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Movements and growth of tagged young-of-the-year Atlantic croaker (*Micropogonias undulatus* L.) in restored and reference marsh creeks in Delaware Bay, USA

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Abstract

The residence time, movements, and growth of tagged young-of-the-year Atlantic croaker, *Micropogonias undulatus* L., were studied from July to October 1998 as measures of the success of a marsh restoration project adjacent to Delaware Bay. A total of 8173 croaker (41–121 mm SL) were tagged from each of two creeks in both marshes during July and August with internal sequential coded wire microtags. A prior tag-retention study in the laboratory found a 95% tag retention rate. Of those tagged, 3.6% were recaptured within and nearby the study creeks using seines, otter trawls, and weirs during a 105-day period. Recapture percentages ranged from 1.5% to 6.1% in individual creeks in the restored marsh. There was some movement of tagged fish between creeks in the restored marsh and out into the main creek, but 95% of the recaptures were made in the subtidal and intertidal portions of the same creek in which they were tagged. Fewer fish were recaptured at the reference marsh (1.6% recapture; $n = 1489$ tagged) up to 50 days after tagging, with no evidence of movement between creeks. The average individual growth rates for recaptured croaker was the same in both restored (0.69 mm/day) and reference (0.63 mm/day) marshes before egress from the creeks in September and October. As a result, both created creeks in a restored marsh and natural creeks in a reference marsh appeared to be utilized as young-of-the-year habitat in a similar way during the summer and until egress out of

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the marshes during the fall, thus this restoration effort has been successful in creating suitable habitat for Atlantic croaker.

Keywords: *Micropogonias undulatus*; Atlantic croaker; Marsh restoration; Tag-recapture; Residence; Movement; Growth; Delaware Bay

1. Introduction

The Delaware Bay Marsh Restoration Program is one of the largest marsh restoration efforts in North America and was designed in part to restore marsh habitats for young-of-the-year (YOY) and juvenile fishes in Delaware Bay (Weinstein et al., 1997). A primary component of this effort was to open up areas previously closed off to normal tidal flow and to create new creeks. These created creeks were cut into old salt hay farms that were diked for the production of salt hay (*Spartina patens* [Ait.] Muhl.), and then were restored to normal tidal flow and vegetation (*S. alterniflora* Loiseleur). This has opened up large areas of previously inaccessible marsh for potential use by a wide variety of seasonally transient YOY fishes including the Atlantic croaker (Able et al., 2000, submitted for publication).

Young-of-the-year Atlantic croaker, *Micropogonias undulatus* L., are often common components of the fish fauna of tidal creeks in salt marshes (Knudsen and Herke, 1978; Weinstein, 1979; Bozeman and Dean, 1980) and in estuaries (Haven, 1957; Hansen, 1969; Ross, 1988) throughout their range along the east coast of North America and in the Gulf of Mexico. They enter estuarine habitats in the Middle Atlantic Bight in August through October (Chao and Musick, 1977; Ross, 1988; Miller et al., submitted for publication). During fall egress, the larger individuals appear to leave salt marsh habitats earliest (Yakupzack et al., 1977), and in Delaware Bay the entire year class is typically gone from the marshes by November (Miller et al., submitted for publication).

Many of the above surveys have provided a general understanding of how YOY Atlantic croaker use estuarine habitats, but little is known about the movements, growth and habitat utilization patterns of individuals. However, mass marking of YOY Atlantic croaker with fluorescent pigments has been used to study the general movements and growth in a semi-impounded marsh area in Louisiana (Arnoldi et al., 1974; Knudsen and Herke, 1978) and to study the residence times and population dynamics of another sciaenid species, spot, *Leiostomus xanthurus* Lacepède, in tidal creeks in Virginia (Weinstein, 1983; Weinstein et al., 1984; Weinstein and O'Neil, 1986).

This study was designed to test the hypothesis that YOY Atlantic croaker use the created creek habitats in the restored marsh in the same way as they use natural tidal creeks in a reference marsh area, and is the first study to directly examine the individual movement patterns and growth rates of YOY Atlantic croaker. These objectives were designed to improve our understanding of habitat function, and in the process, compare these parameters between restored and reference marshes.

1.1. Study design

To test the hypothesis that YOY Atlantic croaker use restored and natural marshes in the same way, tag and recapture experiments were performed in tidal creeks in both types of marshes. Two created creeks were chosen as study creeks in a restored marsh that was a former salt hay farm (Dennis Township), and two natural tidal creeks were

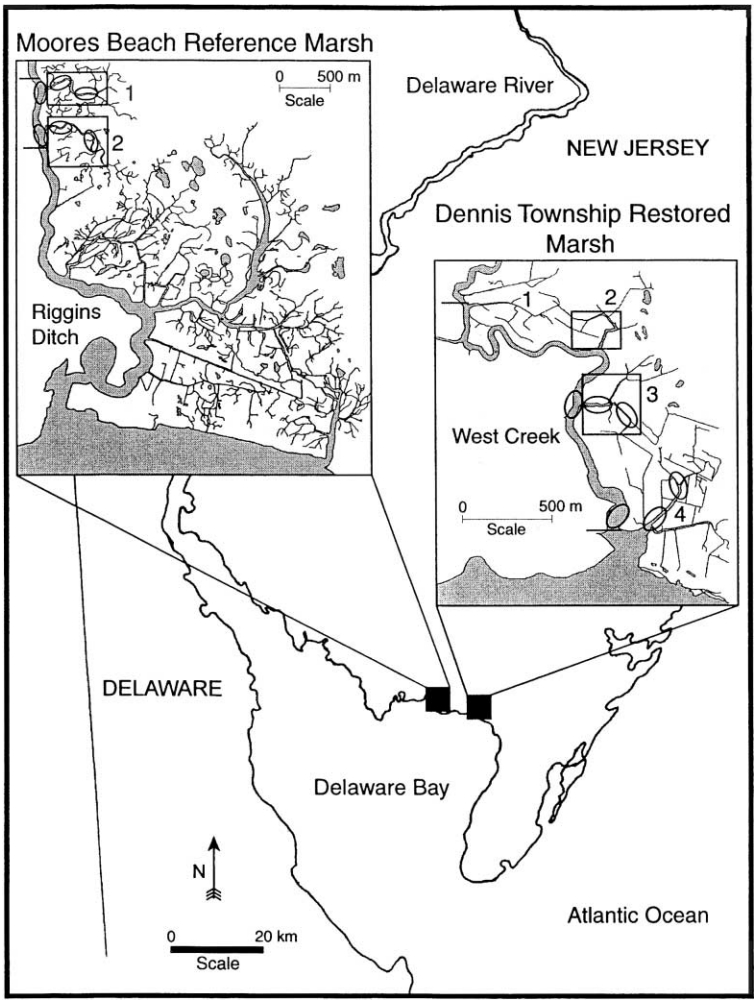


Fig. 1. Map of the study areas and the specific marsh creeks in the Moores Beach reference marsh (Creeks 1 and 2) and the Dennis Township restored marsh (Created Creeks 2 and 3) where young-of-the-year Atlantic croaker were tagged and recaptured (within the rectangles). The range of trawling for recaptures within Riggins Ditch and West Creek is indicated by lines across the creeks, and the monthly trawling sites for a simultaneous study are shown with ovals. All four created creeks at the Dennis Township site where trawling for recaptures occurred are labeled.

chosen in a reference marsh (Moores Beach). Fish were captured in each creek, tagged with coded wire microtags and released back into the same creek. A separate study was performed on the same-sized fish held in tanks to determine the tag retention and tagging mortality rates after tagging. Fish in the tidal creeks were tagged on five or six dates and then the creeks were seined and trawled for tagged fish until all the YOY had apparently moved out of the creeks in the fall. However, tagging efforts in one creek in the reference marsh were abandoned early into the experiment due to the difficulty in collecting enough fish for tagging, but the creek was still trawled to check for tagged fish. A long-term marsh creek fish monitoring survey (Able et al., 2000, submitted for publication) was sampling simultaneously during the study period. This survey consisted of sampling with otter trawls and with weirs set across small intertidal creeks at several sites within the study creeks and in adjacent creeks (Fig. 1) and all fish caught during this survey were checked for tags. Based on returns of individual tagged fish, we determined their residence times, movements, and growth rates in both the restored and reference marshes.

1.2. Study areas

The Moores Beach reference marsh and the Dennis Township restored marsh are located in the mesohaline portion of lower Delaware Bay on the New Jersey side of the bay (Fig. 1). Moores Beach study Creeks 1 and 2 have an extensive dendritic pattern of small tributary creeks and are located in an area with natural creek drainage at the northern edge of an approximately 550 hectare (ha) site. At the 227 ha Dennis Township restored marsh site, a series of channels or "created creeks" were cut into the marsh and the dikes of the salt hay farm were broached in August 1996 (Weinstein et al., 1997) to help provide the proper hydroperiod for revegetation by *S. alterniflora* and to provide habitat for fishes. The channels of created creeks 2 and 3 are about 6–10 m wide and have a depth range of 2–3 m at high tide. The main channels of the two study creeks at the reference site have similar depth ranges, salinities, water temperatures and dissolved oxygen (Table 1) as the created creeks at the restored marsh but have slightly narrower (6–8 m) main channels. The upper reaches of all the creeks in both marsh areas are intertidal. The creeks in both study areas drain into similar-sized larger natural creeks (West Creek at Dennis Township and Riggins Ditch at Moores Beach) that drain directly into Delaware Bay.

Table 1
Environmental characteristics of the restored (Dennis Township) and reference marsh (Moores Beach) in 1998

Study areas	Area (ha)	Dominant vegetation cover	Average and range of surface temperature (°C)	Average and range of surface salinity (‰)	Average and range of surface DO (mg/l)
Restored marsh	227	Sa, Sp	23.4 (15.2–29.2)	16.5 (13.7–21.1)	4.9 (1.6–8.0)
Reference marsh	550	Sa, Sp	23.2 (16.8–29.3)	17.8 (17.0–21.0)	5.0 (0.05–8.9)

The surface temperature, salinity, and dissolved oxygen measurements in each study area were averaged over April to November. The ranges are only for measurements made within the creeks where Atlantic croaker were marked and recaptured from July to October. DO = dissolved oxygen, Sa = *Spartina alterniflora*, Sp = *Spartina patens*.

2. Methods

2.1. Tag retention and mortality

A tag retention study was performed from 6 July to 10 August 1998 to determine tag retention and mortality rates. Two hundred YOY (51–94 mm standard length [SL]), collected from Delaware Bay marshes, were transported to the Rutgers University Marine Field Station and held for 6 days to allow them to acclimate to captivity before being tagged. Three groups of 50 fish were measured to the nearest millimeter and injected with a 1.1 mm coded wire microtag using a Northwest Marine Technology hand-held multishot coded wire tag injector. The tag was injected into the muscle tissue of the nape anterior to the dorsal fin and posterior to the head. The tagged fish were then placed in three separate outdoor 91 × 61 cm circular tanks with flow-through seawater at ambient temperature. Another 50 fish were measured and placed in a fourth tank as controls. Fish were fed either chopped squid or silversides, *Menidia* sp., once daily. After the first week, all the fish were retrieved from each tank, and tested individually with a tag detector to check for tag retention. The control fish were handled in the same manner. This procedure was repeated each week for 5 weeks. At the end of this period, all the fish were measured to determine how much each group of fish had grown.

2.2. Tag and recapture

For the field tag and recapture study from July–October 1998, fish were collected from the study creeks with a 10.3 × 1.4 m bag seine (6 mm stretched mesh) during low tides and placed in coolers and transported to adjacent land-based areas for tagging. After tagging they were transported back to the stretch of creek from which they were

Table 2
Numbers and size ranges of young-of-the-year Atlantic croaker tagged, estimated number retaining tags based on the tag retention and mortality study, and number recaptured of those tagged in each created creek at the restored marsh (Dennis Township) and at the reference marsh (Moores Beach)

Study areas	Tagging period	Number tagged	Sized range tagged (mm SL)	Estimated number retaining tag	Number recaptured	Size range of recaptures (mm SL)	Recapture percent
Restored marsh							
Creek 2	15 Jul–31 Aug	3651	50–117	3432	209	59–147	6.1
Creek 3	2 Jul–17 Aug	3033	41–121	2851	44	65–123	1.5
West Creek	–	–	–	–	(7)	84–133	–
Reference marsh							
Creek 1	17 Jul–13 Aug	1414	57–117	1328	21	68–106	1.6
Creek 2	3–4 Aug	65	79–109	61	0	–	0
Riggins Ditch	–	–	–	–	(0)		0

The number of those recaptures that were made in the larger adjacent creeks are in parenthesis.

collected, or to a central location if fish were collected from different stretches of a creek. During tagging (Table 2), fish were measured to the nearest millimeter SL and then injected with a coded wire tag in the nape area as they were in the tag-retention study. Reference tags were saved in silicone strips on the data sheets before and after the tag injected into each fish to enable identification of individuals upon recapture by matching the code sequences of the tags from the recaptured fish with those in the data sheets. At Reference Creek 2, the catch rate was so low that further efforts to tag fish there were abandoned after early August.

Recapture efforts occurred in a variety of ways in the creeks in which fish were tagged, in other created creeks at the restored marsh and in the larger creeks adjacent to each of the tagging sites (Fig. 1, Table 2). Seining was used to recapture fish at low tide, while otter trawling and weirs were used during high tide. Trawling with a 4.9-m otter trawl (6-mm stretched cod end mesh) was used to evaluate the distribution of tagged fish in the study creeks, in Created Creeks 1 and 4, and from the mouth of West Creek up to Created Creek 1 in West Creek and in Riggins Ditch between the two reference creeks at Moores Beach (Fig. 1). In addition, other otter trawling at fixed sites, which was part of a larger sampling program (Able et al., submitted for publication; Miller et al., submitted for publication), occurred in all but one of the study creeks, in the adjoining larger creeks (West Creek and Riggins Ditch) and in the Created Creeks 1 and 4 at the restored marsh at Dennis Township (Fig. 1). Also, each month weirs were set across small intertidal creeks in the upper reaches of Reference Creek 1 and Created Creek 3 from July to October, 1998. These weirs were $2.0 \times 1.5 \times 1.5$ m, with 5.0×1.5 m wings and 6.0 mm stretched mesh. Hydrological measurements were made at the beginning and end of most collections or recapture efforts using a hand held temperature, salinity and dissolved oxygen meter.

Recaptured fish were measured to the nearest millimeter SL before preservation, but a few were fixed in 95% ETOH in the field prior to measurement and later adjusted for shrinkage based on a regression of fresh to preserved lengths ($N = 90$, 70–120 mm SL, $y = 0.65 + 1.045x$, $r^2 = 0.97$). Tags were subsequently dissected out, read with a dissecting microscope and their sequence numbers were matched to individual tagged fish. Individual growth rate estimates were calculated by dividing the increase in length of each fish by the number of days between tagging and recapture for fish recaptured at least 3 days after tagging.

3. Results

3.1. Tag retention and mortality

The laboratory tag retention and mortality study for YOY Atlantic croaker (51–94 mm SL) found that 95% of 150 tagged fish retained their tags after 35 days and that there was only one mortality associated with tag injection. Three fish (68–90 mm SL) lost their tags in the first week, four (78–88 mm SL) lost them in the second week, and one (100 mm SL) lost its tag in the fifth week. The three tagged fish that died during the duration of this study all had severe caudal fin rot. Because only one of these had a

wound caused by the needle of the tag injector, the other two mortalities were not considered to be directly tagging related. Therefore, total tag loss due to loss of individual tags and mortality was assumed to be 9 fish out of 150, or 6%, and the number of tagged fish released in the field was reduced by 6% when calculating final recapture percentages. Tagging did not appear to have a significant effect on the growth of the tagged fish compared to the controls during the 35 days of this study. The total lengths of the three groups of tagged fish and the control group were not significantly different at the beginning (ANOVA, $p = 0.8$) or at the end of the experiment (Kruskal–Wallis test, $p = 0.3$). The increase in the average lengths of each group of fish indicated average daily growth rates of 0.52 mm/day for the controls and 0.45–0.54 mm/day for the three groups of tagged croaker.

3.2. Tag and recapture

A total of 8173 YOY Atlantic croaker ranging in size from 41–121 mm SL (Fig. 2) were tagged from early July to mid-August in the four study creeks at both restored and

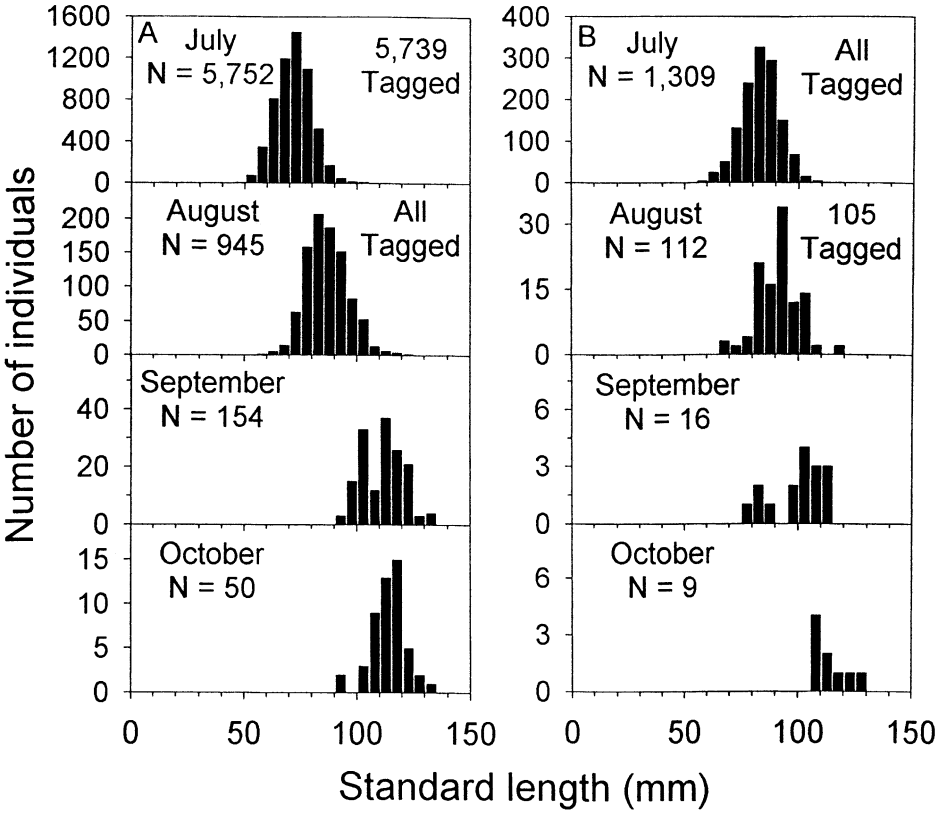


Fig. 2. Length frequency distributions for tagged and untagged young-of-the-year Atlantic croaker caught from July to October at (A) the Dennis Township restored marsh and at (B) the Moores Beach reference marsh in 1998.

reference sites and 280 (3.6% of those tagged) were recaptured through early October when most fish were moving out of the creeks (Table 2). The highest recapture percentage was in Created Creek 2 at the restored marsh (Dennis Township), where 209 (59–147 mm SL) or 6.1% of the 3432 individuals estimated to retain their tags were recaptured between 15 July and 15 October. Recaptures were made of at least one group of fish tagged in Created Creek 2 on 13 consecutive sampling dates (Table 3). Fish from all five tagging dates were recaptured on 1 October, which was the last day any fish were caught in Created Creek 2. In Created Creek 3, there were fewer recaptures and fewer fish caught in general after early July (Table 4). There were a total of 44 (65–123 mm SL), or 1.5% of the 2851 tagged fish from Created Creek 3 recaptured between 2 July and 4 September (Fig. 2). At the Moores Beach reference marsh a total of 21 (68–106 mm SL), or 1.6%, of the 1424 tagged fish from Reference Creek 1 were recaptured there between 17 July and 13 October (Table 5). None of the 65 croaker tagged in Reference Creek 2 were recaptured on six different sampling dates (Table 2).

Table 3
Summary of tagging and recapture of Atlantic croaker in Created Creek 2 at the Dennis Township restored marsh during 1998

Sampling dates	Recapture method	Tagging dates					Total recaptures	Total caught
		15 Jul	16 Jul	14 Aug	17 Aug	31 Aug		
15 Jul	Seining	(1717)						1717
16 Jul	Seining	10	(1108)				10	1118
24 Jul	Trawling	5	2				7	98
31 Jul	Seining	31	16				47	1500[a]
7 Aug	Seining	16	13				29	1000[a]
11 Aug	Trawling	1					1	11
14 Aug	Seining	11	5	(460)			16	478
17 Aug	Seining	2	7	15	(171)		24	195
31 Aug	Seining	1	6	16	13	(195)	36	231
4 Sept	Seining WC	1[b]		2[bb]			3	–
10 Sept	Trawling			1		2	3	17
14 Sept	Seining			6	1	4[b]	11	30
24 Sept	Trawling	2		2	2	1	7	31
1 Oct	Seining	1	3[b]	5[c]	3	3	15	74
9 Oct	Trawling							0
15 Oct	Seining							0
Total		81	52	48	19	10	209	~6500
Recapture %		5.0	5.0	11.2	11.8	5.5	6.1	

The numbers of fish tagged on each tagging date are in parentheses. Recaptures were made while collecting fish for tagging (seining) or during recapture efforts (seining or trawling). Recapture percentages are calculated based on the number of tagged fish estimated to survive and retain their tags. Untagged fish collected outside of Creek 2 are not included in the totals. Six additional tagged fish were recaptured in Creek 2 (not shown), but their tags were unreadable. WC = West Creek.

[a] Total number of fish was estimated to avoid mortality of unmarked fish.

[b] Indicates a fish that was recaptured in West Creek.

[c] Indicates a fish that was recaptured in Created Creek 3.

Table 4
Summary of tagging and recapture of Atlantic croaker in Created Creek 3 at the Dennis Township restored marsh during 1998

Sampling dates	Recapture method	Tagging dates						Total recapture	Total caught
		2 Jul	7 Jul	8 Jul	13 Jul	14 Jul	17 Aug		
2 Jul	Seining	(468)							468
7 Jul	Seining		(1148)						1156
8 Jul	Seining	5	1	(1199)				6	1208
10 Jul	Trawling	2[a]	1					3	110
13 Jul	Seining		1	1	(49)			2	51
14 Jul	Seining	1	1	1		(50)		3	53
15 Jul	Weir/seining D2	2[b]	1	1				4	202
16 Jul	Seining D2	1[b]						1	–
20 Jul	Trawling		2	2				4	58
22 Jul	Seining		1	1				2	192
24 Jul	Trawling			2		1		3	156
31 Jul	Seining D2				1[b]	2[bb]		3	–
7 Aug	Seining	1	1	3				5	450
17 Aug	Seining	1[b]			1[b]		(119)	2	119
4 Sept	Seining		2[a]	1			3	6	68
11 Sept	Trawling								6
24 Sept	Trawling								5
1 Oct	Seining								6
9 Oct	Trawling								0
15 Oct	Seining								1
Total		13	11	12	2	3	3	44	4309
Recapture%		2.8	0.9	1.0	4.1	1.7	2.5	1.5	

The numbers of fish tagged on each tagging date are in parentheses. Recaptures were made while collecting fish for tagging (seining) or during recapture efforts (seining or trawling). Untagged fish collected outside of Creek 3 are not included in the totals. WC = West Creek, D = Dennis Creek.

[a] Indicates a fish that was recaptured in West Creek.

[b] Indicates a fish that was recaptured in Dennis Creek 2.

3.3. Residence time and movements

Many YOY Atlantic croaker appeared to remain within the same tidal creek in which they were tagged in both the restored and reference marshes until seasonal egress. The numbers of fish caught dropped off markedly in the second half of August and decreased through September until only seven fish were caught in any of the study creeks after 1 October (Tables 3, 4 and 5). The vast majority (95%) of the recaptures were caught in the same creek in which they were tagged (subsequently referred to as their home creek) into September in Created Creek 3 and Reference Creek 1 and into early October in Created Creek 2. The home creek fidelity for recaptured fish that were tagged in Created Creek 2 was 97%, and those 203 recaptures were made after they had been at large for 1–78 days (Fig. 3), with the last 14 recaptures being made on 1 October. The home creek fidelity for recaptures of Created Creek 3 fish caught from 1 to 59 days after tagging was 79% (Fig. 3), with the last four recaptures being made on 4 September. All of the recaptures of Reference Creek 1 fish were made in their home creek from 11 to 50 days after tagging

Table 5
Summary of tagging and recapture of Atlantic croaker in Creek 1 at the Moores Beach reference marsh during 1998

Sampling dates	Recapture method	Tagging dates					Total recaptures	Total caught
		17 Jul	29 Jul	30 Jul	12 Aug	13 Aug		
17 Jul	Tagging	(458)						458
29 Jul	Tagging		(106)				7	106
30 Jul	Tagging	7		(745)			4	752
10 Aug	Weirs	1		3			2	17
12 Aug	Tagging	1		1	(54)		2	57
13 Aug	Tagging			2		(51)		54
25 Aug	Trawling		1	1			2	11
3 Sept	Seining		1	1		1	3	12
18 Sept	Trawling			1			1	8
30 Sept	Seining							0
8 Oct	Trawling							6
13 Oct	Seining							0
Total		9	2	9	0	1	21	1491
Recapture %		2.0	2.0	1.3	–	2.1	1.6	

The numbers of fish tagged on each tagging date are in parentheses. Recaptures were made while collecting fish for tagging (seining) or during recapture efforts (seining or trawling).

(Fig. 3), with the last recapture being made on 18 September. Therefore, tagged fish were among those present in all three creeks until most or all YOY croaker had moved out of the creeks (Tables 3, 4 and 5). Egress of some of the largest YOY probably began in August and was completed in September and early October when water temperatures dropped to 15–19 °C after ranging from 22 to 29 °C during July, August and September.

The movements within their home creeks indicated that some fish used the entire extent of the tidal creeks, including both subtidal and intertidal habitats. Because most of the tagged fish were originally caught in the lower subtidal reaches of each creek during low tide, recaptures during high tide trawling, in the weirs, or during seining on the rising tide in the intertidal zone indicated that at least some individuals moved into the upper reaches of the creeks and into the small tributaries close to the marsh surface during high tide. In the restored marsh, there were 18 recaptures made in the intertidal zone of Created Creek 2 and at least five in Created Creek 3 (Fig. 4). Three of the five recaptures in the intertidal zone of Created Creek 3 were among the 256 total individuals caught in the high tide weirs across two small intertidal tributaries. In the reference marsh, there were five fish collected in the intertidal zone, four of which were caught among the 29 caught in the weirs in Reference Creek 1.

Fish that did move between creeks typically moved from Created Creek 3 to Created Creek 2 at the restored marsh. There were seven tagged fish from Created Creek 3 that were recaptured in the lower reach of Created Creek 2 from 8 to 47 days after being tagged (Fig. 4). These were recaptured at distances between 685 and 770 m away from the release site. The one fish from Created Creek 2 that moved into Created Creek 3 was caught 48 days later in the southern-most branch of Created Creek 3 and was one of the longest movements (between 710 and 815 m) observed during this study (Fig. 4). Five other fish

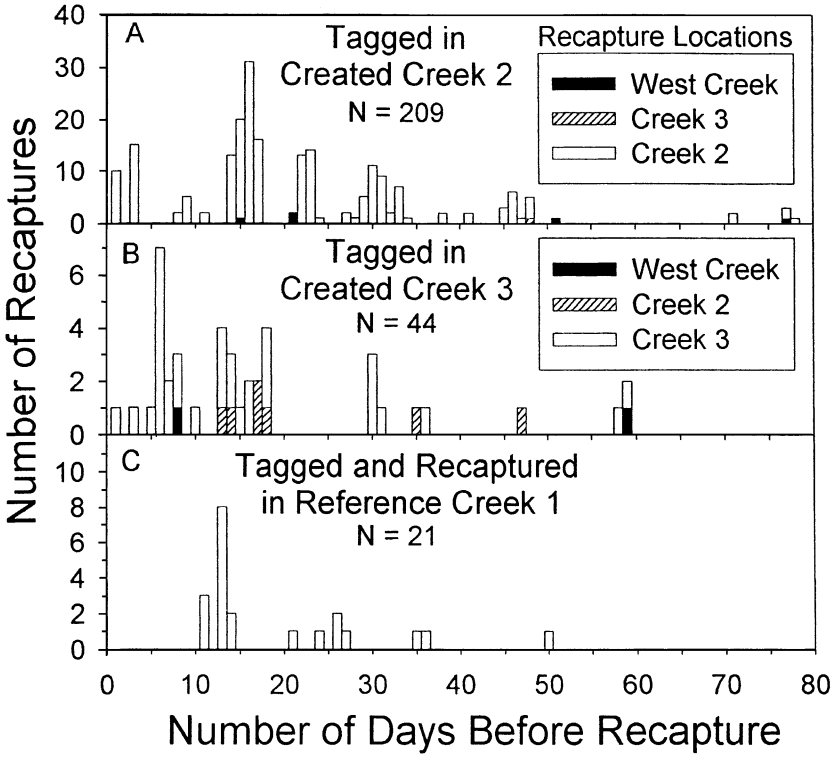
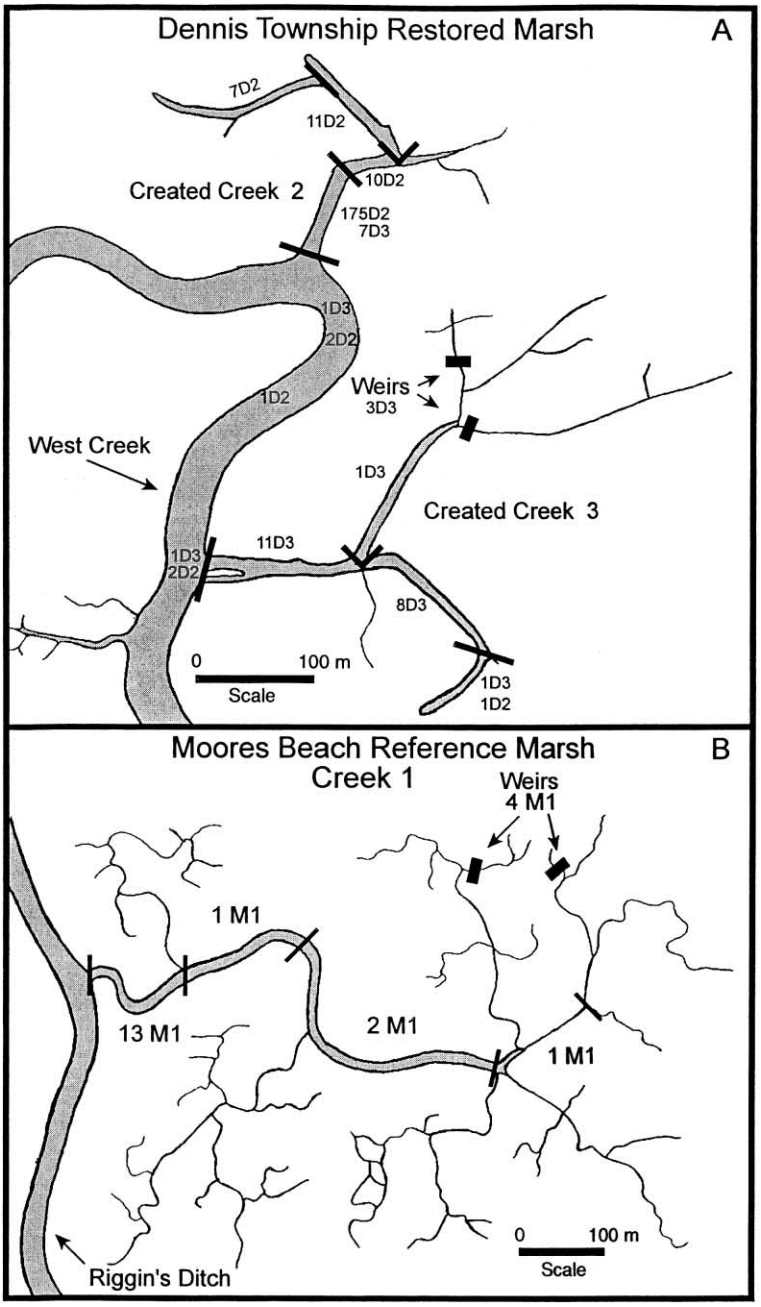


Fig. 3. The number of days before recapture and recapture locations of young-of-the-year Atlantic croaker tagged in Created Creeks 2 and 3 at the Dennis Township restored marsh site and at Creek 1 at the Moores Beach reference marsh between July and October 1998. See Fig. 1 and Fig. 4 for locations of creeks.

from Created Creek 2 were caught during the September and October low tide seining in West Creek, between 95 and 240 m downstream of the mouth of Created Creek 2 (Fig. 4). The only recapture among the 755 croaker collected in West Creek during otter trawling from July to October ($n=93$ tows) was a fish from Created Creek 3 that was collected between 250 and 700 m upstream, closer to the mouth of Creek 2. Trawling in the other Created Creeks 1 and 4 at the Dennis Township site (Fig. 1) collected 35 and 424 individuals in 12 and 41 tows, respectively, none of which had been tagged. Similarly, no tagged individuals were among the 314 YOY that were collected in 62 trawls in Riggins Ditch or among the 37 individuals in 75 tows in Reference Creek 2 at Moores Beach.

3.4. Growth rates

The individual average daily growth rates of YOY recaptured 3–78 days after tagging in all three creeks showed a mode of 0.6–0.7 mm/day (Fig. 5) and were similar between the restored and reference marshes. The overall average growth rate was 0.68 (0–1.4) mm/day for all recaptures. The average for the fish that were recaptured 40–78 days after tagging was slightly higher at 0.74 (0.43–1.0) mm/day. The latter growth rates were


Dennis Township Restored Marsh
A
7D2
11D2
10D2
Created Creek 2
175D2
7D3
1D3
2D2
1D2
Weirs
3D3
West Creek
1D3
Created Creek 3
11D3
1D3
2D2
8D3
0
100 m
Scale
1D3
1D2
Moores Beach Reference Marsh
Creek 1
B
Weirs
4 M1
1 M1
13 M1
2 M1
1 M1
0
100 m
Scale
Riggin's Ditch

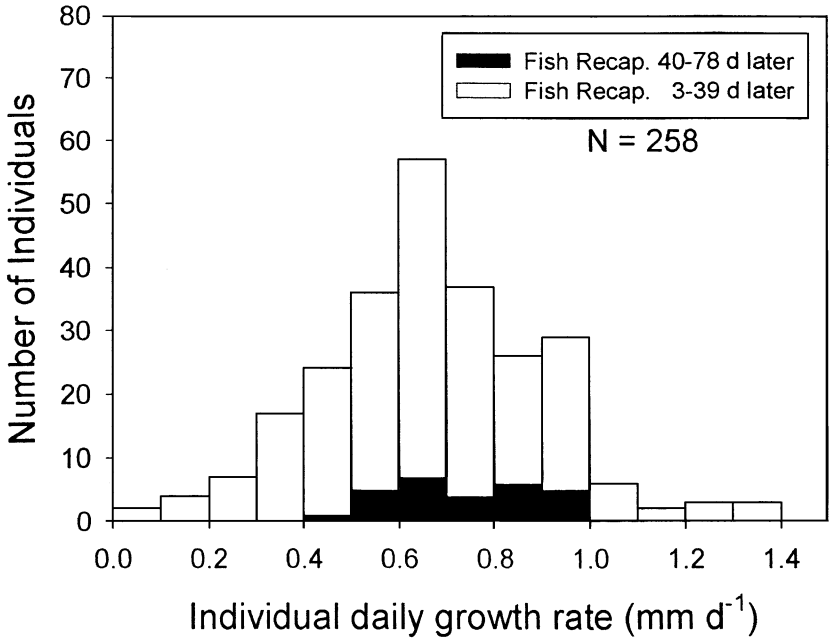


Fig. 5. Frequency distribution of the individual daily growth rates of young-of-the-year Atlantic croaker that were recaptured 3–39 or 40–78 days after being tagged in tidal creeks in both the restored reference marshes.

probably the best estimates, because 73% of the recaptures had growth rates within the range of 0.51–1.0 mm/day. The average growth rates of the 16 individual groups of tagged fish in the two study areas ranged from 0.45 mm/day at Moores Beach to 0.96 mm/day at Created Creek 3. However, the overall growth rates at each site were not significantly different (Kruskal–Wallis test, $p = 0.07$) among Created Creek 2 (0.68 mm/day) and Created Creek 3 (0.74 mm/day) at the restored marsh (combined = 0.69 mm/day), or at Reference Creek 1 (0.63 mm/day).

4. Discussion

4.1. Evaluation of tagging and recapture techniques

This is the first study to use coded wire microtags with Atlantic croaker, and the relatively high tag retention and recapture rates suggest this is a good technique for

Fig. 4. Location and number of recaptured young-of-the-year Atlantic croaker (A) tagged in Created Creek 2 (recaptures indicated by D2) and Created Creek 3 (recaptures indicated by D3) in the Dennis Township restored marsh (11 additional recaptures made throughout Created Creek 3 during collection of fish for tagging are not shown) and (B) in Reference Creek 1 (recaptures indicated by M1) at the Moores Beach reference marsh. The boundaries of creek sections where the number of recaptures are listed are indicated by the black bars.

studying the YOY of this species. The rates of tag retention and survival found in this study is about as high or higher than in tag retention studies using coded wire microtags with red drum, *Sciaenops ocellatus* (L.), (Bumguardner et al., 1990; Szedlmayer and Howe, 1995), striped bass, *Morone saxatilis* (Walbaum), (Klar and Parker, 1986; Dunning et al., 1990) and common snook, *Centropomus undecimalis* (Bloch), (Wallin et al., 1997). The advantages of using sequential code wire microtags with small fish are that each tagged fish can be identified when recaptured, enabling individual movement and growth data to be obtained, without the potential behavioral effect of an increased threat of predation or without the reduction in swimming efficiency that might be associated with external tags (Serafy et al., 1995). Previous studies with YOY Atlantic croaker in semi-impounded marsh areas in Louisiana used fluorescent pigments to mark over 200,000 fish combined, but had less than 200 recaptures (Arnoldi et al., 1974; Knudsen and Herke,1978).

Recapture rates were variable between individual creeks and these rates may have varied as the result of disturbance from other ongoing studies, or differences in sampling efficiencies among creeks. The highest recapture rates for fish in Created Creek 2 may partly be due to the greater number of fish that were consistently caught and tagged in August. This resulted in a very high proportion of recaptures (up to 36%). However, in Created Creek 3, the lower numbers of tagged and untagged fish caught after early July and the increased amount of movement into Created Creek 2, suggested that disturbance within Created Creek 3 may have caused some proportion of fish using that creek to move to other areas. The additional sampling activity in Created Creek 3 was associated with other simultaneous studies in the restored marsh (Able et al., submitted for publication; Miller et al., submitted for publication) and resulted in more boat traffic, seining and trawling than in Created Creek 2. This greater activity may have disturbed the YOY enough to result in movement out of the creek. It is also possible that the lower catches in the natural creeks were partly due to the different geomorphology of the creek bottoms (Miller, personal observation) but this could not be evaluated.

4.2. Residence time, habitat fidelity and movements

The findings of this study and a monthly trawling survey that sampled from 1996 to 1999 at six different marsh areas adjacent to Delaware Bay, including the two studied here (Miller et al., submitted for publication), suggest that each year class of YOY Atlantic croaker were resident in tidal creeks through the summer and early fall in both the restored and reference marshes. The presence of fish from almost all the tagging groups, throughout much of the recapture period, clearly indicated that many of these fish were remaining within the same local area. This high degree of habitat fidelity suggests that they may have well-defined home ranges associated with individual tidal creeks until fall egress.

Other YOY of estuarine fishes show a relatively high degree of habitat fidelity similar to that observed for Atlantic croaker in this study. Several species have shown a strong tendency to remain within the same tidal creek including *L. xanthurus* (Weinstein, 1983; Weinstein et al., 1984; Weinstein and O'Neil, 1986) and young-of-the-year summer flounder, *Paralichthys dentatus* (L.) (Rountree and Able, 1992, Szedlmayer and Able,

1993), while large juvenile and adult *Fundulus heteroclitus* (L.) (Lotrich, 1975; Teo and Able, submitted for publication) did the same. In other estuarine habitats, YOY black sea bass were found to remain within the same area (Able and Hales, 1997) as did two labrids (*Tautoga onitis* [L.] and *Tautogolabrus adspersus* [Walbaum]; Able and Hales, unpublished data) and butterflyfish, *Chaetodon* spp. (McBride and Able, 1998). However, other estuarine species (*Syngnathus fuscus* Storer and *Gobiosoma bosc* [Lacepède]) have not shown a tendency to remain within the same area after settlement (Sogard, 1989). Thus, while there appears to be a number of species that are resident after settlement, others are not, so studies on a wider range of estuarine species are needed to determine the possible reasons for these differences.

Despite the tendency for YOY Atlantic croaker to have a small, low-tide home range, they were found to move up into the intertidal portions of tidal creeks during high tide, even moving into the small intertidal tributary creeks. The presence of tagged fish during the low tide seining in West Creek indicated that some fish move into the main creek during low tide or moved permanently into these areas after the disturbance from sampling or as they are undergoing seasonal movements into deeper water. Tidal movements have been observed for a wide variety of YOY and juvenile fishes that move into or within marsh creeks along the Atlantic coast. Up to 51 species of fishes, including Atlantic croaker and three other sciaenids, have been found to move into intertidal creeks during high tide in South Carolina (Cain and Dean, 1976; Bozeman and Dean, 1980). Of these, silver perch, *Bairdiella chrysoura* (Lacepède), has shown distinct movements in and out of creeks (Kleypas and Dean, 1983) as have *F. heteroclitus* and *Menidia menidia* (L.) (Butner and Brattstrom, 1960; Teo and Able, submitted for publication). More detailed observations of tidal movements of fish up and down creeks have been described for large young-of-the-year summer flounder (Szedlmayer and Able, 1993) and juvenile American eels, *Anguilla rostrata* (Lesueur), tracked with ultrasonic transmitters (Helfman et al., 1983). As a result, these tide-based movement patterns should be taken into account when trying to define essential fish habitat for estuarine fishes.

4.3. Growth rates

The individual growth rates determined during this study for YOY Atlantic croaker showed no differences between the restored and reference marshes and were similar to summertime growth rates indicated by length-frequency data for YOY in Delaware Bay and in other nursery areas along the Atlantic coast. During this study, the growth rates of the recaptures after 40–78 days (0.74 mm/day) should have been the most reliable, because these rates were based on fish that were at large for a longer period of time and would be proportionally less biased as a result of loss of energy reserves during capture, holding and tagging. In Delaware Bay, growth rates of YOY throughout the bay and in tidal creeks, based on the progression of median lengths, ranged from 0.8–1.4 mm/day from May through August (Miller et al., submitted for publication). Length-frequency data from trawling surveys in other nursery areas in the Middle Atlantic Bight and North Carolina (Haven, 1957; Chao and Musick, 1977; Ross, 1988) showed modal progression during summer that suggested growth rates of 0.6–1.3 mm/day (Miller et al., submitted for publication).

Other published growth rate estimates for YOY Atlantic croaker along the Atlantic coast have been considerably lower. Estimates for the first year of growth based on length frequency data from six studies along the Atlantic coast that were prorated to a daily growth rate ranged from 0.32 to 0.41 mm/day (Knudsen and Herke, 1978). However, length frequency based estimates may underestimate growth rates later in the season when there may be a size-selective gear bias towards smaller fish or larger fish may be emigrating from sampling areas (Knudsen and Herke, 1978; Currin et al., 1984). A similar estimate of the mean instantaneous annual growth rate was 0.35 mm/day for the first year of growth for Atlantic croaker in North Carolina that was based on scale analysis (Ross, 1988). Growth rates calculated using the otoliths of larval and YOY croaker <70 mm SL collected in the Middle Atlantic Bight and in Chesapeake Bay from September to March were also relatively low (0.18–0.41 mm/day, Nixon and Jones, 1997) compared to this study. These growth estimates are probably lower than those observed during this study and those observed during the summer in several other studies, because they included periods of growth during the winter months when little growth appears to occur (Haven, 1957; Chao and Musick, 1977; Ross, 1988; Miller et al., submitted for publication).

Other species of YOY sciaenids also show fast summertime growth rates in estuarine areas along the Atlantic coast of North America. Length frequency and aging analyses have indicated that YOY weakfish, *Cynoscion regalis* (Bloch and Schneider), grow at rates ranging from 0.83 to 1.09 mm/day from summer to early fall in Chesapeake Bay (Szedlmayer et al., 1990), which is similar to the apparent YOY growth rates of other species of weakfish, *C. arenarius* Ginsburg, and *C. nothus* (Holbrook), in the Gulf of Mexico (DeVries and Chittenden, 1982; Shlossman and Chittenden, 1991). Length frequencies of YOY black drum, *Pogonias cromis* (L.), have indicated growth rates of about 1.2 mm/day in Delaware Bay (Able and Fahay, 1998) and 0.8–0.9 mm/day in Tampa Bay, FL (Peters and McMichael, 1990). Black drum tagged with coded wire microtags and recaptured after 14–62 days in marsh creeks during this study had an average individual growth rate of 1.0 mm/day ($n=4$; range: 0.57–1.4 mm/day) from mid-August to mid-October (Miller and Able, unpublished data). A study of YOY northern kingfish (*Menticirrhus saxatilis* [Bloch and Schneider]) tagged with coded wire tags and recaptured along an estuarine beach in Great Bay, NJ, found a higher average individual growth rate of 1.8 mm/day (Miller et al., submitted for publication). However, a growth rate estimate of silver perch based on length frequency data (0.75 mm/day) was relatively low (Able and Fahay, 1998), and growth estimates for spot often have been even lower (predominantly <0.7 mm/day) in many areas (Weinstein and Walters, 1981; Weinstein, 1983; Able and Fahay, 1998). These previous studies with other sciaenids indicate that the individual growth rates observed during this study are within the typical range of growth rates for YOY sciaenids.

4.4. Comparison between restored and reference marshes

Young-of-the-year Atlantic croaker appeared to utilize marsh creek habitats in both the restored and reference marshes in a similar way. They were a dominant component of the fish fauna in both marsh types over several years (Able et al., 2000, submitted for

publication). In fact, there were higher catch rates of YOY Atlantic croaker in the subtidal and intertidal portions of the restored marsh during the spring and summer than in similar habitats in the reference marsh in 1997, 1998 and 1999 (Miller et al., submitted for publication). In addition, their behavior and growth was similar between marsh types. Fish moved into intertidal habitats during high tide and were consistently recaptured in their home creeks in both restored and reference marshes at low tide and fish showed similar patterns of egress from both marsh types in fall. Also, growth rates were the same in both types of marshes. As a result, the created creeks in the restored marsh appeared to be providing YOY Atlantic croaker habitats of at least equal quality as the reference creeks for large numbers of fish. Thus, these data, together with prior studies of the distribution, abundance and species composition of fishes (Able et al., 2000, submitted for publication) and blue crabs (Jivoff and Able, submitted for publication) indicate that, by these measures, restoration of former salt hay farms in Delaware Bay has been successful.

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