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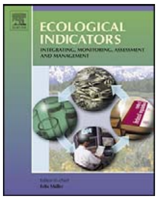

Short communication

Seasonal predictability of benthic macroinvertebrate metrics and community structure with maturity-weighted abundances in a Missouri Ozark stream, USA

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ABSTRACT

Benthic macroinvertebrates in lotic habitats are influenced by a wide range of physical and chemical environmental factors that change over a temporal continuum. Within a year, different species can occupy the same space at different points in time. Thus, the community structure itself is in flux from season to season. This study analyzed the structure of a riffle macroinvertebrate community in a single stream from a series of monthly samples over a year cycle. The goals of this study were to: (1) identify community measures that were least variable over the continuum and predict them in test samples from the next year; (2) explore the usefulness of maturity data in analyzing community structure; (3) construct a temporal River Invertebrate Prediction and Classification System like (RIVPACS-like) model that classifies seasons based on biota and predicts an expected community for any season. From a set of 120 metrics, nine metrics representing 5 measurement categories displaying low variability over the annual continuum were selected for multiple regression analysis. The Biotic Index was fairly predictable between years, regardless of season, whereas other measures were less so. Metrics with standard abundances compared to their maturity-weighted analogues revealed that measures based on finer taxonomic resolution or functional groups were more likely to differ. Three biologically determined seasons were identified from cluster analysis during the process of creating a multivariate predictive model. Temporal environmental variables were used to determine test date group membership and comparisons of expected to observed communities revealed that 1 of 3 test dates was predicted well by the model. Our results demonstrate that macroinvertebrate community structures can express high variability over a short period of time and this phenomenon deserves more understanding with regard to interpreting biological assessment results.

1. Introduction

Aquatic macroinvertebrate communities in temperate lotic systems are influenced by seasonal changes. Many aquatic insect life histories and development rates are influenced by temperature (Vannote and Sweeney, 1980; Sweeney, 1984; Ward, 1992; Williams and Feltmate, 1992) and other physico-temporal factors (Wohl et al., 1995; Robinson and Minshall, 1998), while thermal conditions temporally partition resources (Cummins and Merrit, 1996). Seasonal precipitation and discharge have been shown to be significant factors influencing community structure from year to year (McElravy et al., 1989). Differences in disturbance rates can dictate the number and types of species (obligate vs. specialist) that may coexist within a habitat (Ward, 1989). Stream 'patches' change temporally (Wiens, 2002) and a snapshot of environmental conditions measured at the time of sampling may not reflect important events that could have affected the community prior to sampling (Cooper and Barmuta, 1993). It is important to recognize that macroinvertebrate communities fluctuate and samples from one point in time may appear quite different from other points in time.

Macroinvertebrate metrics are common components of biological water quality assessment studies. In general, metrics require rigorous testing in order to provide the most meaningful understanding of their relationships with environmental factors (Norris, 1995). Screening of metrics as a step in developing measures of biological condition usually includes examination of metric variability at reference sites as recommended in designing a Benthic Index of Biotic Integrity (B-IBI) (Barbour et al., 1999; Flotemersch et al., 2006). Even though many monitoring programs specify an index period for sampling, temporal effects within that period may be unaccounted. Some studies have investigated annual variation in community structure (e.g., McElravy et al., 1989; Robinson et al., 2000). However, relatively few studies have investigated seasonal

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differences in metric values (Hilsenhoff, 1977; Murphy, 1978; Jones et al., 1981; Armitage et al., 1983; Lenat, 1993; Zamora-Muñoz et al., 1995; Linke et al., 1999; Maloney and Feminella, 2006; Leunda et al., 2009). Metrics with the least variability within a single year are most favorable as measures for biological assessment because they will be more consistent with regard to seasonal differences.

Many macroinvertebrate species exhibit ontogenetic shifts in habitat preferences (Minshall, 1984; Buffagni et al., 1995; Lloyd and Sites, 2000; Reich and Downes, 2004) and feeding strategies or prey items (Norris, 1995), even between immature stages (Snellen and Stewart, 1979; Gibbs and Mingo, 1986). Many aquatic macroinvertebrates are r-select and display high mortality, therefore high abundances of individuals can be observed during early stages of a population's development. It stands to reason that an early instar compared to a conspecific later instar will feed on less material and will represent less of a nutritive food source for predators. Weighting individuals according to a set of maturity classifications can provide data with less emphasis to early instars and possibly better precision for analyzing the functional composition of the community. Classifications based on maturity have been used in life histories studies to characterize population growth (Clifford, 1969; Bretschko, 1985; Kosnicki and Burian, 2003), however, maturity data has not been used to weight community structure.

Multivariate techniques for predictive modeling in applied stream ecology have received considerable attention since the development of the River Invertebrate Prediction and Classification System (RIVPACS) (Wright et al., 1984). Contemporary RIVPACS-like models utilize presence–absence data to obtain expected assemblages from each taxon's frequency of occurrence within classified groups, and thus the probability of any taxon occurring is between 0 and 1 (but see Clarke et al., 2003). Rather than predicting the expected assemblage based on the probability of a taxon's occurrence, it is also possible to use relative abundance data in constructing an expected community. This would allow the use of abundance based similarity indices in comparing an observed community to an expected community predicted by the model (see Flotemersch et al., 2006).

A RIVPACS-like model designed for a temporal gradient will cluster taxa of sampling dates into seasons. Discriminant functions may best utilize temporal variables (i.e., degree days) as a means of predicting group membership to season. The capture probability for test sites could be calculated based on the probability of belonging to each season and the taxonomic frequencies within those seasons. Defining seasons based on biological data may be useful for comparing communities from different years.

The goal of this investigation was to explore the seasonal variability of communities at a single site. Specifically, we (1) identify metrics that exhibit minimal seasonal variation and attempt to predict their values; (2) demonstrate the potential utility of maturity structured data; (3) develop a temporal RIVPACS-like model for examining and predicting seasonal community structure.

2. Material and methods

2.1. Sampling and processing

The Burris Fork is a temperate 2nd order wadeable stream in the Inner Ozark Border subsection of the Ozark Highlands ecoregion of the United States (Omernik, 1987; Nigh and Schroeder, 2002) and has been designated by the state of Missouri as a reference stream for development of regional biocriteria (Rabeni et al., 1997; Sarver et al., 2002). Samples were taken from a 300 m reach 11 km south of California, Missouri, USA (38°33′10.24″N; 92°34′13.66″W; 236 m in elevation). Macroinvertebrates were sampled from 3 separate riffles with a 500 μm mesh D-frame kick net by physically disturbing 1 m of substrate upstream of the net (ca. 0.3 m^2) for 1 min. Each sample was transferred to a container containing 95% ethanol and taken to the laboratory for identification and enumeration. Dissolved oxygen (mg/L and percent), conductivity (μS), pH, temperature (°C) (YSI 85 and YSI 60, Yellow Springs, OH, USA), and current velocity (m/s) (AR 2000) were measured at each sample point. Two StowAway TidbiT temperature data loggers (Onset Computer Corporation, Bourne, MA, USA) bolted to metal stakes were positioned just above the substrate surface and programmed to record every 40 min starting at 12:01 am on the winter solstice (21 December 2002). Daily precipitation data were obtained from the United States Department of Commerce, National Oceanic and Atmospheric Administration, weather station in California, Missouri.

Samples were taken ca. monthly for 12 dates from 20 December 2002 to 28 November 2003. This time frame was designated as the Model Development Period (MDP). Three test dates (t1, t2, and t3) were sampled on 21 December 2003, 23 March 2004, and 3 October 2004 to represent different time points for the purpose of validating models constructed from data collected during the MDP.

Means of environmental variables were calculated for each date. Cumulative degree days > 0 °C were calculated from temperature logger data. Due to logger malfunction and loss, in-stream temperature data were available only until 25 March 2004. Degree days from this point on were estimated using linear regression with data from loggers at this site and loggers deployed in a nearby stream ($n = 461$, $R^2 = 0.99$). Fixed period cumulative precipitation and degree days were calculated for periods of 4, 7, and 14 days previous to the sampling dates. Back calculations for fixed count degree days for 20 December 2002 were estimated from a second order polynomial regression of daily mean water temperatures and daily mean air temperatures obtained from the weather station ($n = 461$, $R^2 = 0.92$).

Whole samples of macroinvertebrates were sorted and identified to the genus or species level, except for oligochaetes which were left at class. Chironomids were counted at the family level, then at least 11% of the individuals were subsampled. Subsampled chironomids were cleared in 10% KOH overnight, transferred to 100% ethanol, and slide-mounted with Euparal. Relative abundances from these identifications were calculated for each sample. Macroinvertebrates from each kick sample were numerically pooled, representing ca. 1 m^2 of riffle community for each date.

When clear taxonomic associations between sample dates could be made, coarse level identifications were elevated to finer levels, but when associations were not apparent, taxa were collapsed into coarser level identifications (usually from species to genus). In this way, operational taxonomic units (OTUs) were established, allowing for control of ambiguous taxa among sample dates (Cuffney et al., 2007). OTUs and their abundances were joined to a database with functional feeding group (FFG), tolerance values, and other taxonomic information obtained from the Missouri Department of Natural Resources (Sarver, 2001) and other sources (Merritt and Cummins, 1996; Barbour et al., 1999; Bode et al., 2002).

During the identification process, each non-oligochaete individual was assigned to a maturity class (I: early; II: middle; III: late; IV: pupae/adult, for Trichoptera, Coleoptera and Diptera). Classifications were based on qualitative observation of size and morphological development of each specimen following the guidelines in Table 1. The classes were used to weight abundances in thirds; the total number of individuals in class I was multiplied by 0.33, class II by 0.67, and classes III and IV were counted 1 for 1. Thus, a second dataset was created with maturity-weighted (MW) abundances. Transient non-benthic OTU's (e.g., Veliidae, Cladocera), singletons, and taxa with an average relative abundance < 0.1% were eliminated before analysis.