Development of the New Jersey Pinelands Macroinvertebrate Index (PMI)

Prepared for:

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U. S. Environmental Protection Agency

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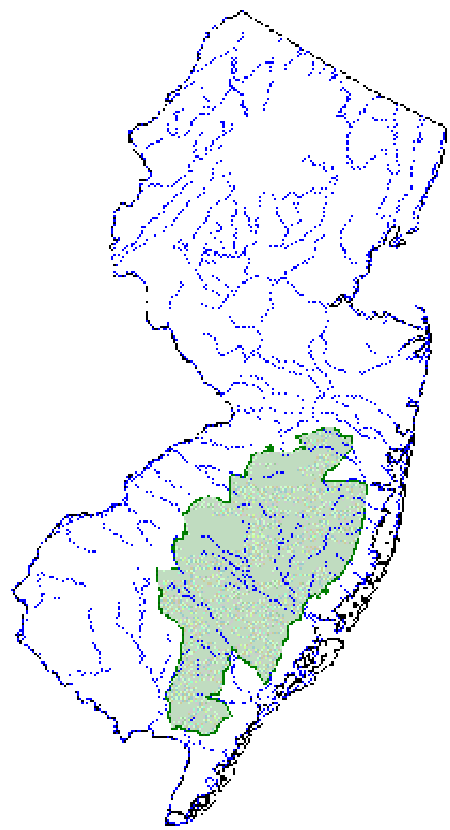

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Final Report

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ABSTRACT

The New Jersey Pinelands are ecologically distinct from the rest of New Jersey. Pinelands streams are naturally acidic, colored by tannins, low gradient, and have low specific conductance. Methods to assess the ecological integrity of New Jersey streams and to distinguish degraded from reference conditions are not adequate for Pinelands streams because natural Pinelands streams do not resemble high quality streams in other parts of the state. In this study, the Pinelands Macroinvertebrate Index (PMI) was developed for bioassessment of streams of the Pinelands ecosystem. The multimetric index development process began by identifying reference and degraded sites using land cover and water chemistry criteria. The PMI was calibrated using data on benthic macroinvertebrates collected between April 1 and November 30 of 1995-2002. The index was tested using data collected at the same sites, but on different sampling dates. Sample results (lists of taxa and numbers of individuals) were used to calculate a series of biological metrics representing benthic macroinvertebrate taxa richness, evenness, composition, pollution tolerance, functional feeding groups, and habit. The efficiency of each metric in detecting degraded conditions was then calculated. Seven metrics with high discrimination efficiencies and representing a wide range of taxonomic attributes were then scored and averaged into the PMI, which correctly identified 94% of the degraded sites for calibration data, and 50% and 100% of reference and degraded verification data, respectively. The seven metrics in the index included: insect taxa, non-insect taxa, percent Plecoptera and Trichoptera, percent Mollusca and Amphipoda, percent Diptera excluding Tanytarsini, Beck's Biotic Index, and percent filterers.

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1.0 Introduction

A primary goal of the Clean Water Act is to preserve and protect the biological integrity of the Nation's waters. To that end, methods have been developed for evaluating the biological condition of waterbodies. Biological assessments are increasingly employed for this purpose, using biological surveys and other direct measurements of the resident biota and environmental conditions. The use of biological data has several advantages over the use of physical or chemical data in assessing waterbody condition. First, the resource to be protected is directly measured, rather than the environmental conditions that are perceived to be stressing the resource. Second, the biotic community integrates stresses over time, so a short-term event (e.g., contamination that moves as a plug through the system) is more likely to be detected in the biota than in physical or chemical monitoring. Finally, the biotic community integrates the effects of multiple stressors, reflecting the impact of factors that may not be measured as well as the possible synergistic effects of multiple stressors.

The benthic macroinvertebrate assemblage is an appropriate indicator of biological condition. Benthic macroinvertebrates include a considerable diversity of taxa that are variably responsive to multiple types of stressors (Rosenburg and Resh 1992). Many taxa reside in limited habitat ranges throughout their aquatic life stages, during which they are exposed to stressors that are both permanent (e.g., habitat degradation) and temporary (e.g., toxicants in the water column). The benthic community can be measured using characteristics of the individual taxa and their richness and composition within the sample. Because of the broad diversity of the benthic macroinvertebrate assemblage, many different measurements, or metrics, can be calculated. Any single metric may show a response trend that corresponds to measures of physical and/or chemical stress. However, individual metrics may be responsive to a limited number of stressor types or to a limited range of stress. When the most responsive metrics are identified and combined, this combination, when compared to any of the single component metrics, will be more responsive to multiple stressors, will perform better throughout the range of stressor conditions, and will be less variable (Buikema and Voshell 1993, Hughes et al. 1998). A combination of responsive metrics is generally called an Index of Biological Integrity (IBI; Karr et al. 1986). Regionally calibrated IBI's are widely accepted indicators of biological integrity (Gibson et al. 1996, ITFM 1995, Davis et al. 1996).

The New Jersey Department of Environmental Protection (NJDEP) developed an IBI, known as the New Jersey Impairment Score (NJIS; NJDEP AMNET website, Kurtenbach 1990) based on Rapid Bioassessment Protocols (Barbour et al. 1999). The NJIS has been used to assess sites in the Ambient Biomonitoring Network (AMNET), a statewide network of monitoring sites for macroinvertebrates, fish, physical habitat, and water quality. For the NJIS, five metrics are rated on a three tier scale and the metric scores are combined into an index used to assess the environmental conditions of wadeable streams. While the NJIS is considered an effective bioassessment tool for most of New Jersey, it does not perform well with data from the ecologically distinct Pinelands (Kennen 1999). The goal of this project, therefore, is to analyze available environmental and macroinvertebrate data collected in the Pinelands, and develop a multi-metric index for use in assessing biological integrity in Pinelands streams.

1.1 The Pinelands Ecosystem

The Pinelands ecosystem covers a large part of the coastal plain of southern New Jersey. Much of this ecosystem is encompassed in the Pinelands National Reserve, an area of approximately 1.1 million acres (22% of the state's total area) protected in 1978 and declared a Biosphere Reserve in 1983 (Figure 1). Drainage patterns converge into Rancocas Creek, Mullica River, Great Egg Harbor River and several smaller rivers that drain into the Atlantic Ocean. Rancocas Creek in the northern part of the Pinelands drains from the east to the Delaware River in the west. The Mullica River drains the central Pinelands from west to east. The southern Pinelands are drained to Great Egg Harbor.

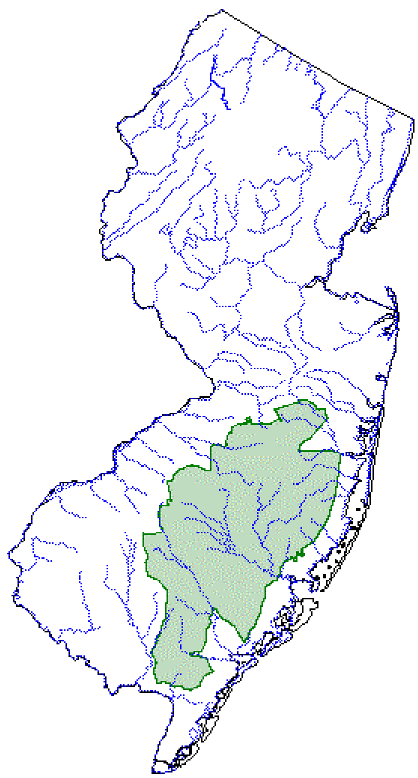

Figure 1. Boundary of the Pinelands National Reserve (shaded) within southern New Jersey, showing major river drainages.

Many aspects of the Pinelands differ naturally from other New Jersey ecosystems. The terrain is relatively flat and sandy, supporting stands of pine and oak trees. Streams are generally low-gradient, slow-moving, and sandy bottomed. The water is colored with tannins, is naturally acidic (pH<5.5), and has low specific conductance (<75 µS/cm) (Zampella et al. 2001, Zampella et al. 2003). The benthic macroinvertebrate and fish communities that thrive in these unique

Pineland conditions differ from those in the less acidic streams outside of the Pinelands (Kennon 1999, Zampella and Bunnell 1998).

As is the case elsewhere in New Jersey, aquatic resources in the Pinelands are threatened by continued degradation from numerous anthropogenic stressors, including urban centers, logging, and agriculture, including cranberry bogs. This development and the associated pollutants change the character of Pineland streams by raising the pH and specific conductance of the water (Zampella and Laidig 1997); such increases are often correlated with changes in other analytes such as calcium, magnesium, ammonia, nitrate, and phosphorus (Zampella 1994).

The changes in the physical and chemical characteristics of the watershed and water column have effects on the resident biota. Zampella and Laidig (1997) found that disturbed watersheds supported a greater number of exotic plant species that replaced native Pinelands species. Similarly, the presence of native frog species was negatively correlated with pH, conductivity, and percentage of developed land, while the presence of the non-Pinelands bullfrog (*Rana catesbeiana*) was positively correlated with disturbed conditions (Zampella et al. 2003). Among fish, exotic species were more common in disturbed streams than undisturbed streams, but displacement of native fish species was not noted (Zampella and Bunnell 1998). A major focus of this study is to identify metrics of the macroinvertebrate community that are responsive to stressors in the Pinelands and that discriminate degraded sites from undegraded sites. These most responsive metrics will then be integrated into an index of biological integrity for Pinelands macroinvertebrates.

1.2 Approach to Index Development

The premise of the index development process is that physical and chemical disturbances are reflected by changes in the benthic macroinvertebrate community. Physical and chemical characteristics can first be used to distinguish minimally disturbed (reference) sites from sites with anthropogenic disturbance. The benthic macroinvertebrate data from these sites can then be used to identify a biological reference condition that is distinct from the non-reference, or degraded, condition. Meaningful biological signals of disturbance are summarized in a multimetric index that can be used to evaluate biological integrity in sites of unknown quality. The development of a multimetric IBI calibrated on the benthic macroinvertebrate and environmental data collected in and around the Pinelands follows a series of steps, as follows:

1. Collect and organize the data, separating calibration and verification data;
2. Define reference and degraded sites;
3. Stratify natural biological conditions;
4. Calculate biological metrics and determine sensitivity of each metric;
5. Combine appropriate metrics into index alternatives;
6. Select the most appropriate index for application in the Pinelands based on sensitivity and variability, and;
7. Assess performance of the index.

This report is organized along the lines of the index development process, with methods and results explained for each step. Appendices include site assessments using the recommended index.

2.0 Data Sources and Organization

The NJDEP provided benthic macroinvertebrate, water quality, habitat, and land use data for this analysis. The data were collected between 1991 and 2003 throughout New Jersey. Benthic macroinvertebrates were collected using a D-framed kick net (800x900 micron mesh size, 1-foot wide) with the multi-habitat, “jab and sweep” method as described by the Mid Atlantic Coastal Streams workgroup. The most productive habitats – woody debris, submerged macrophytes, and submerged portions of the banks – were targeted in proportion to their extent in the sample reach. A minimum of 20 jabs/sweeps were taken over a stream distance not in excess of 100 meters. Level of effort was consistent for all sites. Where possible, samples were taken on the upstream side of any road crossings, sufficiently upstream of the influence of any channel alterations due to bridges. The entire sample was sieved using a #30 mesh sieve bucket, put into wide-mouth jars, and preserved with 5 to 10% formalin (to 20% in cases of excessive organic loading).

In the laboratory, the composited sample was rinsed and evenly distributed in a light-colored pan marked with grids of equal size. Using low-power magnification (6.3x), all organisms greater than 2mm in size were then removed from randomly selected grids until a total of at least 100 organisms were obtained. Organisms were generally of sufficiently good condition to allow for genus level identification.

Data were received from NJDEP in spreadsheet, database, and GIS formats, and included benthic macroinvertebrate, water quality, habitat, and land use information. The data were reformatted and compiled in the Ecological Data Application System (EDAS), a Microsoft Access relational database. EDAS was used primarily for data storage and metric calculation. Once the data were organized in EDAS, they were exported as flat files to statistical programs for analysis (Statistica and PC-ORD).

Using ArcView GIS, sampling stations were categorized as “Pinelands” or “Pinelands Buffer”. Sites within the Pinelands National Reserve were considered “Pinelands” sites. However, this political boundary may not encompass all streams with the low pH and low specific conductance characteristics that are unique to the Pinelands ecosystem. To accommodate such sites, stations within 5 km of the Pinelands political boundary were identified as “Pineland Buffer” sites. These sites were considered as possible reference sites subject to meeting specific ecological criteria (see Section 3.1).

Nine hundred and twenty-seven (927) Pineland and Pineland Buffer samples were identified in 311 sites. If a sample or site met any one of the following conditions, it was excluded:

1. Winter samples - Because winter benthic communities may naturally differ from warmer-season benthic communities, samples were excluded if they were collected between December 1 and March 31.
2. Samples collected before 1995 – Methods and personnel have changed over time and NJDEP is not confident that samples collected prior to 1995 are comparable to later samples.
3. Sample size – Samples were sub-sampled to a target size of 100 organisms. Most samples contained between 100 and 120 organisms. Samples were excluded if they had less than 80 or more than 160 organisms.
4. Pineland Buffer sites that did not meet reference criteria (see section 3.1).
5. Samples with no biological data.

After excluding these samples, 114 valid samples were identified from 64 sites.

2.1 Selecting Samples for Calibration and Verification of the Index

A multimetric index is a model of collective metric responses to environmental stress. The model is developed, or calibrated, using one set of data. The effectiveness of the model at distinguishing reference from degraded sites is verified using a separate, preferably independent, data set. The Pinelands macroinvertebrate samples were collected over several years with repeat visits to established sites over time. When multiple samples were recorded between 1995 and 2002, one sample per site was randomly selected to be used in calibrating the model. The remaining samples were reserved as verification data. The verification data are not truly independent from calibration data because they were collected from the same sites. This method of selecting calibration and verification data was chosen to ensure adequate samples sizes in the calibration data used in developing the model. Truly independent verification data may be collected in future NJDEP efforts.

3.0 Defining Reference and Degraded Sites

Reference sites represent relatively unimpacted conditions as measured by chemical and physical data. They may be sites that have escaped human activities that alter stream integrity, or they may have recovered from some past alterations. The variables available in the Pinelands dataset for defining reference sites include land use, field chemistry, and habitat assessments (Appendix A). Once reference sites are identified using physical and chemical data, their biological samples are used to describe the biological reference condition, which is a standard to which other samples can be compared for identifying impairment status. Reference sites are also used to describe natural variation of the biological and environmental components of a system.

Degraded sites represent conditions that have been degraded by human activities, as measured by physical and chemical data. They are expected to have biological samples that differ from reference conditions. Biological metrics with values that consistently differ between reference and degraded sites are apparently responsive to the stressors in the degraded sites.

"Intermediate" sites are those classified as neither reference nor degraded. They are expected to have intermediate levels of stress, and are used to assess linearity or non-linearity of metric responses to stress. Non-monotonic metrics (i.e., those that increase or decrease with intermediate stress relative to both higher and lower stress levels) are more difficult to interpret in the multimetric index context.

3.1 Identifying Reference Sites

Of the Pineland and Pineland Buffer calibration sites, reference sites were identified in two ways. First, the NJDEP classified nine sites as "Reference" based on professional judgment of favorable site and watershed conditions. Second, criteria on predicted land use intensity, land cover, and location relative to dams were applied (Table 1). To qualify as Reference, a site had to meet all the reference criteria, the first of which was predicted land use intensity. This parameter comes from a study of watershed disturbance in the Pinelands (Dow and Zampella 2000), which found that pH and specific conductance could be combined to calculate predicted land use to explain most of the variation in watershed disturbance from either developed or agricultural land uses. Percent predicted intensive land use (*PLU%*) was thus calculated using the following equation from Dow and Zampella (2000):

$$PLU\% = 12\,pH + 61\log(spec.cond.) - 148$$

using mean values for pH and log(specific conductance).

Table 1. Criteria for Reference and Degraded site classification. To be designated reference, all reference criteria must be met. To be designated degraded, any one of the criteria must be met.

Environmental Parameter	Reference Criteria Level	Degraded Criteria Level
Predicted intensive land use (PLU%)	< 10%	>25%
Percent agricultural land cover	< 10%	>25%
Percent urban land cover	< 10%	>50%
Below Dam	No	No criterion

Zampella (1994) found that the four least disturbed of 14 sites within the Pinelands all had ≤ 10% land altered from either urban or agricultural development. Similarly, the nine sites classified as Reference by the NJDEP ranged from 0 – 8.6% altered land. To have a sample size sufficient for the development of a multimetric index, we chose slightly more liberal criteria: <10% land in agricultural and <10% land in urban development.

In addition to the nine sites identified as reference by NJDEP, another nine met the reference criteria, for a total of 18 reference sites. Two of these (Gibson Creek and Wrangel Brook) were located in the Pinelands Buffer, outside of the Pinelands political boundary. Although three of the sites designated as Reference by the NJDEP had predicted land use intensities between 10% and 15%, their classification remained Reference because the judgment of the field biologists was valued more than the predictive abilities of the regression equation.

3.2 Identifying Degraded Sites

As with Reference sites, Degraded sites were identified in two ways: by NJDEP designation and by land use criteria. Sites outside of the political boundary of the Pinelands were not considered as degraded sites, because natural non-Pineland conditions (higher pH and conductivity) could be mistaken for degraded Pineland conditions.

Nine sites were identified as degraded by NJDEP. Data on actual land use and land use predicted by water chemistry from these nine sites were used as guides for selecting numeric criteria to identify additional degraded sites (Table 1). Sites with greater than 25% urban or agricultural land use in the watershed were considered degraded. This threshold was based on the median of intensive land uses in the NJDEP-designated degraded sites (25.8% urban and 27.7% agricultural). Sites with greater than 50% predicted intensive land use were also considered degraded. This threshold was based on the median predicted intensive land use in NJDEP-designated degraded sites, which was 51%. Application of the criteria resulted in nine sites identified as degraded in addition to the nine NJDEP-designated degraded sites, for a total of 18.

Reference and degraded criteria were applied to sites with both calibration and verification samples, resulting in sufficient sample sizes for development and verification of a multimetric index (Table 2).

Table 2. Number of samples among classes of calibration/verification status and reference/ degraded/intermediate conditions.

	Reference	**Degraded**	**Intermediate**	**Totals**
Calibration	18	18	27	63
Verification	18	18	15	51
Totals	36	36	42	114

4.0 Site Stratification

Multimetric indices are based on reference biological conditions and comparisons to those conditions. The reference condition is expected to vary due to natural differences among reference sites. If the differences are consistently associated with variable natural characteristics, then identification of multiple reference categories, or strata, would allow definition of multiple expectations of natural reference conditions. This would increase the chances of identifying truly degraded sites and decrease the chances of erroneously assessing a site as biologically impaired when it is actually of a different natural type.

We tested for strata within the 18 reference sites using the ordination method called non-metric multidimensional scaling (NMS; see Appendix B). Results suggested that stratification is unnecessary. Rather, all reference sites within the Pinelands should contribute to the definition of the reference condition, realizing that there is natural variability within the reference sites.

For example, two of the reference sites (Jake's Brook and Skit Brook) were relative outliers in the ordination diagrams, perhaps due to poor habitat and high temperature conditions, respectively.

5.0 Metric Calculations and Responses to Stress

A biological metric is a numerical expression of a biological community attribute that responds to human disturbance in a predictable fashion. Metrics were considered for inclusion in this multimetric index on the basis of discrimination efficiency, low inter-annual or seasonal variability, ecological meaningfulness, contribution of representative and unique information, and sufficient range of values. They were organized into six categories: richness, composition, evenness, pollution tolerance, functional feeding group, and habit (mode of locomotion).

5.1 Methods

A suite of commonly applied, empirically proven, and theoretically responsive metrics was calculated for possible inclusion in a multimetric index (Appendix C). Additional metrics were calculated to describe the unique responses observed in this data set. These metrics included percent Plecoptera and Trichoptera, percent Mollusca and Amphipoda, and percent Diptera excluding the midge tribe Tanytarsini. The use of the metric percent Ephemeroptera, Plecoptera, and Trichoptera (%EPT) has precedence in biomonitoring programs, but in the Pinelands data set the Ephemeroptera (mayflies) as a group were as abundant in reference samples as they were in degraded samples. The metric percent Crustacea and Mollusca is more discriminating in the Pinelands if the isopods are excluded from the Crustacea group because they were not responsive to stress. In general, flies and midges decrease in abundance with increasing stress in the Pinelands. However, midges of the tribe Tanytarsini increase in abundance with increasing stress. Excluding this tribe from the percent Diptera calculation thus results in a more responsive metric.

Tolerance metrics were based on both Hilsenhoff tolerance values and Tiered Aquatic Life Use (TALU) taxa attribute groups. Hilsenhoff tolerance values are on a 0 to 10 scale (most sensitive to most tolerant). The Hilsenhoff scale was derived primarily to address taxa tolerance to organic pollutants (Hilsenhoff 1987). Attributes associated with taxa for TALU analysis range from sensitive-endemic to pollution tolerant. TALU attributes were assigned to taxa by consensus during a workshop on assessment of New Jersey's non-Pinelands streams (Gerritsen and Leppo 2005). Because the biologists were not focused on Pinelands sites while assigning attributes, applicability within the Pinelands is unknown.

All richness metrics (e.g., insect taxa and non-insect taxa) were calculated such that only unique taxa are counted. Those taxa that were identified at higher taxonomic levels because of damage or under-developed features were not counted as unique taxa if other individuals in the sample were identified to a lower taxonomic level within the same sample. Metrics were calculated using the taxonomic level recorded by NJ DEP biologists, usually genus, occasionally species or family. Habit metrics were calculated using insect taxa only. Habit attributes were not assigned to non-insects by NJDEP. Metrics were calculated in EDAS. Once calculated, the metrics were imported into the statistical package Statistica (1997) for further analysis.

5.1.1 Discrimination efficiency

Discrimination efficiency (DE) is the capacity of the biological metric or index to detect stressed conditions. It is measured as the percentage of degraded sites that have values lower than the 25^{th} percentile of reference values (Stribling et al. 2000). For metrics that increase with increasing stress, DE is the percentage of degraded sites that have values higher than the 75^{th} percentile of reference values. DE can be visualized on box plots of reference and degraded metric or index values with the inter-quartile range plotted as the box (Figure 2). When there is no overlap of boxes representing reference and degraded sites, the DE is greater than 75%. A metric with a high DE thus has a greater ability to detect stress than metrics with low DEs. Metrics with DEs <25% do not discriminate and were not considered for inclusion in the index.

Metric values for intermediate (undesignated) sites were also included on box plots in Appendix D. Intermediate sites represent levels of stress intermediate between reference and degraded sites; their inclusion thus allows a visual assessment of the linearity of a metric response to stress.

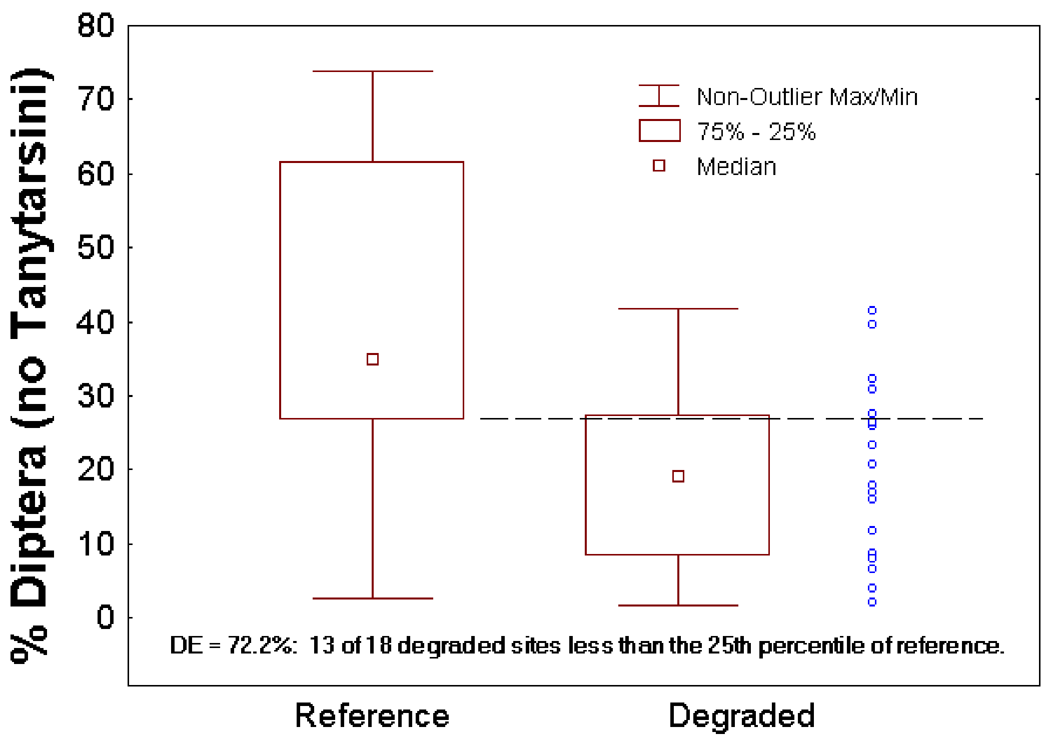

Figure 2. Illustration of metric discrimination efficiency (DE) between reference and degraded site samples. Circles represent actual data from degraded site samples.

5.1.2 Metric variability

Metric variability was measured within the reference calibration sites and among seasons and years. The coefficient of variability (CV) standardizes variability as a function of mean values (CV = standard deviation / mean). When comparing metrics, those with lower variability in the reference conditions are preferable to those with higher variability.

Repeat samples within sites were used to estimate metric variability in two ways: seasonal variability within individual years and annual variability among years but within identical seasons. Seasonal samples were selected such that the sample dates were separated by three months within the same year. Most of the seasonally repeated sites were sampled in 1995 and 2002. Annually repeated sites were selected such that the sample dates were separated by at least 11 months and the dates within each year differed by no more than 30 days. Most of the annually repeated sites were sampled in 1995 and 2000. The dataset contained 31 sites with repeat samples for annual analysis (29 sample pairs and 2 sample triplicates) and 20 sites with duplicate sampling for seasonal analysis.

Variance of metrics among seasons and years was estimated using the error term from analysis of variance (ANOVA) where the sample replicate identifier was the grouping variable (main effect) and the metric value was the dependent variable. The mean squared error (MSE) is an estimate of the average *within* variance of replicates for all samples included in the analysis. Variability was standardized as CV (CV = root MSE / mean of replicated samples). Variability was also calculated as a CV within reference calibration sites (CV = standard deviation within reference sites / mean in reference sites).

Lower CVs indicate lower variability in relation to means. There was no threshold CV above which metrics would not be included in the index, but metrics with low CVs were preferred over those with high CVs.

5.1.3 Other metric considerations

Ecologically meaningful metrics are those for which the assemblage response mechanisms are understandable and are represented by the calculated value. Ecological meaningfulness is a professional judgment based on theoretical or observed response mechanisms. Those metrics that respond in the Pinelands according to expectations established in other studies are defensible.

Metrics contribute information representative of integrity if they are from diverse metric categories. As many metric categories as practical should be represented in an index so that signals of various stressors can be integrated into the index. While several metrics should be included to represent biological integrity, those that are included should not be redundant with each other. Redundancy was evaluated using a Pearson Product-Moment correlation analysis.

For metrics to discriminate on a gradient of stress, they must have a sufficient range of values. Metrics with limited ranges (e.g., richness of taxa poor groups or percentages of rare taxa) may have good discrimination efficiency. However, small metric value changes will result in large and perhaps meaningless metric scoring changes.

5.2 Metric Results

Seventy-seven (77) metrics were calculated in the six metric categories (Table 3). Within calibration samples, 53 metrics responded with at least 25 percent of degraded sites worse than the 25th or 75th percentile of reference. Metrics were excluded from consideration in possible index alternatives if they did not discriminate or discriminated weakly between reference and degraded sites, were conceptually redundant with other, more discriminating metrics, or were not representative of the benthic community. The habit metrics were not representative (and were not used) because habit attributes were only assigned to insect taxa. Box plots of metric distributions in reference, degraded, and intermediate samples confirm that metrics responded more or less linearly, with no metric improvement compared to reference in samples with intermediate stress levels (Appendix D).

Overall, metrics based on Crustacea and Mollusca had the highest DEs (78 – 83%; Table 3). Non-insect taxa had a DE of 83%. Of the Crustacea, amphipods were responsive to stress (50%), while isopods were unresponsive (<25%). Of the Mollusca, bivalves were more responsive than gastropods (78 : 61%). As expected, Crustacea, Mollusca, and non-insects increased in taxa and percent composition with increasing levels of stress.

In the richness category, the highest DEs were associated with non-insect taxa and Crustacea and Mollusca taxa (DE = 83 and 78%, respectively). The non-insect taxa metric was less variable than the Crustacea and Mollusca taxa metric in the reference samples and among seasons. Other responsive richness metrics include insect taxa and Mollusca taxa (DE = 67%). Coefficients of variability were less than 1.0 for most of the richness metrics.

Percent Mollusca was the most responsive composition metric (DE = 83%). Other responsive composition metrics include % Crustacea and Mollusca, % Mollusca and Amphipoda, and % Bivalvia (DE = 78%), and % non-insects, % Plecoptera, % Trichoptera, and % Diptera excluding Tanytarsini (DE = 72%). Of the responsive composition metrics, Plecoptera, Coleoptera, Mollusca, and Bivalvia had the greatest variability (CV > 2.0).

None of the evenness metrics performed well at discriminating, though variability was low. Only Margalef's Index had a DE greater than 25%. Of the pollution tolerance metrics, tolerant taxa using attributes based on Tiered Aquatic Life Use (TALU) had the highest DE (72%). Percent intolerant had the second highest DE (67%). Most of the CV's for tolerance metrics were less than 0.50. The most responsive metrics in the functional feeding group and habit categories were % filterers (DE = 67%) and % burrowers (DE = 56%), respectively. Percent filterers had a CV of 1.04 in the reference sites, where the mean value and standard deviation were near 17.

Table 3. Metric variability and discrimination efficiency. Variability is reported as a coefficient of variability (CV) in the reference calibration data, in annually re-sampled stations, and in seasonally re-sampled stations. Discrimination efficiency (DE) is the percentage of degraded sites with metric values worse than the 25th or 75th percentile of reference. Metrics that decrease or increase with increasing stress are noted with – and + signs, respectively. "NR" indicates no response to stress. Reasons for excluding metrics from index alternatives included: A) the metric does not show a response to increasing stress, B) the metric is a component of a similar metric, and the similar metric has better performance, C) the metric DE is weak (< 50), or D) the metric attribute has only been assigned to insect taxa.

	Metric	**Ref/Calib CV**	**Annual CV**	**Seasonal CV**	**DE**	**Trend w/ > stress**	**Reason for excluding**
Richness	Total taxa	0.22	0.22	0.22	<25	NR	A
	Insect taxa	0.24	0.27	0.28	66.7	-	
	Non-insect taxa	0.58	0.42	0.36	83.3	+	
	EPT taxa	0.51	0.43	0.44	61.1	-	B
	Plecoptera & Trichoptera taxa	0.49	0.51	0.41	61.1	-	
	Ephemeroptera taxa	0.84	0.43	0.79	<25	NR	A
	Plecoptera taxa	0.67	0.62	0.55	61.1	-	B
	Trichoptera taxa	0.53	0.55	0.43	55.6	-	B
	Coleoptera taxa	0.68	0.62	0.61	33.3	+	C
	Diptera taxa	0.43	0.33	0.40	33.3	-	C
	Chironomidae taxa	0.49	0.31	0.41	<25	NR	A
	Orthocladiinae taxa	0.68	0.46	0.65	38.9	-	C
	Tanytarsini taxa	1.03	0.82	0.64	44.4	+	C
	Tanypodinae taxa	0.81	0.60	0.60	<25	NR	A
	Oligochaeta taxa	0.74	0.56	0.51	50.0	+	B
	Crustacea & Mollusca taxa	0.65	0.42	0.47	77.8	+	
	Mollusca taxa	1.78	0.62	0.71	66.7	+	B
	Crustacea taxa	0.68	0.43	0.45	50.0	+	B
Composition	Non-insect percent	1.09	0.42	0.60	72.2	+	
	EPT percent	0.73	0.54	0.61	55.6	-	B
	EPT percent no Baetidae	0.73	0.53	0.65	61.1	-	
	Ephemeroptera percent	1.23	0.74	1.33	<25	NR	A
	Ephemeroptera percent no Baetidae	1.23	0.86	1.66	<25	NR	A
	Plecoptera percent	1.30	1.48	2.29	72.2	-	
	Trichoptera percent	0.77	0.61	0.56	72.2	-	
	Plecoptera & Trichoptera percent	0.70	0.63	0.68	66.7	-	
	Coleoptera percent	1.40	0.76	2.20	66.7	+	
	Odonata percent	1.11	1.11	0.86	<25	NR	A
	Diptera percent	0.56	0.36	0.57	61.1	-	B
	Diptera percent no Tanytarsini	0.57	0.42	0.62	72.2	-	
	Chironomidae percent	0.74	0.46	0.63	<25	NR	A
	Chironomidae percent no Tanytarsini	0.77	0.49	0.70	<25	NR	A
	Orthocladiinae percent	1.06	1.11	1.13	38.9	-	C
	Tanytarsini percent	1.44	1.43	1.48	55.6	+	B
	Tanypodinae percent	1.24	0.87	0.87	<25	NR	A

Table 3 (continued).

		Ref/Calib CV	Annual CV	Seasonal CV	DE	Trend w/ > stress	Reason for excluding
Composition	Crustacea & Mollusca percent	1.76	0.68	0.76	77.8	+	
	Mollusca percent	2.25	0.92	1.08	83.3	+	
	Amphipoda percent	1.87	0.93	1.47	50.0	+	
	Mollusca & Amphipoda percent	1.38	0.71	0.95	77.8	+	
	Gastropoda percent	2.94	2.44	2.09	61.1	+	B
	Bivalvia percent	2.59	1.17	1.34	77.8	+	B
	Isopoda percent	1.98	1.18	1.11	<25	NR	A
	Oligochaeta percent	0.79	0.92	0.97	38.9	+	C
Evenness	Shannon-Weiner Index	0.19	0.13	0.18	<25	NR	A
	Evenness	0.19	0.14	0.13	<25	NR	A
	Margalef's Index	0.24	0.21	0.16	27.8	+	C
	Simpson's Index	0.74	0.52	0.39	<25	NR	A
	Percent dominant taxon	0.55	0.36	0.56	<25	NR	A
	Percent 2 dominant taxa	0.41	0.27	0.34	<25	NR	A
Pollution Tolerance	Beck's BI (Hilsenhoff values)	0.49	0.43	0.39	61.1	-	
	Beck's BI (TALU values)	0.50	0.41	0.46	55.6	-	
	Hilsenhoff's Biotic Index	0.24	0.12	0.15	38.9	+	C
	Intolerant percent	0.91	0.82	0.80	66.7	-	
	Tolerant percent	0.64	0.35	0.44	44.4	+	C
	Intolerant taxa	0.64	0.50	0.47	50.0	-	
	Tolerant taxa (Hilsenhoff values)	0.52	0.24	0.25	50.0	+	
	Tolerant taxa (TALU values)	0.38	0.23	0.19	72.2	+	
Functional Feeding Groups	Collector percent	0.51	0.29	0.45	<25	NR	A
	Filterer percent	1.04	0.55	0.63	66.7	+	
	Predator percent	0.65	0.57	0.38	<25	NR	A
	Scraper percent	1.21	0.98	1.09	<25	NR	A
	Shredder percent	0.75	0.71	1.22	44.4	-	C
	Collector taxa	0.33	0.23	0.29	<25	NR	A
	Filterer taxa	0.60	0.49	0.45	50. 0	+	B
	Predator taxa	0.41	0.42	0.37	44.4	-	C
	Scraper taxa	1.03	0.70	0.49	<25	NR	A
	Shredder taxa	0.32	0.47	0.48	61.1	-	
Habit	Burrower percent	0.78	0.96	0.59	55.6	-	D
	Climber percent	0.78	0.97	0.88	38.9	+	D
	Clinger percent	0.66	0.55	0.50	50.0	-	D
	Sprawler percent	0.68	0.52	0.90	50	-	D
	Swimmer percent	0.90	0.73	1.01	<25	NR	D
	Burrower taxa	0.30	0.53	0.38	50	-	D
	Climber taxa	0.52	0.54	0.42	<25	NR	D
	Clinger taxa	0.53	0.38	0.42	33.3	-	D
	Sprawler taxa	0.40	0.39	0.48	44.4	-	D
	Swimmer taxa	0.74	0.66	0.63	<25	NR	D

6.0 Index Composition

A multimetric index is a combination of metric scores that indicates a degree of biological stress in the stream community (Barbour et al. 1999). Individual metrics are candidate for inclusion in the index if they:

- discriminate well between reference and degraded sites;
- are ecologically meaningful (mechanisms of responses can be explained);
- represent diverse types of community information (multiple metric categories); and
- are not redundant with other metrics in the index.

Several index alternatives were calculated using an iterative process of adding and removing metrics, calculating the index, and evaluating index responsiveness and variability. The first index alternatives included those metrics that had the highest DEs within each metric category. Subsequent index alternatives were formulated by adding, removing, or replacing one metric at a time from the initial index alternatives that performed well. The index alternative recommended as the Pinelands Macroinvertebrate Index (PMI) was one that met the criteria listed above and that could not be improved (increased DE, lower variability) by substituting, adding, or removing metrics.

Metrics are scored on a common scale prior to combination in an index. The scale ranges from 0 to 100 and the optimal score is determined by the distribution of data. For metrics that decrease with increasing stress, the 95th percentile of all Pinelands data was considered optimal and scored as 100 points. All other metric values were scored as a percentage of the 95th percentile value (Figure 3) except those that exceeded 100, which were assigned a score of 100. The 95th percentile value was selected as optimal instead of the maximum so that outlying values would not skew the scoring scale.

Each alternative index was evaluated based on discrimination efficiency (DE, calculated as for individual metrics), separation of reference and degraded index means, the inter-quartile range of reference index scores, and variability within reference samples, among seasons, and among years.

6.1 Index Composition Results

Forty-five (45) index alternatives were calculated and tested (Appendix E). The index alternative that is recommended for adoption as the PMI contains seven metrics, as follows:

Insect taxa
Non-insect taxa
Percent Plecoptera and Trichoptera
Percent Diptera excluding Tanytarsini
Percent Mollusca and Amphipoda
Beck's Biotic Index (using Hilsenhoff taxa attributes)
Percent Filterers

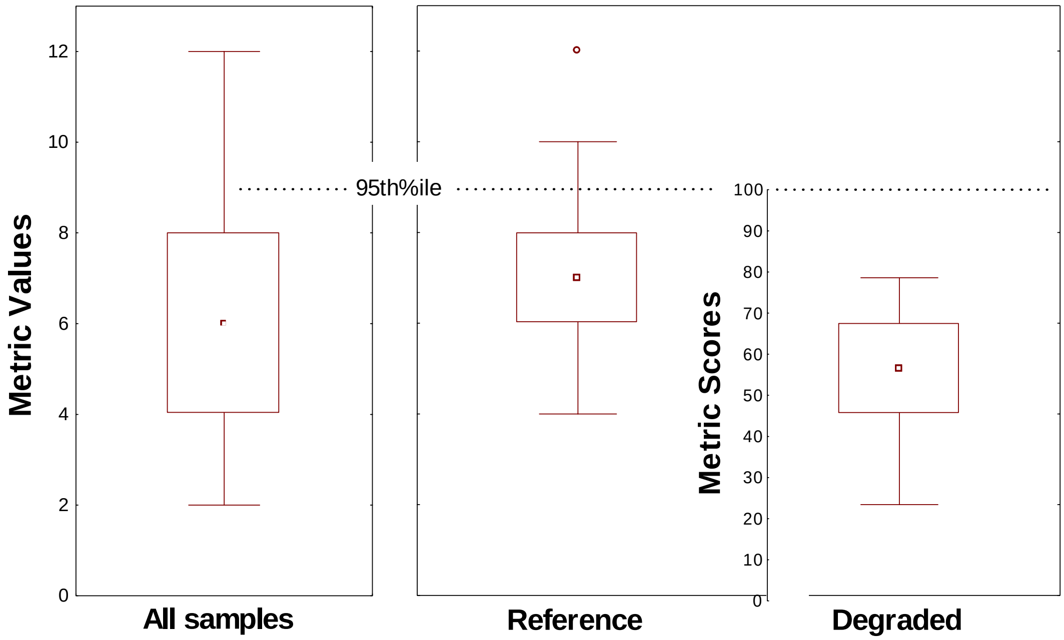

Figure 3. Metric scoring schematic for metrics that decrease with increasing stress.
For metrics that increased with increasing stress, the 5th percentile of the data was considered optimal and assigned a value of 100 points. Metric values are scaled down towards 0. The lower end of the scoring scale is defined as the maximum metric value encountered in the Pinelands dataset.

The two richness metrics, insect taxa and non-insect taxa, together account for all taxa in the samples, as does the commonly used metric, total taxa richness. Like total taxa richness, taxa richness of insects decreases with increasing stress in the Pinelands. However, non-insect taxa increase. The Crustacea and Mollusca taxa metric discriminated well (78%), but it was not used in the index for two reasons. First, the combination insect and non-insect taxa metrics were preferable because of their complete coverage of taxa and second, the Crustacea and Mollusca taxa are represented as a component of the preferable non-insect taxa metric. Although they represent slightly different components of the benthic assemblage, the non-insect and Crustacea and Mollusca metrics were were correlated (r = 0.79).

Three composition metrics were included in the index, percent Plecoptera and Trichoptera, percent Diptera excluding Tanytarsini, and percent Mollusca and Amphipoda. A fourth, percent Coleoptera, had a high DE (67%), but was also highly variable within the reference sites (CV = 1.40) and over seasons (CV = 2.20), and so it was not included. The Beck's Biotic Index did not have the highest DE compared to other tolerance metrics (e.g., percent intolerant, tolerant taxa using TALU values). However, it performed as well or better than the other metrics when combined in the index and was favored because the response mechanism is well understood (see description below).

No metrics used in the index were correlated at r > 0.85 or r < -0.85 (Table 4). The highest correlation was between insect taxa and the Beck's Biotic Index (r = 0.83).

Table 4. Correlations (Pearson Product-Moment) among candidate metrics of the PMI (calibration and verification data combined).

	Insect taxa	**Non-insect taxa**	**Plecoptera-Tricoptera taxa**	**Crustacea-Mollusca taxa**	**Non-insect %**	**EPT % (no Baetidae)**	**Plecoptera %**	**Tricoptera %**	**Plecoptera-Tricoptera %**	**Coleoptera %**	**Diptera % (no Tanytarsini)**	**Crustacea-Mollusca %**
Insect taxa	1											
Non-insect taxa	-0.06	1										
Plecoptera-Tricoptera taxa	0.80	-0.26	1									
Crustacea-Mollusca taxa	-0.13	0.79	-0.27	1								
Non-insect %	-0.54	0.52	-0.52	0.47	1							
EPT (no Baetidae) %	0.49	-0.37	0.70	-0.32	-0.61	1						
Plecoptera %	0.20	-0.17	0.31	-0.15	-0.30	0.48	1					
Tricoptera %	0.41	-0.31	0.62	-0.29	-0.50	0.83	0.10	1				
Plecoptera-Tricoptera %	0.44	-0.34	0.67	-0.31	-0.56	0.92	0.53	0.90	1			
Coleoptera %	0.17	-0.03	0.13	-0.01	-0.17	0.12	0.02	0.14	0.13	1		
Diptera (no Tanytarsini) %	0.05	-0.28	-0.09	-0.29	-0.51	-0.24	-0.07	-0.21	-0.21	-0.16	1	
Crustacea-Mollusca %	-0.32	0.38	-0.30	0.56	0.67	-0.41	-0.21	-0.34	-0.38	-0.09	-0.37	1
Mollusca %	-0.23	0.44	-0.24	0.57	0.49	-0.29	-0.14	-0.24	-0.27	-0.04	-0.29	0.65
Mollusca-Amphipoda %	-0.31	0.41	-0.30	0.59	0.62	-0.36	-0.17	-0.30	-0.33	-0.07	-0.37	0.87
Amphipoda %	-0.20	0.11	-0.17	0.22	0.37	-0.21	-0.09	-0.18	-0.19	-0.06	-0.23	0.57
Beck’s BI (Hilsenhoff)	0.83	-0.24	0.90	-0.24	-0.54	0.65	0.33	0.53	0.60	0.19	-0.05	-0.32
Beck’s BI (TALU)	0.82	-0.28	0.90	-0.27	-0.55	0.65	0.34	0.50	0.58	0.15	-0.04	-0.32
Hilsenhoff’s Biotic Index	-0.52	0.40	-0.64	0.30	0.72	-0.74	-0.47	-0.58	-0.70	-0.19	-0.12	0.36
Intolerant %	0.39	-0.37	0.57	-0.32	-0.53	0.67	0.57	0.49	0.67	0.12	0.01	-0.37
Intolerant taxa	0.78	-0.26	0.89	-0.26	-0.51	0.65	0.34	0.53	0.60	0.17	-0.07	-0.31
Tolerant taxa (Hilsenhoff)	0.27	0.74	-0.09	0.52	0.25	-0.29	-0.18	-0.24	-0.28	-0.05	-0.08	0.18
Tolerant taxa (TALU)	0.70	0.56	0.33	0.37	-0.09	0.05	-0.03	0.07	0.04	0.10	-0.06	-0.02
Filterer %	0.05	0.04	0.11	0.07	-0.15	0.15	-0.06	0.31	0.24	-0.02	0.02	-0.02
Shredder taxa	0.73	-0.08	0.69	-0.12	-0.40	0.41	0.28	0.32	0.39	0.09	0.04	-0.23

Table 4 (continued).

	Mollusca %	Mollusca-Amphipoda %	Amphipoda %	Beck's BI	Beck's BI (TALU)	HBI	Intolerant %	Intolerant taxa	Tolerant taxa	Tolerant taxa (TALU)	Filterer %	Shredder taxa
Mollusca %	1											
Mollusca-Amphipoda %	0.75	1										
Amphipoda %	-0.03	0.63	1									
Beck's BI (Hilsenhoff)	-0.25	-0.31	-0.17	1								
Beck's BI (TALU)	-0.26	-0.32	-0.18	0.96	1							
Hilsenhoff's Biotic Index	0.28	0.30	0.13	-0.69	-0.67	1						
Intolerant %	-0.27	-0.32	-0.17	0.62	0.61	-0.82	1					
Intolerant taxa	-0.23	-0.29	-0.17	0.96	0.94	-0.67	0.66	1				
Tolerant taxa (Hilsenhoff)	0.26	0.19	-0.02	-0.11	-0.12	0.36	-0.34	-0.13	1			
Tolerant taxa (TALU)	0.09	0.02	-0.09	0.34	0.28	-0.05	-0.06	0.28	0.75	1		
Filterer %	0.27	0.08	-0.20	0.08	0.05	-0.29	0.15	0.08	-0.08	0.05	1	
Shredder taxa	-0.21	-0.26	-0.14	0.68	0.69	-0.42	0.36	0.66	0.13	0.42	-0.02	1

Seventeen of the 18 degraded sites had index scores lower than the 25th percentile of the reference site scores (Figure 4) resulting in an index DE of 94.4%. The mean separation of index scores between reference and degraded sites was 22.4 points. The inter-quartile range of reference index values was 8 points. One reference site with an outlying PMI score (Jakes Brook) also had the lowest overall habitat score (161) of all reference sites, scoring 4 out of 20 for pool variability.

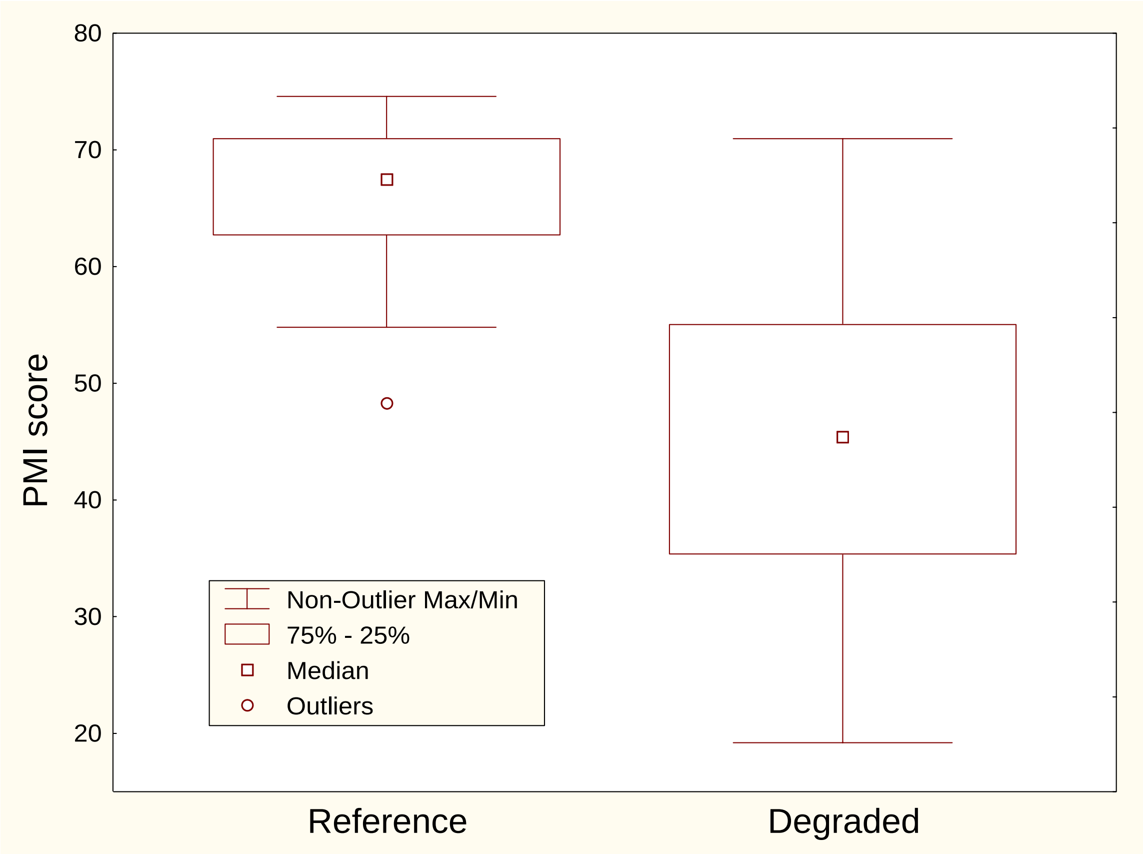

Figure 4. PMI values in reference and degraded Pinelands sites, calibration data

6.2 Interpretation of Index Metrics

The mechanisms by which stresses in the Pinelands cause changes in the benthic macroinvertebrate community are poorly understood partly because the nature of the stresses is unusual. In most systems, acidic water (low pH) is not the undisturbed condition; rather, acidification of streams represents a stress on the aquatic biota. This contrasts with streams in the Pinelands, which are naturally acidic (pH<5.5). Degraded Pinelands streams tend to have higher pH, but the effects of this on the Pinelands aquatic biota are not well understood. Zampella (1994) found that, in addition to pH, several other environmental variables change predictably along a degradation gradient. These include specific conductance, calcium, magnesium, nitrate, ammonia, and phosphorus. Because these variables are all highly correlated, discerning the effect of any one of them on aquatic macroinvertebrates is difficult without further experimental study. It is likely that their effects may be cumulative or synergistic. Although the mechanisms by which aquatic macroinvertebrates respond to environmental stressors may not be fully explained, the fact that many metrics are responsive to a general gradient of stress (reference – degraded) suggests that they are responding to a common suite of stressors. The metrics in the index were therefore selected largely based on their demonstrated responses in this data set.

Insect taxa

The median, 25th percentile, and non-outlier minimum of insect taxa in reference Pinelands samples were 23.5, 20, and 16 taxa, respectively (Figure 5a). A single reference sample had a low outlier value of 8 taxa. In contrast, the median value of insect taxa in degraded samples was 17.5, and almost half of the degraded samples had 16 or fewer insect taxa.

High taxa richness usually correlates with increased ecological health of the stream and suggests that niche space, habitat, and food sources are adequate to support the survival and propagation of many species. Generalist and tolerant taxa may inhabit both high and low quality streams, but specialists and sensitive taxa will only inhabit streams that support their particular requirements. Some of the sensitive taxa are territorial or otherwise limited by availability of sufficient and adequate habitat and water quality. They may occur in small numbers or low densities, leaving them susceptible to local extirpation when conditions become less than adequate.

Non-insect taxa

Non-insects are apparently inhibited by the low pH conditions in undisturbed Pinelands streams. In this data set, snails, worms, and flatworms are more common in degraded sites compared to reference sites. Half of the reference samples had between two and four non-insect taxa, whereas three-quarters of the degraded samples had more than six non-insect taxa (Figure 5a).

Calcium and pH are highly correlated in acidic streams (e.g., Zampella, 1994). Silica sands dominate soils and sediments of the Pinelands, therefore calcium salts are naturally absent and waters are unbuffered. Roads, dwellings, bridges, etc. are a source of calcium buffering and alkalinity. At higher pH values, as are found in the degraded sites, calcium is more available. Many non-insects, especially mollusks and some crustaceans, require calcium for the development of their shells and exoskeletons. The greater availability of calcium in degraded sites may make those sites more favorable for mollusks and other non-insects.

Percent Plecoptera and Trichoptera

Most of the stoneflies (Plecoptera) are predators or shredders (Merritt and Cummins 1996), dependent on animal food sources or coarse particulate matter. They are generally clingers, dependent on stable substrate, and generally require high dissolved oxygen concentrations. Small numbers of stoneflies in a sample indicate that the stream may have a dissolved oxygen stressor (heat, low aeration, high oxygen demand) or a substrate stressor (high deposition or excessive fine sediments).

Caddisflies (Trichoptera) are filterer, shredder, and collector feeders that cling, climb, or sprawl on the substrates (Merritt and Cummins 1996). As a group they are sensitive to organic pollution that may accompany more intensive land use. Half of the reference samples had between 7 and 34% Plecoptera and Trichoptera, whereas three-quarters of the degraded samples had less than 10% (Figure 5a).

Percent Diptera excluding Tanytarsini
True flies (Diptera) are diverse in habit, feeding mechanisms, and pollution tolerance (Merritt and Cummins 1996). They can be found freely suspended or swimming, among aquatic vegetation, and buried in sediments. Midges (Chironomidae) make up a large proportion of this group. Percentages of Diptera (and midges especially) are generally expected to increase with increasing stress. In the Pinelands, the opposite effect was observed. The Tanytarsini has been found in previous studies to be generally more sensitive to stress than other midges (Stribling et al. 1998). They also responded to stress opposite expectations, increasing in the degraded sites. The increase of Tanytarsini with stress may be attributed to their filter feeding mechanism (see below). The decrease in Diptera (except for Tanytarsini) may be explained by the relative increase in other taxa groups as stress levels increase in the Pinelands. Half of the reference sites had between 27 and 62% Diptera (without Tanytarsini) and three-quarters of the degraded sites had less than 27% (Figure 5a).

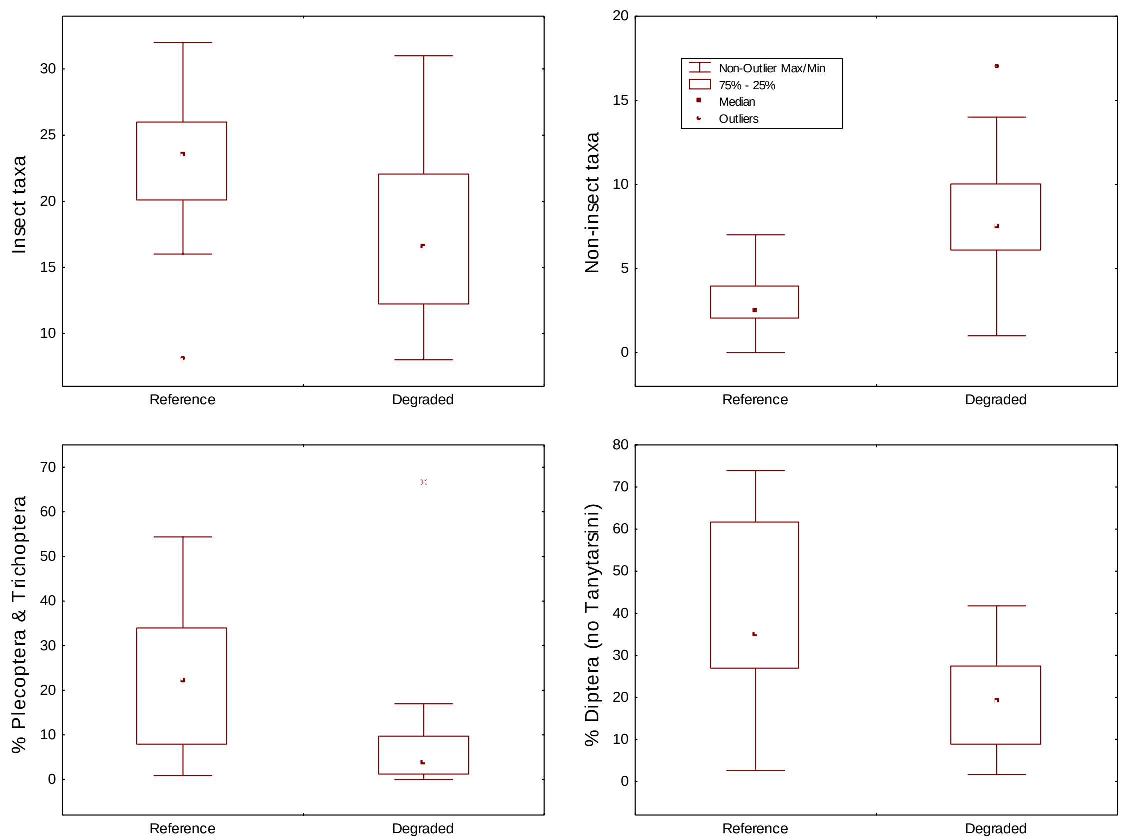

Figure 5a. Metric discrimination between reference and degraded sites.

Percent Mollusca and Amphipoda

The possible mechanisms for mollusk and amphipod increase with increasing stress were discussed above in relation to non-insect taxa increases. Mollusks may be sensitive to the low pH, low calcium reference conditions and amphipods may find more food resources with increased stresses. Three-quarters of the reference sites had less than 4% Mollusca and Amphipoda, whereas three-quarters of the degraded sites had more than 4% (Figure 5b). Mollusks are more dominant than amphipods in this metric.

Beck's Biotic Index

The weighted enumeration of intolerant taxa in the community expresses the richness of taxa in the most sensitive and second most sensitive classes. Since the most sensitive taxa are weighted more heavily, their presence in the assemblage is more important to this metric. The metric increases with better water and habitat quality because sensitive taxa can thrive in the absence of stress. The interquartile ranges for Beck's Biotic index in reference and degraded sites are 7 – 16 and 2 – 11, respectively (Figure 5b). Beck's Biotic Index is calculated as 2*(most sensitive taxa richness) + (moderately sensitive taxa richness). Most sensitive and moderately sensitive taxa correspond to those taxa having Hilsenhoff tolerance values of 0 - 1, and 2 - 4, respectively.

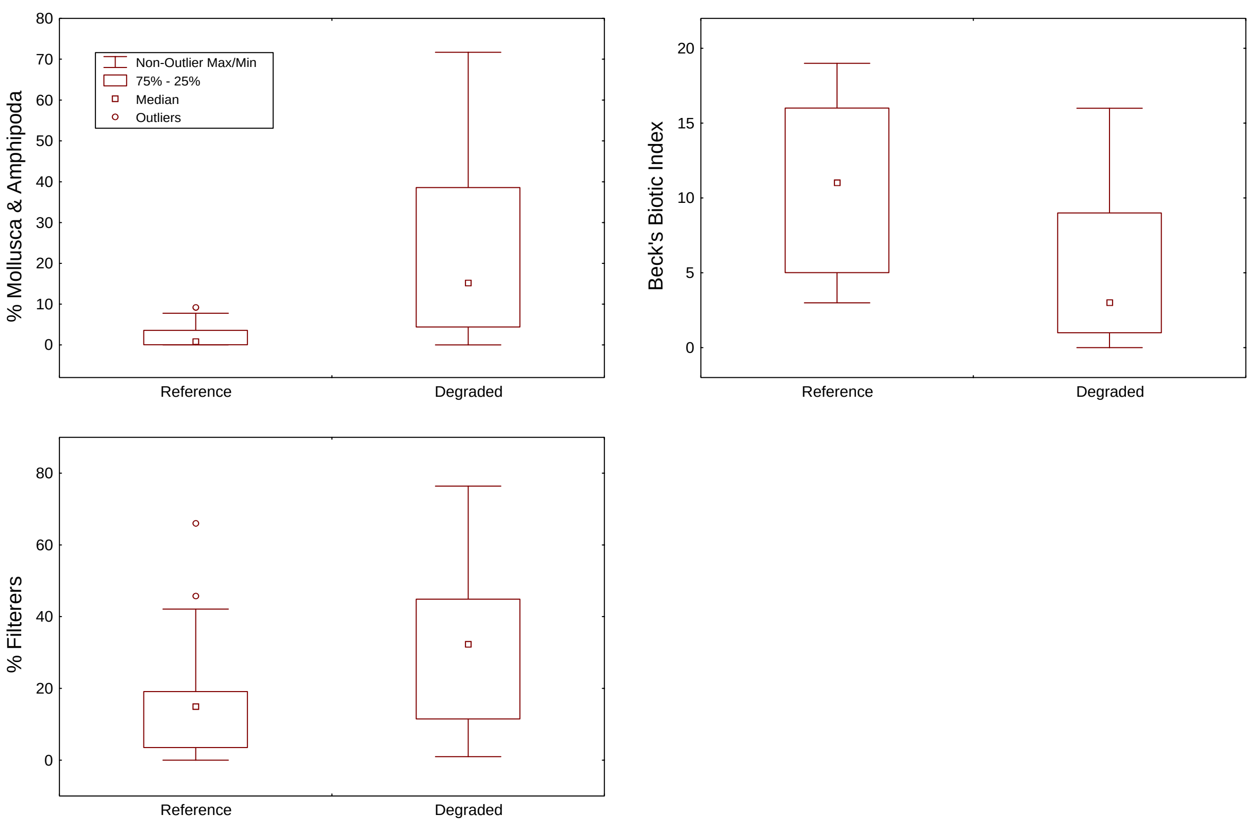

Figure 5b. PMI metric discrimination between reference and degraded sites.

Percent Filterers
As stressors increase in Pinelands streams, nutrients and ions also increase (Zampella 1994). Suspended particles that are food resources for filter feeders may also increase, allowing their proliferation. Filterers can decrease in response to toxic stresses (Barbour et al. 1996), but this does not appear to be the dominant process in the Pinelands. Blackflies, pisidiid clams, net-spinning caddisflies, and tanytarsine midges are the most abundant filterers. In half the reference sites, filterers comprise between 3 and 19% of the assemblage. In degraded sites filterers make up between 11 and 45% of the assemblage in half the sites (Figure 5b). When this metric was removed from the PMI, index DE was reduced from 94.4% to 66.7% (Appendix E, alternative 23).

One calibration reference sample from Black Run had 66% blackflies (Diptera: Simuliidae). This sample was collected April 5th, 2001. NJDEP biologists use professional judgment when assessing early spring samples with a predominance of blackflies for three reasons: 1) the taxon is abundant during short reproductive periods, 2) temporary super-abundance is not known to indicate high quality or low quality stream conditions, and 3) blackfly super-abundance can influence metric results in a way that is not representative of biotic integrity. In Black Run, the percent filterer metric received a low score, but because the other index metrics had high scores, the sample received a PMI score that was similar to other reference samples. This shows that the PMI is robust to temporary super-abundance of blackflies (in this case), but index results from samples that are collected in early spring and are dominated by blackflies should still be interpreted carefully.

6.3 Index Variability by Season and Year

Annual and seasonal standard deviations of the PMI within sites were slightly less than the variability measured among reference sites (Table 5). The temporal variability among reference sites was less than temporal variability among degraded sites. Data were insufficient for assessing which season might be less variable.

Table 5. Variability of the PMI among reference sites, among years, and among seasons. Temporal variability was calculated for all samples, reference only (ref) and degraded only (deg).

	Among Reference Sites	Annual (ref/deg)	Seasonal (ref/deg)
PMI Std. Dev.	6.8	6.5 (5.8 / 7.8)	5.6 (4.2 / 6.1)

6.4 Index Verification

The index discriminated adequately using the verification data (Figure 6). All (100%) of the degraded index values were below the calibration reference 25th percentile (__) and 50% of reference index values were above. Compared to calibration index values the verification index values were generally lower in both reference and degraded sites. The poor performance in reference verification sites (50% instead of 75% above the calibration 25th percentile) can be attributed to the random selection of calibration and verification data.

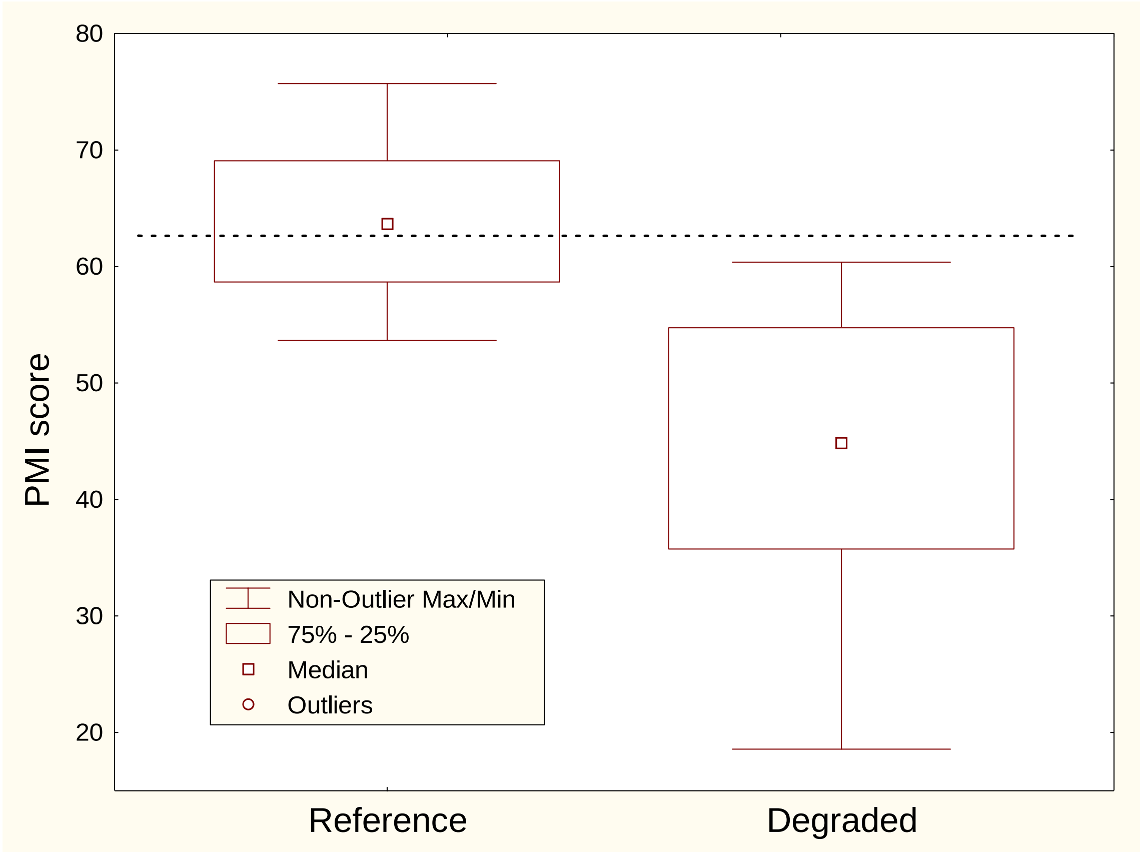

Figure 6. PMI values in reference and degraded Pinelands sites, verification data. The 25th percentile of calibration reference samples is represented as a dashed line.

6.5 Comparison to the NJ Impairment Score (NJIS)

The index that is currently used for rapid bioassessment in the rest of (non-Pinelands) New Jersey is based on the following 5 metrics: taxa richness (total families), EPT, percent dominance, percent EPT, and the Hilsenhoff Biotic Index (NJDEP AMNET website). The metrics are scored on a 0 – 3 – 6 scale using family level taxonomic information. Metric scores are added to arrive at an index value, the NJIS, with a possible maximum of 30 points.

When the NJIS was applied to the calibration data, discrimination of reference and degraded sites was unsatisfactory (Figure 7). For this analysis, the NJIS was calculated in two ways: 1) scoring on a 100 point scale with the 95th percentile of the data determining optimal metric scores using operational level taxonomy (comparable to the PMI) and 2) using the 0 – 3 – 6 scoring criteria with family level taxonomy as it is applied throughout the State outside of the Pinelands. On the 100 point scale the DE was 61.1 and on the 0 – 3 – 6 scale the DE was 44.4.

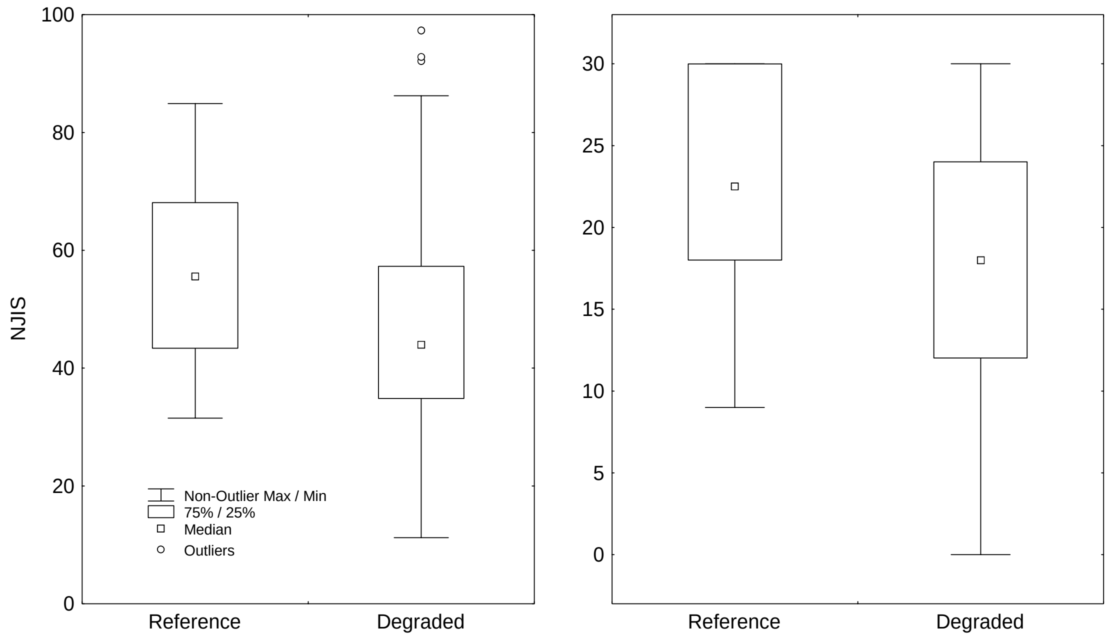

Figure 7. The New Jersey Impairment Score (NJIS) in reference and degraded sites of the Pinelands. The index metrics were scored in two ways: A) on a 100 point scale comparable to the PMI, and B) on a 30 point scale as applied outside of the Pinelands.

6.6 Application of the PMI

The index can be calculated for any sample collected within the NJ Pinelands using the NJDEP methods (see Section 1.1), following three steps. First, the macroinvertebrate sample must be collected between April 1 – November 30 and processed according to NJDEP standards. Second, the metrics must be calculated using taxa attributes (tolerance values, functional feeding groups) supplied by NJDEP. Third, metric scores must be calculated using the scoring formulae in Table 6, and scores of the seven index metrics are averaged to arrive at the PMI. Appendix F contains the results of this process for the data used to develop this model.

Table 6. Scoring formulas for metrics in the PMI. The scoring scale is 0 – 100. Calculated scores that are outside of that range are re-set to the closest extreme before scores are averaged as an index. Direction of metric change with increasing stress is shown with + or – signs.

Metric #	Metric Name	Scoring formula
1	Insect taxa (-)	100 * metric #1 / 37
2	Non-insect taxa (+)	100 * (17- metric #2) / (17-1)
3	Percent Plecoptera and Trichoptera (-)	100 * metric #3 / 59
4	Percent Diptera excluding Tanytarsini (-)	100 * metric #4 / 75
5	Percent Mollusca and Amphipoda (+)	100 * (84- metric #5) / (84-0)
6	Beck's Biotic Index (-)	100 * metric #6 / 26
7	Percent Filterers (+)	100 * (93- metric #7) / (93-0)

The PMI value calculated for a new observation is compared to the entire (calibration and verification) reference PMI distribution to estimate similarity to, or departure from, reference conditions. A threshold of impairment may be derived from the reference PMI distribution. If the 25th percentile is used (60.5 PMI points, Table 7), then roughly 25% of reference sites will be below the threshold, as will 88.9% of degraded sites. In other words, 25% of true reference sites will be incorrectly identified as degraded; this is referred to as Type I error. On the other hand, only 11.1% of true degraded sites will be incorrectly identified as reference; this is referred to as Type II error. Using a 25th percentile thus minimizes Type II error, at the expense of Type I error.

Type I index errors include those sites that meet reference physical and chemical criteria but that have lower PMI scores. Errors of this type can be attributed to incorrect reference designations, unperceived and unmeasured stressors, biological variability, and index development and calibration error. Type II errors include those sites that meet degraded physical and chemical criteria but that have higher PMI scores. Errors of this type can be attributed to incorrect degraded designations, stressors that are buffered by some unknown or unmeasured interaction, biological variability, and index development and calibration error. Minimizing the rate of type II errors is more protective of the natural resource than minimizing Type I errors. Thus, allowing some reference sites to be called impaired simultaneously allows more impaired sites to be recognized.

Although the use of the 25th percentile of the reference condition is standard in multimetric index bioassessment, other thresholds may be chosen that alter the Type I and Type II errors (Table 7). If a lower Type I error rate is desired, a lower threshold may be chosen (e.g., 15th percentile; 60.1 PMI points). At the 15th percentile of reference, the percentage of true degraded sites incorrectly identified as reference remains 11.1%. The 25th through 15th percentiles lie within a half point spread of the PMI. While we show statistical advantage of using the 15th percentile, in this data set it is practically equivalent to using the 25th percentile, largely because the numbers of sites and samples is relatively small. The minimum threshold level is the 5th percentile, which would result in no incorrectly identified reference sites, but 55.6% incorrectly identified degraded sites. Calibration and verification data were averaged for this analysis in order to arrive at threshold levels that reflect all the variation found in the data set.

Table 7. PMI percentiles for consideration as thresholds with associated error rates. These statistics were based on average index scores, using both calibration and verification data.

Reference Statistic	PMI %ile	DE	Type I error	Type II error
Median	66.7	94.4	50	5.6
25th	60.5	88.9	25	11.1
20th	60.4	88.9	20	11.1
15th	60.1	88.9	15	11.1
10th	54.8	77.8	10	22.2
5th/min	48.3	44.4	0	55.6

6.7 Index Performance

The PMI is efficient at discriminating reference and degraded sites based on the benthic macroinvertebrate metrics. At 60.1 PMI points, there is 15% Type I error and 11.1% Type II error (Table 7). At this threshold, the total error rate is lower than with other thresholds. The PMI is less variable in reference sites compared to degraded sites (Figure 8). Within reference sites, variability appears to be lower in spring samples compared to summer or fall. Spring samples may be more reliable indicators of Pinelands stream conditions.

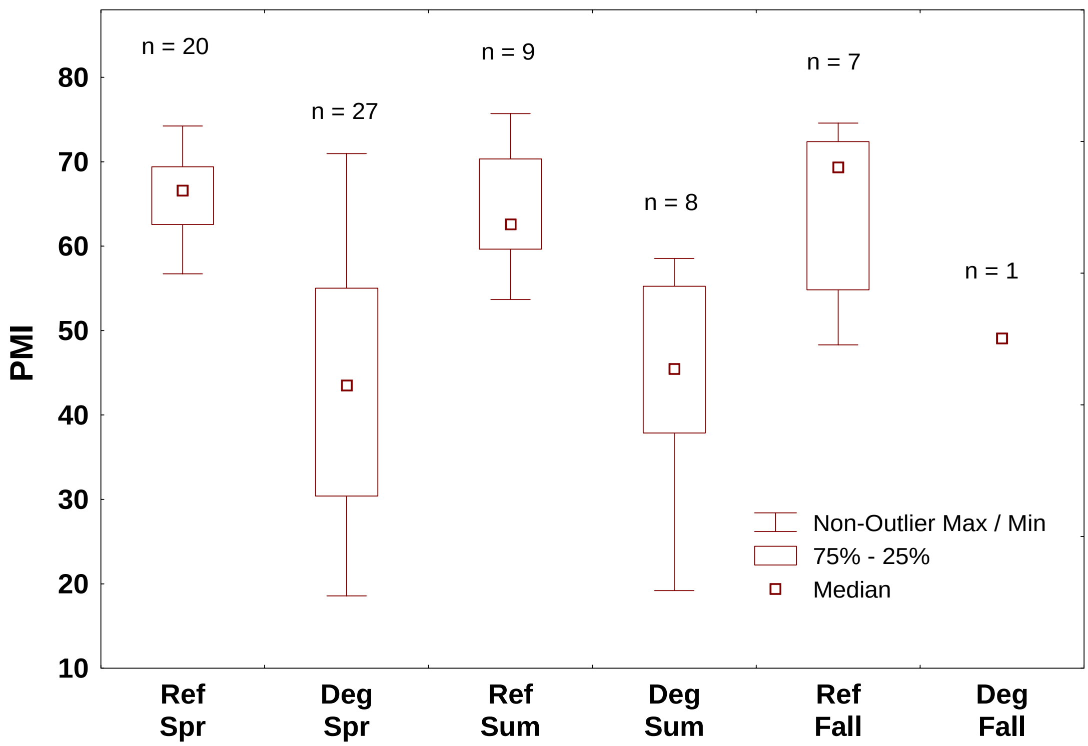

Figure 8. PMI scores by reference status and season.

The two reference sites with the lowest PMI scores were Jake's Brook and Black's Brook. The two degraded sites with the highest PMI scores were in the Great Egg Harbor River. The poor reference sites and high-quality degraded sites were designated reference and degraded based on land use criteria (Table 1); status was not confirmed by NJDEP field biologists (Figure 9).

The PMI scores were plotted in relation to the first axis of a principle components analysis using available environmental variables (Figure 10). Land uses, pH, and specific conductance loaded heavily on PCA factor 1, which explained 50.9% of the variance. The response curve appears to be generally linear, though it may be steeper where land use intensity, pH, and specific conductance are highest (negative end of the PCA axis). When applying the PMI, investigators should keep in mind that the index may be more sensitive to severe stresses than it is to moderate stresses.

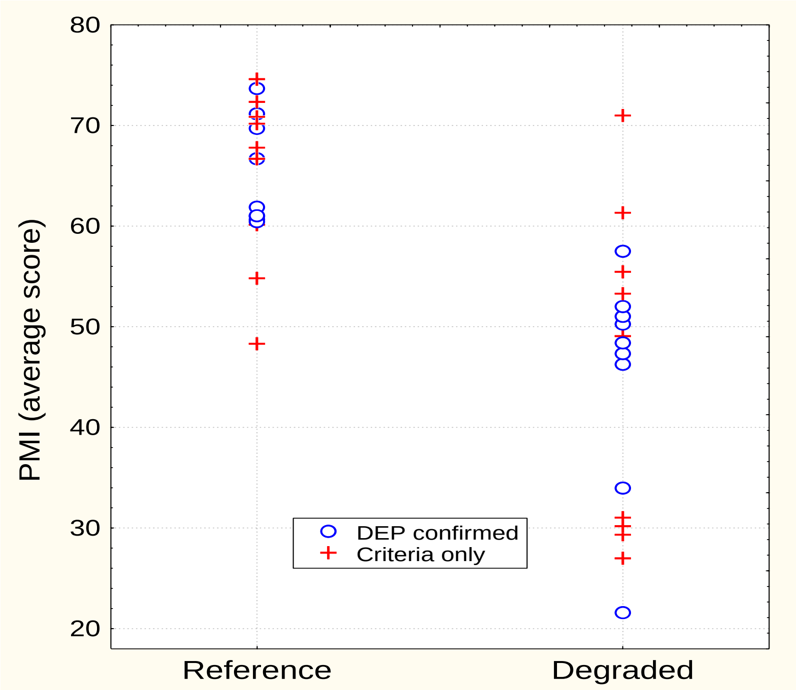

Figure 9. Average PMI scores in reference and degraded sites, showing sites with confirmed reference status and those that were identified using numeric site criteria only.

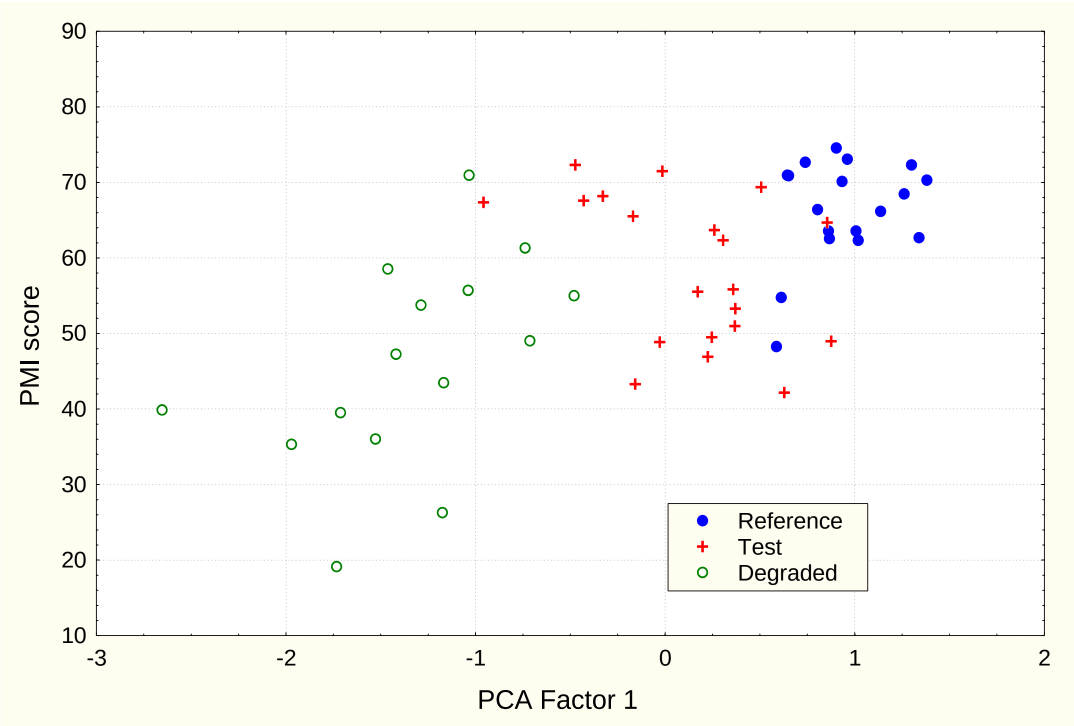

Figure 10. PMI scores in relation to PCA factor 1 showing reference, intermediate (test), and degraded calibration samples.

7.0 Conclusions

The Pinelands Macroinvertebrate Index (PMI) was developed as a tool for identifying biological degradation in the New Jersey Pinelands. Seven metrics are calculated and scored for inclusion in the index, including:

- Insect taxa
- Non-insect taxa
- Percent Plecoptera and Trichoptera
- Percent Diptera excluding Tanytarsini
- Percent Mollusca and Amphipoda
- Beck's Biotic Index
- Percent Filterers

For averaged calibration and verification data, sixteen of eighteen (89%) degraded sites had PMI scores lower than the 25th percentile of reference scores. At a PMI threshold value of 60.1, the total error rate of the index is minimized.

We recommend applying the PMI in Pinelands sites where samples are collected between April 1 and November 30 and processed using NJDEP protocols. Metrics must be calculated using taxa identifications at levels comparable to NJDEP levels (mostly genus), attributes defined by NJDEP, and formulae in Table 6 of this report. We also recommend using the PMI value of 60 as a threshold for identifying biological samples and sites that are similar to reference (above 60) and degraded (below 60). While this PMI value may become a biocriterion in the future, this report provides only technical recommendations, not programmatic criteria or standards.

We further recommend that the PMI should be refined using additional data points, preferably in previously unsampled sites. This addition to the current data set would allow for identification of truly independent verification data and would provide a larger calibration data set for future refinement of the index. Samples should be collected during the April 1 to November 30 sampling period. The state might consider narrowing the index period to reduce the variability introduced by seasonal changes in the benthic assemblage.

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APPENDIX A

ENVIRONMENTAL DATA

Table A-1. Environmental variables used in reference and degraded site identification.

Station ID	Waterbody	Calibration status	Reference status	Date	Predicted Land Use	Percent urban	Percent agriculture	Total habitat score	Conductivity	pH
AN0145	Mt Misery Bk	Verif	Ref	06/25/2002	4.26	1.67	1.54	183	30	4.3
AN0145	Mt Misery Bk	Calib	Ref	09/19/2002	4.26	1.67	1.54	185	28	5.3
AN0146	McDonalds Br	Verif	Intermed	06/11/1991	-1.43	0	0			
AN0146	McDonalds Br	Verif	Intermed	09/24/1991	-1.43	0	0			
AN0146	McDonalds Br	Verif	Intermed	04/17/1991	-1.43	0	0			
AN0164	Black Run	Verif	Ref	04/02/1998	5.10	3.6	0	181	44	4.4
AN0164	Black Run	Calib	Ref	04/05/2001	5.10	3.6	0	180	38	5.1
AN0164	Black Run	Verif	Ref	09/24/1991	5.10	3.6	0			
AN0164	Black Run	Verif	Ref	04/10/1991	5.10	3.6	0			
AN0164	Black Run	Verif	Ref	06/11/1991	5.10	3.6	0			
AN0165	UNT to Black Run	Verif	Ref	04/05/2001	9.32	0.08	1.35	159	67	3.9
AN0165	UNT to Black Run	Calib	Ref	04/02/1998	9.32	0.08	1.35	178	70	3.8
AN0165	UNT to Black Run	Verif	Ref	06/11/1991	9.32	0.08	1.35			
AN0165	UNT to Black Run	Verif	Ref	09/24/1991	9.32	0.08	1.35			
AN0165	UNT to Black Run	Verif	Ref	04/10/1991	9.32	0.08	1.35			
AN0166	Barton Run	Verif	Deg	04/28/1998	63.09	39.19	5.57	157	113	6.5
AN0166	Barton Run	Verif	Deg	04/05/2001	63.09	39.19	5.57	133	134	6.6
AN0166	Barton Run	Calib	Deg	09/12/2002	63.09	39.19	5.57	158	139	6.5
AN0166	Barton Run	Verif	Deg	04/14/1993	63.09	39.19	5.57			
AN0166	Barton Run	Verif	Deg	06/25/2002	63.09	39.19	5.57	167	147	6.2
AN0167	Kettle Run	Verif	Deg	04/02/1998	58.26	49.17	1.05	139	84	6.5
AN0167	Kettle Run	Calib	Deg	04/03/2001	58.26	49.17	1.05	135	116	7.6
AN0167	Kettle Run	Verif	Deg	04/14/1993	58.26	49.17	1.05			
AN0168	Haynes Ck	Verif	Deg	04/28/1998	44.02	40.4	1.13	148	82	6.2
AN0168	Haynes Ck	Verif	Deg	04/14/1993	44.02	40.4	1.13			
AN0168	Haynes Ck	Calib	Deg	04/05/2001	44.02	40.4	1.13	148	80	6.4
AN0519	Toms River	Verif	Intermed	10/12/1994	41.20	18.45	3.81			

Station ID	Waterbody	Calibration status	Reference status	Date	Predicted Land Use	Percent urban	Percent agriculture	Total habitat score	Conductivity	pH
AN0519	Toms River	Calib	Intermed	10/14/1999	41.20	18.45	3.81	164	100	5.6
AN0521	Maple Root Br	Calib	Intermed	10/14/1999	18.31	6.17	3.21	161	87	4
AN0521	Maple Root Br	Verif	Intermed	10/12/1994	18.31	6.17	3.21			
AN0522	Dove Mill Br	Calib	Intermed	10/14/1999	32.38	19.26	4.8	163	75	5.5
AN0522	Dove Mill Br	Verif	Intermed	10/13/1994	32.38	19.26	4.8			
AN0523	Toms River	Calib	Intermed	10/14/1999	38.70	16.11	4.4	169	91	5.6
AN0523	Toms River	Verif	Intermed	10/13/1994	38.70	16.11	4.4			
AN0525	UNT to Ridgeway Br (Bordens Mill Br)	Verif	Deg	10/18/1994			30.8			
AN0525A	UNT to Ridgeway Br	Calib	Deg	10/12/1999	26.19	14.2	25.71	173	65	5.3
AN0526	Shannae Bk	Calib	Intermed	10/12/1999	19.90	6.46	10.1	188	49	5.4
AN0526	Shannae Bk	Verif	Intermed	10/18/1994	19.90	6.46	10.1			
AN0527	Ridgeway Br	Calib	Intermed	10/19/1999	19.02	7.86	5.69	169	78	4.3
AN0527	Ridgeway Br	Verif	Intermed	10/19/1994	19.02	7.86	5.69			
AN0529	Blacks Br	Calib	Intermed	10/12/1999	22.78	12.06	0.15	193	75	4.7
AN0529	Blacks Br	Verif	Intermed	10/18/1994	22.78	12.06	0.15			
AN0530	Blacks Br	Calib	Ref	10/12/1999	8.04	6.89	0.85	171	43	4.7
AN0530	Blacks Br	Verif	Ref	10/19/1994	8.04	6.89	0.85			
AN0531	Old Hurricane Br	Verif	Ref	06/24/2002	15.62	4.99	1.67	183	46	4.3
AN0531	Old Hurricane Br	Verif	Ref	09/19/2002	15.62	4.99	1.67	187	33	5.4
AN0531	Old Hurricane Br	Calib	Ref	11/04/1999	15.62	4.99	1.67	169	77	3.5
AN0531	Old Hurricane Br	Verif	Ref	05/16/1991	15.62	4.99	1.67			
AN0531	Old Hurricane Br	Verif	Ref	11/14/1990	15.62	4.99	1.67			
AN0531	Old Hurricane Br	Verif	Ref	07/11/1991	15.62	4.99	1.67		40	6.9
AN0536	Wrangel Bk	Calib	Ref	11/04/1999	6.84	0.78	1.89	176	43	4.6
AN0536	Wrangel Bk	Verif	Ref	11/03/1994	6.84	0.78	1.89			
AN0540	Davenport Br	Verif	Intermed	11/29/1994	11.88	31.96	0.9			
AN0540	Davenport Br	Calib	Intermed	11/04/1999	11.88	31.96	0.9	178	52	4.6
AN0542	Jakes Br	Verif	Intermed	11/29/1994	25.47	0	0			
AN0542	Jakes Br	Calib	Intermed	11/04/1999	25.47	0	0	175	114	4

Station ID	Waterbody	Calibration status	Reference status	Date	Predicted Land Use	Percent urban	Percent agriculture	Total habitat score	Conductivity	pH
AN0543	Jakes Br	Verif	Ref	11/29/1994	5.88	7.52	0.58			
AN0543	Jakes Br	Calib	Ref	11/09/1999	5.88	7.52	0.58	161	52	4.1
AN0545	Webbs Mill Br	Verif	Intermed	11/14/1990	-0.58	0	3.26			
AN0548	Cedar Ck	Verif	Ref	09/19/2002	6.30	1.98	1.47	187	29	6
AN0548	Cedar Ck	Calib	Ref	06/05/2003	6.30	1.98	1.47	186	48.3	4.2
AN0551	N Br Forked River	Verif	Ref	11/29/1994	4.30	0.03	0			
AN0551	N Br Forked River	Calib	Ref	11/09/1999	4.30	0.03	0	178	49	4.1
AN0565	Hays Mill Ck	Calib	Deg	06/25/2002	51.40	43.8	10.94	179	83	6.4
AN0565	Hays Mill Ck	Verif	Deg	09/12/2002	51.40	43.8	10.94	178	116	6.8
AN0568	Prices Br	Verif	Deg	04/04/1991	34.96	18.16	30.14			
AN0571	Albertson Bk	Verif	Deg	06/20/2002	43.41	25.39	25.61	166	65	6.6
AN0571	Albertson Bk	Calib	Deg	09/10/2002	43.41	25.39	25.61	163	79	7.7
AN0574	Great Swamp Bk	Verif	Deg	09/05/2002	52.60	12.66	53.32	169	173	5.9
AN0574	Great Swamp Bk	Calib	Deg	06/13/2002	52.60	12.66	53.32	192	105	5.8
AN0575	Cedar Bk	Calib	Deg	06/13/2002	63.06	51.99	36.41	150	151	6.1
AN0575	Cedar Bk	Verif	Deg	09/05/2002	63.06	51.99	36.41	159	157	5.8
AN0578	Hammonton Ck	Calib	Deg	09/05/2002	41.88	15.89	26.06	184	121	6.2
AN0578	Hammonton Ck	Verif	Deg	06/13/2002	41.88	15.89	26.06	182	68	6.4
AN0581	Skit Br	Verif	Ref	09/12/2002	2.44	0	0.23	183	32	5.5
AN0581	Skit Br	Calib	Ref	06/13/2002	2.44	0	0.23	187	29	4.7
AN0584	Springers Bk	Verif	Deg	06/18/2002	60.52	25.81	32.53	171	190	5.6
AN0584	Springers Bk	Calib	Deg	09/12/2002	60.52	25.81	32.53	173	208	5.8
AN0586A	Batsto River	Verif	Intermed	07/15/1998	8.00	4.49	16.49			
AN0586A	Batsto River	Calib	Intermed	10/13/1998	8.00	4.49	16.49			
AN0587	Pen Swamp Br	Verif	Ref	09/17/2002	5.10	0	0	186	33	4.7
AN0587	Pen Swamp Br	Calib	Ref	06/18/2002	5.10	0	0	175	78	3.2
AN0587	Pen Swamp Br	Verif	Ref	11/02/1995	5.10	0	0			
AN0587	Pen Swamp Br	Verif	Ref	05/12/1995	5.10	0	0			
AN0587	Pen Swamp Br	Verif	Ref	08/08/1995	5.10	0	0			

Station ID	Waterbody	Calibration status	Reference status	Date	Predicted Land Use	Percent urban	Percent agriculture	Total habitat score	Conductivity	pH
AN0590	Landing Ck	Calib	Intermed	04/06/1995			4.86			
AN0590	Landing Ck	Verif	Intermed	04/04/2000			4.86	151		
AN0593	Indian Cabin Ck	Verif	Intermed	04/04/2000			1.77	180		
AN0593	Indian Cabin Ck	Calib	Intermed	04/06/1995			1.77			
AN0596	West Br Wading River	Verif	Intermed	04/04/1991	14.65	4	5.4			
AN0600	Tulpehocken Ck	Verif	Ref	06/19/2003	12.80	0.02	0.18	189	44	4.1
AN0600	Tulpehocken Ck	Calib	Ref	09/17/2002	12.80	0.02	0.18	178	29	6.4
AN0605	Papoose Br	Calib	Ref	09/19/2002	0.78	0.04	0.19	188	23	5
AN0605	Papoose Br	Verif	Ref	06/24/2002	0.78	0.04	0.19	185	30	4.36
AN0607	Oswego River (E Br Wading River)	Verif	Intermed	05/16/1991	2.70	1.21	2.01			
AN0607	Oswego River (E Br Wading River)	Verif	Intermed	09/23/1991	2.70	1.21	2.01			
AN0612	East Br Bass River	Calib	Ref	09/17/2002	6.66	1.32	0	184	39	4.6
AN0612	East Br Bass River	Verif	Ref	06/24/2002	6.66	1.32	0	179	35	4.29
AN0617	S Br Absecon Ck	Verif	Deg	06/21/1995	21.51	40.38	0.11			
AN0617	S Br Absecon Ck	Calib	Deg	06/13/2000	21.51	40.38	0.11	166	57	5.2
AN0618	Mill Br (Fenton's Mill)	Verif	Intermed	04/11/1995	11.65	31.17	1.14			
AN0618	Mill Br (Fenton's Mill)	Calib	Intermed	04/06/2000	11.65	31.17	1.14	168	45	4.9
AN0623	Great Egg Harbor River	Calib	Deg	06/13/2000	32.91	37.77	9.3	183	74	6.5
AN0623	Great Egg Harbor River	Verif	Deg	06/03/1993	32.91	37.77	9.3			
AN0623	Great Egg Harbor River	Verif	Deg	04/13/1993	32.91	37.77	9.3			
AN0623	Great Egg Harbor River	Verif	Deg	09/09/1992	32.91	37.77	9.3			
AN0625	Great Egg Harbor River	Calib	Deg	06/13/2000	30.77	31.31	8.06	186	63	6.5
AN0625	Great Egg Harbor River	Verif	Deg	06/03/1993	30.77	31.31	8.06			
AN0625	Great Egg Harbor River	Verif	Deg	04/13/1993	30.77	31.31	8.06			
AN0625	Great Egg Harbor River	Verif	Deg	09/09/1992	30.77	31.31	8.06			
AN0626	Penny Pot Stream	Verif	Deg	06/20/2002	49.16	14.64	36.76	174	110	5.4
AN0626	Penny Pot Stream	Calib	Deg	09/10/2002	49.16	14.64	36.76	174	157	6.2
AN0627	Hospitality Br	Verif	Deg	05/31/1995	32.89	28.89	27.67			
AN0627	Hospitality Br	Verif	Deg	09/10/2002	32.89	28.89	27.67	176	104	6.1

Station ID	Waterbody	Calibration status	Reference status	Date	Predicted Land Use	Percent urban	Percent agriculture	Total habitat score	Conductivity	pH
AN0627	Hospitality Br	Verif	Deg	05/02/2000	32.89	28.89	27.67	176	65	6.1
AN0627	Hospitality Br	Calib	Deg	06/20/2002	32.89	28.89	27.67	170	54	5.9
AN0628	Hospitality Br	Calib	Deg	05/23/1995	40.54	30.85	21.27			
AN0628	Hospitality Br	Verif	Deg	05/04/2000	40.54	30.85	21.27	148	62	6.6
AN0629	Faraway Br	Calib	Intermed	05/04/2000	4.93	14.85	3.75	180	40	4.6
AN0629	Faraway Br	Verif	Intermed	05/23/1995	4.93	14.85	3.75			
AN0630	White Oak Br	Verif	Intermed	05/23/1995	8.98	11.27	9.44			
AN0630	White Oak Br	Calib	Intermed	05/02/2000	8.98	11.27	9.44	176	64	3.9
AN0631	Marsh Lake Br (Collings Br)	Verif	Deg	05/02/2000	27.10	8.88	35.12	149	49	6
AN0631	Marsh Lake Br (Collings Br)	Calib	Deg	05/31/1995	27.10	8.88	35.12			
AN0632	Marsh Lake Br (Collings Br)	Verif	Deg	05/04/2000	41.39	9.1	26.34	178	92	5.8
AN0632	Marsh Lake Br (Collings Br)	Calib	Deg	05/23/1995	41.39	9.1	26.34			
AN0634	Three Pond Bk	Verif	Intermed	05/23/1995	13.58	5.95	1.31			
AN0634	Three Pond Bk	Calib	Intermed	05/04/2000	13.58	5.95	1.31	178	53	4.7
AN0635	Great Egg Harbor River	Calib	Intermed	06/08/2000	24.90	20.84	13.32	143	53	6.1
AN0635	Great Egg Harbor River	Verif	Intermed	04/13/1993	24.90	20.84	13.32			
AN0635	Great Egg Harbor River	Verif	Intermed	09/09/1992	24.90	20.84	13.32			
AN0635	Great Egg Harbor River	Verif	Intermed	06/03/1993	24.90	20.84	13.32			
AN0638	Mare Run	Verif	Ref	09/10/2002	14.52	6.09	2.5	178	75	5.9
AN0638	Mare Run	Calib	Ref	05/04/2000	14.52	6.09	2.5	180	38	4.5
AN0638	Mare Run	Verif	Ref	06/20/2002	14.52	6.09	2.5	165	25	5.8
AN0638	Mare Run	Verif	Ref	05/16/1995	14.52	6.09	2.5			
AN0639	Watering Race	Verif	Intermed	04/04/2000			3.05	175		
AN0639	Watering Race	Verif	Intermed	04/11/1995			3.05			
AN0640	Babcock Ck	Calib	Intermed	05/09/1995	20.86	16.56	7.68			
AN0640	Babcock Ck	Verif	Intermed	05/11/2000	20.86	16.56	7.68	184	73	4.6
AN0643	South River	Verif	Intermed	05/10/2000	34.21	15.08	22.22	175	88	5.3
AN0643	South River	Calib	Intermed	05/16/1995	34.21	15.08	22.22			
AN0644	South River	Calib	Intermed	05/10/2000	28.96	10.23	9.49	180	48	6.2

Station ID	Waterbody	Calibration status	Reference status	Date	Predicted Land Use	Percent urban	Percent agriculture	Total habitat score	Conductivity	pH
AN0644	South River	Verif	Intermed	05/16/1995	28.96	10.23	9.49			
AN0645	Stephens Ck	Calib	Intermed	05/10/2000	2.61	10.83	1.08	151	32	4.9
AN0645	Stephens Ck	Verif	Intermed	05/16/1995	2.61	10.83	1.08			
AN0647	Gibson Ck	Calib	Ref	05/16/2000	-1.50	8.28	1.85	179	30	4.7
AN0647	Gibson Ck	Verif	Ref	05/09/1995	-1.50	8.28	1.85			
AN0648	Tuckahoe River	Calib	Intermed	06/07/2000	0.51	13.03	5.72	178	27	5.1
AN0648	Tuckahoe River	Verif	Intermed	06/01/1995	0.51	13.03	5.72			
AN0649	Tuckahoe River	Verif	Intermed	06/01/1995	0.87	7.08	11.23			
AN0649	Tuckahoe River	Calib	Intermed	06/07/2000	0.87	7.08	11.23	178	25	5.3
AN0649	Tuckahoe River	Verif	Intermed	09/12/1995	0.87	7.08	11.23			
AN0651	McNeals Br	Calib	Ref	06/08/2000	0.93	7.79	0.38	184	36	4.5
AN0651	McNeals Br	Verif	Ref	06/01/1995	0.93	7.79	0.38			
AN0651	McNeals Br	Verif	Ref	09/12/1995	0.93	7.79	0.38			
AN0652	Mill Ck	Verif	Intermed	06/08/2000	10.87	3.84	2.28	177	60	4.2
AN0652	Mill Ck	Calib	Intermed	06/01/1995	10.87	3.84	2.28			
AN0762	Manumuskin River	Calib	Intermed	11/01/2000	11.26	7.02	15.39	173	37	5.3
AN0762	Manumuskin River	Verif	Intermed	11/28/1995	11.26	7.02	15.39			
AN0763	Manumuskin River	Calib	Ref	06/12/2001	-3.39	3.96	7.17	174	32	4.4
AN0763	Manumuskin River	Verif	Ref	11/28/1995	-3.39	3.96	7.17			
AN0764	Muskee Ck (Middle Br)	Calib	Intermed	10/03/2000	22.59	0.57	0.74	185	65	5
AN0764	Muskee Ck (Middle Br)	Verif	Intermed	10/31/1995	22.59	0.57	0.74			

APPENDIX B

SITE STRATIFICATION

Appendix B. Site stratification

B.1 Stratification methods

Identifying strata among Pinelands reference sites requires identification of biological gradients or assemblage types, association of the biological gradient with natural variables, and sufficient sample size for development of a multimetric index after dividing the reference sites into multiple strata. Biological gradients are explored using non-metric multidimensional scaling (NMS), a comparison of taxa within each sample and an arrangement of the samples so that similar samples plot closer together than dissimilar samples in multiple dimensions. Natural environmental variables can be associated with the biological gradient through correlations with the biologically defined axes of the NMS diagram. NMS is a robust method for detecting similarity and differences among ecological community samples and works as well using presence/absence data as relative abundance data (McCune and Mefford 1999).

At the outset of the analysis, we did not expect to find a natural biological gradient among reference Pinelands sites. This is because we had already isolated Pinelands sites from other New Jersey sites on the basis of the unique natural conditions in the Pinelands region and we had defined reference sites based on unique natural water quality as well as limited development in the watershed. We expected that all reference Pinelands sites would be similar to each other and that a single reference condition could be defined.

We used NMS to confirm our expectations. A site by taxa matrix was compiled. Similarity among reference biological samples was made using the Bray-Curtis similarity measure. The Bray-Curtis (BC) formula is sometimes written in shorthand as

$$BC = 1-2W/(A+B)$$

where W is the sum of shared abundances and A and B are the sums of abundances in individual sample units. The ordination software (PC-Ord, McCune and Mefford 1999) calculates a site by site matrix of BC similarity from which the arrangement of samples in the ordination diagram is derived. Multiple dimensions are compressed into two or three dimensions that we can perceive.

Rare and ambiguous taxa are not useful in the NMS ordination. Rare taxa were defined as those that occurred in only one of the 18 reference samples. Ambiguous taxa are those that are identified at higher taxonomic levels because of damaged or undeveloped specimens. The site by taxa matrix was therefore reduced to retain as much information as possible while excluding rare and ambiguous taxa. When several rare genera occurred within one family or when several identifications were at the family level, then all individuals were counted at the family level. When most identifications within a family were made at genus level, then the fewer identifications made at family level were excluded from the analysis. The site by environmental variable matrix included location information, water quality data, habitat scores, and land use coverages.

B.2 Stratification results

The NMS ordinations of taxa relative abundance in 18 reference samples did not show a clear division by site strata (Figure B-1). The variables that were strongly correlated with the ordination axes included sediment deposition score on the first axis (r = -0.61), water temperature on the second axis (r = 0.67), and pool variability score on the third axis (r = 0.68). Plots of environmental variables with the NMS axes revealed linear relationships with no breakpoints that could be used to define site strata. One site (AN0543, Jake's Brook) appeared as an outlier on the third axis (low pool variability score).

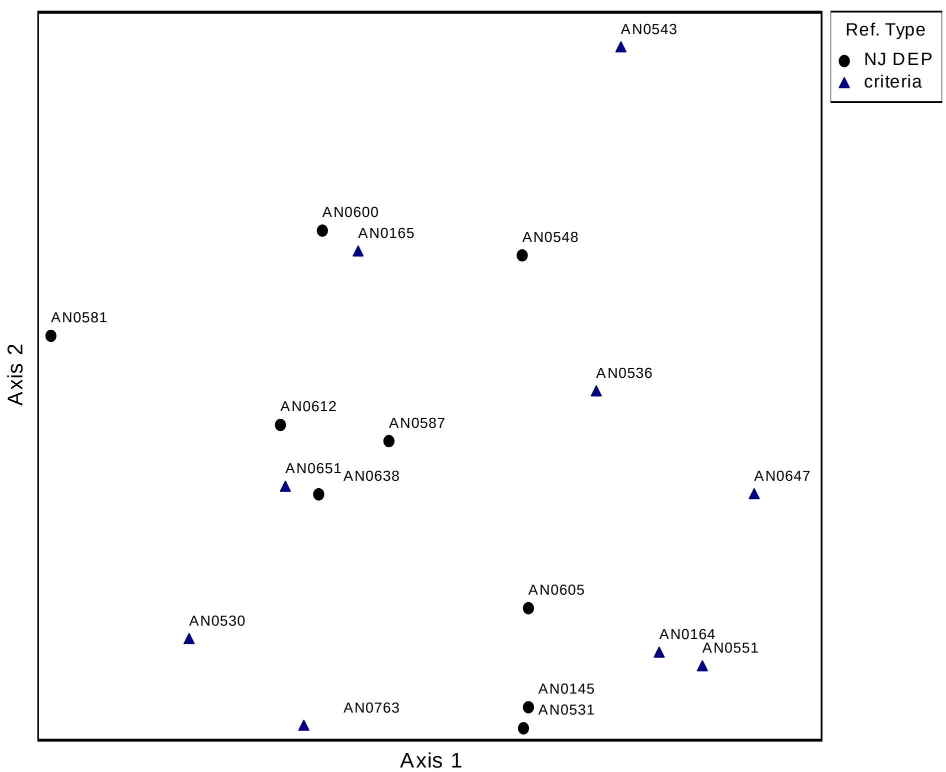


Figure B-1. NMS diagram of reference sites in dimensions defined by similarity in taxa presence/absence. Reference sites were either selected by NJ DEP or by application of reference criteria.

Similar results were obtained using taxa presence/absence in NMS ordinations (Figure B-2). The variables that were strongly correlated with the ordination axes included water temperature on the first axis (r = -0.72), pool variability score and percent wetland on the second axis (r = -0.57 and r = 0.56, respectively), and longitude on the third axis (r = 0.45). Plots of environmental variables with the NMS axes revealed linear relationships with no breakpoints that could be used to define site strata. One site (AN0581, Skit Brook) might be considered an outlier on the first axis (high water temperature) and a second site (AN0543, Jake's Brook) appeared as an outlier on the second axis (low pool variability score).

The conclusion drawn from ordination of 18 reference sites is that the reference condition in the Pinelands should not be stratified. Rather, all reference sites within the Pinelands should contribute to the definition of the reference condition, realizing that there is a natural gradient within the reference sites. The most highly correlated variables may be good descriptors of the natural gradients within reference sites, though some correlations are driven by individual values (such as one extremely low pool variability score). The sites with somewhat different biological composition and taxa should be classified cautiously as reference sites. Jake's Brook may have habitat degradation and Skit Brook may be warmer than natural for some reason that is not identified in the database.

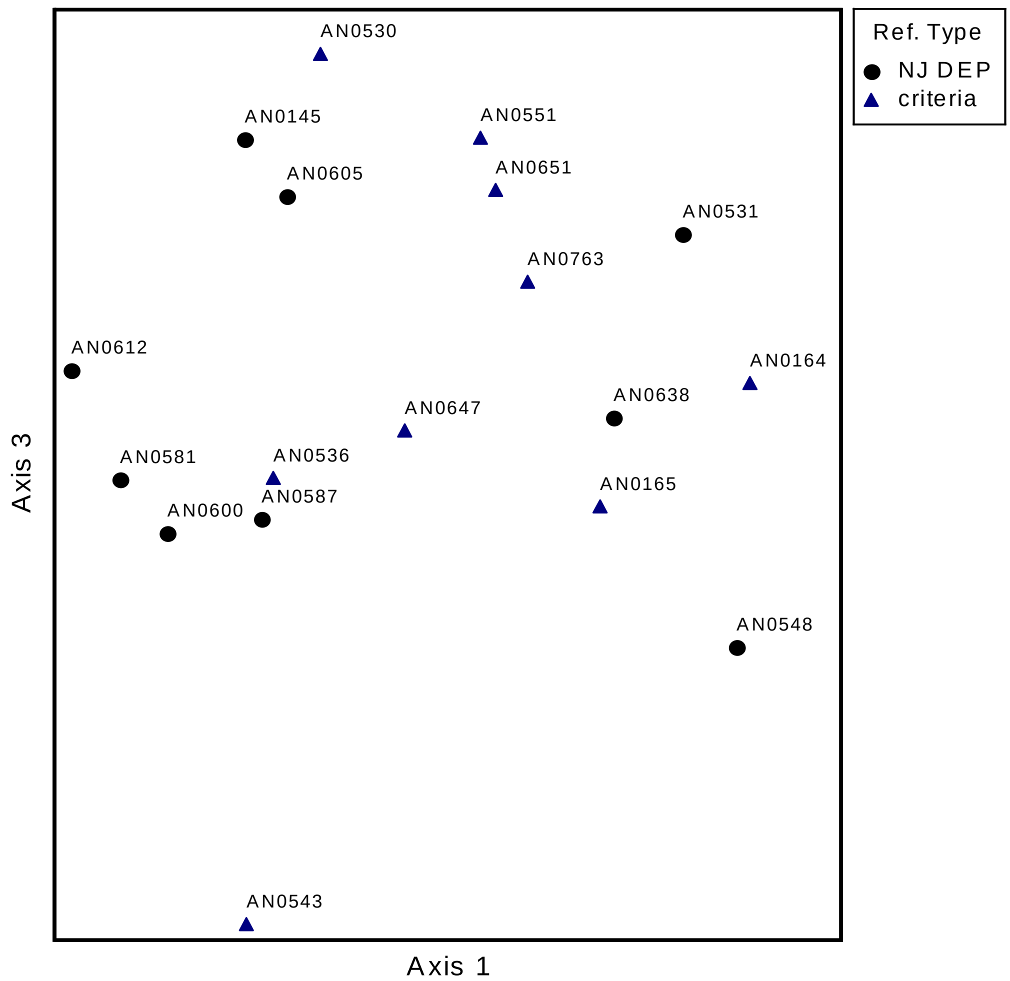


Figure B-2. NMS diagram of reference sites in dimensions defined by similarity in taxa relative abundance. Reference sites were either selected by NJ DEP or by application of reference criteria.

APPENDIX C

METRIC DESCRIPTIONS

Table C-1. Definitions of the evaluated metrics and predicted trend of metric response to increasing stress (compiled from DeShon 1995, Barbour et al.1996, Fore et al. 1996, Hayslip 1993, Smith and Voshell 1997). “Trend” = predicted trend of response to increasing stress: “+” = increase; “-” = decrease; “+/-“ = variable.

MEASURE	DEFINITION	TREND
RICHNESS MEASURES		
Total taxa	Measures the overall variety of the macroinvertebrate assemblage	-
Insect taxa	Number of taxa in the class Insecta	-
Non-insect taxa	All non-insect taxa, including crustaceans, mollusks, worms, etc…	+
EPT taxa	Number of taxa in the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies)	-
Plecoptera & Trichoptera taxa	Number of taxa in the insect orders Plecoptera (stoneflies) and Trichoptera (caddisflies)	-
Ephemeroptera taxa	Number of mayfly taxa	-
Plecoptera taxa	Number of stonefly taxa	-
Trichoptera taxa	Number of caddisfly taxa	-
Coleoptera taxa	Number of beetle taxa	-
Diptera taxa	Number of true fly taxa, including midges	-
Chironomidae taxa	Number of chironomid (midge) taxa	-
Orthocladiinae taxa	Number of taxa in Orthocladini subfamily of the Chironimid family	-
Tanytarsini taxa	Number of taxa in Tanytarsini tribe of the Chironimid family	-
Tanypodinae taxa	Number of taxa in Tanypodinae subfamily of the Chironimid family	-
Oligochaeta taxa	Number of segmented worm taxa	+
Crustacea & Mollusca taxa	Number of crustacean and mollusk taxa	+
Mollusca taxa	Number of mollusk taxa	+
Crustacea taxa	Number of crustacea taxa	+
COMPOSITION MEASURES		
Non-insect percent	Percent of the total sample count that are worms, mollusks, crustaceans, etc.	+
EPT percent	Percent of the total sample count that are mayfly, stonefly, and caddisfly larvae or nymphs	-
EPT percent excluding Baetidae	Percent of the total sample count that are mayfly, stonefly, and caddisfly larvae or nymphs excluding baetid mayflies	-
Ephemeroptera percent	Percent of the total sample count that are mayfly larvae or nymphs	-
Ephemeroptera percent excluding Baetidae	Percent of the total sample count that are mayfly larvae or nymphs excluding baetid mayflies	-
Plecoptera percent	Percent of the total sample count that are stonefly larvae or nymphs	-
Trichoptera percent	Percent of the total sample count that are caddisfly larvae or nymphs	-
Plecoptera & Trichoptera percent	Percent of the total sample count that are stonefliy and caddisfly larvae or nymphs	-
Coleoptera percent	Percent of the total sample count that are beetles	-
Odonata percent	Percent of the total sample count that are dragonflies	-

MEASURE	DEFINITION	TREND
Diptera percent	Percent of the total sample count that are true fly larvae	-
Diptera percent excluding Tanytarsini	Percent of the total sample count that are true fly larvae, excluding the tribe Tanytarsini	+
Chironomidae percent	Percent of the total sample count that are midge larvae	+
Chironomidae percent excluding Tanytarsini	Percent of the total sample count that are midges, excluding the Tanytarsini	+
Orthocladiinae percent	Percent of the total sample count that are in the midge subfamily Orthocladiinae	+
Tanytarsini Percent	Percent of the total sample count that are in the midge tribe Tanytarsini	+/-
Tanypodinae percent	Percent of the total sample count that are in the midge subfamily Tanypodinae	+/-
Crustacea & Mollusca percent	Percent of the total sample count that are crustaceans and mollusks	+
Mollusca percent	Percent of the total sample count that are mollusks	+
Amphipoda percent	Percent of the total sample count that are amphipods	+
Mollusca & Amphipoda percent	Percent of the total sample count that are mollusks and amphipods	+
Gastropoda percent	Percent of the total sample count that are gastropods	+
Bivalvia percent	Percent of the total sample count that are bivalves	+
Isopoda percent	Percent of the total sample count that are isopods	+
Oligochaeta percent	Percent of the total sample count that are aquatic worms	+
EVENNESS MEASURES		
Shannon-Wiener Index	An index of the richness and the distribution of individuals within each taxon	-
Evenness	Shannon-Wiener Index divided by the maximum obtainable Shannon-Wiener Index value	-
Margaleff's Index	Provides a measure of species richness that is roughly normalized for sample size	-
Simpson's Index	The probability of two individuals in a sample being of the same species	+
Percent dominant taxon	Measures the dominance of the single most abundant taxon	+
Percent 2 dominant taxa	Measures the dominance of the two most abundant taxa	+
POLLUTION TOLERANCE MEASURES		
Beck's Biotic Index (Hilsenhoff values)	Twice the number of organisms considered most sensitive to perturbation (Hilsenhoff value 0 or 1) + the number of organisms considered moderately sensitive (value 2, 3, or 4)	-
Beck's Biotic Index (TALU* values)	Twice the number of organisms considered most sensitive to perturbation (TALU attribute 1 or 2) + the number of organisms considered moderately sensitive (attribute 3)	-
Hilsenhoff's Biotic Index	The HBI is the average tolerance value of individuals. It is calculated by multiplying the number of individuals of each taxon by their tolerance value, summing the products, and dividing by the total number of individuals with tolerance values.	+
Intolerant percent (Hilsenhoff values)	Percent of the total individuals considered to be intolerant of various types of perturbation (Hilsenhoff values 0 – 3)	-
Tolerant percent (Hilsenhoff values)	Percent of the total individuals considered to be tolerant of various types of perturbation (Hilsenhoff values 7 – 10)	+
Intolerant taxa	Taxa richness of those organisms considered to be sensitive	-

MEASURE	DEFINITION	TREND
(Hilsenhoff values)	to perturbation (Hilsenhoff values 0 – 3)	
Tolerant taxa (Hilsenhoff values)	Taxa richness of those organisms considered to be insensitive to perturbation (Hilsenhoff values 7 - 10)	+
Tolerant taxa (TALU* values)	Taxa richness of those organisms considered to be insensitive to perturbation (TALU attributes 4, 5, or 6)	+
FUNCTIONAL FEEDING GROUP MEASURES		
Collector percent	Percentage of sample that collects organic debris from substrates and sediments	-
Filterer percent	Percentage of sample that filters suspended detritus	+/-
Predator percent	Percentage of sample that consumes living prey organisms	+/-
Scraper percent	Percentage of sample that scrapes substrate to remove food particles	-
Shredder percent	Percentage of sample that shreds organic litter	-
Collector taxa	Number of taxa that collect organic debris from substrates and sediments	-
Filterer taxa	Number of taxa that filter suspended detritus	+/-
Predator taxa	Number of taxa that consume living prey organisms	+/-
Scraper taxa	Number of taxa that scrape substrate to remove food particles	-
Shredder taxa	Number of taxa that shred organic litter	-
HABIT MEASURES		
Burrower percent	Percentage of sample that inhabits fine sediments	+
Climber percent	Percentage of sample that climbs about aquatic substrates, including plants and debris	+/-
Clinger percent	Percentage of sample that attaches to plants, rocks, and other substrates	-
Sprawler percent	Percentage of sample that inhabits surfaces of leaves and sediments	+/-
Swimmer percent	Percentage of sample that swims freely in the water column	+/-
Burrower taxa	Number of taxa that inhabit fine sediments	-
Climber taxa	Number of taxa that climb about aquatic substrates, including plants and debris	-
Clinger taxa	Number of taxa that attach to plants, rocks, and other substrates	-
Sprawler taxa	Number of taxa that inhabit surfaces of leaves and sediments	-
Swimmer taxa	Number of taxa that swim freely in the water column	-

* TALU refers to the Tiered Aquatic Life Use approach to waterbody assessment as promoted by the U.S. EPA (Gerritsen and Leppo 2005). Workshops were convened in New Jersey, during which state biologists assigned attributes to each taxon on a scale of 1 to 6. The scale describes rare and endemic (usually sensitive) taxa on the low end and pollution tolerant taxa on the high end. Because the workgroup assigned these attributes for all or New Jersey and not specifically for the Pinelands, the utility of metrics based on the TALU attributes was downweighted during evaluation of the index for the Pinelands.

APPENDIX D

METRIC DISCRIMINATIONS

Table D-1. Richness metric comparisons among reference, intermediate (test), and degraded calibration sites.

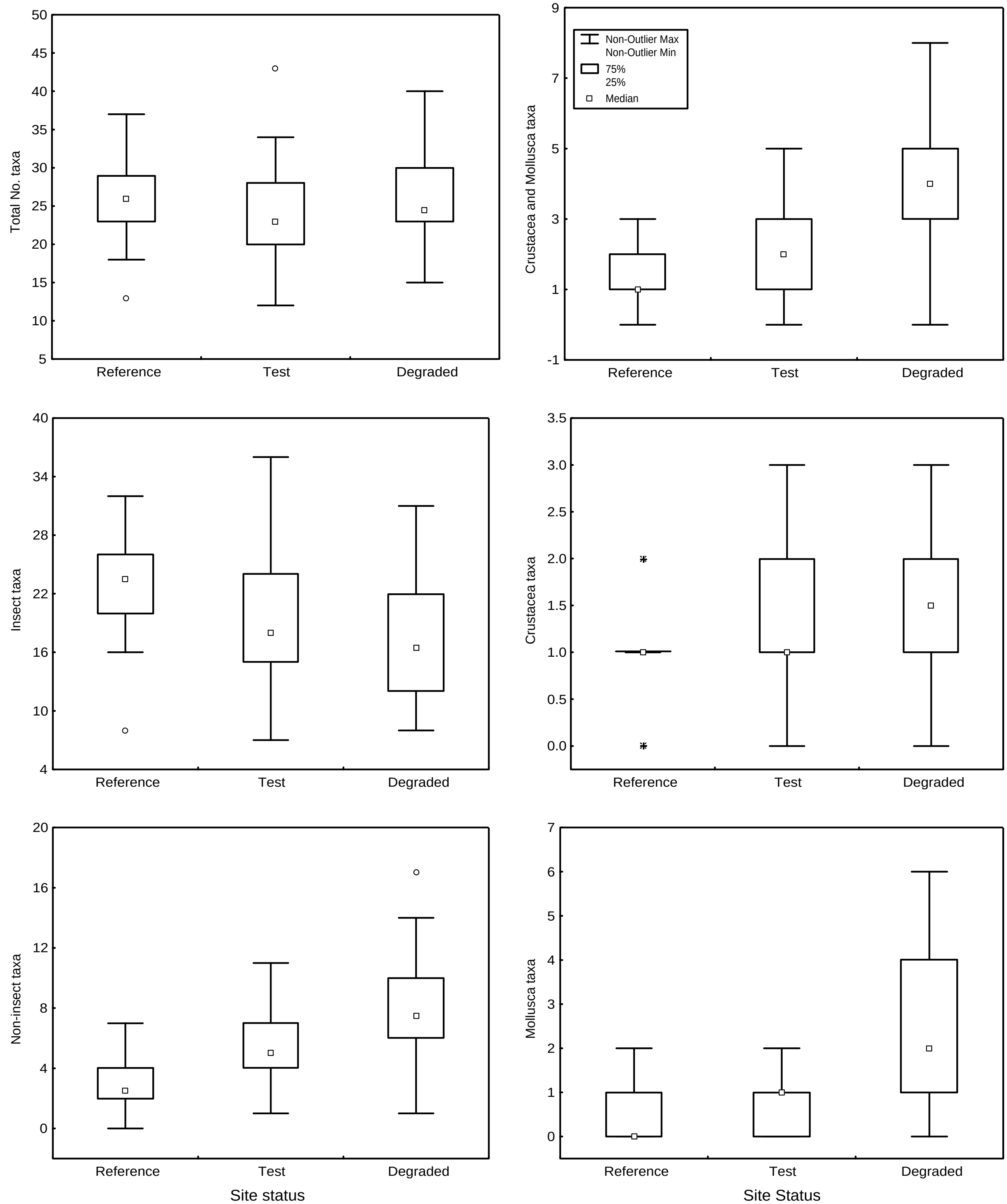


Table D-1 (continued). Richness metric comparisons among reference, intermediate (test), and degraded calibration sites.

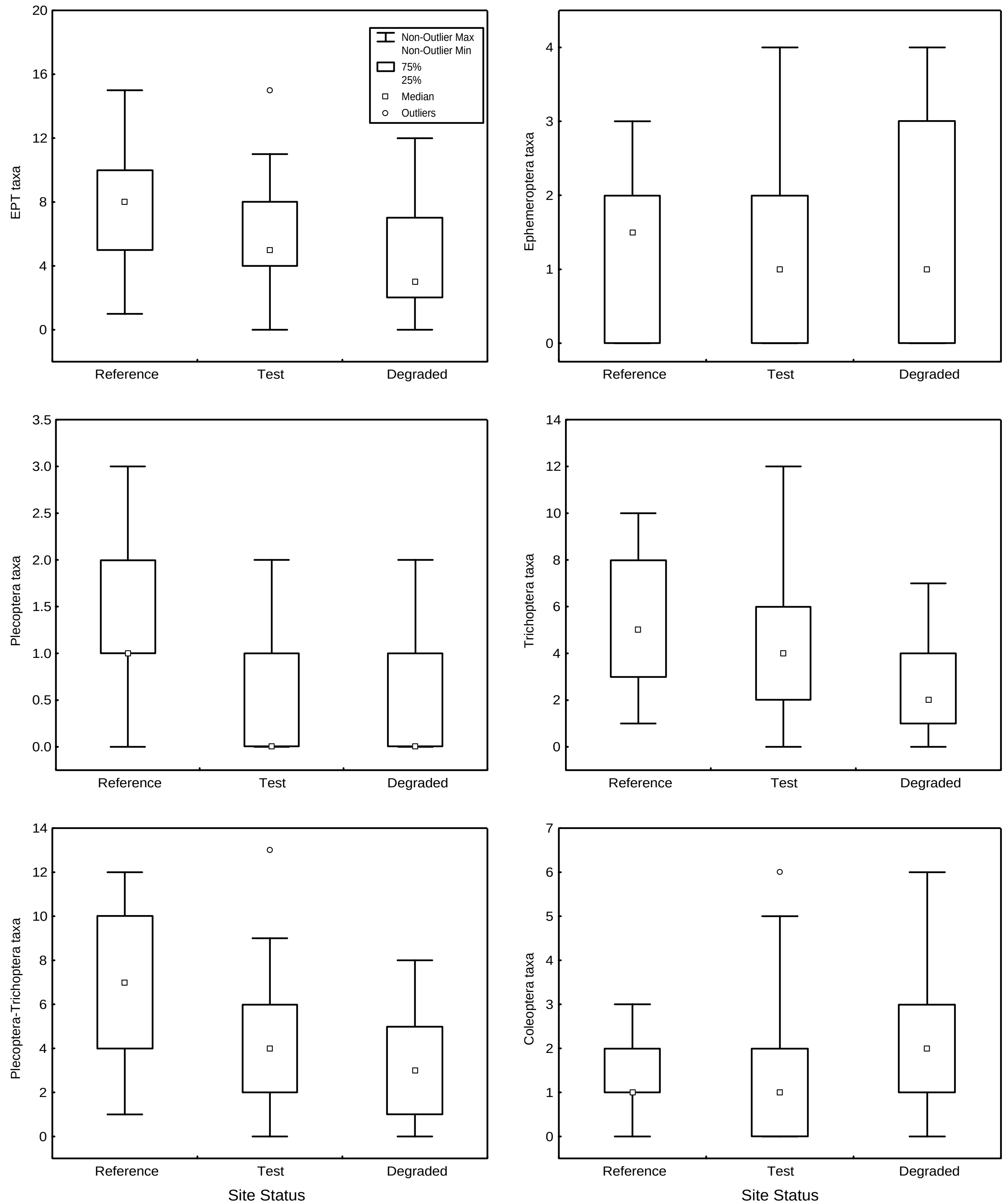


Table D-1 (continued). Richness metric comparisons among reference, intermediate (test), and degraded calibration sites.

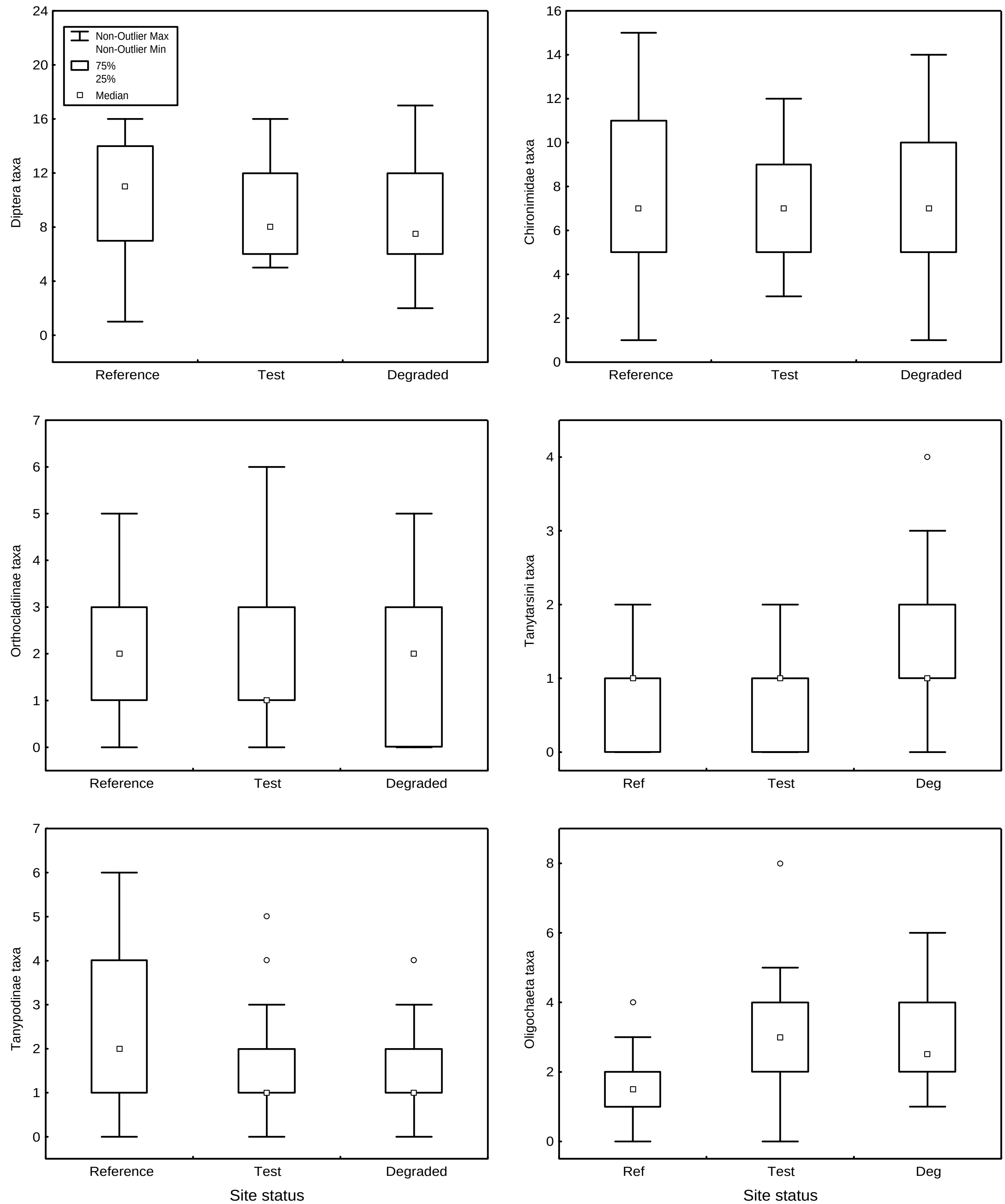


Table D-2. Composition metric comparisons among reference, intermediate (test), and degraded calibration sites.

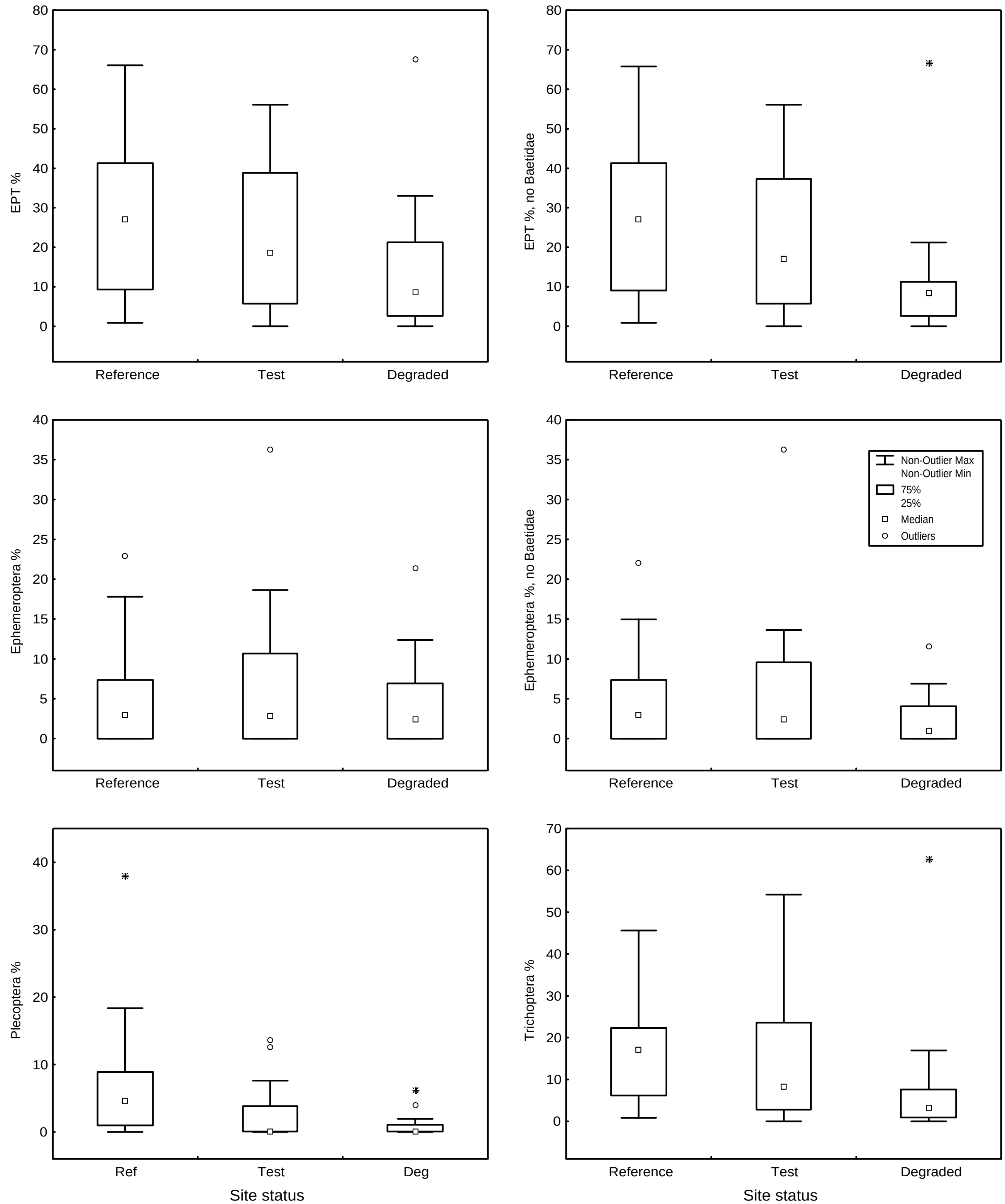


Table D-2 (continued). Composition metric comparisons among reference, intermediate (test), and degraded calibration sites.

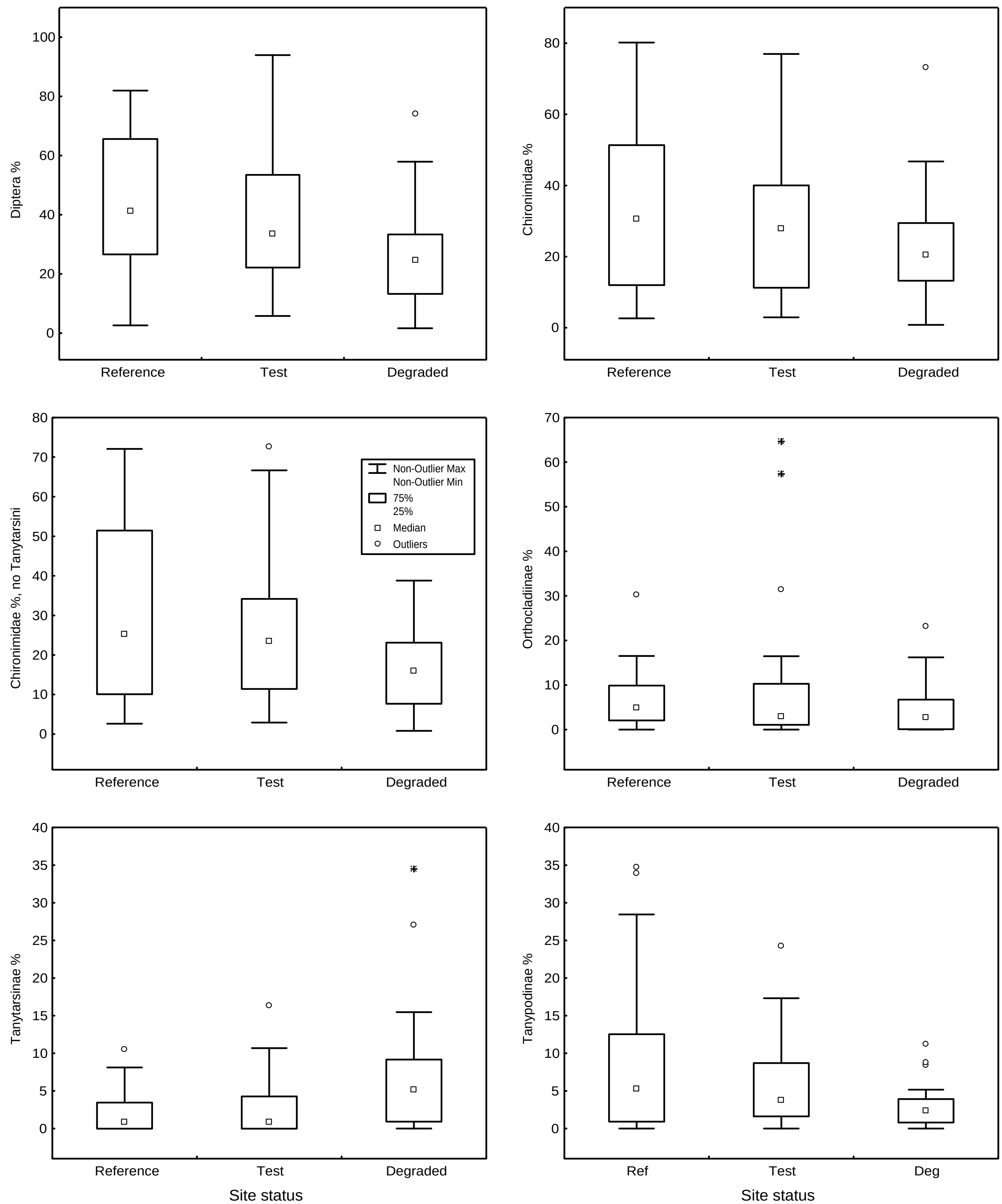


Table D-2 (continued). Composition metric comparisons among reference, intermediate (test), and degraded calibration sites.

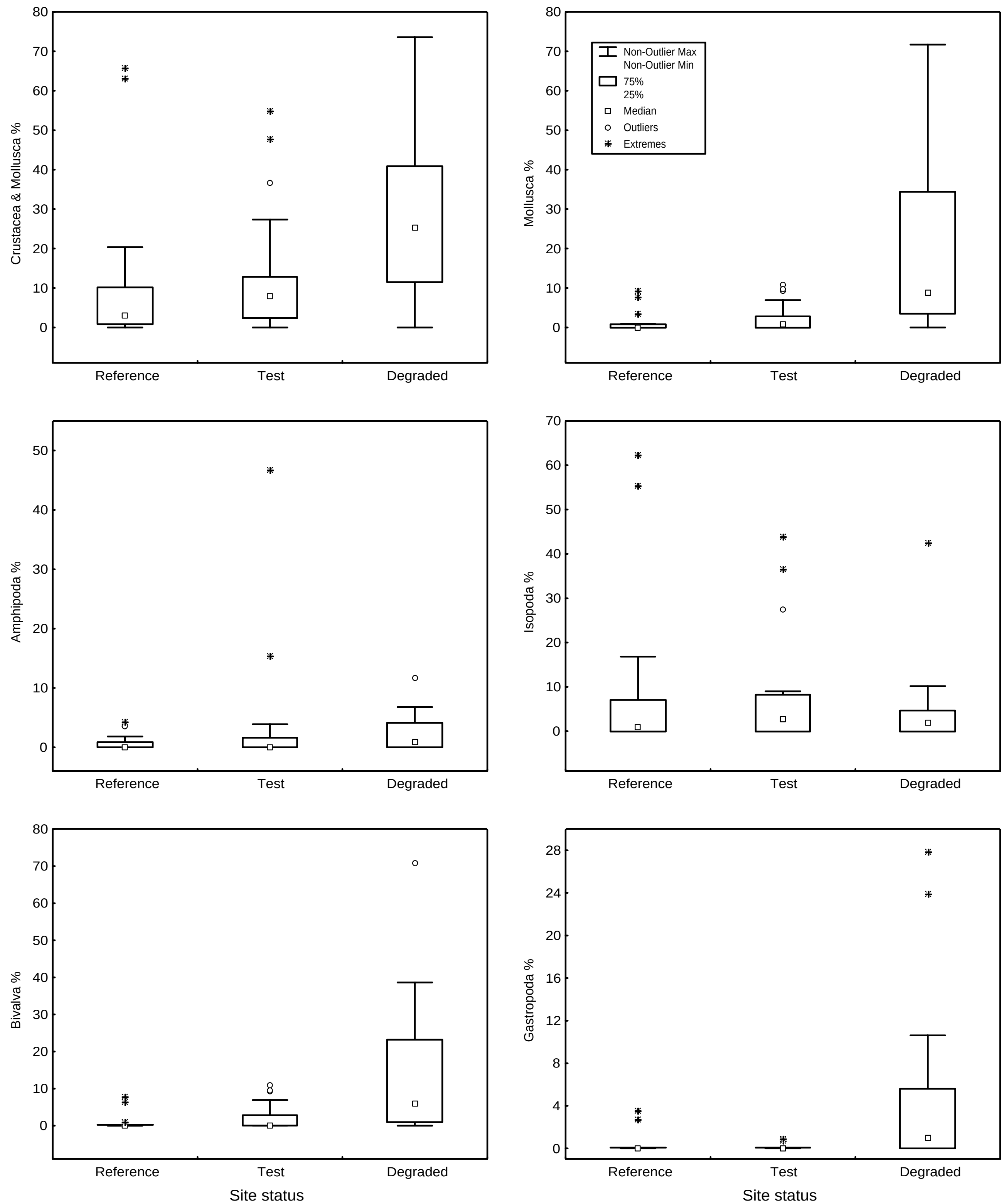


Table D-2 (continued). Composition metric comparisons among reference, intermediate (test), and degraded calibration sites.

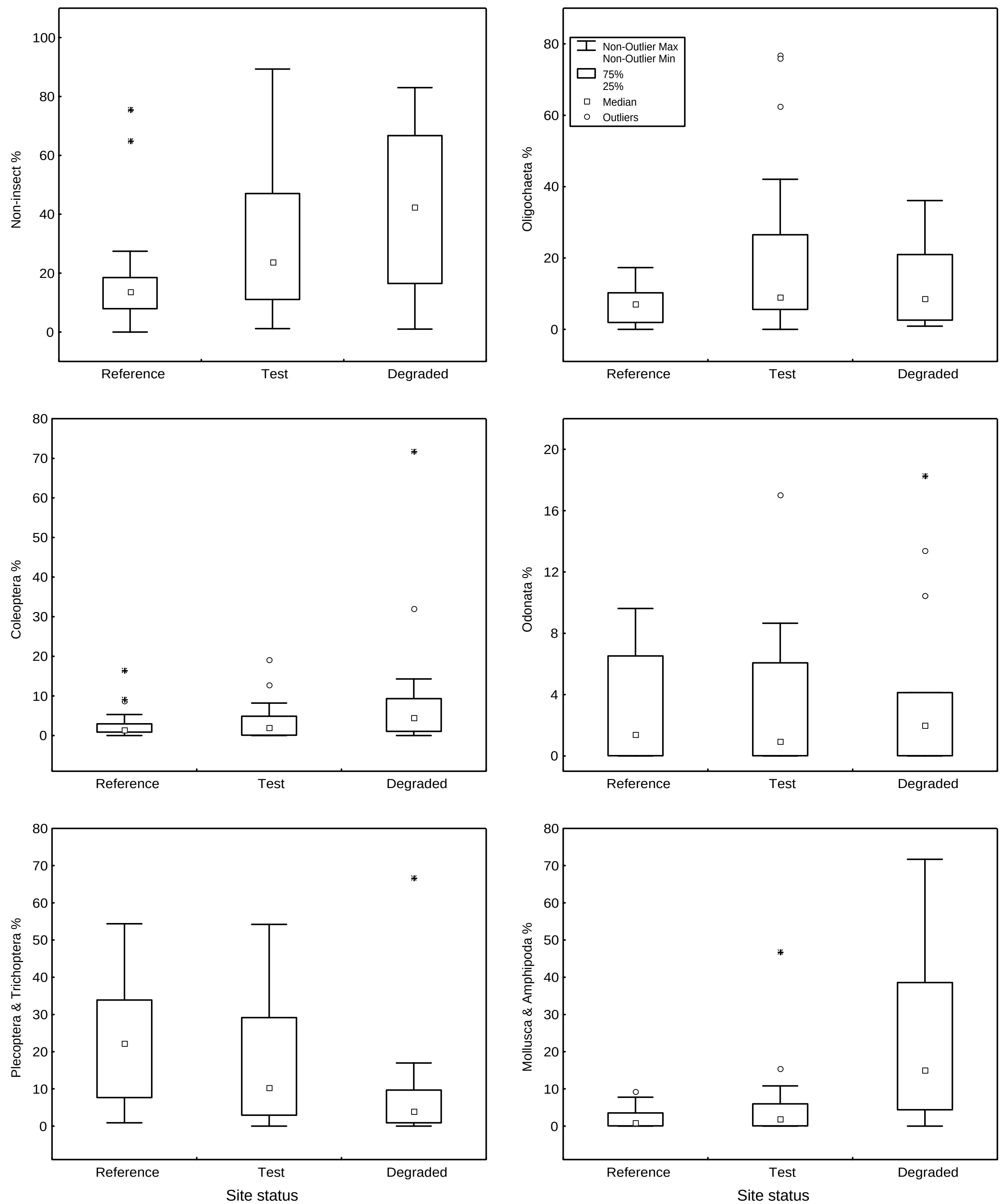


Table D-3. Pollution tolerance metric comparisons among reference, intermediate (test), and degraded calibration sites.

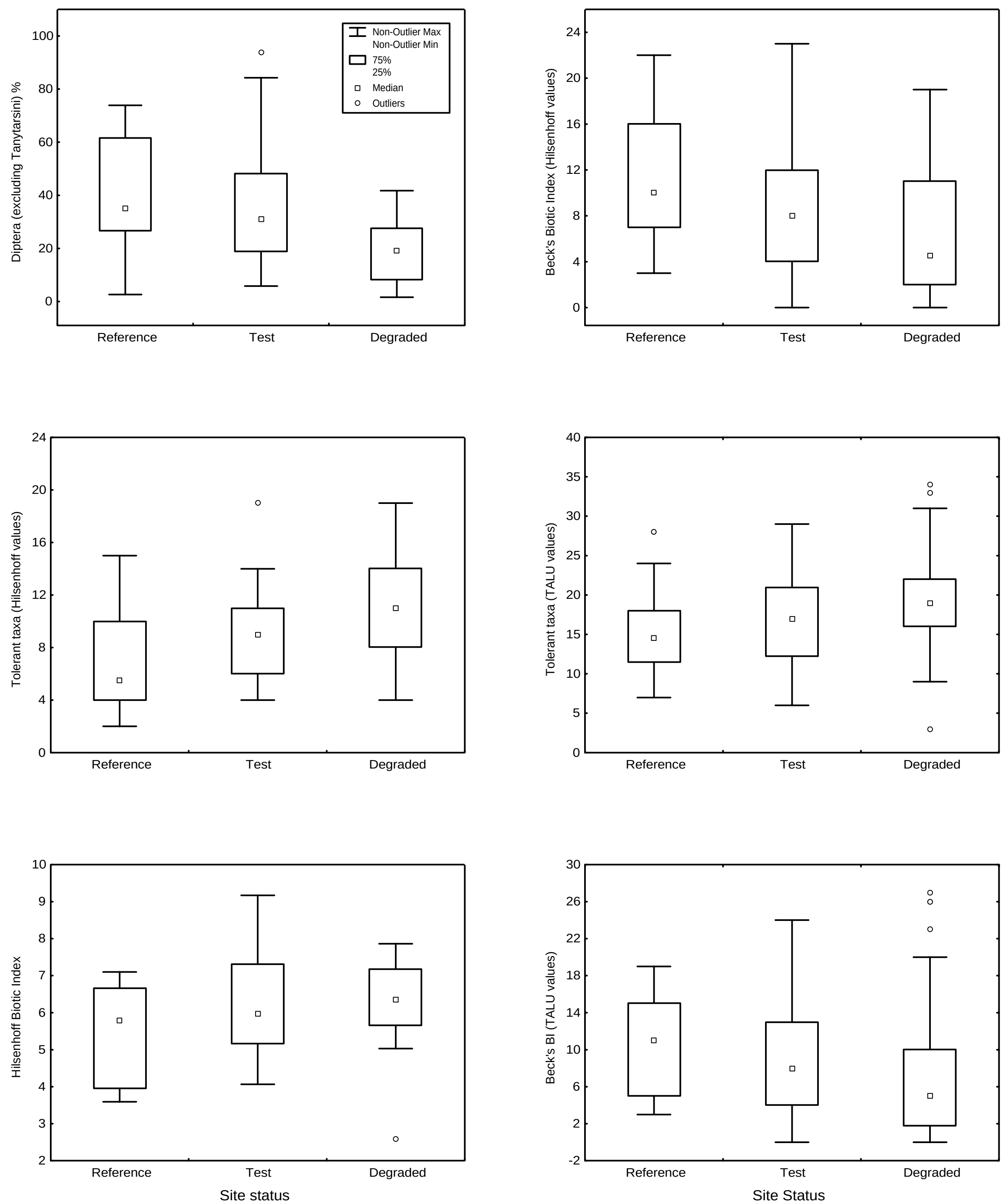
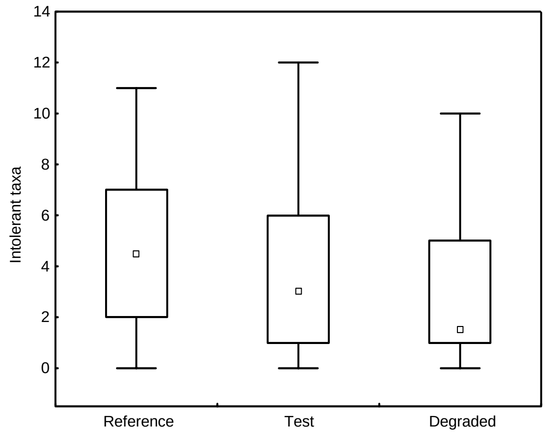
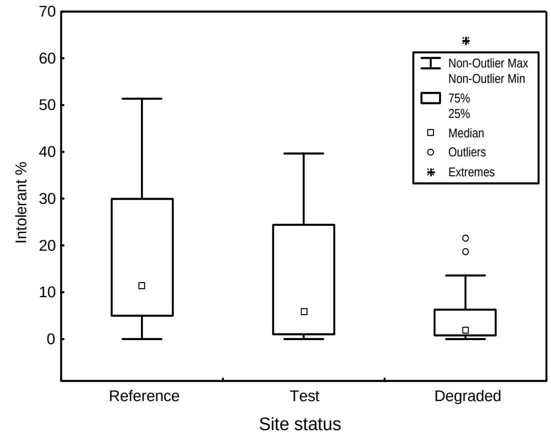


Table D-3 (continued). Pollution tolerance metric comparisons among reference, intermediate (test), and degraded calibration sites.





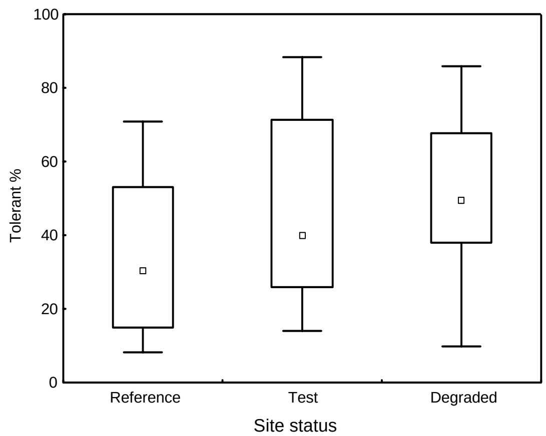


Table D-4. Evenness metric comparisons among reference, intermediate (test), and degraded calibration sites.

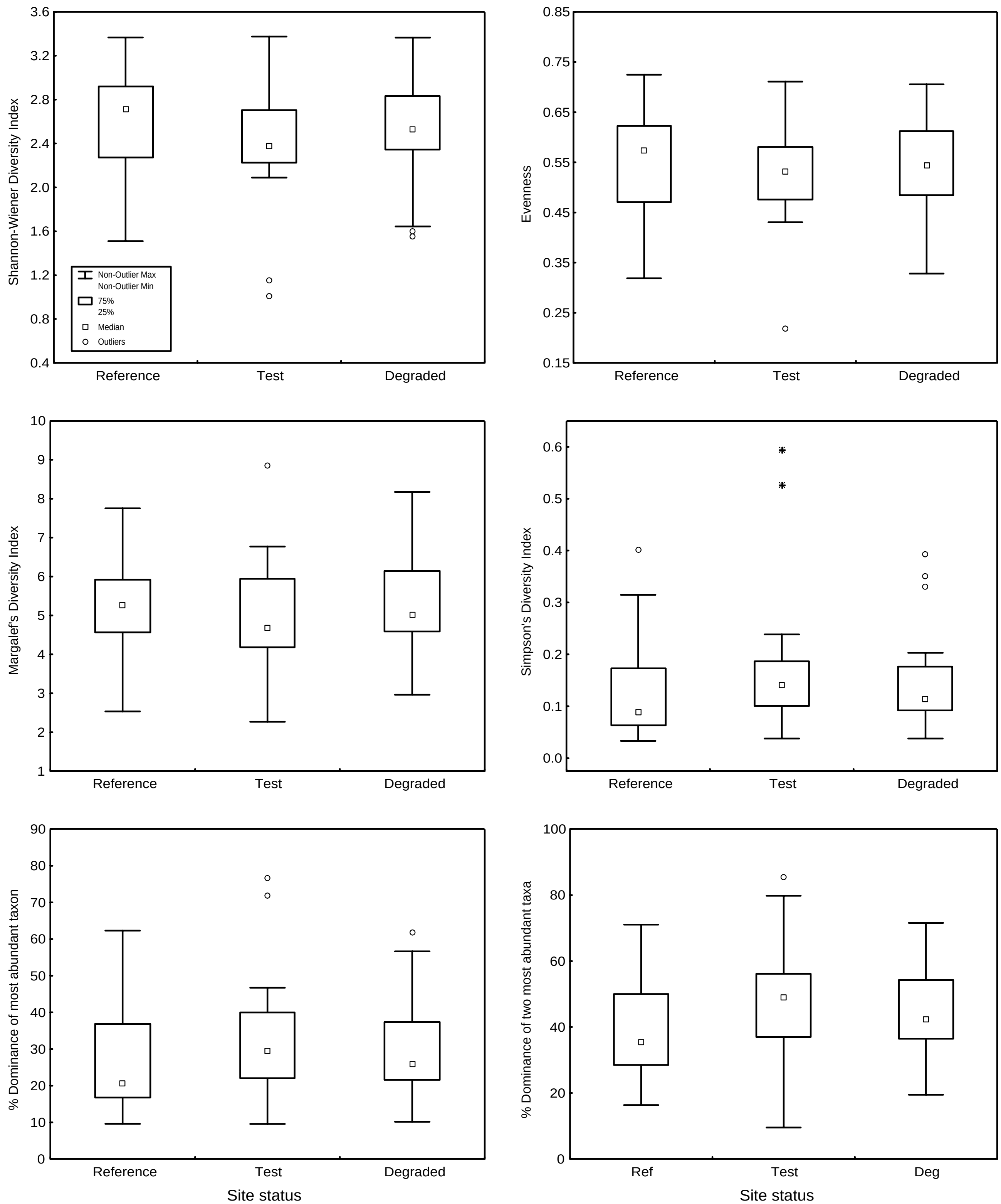


Table D-5. Feeding metric comparisons among reference, intermediate (test), and degraded calibration sites.

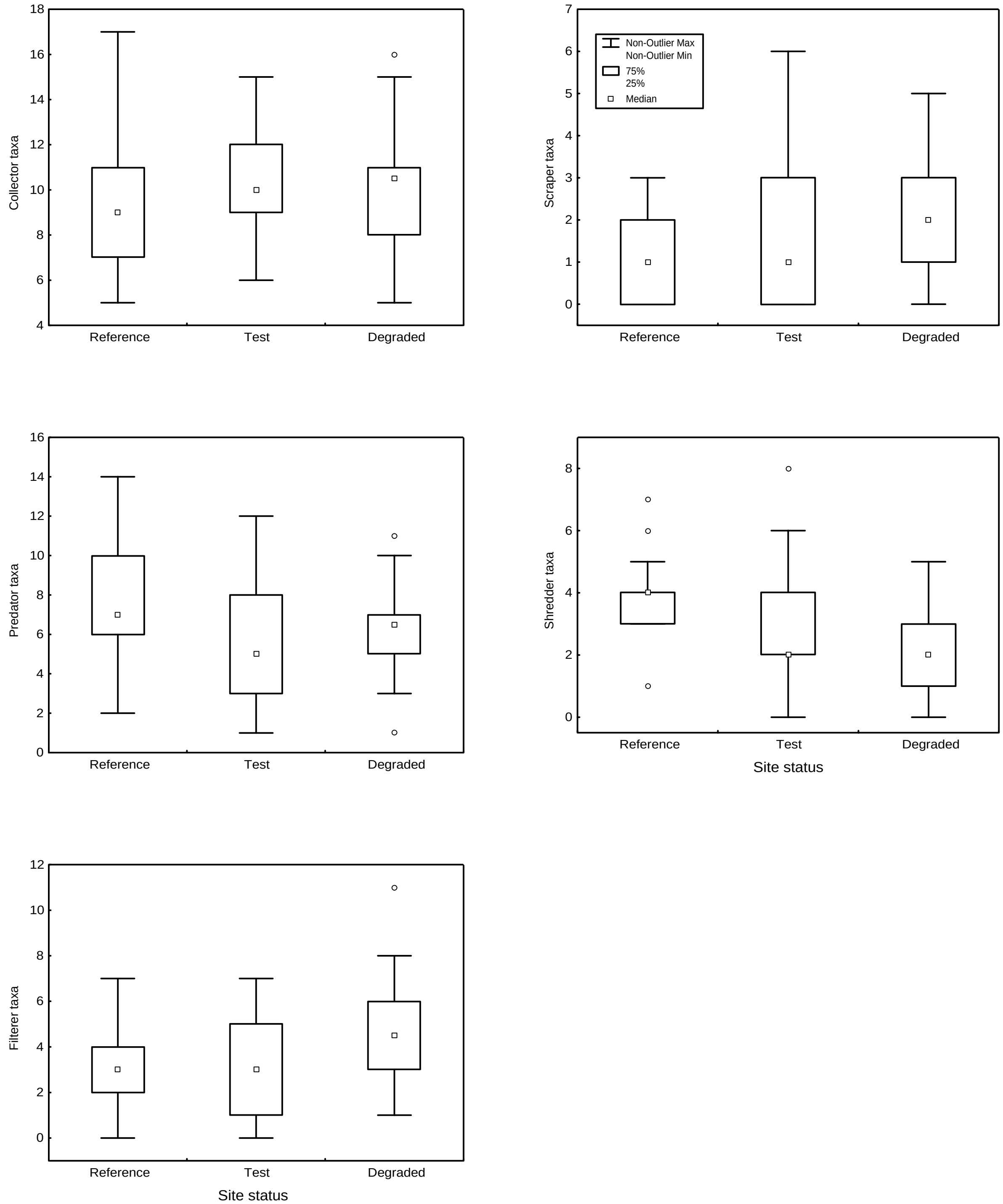


Table D-5 (continued). Feeding metric comparisons among reference, intermediate (test), and degraded calibration sites.

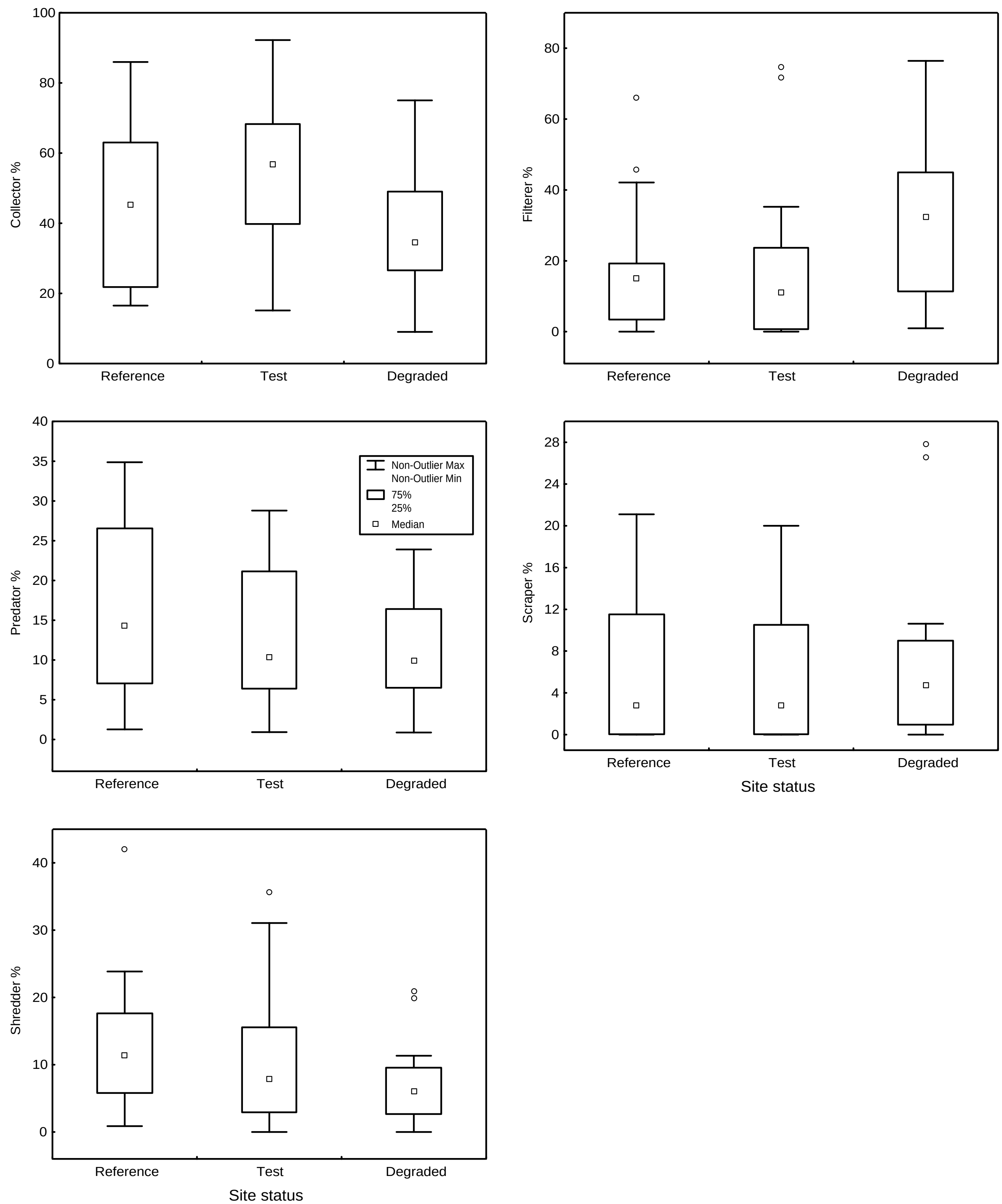


Table D-6. Habit metric comparisons among reference, intermediate (test), and degraded calibration sites.

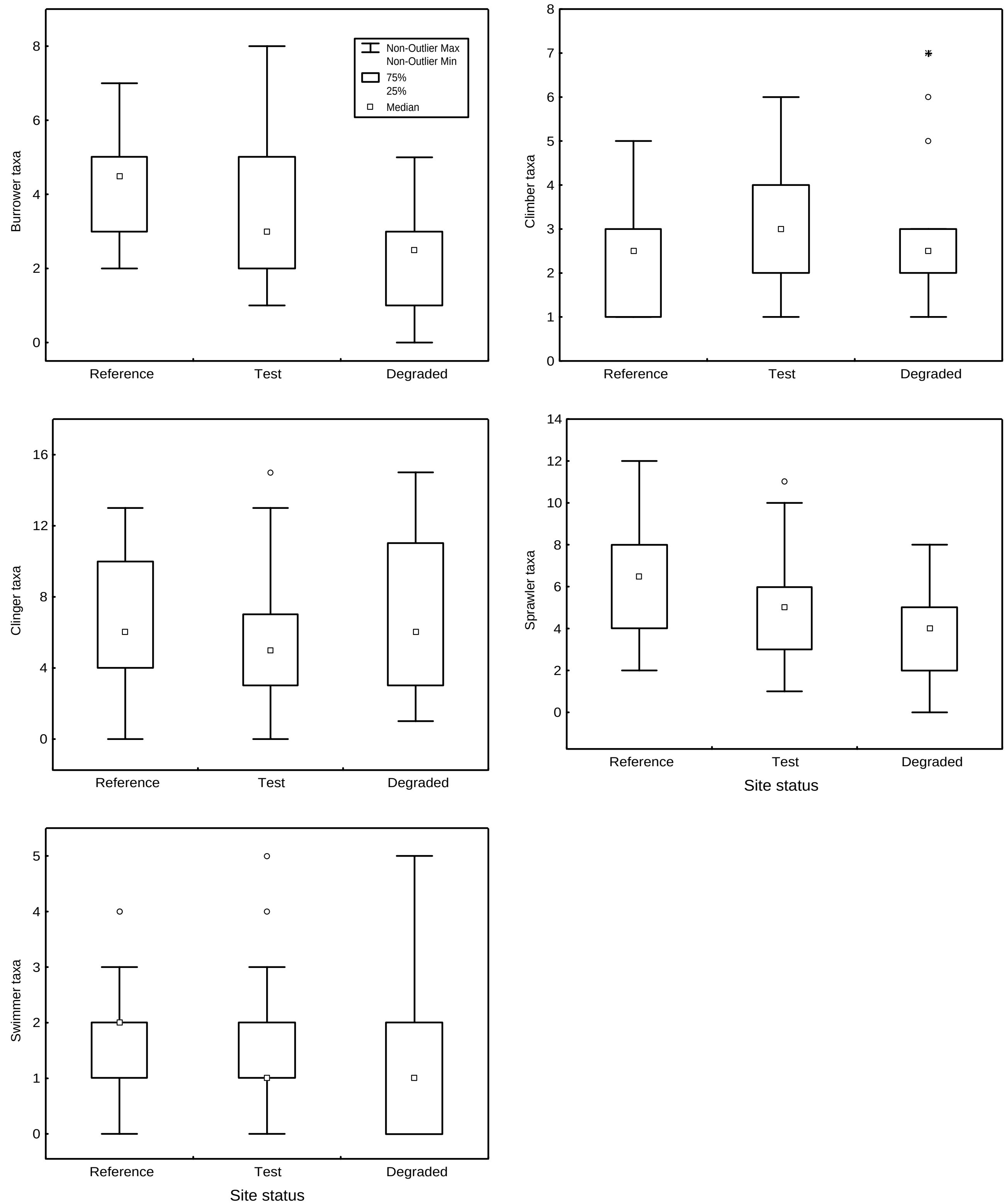
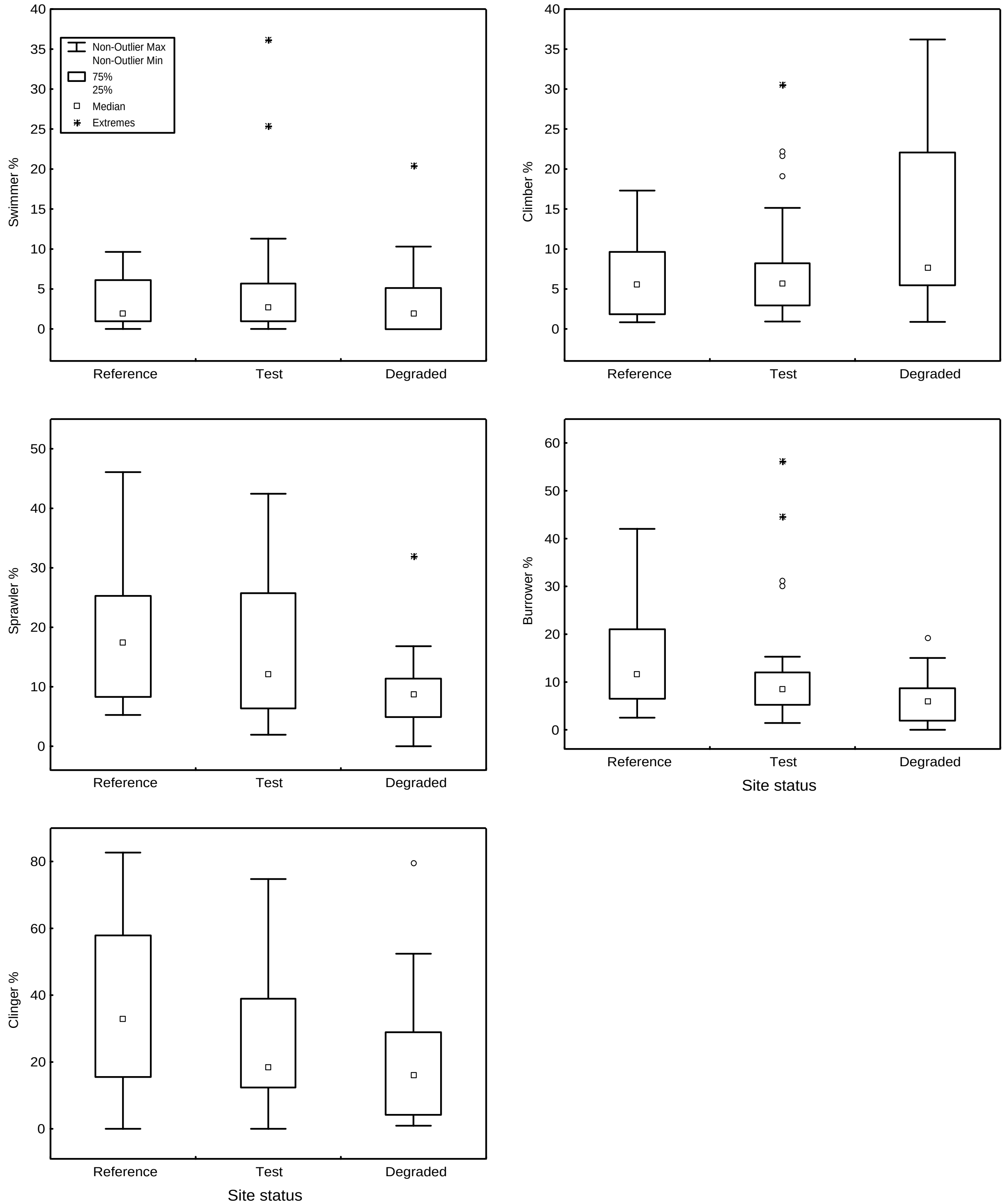


Table D-6 (continued). Habit metric comparisons among reference, intermediate (test), and degraded calibration sites.



APPENDIX E

INDEX COMPOSITION ALTERNATIVES

Forenotes to Table E-1

1. The NJ rapid bioassessment index scored on a 30 point scale.
2. The NJ rapid bioassessment index scored on a 100 point scale.
3. Index alternatives were numbered sequentially. Numbers in the column indicate that the associated metric was included in the index alternative.
4. Discrimination efficiency is the percentage of stressed sites (n = 18) that have index values below the 25th percentile of reference index values (n = 18).
5. Root mean squared error is an estimate of standard deviation for samples collected in different years or seasons.
6. Verification discrimination efficiency is the percentage of degraded verification samples below the calibration reference 25th percentile. Reference DE is the percentage of reference verification samples above the calibration reference 25th percentile.

Appendix E-1. Results of alternative index combinations.

Metric	NJ30[1]	NJ100[2]	Ind.1[3]	Ind.2	Ind.3	Ind.4	Ind.5	Ind.6	Ind.7
Total taxa (families)	NJ	NJ							
Insect taxa			1	2		4	5	6	7
Non-insect taxa			1	2		4	5	6	7
EPT (families)	NJ	NJ							
Plecoptera-Trichoptera taxa					3				
Crustacea-Mollusca taxa					3				
Non-insect %					3				
EPT %	NJ	NJ							
EPT% no Baetidae						4			
Plecoptera %				2			5	6	7
Trichoptera %				2			5	6	7
Plecoptera-Trichoptera %									
Coleoptera %									
Diptera % excluding Tanytarsinae									
Crustacea-Mollusca %			1						
Mollusca %				2		4	5	6	7
Amphipoda %									
Mollusca-Amphipoda %									
Beck's BI (Hilsenhoff)				2				6	
Beck's BI (TALU)									
HBI	NJ	NJ			3				
Intolerant taxa									
Intolerant %			1			4	5		7
Tolerant taxa (Hilsenhoff)									
Tolerant taxa (TALU)									
% dominant family	NJ	NJ							
Filterer %			1	2	3	4	5	6	7
Shredder taxa				2			5		7
Clinger %			1						
Sprawler taxa									
25th percentile ref	18.0	43.9	59.0	53.4	64.2	58.2	52.0	53.6	52.0
DE[4]	44.4	61.1	77.8	88.9	83.3	83.3	88.9.	77.8	88.9
ref-deg difference	6.3	12.1	19.7	21.1	22.0	20.8	21.0	20.1	21.0
mean ref	23.0	57.3	65.2	60.6	70.9	66.2	58.8	61.1	58.8
mean deg	17	45.2	45.5	39.5	48.9	45.4	37.8	41.0	37.8
RMSE annual[5]	3.0	8.9	8.2	6.3	6.4	6.9	6.3	6.4	6.3
RMSE season	4.5	8.7	6.6	6.5	6.7	6.7	6.0	5.8	6.0
Inter-quartile range ref	12.0	24.9	15.4	16.9	15.8	17.0	16.9	14.6	16.9
Verification DE[6]	78.9	52.6	100	100	100	100	100	95	100
Verification Ref DE	76.2	81.0	76.2	66.7	61.9	81.0	71.4	76.2	71.4

Appendix E-1 (continued). Results of alternative index combinations.

Metric	Ind.8	Ind.9	Ind.10	Ind.11	Ind.12	Ind.13	Ind.14	Ind.15	Ind.16
Total taxa (families)									
Insect taxa		9	10		12		14	15	16
Non-insect taxa		9	10	11	12		14	15	16
EPT (families)									
Plecoptera-Trichoptera taxa	8			11		13			
Crustacea-Mollusca taxa	8					13			
Non-insect %	8	9				13			
EPT %									
EPT% no Baetidae									
Plecoptera %					12		14	15	16
Trichoptera %					12		14	15	16
Plecoptera-Trichoptera %									
Coleoptera %									
Diptera % excluding Tanytarsinae									16
Crustacea-Mollusca %									
Mollusca %			10	11	12		14		
Amphipoda %							14		
Mollusca-Amphipoda %								15	16
Beck’s BI (Hilsenhoff)									
Beck’s BI (TALU)									
HBI					12				
Intolerant taxa						13	14	15	16
Intolerant %	8	9	10	11					
Tolerant taxa (Hilsenhoff)									
Tolerant taxa (TALU)									
% dominant family									
Filterer %	8	9	10	11		13	14	15	16
Shredder taxa									
Clinger %					12				
Sprawler taxa									
25th percentile ref	58.5	64.5	66.5	63.5	44.4	60.5	58.0	51.9	55.7
DE	83.3	88.9	83.3	88.9	77.8	88.9	77.8	77.8	88.9
ref-deg difference	22.8	21.3	19.9	22.5	20.0	23.8	18.5	20.9	21.9
mean ref	65.7	67.5	71.2	69.2	57.9	68.5	65.7	60.9	60.2
mean deg	42.8	46.3	51.3	46.6	38.0	44.7	47.2	40.0	38.3
RMSE annual	6.4	8.4	6.7	6.3	7.7	6.7	5.5	6.3	6.2
RMSE season	6.9	6.9	5.8	6.3	7.7	6.9	5.3	6.0	5.1
Inter-quartile ref	17.9	9.7	10.0	15.0	30.7	18.5	16.5	18.8	11.2
Verification DE	100	100	100	100	63	100.0	100.0	94.7	100.0
Verification Ref DE	66.7	66.7	71.4	66.7	90.5	66.7	76.2	81.0	66.7

Appendix E-1 (continued). Results of alternative index combinations.

Metric	Ind.17	Ind.18	Ind.19	**Ind.20***	Ind.21	Ind.22	Ind.23	Ind. 24	Ind. 25
Total taxa (families)									
Insect taxa	17	18	19	**20**	21	22	23	24	25
Non-insect taxa	17	18	19	**20**	21	22	23	24	25
EPT (families)									
Plecoptera-Trichoptera taxa									
Crustacea-Mollusca taxa									
Non-insect %			19						
EPT %									
EPT% no Baetidae									
Plecoptera %									
Trichoptera %									
Plecoptera-Trichoptera %	17	18	19	**20**	21	22	23	24	25
Coleoptera %									25
Diptera % excluding Tanytarsinae	17			**20**		22	23	24	25
Crustacea-Mollusca %									
Mollusca %									
Amphipoda %									
Mollusca-Amphipoda %	17	18		**20**	21	22	23	24	25
Beck’s BI (Hilsenhoff)				**20**	21		23		
Beck’s BI (TALU)								24	25
HBI									
Intolerant taxa	17	18	19			22			
Intolerant %									
Tolerant taxa (Hilsenhoff)									
Tolerant taxa (TALU)									
% dominant family									
Filterer %	17	18	19	**20**	21			24	25
Shredder taxa									
Clinger %									
Sprawler taxa									
25th percentile ref	62.7	60.1	56.8	**62.7**	60.2	56.9	53.7	63.3	66.2
DE	94.4	77.8	83.3	**94.4**	77.8	88.9	66.7	94.4	94.4
ref-deg difference	23.0	22.1	22.9	**22.4**	21.4	24.0	22.3	23.2	21.8
mean ref	66.3	68.2	65.3	**66.3**	68.2	63.8	65.6	67.1	69.5
mean deg	43.3	46.1	42.4	**43.9**	46.8	39.7	43.3	43.9	47.7
RMSE annual	6.5	6.7	8.0	**6.5**	6.7	7.4	7.7	6.6	5.6
RMSE season	5.3	6.6	7.3	**5.6**	6.3	7.9	9.4	6.2	6.1
Inter-quartile ref	9.6	17.0	18.9	**8.2**	16.0	16.6	22.4	9.3	8.7
Verification DE	100.0	100.0	100.0	**100.0**	100.0	100.0	78.9	100.0	100.0
Verification Ref DE	57.1	76.2	76.2	**57.1**	76.2	66.7	76.2	57.1	52.4

***Index 20 is the recommended PMI**

Appendix E-1 (continued). Results of alternative index combinations.

Metric	Ind.26	Ind.27	Ind.28	Ind.29	Ind.30	Ind.31	Ind.32	Ind.33	Ind.34
Total taxa (families)									
Insect taxa	26	27	28	29	30	31	32	33	34
Non-insect taxa	26	27	28	29	30	31	32	33	34
EPT (families)									
Plecoptera-Trichoptera taxa									
Crustacea-Mollusca taxa									
Non-insect %									
EPT %									
EPT% no Baetidae									
Plecoptera %								33	
Trichoptera %									34
Plecoptera-Trichoptera %	26	27	28	29	30	31			
Coleoptera %					30	31	32	33	34
Diptera % excluding Tanytarsinae	26	27	28	29	30		32	33	34
Crustacea-Mollusca %									
Mollusca %									
Amphipoda %									
Mollusca-Amphipoda %	26	27	28	29	30	31	32	33	34
Beck’s BI (Hilsenhoff)									
Beck’s BI (TALU)						31	32	33	34
HBI									
Intolerant taxa									
Intolerant %									
Tolerant taxa (Hilsenhoff)	26	27							
Tolerant taxa (TALU)			28	29	30				
% dominant family									
Filterer %	26	27	28	29	30	31	32	33	34
Shredder taxa									
Clinger %									
Sprawler taxa		27		29					
25th percentile ref	67.4	66.3	65.8	64.8	67.3	64.7	72.5	67.1	65.0
DE	88.9	100.0	88.9	100.0	88.9	83.3	94.4	94.4	94.4
ref-deg difference	23.2	23.1	21.6	21.7	20.4	20.8	21.2	21.8	20.4
mean ref	71.1	67.8	70.0	66.9	72.0	71.6	73.7	68.3	67.9
mean deg	47.9	44.7	48.4	45.2	51.7	50.7	52.6	46.6	47.5
RMSE annual	6.5	6.7	6.1	6.3	5.2	5.5	6.0	6.0	5.3
RMSE season	5.4	6.7	5.1	6.3	5.0	6.7	6.2	5.9	6.1
Inter-quartile ref	7.6	5.2	8.2	5.4	9.2	15.3	4.3	6.0	8.2
Verification DE	94.7	100.0	94.7	100.0	89.5	100.0	94.7	100.0	100.0
Verification Ref DE	52.4	52.4	52.4	52.4	47.6	76.2	52.4	47.6	52.4

Appendix E-1 (continued). Results of alternative index combinations.

Metric	Ind.35	Ind.36	Ind.37	Ind.38	Ind.39	Ind.40	Ind.41	Ind.42	Ind.43
Total taxa (families)									
Insect taxa	35	36	37	38	39		41	42	43
Non-insect taxa	35	36	37	38	39		41	42	43
EPT (families)									
Plecoptera-Trichoptera taxa									
Crustacea-Mollusca taxa									
Non-insect %									
EPT %									
EPT% no Baetidae									
Plecoptera %	35	36	37			40			
Trichoptera %	35	36	37			40			
Plecoptera-Trichoptera %				38	39		41	42	43
Coleoptera %	35	36		38	39	40	41	42	43
Diptera % excluding Tanytarsinae	35		37	38	39	40	41	42	43
Crustacea-Mollusca %									
Mollusca %									
Amphipoda %									
Mollusca-Amphipoda %	35	36	37		39	40	41	42	43
Beck’s BI (Hilsenhoff)									
Beck’s BI (TALU)	35	36	37	38	39		41		
HBI									
Intolerant taxa									
Intolerant %									
Tolerant taxa (Hilsenhoff)								42	
Tolerant taxa (TALU)									43
% dominant family									
Filterer %	35	36	37	38					
Shredder taxa							41	42	43
Clinger %									
Sprawler taxa									
25th percentile ref	60.1	58.1	56.6	61.7	61.4	55.3	60.8	65.4	64.0
DE	94.4	83.3	94.4	94.4	88.9	94.4	94.4	88.9	88.9
ref-deg difference	21.0	20.0	22.1	21.6	22.5	20.8	23.2	23.1	21.7
mean ref	63.7	64.8	60.9	65.5	67.8	59.2	66.5	69.9	69.0
mean deg	42.8	44.8	38.8	43.9	45.3	38.4	43.3	46.8	47.3
RMSE annual	5.4	5.4	6.2	6.1	6.3	5.4	6.3		
RMSE season	5.7	6.1	5.9	6.2	8.2	7.6	8.2		
Inter-quartile ref	9.3	14.7	10.2	9.6	14.6	9.8	12.3	10.7	9.6
Verification DE	100.0	100.0	100.0	100.0	84.2	89.5	89.5	100.0	100.0
Verification Ref DE	61.9	76.2	61.9	57.1	71.4	66.7	66.7	66.7	57.1

Appendix E-1 (continued). Results of alternative index combinations.

Metric	Ind.44	Ind.45
Total taxa (families)		
Insect taxa		
Non-insect taxa		
EPT (families)		
Plecoptera-Trichoptera taxa		
Crustacea-Mollusca taxa		
Non-insect %		
EPT %		
EPT% no Baetidae		
Plecoptera %	44	45
Trichoptera %	44	45
Plecoptera-Trichoptera %		
Coleoptera %	44	45
Diptera % excluding Tanytarsinae	44	45
Crustacea-Mollusca %		
Mollusca %		
Amphipoda %		
Mollusca-Amphipoda %	44	45
Beck’s BI (Hilsenhoff)		
Beck’s BI (TALU)	44	
HBI		
Intolerant taxa		
Intolerant %		
Tolerant taxa (Hilsenhoff)		
Tolerant taxa (TALU)		45
% dominant family		
Filterer %		
Shredder taxa		
Clinger %		
Sprawler taxa		
25th percentile ref	51.3	49.9
DE	88.9	88.9
ref-deg difference	21.3	19.3
mean ref	57.47286	60.84634
mean deg	36.21534	41.50866
RMSE annual		
RMSE season		
Inter-quartile ref	15.58581	17.37047
Verification DE	84.2	63.2
Verification Ref DE	71.4	90.5

APPENDIX F

PMI METRICS AND SCORES

Appendix F-1. Metrics calculated for Pinelands samples. The PMI was developed using calibration reference and degraded (“Calib”, “ref”, and “deg”) samples. Verification data (Verif”) were used to confirm the discrimination ability of the PMI. Samples were not used (“Inval”) if they were collected in winter months or before 1995. Intermediate (Intermed) samples were neither reference nor degraded and were used only to illustrate metric and index performance in these moderately impacted sites.

Station ID	Waterbody	Calibration status	Reference status	Date	PMI	Total Individuals	Insect taxa	Non-insect taxa	% Plecop. and Trichoptera	% Diptera excluding Tanytarsini	% Mollusca and Amphipoda	Beck’s Biotic Index	% Filterers
AN0145	Mt Misery Bk	Verif	Ref	6/25/02	74.38	107	22	2	58.88	20.56	0.00	17	24.30
AN0145	Mt Misery Bk	Calib	Ref	9/19/02	73.23	114	28	2	54.39	8.77	0.88	22	42.11
AN0146	McDonalds Br	Inval	Intermed	6/11/91	54.38	48	6	3	0.00	56.25	0.00	0	0.00
AN0146	McDonalds Br	Inval	Intermed	9/24/91	59.86	53	7	3	5.66	71.70	0.00	3	5.66
AN0146	McDonalds Br	Inval	Intermed	4/17/91	66.30	61	16	3	21.31	57.38	0.00	9	14.75
AN0164	Black Run	Verif	Ref	4/2/98	65.51	120	23	2	28.33	30.00	0.00	11	26.67
AN0164	Black Run	Calib	Ref	4/5/01	70.94	156	24	0	29.49	61.54	0.00	17	66.03
AN0164	Black Run	Inval	Ref	9/24/91	77.21	479	36	4	56.99	17.33	0.00	22	42.17
AN0164	Black Run	Inval	Ref	4/10/91	73.41	549	44	6	21.49	27.69	0.18	23	37.52
AN0164	Black Run	Inval	Ref	6/11/91	82.29	1318	37	5	70.11	17.37	0.38	18	12.75
AN0165	UNT to Black Run	Verif	Ref	4/5/01	57.29	111	10	5	28.83	55.86	0.90	4	39.64
AN0165	UNT to Black Run	Calib	Ref	4/2/98	63.86	113	17	3	11.50	64.60	0.00	6	15.93
AN0165	UNT to Black Run	Inval	Ref	6/11/91	60.74	239	15	5	0.00	66.95	0.84	5	1.67
AN0165	UNT to Black Run	Inval	Ref	9/24/91	60.86	438	17	5	2.28	61.42	0.00	4	0.00
AN0165	UNT to Black Run	Inval	Ref	4/10/91	60.01	1668	24	6	2.22	87.59	0.06	9	68.41
AN0166	Barton Run	Verif	Deg	4/28/98	38.18	96	12	13	3.13	6.25	16.67	4	10.42
AN0166	Barton Run	Verif	Deg	4/5/01	37.95	106	23	16	4.72	9.43	45.28	7	10.38
AN0166	Barton Run	Calib	Deg	9/12/02	36.80	113	9	6	0.88	11.50	11.50	5	58.41
AN0166	Barton Run	Inval	Deg	4/14/93	17.02	122	8	10	4.92	2.46	83.61	2	69.67
AN0166	Barton Run	Verif	Deg	6/25/02	29.25	133	6	14	0.00	33.08	49.62	3	36.84
AN0167	Kettle Run	Verif	Deg	4/2/98	20.27	101	12	13	3.96	6.93	69.31	3	67.33
AN0167	Kettle Run	Calib	Deg	4/3/01	36.63	105	13	10	7.62	32.38	39.05	4	52.38
AN0167	Kettle Run	Inval	Deg	4/14/93	34.37	142	10	8	4.93	11.97	30.28	0	35.21

Station ID	Waterbody	Calibration status	Reference status	Date	PMI	Total Individuals	Insect taxa	Non-insect taxa	% Plecop. and Trichoptera	% Diptera excluding Tanytarsini	% Mollusca and Amphipoda	Beck's Biotic Index	% Filterers
AN0168	Haynes Ck	Verif	Deg	4/28/98	37.30	87	11	12	4.60	18.39	24.14	4	27.59
AN0168	Haynes Ck	Inval	Deg	4/14/93	39.42	121	13	11	33.88	10.74	21.49	2	56.20
AN0168	Haynes Ck	Calib	Deg	4/5/01	26.47	122	9	14	4.92	1.64	38.52		32.79
AN0519	Toms River	Inval	Intermed	10/12/94	67.48	111	17	2	37.84	31.53	0.90	18	39.64
AN0519	Toms River	Calib	Intermed	10/14/99	73.17	115	36	7	27.83	21.74	2.61	22	10.43
AN0521	Maple Root Br	Calib	Intermed	10/14/99	64.41	105	15	6	3.81	70.48	1.90	10	0.00
AN0521	Maple Root Br	Inval	Intermed	10/12/94	65.48	116	14	3	18.10	50.00	0.00	9	0.86
AN0522	Dove Mill Br	Calib	Intermed	10/14/99	67.77	73	18	2	35.62	39.73	9.59	11	12.33
AN0522	Dove Mill Br	Inval	Intermed	10/13/94	73.72	480	39	5	30.42	15.21	2.29	20	13.33
AN0523	Toms River	Calib	Intermed	10/14/99	68.79	109	23	5	38.53	33.03	9.17	14	11.01
AN0523	Toms River	Inval	Intermed	10/13/94	85.78	131	23	3	51.15	33.59	0.00	32	5.34
AN0525	UNT to Ridgeway Br (Bordens Mill Br)	Inval	Deg	10/18/94	44.69	11	3	1	0.00	18.18	0.00	0	18.18
AN0525A	UNT to Ridgeway Br	Calib	Deg	10/12/99	49.93	104	16	7	0.00	23.08	2.88	3	0.96
AN0526	Shannae Bk	Calib	Intermed	10/12/99	50.51	88	17	8	3.41	13.64	1.14	6	1.14
AN0526	Shannae Bk	Inval	Intermed	10/18/94	60.95	111	15	3	40.54	18.92	0.90	5	14.41
AN0527	Ridgeway Br	Calib	Intermed	10/19/99	55.97	58	14	4	10.34	18.97	0.00	7	0.00
AN0527	Ridgeway Br	Inval	Intermed	10/19/94	60.06	121	13	2	6.61	41.32	0.00	7	2.48
AN0529	Blacks Br	Calib	Intermed	10/12/99	69.42	85	27	1	24.71	48.24	0.00	8	22.35
AN0529	Blacks Br	Inval	Intermed	10/18/94	63.71	118	31	3	25.42	24.58	23.73	16	33.90
AN0530	Blacks Br	Calib	Ref	10/12/99	55.22	103	20	4	22.33	2.91	7.77	9	17.48
AN0530	Blacks Br	Inval	Ref	10/19/94	58.19	134	19	9	16.42	36.57	2.24	9	9.70
AN0531	Old Hurricane Br	Verif	Ref	6/24/02	67.35	105	24	5	21.90	45.71	0.00	17	33.33
AN0531	Old Hurricane Br	Verif	Ref	9/19/02	75.70	117	29	1	46.15	29.91	0.00	18	33.33
AN0531	Old Hurricane Br	Calib	Ref	11/4/99	70.94	118	25	1	43.22	29.66	0.00	17	45.76
AN0531	Old Hurricane Br	Inval	Ref	5/16/91	74.01	349	25	5	51.29	23.21	0.00	23	32.38
AN0531	Old Hurricane Br	Inval	Ref	11/14/90	77.40	1289	29	3	65.40	8.92	0.00	26	45.38

Station ID	Waterbody	Calibration status	Reference status	Date	PMI	Total Individuals	Insect taxa	Non-insect taxa	% Plecop. and Trichoptera	% Diptera excluding Tanytarsini	% Mollusca and Amphipoda	Beck's Biotic Index	% Filterers
AN0531	Old Hurricane Br	Inval	Ref	7/11/91	80.26	1512	39	5	69.05	11.38	0.00	29	61.64
AN0536	Wrangel Bk	Calib	Ref	11/4/99	74.72	100	25	2	48.00	30.00	0.00	15	17.00
AN0536	Wrangel Bk	Inval	Ref	11/3/94	67.18	114	19	2	21.93	37.72	0.00	12	8.77
AN0540	Davenport Br	Inval	Intermed	11/29/94	51.38	107	9	6	71.03	3.74	4.67	5	71.96
AN0540	Davenport Br	Calib	Intermed	11/4/99	49.88	107	12	8	54.21	27.10	4.67	3	74.77
AN0542	Jakes Br	Inval	Intermed	11/29/94	60.27	103	12	3	4.85	40.78	0.00	10	0.97
AN0542	Jakes Br	Calib	Intermed	11/4/99	49.28	103	9	3	2.91	5.83	3.88	6	0.00
AN0543	Jakes Br	Inval	Ref	11/29/94	53.34	109	9	3	29.36	1.83	0.00	5	11.01
AN0543	Jakes Br	Calib	Ref	11/9/99	48.88	114	8	5	7.89	2.63	3.51	8	1.75
AN0545	Webbs Mill Br	Inval	Intermed	11/14/90	47.98	243	16	11	7.82	35.80	38.68	8	0.41
AN0548	Cedar Ck	Verif	Ref	9/19/02	60.49	102	19	4	60.78	10.78	0.98	11	65.69
AN0548	Cedar Ck	Calib	Ref	6/5/03	63.19	109	27	7	6.42	61.47	9.17	7	7.34
AN0551	N Br Forked River	Inval	Ref	11/29/94	69.20	108	25	8	19.44	52.78	1.85	16	8.33
AN0551	N Br Forked River	Calib	Ref	11/9/99	72.50	109	25	2	43.12	26.61	0.92	17	25.69
AN0565	Hays Mill Ck	Calib	Deg	6/25/02	54.62	107	28	7	7.48	30.84	17.76	14	44.86
AN0565	Hays Mill Ck	Verif	Deg	9/12/02	47.72	112	18	8	7.14	16.07	40.18	13	12.50
AN0568	Prices Br	Inval	Deg	4/4/91	45.94	217	20	11	5.53	37.33	26.73	2	13.82
AN0571	Albertson Bk	Verif	Deg	6/20/02	53.66	100	21	6	16.00	29.00	21.00	14	46.00
AN0571	Albertson Bk	Calib	Deg	9/10/02	40.82	113	20	10	9.73	6.19	45.13	11	31.86
AN0574	Great Swamp Bk	Verif	Deg	9/5/02	55.31	104	22	5	13.46	33.65	2.88	7	39.42
AN0574	Great Swamp Bk	Calib	Deg	6/13/02	48.31	105	19	8	2.86	25.71	12.38	3	11.43
AN0575	Cedar Bk	Calib	Deg	6/13/02	41.04	97	15	9	0.00	20.62	31.96	1	4.12
AN0575	Cedar Bk	Verif	Deg	9/5/02	55.31	104	22	5	13.46	33.65	2.88	7	39.42
AN0578	Hammonton Ck	Calib	Deg	9/5/02	56.57	97	25	7	7.22	8.25	7.22	19	25.77
AN0578	Hammonton Ck	Verif	Deg	6/13/02	49.68	112	18	11	6.25	23.21	11.61	9	9.82
AN0581	Skit Br	Verif	Ref	9/12/02	61.31	113	25	3	13.27	21.24	0.00	9	12.39
AN0581	Skit Br	Calib	Ref	6/13/02	62.86	115	16	2	0.87	69.57	0.00	3	3.48

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AN0584	Springers Bk	Verif	Deg	6/18/02	25.24	99	3	10	0.00	1.01	39.39	1	39.39
AN0584	Springers Bk	Calib	Deg	9/12/02	20.04	106	8	7	0.00	7.55	71.70	2	76.42
AN0586A	Batsto River	Verif	Intermed	7/15/98	68.76	1	1	0	100.00	0.00	0.00	1	0.00
AN0586A	Batsto River	Calib	Intermed	10/13/98	57.85	111	19	4	30.63	13.51	10.81	10	24.32
AN0587	Pen Swamp Br	Verif	Ref	9/17/02	54.09	102	13	4	22.55	21.57	4.90	5	19.61
AN0587	Pen Swamp Br	Calib	Ref	6/18/02	68.92	115	22	4	31.30	54.78	4.35	10	19.13
AN0587	Pen Swamp Br	Verif	Ref	11/2/95	60.50	138	22	6	22.46	30.43	14.49	13	19.57
AN0587	Pen Swamp Br	Verif	Ref	5/12/95	70.81	263	23	5	10.27	74.14	2.28	13	8.37
AN0587	Pen Swamp Br	Verif	Ref	8/8/95	72.94	429	31	7	25.64	50.12	7.23	18	11.66
AN0590	Landing Ck	Calib	Intermed	4/6/95	40.98	100	7	11	1.00	11.00	2.00	2	1.00
AN0590	Landing Ck	Verif	Intermed	4/4/00	42.20	108	4	8	0.00	11.11	0.93	2	0.00
AN0593	Indian Cabin Ck	Verif	Intermed	4/4/00	65.10	118	19	2	2.54	64.41	0.00	6	3.39
AN0593	Indian Cabin Ck	Calib	Intermed	4/6/95	65.20	139	16	4	2.88	74.10	0.72	7	0.72
AN0596	West Br Wading River	Inval	Intermed	4/4/91	50.74	861	8	3	0.81	95.82	0.00	4	93.38
AN0600	Tulpehocken Ck	Verif	Ref	6/19/03	58.81	100	20	5	2.00	50.00	8.00	5	1.00
AN0600	Tulpehocken Ck	Calib	Ref	9/17/02	63.30	109	21	6	6.42	57.80	1.83	7	0.00
AN0605	Papoose Br	Calib	Ref	9/19/02	70.73	107	26	4	26.17	37.38	0.00	16	14.02
AN0605	Papoose Br	Verif	Ref	6/24/02	69.64	108	25	5	27.78	38.89	0.00	13	7.41
AN0607	Oswego River (E Br Wading River)	Inval	Intermed	5/16/91	62.08	110	18	4	55.45	24.55	0.00	9	55.45
AN0607	Oswego River (E Br Wading River)	Inval	Intermed	9/23/91	59.42	303	24	7	51.49	13.53	0.00	11	60.40
AN0612	East Br Bass River	Calib	Ref	9/17/02	66.77	104	32	5	22.12	32.69	0.00	10	16.35
AN0612	East Br Bass River	Verif	Ref	6/24/02	67.55	113	25	4	17.70	66.37	4.42	5	10.62
AN0617	S Br Absecon Ck	Verif	Deg	6/21/95	56.85	110	18	8	13.64	29.09	11.82	12	7.27
AN0617	S Br Absecon Ck	Calib	Deg	6/13/00	55.45	116	19	4	2.59	39.66	4.31	10	35.34
AN0618	Mill Br (Fenton's	Verif	Intermed	4/11/95	45.74	120	24	10	11.67	16.67	39.17	4	7.50

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	Mill)												
AN0618	Mill Br (Fenton's Mill)	Calib	Intermed	4/6/00	43.92	122	18	5	4.10	9.84	46.72	4	0.00
AN0623	Great Egg Harbor River	Calib	Deg	6/13/00	71.10	103	31	2	11.65	41.75	0.00	16	16.50
AN0623	Great Egg Harbor River	Inval	Deg	6/3/93	65.63	208	31	6	18.75	18.27	0.96	20	27.88
AN0623	Great Egg Harbor River	Inval	Deg	4/13/93	77.24	346	42	8	42.49	17.92	10.98	27	21.10
AN0623	Great Egg Harbor River	Inval	Deg	9/9/92	89.00	701	50	7	66.62	17.26	0.43	36	50.64
AN0625	Great Egg Harbor River	Calib	Deg	6/13/00	63.19	102	16	1	66.67	17.65	0.00	10	70.59
AN0625	Great Egg Harbor River	Inval	Deg	6/3/93	79.14	511	31	3	58.71	19.18	0.00	27	44.81
AN0625	Great Egg Harbor River	Inval	Deg	4/13/93	87.11	530	42	5	63.58	10.57	0.57	30	17.92
AN0625	Great Egg Harbor River	Inval	Deg	9/9/92	84.51	1184	44	4	74.49	8.95	0.00	32	67.74
AN0626	Penny Pot Stream	Verif	Deg	6/20/02	57.01	112	12	5	8.93	55.36	2.68	7	23.21
AN0626	Penny Pot Stream	Calib	Deg	9/10/02	59.26	113	22	6	9.73	27.43	3.54	11	8.85
AN0627	Hospitality Br	Verif	Deg	5/31/95	46.54	104	12	8	0.00	17.31	2.88	3	0.96
AN0627	Hospitality Br	Verif	Deg	9/10/02	45.28	105	13	9	14.29	1.90	16.19	8	13.33
AN0627	Hospitality Br	Verif	Deg	5/2/00	60.95	106	21	5	1.89	67.92	8.49	4	7.55
AN0627	Hospitality Br	Calib	Deg	6/20/02	44.49	120	17	8	2.50	16.67	17.50	1	6.67
AN0628	Hospitality Br	Calib	Deg	5/23/95	23.73	145	12	17	1.38	3.45	41.38	2	44.14
AN0628	Hospitality Br	Verif	Deg	5/4/00	39.11	158	24	15	5.06	13.92	22.15	2	24.05
AN0629	Faraway Br	Calib	Intermed	5/4/00	56.01	104	24	2	2.88	25.00	0.00	2	12.50
AN0629	Faraway Br	Verif	Intermed	5/23/95	42.02	131	15	16	5.34	7.63	1.53	5	3.82
AN0630	White Oak Br	Verif	Intermed	5/23/95	59.54	102	15	3	1.96	81.37	0.00	5	41.18

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AN0630	White Oak Br	Calib	Intermed	5/2/00	51.50	198	9	4	0.00	93.94	0.00	1	71.72
AN0631	Marsh Lake Br (Collings Br)	Verif	Deg	5/2/00	30.96	101	8	5	0.99	6.93	42.57	1	44.55
AN0631	Marsh Lake Br (Collings Br)	Calib	Deg	5/31/95	31.39	108	8	11	0.00	15.74	30.56	0	31.48
AN0632	Marsh Lake Br (Collings Br)	Verif	Deg	5/4/00	60.25	114	30	9	17.54	55.26	4.39	9	46.49
AN0632	Marsh Lake Br (Collings Br)	Calib	Deg	5/23/95	48.97	118	28	12	16.95	26.27	12.71	5	39.83
AN0634	Three Pond Bk	Verif	Intermed	5/23/95	54.91	127	16	7	3.15	54.33	4.72	3	10.24
AN0634	Three Pond Bk	Calib	Intermed	5/4/00	43.36	128	13	9	1.56	17.97	5.47	1	12.50
AN0635	Great Egg Harbor River	Calib	Intermed	6/8/00	67.67	122	23	3	42.62	25.41	0.00	14	35.25
AN0635	Great Egg Harbor River	Inval	Intermed	4/13/93	79.36	264	26	1	68.56	7.58	0.00	22	23.86
AN0635	Great Egg Harbor River	Inval	Intermed	9/9/92	80.30	671	30	1	78.09	8.49	0.00	25	54.69
AN0635	Great Egg Harbor River	Inval	Intermed	6/3/93	76.52	1024	33	2	69.82	6.35	0.00	23	59.08
AN0638	Mare Run	Verif	Ref	9/10/02	59.10	110	22	4	16.36	15.45	2.73	7	1.82
AN0638	Mare Run	Calib	Ref	5/4/00	66.57	111	21	2	6.31	73.87	3.60	3	1.80
AN0638	Mare Run	Verif	Ref	6/20/02	62.51	117	17	5	7.69	71.79	2.56	3	4.27
AN0638	Mare Run	Verif	Ref	5/16/95	58.00	144	25	8	11.81	44.44	2.78	7	25.69
AN0639	Watering Race	Verif	Intermed	4/4/00	64.29	115	23	5	1.74	59.13	0.87	10	9.57
AN0639	Watering Race	Verif	Intermed	4/11/95	64.39	353	26	7	3.12	64.31	11.05	10	3.97
AN0640	Babcock Ck	Calib	Intermed	5/9/95	53.44	107	18	10	5.61	31.78	2.80	11	16.82
AN0640	Babcock Ck	Verif	Intermed	5/11/00	69.52	112	21	3	46.43	23.21	0.00	10	7.14
AN0643	South River	Verif	Intermed	5/10/00	68.46	113	22	4	24.78	61.06	4.42	7	8.85
AN0643	South River	Calib	Intermed	5/16/95	72.00	132	26	4	32.58	36.36	0.76	13	3.03
AN0644	South River	Calib	Intermed	5/10/00	65.99	110	27	4	14.55	30.91	0.91	17	23.64

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AN0644	South River	Verif	Intermed	5/16/95	74.44	137	32	2	37.23	31.39	1.46	23	48.18
AN0645	Stephens Ck	Calib	Intermed	5/10/00	64.42	108	17	3	3.70	84.26	0.00	8	31.48
AN0645	Stephens Ck	Verif	Intermed	5/16/95	74.32	138	37	4	15.22	39.86	2.90	21	18.84
AN0647	Gibson Ck	Calib	Ref	5/16/00	72.84	109	23	2	33.94	32.11	0.00	16	8.26
AN0647	Gibson Ck	Verif	Ref	5/9/95	69.04	125	21	1	32.00	31.20	0.00	12	14.40
AN0648	Tuckahoe River	Calib	Intermed	6/7/00	54.01	104	24	6	3.85	26.92	15.38	4	0.00
AN0648	Tuckahoe River	Verif	Intermed	6/1/95	51.77	151	23	9	5.30	21.19	2.65	4	6.62
AN0649	Tuckahoe River	Verif	Intermed	6/1/95	54.39	109	23	10	14.68	12.84	4.59	12	15.60
AN0649	Tuckahoe River	Calib	Intermed	6/7/00	51.85	118	16	7	0.00	22.03	5.93	8	1.69
AN0649	Tuckahoe River	Verif	Intermed	9/12/95	71.10	1113	40	7	16.44	44.38	0.45	23	50.04
AN0651	McNeals Br	Calib	Ref	6/8/00	63.88	113	26	3	21.24	26.55	3.54	6	2.65
AN0651	McNeals Br	Verif	Ref	6/1/95	70.73	126	34	8	30.16	34.92	3.17	14	7.14
AN0651	McNeals Br	Verif	Ref	9/12/95	69.43	385	36	9	29.35	13.25	3.90	19	4.68
AN0652	Mill Ck	Verif	Intermed	6/8/00	60.57	111	18	5	16.22	50.45	0.90	6	18.92
AN0652	Mill Ck	Calib	Intermed	6/1/95	69.18	131	29	5	26.72	32.82	0.76	12	6.87
AN0762	Manumuskin River	Calib	Intermed	11/1/00	71.92	106	25	4	29.25	33.02	0.00	23	28.30
AN0762	Manumuskin River	Verif	Intermed	11/28/95	70.72	204	30	8	34.31	21.08	2.45	27	33.82
AN0763	Manumuskin River	Calib	Ref	6/12/01	71.11	119	18	2	7.56	70.59	0.84	14	5.04
AN0763	Manumuskin River	Verif	Ref	11/28/95	70.49	124	32	9	33.87	28.23	2.42	22	25.81
AN0764	Muskee Ck (Middle Br)	Calib	Intermed	10/3/00	65.28	108	16	5	11.11	67.59	0.93	7	0.00
AN0764	Muskee Ck (Middle Br)	Verif	Intermed	10/31/95	69.85	117	27	3	33.33	29.91	1.71	11	9.40