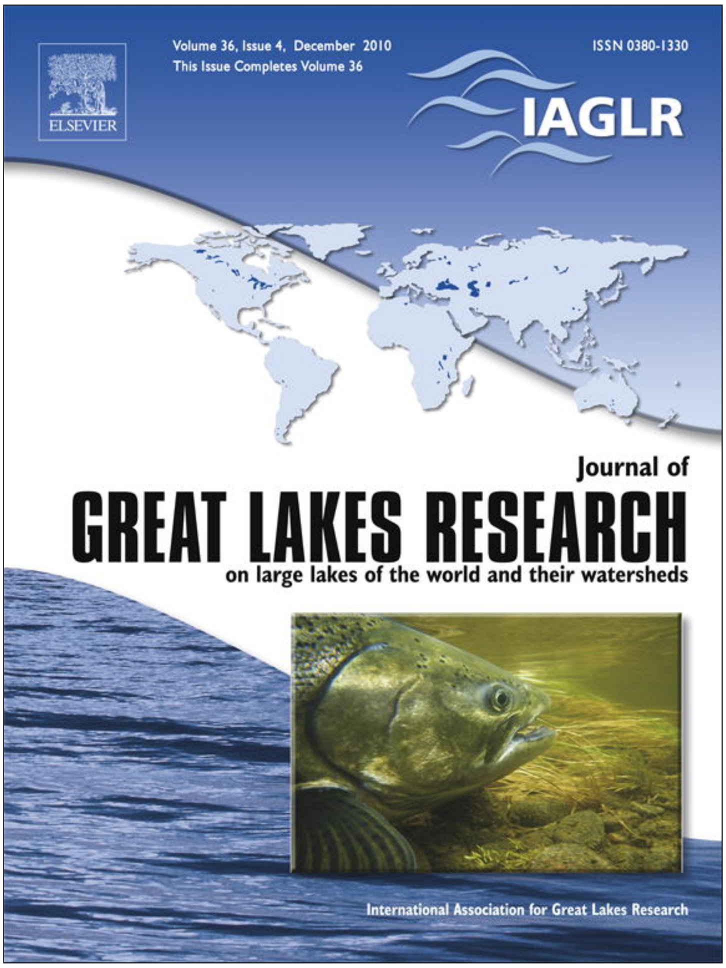
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Notes

First record of migrating silver American eels (*Anguilla rostrata*) in the St. Lawrence Estuary originating from a stocking program

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ABSTRACT

In fall 2009, six migrating silver American eels (*Anguilla rostrata*) originating from a stocking program were caught in the brackish waters of the St. Lawrence Estuary. These maturing eels were all females with gonads developed at a similar stage as other migrating eels in the estuary. Fluorescent oxytetracycline marks observed on the otoliths allowed us to assert without any doubt that they came from glass eels caught in Nova Scotia and stocked 4 years earlier in the Richelieu River, 500 km upstream from the recapture location. Their length varied between 570 and 668 mm, which is within the size range of naturally recruited female silver eels in Nova Scotia, while silver eel are most generally longer than 80 cm in the St. Lawrence estuary. Their growth rate was also exceptionally fast. This direct observation is the first evidence that American eels stocked as glass eels can migrate seaward at least as far as the estuary in synchrony with naturally recruited female silver eels en route to their spawning grounds in the Sargasso Sea.

Introduction

American eel (*Anguilla rostrata*) has a complex life history. It spawns in the Sargasso Sea (Atlantic Ocean) and larvae drifts within ocean currents towards continental shelf. Postlarval eels (glass eel life stage) enter river mouths and estuaries to reach growth habitats and rapidly become pigmented. They disperse throughout waterbodies and spend their juvenile growth phase (yellow eel life stage), feeding on insects, crustaceans and fish for up to 25 years. At the onset of maturing phase (silver eel life stage) they undertake their migration back to the spawning grounds in the Sargasso Sea, spawn and die (Jessop, 2010).

American eel was formerly one of the most common migratory fish species inhabiting accessible North American habitats connected to the Atlantic Ocean (MacGregor et al., 2009). Habitat alteration and fragmentation, turbine mortality and fishery operations during the last century led to a serious contraction of the distribution range and a steep decline in population abundance, especially in the St. Lawrence River system and Lake Ontario (COSEWIC, 2006). While awareness has recently grown among stakeholders and managers in Canada, mitigation and enhancement options are limited for this long-lived panmictic species. Action is already being taken to regain access to growth habitat above dams and to stop or reduce fishery mortality, and research effort is increasing to lower turbine passage mortality at large hydro dams on the St. Lawrence River (COSEWIC, 2006). These measures are being put in place to stop the decline and tentatively reverse the trend over the next decades, but in the short term there are few options for increasing population abundance on a regional level in the face of low natural recruitment.

Fish stocking may be seen as a useful means to increase populations rapidly and ultimately boost escapement of maturing silver-phase eels (Verreault et al., 2009). Eel stocking cannot be done through artificial reproduction. In spite of some experimental success, young larvae starve soon after hatching (Kagawa et al. 2005) and stocking relies exclusively on wild recruits as seed source. Although this practice has been used intensively for more than half a century in Europe as a way to increase local populations of the closely related European eel (*Anguilla anguilla*) (Wickström et al. 1996), there is still considerable debate about its real outcome as a long-term means to compensate for low abundance of maturing eels (Limburg et al., 2003; Westin, 2003; Shiao et al., 2006). The main objections are related to the ability of the stocked eels to migrate back as spawners and find their way out to the Sargasso Sea for spawning.

Despite these uncertainties, an ongoing experimental stocking program was initiated in 2005 in the Richelieu River, which connects the St. Lawrence River to Lake Champlain, where a sharp decline in eel recruitment has been documented since the 1970s (Verdon et al., 2003). A similar project was initiated in fall 2006 in the Upper St. Lawrence-Lake Ontario system (Fig. 1). These stockings were not initiated to increase eel fisheries but rather for increasing potential spawners abundance and escapement to the Sargasso Sea. Monitoring was set up in order to evaluate the spread, growth rates, sex ratio and health status of the stocked eels and their impact on escapement. The objectives of this paper is to describe the first direct observations of

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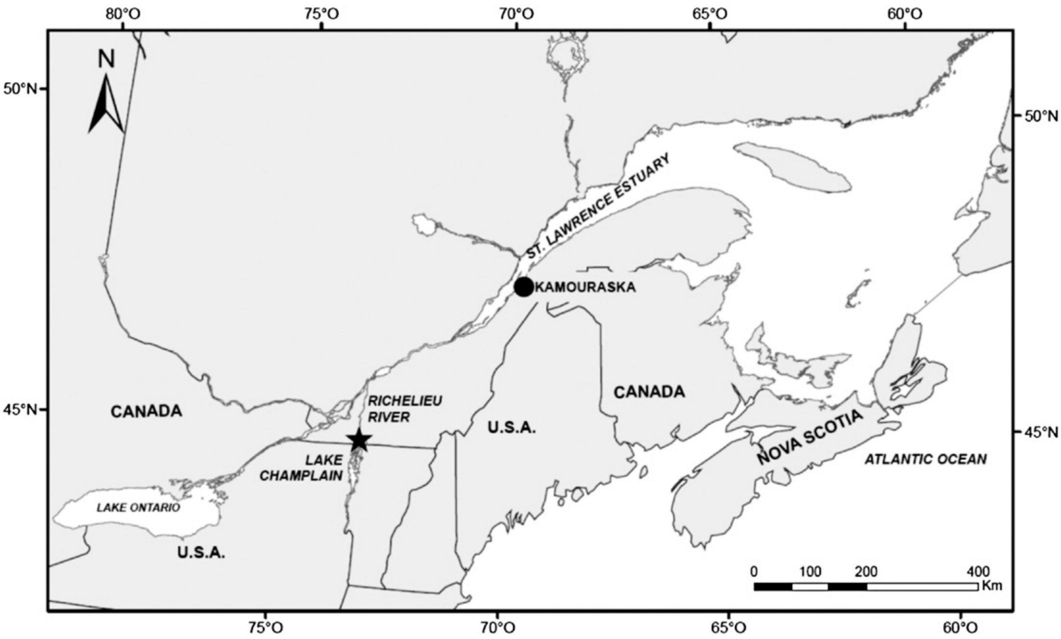

Fig. 1. American eel stocking (star) and recapture (circle) sites in the St. Lawrence system.

migrating silver eels originating from this stocking program in North America and their significance on future population abundance.

Methodology

Glass eels (0.08 g to 0.28 g; 42 mm to 68 mm TL) from river mouths along the Atlantic coast of Nova Scotia (Canada) are the only source for all stocking programs in Canada. They are caught in early May and kept in quarantine for approximately one week for pathogen and parasite screening. Then, they are mass-marked in a hyperosmotic solution with oxytetracycline (OTC) in accordance with Alcobendas et al. (1991) methodology prior to being transferred to the receiving water bodies, i.e., the Richelieu River, the Upper St. Lawrence River or Lake Ontario (Fig. 1). Stocked numbers vary annually (Table 1) and, every year, a random sample is collected before stocking; otoliths (saggitae) are removed and checked under microscope with UV light (360/40 nm) for OTC mark detection.

During the fall of 2009, eel fishers in the St. Lawrence Estuary harvested some unusually small silver eels for the first time in this traditional fishery, raising concerns about the origin of these uncommon migrants in their catches. A quick telephone survey was carried out with all eel fishers (n = 15) to determine the number of small silver eels less than 700 mm and the extent of this small silver-eel run in the harvest. Specimens were gathered and measured for length (±1 mm) and weight (±1.0 g), and sagittal otoliths were removed. Skin colour was determined in accordance with Okamura et al. (2007). Otoliths were processed for age determination using a five-stage procedure : 1) cleaning with sodium hypochlorite; 2) embedding in epoxy resin; 3) sanding on 800-grit paper and polishing with aluminum oxide powder; 4) etching with EDTA solution, and finally; 5) staining with 0.01% toluidine blue (Verreault et al., 2009). Otoliths were observed with binocular microscope (60X) under transmitted light for aging. Tetracycline mark was then detected with the same procedure used for glass eels prior stocking. Sex identification was performed by morphological examination.

Table 1
American eel stocking in Canadian waters.

Year	Richelieu River		Lake Ontario	
	Numbers	Biomass (kg)	Numbers	Biomass (kg)
2005	600 000	105	-	-
2006	1 000 000	200	167 000	100
2007	421 500	74.2	437 000	90
2008	746 000	145	2 001 000	375
2009	-	-	1 303 000	300

Results

Six small silver eels were gathered from fishers at the end of October in Kamouraska, the most important area for eel fisheries in the brackish waters of the St. Lawrence Estuary. Their length and weight ranged from 570 mm to 668 mm and from 387.4 g to 675.1 g, and averaged 614.5 mm (SD = 36.3) and 502.8 g (SD = 108.5). Examination of the gonads and skin colour confirmed that all specimens were maturing female silver eels at the S2 stage (Okamura et al., 2007). A clear fluorescent yellow mark was observed on every otolith and an age estimation of 4 years showed that the six eels belonged to the group of 600,000 glass eels stocked in 2005. Average growth was estimated at 138.5 mm/year (SD = 9.1) A telephone survey allowed us to estimate that approximately 35 silver eels (< 700 mm) were harvested in fall 2009 in the St. Lawrence Estuary; this represents a very small proportion of the estimated 17,300 silver eels harvested in 2009 (Guy Verreault, unpublished data).

Discussion

The direct observation of migrating silver American eels originating from stocked individuals is the first documented evidence of their ability to find their way out of the stocking location and migrate back towards their spawning grounds at the same time as naturally recruited silver eels in the St. Lawrence system 4 years only after being stocked in freshwater habitat. Their young age (4+) and small size (570–668 mm) is very unusual for maturing eels in the St. Lawrence River system. Moreover, we can assert that these eels come from the Richelieu River stocking operation conducted in May 2005, about 500 km upstream from the St. Lawrence Estuary. That year saw the first large-scale eel stocking operation in the St. Lawrence system and in North America. An estimated 600,000 glass eels from the Atlantic coast of Nova Scotia were OTC marked and stocked about 10 km north of the Canada/United States border, close to the Lake Champlain outlet. Fourteen months later, one stocked eel was caught in the southern section of Lake Champlain (Putnam Creek, USA), 135 km from the stocking location. An increasing number of captures has been reported since 2006, totalling more than 60 small eels (< 60 cm TL), at various locations during sea lamprey (*Petromyzon marinus*) electrofishing surveys carried out in the U.S. part of this 1,127-km^2 lake. These preliminary observations suggest that the spread and growth of transferred glass eels can be very fast and that upstream migratory behaviour persisted for at least some of them. However, these observations do not clearly confirm that these six silver eels experienced their growth in Lake Champlain, seeing that downstream movement of stocked eels was also observed in the Richelieu River, as shown by the fact that 38.3% of the small yellow eels (192 mm to 730 mm) ascending the Chambly dam eel ladder in 2009, 40 km downstream from the stocking site, were OTC marked (Guy Verreault, unpublished data).

Female American eels in the St. Lawrence River system and in Nova Scotia usually spend a minimum of two decades in fresh water before becoming silver and migrating back to the spawning grounds (Jessop, 2010). This author observed that female American eels begin their spawning migration at an average length varying between 47 and 104 cm, and that this length correlates with latitude and distance to the spawning grounds. In late 1970s, Facey and LaBar (1981) estimated mean age for yellow eels at 15.9 years in Lake Champlain and noted a steep decline in length frequency over 80 cm. This could be indicative of size for outmigrating eels from Lake Champlain at that time. In the St. Lawrence system, total length of silver females averaged 93.5 cm (SD = 8.4) in 2009, while naturally recruited female silver eels in four Nova Scotia rivers show a mean length ranging from 468 to 645 mm (Jessop, 2010).

Nova Scotia is the same origin as for glass eels stocked in the Richelieu in 2005. Observation of growth rates and length at migration points towards a possible effect of origin on stocked eels. Côté et al. (2009) showed that origin clearly influences growth of glass eels raised in the same environment but coming from two different locations. A mean annual growth of 138.5 mm/year was estimated for the six recaptured eels, a value slightly higher than the 117.5 mm/year after 4 years observed for glass eels originating from New Brunswick and stocked in an eel-free lake in Quebec (Verreault et al., 2009), and clearly exceeding the usual 43 to 48 mm/year reported for silver eels in the St. Lawrence River system (Jessop, 2010). In the context of panmixia, the influence of origin on length at migration remains unclear, and the unusually short stay in freshwater can also be related to the fact that in an environment almost free of their congeners, stocked eels may have experienced a fast growth rate. Jessop (2010) has demonstrated that the mean age at migration decreases significantly, from 21.9 to 5.8 years, with increasing annual growth rate ranging between 26.5 and 85.9 mm/year.

As far as we know, there is no other documented direct observation relating to the spawning migration of eels previously stocked as glass eels, for either the American or European eel. Moreover, this recent finding raises one of the main uncertainties surrounding eel stocking programs. Based on his tagging studies, Westin (2003) stated that stocked eels were disoriented and unable to find their way out from the Baltic Sea. Using otolith Sr:Ca profiles of 108 European eels, Shiao et al. (2006) concluded that there was no evidence that stocked eels from inland lakes of eastern Lithuania emigrate downriver and contribute to eel stocks in the Curonian Lagoon or along the Baltic coast. On the other hand, based on the same approach, Limburg et al. (2003) found indirect evidence that stocked eels can migrate at least to the outlet of the Baltic Sea into the ocean. Our study proves without a doubt that stocked eels can migrate, along with naturally recruited silver eels, back at least to the brackish waters of the St. Lawrence Estuary. We cannot speculate on their chances of reaching the Sargasso Sea but apart from their small length, they exhibit the same migration pattern as naturally recruited silver eels moving through the estuary. We do not know exactly how many stocked eels have migrated as silver eels but with an estimated number of 35 harvested by fishers, the six specimens brought back to our laboratory are probably only a part of what could have been migrating through the estuary in 2009. Fishing gears used in this traditional fishery target essentially large migrant eels and gear selectivity is unknown for specimens with length less than 75 cm. We can assume that only a fraction of these small migrating silver eels have been retained in the fishing gears and this impede any sound abundance estimates. As an alternate hypothesis, these small silver eels could be the individuals with fastest growth rates being only a fraction of what was stocked. Others are still growing and will initiate spawning migration at an older age and larger size. Future monitoring should be maintained to increase our knowledge on this issue.

This study should not be seen as a final answer to the debate surrounding eel stocking as a conservation measure for depleted stocks. In fact, it raises more questions on the ability of these small migrants to reach the spawning grounds and their real capacity to contribute to stock rebuilding. Their small size implies low individual fecundity and we do not know what would be the real benefit on the global declining abundance for this species of concern. Rather, it advocates seizing the opportunity presented by these stocked eels to increase our knowledge through a rigorous scientific protocol, in order to measure the real output and impacts on population level. In all probability, numbers of migrants originating from stocking programs should increase in the next few years and represent a real chance to enhance the scientific research on eel stocking as a means to increase recruitment and reverse the current American eel decline.

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