Benthic Macroinvertebrate Indicators of Water Quality Degradation

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Abstract

The City of Austin has collected over half a million benthic macroinvertebrates at more than three hundred sites over the past twenty years for assessments of surface water quality. This large data set provides an excellent opportunity for analysis of impacts to organism distribution and community composition from different amounts of impervious cover. In this report, benthic macroinvertebrate metric parameter data and pollution-sensitive taxa from historic biological assessments are evaluated for correlation with increasing impervious cover and selected based on sensitivity to low amounts of impervious cover. Of the 23 metrics and six taxa selected in this study, the pollution-intolerant taxa Perlesta, Thraulodes and Leptohyphes were identified to be the most critically affected. Conclusions include a complete loss of taxa occurrence at 34% impervious cover, and a clear signal of aquatic community degradation for watersheds that exceed 15% impervious cover. This analysis may be used to evaluate current development regulations, use as performance measures for water quality improvement projects and identify areas of high aquatic integrity that merit protection.

Introduction

An important component of a comprehensive water quality monitoring program is the evaluation of the biological community. The biological community can indicate water quality issues that are not specifically targeted using conventional chemical or physical monitoring. Routine parameters collected from baseflow grab samples (i.e. temperature, dissolved oxygen, specific conductance, pH, nutrients, and turbidity) may not reliably identify a clear signal of degradation in a stream due to stressors such as an altered hydrograph, acute wastewater spills or episodic inputs of toxins such as pesticides/herbicides. However, these stressors can result in changes to the assemblage of the resident benthic community which is an aspect of aquatic integrity that can be measured. An additional benefit of evaluating the biological community is a broad temporal perspective. While a standard water chemistry grab sample may be limited to an indication of ambient conditions, a biological assessment can reflect the antecedent conditions spanning the previous weeks, months and even years for sites that include long-lived taxa.

Biological monitoring methods which use direct measurements of the resident biota to evaluate the relative integrity of aquatic resources are called bioassessments. Organisms commonly used in bioassessments are benthic macroinvertebrates, which are bottom-dwelling invertebrates that are easily seen without magnification and that require aquatic habitat to complete their lifecycle. Benthic macroinvertebrates have long been used in bioassessments and are appropriate indicators of water quality since many of these organisms are sensitive to physical and chemical perturbations in their habitat. Indications of changes to the community may manifest as lower diversity, alterations to functional feeding group dominance, increases of tolerant taxa, or the loss of pollution intolerant species. For example, the Environmental Protection Agency (EPA) and Texas Commission on Environmental Quality (TCEQ) have designated pollution tolerance index (PTI) values for most benthic macroinvertebrates. PTI values range from 10 (most tolerant to pollution) to 0 (most intolerant to pollution). The use of biological indicators (such as the PTI) to assess degradation of aquatic communities is well documented in the literature (Wang et al. 1997 2000, Lenat and Crawford 1994, Crunkilton et al 1996). This relationship is further corroborated by the results of City of Austin bioassessments. City bioassessments indicate that pollution-intolerant taxa are found less frequently in the highly developed urban core (an area of increased stressors) of the City of Austin than found in the suburban and rural periphery (Figure 1).

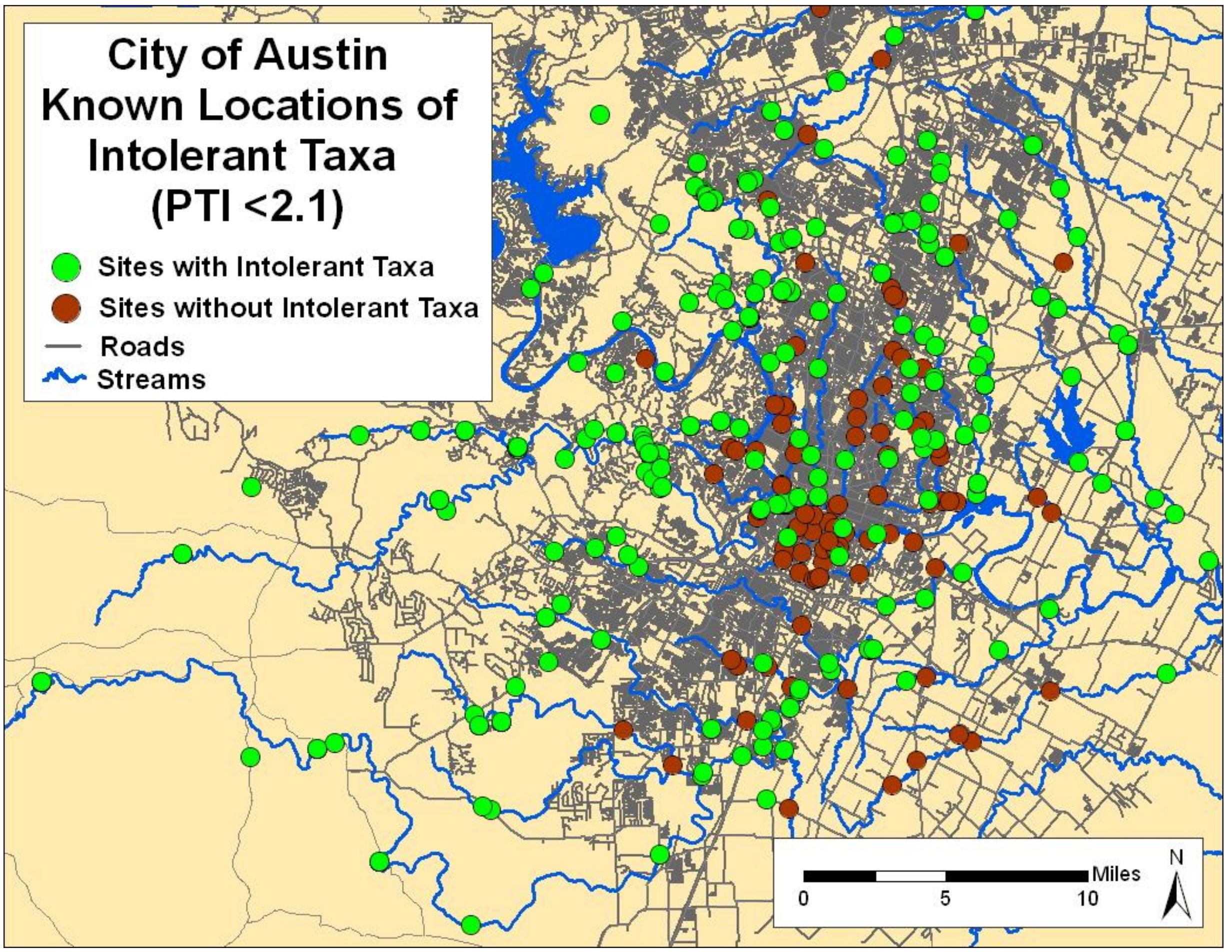


Figure 1. Locations of pollution-intolerant benthic macroinvertebrates in the City of Austin and surrounding communities. Dense roadways (grey lines) correlate with urbanization. The densely urban areas (central) are more likely to lack intolerant taxa (shown as brown circles) with an increasing gradient of occurrence intolerant species toward suburban and rural areas.

Biological stressors associated with urban development are diverse, but a common thread is an increase in impervious cover. Among other negative externalities, an increase in the impervious cover of a watershed exacerbates the “flashiness” of storm events which increases scour, erosion, deposition, sediment transport and other habitat-altering forces. In the Austin area, the relationship between the impervious cover of a watershed and the biological integrity of the receiving water is complicated by several factors. These factors include a natural gradient of habitat-type across different ecoregions, a variability of hydrology due to a transition in geological formations and subtle complexities of changing land use and development regulations which transition from urban to rural areas. These factors make it difficult to determine the minimum threshold of development in which aquatic biological integrity can be said to be degraded. As suburban communities sprawl outward consuming rural land, it has become increasingly important to identify potential thresholds for biotic degradation in order to identify development regulations that maintain aquatic integrity.

The City of Austin has a history of environmental resource management that has resulted in a long-term, extensive, and quality-assured water quality monitoring dataset. This dataset combined with advances in GIS-based information are enabling greater resolution of the impacts caused by development. Since 1993, the City of Austin has collected over half a million benthic macroinvertebrates at more than 300 bioassessment sites in Travis, Hays and Williamson Counties. The bioassessments have been conducted at sites within watersheds along a gradient of development including urban (>30% impervious cover), suburban (10-30% impervious cover) and rural (<10% impervious cover). The resulting data indicate that select indicator taxa and community associations may provide sensitive local predictors of low levels of degradation that may be helpful in the development of policies and practices that protect overall stream health.

Methods

Benthic macroinvertebrate bioassessments by the City of Austin have primarily utilized surber sampling (Figure 2) when adequate riffle habitat is available but have also included kicknet sampling (Figure 3) in lakes and streams that lack riffle habitat. City of Austin collection methods generally follow Federal and State guidance with some modifications described below.

Figure 2. Surber sampling

Figure 3. Kicknet sampling

The Environmental Protection Agency (EPA) and Texas Commission on Environmental Quality (TCEQ) have identified a range of univariate metrics for use in bioassessments. These parameters measure one or more aspects of the benthic community such as diversity, dominance, community structure and trophic balance in addition to other taxa-specific characteristics. Descriptions of each metric, the rational for its use, and a rubric for assessing aquatic integrity based on each parameter can be found in Federal and State methodologies as described in EPA (Barbour, 1999) and TCEQ (2005) procedure manuals. For the purposes of this report, the following 23 metrics were evaluated:

- Taxa richness
- Percent dominant taxon (top 1)
- Percent dominant taxa (top 3)
- Ephemeroptera/plecoptera/trichoptera (EPT) taxa
- Percent of total as EPT
- Ratio of EPT / EPT + chironomidae
- Number of ephemeroptera taxa
- Percent of total trichoptera as hydropsychidae
- Number of non-insect taxa
- Number of diptera taxa
- Percent chironomidae
- Percent of number as elmidae
- Hilsenhoff biotic index (average PTI)
- Ratio of intolerant to tolerant taxa
- Number of intolerant taxa
- Percent grazers
- Percent filterers
- Percent predators
- Percent of collector-gatherers
- Percent dominant functional feeding group
- City of Austin EII Habitat index
- City of Austin EII multi-parametric score
- TCEQ multi-parametric Aquatic Life Use score

In addition to these 23 metrics, individual pollution-intolerant taxa were evaluated for their occurrence in watersheds of differing impervious cover. PTI values range from 10 (most tolerant to pollution) to 0 (most intolerant to pollution). For this report, the three most pollution-intolerant categories (0, 1 and 2) were selected to represent "intolerant taxa". The City of Austin has collected at least 16 taxa from these categories (Table 1).

Table 1. Intolerant Taxa known to the City of Austin
→ → → Increasing tolerance to pollution → → →

PTI 0	PTI 1	PTI 2
Agapetus	*Protoptila*	*Chimarra*
Marilia		*Helicopsyche*
Perlesta		*Hexacylloepus*
Zealeuctra		*Leptohyphes*
		Microcylloepus
		Neoelmis
		Oxyethira
		Paraleptophlebia
		Phylloicus
		Thraulodes
		Traverella

Although all of the 16 taxa shown in Table 1 are intolerant, not all are suitable candidates for citywide watershed comparisons. A good candidate for this study would be widespread and numerous. Unfortunately, most of the 16 taxa either have highly specific habitat requirements or are rare in occurrence. For example, the caddisfly *Phylloicus ornatus* has infrequent occurrence and is a resident of perennial springs with clear, cold groundwater and would therefore not be found at most locations across Austin watersheds regardless of the ambient water quality. Conversely, the high frequency of occurrence (33,150 individuals) and widespread habitat of *Chimarra* enables more robust statistical strength. Six taxa that met the criteria as widespread and numerous were:

- *Perlesta* (stonefly)
- *Microcylloepus* (riffle beetle)
- *Marilia* (caddisfly)
- *Chimarra* (caddisfly)
- *Thraulodes* (mayfly)
- *Leptohyphes* (mayfly)

These six taxa comprised 97% of the total number of individuals (57,413) collected by the City of Austin that have a PTI less than or equal to 2.

Calculation of the percent impervious cover for the watershed for each site began by obtaining a GIS layer of parcel units from the county appraisal districts. A land use category was then assigned to each discreet parcel unit (Figure 4) using standard City of Austin criteria. The City uses a modified version of the land use classification systems used by James Anderson of the United States Geological Survey. In 2003, the City expanded the classification system to include a variety of residential, industrial, open space, and transportation uses by adding additional sub-codes. The sub-codes always relate to a more general land use code. This allows the City to maintain two coding systems in the GIS. A table showing the specific and general land use codes is available in the metadata available for download on the City GIS data depot. The categories of land use were determined primarily from known zoning but also included historical data and aerial photography for verification.

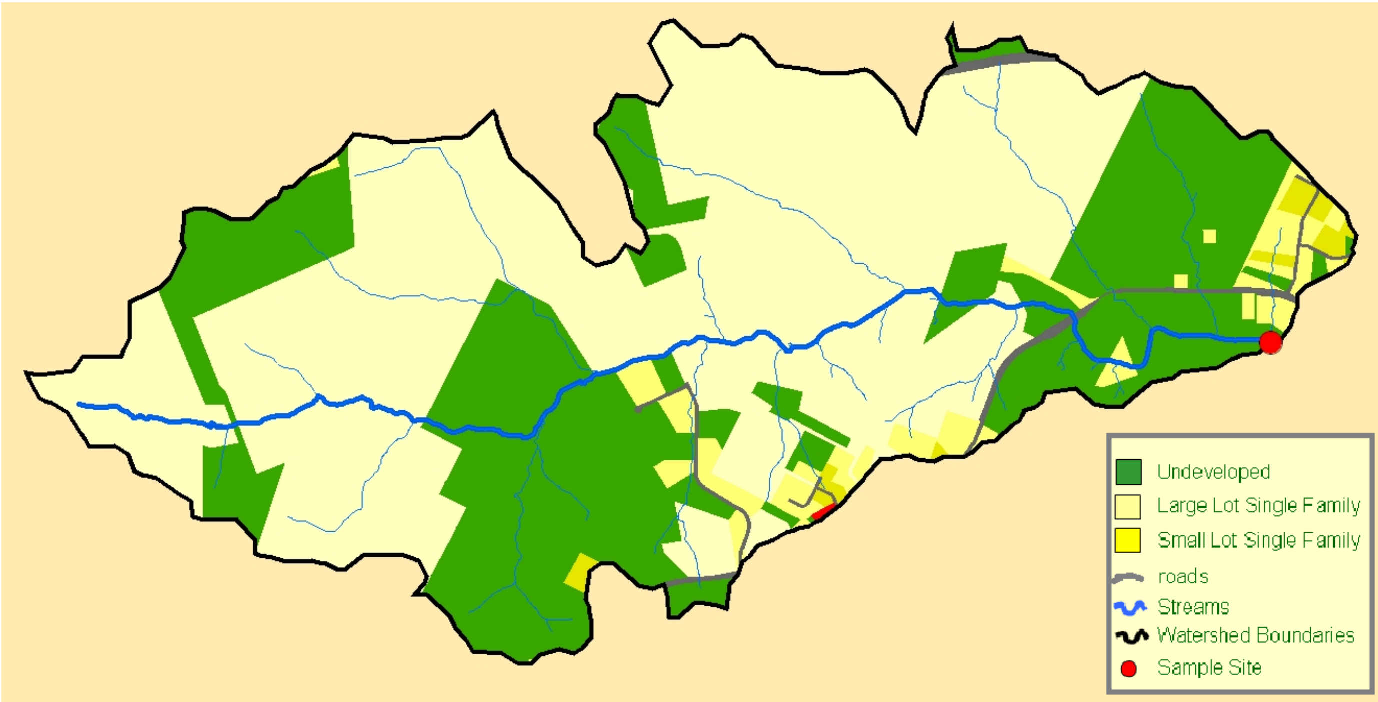


Figure 4. Example of land use parcel units for a watershed of a suburban sample site

The City of Austin Watershed Protection Department maintains an established assumption for the percent impervious cover for each land use category based on previous GIS assessments. For example, the land use category "small lot single-family residential" is assigned a 27% impervious cover assumption based on empirical data of a sample subset of existing small lot single-family residence parcels in the City of Austin. Impervious cover percentage for the entire watershed of each sample site was determined by converting the parcel coverage into land use categories, dividing the areas into a 10-meter grid which was then combined to determine the total impervious cover for a watershed by clipping the coverage from watershed boundaries defined by using the flow accumulation function in ArcMap.

Analysis of data included a linear regression for each of the 29 response variables (23 metrics, 6 taxa) versus impervious cover performed in SAS using PROC GLM to determine which response variables had significant relationships to impervious cover. To aid in comparison of multiple univariate regression outputs, dependent variables were normalized prior to regression analysis by expressing them as a fractional percentage of the minimum-to-maximum range using the "best" and "worst" values observed for that dependent variable, or:

Normalized value = (result value – min value observed)/(max value observed – min value observed)

For the 6 individual intolerant taxa, a normalized score of 0 indicates a zero probability of taxa occurrence at that site/date and a 1 indicates a 100% incidence of occurrence for a taxon. Probability of occurrence for intolerant taxa was determined by dividing the number of sample events in which study taxa were collected by the total number of sampling events. For example, a probability of occurrence of 0 indicates that the taxon was never collected during any sample events for the given site and a probability of occurrence of 1 indicates that 100% of the sample events at that site included collection of the taxon.

Results

Of the 29 (23 metrics and 6 taxa) biological response variables evaluated, 22 (17 metrics and 5 taxa) exhibited a significant negative relationship with impervious cover (Figure 5).

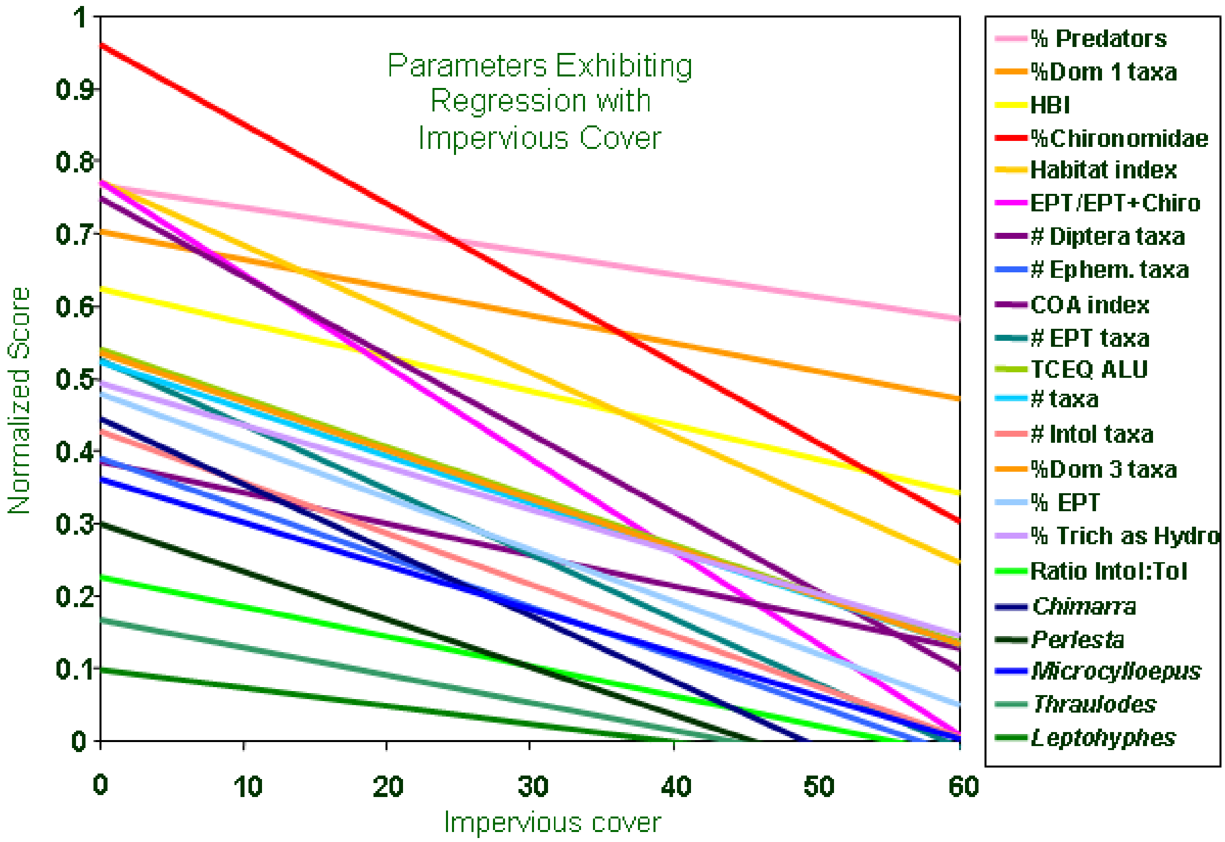


Figure 5. Linear regression analysis showing significant relationships (all negative responses) to increasing impervious cover for 17 metrics and 5 pollution-intolerant taxa. The trend line for the intolerant taxa *Perlesta*, *Thraulodes* and *Leptohyphes* reached a normalized score of zero at the lowest amount of impervious cover.

The steepness of the regression line for each response variable indicates how responsive the variable is to impervious cover over all. The regression lines which reach a normalized score of zero at a lower percentage of impervious cover are of interest because they may indicate increased sensitivity at very low levels of impervious cover. Of the 22 significant relationships to impervious cover, the three variables that reached a normalized score of zero at the lowest percentage of impervious cover were the taxa *Perlesta*, *Thraulodes* and *Leptohyphes*.

Figures 6a, 6b and 6c present plot graphs of the normalized occurrence of the taxa *Perlesta*, *Thraulodes* and *Leptohyphes* for a more detailed analysis of taxa response to impervious cover. All three taxa appear to have a survival or persistence threshold at or below 34% impervious cover. *Leptohyphes* and *Thraulodes* both appear to indicate a higher sensitivity to impervious cover as the bulk of occurrence was in watersheds with less than 15% with rare occurrence in watersheds between 15-34%. The majority of occurrences of the three intolerant taxa were located in the 0 to 15% impervious cover range.

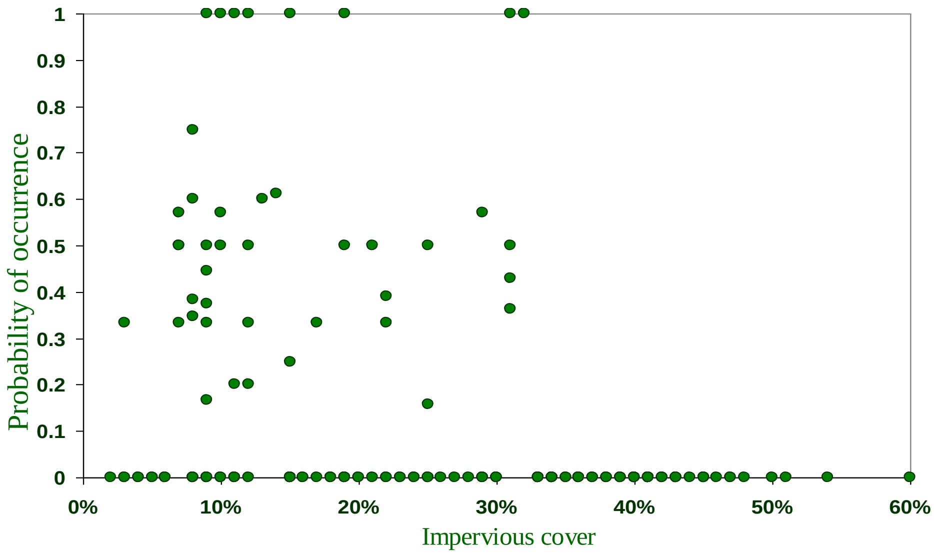
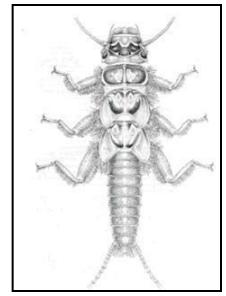


Figure 6a. Probability of occurrence of the stonefly *Perlesta* at sites with increasing impervious cover



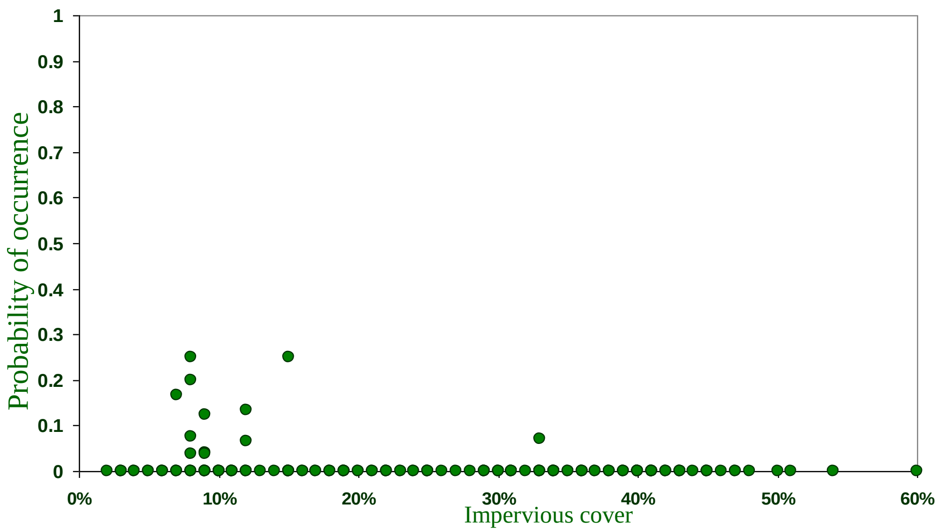
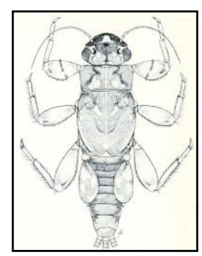


Figure 6b. Probability of occurrence of the stonefly *Leptohyphes* at sites with increasing impervious cover



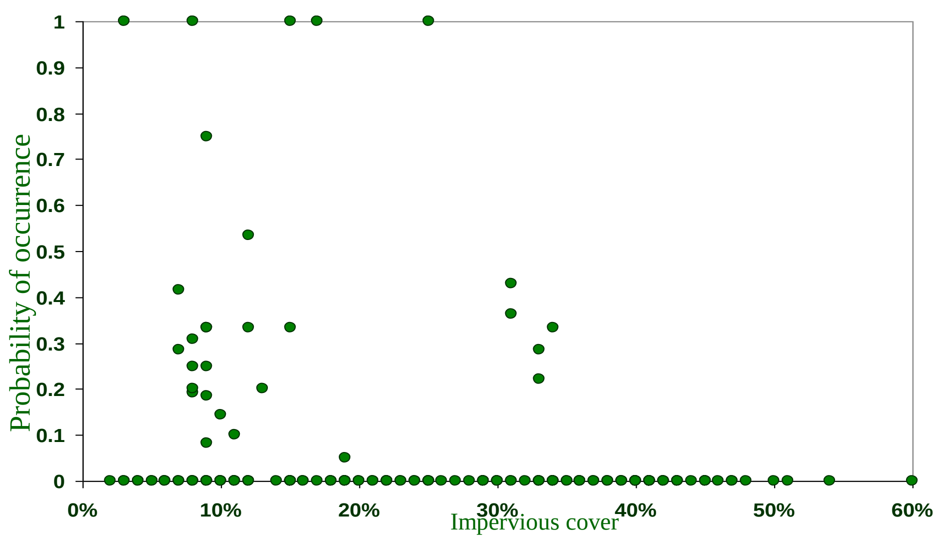
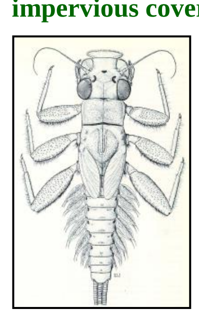


Figure 6b. Probability of occurrence of the stonefly *Thraulodes* at sites with increasing impervious cover



Conclusions

This exercise provides an example for the use of biological data from bioassessments and GIS to explore the impacts of impervious cover on some important measures of aquatic integrity. Urbanization and increased impervious cover have long been known to impact the biological community but substantiating these impacts in low levels of impervious cover is meaningful to municipalities that desire to regulate development in a manner that supports high aquatic integrity. Of the 29 parameters evaluated in this study, 22 showed a statistically significant response to increasing impervious cover in Austin watersheds. Of these 22 parameters, the three that appeared to be the most critically affected at low levels of impervious cover were the pollution intolerant taxa *Perlesta*, *Leptohyphes* and *Thraulodes*. A critical survival or persistence threshold for all three taxa was apparent at 34% impervious cover, above which these sensitive taxa disappear completely, and the majority of occurrence of these three taxa was in watersheds with less than 15% impervious cover. These results suggest that the most protective impervious cover limitations in Austin (currently 15% net site area in the Barton Springs Zone) are only protective of the extinction of our most sensitive taxa and are probably well above where significant ecological degradation begins to occur. Should the City of Austin, or other municipalities desire to protect aquatic integrity with a goal of non-degradation, further research into more subtle taxa and community level responses is necessary.

Recommendations

Although the City of Austin has utilized multi-metric tools for aquatic integrity scoring, the results of this study indicate that indicator taxa may be a useful tool in the assessment of watershed health and indicative of development thresholds that do not result in degradation. The taxa identified in this report, and other ubiquitous intolerant taxa should be further explored for use as a supplement to multi-metric aquatic life use scoring. This report should be a resource in further investigating a threshold for impervious cover that maintains high aquatic integrity.

Acknowledgements

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