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Original article

Isotopic metrics as a tool for assessing the effects of mine pollution on stream food webs

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ABSTRACT

Most tools used to assess pollution impacts are based on structural, or less frequently, functional aspects of biotic communities. However, the application of measures that take a food web approach to understand the effects of stress on stream ecosystems offers a new perspective and promising insights. We assessed quantitative isotopic metrics, which describe characteristics of food web structure, as indicators of acid mine drainage (AMD) in 12 streams along a stress gradient and compared these metrics with traditional structural and functional metrics. The gradient ranged from highly stressed (pH < 3) streams with elevated concentrations of dissolved metals (Fe and Al) to moderately acidic streams (pH 3.6–4.9) with substrata coated in metal hydroxide precipitates and circumneutral reference streams. Key differences in food web structure were detected by the isotopic metrics. Specifically, fewer trophic levels and reduced trophic diversity characterized food webs in all mining impacted streams but the differences were not significant along the gradient. In contrast, most structural and functional metrics were significant predictors of AMD as stress increased. Therefore, our results suggest that isotopic metrics offer little advantage over traditional metrics in terms of detecting impacts for biomonitoring purposes. However, they do provide additional insights into how whole food webs are disrupted, and are likely to be more useful for guiding stream management and rehabilitation strategies.

1. Introduction

Biomonitoring tools are commonly used to assess the impacts of pollution on streams. Traditionally, metrics that describe community structure (e.g., taxonomic richness and diversity) have been widely used, while attempts to identify specific effects of pollution have resulted in the proliferation of single and multi-metric indices and predictive models. Many of these approaches are derived from species tolerance scores and have been developed for a particular type of pollution (e.g., organic) or region (Downes et al., 2002). Metrics using algae, benthic invertebrates, and fish communities have all been used as indicators of pollution, but efforts are typically focused on only one community, usually invertebrates, despite the importance of links between trophic levels for understanding effects of stress on ecosystems (Attrill and Depledge, 1997; Woodward, 2009). Furthermore, while individual structural metrics can detect the loss of sensitive species or reductions in diversity, it is not always clear how community-based changes affect ecosystem function. Recently, several functional measures have been proposed as indicators of stream health (e.g., Young et al., 2008; Niyogi et al., 2013). Functional measures are likely to better identify how ecological processes are affected by pollution and can include direct in-stream measurements of key ecosystems processes (e.g., leaf litter breakdown; Gessner and Chauvet, 2002) or the assignment of biological traits to species that allow for rapid, indirect assessment of function (e.g., feeding habits, body size; Dolédec et al., 1999). Invertebrate functional feeding groups (FFGs) have also been used as indirect functional measures, as they reflect changes in resource availability with human impacts (Palmer et al., 1996; Harding et al., 1999). Functional approaches can be used to complement structural measures and provide a more complete understanding of the effects of anthropogenic stress on ecosystems (Young et al., 2008; Friberg et al., 2009; Woodward et al., 2012). However, a food web approach to assessing stream health offers several advantages by building on the strengths of traditional metrics for detecting impacts, connecting responses among species and trophic levels, and integrating aspects of structure and function provided by other measures. Although food web structure is increasingly being investigated in order to better understand and predict human impacts on aquatic ecosystems (e.g., Layer et al., 2010; Rawcliffe et al., 2010; Woodward et al., 2010), it has not yet been used as a biomonitoring tool.

Food webs are often constructed using stable isotope analysis due to the valuable dietary (δ^{13}C) and trophic structure (δ^{15}N) information integrated into consumers' isotopic signatures (Peterson and Fry, 1987; Post, 2002). Layman et al. (2007a) proposed several

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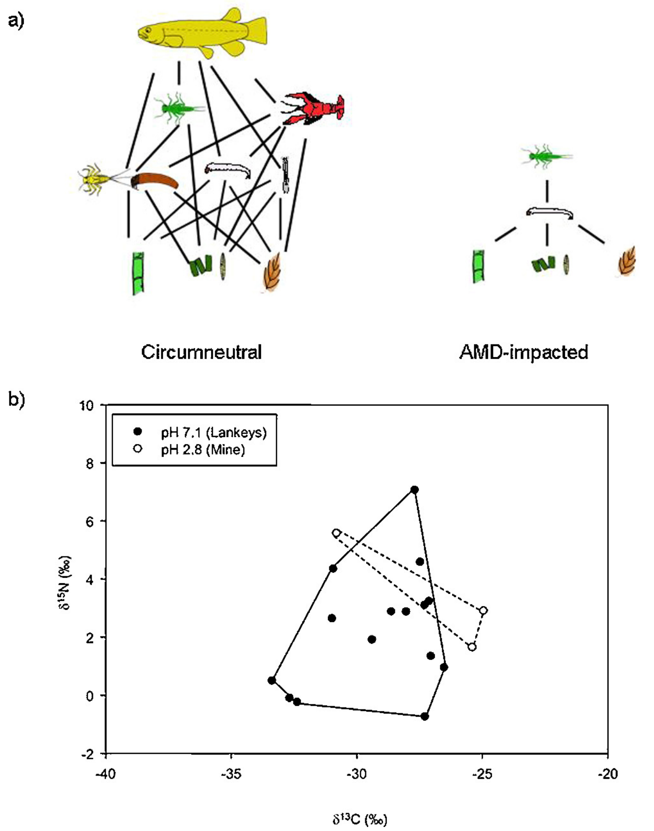

Fig. 1. (a) The nature of food webs in circumneutral and AMD-impacted streams. (b) Stable isotope biplot of δ^{15}N and δ^{13}C values for consumers in two streams at either end of the AMD gradient in this study. Open circles represent consumers from a highly stressed stream (pH 2.8) and closed circles represent consumers from a circumneutral stream (pH 7.1). Each symbol represents the mean value of 2–16 individuals for a particular consumer species. Lines enclose the convex hull area in isotopic space used to calculate isotopic metrics (e.g., NR = δ^{15}N range, CR = δ^{13}C range, TA = area enclosed in polygon, etc.).

quantitative isotopic metrics, which depict food webs based on the relative spacing of consumer species in isotopic space, and thus condense food web complexity into single values that describe different aspects of food web structure (e.g., extent of basal resource use, trophic diversity). An advantage of such metrics is that they can be compared across “similarly defined” (e.g., standardized sampling methodology, level of taxonomic resolution, and link criteria) food webs that lack common species, as is typical across wide environmental gradients. Their value as a tool for examining food web responses to human impacts has been demonstrated in fragmented tidal creeks (Layman et al., 2007b), eutrophic ponds (Rawcliffe et al., 2010), hydrologically disturbed marshes (Sargeant et al., 2010), and invasive lake macrophyte beds (Kovalenko and Dibble, 2011) but not in streams receiving chemical pollutants. Recent work has shown radical re-structuring of food webs in streams receiving acid mine drainage (AMD; Hogsden and Harding, 2012a; Fig. 1a), and suggests that isotopic metrics could be useful for identifying and interpreting impacts of mine pollution. Stable isotopes have previously been used in AMD streams to trace metal accumulation using δ^{15}N-inferred trophic positions of invertebrates (Quinn et al., 2003).

Streams polluted with AMD are often highly acidic and contain elevated concentrations of dissolved metals (e.g., Al, Fe, and Zn), resulting in marked declines in species diversity and impairment of some ecosystem processes (see review by Hogsden and Harding, 2012b). Furthermore, AMD becomes diluted when it enters circumneutral waters and its acidity can be reduced so that some soluble metals are precipitated. Metal hydroxides precipitated onto stream substrata impose an additional physical stressor (Kelly, 1988). The negative effects of AMD on stream ecosystems have been widely assessed using structural metrics or biotic indices based on benthic invertebrate community composition, but less often using direct (e.g., nutrient uptake, Northington et al., 2011; organic matter breakdown, Niyogi et al., 2013) or indirect functional measures such FFG analysis (Gerhardt et al., 2004). Although invertebrate species richness and richness of invertebrates belonging to the orders Ephemeroptera, Plecoptera, andTrichoptera (EPT) appear to be the most useful structural indicators, and complement AMD-specific indices, other metrics may not provide robust assessments within streams affected by AMD (e.g., % EPT; Gray and Delaney, 2010; Gray and Harding, 2012). Furthermore, the relationships between structural and functional measures in mine-polluted streams are not always clear (Northington et al., 2011; Niyogi et al., 2013).

In this study, we assessed the potential use of isotopic metrics as indicators of mine drainage pollution in streams. To do this, we compared isotopic metrics with traditional structural and functional metrics used for monitoring stream health and evaluated them along a pollution gradient from circumneutral reference streams to highly impacted AMD streams. We expected that the isotopic metrics would be a useful tool to detect AMD impacts in stream food webs as stress increased along the gradient and provide novel insights into ecological responses in these stressed ecosystems.

2. Methods

2.1. Study area and stream characteristics

The study was conducted in the Buller-Grey region, an area with a long history of coal mining, on the north-west of the South Island, New Zealand. The region, part of the Westland Forest ecoregion, has spatially consistent climatic conditions, geology, and freshwater biota (Harding et al., 1997). We selected twelve streams that were distributed along an AMD gradient from unimpacted reference to highly impacted streams based on known and relatively constant water chemistry (e.g., pH, conductivity, dissolved Al and Fe concentrations) over time (Winterbourn et al., 2000b; Greig et al., 2010; Hogsden and Harding, 2012a). The gradient included three reference streams and nine streams receiving AMD inputs from historical or current coal mining activities. All streams were of similar size (first or second order), had cobble-gravel substrates or bedrock, and were surrounded by native podocarp forest or scrub vegetation.

All sampling was conducted in December 2009 (austral summer) under baseflow conditions. Stream water pH and conductivity (at 25 °C) were measured in the field using standard meters (YSI 63 and YSI 550A, YSI Environmental Incorporated, OH, USA) to confirm the degree of AMD impact on each stream. Water samples were also collected for dissolved metal analysis. These samples were filtered in the field (0.45 μm mixed cellulose ester filter), acidified with nitric acid, and kept cool prior to analysis using an ICP-MS (Hill Laboratories, Hamilton, New Zealand). Metal hydroxide precipitates present on stream substrata were quantified as present or absent based on visual observation in the field.

2.2. Stable isotope sampling and analysis

Our study streams contained a diverse fauna of invertebrates and fish, although the same species were not present in all streams. Therefore, we focused on common taxa found in earlier studies (Winterbourn, 1998; Greig et al., 2010; Hogsden and Harding, 2012a) to provide a robust representation of consumers. Invertebrates for stable isotope analysis were collected by kick-net (500 μm mesh) and sorted by taxa, placed in vials in the