



What controls distribution of larval and juvenile yellow perch? The role of habitat characteristics and spatial processes in a large, shallow lake



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ABSTRACT

The goal of this study was to determine the relative contribution of environmental and spatial processes governing the distribution of larval and juvenile yellow perch (*Perca flavescens*) in two shallow embayments of a large fluvial lake on the St. Lawrence River system. We tested the hypotheses that: i) larval distribution is not related to habitat characteristics, presumably due to their relatively low swimming capacity, whereas ii) these environmental variables drive juvenile distribution, reflecting a more active habitat selection. This study is one of the first attempts to partition the relative roles of environmental and spatial factors in shaping the distribution of a freshwater fish through its early ontogeny. We show that larvae were not spatially aggregated within the embayments and that habitat characteristics, mainly related to aquatic vegetation, played an important role in explaining their distribution. In contrast, juvenile abundances were not significantly related to habitat characteristics, despite being spatially structured over multiple scales. Contrary to our predictions, habitat association was stronger for larvae than for juveniles which were aggregated independent of habitat characteristics. Increased swimming capacities may thus facilitate the aggregation of juveniles rather than strengthening their association with habitat, at least at the scales considered here (ca 3 km²). These results shed a new light on the factors governing larval and juvenile yellow perch distribution, suggesting that active habitat choice might begin earlier than previously thought.

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Introduction

The ontogeny of mobile aquatic organisms occurs in ecosystems that are structured over multiple spatial scales, ranging from millimetres (e.g., substrate structure) to hundreds of metres (e.g., spatial distribution of macrophytes) (Brind'Amour et al., 2005; Weaver et al., 1997). Habitat features also vary along temporal scales, thus rendering aquatic environments even more complex. To cope with a changing environment and to optimize habitat use, fish need to modify their habitat selection through time and space. This is especially true for the age-0 stage, during which many species undergo extensive morphological changes associated with shifts in both food and habitat (Persson and Greenberg, 1990; Werner and Gilliam, 1984). Factors influencing the habitat use of age-0 fish during their ontogeny are not fully understood. Because of their relatively poor swimming ability (Houde, 1969) and high potential for drift (Dettmers et al., 2005), the spatial distribution of pelagic fish

larvae should be mainly passive and weakly associated with micro-habitat characteristics (Copp, 1997). In contrast, habitat association should be stronger for juvenile fish, which are more likely to show active habitat selection (King, 2004).

Determining the independent contribution of environmental (i.e. habitat characteristics, competition, predation, etc.) and spatial factors (i.e. geographical localisation of sampling events) shaping the distribution of early stages of freshwater fish should improve our understanding of the way species are affected by habitat characteristics and physical processes. Since environmental and spatial factors are intrinsically entangled in field studies, it is often difficult to assess the exact role of each component. It is therefore necessary to explicitly consider the spatial structure of ecological data, which allows one not only to control for biases due to spatial autocorrelation (Keitt et al., 2002; Kühn, 2007) but also to properly extract and interpret the spatial and environmental structure of the data (Borcard et al., 2004).

Age-0 *Perca* spp. (*Perca flavescens* and *P. fluviatilis*) are a good model to assess the ontogenetic changes of habitat associations because they typically experience an onshore–offshore habitat shift during ontogeny (Post and McQueen, 1988). Although passive transportation could play a major role in determining the spatial distribution of pelagic larvae

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(Dettmers et al., 2005; Mielhs and Dettmers, 2011), juveniles are more mobile and are able to actively return onshore (Whiteside et al., 1985). Predation risk and lower food abundance in offshore habitats have been suggested as potential explanations for the return of age-0 yellow perch to the littoral zone (Post and McQueen, 1988). Because of their lower swimming capacity, the distribution of larval yellow perch is not expected to be strongly determined by habitat characteristics. In contrast, due to their higher mobility, habitat associations are expected to be stronger in juveniles, with environmental factors better explaining their distribution than that of larvae.

The present study aimed determining the relative contribution of habitat characteristics and spatial processes in explaining the distribution of larval and juvenile yellow perch in a shallow freshwater ecosystem covered with extensive vegetated areas. Current knowledge about *Perca* spp. habitat shift is poor for systems lacking a true offshore habitat because this phenomenon was typically studied in lacustrine systems with a narrow littoral zone and a well-defined deeper pelagic habitat (Mielhs and Dettmers, 2011; Post and McQueen, 1988; Urho, 1996). Because important fish nursery areas such as the floodplain of fluvial lakes of the St. Lawrence River system (Québec, Canada) are dominated by shallow patchy vegetation (Mingelbier et al., 2008), we suspected that a true onshore–offshore migration does not occur in these systems. Although atypical of deeper lakes, they are well suited to analyze early habitat associations in yellow perch in systems lacking a true pelagic zone. In this study, we analyzed the spatial distribution of larvae and juveniles yellow perch in the largest fluvial lake of the St. Lawrence River system and tested the influence of habitat factors separately for the two ontogenetic stages. We tested the strength of the habitat association at different spatial scales by determining the independent contribution of habitat and spatial variables on both larvae and juvenile yellow perch distribution.

Methods

Study site

The study was conducted in two contrasting shallow embayments of Lake Saint-Pierre (Maskinongé Bay: 46°12' N, 72°58' W, and Fer à Cheval Bay: 46°11' N, 72°45' W; Fig. 1; Table 1), a large fluvial lake of the St. Lawrence River, Québec, Canada. Lake Saint-Pierre is approximately 35 km long and 15 km wide with a mean depth of 3.17 m at mean discharge, except for the 11.3 m deep navigation channel that bisects the lake. Maskinongé and Fer à Cheval bays were chosen because they represent the two main spawning grounds of Lake Saint-Pierre and because the north and the south shore exhibit contrasting physico-chemical characteristics (see Frenette et al., 2003, and Vis et al., 2003 for a complete description of the differences between the two shores). The north shore of the lake is characterized by brown-coloured water, rich in suspended particles, high total phosphorus concentration, and relatively high dissolved organic carbon (Frenette et al., 2003). Tributaries draining farmland bring nutrient-rich waters along the south shore (Vis et al., 2003).

The shallow depth, gentle slope, slow current, high nutrient content, and major seasonal flooding that prevail in the littoral zone of Lake Saint-Pierre favour the development of large beds of submerged aquatic vegetation (Frenette and Vincent, 2003; Vis et al., 2003). During mid-summer, approximately 44% of the lake's surface area is covered by submerged macrophytes, 10% by emergent macrophytes, and 46% is open water. Submerged vegetation is dominated by *Vallisneria americana*, *Potamogeton richardsonii*, and *P. pectinatus*. The bays of Lake Saint-Pierre are also colonized by emergent plants such as *Schoenoplectus lacustris*, *Sagittaria latifolia*, and *Sparganium eurycarpum*. Plant bed distribution is patchy, and the above-ground dry biomass of sampled sites was found to range from approximately 0 to 250 g m⁻² (see Frenette et al., 2003 and Vis et al., 2003 for detailed descriptions of the study site).

Fish sampling

Age-0 fish were sampled at two ontogenetic stages during the summer of 2003. The larval stage was sampled from 26 May to 9 June (hereafter “larvae”; mean total length: 13.6 ± 2.2 mm) and juveniles were sampled from 2 to 17 July (hereafter “juveniles”; mean total length: 36.6 ± 5.5 mm). A lag of four weeks was allowed between sampling events in order to allow yellow perch larvae to develop into juveniles. Fish were sampled using pop-nets, a sampling gear designed to collect small-bodied fishes as well as both larvae and juveniles of larger fish such as yellow perch (Paradis et al., 2008). The same fishing gears were used to collect both larvae and juveniles in order to standardize the sampling technique both within and between sampling events. In a previous paper, we showed that passive pop-nets are more suitable than active sampling gears like push-nets to collect both larvae and juvenile yellow perch at shallow depths (Paradis et al., 2008). We also showed that choice of sampling gear did not bias the range of lengths of yellow perch larvae sampled with either 1.2 mm-mesh pop-nets or 500 µm-mesh push-nets (Paradis et al., 2008). Each pop-net consisted of two 4 × 4 m frames of rigid polyvinyl chloride (PVC) pipes (5 cm diameter), one floating with trapped air and one weighted with steel rods and anchored to the bottom (Dewey et al., 1989; Paradis et al., 2008; Serafy et al., 1988). A net (1.5 m high, 1.2 mm mesh) linked the two frames, with the top and bottom opened. The upper and lower frames were tied together and held to the bottom of the sampling site, allowing time for fish to recolonize the site after installation. Twelve hours later, during daytime, a pin-key attached to a rope was used to release remotely the buoyant frame from the ballast frame. Fish confined in the pop-net were collected using a small stick seine (4 m long × 1.5 m high; 1.2 mm mesh). Vegetation inside the pop-net was removed manually when too abundant. Four hauls were used within each trap (Dewey, 1992). At the end of each sweep, the leadline was rapidly pulled to the surface and fish were collected using a sieve (0.36 mm mesh). In May, the minimum and maximum distances between two adjacent sampling stations (i.e., neighbours) were 25 m and 550 m, respectively, at the Maskinongé site (n = 37; maximum distance between farthest stations: 1.94 km; total polygon surface area sampled: 1.90 km²) and between 49 m and 370 m at the Fer à Cheval site (n = 32; maximum distance between farthest stations was 1.86 km and total polygon surface area sampled was 1.36 km²; Fig. 1). In July, the minimum and maximum distances between two adjacent sampling stations were 20 m and 994 m, respectively, at the Maskinongé site (n = 41; maximum distance between farthest stations was 1.90 km; total polygon surface area sampled was 2.03 km²) and between 2.4 m and 282 m at the Fer à Cheval site (n = 39; maximum distance between farthest stations was 2.43 km; total polygon surface area was 1.77 km²; Fig. 1). Sampling sites were randomly chosen according to a stratified sampling procedure. Within each bay, sampling stations were located in order to sample three depth strata (0.50–0.75 m, 0.75–1.00 m, and 1.00–1.25 m) and all vegetation densities encountered during the sampling event (Table 1; see methods above).

Captured fish were sacrificed with an overdose of 10% eugenol and preserved immediately in 10% formalin or 75% alcohol. All fish captured were identified to species (Auer, 1982; Scott and Crossman, 1973). The abundance of age-0 yellow perch was expressed in catch per unit effort (CPUE; ind. m⁻²). A total of 12 388 age-0 fish belonging to 25 species were sampled in May and July at the two sites. In this study, we analyzed only the spatial distribution of age-0 yellow perch which made up 18% of the total number of fish captured and was the most abundant species in the samples. The total abundance of small bodied fish >0 + other than yellow perch was used as an independent variable in the statistical analyses; these species were mainly small golden shiner (*Notemigonus crysoleucas*) and brown bullhead (*Ameiurus nebulosus*) in May and small brown bullhead, rock bass (*Ambloplites rupestris*), pumpkinseed (*Lepomis gibbosus*), and northern pike (*Esox lucius*) in July.

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