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Review Article

A review of macroinvertebrate- and fish-based stream health indices

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ABSTRACT

The focus of this review is to discuss the current uses and developments of macroinvertebrate and fish indicators in riverine ecosystems. Macroinvertebrates and fish are commonly used indicators of stream heath, due to their ability to represent degradation occurring at the local or regional scales, respectively. A total of 78 macroinvertebrate and fish indices were reviewed, and the frequently used macroinvertebrate and fish indices are discussed in detail in the context of aquatic ecosystem health evaluation. This review also discusses several types of common components, or metrics, used in the creation of indices. Following this, the review will focus on the different methods used for macroinvertebrate and fish collection, in both wadeable and non-wadeable aquatic ecosystems. With the basics of macroinvertebrate and fish indices discussed, emphasis will be placed on the application of indices and the different regions for which they are developed. The final section will provide a summary of the benefits and limitations of macroinvertebrate and fish indices. In general, the majority of studies have been performed in wadeable streams; therefore, our knowledge about these indices in non-wadeable streams is limited, which should be the subject of future research.

1. Introduction

As the human population continues to grow, it can be expected that anthropogenic activities will have impacts on the environment (Walters et al., 2009; Young and Collier, 2009; Dos Santos et al., 2011; Pander and Geist, 2013). This in combination with changing climates will only amplify the impacts on stream ecosystems (Meyer et al., 1999; Ridoutt and Pfister, 2010). To determine how climate change and anthropogenic activities impact aquatic ecosystems, it has been recognized that monitoring the health of streams is required. Furthermore this helps ensure that stream systems are able to function and will be able to provide ecosystem services for future generations (USGS, 2013). Stream health can be defined as the chemical, physical, and biological condition of a stream (Karr, 1999; Maddock, 1999). This definition describes aspects of a very complex system, in which organisms interact with their surrounding and vice versa.

To evaluate stream health three components are often used, which include: chemical, physical, and biological integrity of the surface water (Karr, 1981; Karr et al., 1986; Butcher et al., 2003a). Traditionally of these three, chemical is the most commonly used to evaluate stream health; however, recently it has be recognized that the use of biological integrity can lead to a better understanding of what is occurring in the ecosystem as well as identify the cause of degradations (EPA, 2011). And with the high diversity found within aquatic ecosystems (Pander and Geist, 2013), there are many organisms, such as algae,

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amphibians, diatoms, fish, macroinvertebrates, mammals, microorganisms, periphyton, phytoplankton, plants, reptiles, and zooplankton, that can be included in the decision making process to evaluate the quality of the stream health. Another benefit to using biological indicators for evaluating stream health is that they not only take into account biological factors but also the physical and chemical characteristics of the system (Brazner et al., 2007; Pelletier et al., 2012; Leigh et al., 2013). This is because biological factors are influenced by the physical and chemical characteristics of the ecosystem. By using indicators to evaluate the biotic integrity, environmental resource managers are able to identify degraded areas and can allocate resources to restore the ecosystems with the greatest needs (Butcher et al., 2003a; Walters et al., 2009; Einheuser et al., 2012; Pelletier et al., 2012), in the most cost-effective way (Neumann et al., 2003b). The specific objectives for this study were to (1) determine the origins and applications of macroinvertebrate and fish stream health indices; (2) summarize the benefits and limitations of existing macroinvertebrate and fish stream health indices; and (3) identify the knowledge gaps within the field of biomonitoring that require additional research. This will be done by first reviewing the individual components, collection strategies, and applications of stream health indices. Following these sections the paper will explore macroinvertebrate and fish based indices as well as more detailed reviews of the major indices being used in the field.

2. Stream health indices

Stream health indices are evaluation systems that are used to assess aquatic ecosystems conditions for individual streams (Hu et al., 2007). These indices are also used to for comparison purposes among different ecoregions (Butcher et al., 2003a). In general, stream health indices are divided into three general groups: biotic indices, multi-metric indices, and multivariate methods (Ollis et al., 2006).

2.1. Biotic indices

Biotic indices or uni-metric, such as the Hilsenhoff Biotic Index (Hilsenhoff, 1977), utilize only one metric or characteristic to evaluate stream health. Originally, biotic indices focused on organism tolerances to organic pollution (Hilsenhoff, 1987; Ollis et al., 2006). This allowed for the identification of regional degradations. However there are many stressors that can impact stream health besides organic pollution. Therefore, to advance the use of biotic indices additional organisms should be selected that are sensitive to other pollutions such as nitrogen, sediment, and temperature (Smith et al., 2007; Haase and Nolte, 2008). One of the benefits of biotic index is that stream health can be determined by simple calculation of one metric. However, this approach did not take into account the combined impacts of multiple stressors within streams or the complex nature of stream ecosystems. This led to the development of more complex stream health indices such as multi-metric indices and multivariate methods.

2.2. Multi-metric indices

Multi-metric indices, such as the Index of Biotic Integrity (Karr, 1981) and the Benthic Index of Biotic Integrity (Kerans and Karr, 1994), utilize several metrics or characteristics to evaluate stream health. The development of multi-metric indices takes into account the following factors: metric selection (Stoddard et al., 2008), survey design (Hughes and Peck, 2008), sampling procedures (Hughes and Peck, 2008), organism taxonomic identification level (Waite et al., 2004; Chessman et al., 2007), number and types of sampled habitats (Chessman et al., 2007), and organism classification and identification (Cuffney et al., 2007). By accounting for the complexity of stream ecosystems a more comprehensive view of what is occurring within streams can be made (Thorne and Williams, 1997; Rakocinski, 2012). This provides decision makers and stakeholders with more detailed information about the degradation within the streams and allows them to effectively implement mitigation practices. However, with the increased complexity of multi-metric indices the calculations required to determine stream health are more complicated than those used by biotic indices.

2.3. Multivariate methods

Multivariate methods require the development of models to relate physical and chemical stream features to observed organisms (Wright et al., 1998). Several commonly used multivariate models include the River Invertebrate Prediction and Classification System (RIVPACS), Two-Way Indicator Species Analysis (TWINSPAN), Detrended Correspondence Analysis (DCA), and the Australian River Assessment Scheme (AusRivAS). After the models were developed, they can be used to evaluate stream health beyond sampling points. The data inputs to the models can be simulated from calibrated watershed models. This makes multivariate methods very useful for identifying degraded areas. However, the model development can be challenging and there is an uncertainty in their predictions. Therefore, it is recommended that multivariate methods be used in combination with multi-metric and biotic indices for evaluating the stream health (Reynoldson et al., 1997).

3. Metrics

Metrics are individual characteristics of the ecosystem used to provide information about the conditions within streams (Barbour et al., 1999; Butcher et al., 2003a). Biological metrics include species abundance and condition, species richness and composition, and trophic composition. These metrics are used to describe stream health (Van Hoey et al., 2007) through development of stream health indices.

3.1. Species abundance and condition

Metrics that are used to describe the number and condition of each species found in the rivers are known as species abundance and condition metrics. These include