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Sensitivity of structural and functional indicators depends on type and resolution of anthropogenic activities

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ABSTRACT

Few researchers have assessed the important management questions regarding the sensitivity of indicators of aquatic ecosystem condition and the specificity with which anthropogenic development activities are described. Furthermore, there is limited knowledge as to the potential of structural and functional indicators to generate complementary knowledge about ecological condition that can be used to inform watershed management. We assessed 20 metrics of ecological structure and function at 19 riverine sites across the Red River watershed in the summer of 2010 using a gradient approach to test predictions that: (1) indicator sensitivity would vary with the specificity at which landscape development is described (i.e., coarse – land use [e.g., agriculture], medium – specific human activities [e.g., crop cultivation] and fine – management practices [e.g., crop rotation]); and (2) structural and functional indicators respond to different types and specificity of anthropogenic development. Evaluation of indicators revealed that indicator sensitivity was frequently greater for assessment of specific human activities (i.e., wastewater treatment, crop cultivation or livestock production), than for broad land-use categories (i.e., agriculture or urban). Structural and functional indicators were often associated with different types of anthropogenic development suggesting additive rather than redundant assessment information. Structural indicators were almost exclusively associated with crop cultivation and agricultural land cover. In contrast, functional indicators were generally associated with gradients of wastewater treatment and urban land cover. Our results demonstrate that aquatic ecosystem assessment programs would benefit from considering the specific anthropogenic development activity to be assessed and managed in order to evaluate and select the most sensitive indicators of stream condition. Furthermore, combined use of structural and functional indicators in aquatic monitoring program appears to improve detection of anthropogenic impacts in a multiple stressor environment.

1. Introduction

Aquatic monitoring and assessment programs have traditionally focused on the use of indicators of ecological structure (hereafter called structural indicators), particularly abundance-based metrics of diatom, benthic macroinvertebrate and fish assemblages (e.g., Karr, 1981; Hellawell, 1986; Rosenberg and Resh, 1993; Philibert et al., 2006). These structural indicators are attractive because of the ease with which they are surveyed and the large number of widely accepted methods for data collection, analysis and interpretation. Nevertheless, increasing evidence suggests that structural indicators do not always integrate functional processes that are critical to maintenance of aquatic ecosystem integrity (Bunn and Davies, 2000; Izagirre et al., 2008; Young and Collier, 2009). Recognition of the potential of functional processes as indicators (hereafter called functional indicators) of aquatic ecosystem condition has resulted in researchers advocating quantification of ecosystem process for use in monitoring programs, including stream metabolism, decomposition rates, and stable isotope tracers (Bunn et al., 1999; Gessner and Chauvet, 2002; Palmer and Fieria, 2012). However,

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comparisons of the difference in sensitivity of structural and function indicators are few (but see Clapcott et al., 2010), and as such the benefits of using both types of indicators are not well documented.

The sensitivity of structural and functional indicators to detect effects of human activities is typically evaluated by determining the degree and nature of association between indicator and a stressor (e.g., Maceda-Veiga and De Sostoa, 2011; Schafer et al., 2011; Relyea et al., 2012). Aquatic researchers have also evaluated indicator utility in relation to anthropogenic activities considered to be key drivers of in-stream conditions (e.g., Brazner et al., 2007; Young and Collier, 2009). For example, structural and functional indicators of aquatic ecological condition have been correlated with land use data (see review by Allan, 2004), and GIS-based land cover indicators are commonly used to assess exposure of aquatic ecosystems to anthropogenic development (Gergel et al., 2002; Johnson and Host, 2010). Nevertheless, relationships between land use information and aquatic condition often leave a substantial amount of variability unexplained (Poor et al., 2008). A significant proportion of this unexplained variation may be due to land use information that is a spatially coarse, thus masking important spatial and temporal differences in type and intensity of anthropogenic development activities (Richards et al., 1996). Indicator sensitivity might be better evaluated against more explicit descriptions of anthropogenic development, such as specific human activities (e.g., livestock production) or management practices (e.g., manure storage and management).

The goal of this paper was to determine if the sensitivity of indicators of stream ecological condition differs according to the specificity with which anthropogenic development is described. To address this knowledge gap we examined the strength of associations between descriptions of anthropogenic development resolved at different grain sizes and structural and functional ecological indicators for stream ecosystems in the Canadian Prairies. We differentiated three resolutions of development: two finer classifications that specified particular human activities or management practices, and a coarser classification that described overall land use in the catchment. We hypothesized that: (1) indicator sensitivity would increase with increasing resolution of anthropogenic development descriptors; and (2) sensitivity of structural versus functional indicators would differ with descriptor type. The results of this study will provide much needed information on the most sensitive indicators for monitoring the understudied streams of the temperate grassland biome, as well as contributing to knowledge of the broad scale consistency in the sensitivity of commonly used or advocated indicators of ecological structure and function.

2. Methods

This study included 19 of 29 medium sized (range = 64–424 km^2) subcatchments within the Red River Valley of southern Manitoba, Canada, previously described by Yates et al. (2012, Fig. 1). Subcatchments were representative of regional grassland streams exposed to gradients in land use (i.e., agricultural and urban land cover), as well as three nutrient-releasing human activities: (1) crop cultivation; (2) livestock production; and (3) human wastewater treatment. Study streams included small to mid-sized, low gradient streams with fine bed particle sizes (<2 mm) in order to minimize natural variation at the site reach (i.e., one pool-riffle sequence) and upstream segment (i.e., 1 km upstream of the site). Subcatchments did vary in natural character at the basin scale, as the uppermost reaches of several of the basins were either on the Manitoba escarpment or the transition zone between the Red River plain and the Canadian Shield. Historic vegetation cover in all sites would have been open grassland or deciduous parkland (Bossenmaier and Vogal, 1974). Natural riparian vegetation would have been either trees or grasses although due to agricultural development only 6 of the selected sites had any significant natural cover in the upstream segment, the remaining streams were characterized by exotic grasses or cropland. Natural channel morphology of the streams is meandering although many of the streams have been straightened and entrenched to improve drainage of surrounding lands during wet periods. Although none of sites were co-located with gauging stations, studies have found that regional streamflow is dominated by surface runoff with the majority of the flow volume occurring during and following snowmelt (Glozier et al., 2006; Corriveau et al., 2013).

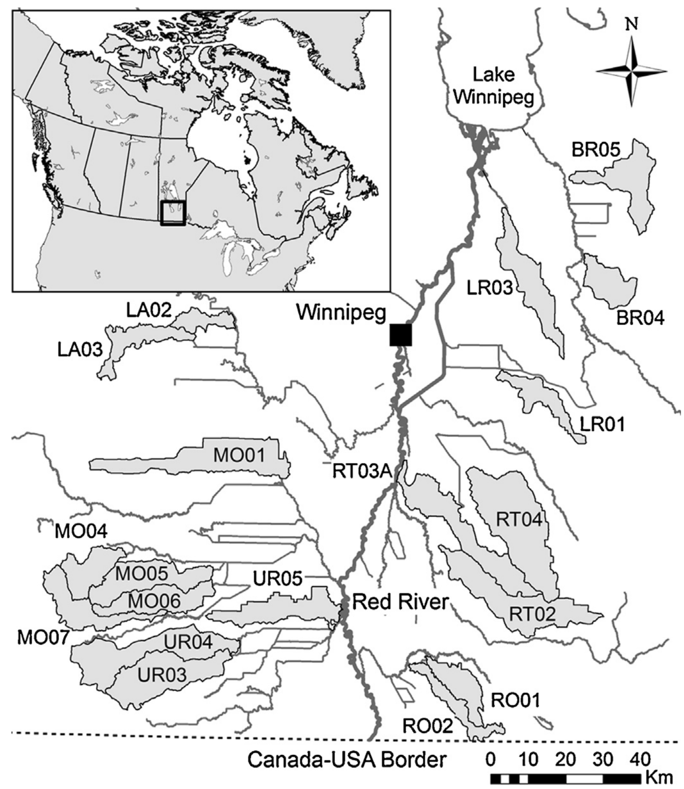

Fig. 1. Location of the 19 sampled sub-catchments near the city of Winnipeg in the Red River Valley of southern Manitoba, Canada. Inset indicates location of the study region in Canada.

2.1. *Description of land use, human activity and management practices*

Patterns in land use were represented by the proportion of land in each subcatchment designated as agriculture or urban (Table 1). Land cover was determined from a 20 m resolution land cover layer maintained by the Government of Manitoba (available at https://mli2.gov.mb.ca). Agricultural lands included pasture, cultivated fields and forage crops, whereas urban cover included any built-up areas such as villages, towns and cities. The proportions of agricultural and urban lands were determined by dividing the areal sum of each land use type by the total area of the subcatchments. Resulting proportions were transformed using the arcsine-square root transformation to improve normality.

Human activities were described using three human activity gradients (HAGs) generated for 29 subcatchments in the Red River Valley by Yates et al. (2012) representing among subcatchment variation in human wastewater treatment (WWT), crop cultivation and livestock production. The HAGs were derived from existing databases and summarized using separate principal component