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Nearshore habitat associations of stocked American eel, *Anguilla rostrata*, in Lake Ontario and the upper St. Lawrence River

Megan H.M. Lloyst [a,1], Thomas C. Pratt [b,*], Scott M. Reid [c,2], Michael G. Fox [d,3]

[a] Environmental and Life Sciences Program, Trent University, Peterborough, ON K9J 7B8, Canada
[b] Great Lakes Laboratory for Fisheries and Aquatic Sciences, Fisheries and Oceans Canada, Sault Ste. Marie, ON P6A 2E5, Canada
[c] Aquatic Research and Development Section, Ontario Ministry of Natural Resources, Trent University, Peterborough, ON K9J 7B8, Canada
[d] Environmental and Resource Studies Program and Department of Biology, Trent University, Peterborough, ON K9J 7B8, Canada

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ABSTRACT

Approximately 3.9 million glass and elver stage American eels (*Anguilla rostrata*), life stages never before represented in Lake Ontario, were stocked into two locations, the upper St. Lawrence River and the Bay of Quinte, to help recover a segment of the panmictic population under severe decline. We characterized near-shore patterns of abundance and size and indicated habitat associations in the two stocking locations. Generalized additive models identified that in spring, eel presence was positively associated with the percentage of soft (organic or silt) substrate, and negatively associated with gravel substrate. In the fall, eel presence was positively associated with rubble substrate. Canonical correspondence analysis demonstrated eel habitat preferences that change as eels grow, and that these preferences do not vary with season. Small eels (<150–250 mm) preferred coarse substrates (gravel, cobble, and boulder) whereas larger eels (351–450 mm) preferred silt substrates with moderate macrophyte cover located in deeper water (0.7–>1 m). These habitat shifts are likely due to a combination of physical space requirements, habitat availability and prey preference changing with increasing body size. The availability of suitable habitats differed between main stocking locations, yet neither location had an ideal mix of coarse substrates (for smaller eels) and fine substrates (for larger eels). The observed habitat shifts resulted in the stocked American eels utilizing an array of habitats, fitting the general view of the species as a habitat generalist, but it is apparent that in the Great Lakes eels use specific substrate features that change with increasing length.

Introduction

Catastrophic declines in American eel (*Anguilla rostrata*) recruitment to Lake Ontario are well documented (Casselman, 2003; MacGregor et al., 2009; Pratt and Mathers, 2011). The number of eels recruiting to Lake Ontario decreased over 99%, based on an eel ladder index that passed an average of ~800,000 individuals in the early 1980s to ~5000 individuals in 2000. This major decline triggered a number of management actions directed specifically at this segment of the panmictic population, including the closure of commercial and recreational fisheries in the Province of Ontario to eliminate fishing mortality, the implementation of a trap-and-transport project to pass outmigrating eels that are initiating their spawning-phase around hydroelectric facilities to reduce turbine mortality, and the translocation of ~3.9 million glass eels and elvers to Lake Ontario watershed to supplement natural recruitment (MacGregor et al., 2008; Pratt and Threader, 2011).

The American eel is a unique species in the Laurentian Great Lakes because of its catadromous life history. Widely distributed from Venezuela to Greenland in freshwater, brackish and marine coastal ecosystems (Helfman et al., 1987), American eels comprise a single breeding population (Côté et al., 2013). Larval-stage eels are transported on oceanic currents for up to 1 year, after which they metamorphose into glass eels and move into continental waters. Eels then move into a growth phase, termed yellow-phase, which can last over 20 years before they mature and outmigrate as silver-stage eels (Jessop, 2010).

Naturally migrating yellow-stage eels moving into Lake Ontario are, on average, 6–8 years old after migrating up the St. Lawrence River, arriving at a length of 30–35 cm (Zhu et al., 2013). In contrast, age-0 glass eels and elvers stocked from 2006 to 2010 into the Lake Ontario watershed came directly from commercial glass eel fishers in Atlantic Canada and were transplanted at lengths that averaged only 6 cm (Pratt and Threader, 2011). Stocking locations included areas of shallow depth (0.75 m to 1.5 m), mud and rock substrates, and emergent and submerged macrophytes. Two locations (Bay of Quinte and the upper St. Lawrence River near Mallorytown Landing) were stocked based on

* Corresponding author. Tel.: +1 705 941 2667.
E-mail addresses: meganlloyst@trentu.ca (M.H.M. Lloyst), thomas.pratt@dfo-mpo.gc.ca (T.C. Pratt), reid.scott@ontario.ca (S.M. Reid), mfox@trentu.ca (M.G. Fox).
[1] Tel.: +1 705 933 6335.
[2] Tel.: +1 705 755 2267.
[3] Tel.: +1 705 748 1011.

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the location of historically productive yellow eel fisheries. As glass eels and elvers are novel life stages in the Lake Ontario watershed, it was not known what habitat(s) they would occupy prior to the onset of this study. It is also uncertain whether the formerly productive habitat for American eel in Lake Ontario is still productive, given the extensive physical and biotic changes wrought by repeated invasions of aquatic invasive species over the past few decades (e.g., Johannsson et al., 2011; Mills et al., 2003; Stewart et al., 2010).

The yellow-stage American eel is benthic oriented and is characterized as a habitat generalist as they can be found at a wide range of depths, temperatures and salinities, and over a variety of substrates (Greene et al., 2009; Pratt et al., 2014). This characterization may hide the fact that, as eels grow, they undergo ontogenetic shifts, and studies have identified differences in the habitat use (depth, velocity and substrate composition) of small and large eels (Machut et al., 2007; Meffe and Sheldon, 1988). This is consistent with the fact that different sized eels consume different prey types. Smaller American eels are limited by gape to the types and sizes of prey items that they can consume with smaller eels feeding primarily on smaller invertebrates, whereas larger eels feed mainly on fish or large crustaceans (Stacey, 2013; Wenner and Musick, 1975). In addition, eels are well adapted to live in interstitial spaces within the substratum, and they can burrow in mud substrates (Koehn et al., 1994; Tesch, 2003; Tomie et al., 2013). It might be expected that shifts in substrate preference would be necessary as eels grow simply because their physical requirements change as they get larger. Seasonal variation in habitat associations of American eel may occur as a result of seasonal changes in the abundance and distribution of food and macrophyte cover, as seasonal variation in feeding has been observed for the European eel (*Anguilla anguilla*; Bouchereau et al., 2009). Thus, the few studies of habitat associations of American eel at specific sizes may have led to the impression that eels are habitat generalists when in reality they may have specific habitat requirements at various life stages.

The purpose of our study was to assess nearshore habitat selection by American eel stocked in Lake Ontario and the upper St. Lawrence River. Specific objectives were to determine whether habitat selection was related to eel size, and whether selection varied seasonally. We hypothesized that habitat preferences would shift both seasonally and with increasing body size, given the observations of seasonal and ontogenetic shifts in other eel studies (Bouchereau et al., 2009; Machut et al., 2007; Meffe and Sheldon, 1988; Wenner and Musick, 1975). In addition, we were interested in assessing whether both stocking locations contained suitable habitat to support eels despite the trophic changes that have devastated other fishes in Lake Ontario (Mills et al., 2003). As eels are flexible in their prey selection and most of the trophic changes have resulted in the increased benthification of the Lake Ontario ecosystem, which is where eels generally feed and reside, our expectation was that suitable habitat would still be available for eels.

Methods

Study area

This study was conducted in the Bay of Quinte located in the eastern part of Lake Ontario, and the upper St. Lawrence River (Fig. 1). Lake Ontario is a mesotrophic lake; and, because of seasonal temperature changes, the lake stratifies and supports populations of warm and coldwater fishes, both of which are represented in the Bay of Quinte and the upper St. Lawrence River. The Z-shaped Bay of Quinte is 64 km in length and has a surface area of 254 km^2. The upper portion of the bay (Big Bay, Telegraph Narrows) is relatively shallow with a mean and maximum depth of 3.2 m and 8 m, respectively, whereas the middle portion of the bay (Long Reach, Hay Bay) is deeper with a mean depth of 6.3 m and maximum depth of 17 m (Hurley and Christie, 1977). The substrate changes from primarily gravel bars and sandy bays in nearshore areas to bedrock and gravel further offshore, and ultimately to mud in deeper sections (Dermott, 2001; Hurley and Christie, 1977). Macrophytes are present along the shoreline of the entire bay (Crowder and Bristow, 1986). The upper St. Lawrence River extends 180 km from the outlet of Lake Ontario to the Robert Moses-Robert H. Saunders Power Dam, at Cornwall Ontario. Almost all of the river's water is supplied by Lake Ontario. Water levels are controlled by the hydroelectric facility. The river provides a wide range of habitat types and a diverse plant and fish community. However, the river does not thermally stratify; and, in the summer, the water is too warm to support coldwater fishes (LaPan et al., 2002). Stocking and sampling locations can be seen in Fig. 1, while stocking numbers, dates and eel lengths and weights at the time of stocking are reported in Table 1.

Eel sampling

Habitat associations were studied in conjunction with a stocking experiment and monitoring program in the spring and fall of 2010 and 2011 (Table 2). Boat electrofishing was used in predetermined 100 m transects that ran parallel to shore at depths of 1.5 m or shallower. Transects were selected to represent the substrate types present within the study locations, and where habitat did not vary much along a given transect. The same transects were sampled each year and season unless macrophyte growth or water depth inhibited boat access, in which case a new transect was sampled nearby or the transect was not sampled for that season. In general, more transects were fishable during the fall when water levels had stabilized (Table 2). The vessel used for this research was a 4.3 m Smith-Root SR-14h boat equipped with a Model 5.0 GPP generator and operated with boom anodes and hull cathode arrays. The generator was set to 2.5 A of DC current. Assessments were conducted during calm nights to maximize eel detection probabilities. Each transect took about 5 min to complete. Netters used long handled nets (6.4 mm mesh) to capture observed eels. Captured eels were placed in a 100 L live well, and were processed at the end of each transect. Netters also enumerated eels that they saw but were unable to capture. We are confident that virtually all eels observed in this study were stocked because stocked eels are distinguishable from naturally occurring eels that migrate up the St. Lawrence River through the Moses Saunders dam eel ladder by oxytetracycline hydrochloride (OTC-HCL) markings (Pratt and Threader, 2011). In both sampling years, all captured eels that were sacrificed for origin assessment ($n = 335$) were identified as stocked, so we believe that it is likely that the vast majority of eels that were only enumerated or were captured and released were also stocked.

Eel habitat assessment

Water chemistry, substrate type and macrophyte density were assessed when each transect was completed. Measured parameters included conductivity, water depth, water/air temperature and dissolved oxygen concentration, which were taken from the midpoint of the 100 m transect. Parameters were measured with an ECTest waterproof conductivity meter and a YSI 550A temperature/DO meter. Mean transect depths were recorded from the on-board GPS-linked echosounder.

Substrate type was visually classified as a percentage, using eight categories based on particle diameter: bedrock, boulder (300–600 mm), rubble (100–300 mm), cobble (75–100 mm), gravel (5–75 mm), sand (1–5 mm), silt (<1 mm) and organic material. Substrate was assessed at the beginning and the end of each transect. The dominant substrate type for each transect was used to provide a simple contrast of habitat availability and eel density, while the percentage of substrate types were used in the modeling analysis. Macrophyte density was concurrently assessed, with percent cover of the transect classified into one of four categories: none (0%); sparse (0–25%); moderate (25–50%); and dense (50–100%).