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Detecting significant change in stream benthic macroinvertebrate communities in wilderness areas

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ABSTRACT

A major challenge in the biological monitoring of stream ecosystems in protected wilderness areas is discerning whether temporal changes in community structure are significantly outside of a reference condition that represents natural or acceptable annual variation in population cycles. Otherwise sites could erroneously be classified as impaired. Long-term datasets are essential for understanding these trends, to ascertain whether any changes in community structure significantly beyond the reference condition are permanent shifts or with time move back to within previous limits. To this end, we searched for long-term (>8 years) quantitative data sets of macroinvertebrate communities in wadeable rivers collected by similar methods and time of year in protected wilderness areas with minimal anthropogenic disturbance. Four geographic areas with datasets that met these criteria in the USA were identified, namely: McLaughlin Nature Reserve in California (1 stream), Great Smoky Mountains National Park in Tennessee-North Carolina (14 streams), Wind River Wilderness Areas in Wyoming (3 streams) and Denali National Park and Preserve in Alaska (6 streams).

Two statistical approaches were applied: Taxonomic Distinctness (TD) to describe changes in diversity over time and non-metric multidimensional scaling (MDS) to describe changes over time in community persistence (Jaccards Index) and community stability (Bray–Curtis Index). Control charts were used to determine if years in MDS plots were significantly outside a reference condition. For Hunting Creek, TD showed three years outside natural variation which could be attributed to severe hydrological events but years outside the natural-variation funnel at sites in other geographical areas were inconsistent and could not be explained by environmental variables. TD identified simulated severe pollutant events which caused the removal of entire invertebrate assemblages but not simulated water temperature shifts.

Within a region, both MDS analyses typically identified similar years as exceeding reference condition variation, illustrating the utility of the approach for identifying wider spatial scale effects that influence more than one stream. MDS responded to both simulated water temperature stress and a pollutant event, and generally outlying years on MDS plots could be explained by environmental variables, particularly higher precipitation. Multivariate control charts successfully identified whether shifts in community structure identified by MDS were significant and whether the shift represented a press disturbance (long-term change) or a pulse disturbance. We consider a combination of TD and MDS with control charts to be a potentially powerful tool for determining years significantly outside of a reference condition variation.

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1. Introduction

The National Parks Omnibus Management Act of 1998 directs the U.S. National Park Service to report trends in the condition of park resources to Congress annually. This mandate requires managers to determine whether observed changes are within natural variation or result from anthropogenic influence. Making this distinction avoids Type I errors whereby natural variation could be mistaken for impairment. For example, it requires managers to know whether natural events, such as floods or droughts that shift communities outside their normal range of variability are significant directional events or whether the community will eventually revert to its original condition. Twenty-five of the National Park Service's 32 park networks have identified changes in benthic macroinvertebrates outside their natural range of variability as important water quality indicators.

Standard macroinvertebrate monitoring techniques (e.g., River Invertebrate Prediction and Classification System [RIVPACS], Wright, 2000; Index of Biotic Integrity [IBI], Kerans and Karr, 1994) applied worldwide compare test sites of interest with communities from "reference sites" classified as unimpaired, or in the case of RIVPACS, an expected community given no impairment. These methods are based on the observed, predictable response of macroinvertebrate communities to a variety of stressors on a continuum from mild to severe (Karr, 1999). Ideally, reference sites are selected in relatively pristine areas with negligible or no anthropogenic influence (Bailey et al., 2008). In these cases, the natural range of variation in the reference sites is assumed to be small compared to the much greater "signal" resulting from anthropogenic impairment, therefore natural variation is not included in the definition of expected community structure.

However, substantial natural variation in community composition over inter-annual time scales has been shown in the few studies that examined year-to-year temporal changes in macroinvertebrate communities in reference streams (Robinson et al., 2000; Bêche et al., 2006; Scarsbrook, 2002; Milner et al., 2006). Consequently, managers of protected areas are faced with monitoring reference sites using standard methods (e.g., IBI, RIVPACS) but needing to know whether observed changes are outside the range of natural variation – a question that cannot be answered by these methods. Thus, managers of protected areas require methods of change detection that define a reference condition that incorporates natural variation. Defining natural variation is problematic because there is no single, unambiguous definition, few sites are absolutely pristine, and data to describe a defined period thought to incorporate unimpaired natural variation are frequently unavailable. This is especially the case if managers wish to describe conditions prior to the onset of anthropogenic climate change. We do not attempt to address these issues. Rather, we illustrate several alternative means whereby a protected wilderness area manager can determine statistically significant departures from a reference condition once that condition is defined based on the best available information and management goals (Reynoldson et al., 1997; Stoddard et al., 2006).

To test potential assessment methods appropriate for natural areas, we identified long-term quantitative datasets of riverine macroinvertebrate communities collected in protected areas with minimal anthropogenic disturbance. Selected sites possessed at least eight years of record sampled by a similar method and at a similar time of the year to eliminate possible seasonal effects in community structure. Four geographic areas were identified which met these criteria and all were located in national parks and wilderness areas within the USA, namely; Denali National Park in Alaska, McLaughlin Nature Reserve in California, Great Smoky Mountains National Park in Tennessee-North Carolina and Wind River Wilderness Area in Wyoming.

Two statistical approaches used by others to detect change in aquatic communities were applied; Taxonomic Distinctness (TD) to describe changes in diversity over time and non-metric multidimensional scaling (MDS) to describe changes over time in community persistence (Jaccards Index) and stability (Bray–Curtis Index). TD uses a master taxonomic list compiled from multiple streams in a region to describe the reference condition. This method has been widely used with success in marine communities to identify environmental disturbance (e.g., Clarke and Warwick, 1998, 1999; Hall and Greenstreet, 1998; Leonard et al., 2006) but has been applied to streams with mixed results as to its value for biological monitoring. Both Abellan et al. (2006) and Bhat and Magurran (2006) found TD unable to distinguish between sites with differing levels of human disturbance using beetle and riverine fish communities respectively. Conversely, Marchant (2007) suggested that TD was more sensitive than species richness for identifying disturbed sites. However, these findings represent higher levels of impact than expected in protected wilderness areas so may not be relevant.

MDS has been used to describe changes in community persistence and stability because it is recognized that environmental changes do not consistently cause a response in diversity (Connell, 1978) and that diversity measures may be less sensitive than multivariate methods for detecting community changes (Gray et al., 1990; Warwick and Clarke, 1991; Dawson Shepard et al., 1992; Clarke and Warwick, 2001). Persistence is defined as the constancy of taxa presence over time and involves elements of both resistance (the ability to resist disturbance) and resilience (the ability to recover from disturbance) (Holling, 1973). Persistence can be described using a multivariate ordination based on Jaccards' Coefficient (Townsend et al., 1987), while compositional stability (similar relative abundance) can be described using the Bray–Curtis Index (Scarsbrook, 2002). Anderson and Thompson (2004) proposed a bootstrapping method for evaluating whether a given point in a multivariate time series is outside the reference condition based on distances among points on a multivariate ordination. The reference condition can be defined as any subset of observations from the available time series of data in the wilderness area.

2. Methods

2.1. Site selection

Study sites were found in four distinct geographic regions within the USA: Wind River Wilderness, WY (Wind – 3 sites); Great Smoky Mountains National Park, TN-NC (Smokies – 14 sites); Denali National Park, AK (Denali – 6 sites); and McLaughlin Nature Reserve, CA (McLaughlin – 1 site) (Fig. 1 and Table 1). At least eight years of consistently collected and classified macroinvertebrate community data were found at all sites with no more than a one-year gap between years except for Smokies-Cataloochee and all Wind sites where a two-year gap existed in some years but overall records were longer. As will be shown, eight years can be justified as an adequate time series for change detection. Collection methods (kick net or Surber sampler) to sample riffle habitats varied among the geographic areas, but were always consistent within each geographic region as was mesh size (330–500 μm). Sites will be referred to by their regional abbreviation and stream name. A summary of site characteristics, collecting methods and level of taxonomic discrimination (Table 1) illustrates the breadth of data used in our analyses. Years of record span the period from 1984 to 2006, although no individual site or region was complete for the entire period. McLaughlin-Hunting Creek (1984–2003) and Wind-Deep Lake (1985–2005) possessed the longest records. Most sites in the Smokies possessed data from 1993 to 2001; most records for sites in Denali span 1994 to 2004 (Table 1).