll a (Method 10200 H; APHA 1992). Since we did not correct for pheophytins, we consider the measurements to be total chlorophyll. In 1993 we started using hot ethanol to extract chlorophyll pigments from the filters (Sartory and Grobbelarr 1984). We calculated chlorophyll concentrations with the same equations we had used for the acetone extractions. To ensure that there was no difference in the results obtained from the two methods, we collected water samples in duplicate from several Florida lakes covering a range in chlorophyll concentrations for a total of 108 pairs of samples. All samples were filtered to concentrate the algal chlorophylls using our standard procedure. Chlorophyll was extracted from one filter of each pair with acetone and grinding while the other filter was extracted with hot ethanol. Chlorophyll values were calculated for both procedures and compared.

Comparison of Samples Collected by Volunteers and Professionals

A comparison of data on chlorophyll, TP, TN, and Secchi depth collected by volunteers with data collected by professionals was made on 125 LAKEWATCH lakes in 1991. Each lake was sampled simultaneously by the professional staff from the Department of Fisheries and Aquatic Sciences and the lake volunteers once during the winter (January, February, and March) and once during the summer (June, July, August, and September). On each sampling date the volunteers sampled at their usual stations, and the professionals accompanied them and took their own samples and Secchi disk readings. The professionals covered their sample bottles with ice and transported them to the laboratory at Gainesville,

Florida where the water samples were preserved and analyzed within recommended storage times (APHA 1992). Water and chlorophyll samples collected by the volunteers were stored frozen at their homes for up to three months following the usual LAKEWATCH protocols.

Freezing for Sample Preservation

To determine if freezing was a valid means of preserving water samples prior to analysis, we compared results of chlorophyll, TP, TN, pH, total alkalinity, and specific conductance obtained from fresh samples with results obtained for frozen lake water stored over a 150-day period. Samples were collected from 12 Florida lakes with surface areas ranging from 37 ha to 3008 ha and mean depths ranging from 1.5 m to 8.0 m (Table 1). The 12 study lakes lie in four distinct lake regions: Upper Santa Fe Flatwoods, Trail Ridge, Central Valley, and Ocala Scrub (Griffith et al. 1997). Lakes were chosen so that 4 were eutrophic, 4 were mesotrophic and 4 were oligotrophic. Waters were classified using average surface chlorophyll concentrations from the Florida LAKEWATCH database (LAKEWATCH 1998) and the classification system of Forsberg and Ryding (1980).

At each lake a boat was used to sample water away from shore at one location. Water was dipped from the surface of the lake with a bucket and placed in a large plastic container. Enough water was placed in the container to fill all the required sample bottles without adding more water. With continual mixing thirty-five 1-L Nalgene bottles were filled for chlorophyll analysis and 35 200-ml Nalgene bottles were filled for analyses of TP, TN, pH, total alkalinity, and specific conductance.

On the day of sampling a measured volume of lake water from each of the 35 1-L bottles was filtered through a Gelman Type A-E glass fiber filter to concentrate algal cells for laboratory chlorophyll analysis. Five of the filters from each lake were randomly selected for immediate chlorophyll analysis. The remaining 30 filters from each lake (total number = 360) were stored over desiccant and frozen for future analyses. Five of the 200-ml water bottles from each lake were randomly selected for immediate analyses of TP, TN, pH, total alkalinity, and specific conductance. The remaining 30 bottles from each lake were stored frozen for future analyses.

On days 15, 30, 60, 90, 120, and 150 from date of collection, five chlorophyll filters and five water quality bottles from each lake were randomly selected for analyses. After thawing at room temperature, the bottles were thoroughly shaken and chemical analyses were conducted. Chlorophyll concentrations were determined spectrophotometrically following pigment extraction with 90% ethanol (Sartory and Grobbelaar 1984). TP and TN concentrations were determined using Florida LAKEWATCH's protocols described earlier.

An Accumet model 10 pH meter calibrated with buffers of pH 4.0, 7.0, and 10.0 was used to measure pH. Total alkalinity ($mg \cdot L^{-1}$ as $CaCO_3$) was determined by titration with 0.02 N sulfuric acid (APHA 1992). All samples were titrated to a pH of 4.5 to standardize titrations and to avoid interference from silicates, phosphates, and other materials. Reported alkalinities may be slightly greater than true alkalinities in

Table 1.–Locations, surface areas, and mean depths of study lakes. Data obtained from Gazetteer of Florida lakes (Shafer et al. 1986) and the Florida LAKEWATCH database (LAKEWATCH 1998). Waters were classified using average surface chlorophyll concentrations and the classification system of Forsberg and Ryding (1980).

Lake	County	Latitude	Longitude	Surface Area (ha)	Mean Depth (m)	Trophic State
Bivens Arm	Alachua	29°37'38"	82°20'45"	76	2.0	eutrophic
Lochloosa	Alachua	29°31'38"	82°08'26"	2286	2.0	eutrophic
Newnans	Alachua	29°38'42"	82°13'08"	3008	1.5	eutrophic
Rowell	Bradford	29°55'45"	82°09'32"	147	1.3	eutrophic
Alto	Alachua	29°46'46"	82°08'52"	232	4.0	mesotrophic
Hampton	Bradford	29°51'34"	82°10'08"	442	3.0	mesotrophic
Sampson	Bradford	29°55'40"	82°11'18"	755	2.0	mesotrophic
Santa Fe	Alachua	29°44'33"	82°04'37"	2011	6.0	mesotrophic
Beakman	Lake	29°07'30"	81°37'35"	37	2.5	oligotrophic
Kingsley	Clay	29°57'55"	82°00'13"	583	8.0	oligotrophic
Mill Dam	Marion	29°10'54"	81°50'27"	125	4.0	oligotrophic
Wildcat	Lake	29°09'43"	81°37'39"	142	5.0	oligotrophic

some lakes because the equivalence point occurs at pH > 4.5 in low alkalinity samples and some of the study lakes have low total alkalinities. Specific conductance (μS·cm⁻¹ at 25 C) was measured using standard methods (Method 2510: APHA 1992) and a Yellow Springs Instrument Model 35 conductance meter.

Statistical Procedures

Statistical computations were performed using various procedures in SAS and JMP statistical packages (SAS Institute Inc. 1985, SAS Institute Inc. 1994). Statements of statistical significance are at p ≤ 0.05 unless otherwise stated. For the 125 lakes as a group, the mean Secchi disk, TP, TN, and chlorophyll values obtained by the volunteers were correlated to the mean values obtained by the professionals for both untransformed and log-transformed data. Analyses of variance and covariance using a nested structure (The Nested Procedure; SAS 1985) were used on these data to determine what percent of the variance was due to lake-to-lake differences, seasonal differences, station differences, and the type of sampler (volunteers versus professionals).

Significance of differences for estimates of TP, TN, chlorophyll, pH, total alkalinity, and specific conductance obtained from fresh lake water samples (Day 1) compared with estimates from frozen lake water samples was determined using Dunnett's test, analysis of variance (ANOVA) and regression. All measurements were transformed to their logarithms (base 10) before statistical analyses to accommodate heterogeneity of variances. Our sample size (n=12 lakes) was small, and log-transformation did not guarantee that the data would be normalized. To address this concern, a non-parametric Wilcoxon/Kruskal-Wallis Rank Sums test was also used to determine significance of differences. ANOVA was used to determine the factors that contribute most to observed variability of measurements for the twelve study lakes.

Results

Chlorophyll Extraction with Acetone versus Ethanol

The chlorophyll values in our comparative study ranged from a low of 0.8 to a high of 203 μg·L⁻¹ or about 2 orders of magnitude. There was a high correlation (r = 0.99) between the paired measurements found with the two different methods of extraction (Fig. 1). To determine if one method gave higher or

lower measurements than the other, we determined the differences between each pair by subtracting the chlorophyll value as measured with the ethanol extraction from the value measured with acetone extraction. The average of these differences was 0.82 μg·L⁻¹ with a standard error of 0.51 μg·L⁻¹. A paired t-test showed that this difference was not statistically different from zero at the 5% level of probability. The differences tended to increase somewhat with increasing absolute chlorophyll concentrations, so a similar test was made of the differences when expressed as a per cent. The average per cent difference was -0.2 % with a standard error of 0.4 %. A paired t-test showed that this difference was not statistically different from zero at the 5% level of probability.

These results demonstrate that chlorophyll measurements made with the ethanol method are equivalent to those made with the standard method of grinding with acetone. In our experience the ethanol method requires less technician time in the laboratory. Also, acetone can be harmful to the health of humans, so that there is some hazard to laboratory workers and problems with its disposal. Ethanol does not present this problem. Lastly, the glass grinding tubes sometimes break while the technician holds them. No grinding is required with the ethanol method.

Professional versus Volunteer Sampling

The data collected by the volunteers were comparable to those collected by the professionals. For the 125 Florida lakes sampled in this study, mean Secchi disk depth, TP, TN, and chlorophyll values obtained
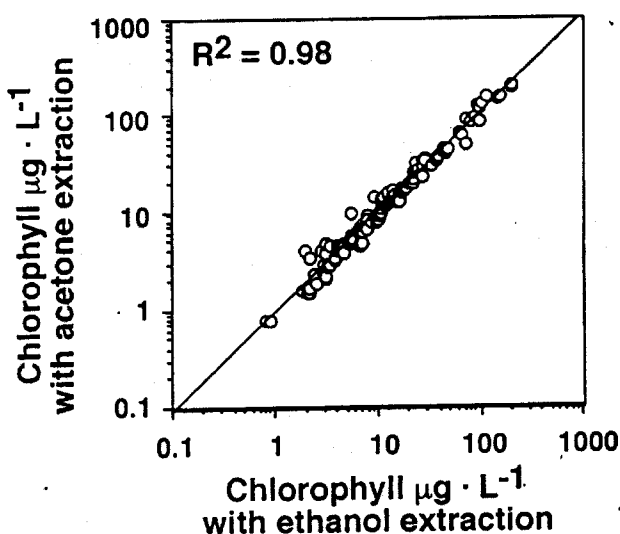

Figure 1.–Comparison of chlorophyll measurements on 159 paired samples made using acetone extraction and ethanol extraction. The line is the best-fit regression line.

by the citizens were strongly correlated to the mean values obtained by the professionals for both non-transformed (r ≥ 0.99) and log-transformed data (r ≥ 0.98) (Fig. 2). Although significant differences were found for some individual lakes between the mean values calculated from the volunteer data versus the professional data (Paired-t test; P < 0.05), there was no pattern of the volunteers reporting either higher or lower values than the professionals. Analyses of variance and covariance using a nested structure (SAS 1985) also demonstrated the type of sampler (volunteers versus professionals) also accounted for < 1% of the variance in the 1991 survey while lake-to-lake differences accounted for 82%, 80%, 69% and 62% of the variance, seasonal differences (winter versus summer) accounted for 17%, 18%, 29% and 20% of the variance in TP, TN, chlorophyll and Secchi values, respectfully and station differences with the exception of Secchi disk readings (16%) accounted for < 1% of the variance. These findings demonstrate that trained volunteers can provide data that are equivalent to those generated by professionals. This is especially true when the objective of the study is to assess the water quality of large numbers of lakes.

Freezing for Sample Preservation

For the 12 lakes used to examine freezing as a means of preservation, the mean chlorophyll concentrations ranged from 1.1 µg·L⁻¹ to 120 µg·L⁻¹. Mean total phosphorus concentrations ranged from 6 µg·L⁻¹ to 875 µg·L⁻¹, and mean total nitrogen concentrations ranged from 450 µg·L⁻¹ to 1870 µg·L⁻¹. Mean pH ranged from 4.7 to 9.2, and mean total alkalinity ranged from 0 mg·L⁻¹ as CaCO₃ to 68 mg·L⁻¹ as CaCO₃. Mean specific conductance ranged from 57 µS·cm⁻¹ at 25C to 255 µS·cm⁻¹ at 25C. These limnological values represent the same wide range of conditions that can be found in the population of Florida lakes (Canfield and Hoyer 1988; Griffith et al. 1997).

For most lakes there was little difference in chemical measurements made in samples preserved by freezing (Figs. 3 and 4) for different lengths of time, and various statistical tests indicated that freezing was a valid means of preserving lake water samples prior to analysis. ANOVA and Wilcoxon/Kruskal-Wallis Rank Sums tests indicated there were no statistically significant differences between dates for mean measured chemistry values for the study lakes (Table 2). Dunnett's test demonstrated no significance of differences between measured mean chemistry values obtained from fresh water samples and chemistry values obtained from stored frozen lake water samples analyzed 15, 30, 60, 90, 120, and 150 days from date of collection.

Further, average chemical measurements made on the day of collection were highly correlated to frozen lake water samples thawed and analyzed periodically over the next 150 days (Table 3).

Analyses of the pH of frozen lake water samples exhibited the greatest amount of variation in measured chemistry. During the 150 days of frozen storage, lakes with pH measurements > 6.5 tended to be less variable than lakes with pH > 6.5 (Figs. 3 and 4). Over 65% of waterbodies in the Florida LAKEWATCH database analyzed prior to January 1998 have pH values greater than 6.5 and are in the range where the variability is greatest. This suggests pH measurements obtained from frozen water samples should only be used for broad classifications of lakes; and that for precise estimates, measurements should be made in the field on fresh samples.

Total alkalinity analyses of frozen lake water samples exhibited no significance of differences in mean values over the 150 days samples were stored frozen. Water samples from lakes with total alkalinity measurements above 2.0 mg·L⁻¹ as CaCO₃ were generally stable, but water samples from lower alkalinity lakes were more variable (Fig. 3). The average coefficient of variation of total alkalinity was 7% for our study lakes. The coefficients of variation of total alkalinity for lakes with concentrations less than 2.0 mg·L⁻¹ as CaCO₃ ranged from 0.0% to 38.0%, while lakes with higher alkalinity (> 2.0 mg·L⁻¹ as CaCO₃) ranged 0.0% to 8.2%. Over 72% of waterbodies in the Florida LAKEWATCH database analyzed prior to January 1998 have total alkalinity concentrations greater than 2.0 mg·L⁻¹ as CaCO₃. Considering the wide range of total alkalinity in Florida lakes (0 to >300 mg·L⁻¹ as CaCO₃), the high variability in very low alkalinity lake would not diminish the usefulness of the information obtained by analyzing frozen water samples for total alkalinity even up to 150 days of storage.

ANOVA indicated the greatest amount of variance (> 95%) in the water chemistry measurements from the study lakes was attributable to differences among lakes. Other factors such as length of time samples were frozen or replicate variability contributed ≤ 3% of the observed variance in our measured water chemistry values among our study lakes. These findings concerning within sample variance are similar to published results concerning within lake variability for measurements of chlorophyll and nutrients (Knowlton et al. 1984, Hanna and Peters 1991, Brown et al. 1999). We, therefore, believe that it is safe for professionals to conclude that within sample and within lake variances for many water quality parameters of interest to lake managers will be small relative to lake-to-lake differences.
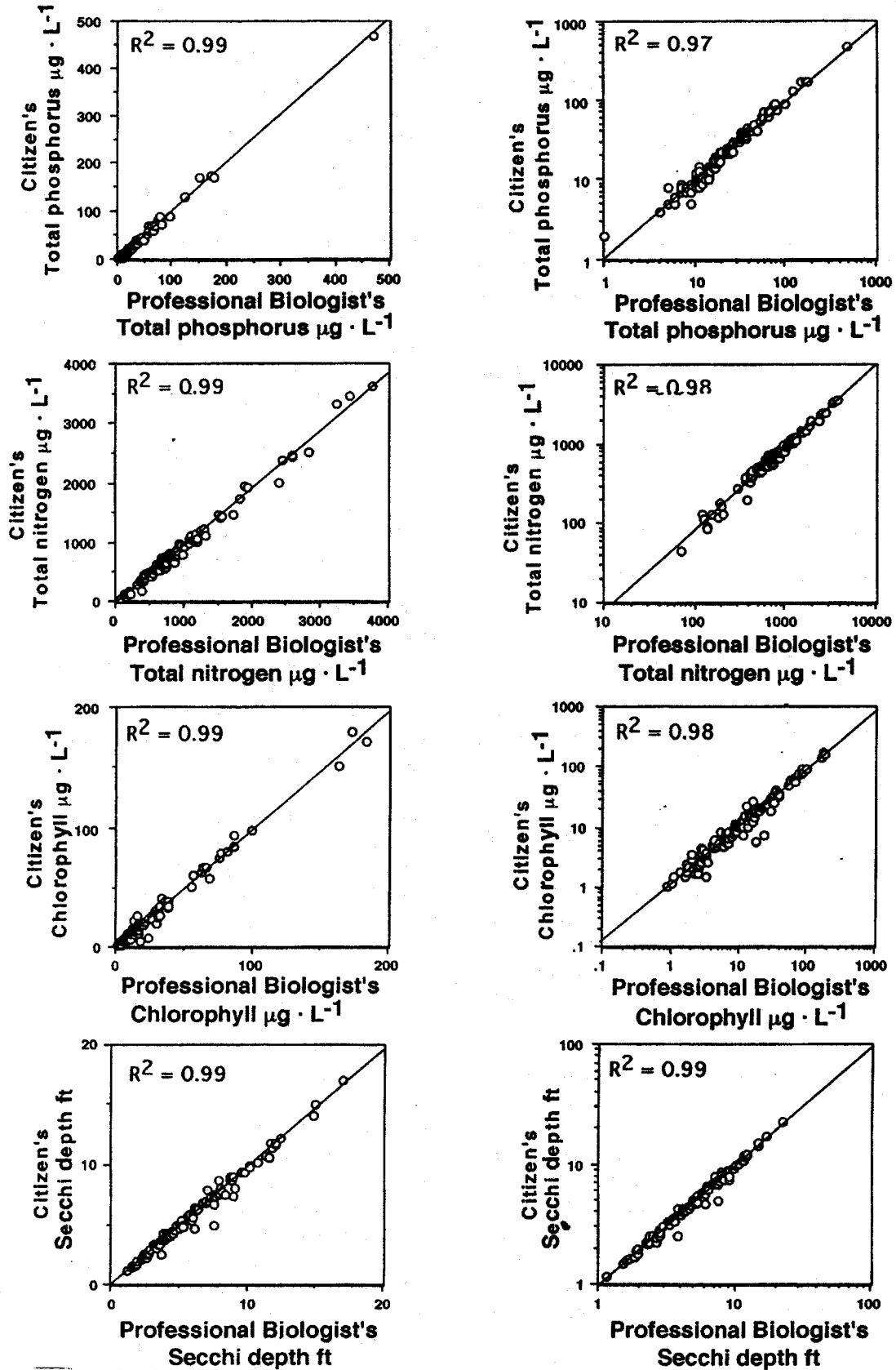
Figure 2.–Mean lake Secchi disk depths, total phosphorus, total nitrogen, and chlorophyll values measured by citizen volunteers and those measured by professionals for untransformed and log-transformed data. Lines are best-fit regression lines.
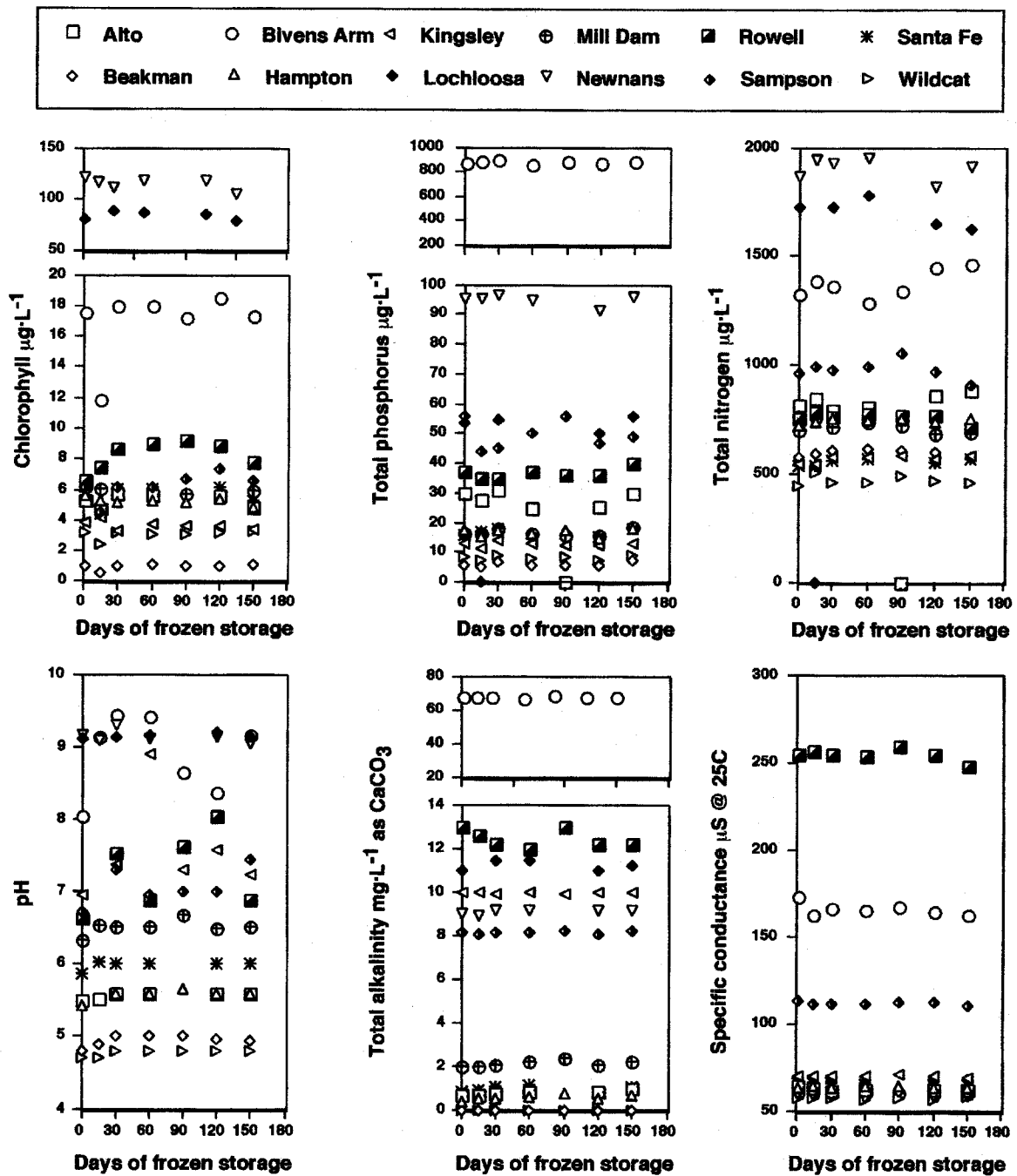
Figure 3.–Chlorophyll, total phosphorus, and total nitrogen concentrations, pH, total alkalinity, and specific conductance versus days of frozen storage. Points represent means of five samples.

Discussion

We conclude, as the did the USEPA (1990), that volunteer monitoring provides a source of credible data. Water quality data produced by volunteer samplers following the LAKEWATCH protocols were just as good as those from samples collected by professional biologists and handled using standard methods of sample preservation. This study demonstrated that freezing water samples and filters for analyses of TP, TN, pH, total alkalinity, specific conductance, and chlorophyll for up to 150 days represents an effective way of sampling lakes by volunteers in order to establish critical baseline and screening data for the major trophic state parameters. Our analyses indicate that any detected differences between fresh and frozen samples measured in the laboratory are small relative

Table 2.–Comparison across study lakes of significance of differences for measurements of chlorophyll, TP, TN, pH, total alkalinity and specific conductance for fresh lake water samples and samples stored frozen up to 150 days.

Comparisons			ANOVA	Wilcoxon/Kruskal-Wallis		
	F-ratio	DF	Prob>F	χ^2	DF	Prob>χ^2
Chlorophyll	1.83	392	0.09	10.46	6	0.11
Total phosphorus	0.00	419	0.99	2.40	6	0.88
Total nitrogen	0.04	419	0.99	1.08	6	0.98
pH	0.63	419	0.71	4.19	6	0.65
Total alkalinity	0.00	419	0.99	0.33	6	0.99
Specific conductance	0.03	419	0.99	1.08	6	0.98

to actual measurements and that any real difference would contribute very little to the environmental variance of concern to most lake managers.

The fact that volunteers can collect credible data means that lake management agencies could amplify their limited budgets by using volunteer monitoring to sample more lakes and to sample them more frequently. This type of investment would allow the agencies to permit the diversion of highly trained personnel into the projects that solve problems rather than just monitoring. The proper use of volunteers would also allow agencies to obtain data where they either have no or limited information. Volunteers should be viewed as partners and the agencies should encourage volunteer monitoring as the primary means for obtaining good cost-effective baseline and screening data.

Major problems associated with expanding the number of volunteers and retaining previously trained volunteers over the long-term is making the sampling for water quality easy and painless to the volunteer

with regard to their time commitment and providing them with feedback on the value and use of the data they have collected. It is incumbent upon those leading volunteer monitoring programs to remember that above all else the personnel are volunteers that need special care and consideration; and if you make the volunteer's life difficult, they will quit. Florida LAKEWATCH has volunteers collect surface water for their analyses and freeze their nutrient and chlorophyll samples at home until they can, at their convenience, either deliver the accumulated samples to the laboratory or established collection stations. The success of Florida LAKEWATCH's sampling protocol is reflected by the fact that volunteers have now provided monthly TP, TN, chlorophyll and Secchi data on over 200 lakes for more than 10 years.

Table 3.–Correlations (r) between measurements of several water quality variables made on lake water samples on the day of collection with frozen lake water samples thawed and analyzed 15, 30, 60, 90, 120, and 150 days from collection. The initial sample on the day of collection for each lake is represented by an average of 5 replicates, while the individual measurements are used for the thawed samples.

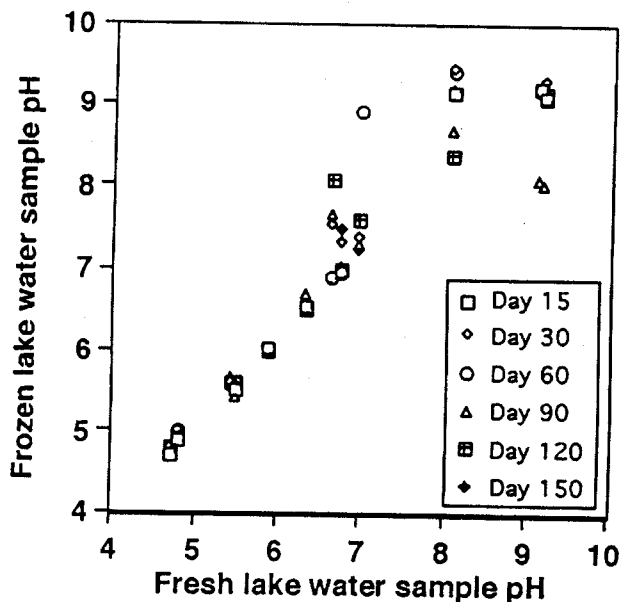| Days stored frozen	Chlorophyll	Total phosphorus	Total nitrogen	pH	Total alkalinity	Specific conductance
15	0.94	0.99	0.99	0.96	1.00	0.99
30	0.99	0.99	0.99	0.97	0.99	0.99
60	0.98	1.00	0.99	0.94	0.99	0.99
90	0.98	1.00	0.99	0.91	0.99	0.99
120	0.99	0.99	0.99	0.97	0.99	0.99
150	0.99	0.99	0.99	0.98	0..99	0.99

Figure 4.–Comparison of fresh pH measurements with measurements obtained from lake water samples stored frozen for 15, 30, 60, 90, and 150 days from time of collection.

samples for frozen storage. We also thank Mary Stonecipher, John Douglas, and Bobby Hutcheson for their tireless efforts in chemical analyses and the independent referees of this manuscript.

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