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The effects of tertiary treated municipal wastewater on fish communities of a small river tributary in Southern Ontario, Canada

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ABSTRACT

Fish community changes associated with a tertiary treated municipal wastewater effluent outfall in the Speed River, Ontario, Canada, were evaluated at nine sites over two seasons (2008) using standardized electrofishing. Habitat evaluations were conducted to ensure that the riffle sites selected were physically similar. The fish community was dominated by several species of darters that differed in their response to the effluent outfall. There was a significant decrease in Greenside Darter (*Etheostoma blennioides*) but an increase in Rainbow Darter (*E. caeruleum*) abundance directly downstream of the outfall. Stable isotope signatures ($\delta^{13}C$ and $\delta^{15}N$), which indicate shifts in energy utilization and flow, increased in Rainbow Darter downstream, but showed no change in Greenside Darter. Rainbow Darter may be exploiting a food source that is not as available at upstream sites giving them a competitive advantage over the Greenside Darter immediately downstream of the outfall.

1. Introduction

Aquatic ecosystem health can be impaired by a variety of human activities that degrade water quality and alter available habitats within a watershed. One of the largest anthropogenic discharges into many waterways is municipal wastewater effluent (MWWE), which can cause issues such as eutrophication, acute toxicity, contamination, and endocrine disruption in receiving environments (Chambers et al., 1997; Tyler et al., 1998; Kilgour et al., 2005). Although treatment processes have improved, continued urbanization may increase the amount and diversity of contaminants in wastewater that need to be treated. Wastewater can be managed in a variety of ways and the choice of treatment process often depends on the volume of waste, characteristics of the effluent, and nature and dilution capacity of the of receiving environment. The primary targets of treatment include reducing biological oxygen demand, total suspended solids, nutrients (phosphorous and/or nitrogen), and pathogenic bacteria (Chambers et al., 1997). However, most treatment plants can only partially remove the diversity of contaminants introduced to the wastewater from households, industry and stormwater. Many treatment facilities that discharge into sensitive receiving environments employ advanced technologies (tertiary treatment) to further reduce nutrients or contaminants of concern (Chambers et al., 1997). Coupled with potentially altered river flows resulting from modified land use, climate change and increased water withdrawals (Palmer et al., 2008), MWWE may increasingly degrade water quality and challenge ecosystem integrity.

Many protocols have been developed utilizing fish as bioindicators of river health (Barbour et al., 1999; Moulton et al., 2002; Stanfield, 2007; Simon, 2006). Earlier studies have shown variable changes in fish communities influenced by urban development and MWWE outfalls (Porter and Janz, 2003; Northington and Hershey, 2006; Yeom et al., 2007) with overall fish abundance either increasing (Porter and Janz, 2003; Winger et al., 2005; Yeom et al., 2007) or decreasing (Dyer and Wang, 2002; Ra et al., 2007) depending on the characteristics of the site and species present. Species diversity varies considerably, also sometimes being decreased (Birge et al., 1989; Ra et al., 2007), while in other studies being increased (Winger et al., 2005). Fish community shifts reported in association with MWWE exposure typically reflect increases in tolerant and omnivorous species (Ra et al., 2007; Yeom et al., 2007). However, the size of population served, design and level of treatment, as well as the receiving environment

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characteristics are unique for each outfall, such that effects observed downstream are not easily generalized across sites.

Stable isotope ratios of nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) are useful tools to indicate shifts in energy flow through food webs (Peterson and Fry, 1987; Jardine et al., 2006) and can be applied to investigate the environmental effects of municipal effluent inputs. Typically $\delta^{15}N$ can be used to indicate the relative trophic position within a food chain, while $\delta^{13}C$ is more useful for indicating dietary origins related to the photosynthetic processes utilized by the primary producers (O'Leary, 1981; Hollander and McKenzie, 1991; France, 1995; Ulseth and Hershey, 2005). Sewage inputs alter the isotopic signatures in ecosystems as a result of the direct influence of the signatures of effluent components or by changing the degree of fractionation occurring in the environment (Steffy and Kilham, 2004; Ulseth and Hershey, 2005; Northington and Hershey, 2006). Loomer (2008) observed changes in carbon and nitrogen isotopic signatures of two species of fish (Greenside Darter, *Etheostoma blenniodes* and Rainbow Darter, *E. caeruleum*), and benthic primary consumers downstream of MWWE outfalls in the Grand River, Ontario. These shifts in isotope ratios suggest that there are changes in how nutrients and energy are incorporated into food webs associated with the MWWE discharges.

The City of Guelph MWWE is discharged into the Speed River, a relatively small tributary of the Grand River. Implementation of tertiary treatment (DenHoed and Robertson, 2003) has improved river water quality to provincial standards over the last two decades (Cooke, 2006). However, a wide variety of contaminants are present in municipal effluents that are not effectively removed even with advanced treatment (Chambers et al., 1997). For example, trace levels of estrogens detected in tertiary treated municipal effluents can have health impacts in fish (Filby et al., 2010; Tyler et al., 1998). With a projected 67% increase in the population to be served by the Guelph wastewater treatment plant by 2031 (Ministry of Public Infrastructure Renewal, 2006), there is concern that increased contaminant loads and reduced effluent quality may degrade the river ecosystem, reversing the progress made over the past few decades. Although water chemistry has been routinely monitored in the Speed River (Cooke, 2006), such chemical assessments alone are not adequate to fully understand the complex interactions and effects of the discharge on aquatic life (Karr, 1981). Consequently, the objective of this study was to determine how MWWE discharges from the City of Guelph alter the fish community of the Speed River using standardized electrofishing and stable isotope signatures.

2. Methods

2.1. Study area

The City of Guelph, Ontario, Canada discharges its municipal wastewater effluent into the Speed River a relatively small tributary of the Grand River (Fig. 1). A mean summer discharge of 2.48 m^3/s (Water Survey of Canada, 2007) results in an effluent dilution of only 7.6% in 2008 (Atkinson, 2010; Gallant, 2010). Construction of a large reservoir (Guelph Lake) upstream of the city and improved treatment plant upgrades, including tertiary treatment in 1970 (DenHoed and Robertson, 2003), has improved effluent quality and dilution capacity such that oxygen levels in the river are consistently above the provincial standard of 4 mg/L (Cooke, 2006). Currently, the City of Guelph treatment plant operates with conventional and extended activated sludge with a solid retention time of time of 15–28 days, denitrification, rotating biological contactors and sand filtration to remove phosphorous (Table 1; City of Guelph Wastewater Treatment Plant, 2007), resulting in high quality effluent compared to other Canadian MWWE (Chambers et al., 1997; Table 2). There are no other major municipal effluent outfalls further upstream. However, there are other potentially confounding factors. There are many low-head impoundments (i.e., 1.4 km upstream of the effluent outfall) and channelization of the river as it flows through the City of Guelph. On the opposite bank from the treatment plant, there is an active gravel pit which continuously discharges groundwater 0.33 km downstream of the outfall. A winter snow dump behind the treatment plant has the potential to act as a source of salt and debris during spring run-off and other precipitation events. In addition, there are numerous small creeks and municipal stormwater drains discharging into the Speed River upstream and downstream of the outfall.

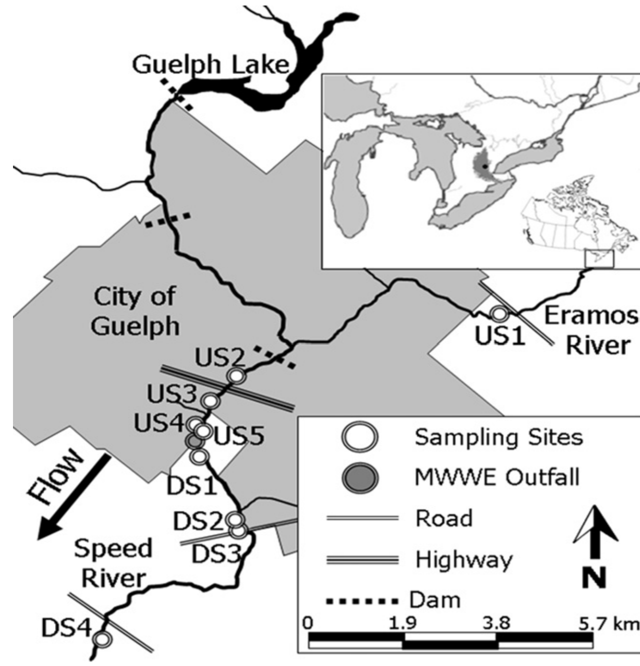

Fig. 1. Map of the Speed River adjacent to Guelph, Ontario, Canada indicating upstream (US1–US5) and downstream (DS1–DS4) 2008 sampling sites relative to the Guelph municipal wastewater effluent outfall. Downstream of DS4 is the Hespeler Dam (6.4 km) and the Speed River enters the main branch of the Grand River (a further 14.5 km downstream) in Cambridge.

2.2. Habitat

Habitat at the sites was assessed using the Ohio EPA Qualitative Habitat Evaluation Index (QHEI) (Rankin, 2006) and a modification of the US EPA's Habitat Assessment in the Rapid Bioassessment Protocols for Wadeable Streams (RBA) (Barbour et al., 1999) protocol to address the characteristics of the sites. The two habitat indices differ slightly but both methods translate habitat information into a numerical value to allow general comparisons. The RBA was modified by replacing the "frequency of riffles" that was not applicable with "percent biofilm on rocks" and "turbidity of water" (MRBA). Each section within the index was also scored out of 10 instead of 20, resulting in a maximum habitat value of 100 per site. Habitat information was collected in August, 2008 using methods described in Barbour et al. (1999) and Stanfield (2007) as outlined by Brown (2010). Characteristics of river habitat parameters were recorded at distances of 1, 5, and 10 m from shore. These included estimates of percent silt, sand, gravel ($<$25 mm, $<$51 mm), cobble ($<$102 mm, $<$152 mm), rock ($>$152 mm, $>$203 mm), bedrock, and plant material covering a 1 m^2 area. Rock shape, bank stability, bank vegetation, riparian width, canopy cover, river width, odor, and turbidity were also recorded. Water velocity was measured at 1, 5, and 10 m from shore using a Brenduler meter stick (Environment Canada, 2010) and validated with a Swoffer flow meter (Model 2100,

Table 1
Description of the City of Guelph wastewater treatment plant for 2008 (City of Guelph Wastewater Treatment Plant, 2007, 2008).

Parameter	Description
Population served	100,000
Capacity m^3/day	64,000
Discharge m^3/day	54,892
Hydraulic retention time	15–28 Days
Secondary treatment	Conventional and Extended Activated Sludge
Tertiary treatment	Rotating Biological Contactors and Sand Filtration
Combined sewers	No
Disinfectant	Sodium Hypochlorite
Dechlorination	Sodium Bisulphite
Current upgrades	Various to reach effluent capacity of 73,330 m^3/day