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# Estimation of daily age and timing of hatching of exotic Asian swamp eels *Monopterus albus* (Zuiew, 1793) in a backwater marsh of the Chattahoochee River, Georgia, USA

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## Summary

Otoliths were used to estimate daily age, growth, and hatching date of the exotic Asian swamp eel (*Monopterus albus*) captured from a backwater marsh of the Chattahoochee River, Georgia, USA. The eels were sampled using leaf litter traps (N = 140) from 17 July to 28 August 2008. The captured (N = 15) Asian swamp eels ranged in total length from 4.9 cm to 12.2 cm, and were estimated to be from 21 to 51 days old (N = 13), and hatched from 13 June to 7 August 2008. Assuming linear growth, these individuals grew an average rate of 0.2 cm per day. To the authors' knowledge, this was the first time otoliths were used to estimate daily age, growth, and hatching date for *M. albus*, which can be useful for understanding the ecology of this species in the wild.

## Introduction

A hermaphroditic species of Synbranchidae that breathes air and crawls over land, the Asian swamp (rice) eel (*Monopterus albus*) is an exotic and invasive species in the continental United States (US) first discovered in 1994 from ponds at the Chattahoochee Nature Center (CNC) in Roswell, Georgia (Starnes et al., 1998; Fig. 1). The Georgia site is one of only five known in the continental US and approximately 800 km from the closest population near St. Petersburg, Florida (Benson, 2009; Nico and Fuller, 2009), resulting in a lack of knowledge of this species in the country. Previously confined to man-made ponds, individuals have now been captured in the natural environment, which is a backwater marsh of the Chattahoochee River, into which the CNC ponds discharge (Freeman et al., 2005).

The extent of the swamp eel into the Chattahoochee River is known in only one marsh (Freeman et al., 2005; National Park Service, unpublished data) and is in the early stage of invasion. Leaf litter traps (LLT), made out of grocery store onion bags and stuffed with leaf litter, have been found to be very efficient at capturing small swamp eels (< 10 cm; Freeman et al., 2005). Prior to the use of leaf litter traps by Freeman et al. (2005), juveniles of this species could not be sampled consistently. As a result, there is a paucity of studies on this life stage for this species in its invaded habitat.

Little information exists regarding the population biology (Straight et al., 2005; Hill and Watson, 2007) or even the identity of this species in its introduced range in the United States (Nico and Fuller, 2009). In fact, Freeman et al. (2005) considered the species in Georgia to be an undescribed species of *Monopterus* (*M.* sp. *cf. albus*) that is most similar to the native eels of Japan and Korea (Collins et al., 2002). Because this species has proven difficult to control with toxicants (Reinert et al., 2006; Schofield and Nico, 2007), a fuller understanding of its ecology in its non-native habitat is needed to develop an integrated pest management strategy. The objective of this study was to use otoliths to estimate the age in days of juvenile Asian swamp eels found in the backwater marsh of the Chattahoochee River, calculate their rate of growth, and estimate their hatching date.

## Materials and methods

### Study area

The Chattahoochee River near the Chattahoochee Nature Center is impounded by Morgan Falls Dam, which was built in 1904, and is stocked with trout (Salmonidae) for a tailwater fishery (Long and Martin, 2008). The impoundment, Bull Sluice Lake, is small (272 ha), shallow, with high sediment loading resulting in a large (26%) percentage of wetland habitat comprised mostly of shallow flats (Georgia Power and GeoSyntec Consultants, 2005), such as the backwater marsh where swamp eels have been discovered (Fig. 1). This backwater marsh is approximately 0.66 ha in surface area and fluctuates in water temperature and depth according to fluctuations in river height, which is a function of discharge from upstream Buford Dam (Freeman et al., 2005).

### Fish sampling

We sampled weekly for juvenile swamp eels at 20 fixed sites in the backwater marsh from 17 July to 28 August 2008 using leaf litter traps (Freeman et al., 2005; Fig. 1). A leaf litter trap is a plastic mesh bag commercially used for shipping produce, such as onions, and is filled with dead leaves and pine needles, tied at both ends, and placed in the water at a depth just below the surface and left in place for a week (Freeman et al., 2005). A leaf litter trap was checked by rapidly pulling the bag out of the water and immediately placing it into a shallow plastic tray, the contents emptied and the container searched for juvenile eels. All captured eels were stored in plastic bags and labeled with the trap and capture date and taken to the laboratory; the leaf litter was replaced and the bag was re-deployed for another week. Twenty leaf litter traps were thus deployed and checked each week in 2008 over a 7-week

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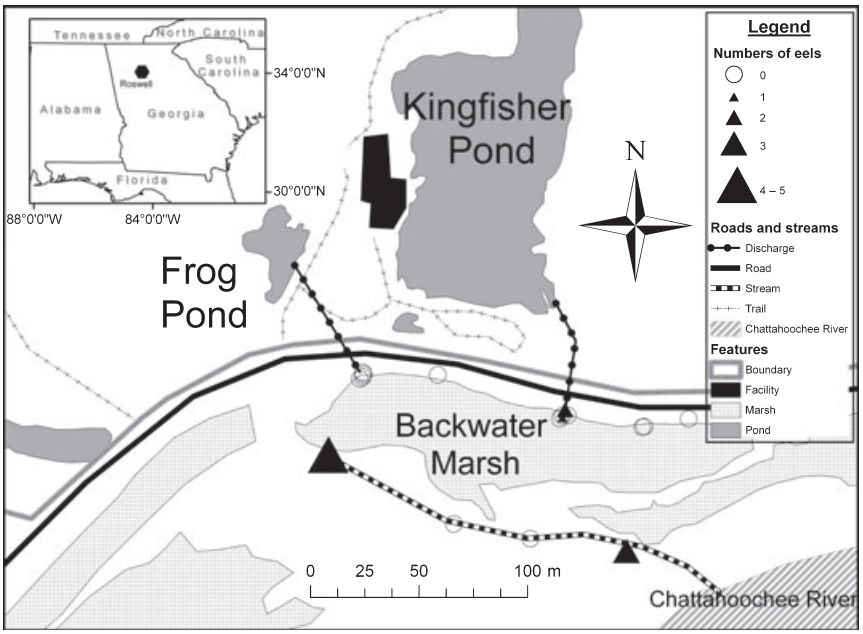


Fig. 1. Map of Chattahoochee River near Chattahoochee Nature Center, Roswell, Georgia, USA, where exotic Asian swamp eels exist in ponds and a backwater marsh

period for a total of 140 samples. In the laboratory, eels were immobilized by freezing, measured for total length (TL; cm) and stored individually in 70% ethanol. Water temperature (°C) and dissolved oxygen (mg $L^{-1}$) were measured during sampling at each trap or group of traps (when placed adjacently) with a YSI model 85 m.

#### Age, growth, and hatch date estimation

An otolith (sagitta) was removed from each captured eel and mounted onto a microscope slide with thermoplastic cement. Each otolith was sanded with 2000 grit sandpaper and polished with a colloidal silica suspension and polishing cloth until daily rings were discernable from the center to the edge (Miller and Storck, 1982; Hayes, 1995). Although daily ring formation has not been validated for *M. albus*, it has been widely demonstrated for many fish species (Pannella, 1971; Campana and Neilson, 1985) and we assumed that rings were formed daily. One reader with experience estimating daily age from otoliths independently counted rings until three counts differed by no more than five. Counts of rings in each otolith were done randomly and non-consecutively using a light microscope at 100×, 200×, or 400× magnification. The median age in days was then calculated and used as the age in days for each fish. We subtracted the age in days from the sampling date to estimate the date of hatching, and estimated growth rates by subtracting 1.4 cm (mean total length at hatching; Guan et al., 1996) from total length and dividing by age.

## Results

From 17 July to 28 August 2008, we captured 15 juvenile Asian swamp eels from a total of 140 sampling events (Table 1). The first fish were captured during the week of 24

Table 1
Date of capture, total length, summary of daily ring counts (count 1–3, median, and maximum difference among counts), estimated hatch date (capture date – median count), and estimated growth rate (length – 1.4 / median count) for juvenile Asian swamp eels (*M. albus*) in a backwater marsh of the Chattahoochee River, Georgia, sampled using leaf litter traps (N = 20) set over a 7-week period

| Specimen number[a] | Capture date | Length (cm) | Otolith ring counts | | | Median count | Maximum difference | Estimated hatch date | Estimated growth rate (cm $day^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| | | | Count 1 | Count 2 | Count 3 | | | | |
| 12 | 24 July | 4.8 | 21 | 26 | 24 | 24 | 5 | 30 June | 0.1 |
| 2 | 24 July | 5 | 23 | 26 | 25 | 25 | 3 | 29 June | 0.1 |
| 9 | 24 July | 5.4 | 28 | 23 | 25 | 25 | 5 | 29 June | 0.2 |
| 11 | 2 August | 9.6 | 52 | 49 | 50 | 50 | 3 | 13 June | 0.2 |
| 6 | 2 August | 5.4 | 20 | 23 | 21 | 21 | 3 | 12 July | 0.2 |
| 1 | 2 August | 4.9 | 22 | 22 | 25 | 22 | 3 | 11 July | 0.2 |
| 7 | 2 August | 12.2 | NA | NA | NA | NA | NA | NA | NA |
| 3 | 8 August | 5.1 | 22 | 25 | 22 | 22 | 3 | 17 July | 0.2 |
| 14 | 16 August | 8.2 | 34 | 36 | 36 | 36 | 2 | 11 July | 0.2 |
| 4 | 28 August | 9.1 | 25 | 24 | 22 | 24 | 3 | 4 August | 0.3 |
| 5 | 28 August | 6.6 | 24 | 28 | 26 | 26 | 4 | 2 August | 0.2 |
| 10 | 28 August | 8.5 | 34 | 35 | 36 | 35 | 2 | 24 July | 0.2 |
| 15 | 28 August | 10.9 | 51 | 49 | 51 | 51 | 2 | 8 July | 0.2 |
| 13 | 28 August | 7.2 | 21 | 23 | 21 | 21 | 2 | 7 August | 0.3 |
| 8 | 28 August | 8 | NA | NA | NA | NA | NA | NA | NA |

NA, otolith was destroyed during preparation.
[a]Specimen number was randomly assigned for daily age estimation.

Table 2
Summary of Asian swamp eels captured and associated physicochemical measurements (SD = standard deviation) in a backwater marsh, Chattahoochee River, Georgia. *M. albus* were sampled using leaf litter traps (N = 20) set over a 7-week period

| Date | Number captured | Number measurements | Water temperature (°C) | | Dissolved oxygen (mg / $L^{-1}$) | |
|---|---|---|---|---|---|---|
| | | | Mean | SD | Mean | SD |
| 17 July 2008 | 0 | 17 | 27.4 | 2.1 | 6.3 | 2.4 |
| 24 July 2008 | 3 | 8 | 29.4 | 0.6 | 4.9 | 1.7 |
| 2 August 2008 | 4 | 10 | 28.6 | 2.4 | 3.2 | 0.9 |
| 8 August 2004 | 1 | 6 | 24.6 | 1.3 | 1.7 | 0.8 |
| 16 August 2008 | 1 | 20 | 18.8 | 1.5 | 6.2 | 1.7 |
| 20 August 2008 | 0 | 1* | 23.4 | NA | 0.8 | NA |
| 28 August 2008 | 6 | 9 | 26.2 | 1.5 | 4.3 | 0.9 |

*Probe malfunction prevented multiple measurements during sampling

July and captured thereafter every week through August 28. Fish length ranged from 4.8 to 12.2 cm (Table 1). Mean water temperature ranged from a minimum of 18.8°C on 16 August to a maximum of 29.4°C on 24 July (Table 2). Mean dissolved oxygen fluctuated widely from near-anoxia of 0.8 on 20 August to near-saturation of 6.3 on 17 July.

We were able to estimate age for 13 of the 15 juvenile Asian swamp eels; two otoliths were destroyed during processing, either lost during removal or sanded too much during preparation (Table 1; Fig. 2). Ring counts of otoliths varied little among each other for each individual. The maximum difference was five; the minimum was two. Using the median count as the estimated age for each individual, the Asian swamp eels we captured ranged from 21 to 51 days old. Most fish were 21 to 26 days old, followed by a group of two that were 35–36 days old and two that were 50–51 days old. Using the difference between capture date and age as an estimate of hatch date, *M. albus* hatched from 13 June to 7 August. Growth rates varied from 0.1 to 0.3 cm per day and averaged 0.2 cm per day.

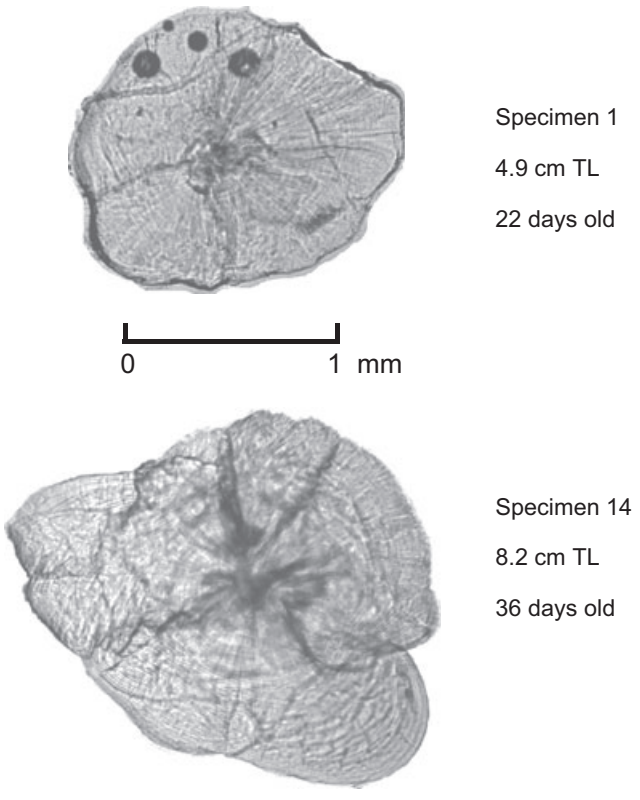


Fig. 2. Photomicrographs of otoliths from juvenile Asian swamp eels captured in a backwater marsh, Chattahoochee River, Georgia, USA

## Discussion

Rings were readily observable with light microscopy and counts were minimally different among viewings, suggesting that rings were formed on a regular basis (i.e. daily). The timing of the first ring is unknown for this species and is necessary to accurately estimate past life history dates, such as hatching or swim-up. Timing of first ring formation varies widely among species, occurring before hatching (e.g. rainbow trout *Onchorhynchus mykiss,* 15 days post-fertilization and before hatching; Salem and Omura, 1998a), at hatching (e.g. ayu *Plecoglossus altivelis*; Salem and Omura, 1998b) and after hatching (e.g. anchovy *Engraulis mordax,* 6 days post-hatching; Methot and Kramer, 1979). It has been hypothesized that daily ring formation is related to the body's ability to sense differences in diurnal light cycles, as is the case for rainbow trout where the first daily ring of the otolith was formed at approximately the same time as the pineal photoreceptors of the eye (Salem and Omura, 1998a). In *Monopterus albus*, the eye vesicles form approximately 3 days post-fertilization and 3 days before hatching (Guan et al., 1996), suggesting that timing of the first ring formation in the otolith is pre-hatch for this species. Given the variability in timing of first ring formation among species, assigning the first ring to the hatch date for *M. albus* seemed the most logical choice in the absence of further information.

This work highlights the utility of using otoliths to estimate daily age for juvenile Asian swamp eels, however, further research is necessary to test the assumptions upon which our study was based. Specifically, research is needed to validate the formation of daily rings, the maximum age at which daily rings can be counted accurately, and to determine at what stage of development (e.g. hatching or swim-up) the first ring forms. We hope that our work stimulates additional work in this field.

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