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Measuring groundwater–surface water interaction and its effect on wetland stream benthic productivity, Trout Lake watershed, northern Wisconsin, USA☆

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Abstract

Measurements of groundwater–surface water exchange at three wetland stream sites were related to patterns in benthic productivity as part of the US Geological Survey's Northern Temperate Lakes–Water, Energy and Biogeochemical Budgets (NTL–WEBB) project. The three sites included one high groundwater discharge (HGD) site, one weak groundwater discharge (WGD) site, and one groundwater recharge (GR) site. Large upward vertical gradients at the HGD site were associated with smallest variation in head below the stream and fewest gradient reversals between the stream and the groundwater beneath the stream, and the stream and the adjacent streambank. The WGD site had the highest number of gradient reversals reflecting the average condition being closest to zero vertical gradient. The duration of groundwater discharge events was related to the amount of discharge, where the HGD site had the longest strong-gradient durations for both horizontal and vertical groundwater flow. Strong groundwater discharge also controlled transient temperature and chemical hyporheic conditions by limiting the infiltration of surface water. Groundwater–surface water interactions were related to highly significant patterns in benthic invertebrate abundance, taxonomic richness, and periphyton respiration. The HGD site abundance was 35% greater than in the WGD site and 53% greater than the GR site; richness and periphyton respiration were also significantly greater ($p \leq 0.001$, 31 and 44%, respectively) in the HGD site than in the GR site. The WGD site had greater abundance (27%), richness (19%) and periphyton respiration (39%) than the GR site. This work suggests groundwater–surface water interactions can strongly influence benthic productivity, thus emphasizing the importance of quantitative hydrology for management of wetland-stream ecosystems in the northern temperate regions.

Keywords: Groundwater–surface water interaction; Wetland; Upwelling; Benthic invertebrates; Periphyton respiration

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1. Introduction

As one of five sites in the US Geological Survey's Water, Energy, and Biogeochemical Budgets (WEBB) Program, the Northern Temperate Lakes (NTL) WEBB project is working to understand processes controlling hydrologic and biogeochemical fluxes at different spatial and temporal scales (Walker and Bullen, 2000). The watershed hydrology of the NTL–WEBB site has been investigated using groundwater flow modeling (Cheng and Anderson, 1994; Hunt et al., 1998; 2003; in press; Pint, 2002) and geochemical/isotope tracing of water (Walker and Krabbenhoft, 1998; Walker et al., 2003). This work has shown that the variety of sources of water (terrestrial and lake recharge) can lead to complex flow systems with a variety of age and provenance occurring where groundwater discharges to the streams (Pint et al., 2003). While several single lake hydrogeologic studies from this area (e.g. Wentz and Rose, 1989; Krabbenhoft and Babiarz, 1992; Rose, 1993) have demonstrated the importance of groundwater–surface water interactions (e.g. Hurley et al., 1985; Lodge et al., 1989; Hagerthey and Kerfoot, 1998), there have been fewer studies that have focused on groundwater–surface water interaction in wetland streams. These studies have addressed the centimeter-scale hydrogeochemistry of the stream hyporheic zone (Schindler and Krabbenhoft, 1998), the effect of wetland area on nutrients exported by streams in the basin (Elder et al., 2000; 2001), and have characterized the hydrology of a single wetland system (Marin, 1986). However, in many cases there is a need to understand how these abiotic characteristics affect biological systems (Hunt and Wilcox, 2003).

Wetland streams in the Trout Lake basin typically receive appreciable groundwater inputs, including some that are focused in discrete reaches. Fisheries biologists in this region have long recognized these microhabitats as critical to brook trout (*Salvelinus fontinalis*), which require the relatively warm, silt-free waters of upwelling zones during winter for embryonic development (Becker, 1983) and the relatively cool summer conditions to escape temperature stress in the main channel as juveniles and adults (Biro, 1998; Baird and Krueger, 2003). Some bottom-dwelling invertebrates also use upwelling zones for critical development stages (Pugsley and Hynes, 1986) and many are likely to thrive in the highly stable thermal environments (Vannote and Sweeney, 1980). Although the relation of microhabitat quality for benthic invertebrates to groundwater flow is not well documented (Boulton et al., 1998), enhanced epibenthic algae growth has been noted in this region (Hagerthey and Kerfoot, 1998) and elsewhere (Coleman and Dahn, 1990; Dent et al., 2000). Increasing algae growth with increasing groundwater flow suggests that quantity of groundwater could indirectly control the abundance and species composition of grazing invertebrates, and benthic communities in general (Ward, 1989; Boulton, 1993; Brunke and Gonser, 1997).

Productivity differences have been related to microhabitat-scale differences in groundwater flux and resulting variation in stream water temperature dynamics, sediment porosity, and nutrient transport rates (Brunke and Gonser, 1997; Dent et al., 2000; Holmes, 2000). These environmental characteristics exert a combination of direct and indirect influences on stream dwelling organisms (Hynes, 1970) that could generate inter-reach productivity gradients driven by variation in hydrologic exchange. If the influence of groundwater discharge is strong enough to create localized high-quality patches for animal populations, then reach-scale hydrologic understanding (and quantitative models) could be used to predict relative biological activity at multiple scales from site to landscape.

The purpose of this study is to assess the spatial and temporal variability of local groundwater interaction with wetland-associated streams at three sites in the Trout Lake watershed, and to relate that variability to the macroinvertebrate and periphyton communities measured at the site. This work focuses on local interactions and biological communities; implications for a larger watershed context are extrapolated from this smaller scale.

2. Study area

The NTL–WEBB study area is located within in the Trout Lake watershed, in the Northern Highlands Lake District of north-central Wisconsin, USA. NTL–WEBB research efforts have focused primarily on Allequash Creek, a large watershed in the Trout Lake