



A Revision of Environmental Integrity Index (EII) Diatom Metrics

By Cara Muscio

City of Austin - Watershed Protection and Development Review Department
Environmental Resource Management Division (ERM)

Abstract

The characteristics of benthic diatom algae make these organisms increasingly useful as tools in water quality bioassessment programs. The Environmental Resource Management Division (ERM) has integrated parameters measuring diatom community structure into the Environmental Integrity Index (EII) program, with promising results. Several metric parameters were reviewed and analyzed using historical EII data. A suite of four metrics that are shown to be impacted by watershed impervious cover were suggested to compose the revised Index of Biotic Integrity for diatoms. These metrics--percent motile diatoms, pollution tolerance index, Cymbelloid richness, and percent similarity to reference--were combined into a multi-metric index that incorporates comparison to established reference conditions.

Introduction

Aquatic organisms integrate all the influential parameters in their habitat, and they indicate conditions for longer periods than do water chemistry samples. Further, if anthropogenic changes in the water quality of aquatic habitats fall outside the tolerance range for a species or a set of species, those taxa will decline and ultimately disappear. The ecological theory underlying bioassessment is that pristine habitats have more diverse and evenly distributed biological communities. Periphyton, or benthic algae, reproduce rapidly, respond quickly to perturbation, and are directly linked to water quality (Biggs, 1996). For this reason, benthic algae can be used to monitor both point and non-point pollutants and changes in stream quality (Lowe and Pan, 1996). These organisms are at the base of the food chain and the interface of chemical, physical, and biotic components of the food web (Rosen, 1995; Stevenson and Pan, 1999). The benthic algal community commonly sampled is composed of diatoms, due to their siliceous frustules and relative ease of collection. Although some diatoms exhibit limited motility, most cannot migrate enough to avoid pollution impacts. Usually, numerous species are present, and each has a suite of tolerances and optima for specific environmental conditions. Because diatoms respond to many environmental variables (nutrients, toxins, light intensity and canopy cover, temperature, competition, grazing pressure, and velocity) they have historically made good environmental indicators (Oklahoma, 1993; Van Dam et al., 1994). In addition, they can be sampled in undisturbed dry habitats, due to their siliceous frustules (Stevenson and Pan, 1999). The use of metric calculations is one common method of analyzing diatom community structure. Often, multi-metric indices are created to analyze the sum of attributes that respond to human alterations of watersheds (Barbour et al., 1999). Metrics provide a summary of ecological information, rather than using specific species optima to predict ecological conditions. They are also useful in communication with the public and in comparative risk assessment (Oklahoma, 1993).

Application of Diatom Bioassessment at ERM

Currently, diatom community structure is utilized in the aquatic life sub-index of the Environmental Integrity Index (EII)(COA, 1997), and in the Onion Creek study (COA, 2001). Diatom community structure has been used within these programs to assess and monitor anthropogenic effects on watersheds. Diatom community metrics have shown promise as bioassessment tools for ERM, but they have been used only minimally. The calculated index value for each site and watershed is part of a complex set of variables that aids management decisions regarding new capital improvement projects, programs, and regulations in Austin watersheds. In the EII Water Quality Technical Assessment Methodology Report (COA, 1997), the periphyton subindex score was the most indicative of site differences during the pilot study. The metrics utilized were percent similarity (comparison with a reference site), and the pollution tolerance index developed in Kentucky (Metzmeier, 1991). Taxa richness, Simpson’s evenness, and simple matching were also calculated, but they were not scored due to inconsistent results (COA,1997).

The primary goal of this revision was to research and apply current metric methods and analytic techniques for periphyton bioassessment data. This information was used to develop and refine the analysis of periphyton data in relation to the goals of ERM monitoring, specifically regarding the EII survey. Recommendations that best met ERM’s goals were suggested as revisions to the EII diatom index. All potential metrics were calculated with current and historical EII data and were then evaluated using percent impervious cover as a surrogate for anthropogenic degradation.

Metric Selection

Barbour et al. (1999) and Stevenson and Pan (1999) suggest a series of metrics to be chosen as applicable to watershed bioassessment projects. Kentucky, Montana, and Oklahoma all use a multi-metric approach to assess periphyton response to human activities. Several metrics are calculated to provide pertinent characteristics of the community, and scored based on predefined criteria. They use taxa richness, Shannon diversity, pollution tolerance index (PTI), percent community similarity, and several others. Table 1 illustrates which metrics are currently used to evaluate richness, composition, tolerance, and trophic/habit measures.

Table 1. Comparison of documented metrics measuring diatom community structure.

Kentucky (Metzmeier, 1992)	Montana (Bahls, 1992)	Oklahoma (Protocol III)	EPA RBP (Barbour et al. , 1999)	Parameter Indicated
Taxa Richness		% Dominance by taxa % Dominant indicator taxa	Taxa Richness	Richness (biotic integrity)
Shannon Diversity	Shannon Diversity	Hills N2 Diversity (reciprocal of Shannon) Modified Hills Evenness	Shannon Diversity	Composition (biotic integrity)
Pollution Tolerance Index	Pollution Tolerance Index	Diatom Index	Pollution Tolerance Index	Sensitivity to pollution
Percent Sensitive Species			Percent Sensitive Species	Sensitivity to pollution
Percent Community Similarity	Percent Community Similarity		Percent Community Similarity	Composition (biotic integrity)
	Percent Motile Diatoms		Percent Motile Diatoms	Trophic/Habit (siltation)
			Percent <i>Achnanthes minutissima</i>	Trophic/Habit (disturbance)

Initially, metrics with the most common usage representing various aspects of the community were selected. Montana (Bahls, 1992) and Kentucky (Metzmeier, 1991) have developed diatom Pollution Tolerance Indices, based on the Lange-Bertalot Pollution Index (Lange-Bertalot, 1979). ERM already included and scored the Kentucky version of a pollution tolerance index (PTI) and a percent similarity metric. Shannon diversity was investigated, due to its widespread use as a measure of both richness and evenness of communities (Lowe and Pan, 1996). Metzmeier (1992) further notes that this index works particularly well in areas stressed by organic pollution. Researchers in Oklahoma (1993) state that diversity and evenness are important measures of community structure and should be included. Stevenson and Pan (1999) add that assessment with regard to reference sites is the best use of diversity related indices, noting that diversity is affected differently depending on pollution type. Nutrient pollution can improve diversity in a nutrient-poor system up to a point, whereas toxics can immediately reduce diversity or diversity in subsequent generations.

In addition, based on research of methodologies in practice, the following metrics were investigated: percent *Achnanthes minutissima*, percent motile diatoms, taxa richness, generic richness, percent dominance of top three taxa, *Cymbella* richness, and percent sensitive species. Taxa richness, or the number of taxa per sample, had been calculated previously with no conclusive results. The percent of motile diatoms was chosen to represent the amount of siltation at sampling sites. Diatoms of the genera *Nitzschia*, *Navicula*, and several revised genera therein are motile, and they would presumably be more present in depositional habitats. The scoring scale of the percent motile diatoms was inverted to illustrate the relationship between high abundance and increased siltation as an undesirable result. *Achnanthes minutissima* (*A. min*) is often found at recently disturbed sites in high quantities. It is often the first diatom to colonize new substrates, and therefore could potentially be used as a measure of recent disturbance. Since taxa richness was a problematic metric, it was thought that percent dominance would better characterize degradation. A community dominated by only a few taxa is thought to be more impaired than a striving community with many taxa (Barbour, 1999). Oklahoma uses the concept of dominance in all of its assessments, defined as the top five species or total that makes up 90% of a population. Generic level richness was considered as an alternate to taxa richness as well. Percent sensitive species is a follow-up metric on the Kentucky diatom pollution tolerance index (Metzmeier, 2001). It indicates the pollution sensitive species by combining their relative abundance at each site. Cymbelloid taxa richness (referred to as *Cymbella* for simplicity) is a similar metric, to highlight the presence of these sensitive species. Ten metrics were evaluated with historical data (Table 2).

Table 2. Metrics evaluated with historical data.

Taxa richness
Generic richness
Percent dominance top 3
Shannon diversity
Simpson diversity
Percent <i>Achnanthes minutissima</i>
Percent motile
Pollution tolerance index
Percent similarity
<i>Cymbella</i> richness (# of Cymbelloid taxa)

Materials and Methods

Metric Revision and Calculation

The current analysis of diatom community structure was examined and evaluated. Information was gathered from a number of current journals and texts, and communications with and recommendations

from several diatomists were solicited. Metrics were selected to represent many aspects of community structure and “health”. The metrics were calculated across all Environmental Integrity Index (EII) data using SAS, version 8 (1999). The equation for Shannon diversity follows:

$$H' = \sum_{i=1}^S -p_i \cdot \ln(p_i), \quad (1)$$

where H is equal to Shannon diversity, S is equal to the number of taxa, and p_i is equal to the fraction of the total number of individuals belonging to taxa i (Morin, 1999). Equation 2 was used to calculate the revised ERM diatom PTI index. Additional information can be found in Diatom Pollution Tolerance Index, (SR-02-02, Muscio, 2002).

$$PTI = \frac{\sum n_i t_i}{N} \quad (2)$$

where n_i is the fraction of taxa i abundance over the total abundance (N) and t is its tolerance value. The remainder of the metric calculations consisted of either the number of a specific group of taxa present, or a relative abundance of a certain group (i.e., Percent motile). The genera used for percent motile calculations were as follows: *Navicula*, *Nitzschia*, *Surirella*, and Austin taxa formerly included in these genera, including *Craticula*, *Diadesmus*, *Luticola*, *Sellaphora*, *Hippodonta*, *Tryblionella*, and *Geisseleria*. *Cymbella* richness also included former genera *Encyonema*, *Encyonopsis*, and *Reimeria*. Percent sensitive species contained taxa assigned the most sensitive designation in the PTI metric.

Calculations were performed first on the raw data, and then with each site score calculated with regard to a bank of reference sites. Graphical plots were constructed for each parameter, illustrating both raw and EII index scores. A regression was performed initially at the watershed level, plotting each metric value against percent impervious cover. The suite of metrics was then regressed against site impervious cover percentages.

In addition to assessing the ability of these metrics to characterize degradation, the metrics themselves were evaluated for theoretical validity and calculation issues. The pollution tolerance index used in the EII survey was developed in Kentucky, and only approximately 35% of the 429 taxa collected in Austin for EII had assigned tolerance values in this metric. The assignment of pollution tolerance values and the monitoring of taxonomic nomenclature changes was a detailed process, discussed in separate documentation (Muscio, 2002). After revising the taxonomic structure of the diatom database, the EII diatom metrics were recalculated. In addition, comments suggested in the bioassessment sub-committee meetings were used to structure metric selection. The scale for the percent motile metric (siltation index) is inverted to indicate larger percentages of motile diatoms in worse water quality conditions.

Index development using reference condition

For each metric, the 5th and 95th percentiles were used to reduce the possibility of outliers determining the range of scores used to compare sites (Table 2). Extreme values were set to the 5th and 95th percentile values. The truncated metric scores are then converted to a 0 to 100 scale with the 5th percentile value determining 0 and the 95th percentile value determining 100, and linear interpolation determining the values in between. For percent motile, the EII metric score is then subtracted from 100 since lower scores imply better conditions. The four EII metric scores are then averaged to get an indexed diatom site score.

Table 2. Percentile ranks for each of the four diatom metrics. Metric scores exceeding these numbers are truncated to these values.

Class	5 %	95 %
<i>Cymbella</i> richness	0	6
Percent motile	1.2	84.6
Percent similarity to reference	8.7	77.6
Pollution tolerance index	1.7	3.3

Reference sites are often used to characterize the natural background variation in metric scores. Choosing reference sites reduces the amount of variability due to habitat, pulse phenomenon, and/or chronic outliers. The sites should represent a stable, homogeneous physical condition that is minimally impaired. Reference sites for the EII were selected from the database based on staff experience, land use maps, and impervious cover values. From each survey, the maximum score from the bank of reference sites for that survey was used to normalize all site scores. If the score exceeded 100, it was set to 100.

Results

The original results of watershed level EII metric calculations are presented in Table 3. The pollution tolerance index and percent similarity yielded relationships (R^2) to percent impervious cover of 0.25 and 0.34, respectively. These metrics were calculated with respect to reference sites and compiled to produce the total EII score. The unscored metrics that did not show significant correlation to impervious cover (Simpson diversity, taxa richness, and simple matching) were not evaluated further.

Table 3. Original EII (reference condition) metrics, with relationship to watershed impervious cover.

Metric	PTI	Percent similarity	Total
Calculation Type	EII	EII	EII
R^2 IC (watershed)	0.25	0.34	0.35

The metrics proposed in this report were calculated based on both watershed and site data. Again, the PTI and percent similarity showed significant correlation to impervious cover. Percent motile diatoms and *Cymbella* richness were also significantly correlated, and both were added as potential metrics. Percent *A. min* did not have a significant regression to impervious cover at the site level, and it was dropped from the calculations. Percent dominance, percent sensitive species, Shannon diversity, and generic richness were not strongly correlated to impervious cover, and they were eliminated. The four metrics that showed significant response were selected for the diatom index within the aquatic life use subindex of the EII. After the taxonomic revision to the species list and historical data, and addition of a new reference method, these regressions were again calculated for site impervious cover. All of the R^2 values increased as a result of these revisions, except for percent similarity. The new method is more robust, and based on a more correct methodology. The site and EII (reference condition) metric scores are shown in Table 4.

Table 4. Metric scores at site and EII level after taxonomic revision. Site score is the raw metric calculation for each watershed site, and EII score represents the score using the reference method outlined previously.

Metric Type	Percent similarity		PTI		<i>Cymbella</i> richness		Percent motile		Total
	Site	EII	Site	EII	Site	EII	Site	EII	EII
New R ²	.31	.31	.44	.44	.22	.23	.31	.31	0.46

Discussion

The preceding evaluation of periphyton metrics has suggested that several changes be made in the EII periphyton index. The four metrics with significant relationships to impervious cover are: the pollution tolerance index (PTI), percent similarity, percent motile diatoms, and *Cymbella* richness. These metrics provide an indication of the diversity of these communities as well as taxa relationships to water quality conditions. The combined R² of these metrics on a site level with regard to impervious cover is 0.46. Given the multitude of other variables that influence diatom growth and development, such as tree canopy and light intensity, seasonal climate variables, grazing, and hydrology, this relationship was significant. In addition to metric selection, the reference site selection and calculation method were also revised. The reference site method for diatom metric analysis is the same method developed by ERM for benthic invertebrates. The PTI was also revised from its first incarnation (Muscio, 2002). Both raw site and EII (with regard to reference condition) relationships to impervious cover improved as a result of these revisions.

Of course no method is without complications, and hydrology appears to be a confounding factor in the assessment of Central Texas creeks. Periods of low summer flow and scouring due to spates may impact the diatom community at the time of sampling. Stevenson (1999) adds that high disturbance regimes may not accrue peak biomass before being disturbed. Lowe and Laliberte (1996) recommend a 3-week delay in sampling periphyton following a bottom-scouring storm. ERM has developed a flow trigger protocol that will be used to evaluate the timing of biological sample collection (Scoggins, 2002). In addition, Rosen (1996) suggests aligning day-month time scales between sampling periods to reduce variability. Though a complete EII sampling group spans 3 years, data in each phase are only compared to reference sites collected in the same time period during the analysis. This should help eliminate variability due to yearly climate cycles (wet/dry years).

Metrics are not the only methodology currently in use to assess diatom communities. There is a growing amount of literature on multivariate analysis using weighted averaging and calibration methods. Multi-metric approaches summarize community information, whereas ordination and calibration techniques are used to predict conditions directly from the biological community surveyed. Stevenson and Pan (1999) and Oklahoma (1993) cite multi-metric approaches as useful in management; However, Steven Porter of the USGS (2001) particularly stressed his preference for calibration models over metrics, asserting that they provide a more quantitative approach. The USGS NAWQA program has been using WA-CALIB and CALIB programs to analyze diatom communities, and it may issue a national standard (Porter, 2001). Many studies have used these methods to create diatom optima and tolerance values for pH (Pan et al., 1996; Van Damm and Mertens, 1995), turbidity (Pan et al., 1996), and nutrient concentrations (Anderson et al., 1993; Pan et al., 1996, Cooper et al., 1999.) The suggestion of Stevenson and Pan (2001) was to use the relative abundance of species, and their environmental sensitivities and optima to use the selected metrics. The next step would be to design a sampling and data analysis plan that calibrates these metrics and develops new ones for the Central Texas area (Stevenson and Pan, 2001; Porter, 2001). Detailed explanation of weighted averaging, calibration, and other multivariate methods of data analysis are presented in Jongman et al. (1995), and ter Braak and Van Dam (1989). For the scale of the

Environmental Integrity Index, the metrics currently recommended for use provide an adequate assessment of the diatom community as a subset of the aquatic life score. For more intensive projects, other methods may be chosen that are more suitable to the level of information desired.

References

- Anderson, N.J., B. Rippey, and C.E. Gibson. 1993. A comparison of sedimentary and diatom inferred phosphorus profiles: implications for defining pre-disturbance nutrient conditions. *Hydrobiologia* 253: 357-366.
- Bahls, L. 1992. *Periphyton Bioassessment Methods for Montana Streams*. Water Quality Bureau. Helena, Montana.
- Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates, and fish. USEPA 8410B-99-002. 2nd ed.
- Biggs, B. 1996. Patterns in benthic algae in streams. *In Algal ecology: freshwater benthic ecosystems*. Academic Press.
- City of Austin. 1997. *Environmental Integrity Index Water Quality Technical Assessment Methodology*. City of Austin Watershed Protection Department, Environmental Resource Management Division.
- Cooper, S.R., J. Huvane, P. Valthiyathan, and C.J. Richardson. 1999. Calibration of diatoms along a nutrient gradient in Florida Everglades Water Conservation Area –2A, USA. *Journal of Paleolimnology* 22: 413-437.
- Jongman, R.H.G., C.J.F. Ter Braak, and O.F.R. Van Tongren, eds. 1995. *Data analysis in community and landscape ecology*. Cambridge University Press.
- Lange-Bertalot, H., 1979, Pollution tolerance of diatoms as a criterion for water quality estimation: *Nova Hedwigia*, v. 64, p. 285-304.
- Lowe, R.L., and G.D. Laliberte. 1996. Benthic Stream Algae Distribution and Structure. *In Methods in stream ecology*. R.F. Haur and G.A. Lamberti, eds. Academic Press.
- Lowe, R.L., and Y. Pan. 1996. Benthic algal communities as biological monitors. *In Algal ecology: freshwater benthic ecosystems*. Academic Press.
- Metzmeier, L. 1991. Use of diatoms in water quality assessments. Division of Water. Frankfort, Kentucky.
- Metzmeier, L. 2001. Personal Communication.
- Morin, P.J. 1999. *Community Ecology*. Blackwell.
- Muscio, C. 2002. The diatom pollution tolerance index. City of Austin Watershed Protection and Development Review Department, Environmental Resource Management Division.

Oklahoma Conservation Commission. 1993. Development of rapid bioassessment protocols for Oklahoma utilizing characteristics of the diatom community.

Pan Y., R.J. Stevenson, B. Hill, A. Herlihy, and G. Collins. 1996. Using diatoms as indicators of ecological conditions in lotic systems: a regional assessment. *J. N. Am. Benthol. Soc.* 15(4):481-495.

Porter, S. 2001. Personal Communication.

Rosen, BH. 1995. Use of periphyton in the development of biocriteria. *In* Biological assessment and criteria-tools for water resources planning and decision making. Lewis.

SAS Institute, Inc. 1999. Version 8. SAS software.

Scoggins, M. 2002. Personal Communication. City of Austin.

Stevenson R.J., and Y. Pan. 1999. *IN* Diatoms: applications for the environmental and earth sciences. Stoermer and Smol, eds. Cambridge.

Stevenson, R.J., and Y. Pan. 2001. Personal Communication.

TerBraak, C.J.F., and H. Van Dam. 1989. Inferring pH from diatoms: a comparison of old and new calibration methods. *Hydrobiologia.* 178: 209-233.

Van Dam, H., A. Mertens, and J. Sinkledam. 1994. A coded checklist and ecological indicator values of freshwater diatoms from the Netherlands. *Netherlands Journal of Aquatic Ecology.* 28(1): 117-133.

Van Dam, H., and A. Mertens. 1995. Long-term changes of diatoms and chemistry in headwater streams polluted by atmospheric deposition of sulphur and nitrogen compounds. *Freshwater Biology.* 54: 579-600.

Acknowledgments:

Martha Turner, Mateo Scoggins, and Mary Gilroy, City of Austin
Lythia Metzmeier, Texas Natural Resource Conservation Commission (now Texas Commission on Environmental Quality)
Loren Bahls, Hannaea
Stephen Porter, USGS, NAWQA
Yi-Kuang Bruce Wang and R Jan Stevenson, Department of Zoology , Michigan State University
Eduardo Morales, Patrick Center for Environmental Research, Natural Academy of Sciences of Philadelphia