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NOTE

Variations in Growth of Tautog in Nursery Areas in Narragansett Bay and Rhode Island Coastal Ponds

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Abstract

In the present study, the growth of juvenile tautogs *Tautoga onitis* in Narragansett Bay (Gaspee Point, Mount Hope Bay, and Rose Island) and Rhode Island coastal ponds (Point Judith and Charleston ponds) was evaluated by means of otolith microstructure. The widths of the daily increments in otoliths in the region that represents the postsettlement period (20–50 d) of tautogs collected in two separate years were compared among these stations. Significant differences were found in the growth trajectories within stations between years as well as among stations in each year. This study demonstrates that there can be significant variability in short-term growth for juvenile tautogs within and among estuaries. This variability may change from year to year, potentially affecting the interpretation of growth. A better understanding of the conditions affecting single factors of tautog production, such as growth over several years, may enable researchers to successfully characterize fish nursery value.

The conservation and management of fish habitats has become an important component of comprehensive fishery management programs (Able 1999; Beck et al. 2001). Coastal marine areas are particularly sensitive fish habitats because they have an important function as nursery grounds for commercially important marine fishes (Beck et al. 2001). Nursery habitat quality has potential effects on growth and survival of juvenile fish and ultimately on recruitment (Minello 1999; Beck et al. 2001). Habitats that promote rapid growth are generally assumed to be high-quality areas for juvenile fish, because rapid growth implies that sufficient food is available and that juveniles will be less vulnerable to size-selective mortality due to predation and environmental stress (Sogard 1997); thus, individuals attaining a larger size at the end of the juvenile period may be more successful in completing the process of migration to the adult habitat. Therefore, a habitat that promotes higher growth rates may contribute more and larger juveniles to the adult population (Beck et al. 2001; Bergenius et al. 2002).

The tautog *Tautoga onitis* is an economically and ecologically important species found in the waters of eastern North America from the Gulf of Maine to North Carolina. Juvenile tautogs depend on the coastal zone for nursery habitats where predation risk is presumably lower and food resources are abundant (Dorf and Powell 1997; Arendt 1999). However, the relative importance of open coastline and enclosed bays and lagoons as nursery habitat for tautogs is still poorly understood (Sogard

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TABLE 1. Mean (SE) fork length (FL; mm) of juvenile tautogs in Rhode Island in 2005 and 2006, by station and year; *N* is the number of fish measured at each station.

	2005			2006		
Station	Sampling date	*N*	FL	Sampling date	*N*	FL
Gaspee Point	Aug 9	17	59.6 (1.2)	Sep 2–31	0	
Mount Hope Bay	Aug 5	17	59.1 (2.1)	Sep 29	21	63.0 (2.9)
Rose Island	Sep 8	20	52.1 (1.2)	Sep 21	17	45.3 (3.5)
Point Judith Lower Pond	Aug 19	18	49.4 (2.1)	Sep 18	19	57.3 (1.5)
Charlestown Pond	Aug 11	17	50.2 (3.0)	Sep 26	18	54.9 (2.7)

et al. 1992; Dorf and Powell 1997; Arendt 1999; Meng et al. 2001; Able et al. 2005).

As juveniles, tautogs are known to have small home ranges. We previously determined that otolith microchemistry could be used as a tool to discriminate juvenile tautogs that inhabit different sites in Rhode Island waters (three in Narragansett Bay, two in coastal ponds) with a high degree of accuracy (Mateo et al. 2010). This constituted a baseline study so that future analysis of otolith cores of adults from the year-classes investigated might identify whether they were disproportionately recruited from certain habitats. In conjunction with that study, we wanted to know whether growth rates of juvenile tautogs from those sampling stations also differed. Thus, the purpose of this study was to evaluate growth within nursery areas for young-of-the-year (age-0) tautogs by using otolith microstructure. The specific questions that this study addresses are (1) are there differences in growth among age-0 tautogs in different nursery habitats, and (2) are spatial differences in the growth of age-0 tautogs within nursery areas consistent between years?

METHODS

Study Sites

Narragansett Bay.—Narragansett Bay covers approximately 260 km^2 and is characterized by a salinity range of about 24–30‰, an annual temperature range of 21–26°C, weak seasonal stratification, and depths of up to 40 m (Dorf 1994; Meng et al. 2000, 2001). Most of Rhode Island's population density and industry is around the Providence River, which flows directly into the West Passage producing an anthropogenic gradient from the upper to lower bay (Dorf 1994; Meng et al. 2000, 2001). Generally the upper bay is dominated by fine sediments and has poorer water quality than the lower bay (Dorf 1994; Meng et al. 2000, 2001).

In Rhode Island, age-0 tautogs were collected with from three sites in Narragansett Bay: Mount Hope Bay (MH), Gaspee Point (GP), and Rose Island (RS); one site in Point Judith Pond (PJ); and one site in Charlestown Pond (CP) (Figure 1). Collections were made in cooperation with Rhode Island Department of Environmental Management (RIDEM) Division Marine Fisheries during August and September of 2005 and 2006. Samples were collected with a 61 × 3.05-m beach seine deployed from a boat. Although sampling was conducted at GP in 2006, no age-0 tautogs were found there that year (see Tables 1 and 2 for the number per station per year). Gaspee Point is in the upper bay in the Providence River. It has the highest nitrogen concentrations owing to runoff from sewage treatment plants (Figure 1). Mount Hope Bay is located to the northeast of Narragansett Bay, with Rhode Island to the south and west and Massachusetts to the north and east. The Bay is the sink for the second largest watershed in Massachusetts, and has several important sources of human impact, including sewage disposal sites and the thermal outfall of the Brayton Point Power Plant within 2 km from of each other (Figure 1). Freshwater exchange with coastal marine waters occurs only through the passages connecting the Sakonnet River and Narragansett Bay. Finally, Rose Island is at the lower bay and the least affected by anthropogenic factors.

TABLE 2. Mean (SE) age (d) of juvenile tautogs in Rhode Island in 2005 and 2006, by station and year; *N* is the number of fish measured at each station.

	2005			2006		
Station	Sampling date	*N*	Age	Sampling date	*N*	Age
Gaspee Point	Aug 9	16	80 (2.9)	Sep 2–31	0	
Mount Hope Bay	Aug 5	14	93.3 (4.4)	Sep 29	15	93.6 (3.9)
Rose Island	Sep 8	15	82.8 (2.3)	Sep 21	11	90.19 (6.52)
Point Judith Lower Pond	Aug 19	13	96.1 (3.8)	Sep 18	12	98 (4.5)
Charlestown Pond	Aug 11	14	83.1 (1.5)	Sep 26	14	88.15 (5.51)

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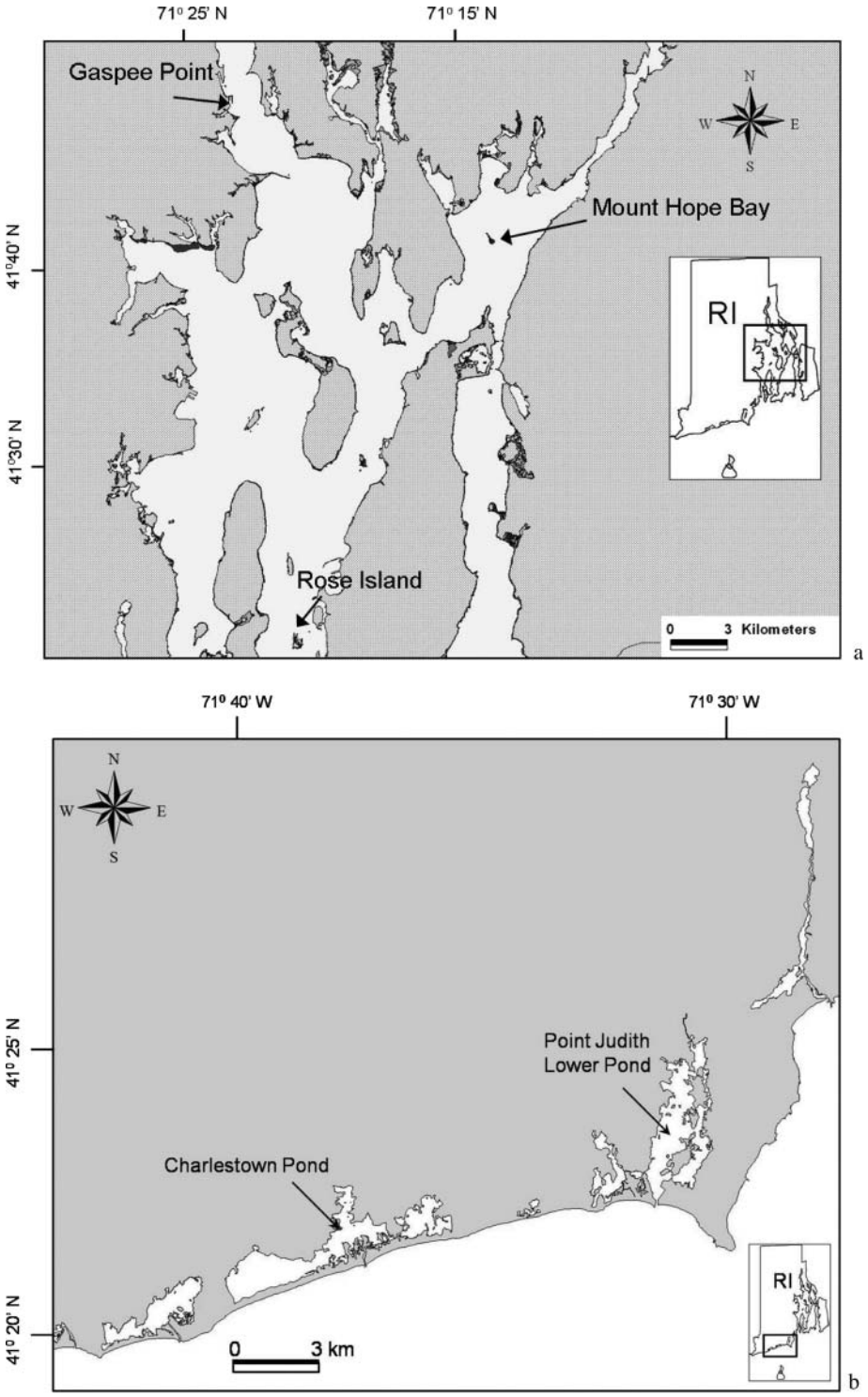


FIGURE 1. Locations of **(a)** sampling stations in Narragansett Bay and **(b)** two coastal ponds from which tautogs were collected in 2005 and 2006.

Rhode Island coastal ponds.—Charlestown and Point Judith ponds are some of Rhode Island's coastal lagoons located on the south shore of the state. These coastal ponds are connected to the Block Island Sound by a single, narrow, permanent, artificial breachway. Point Judith's watershed is the most developed pond owing to residential, industrial, and agricultural activities (Figure 1), and harbors most of Rhode Island's fishing fleet. Charlestown Pond covers 645 ha, has an

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average depth of 1.2 m, and a tidal range of 13.7 cm (Meng et al. 2000). The pond's temperature and salinity ranges are similar to those of Narragansett Bay and because the pond is shallow, it is well mixed. Charlestown Pond is considered one of Rhode Island's cleanest ponds. Although Charlestown Pond has moderate levels of residential development, many areas retain good water clarity, extensive eelgrass beds, and sandy substrates (Meng et al. 2000). All sites sampled were shallow (depths less than 1.5 m). Substrate at all sampling stations consisted primarily of medium to smooth hard bottom (gravel cobble) covered by varying densities of macroalgae (*Ulva lactuca*, *Codium fragile*, and *Gracilaria* spp.) and other filamentous and foliose green red and brown algae. Environmental data (temperature, salinity, dissolved oxygen) were recorded during the sampling period (May to October) by RIDEM Division Marine Fisheries with a YSI meter (Yellow Springs Instruments). Distances among stations within Narragansett Bay were from 14 to 27 km^2.

Otolith Microstructure

Before dissection, fish were weighed (wet weight in grams), and fork length (FL) and standard length (SL) were measured to the nearest 0.1 mm with digital calipers. Both lapillus otoliths were removed (sagittae were used for microchemistry work as part of another study), cleaned of adhering tissue, and stored dry in plastic vials. One lapillus was used for aging; the other one was used as a backup. The formation of daily increments in the sagitta and lapillus has been validated in recently settled tautogs (Sogard et al. 1992; Stremple 1992), and it is assumed that postsettlement increments are also deposited on a daily basis. The lapillus from each fish was mounted on a microscope petrographic slide with thermoplastic glue and ground to the core in the sagittal plane with fine 600-grit sandpaper and lapping film (30 and 3 μm). Otoliths were examined under an Olympus MX-51 transmitted-light microscope at 400× at the National Marine Fisheries Service Laboratory in Narragansett, Rhode Island. By means of Image-Pro image analysis software (Media Cybernetics 1998), daily increments were enumerated, and increment widths were measured along the anterior dorsal section of the otolith from the core to the outer edge on a straight line. We followed a standard protocol for reading and interpreting the otoliths (Searcy and Sponaugle 2001). First, all unclear, abnormally shaped (nonlinear growth axis) lapillus were discarded. A lapillus was read twice independently by the same reader. If the increment counts were within 5% of each other, one measurement was randomly selected for analysis (Searcy and Sponaugle 2001). If the increment counts differed by greater than 5%, the otolith was read again. If the increment counts from the third reading differed from the other readings by greater than 5%, the otolith was discarded. If the difference on the third count was less than 5% of one of the former readings, then one of these two measurements was randomly selected for analysis. By adopting this procedure about 80% of all otoliths collected were used for subsequent analysis.

TABLE 3. Mean otolith increment widths (μm) of juvenile tautogs by year and station for the postsettlement period (20–50 d); *N* is the number of individuals analyzed.

Station	*N*	Mean	SE
	2005		
Gaspee Point	16	6.85	0.36
Mount Hope Bay	14	8.98	0.19
Rose Island	15	6.76	0.14
Charlestown Pond	13	5.81	0.28
Point Judith Lower Pond	14	5.88	0.15
	2006		
Mount Hope Bay	15	9.66	0.31
Rose Island	11	9.39	0.52
Charlestown Pond	12	10.68	0.47
Point Judith Lower Pond	14	9.7	0.43

Otolith increment width was used as a proxy for fish growth, which is based on the assumption that there is a strong relationship between somatic and otolith growth (Thorrold and Hare 2002). Relationships between otolith length and age and FL were assessed with linear regression to test this assumption. Analysis of covariance (ANCOVA) was employed to determine slope differences in the relationships between otolith length versus FL and between age versus FL among years. A wide settlement mark after about 20 d has been previously documented in tautogs (Sogard et al. 1992; Dorf 1994). We observed such a mark in many of our fish, but it was not sufficiently clear in all fish that it could reliably provide a precise age at settlement (although the clear ones were centered around 20 d). Therefore, we adopted 20 d (i.e., the 20th ring) as the ending point for the larval growth period and the beginning of the postsettlement growth for all of our fish.

Given that daily growth data are autocorrelated because the same individuals are compared at different ages, and because otolith daily increment data taken on individual fish are longitudinal in nature (sequential measurements were made on each otolith examined), repeated-measures multivariate analysis of variance (MANOVA) was used to test for differences in growth trajectory among groups (Chambers and Miller 1995). For the MANOVA 30 sequential increments were measured for each fish per site per year (see Table 3 for number of samples per station for the analyses). Pillai's trace *V* was used as the test statistic since it is more robust than Wilks' λ in the case of unequal sample sizes and situations in which covariances are not homogeneous. Differences in growth trajectories during the postsettlement period from 20 to 50 d posthatch in tautog otoliths among stations (RS, MH, PJ, and CP) and years (2005, 2006) were assessed with a two-way repeated-measures MANOVA.

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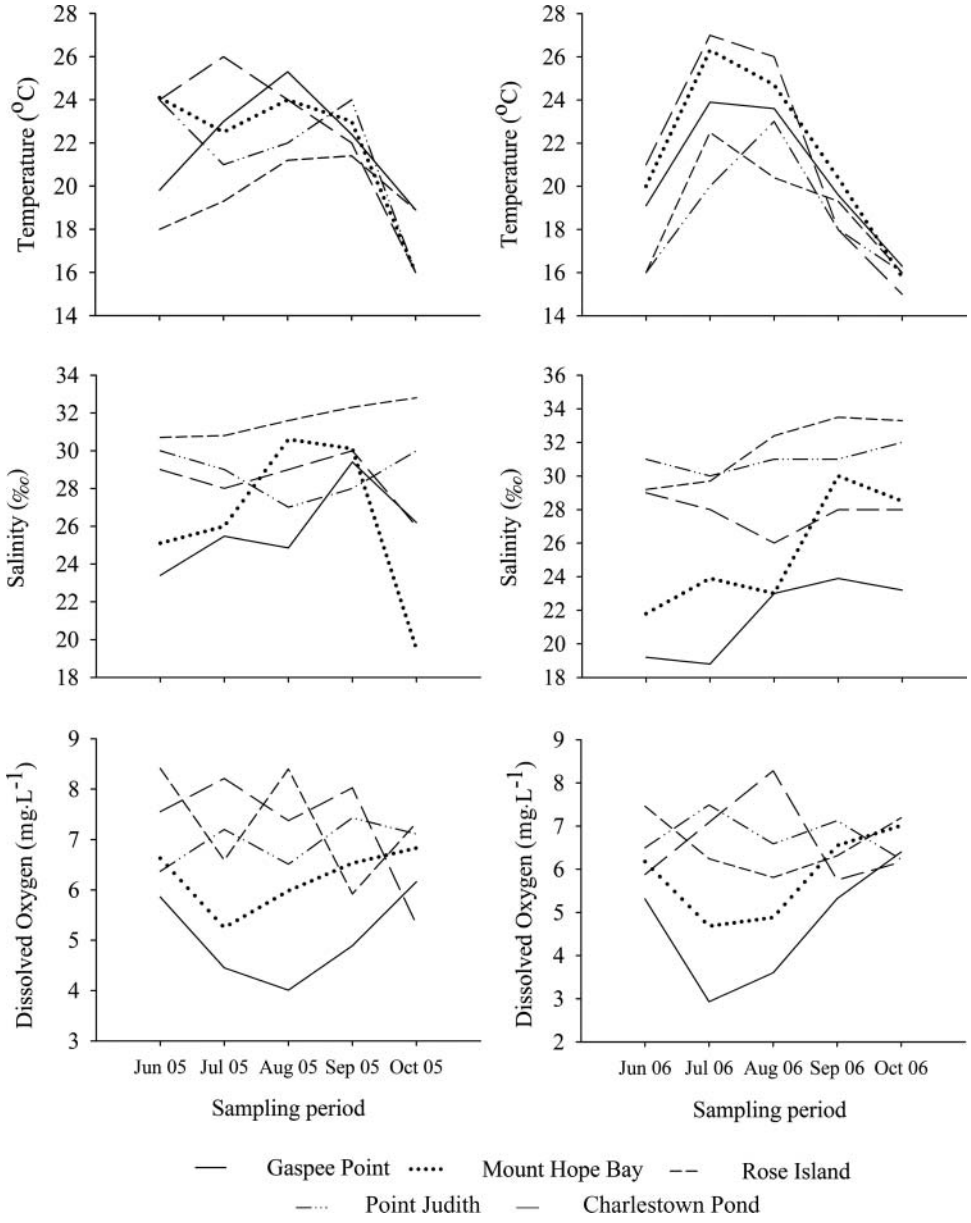


FIGURE 2. Monthly average temperature, salinity, and dissolved oxygen conditions in Narragansett Bay and the Rhode Island coast during sampling in May–October 2005 and 2006.

RESULTS

Environmental Conditions

Environmental conditions varied from site to site and possibly affected fish growth (Figure 2). Data from RIDEM show there were also significant differences in salinity regimes in these regions during the late spring and summer of 2005 and 2006 (H. Stoffel and J. McNamee, RIDEM, unpublished data). The proximity of Rose Island station to the mouth of Narragansett Bay meant that high salinities (up to 30‰) were observed (Figure 2). On the other hand, the lower-salinity stations within the upper region of Narragansett Bay are located much closer to the industrial area and watershed and therefore are potentially more prone to terrestrial influences from freshwater runoff resulting in reduced salinities (20–25‰). Average monthly surface temperatures and salinities during sampling periods at Gaspee Point for 2005 were 22°C and 24.9‰, and for 2006 were 20.6°C and 22.5‰. For Mount Hope Bay, average surface temperatures and salinities were 21.7°C and 27.0‰, and for 2006 were 20.5°C and 24.9‰. Rose Island average surface temperatures and salinities for 2005 were 19.6°C and 31.6‰, whereas for 2006 average surface temperatures and salinities were 17.4°C and 30.8‰. Salinities and temperatures among the two coastal ponds ranged from 26‰ to 29‰ and from 18°C to 24°C across years.

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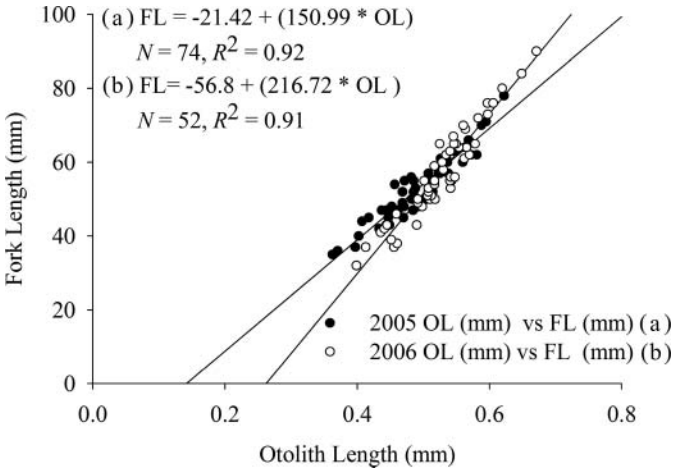


FIGURE 3. Linear regression of fork length (FL) on otolith length (OL) for tautogs collected in **(a)** 2005 and **(b)** 2006.

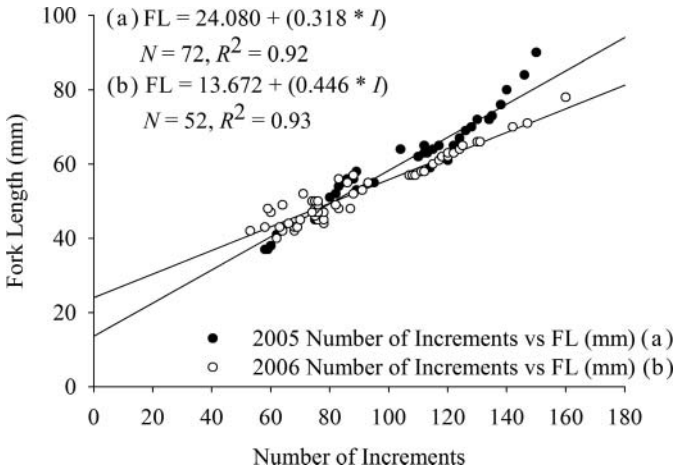


FIGURE 4. Linear regression of fork length (FL) on increment number (I) for tautogs collected in **(a)** 2005 and **(b)** 2006.

Dissolved oxygen (DO) varied the most among sites, which probably accounted for some of the variance in growth. At Gaspee Point, DO was lowest followed by that at Mount Hope Bay. Charlestown Pond and Gaspee Point and had the highest temperatures during the tautog growing season around July–August in 2005 and 2006, whereas Rose Island and Point Judith Pond had the lowest, possibly influencing the tautog growth rates.

Relationships between Fish Size, Otolith Size, and Age

A total of 164 age-0 tautogs with average sizes from 45 to 63 mm FL (Table 1) were collected in the 2 years combined. Data on mean ages across sites within each year are provided in Table 2. The otolith length (OL) of age-0 tautog otoliths had a positive linear significant relationship (least-squares linear regressions: $P < 0.001$) with FL for each of the 2 years, yielding coefficients of determination of 0.92 and 0.91 (Figure 3). Therefore, our assumption of a positive relationship between somatic and otolith growth was met over the size ranged sampled. Significant differences were found between the slopes of the otolith length–FL relationship from age-0 tautogs of 2005 and 2006 (ANCOVA: $F_{1,\,123} = 10.7$, $P < 0.001$). The relationship of age and FL was also significant (least-squares linear regression: $P < 0.001$), yielding determination coefficients of 0.92 and 0.93 (Figure 4). Significant differences existed between the slopes of the age versus FL relationship from age-0 fish of 2005 and 2006 (ANCOVA: $F_{1,\,121} = 8.37$, $P < 0.001$).

Otolith Microstructure

The average width of daily increments in age-0 (20–50-d) tautog otoliths ranged from 3 to 12 μm (Figure 5). Mean increment widths for 2005 and 2006 were 6.8 and 9.8 μm, respectively, for all stations combined. In 2005, fish from MH had the largest increment width (8.69 μm), whereas those from CP had the smallest increment width (5.81 μm). In 2006, fish from CP had the largest increment width (10.69 μm), whereas those from RS had the smallest increment width (9.4 μm) (Table 3). Growth trajectories were significantly faster in 2006 than in 2005 (repeated-measures MANOVA: $F_{30,\,77} = 6.96$, $P < 0.001$) but did vary not among stations (repeated-measures MANOVA: $F_{90,\,237} = 1.48$, $P = 0.292$). A significant interaction was found between year and station (repeated-measures MANOVA: $F_{90,\,207} = 1.504$, $P < 0.008$). In 2005, only the growth trajectories from MH were significantly faster than those from CP (Hotteling T-square = 123.18, $P = 0.007$).

DISCUSSION

This study is the first to document spatial variations in growth for the postsettlement period (20–50 d) for tautogs in estuarine habitats using otolith microstructure. Previous studies have documented spatial growth rates in tautogs, but most of these studies used caged individuals (Sogard et al. 1992; Able et al. 1999; Phelan et al. 2000). However, despite the advantages of caging studies in controlling recent environmental history, excluding predators, and controlling density, there are also difficulties associated with this approach (Peterson and Black 1994). Cages may concentrate or remove nektonic food sources resulting in a corresponding increase or decrease in growth. Artificial confinement of fish to a small area may also reduce perception of growth-based habitat quality if fish typically move over a much larger area to obtain food, or would ordinarily move to avoid poor water quality. Previous studies on age and growth of early juvenile tautogs have combined data from a few individuals from different stations without taking into consideration spatial differences in growth among sampling locations (Sogard et al. 1992; Dorf 1994).

Growth of juvenile tautogs and other juvenile fishes is affected by a number of factors in a nursery habitat. The major factors known to contribute to habitat quality are temperature, oxygen, salinity, predators, water depth, food, habitat structure, and hydrodynamics (Gibson 1994; Beck et al. 2001). Significant

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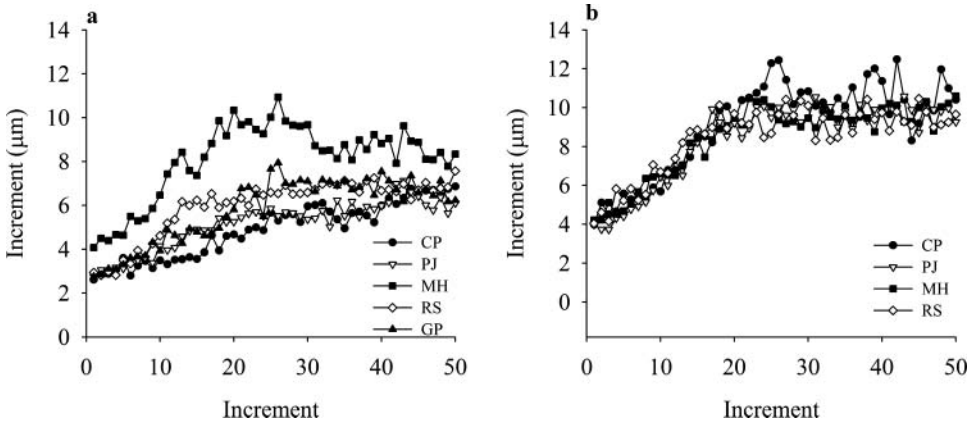


FIGURE 5. Relationships between average otolith increment width (μm) and number of increments for tautogs collected in **(a)** 2005 and **(b)** 2006. Station codes are as follows: GP = Gaspee Point, MH = Mount Hope Bay, RS = Rose Island, PJ = Point Judith Lower Pond, and CP = Charlestown Pond.

differences in the average temperatures among and within the estuaries were probably the cause of some of the variation in somatic growth rates of tautogs among stations within and among estuaries and between years. Spatial comparisons of the recent growth measured in age-0 tautogs in Narragansett Bay revealed consistent patterns in growth among nurseries. Individuals from the southernmost nursery of Narragansett Bay (RS) showed slower growth than individuals from the upper region of the bay. Meng et al. (2001) found similarly that the growth of winter flounder *Pseudopleuronectes americanus* was lower in Sheffield Cove in lower Narragansett Bay than at Gaspee Point in the upper region of Narragansett Bay. Data from RIDEM suggest that for 2005 temperatures from May to August averaged about 18°C in the lower regions of Narragansett Bay (Fort Wetherall), whereas in areas such as Gaspee Point and Mount Hope Bay, average temperatures were about 22°C and 24°C, respectively.

Gaspee Point and Mount Hope Bay are areas with high anthropogenic input from sewage, runoff, and power plant effluent discharges that may vary from year to year. Gaspee Point had the lowest DO among stations, but tautogs grew faster at this station in 2005, possibly because it had one of the highest temperatures among stations. However, we did not capture any fish in Gaspee Point in 2006, probably because DO values were extremely low. On the other hand, Charlestown Pond, which is one of the cleanest ponds, had higher temperature and DO values than the rest of the other sampling sites in both years, but exhibited large variability in the tautog growth trajectories. Fish in Charlestown Pond had the slowest growth in 2005, but the fastest growth in 2006.

Previous growth history as well as size-selective mortality may also influence interpretation of juvenile growth rates (Meekan and Fortier 1996; Searcy and Sponaugle 2001; Bergenius et al. 2002; Grorud-Colvert and Spounagle 2006; Searcy et al. 2007). For example, a variety of studies examining fish at the larval–juvenile transition have shown that faster-growing larvae may continue to grow rapidly as juveniles through competitive advantages gained in size-based dominance hierarchies (Forrester 1990; Booth 1995; Tupper and Boutilier 1997) and developmental advantages associated with relatively faster growth (McCormick and Molony 1992). It is unknown to what extent these larval traits influence the observed postsettlement juvenile tautog growth rates in our study. Searcy et al. (2007) suggested that growth rates may also be affected by mechanisms such as selective mortality of slower- (or faster) growing individuals and negative density dependence (i.e., lower growth at higher conspecific densities). Incorporation of selective mortality into growth-based studies is important because the removal of either slower- or faster-growing individuals from the population will bias interpretation of overall cohort growth. We acknowledge that we used survivors to hindcast growth rates and assumed that there was no bias to survival that would have led to a biased depiction of past growth.

This study demonstrates that there can be significant variability in short-term growth for juvenile tautogs within and among estuaries. This variability in growth rates may change from year to year potentially affecting interpretation of growth. A future analysis of otolith cores from adult tautogs may be able to use juvenile growth as an explanation for any disproportionate recruitment of tautogs from the various habitats sampled in this study.

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