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Influence of the aquatic vegetation landscape on larval fish abundance

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ABSTRACT

Aquatic vegetation (AV) is an important component of aquatic system, affecting habitat carrying capacity and fish productivity. By modulating habitat complexity, AV has the potential to influence the early ontogenetic stages of many fish species. However, understanding how variations in AV abundance influence fish distribution and abundance at the landscape scale of freshwater ecosystems is a considerable challenge due to the difficulty of collecting the high-resolution data needed for such analyses. We used yellow perch (*Perca flavescens*) as a biological model to test the hypothesis that larval fish abundance is positively related to a AV-rich landscape. Combining seven years of extensive larval sampling and satellite imagery, our results suggest that fish larvae tend to be associated with AV habitats after hatching. Based on zero-inflated binomial models, the probability of observing perch larvae increased from approximately 20% in low AV habitats to nearly 100% in dense AV habitats (pseudo-$R^2 = 0.54$). Our results also show that the probability of observing yellow perch larvae was lower during years of low water level and low AV biomass, likely limiting the availability of proper spawning or nursery habitats for fish. Furthermore, we demonstrate that larvae use both new AV as well as vegetative debris from the previous year that persisted through the winter. In agreement with a growing literature, our study gives additional support to the idea that AV plays a key role in freshwater fish recruitment.

Introduction

Aquatic vegetation (AV) increases habitat complexity in both marine (Boström et al., 2006) and freshwater (Jeppesen and Søndergaard, 1998) ecosystems. In addition to the many effects it has on ecosystem functioning by modulating oxygen availability (Caraco et al., 2006) and nutrient cycling (Kalff and Rooney, 2003; Tall et al., 2011), AV is a key component of physical habitat structure. Characteristics such as individual plant architecture as well as AV patch size and fragmentation structure the aquatic habitats at different spatial scales (Boström et al., 2006). By increasing habitat complexity, AV influences predator–prey interactions (Dionne and Folt, 1991; Diehl, 1992) as well as spatial distribution (Eklöv, 1997; Nurminen and Horppila, 2002), abundance (Boström et al., 2006) and community structure of aquatic organisms (Meerhoff et al., 2007).

Even though these effects are relatively well studied at small and meso-scales, the effects of AV landscapes (*i.e.*, at the ecosystem scale) on animal ecology have received little attention and have been mainly studied in marine, coastal and estuarine ecosystems (reviewed in Boström et al., 2006). From these studies, it is generally accepted that AV increases the abundance of some animal populations, supports higher species richness and increases the survival of various animal taxa, including fishes (Smokorowski and Pratt, 2007). For example, many freshwater fish species occupy AV habitats at some stage of their life cycle (Petr, 2000). Near-shore habitats dominated by AV provide (i) refuge from predators, (ii) support for invertebrates, and (iii) foraging habitats for small fish (Pratt and Smokorowski, 2003; Yamaki and Yamamuro, 2013). It was also reported that larval and juvenile fish are more abundant in near-shore lacustrine habitats in mid and late summer, not only because of high temperature, but also because of the shelter and food associated to AV (Wang and Eckmann, 1994; Randall et al., 1996).

Understanding how variations in AV at the landscape scale influence fish abundance in freshwater ecosystems is a considerable challenge due to the difficulty of collecting the high-resolution data needed for such analyses (Deaton et al., 2010). In these ecosystems, AV is often coarsely characterized using qualitative information (*i.e.*, presence/absence, density) estimated locally by visual inspection (Randall et al.,

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1996; Bertolo et al., 2012), which does not provide the fine-scale variations in AV biomass that is necessary for characterizing landscapes. Consequently, the influence of AV structure on predator–prey interactions has been mostly studied in laboratory (Christensen and Persson, 1993) or pond (Persson and Eklov, 1995) experiments, whereas studies on populations and communities were typically limited to comparing systems with and without AV (Jeppesen and Søndergaard, 1998).

The global loss of AV beds is occurring rapidly in many freshwater ecosystems (Batiuk et al., 2000; Deaton et al., 2010; Vermaire et al., 2012), resulting in a decrease of their carrying capacity (Egertson and Downing, 2004). Negative impacts on fish communities are expected because in their ontogenetic stages, many species use AV for foraging or as shelter to avoid predation or cannibalism (Petr, 2000). A compelling example of the strong linkage between AV habitats and fish carrying capacity is provided in Lake Saint-Pierre (LSP, Hudon et al., 2012), where historically important commercial and sport yellow perch fisheries were supported until the mid-1990s (Guénette et al., 1994). Yellow perch experienced a dramatic collapse beginning in the mid-1990s (Guénette et al., 1994). Despite a major reduction in fishing effort, mainly between 2005 and 2010, yellow perch abundance continued to decrease, likely as a consequence of low recruitment (Magnan et al., 2008). The yellow perch stock has been considered as collapsed since 2011, when a five-year moratorium was imposed on both commercial and sport fishing in 2012. The decrease of aquatic habitat quality was suggested as one of the possible causes of the observed collapse. The progressive transformation of 50 km^2 of spring-flooded marshland into perennial crops (1950–1964) and intensive annual cropland between 1964 and 1997 (Richard et al., 2011; de la Chenelière et al., 2014) combined with the shift from AV beds to benthic cyanobacteria documented in 2005–2007 (Vis et al., 2008; Hudon et al., 2012), have profoundly impacted this aquatic ecosystem.

Given that many freshwater fishes have economic and recreational values, studies at the landscape level are critically needed to understand the role of AV on fish abundance and productivity. Here we used yellow perch (*Perca flavescens*) as a biological model to test the hypothesis that larval fish abundance is positively related to AV abundance at the landscape level. To test this hypothesis, we modeled the probability of observing perch larvae in LSP using data from a seven-year survey of larval abundance (2005–2011) that included more than 200 stations per year in conjunction with an annual index of aquatic vegetation derived from satellite imagery.

Materials and methods

Study site

LSP is the largest fluvial lake (≈400 km^2) of the St. Lawrence River (Fig. 1). This lake, formed by a widening in the river, has a relatively slow current (<0.5 m × s^{-1}) and is shallow (mean depth = 3 m), except for a man-made navigation channel (depth > 11 m) that concentrates much of the river flow into its central portion (57–88% of total discharge; Hudon and Carignan, 2008). LSP receives the inflow of five major tributaries (cumulative watershed area = 21,127 km^2) distinguished on the basis of their physical and biogeochemical characteristics (Frenette et al., 2012). The LSP floodplain itself covers approximately 140 km^2, typically for 5–9 weeks during the spring freshet and represents an important spawning ground for yellow perch (Bertolo et al., 2012).

LSP is characterized by large sheltered bays and shallow sloping shorelines that support large emergent marshes and extensive beds of submerged aquatic vegetation to a maximum depth of about 3 m outside the navigation channel (Hudon, 1997). During summer, aquatic plants cover 260 km^2 (85%) of the lake surface area (Vis et al., 2007) and represent an important habitat for juvenile fish. The submerged vegetation is dominated by American eel-grass (*Vallisneria americana* Michx) and various pondweeds (*Potamogeton richardsonii* A. Bennett,

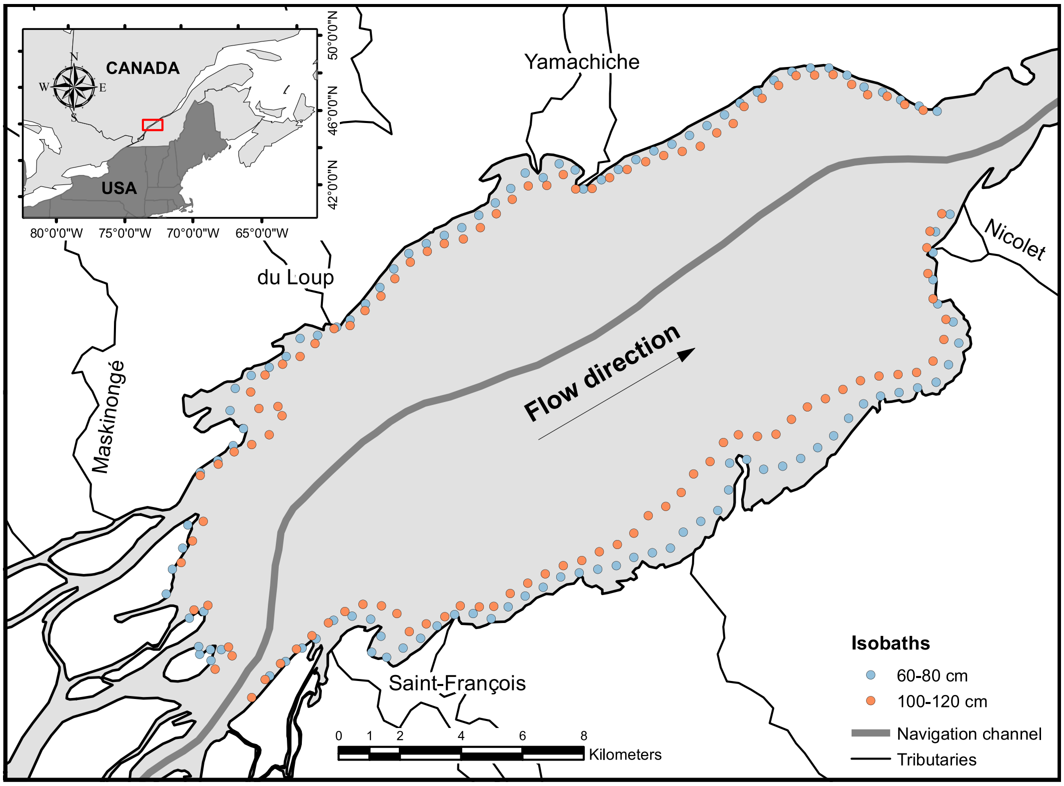

Fig. 1. Study system and sampling sites in Lake Saint-Pierre (LSP). Blue and orange symbols show the locations of the sampling sites located at the 60–80 cm and 100–120 cm isobaths, respectively. Site positions were adjusted each year depending on the water level to make sure they were located at the selected isobaths. For more details on lake bathymetry, see Fig. 1 in Bertolo et al. (2012). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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