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The influence of watershed land use cover on stream fish diversity and size-at-age of a generalist fish

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ABSTRACT

Changes in land use have manifold effects on stream ecosystems. Consequently, the degradation of watersheds can cause extreme responses if the resilience of the stream is exceeded, triggering changes in fish communities and a reorganization of the ecosystem. Fish community surveys are frequently used to evaluate the impact of anthropogenic pressures on freshwater streams. Dynamic indices such as individual growth are also interesting because they integrate the effects of environmental conditions through time, providing an assessment in the long term. In this study we have investigated the ecological implications of watershed land use cover on fish diversity and growth of the generalist species *Umbra limi* (central mudminnow) in six streams in Southern Ontario (Canada). In detail, the growth of *U. limi* has been explored using a Dynamic Energy Budget (DEB) model, which pursues a mechanistic explanation of the bioenergetics of an individual under different environmental conditions. Given the mechanistic approach, the outcomes of the DEB model can provide a solid foundation for extrapolating the conclusions of this study to a broader spatial scale. The results of this study reveal that the proportion of modified land use of the watershed (agricultural and urban land) can reach a tipping point beyond which the functioning of the stream abruptly changes. Consequently, land use cover may be used as a precautionary indicator for watershed management. The results also demonstrate that *U. limi* could be used as a sentinel species to identify potential impacts on fish diversity and size-at-age as a cost-effective indicator for stream monitoring programs.

1. Introduction

Freshwater resource managers have long understood the intimate relationship between watercourses and the lands through which they flow (Hynes, 1975). Ongoing activities such as altered hydrological regimes (e.g. dams), source pollution from agriculture, industry and urban development, and habitat destruction also continue to alter ecological processes (Naiman et al., 1995). The development of watershed lands has been implicated in changes in fish abundance, distribution and community structure (Wang et al., 1997; Rahel, 2002; Allan, 2004), contributing to global declines in both abundance and diversity of freshwater fish (Ricciardi and Rasmussen, 1999; Jelks et al., 2008). Understanding the mechanisms driving relationships between organisms and ecological processes is a requisite for sustainable and responsible watershed development and management (Guégan et al., 1998; Cowx and Gerdeaux, 2004; Lapointe et al., 2014).

Fish community surveys are a frequently employed method used to perform environmental impact assessments (Karr, 1981; Cowx and Gerdeaux, 2004; Nicholson and Jennings, 2004). Fish assemblage composition or community metrics (e.g. biodiversity quality, Feest et al., 2010) in impacted watercourses can be extremely informative, providing insight through the presence or absence of species sensitive to certain environmental characteristics or contaminants (Karr, 1981; Guégan et al., 1998). Habitat characteristics and stream condition are strongly related to watershed land use (Allan, 2004). For example, Wang et al. (1997) found a positive correlation between fish community and forested land and negative correlation with urban and agricultural land in the riparian zone. They also suggested the existence of a threshold of proportional land use alteration beyond which the community

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reorganizes and changes. Therefore, land use cover and community metrics such as structural and functional biodiversity can provide valuable information regarding ecosystem resilience, or lack thereof, in the face of anthropogenic disturbance (Reynolds, 2002).

The use of sentinel species to investigate environmental impacts enables the identification of physiological responses that may not be observable at the community level (Power and McCarty, 1997; Adams and Ham, 2011). The selection of sentinel species depends on hypothesis, site-specific variables and species' characteristics such as site fidelity and growth rate (Munkittrick, 1992). In addition, when the purpose of the study is to compare the status of different sites, the sentinel species must be present in all sites, which can be a challenging factor in heavily degraded streams due to the extirpation of the majority of species. Unlike more sensitive species, the central mudminnow (*Umbra limi* Kirkland 1840) is able to maintain populations in unaltered and heavily degraded systems (until a threshold is reached). *U. limi* has a broad native distribution and is capable of facultative air-breathing and able to withstand extreme variation in water temperatures, enabling the exploitation of diverse habitats compared to other species (Chilton et al., 1984; Martin-Bergmann and Gee, 1985; Currie et al., 2010). With respect to energy acquisition, mudminnows are able to utilize diverse foraging habitats across all seasons (Chilton et al., 1984; Paszkowski, 1984; Scott and Crossman, 1998). Consequently this species is a potential candidate to be used as sentinel species in watersheds with high proportions of disturbance (until a threshold is reached).

Biochemical and physiological indices of freshwater fish have also been used to assess stream condition (Adams and Ham, 2011; Blevins et al., 2013; Nagrodski et al., 2013). Dynamic indices, such as individual growth, are particularly interesting because they integrate the effect of environmental conditions over extended periods of time (Lucas and Beninger, 1985), providing an assessment in the long-term. Accordingly, fish growth rates have been used to empirically compare the condition of different streams (Van Weerd and Komen, 1998; Barton et al., 2002). Additionally, bioenergetic modeling can provide a way to explore the relationship between individual growth and environmental variables, ultimately providing a mechanistic explanation of fish performance (Beyers et al., 2002). A mechanistic explanation of fish growth is always desirable because the conclusions are not restricted to local and specific conditions, allowing extrapolation to other systems (Nisbet et al., 2012).

Dynamic Energy Budget (DEB) theory is a mechanistic theory for the uptake and use of substrates (food, nutrients and light) by an organism and their use for maintenance, growth, maturation and propagation (Kooijman, 2010). DEB theory focuses on an individual organism, with differential equations describing the rates at which energy is utilized throughout all stages of its life cycle in a dynamic environment (Nisbet et al., 2012). DEB builds on the premise that the mechanisms that are responsible for the organization of metabolism are not species-specific and consequently the 'standard' DEB model is assumed to be appropriate for most animals (Sousa et al., 2010). The use of general principles of biology, physics and chemistry and the possibility of estimating growth based on a mechanistic approach make the DEB framework an ideal tool for exploring *U. limi* growth in relation to environmental characteristics.

The effect of watershed land use on stream functioning would potentially exert a significant effect on fish community as well as on the growth of *U. limi*. Consequently, (1) the growth of *U. limi* as a function of watershed land use following a mechanistic approach, and (2) the potential links with fish community composition, together define a testable framework for using *U. limi* as a sentinel species of anthropogenic impact on stream watershed. Thus, the growth *of U. limi* has been explored following a DEB approach and related to watershed land use cover and fish diversity in six streams in Southern Ontario. This hypothesis has been organized into two main research questions:

- H_1: Watershed land use affects fish community composition, food availability and growth of *U. limi*.
- H_2: The simple metric size-at-age of the generalist *U. limi* captures the functioning of freshwater streams and consequently it can be used as a sentinel species in monitoring plans.

2. Materials and methods

2.1. *Study area,* Umbra limi *and community sampling*

This study took place in six tributaries of the St. Lawrence River in the eastern most portion of Ontario, Canada, near the city of Cornwall (Fig. 1) between spring 2012 and spring 2013. Land use data were obtained from the Southern Ontario Land Resource Information System (SOLRIS) and were combined with a GIS layer defining watershed boundaries developed by the local Raisin Region Conservation Authority using Quantum GIS Lisboa (1.8.0). The SOLRIS database includes 23 land cover types, 15 of which are found in the study area. Because watersheds varied in size, the proportion of different land use categories was determined using total hectares allocated to each land use divided by the total watershed area.

Central mudminnow were collected from six tributaries to the St. Lawrence River in the eastern-most portion of Ontario in Fall (Nov-2012) and Spring (Apr-2013). Logistical constraints limited our sampling efforts to 6 of the 9 streams within the study area. The three that were excluded were chosen because they had characteristics that made them difficult to sample (i.e. Fraser Creek, no access points/land owner permission), incomparable to other streams (i.e. Sutherland Creek, extensive restoration work), and had land-use that was extremely similar to other creeks (e.g. Westley's Creek, similar to Gunn and Wood). Fish were collected using backpack electrofishing in the downstream portions of watersheds, euthanized using dropwise addition of clove oil, and transported back to the laboratory for storage at the end of each field day. Each fish was removed from storage, weighed (total and gonads), and measured prior to otolith extraction. For this species, using otoliths to determine fish age is more effective than scales as a result of high scale regeneration, leading to consistent under-aging (Robinson et al., 2010). Large sagittal otoliths were removed from each fish, cleared of debris and stored dry in clearly labeled 1.5 ml vials until mounting.

Otolith preparation techniques followed methods described by Robinson et al. (2010) with slight variation. Single otoliths were mounted to glass slides, sulcus side up, using cyanoacrylate glue and allowed to cure for at least 24 h. Mounted otoliths were then polished to the focus with successively finer diamond lapping film (3 μ, 0.5 μ, 0.1 μ). In cases where the otolith was easily readable without polishing, otoliths were read untreated. Using stereomicroscopes and transmitted light to estimate ages, two different readers estimated age for each fish, and were unaware of fish measurements and the other reader's estimation. Age estimations that agreed were accepted, while a third reader was used in cases of discrepancy.

Fish community data included in this study was part of a larger, multi-year survey effort focusing on coastal wetlands, confluences and tributaries in the area (Suski et al., 2014). Tributary fish community was determined by seasonal sampling of tributaries using a backpack electrofisher (Haltech HT-2000, Guelph, ON, Canada). Two 150 m transects were sampled on the mainstem of each tributary, and site selection was based on land-owner permission and accessibility. This included a 'downstream' and 'upstream' site, 2 and 4 km from the confluence with the St. Lawrence River,