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Growth and Temperature-Induced Mortality of Young-of-the-Year Summer Flounder (*Paralichthys dentatus*) in Southern New Jersey

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From Nov. 1988 through Oct. 1989, we examined the spatial and temporal distribution, growth, and temperature-induced mortality of young-of-the-year summer flounder (*Paralichthys dentatus*) from Great Bay and Little Egg Harbor, New Jersey. We collected *P. dentatus* undergoing metamorphosis (11–15 mm TL) with plankton nets from Nov. 1988 through May 1989, as they entered the study area from adjacent continental shelf waters. Temperature-induced mortality of early postmetamorphic individuals in the laboratory was largely limited to the one instance that ambient winter temperatures dropped below 2 C (58% mortality). Mortality of a control group held in heated water (approx. 15 C) was low (3%). More important, we observed recruitment of postmetamorphic larvae well after this low temperature period in Feb. In mid-June we collected by trawl, benthic young-of-the-year fish almost exclusively (98%) at the mouth of two mesohaline subtidal marsh creeks. After June, young-of-the-year fish became more widespread, and we collected *P. dentatus* in a variety of habitats throughout the study area. In Aug. and Sept. *P. dentatus* were apparently able to avoid the trawl, but we collected large numbers by block nets in polyhaline subtidal marsh creeks. Young-of-the-year *P. dentatus* ranged 200–326 mm TL by Sept. In early Oct. 1989, we collected only two individuals by any method, and presumably most fish had migrated offshore by this time. We estimated growth rate by linear regression of TL on collection date at 1.9 mm/d from May through Sept. ($n = 579$, $r^2 = 0.89$). Examination of otoliths for annuli formation ($n = 313$, range = 126–418 mm TL) showed that the first annulus formed over a range of 275–326 mm TL. The growth rate of young-of-the-year *P. dentatus* in New Jersey was among the fastest for juvenile estuarine fishes. This fast growth rate and the size at first annulus formation indicate that the first mark on otoliths is indeed the first annulus, a conclusion contrary to some earlier interpretations. Thus, *P. dentatus* can survive New Jersey winter temperatures, grow very quickly, and attain a large size at the end of the first summer. These characteristics imply that southern New Jersey estuaries act as important nurseries for this species.

AGE and growth estimates of summer flounder (*Paralichthys dentatus*) in the Mid-Atlantic Bight are problematic, largely due to differences of opinion regarding growth during the first year. It is clear that *P. dentatus* spawn over the continental shelf (Morse, 1981; Able et al., 1990), and at least some individuals undergoing metamorphosis enter New Jersey es-

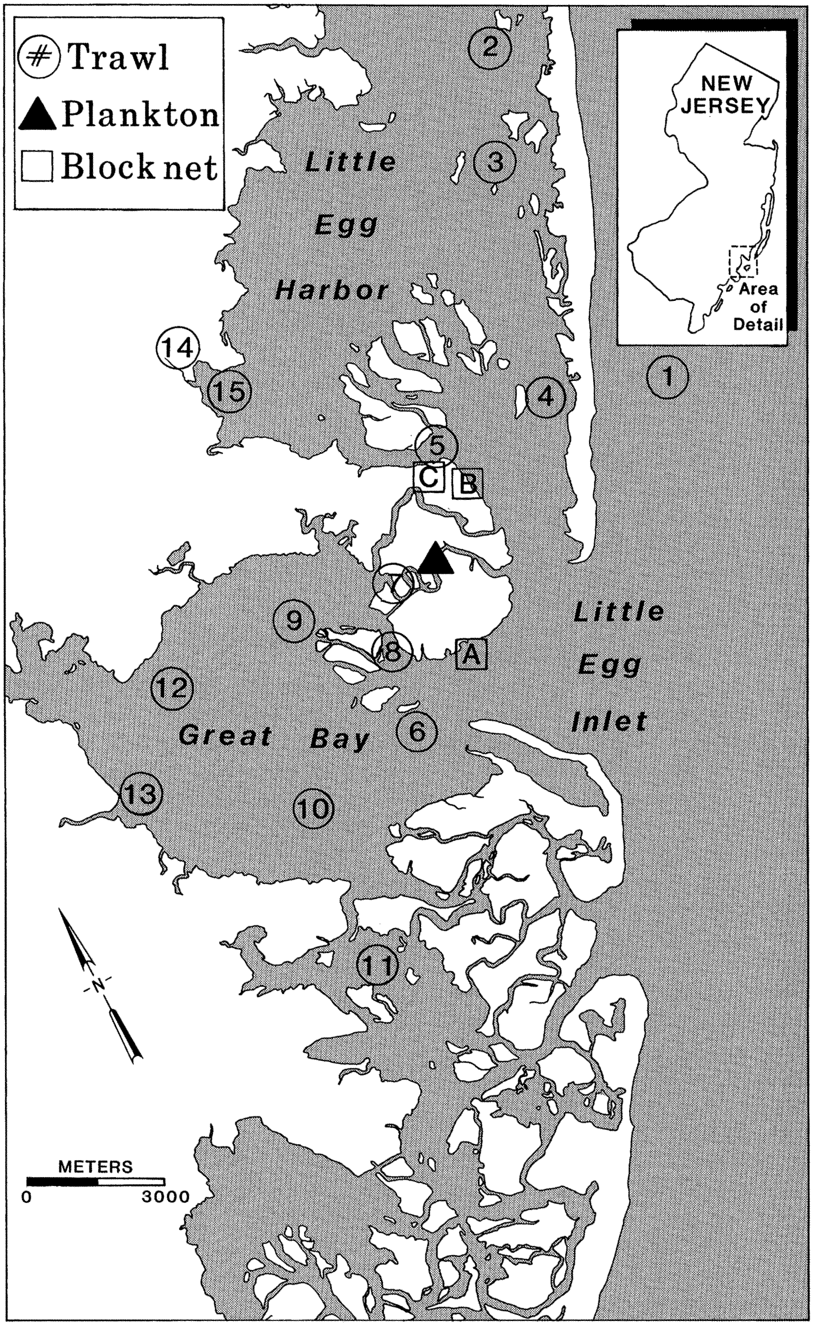

Fig. 1. Trawl (circles), block net (squares), and ichthyoplankton (triangle) sampling locations in Great Bay and Little Egg Harbor estuaries, New Jersey.

tuaries during the late fall and winter (Able et al., 1990). Poole (1961) suggested fish in Great South Bay, New York, reached large sizes of 200–280 mm TL during the first year based on length frequency data. Other authors have suggested a slower growth rate but have noted trouble in detecting the first annulus in otoliths of *P. dentatus* from off Virginia (Eldridge, 1962)

TABLE 1. SAMPLING ACTIVITY FOR YOUNG-OF-THE-YEAR *Paralichthys dentatus* IN GREAT BAY AND LITTLE EGG HARBOR ESTUARIES, NEW JERSEY. * = information lacking.

	Gear				
	Plankton net	Trawl	Block net	Hook/line Gill net Fyke net	Push net
Habitat	Subtidal marsh creek	Varied, channels to shallow flats	Subtidal marsh creek	Subtidal marsh creek	Shallow subtidal mud flat
Depth range (m)	1, 4	1–7	2–3	2–3	1
Temp. range (C)	0–25	−1–29	8–28	8–28	*
Sal. range (ppt)	26–34	5–32	22–33	22–33	*
Sample period	Nov 88–Aug 89	Oct 88–Oct 89	Apr–Oct 89	Aug–Sep 89	May 89
Sample size	471	911	28	*	*
Fish (n)	138	248	245	79	7

and in Delaware Bay (Smith and Daiber, 1977). In North Carolina, Powell (1974, 1982) indicated that the first annulus formed in otoliths at 167 and 171 mm TL, for males and females, respectively. In an attempt to resolve these differences, Smith et al. (NOAA, unpubl.) concluded that the first annulus represented the second year of growth and that Poole's (1961) interpretation of fast growth during the first year was atypical. Based on length frequency data collected in New Jersey, Able et al. (1990) suggested that very fast growth did occur during the first year, in agreement with Poole (1961). However, data reported by Able et al. (1990) were based on composite length frequencies from several sources over several decades. Data from a single-year class showing this faster growth rate were not available and, thus, needed testing.

There are several factors that we believe have delayed resolution of this difference in interpretation of growth rate. First, there is the perception that estuaries in the northeast do not contribute substantially as nursery areas for *P. dentatus* (Poole, 1966), and, thus, detailed studies are frequently unavailable. This has been prompted in part by the belief, although never tested, that *P. dentatus* postlarvae recruiting to northern estuaries are killed by lower temperatures during the winter. Clearly parasite-induced mortality of juveniles is increased by low temperatures (Burreson and Zwerner, 1982, 1984). Second, there may be at least two different stocks along the east coast (Wilk et al., 1980), with potentially different growth rates that are confounding comparisons of growth. The purpose of this research was to determine the growth rate of young-of-the-year *P. dentatus* in a southern New Jersey estuary by intensive sampling of length and age data from samples taken with a variety of gear types in a variety of habitats. In addition, we wanted to determine the effect of winter water temperatures on survival of *P. dentatus* postlarvae.

MATERIALS AND METHODS

Growth.—We sampled Great Bay and Little Egg Harbor estuaries for *P. dentatus* in 1988 and 1989 (Fig. 1), using three main types of sampling gear to collect this species (Table 1). We set two stationary plankton nets (1 m diameter, 1.0 mm mesh) weekly from Nov. 1988 to Aug. 1989, on night flood tides at surface and bottom depths from a bridge. The bridge spans Little Sheepshead Creek, 3.0 km from Little Egg Inlet (Fig. 1). We sampled with both nets at 0.5 hr intervals for the entire flood tide. Prior drogue studies indicate that Atlantic Ocean water flows through this creek on flood tides (Charlesworth, 1968). By making four replicate 2 min tows at 13 locations, in a variety of habitats (Fig. 1), we sampled with an otter trawl (4.9 m opening, 19 mm mesh wings, 6.3 mm mesh liner). We sampled with the trawl monthly from Oct. 1988 to June 1989, thereafter every two weeks until late Sept. 1989, and once in Sept. and Oct. 1989. We set block nets (32 m long, 3 m high, 0.63 mm mesh) at high tide and fished on ebb tides. These nets completely blocked off three subtidal creeks (Fig. 1), and we fished every two weeks from April to Oct. 1989. We counted and measured live TL to the nearest mm for all *P. dentatus*. From a subsample (n = 188, range = 125–326 mm TL) of fish collected in the above sampling effort, we examined otoliths for annuli. In addition, we examined otoliths from fish collected by a New Jersey De-

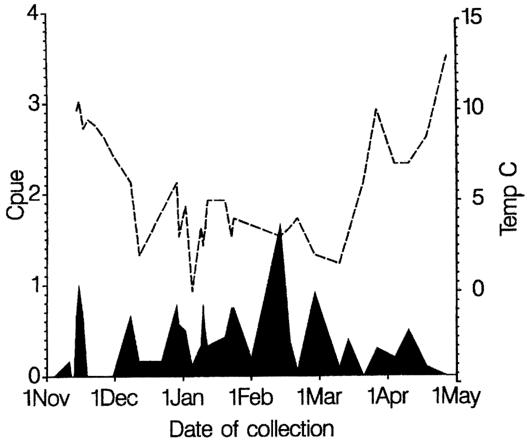

Fig. 2. Catch-per-unit-effort (cpue = number of fish taken/0.5 hr set) of *Paralichthys dentatus* relative to temperature at the ichthyoplankton sampling station from the winter of 1988–1989. Dashed line = temperature; shaded area = cpue. See Figure 1 for sampling location.

partment of Environmental Protection nearshore continental shelf survey and commercial trawl catches off New Jersey (n = 125, range = 276–418 mm TL). We examined otoliths in 95% ethanol at 60× magnification, with reflected light.

Temperature-induced mortality.—We examined percent survival of postlarvae at ambient temperatures during late winter–spring 1989, by placing individual fish in 1.5-liter glass bowls that were immersed in an ambient temperature flow-through water bath. In trial 1, we held fish collected with plankton nets in Dec. 1988 and Jan. 1989 (n = 17, range = 11–17 mm TL) at approx. 15 C until 28 Jan. 1989; then we acclimated them to lower ambient temperatures over a 5-day period. At the same time, we held a control group (n = 21, range = 11–17 mm TL) under the same laboratory conditions at approx. 15 C. Thereafter, we recorded temperatures and mortalities daily. On 4 March 1989 (38 d), we sacrificed remaining fish for studies on otolith microincrements (Szedlmayer and Able, in press). In trial 2, we placed fish (n = 17, range = 11–17 mm TL) in ambient temperature immediately after capture on 14 and 17 Feb. 1989, and recorded temperatures and mortalities until 6 May 1989 (82 d), when ambient temperatures were consistently greater than 12 C. In all bowls, we changed the water

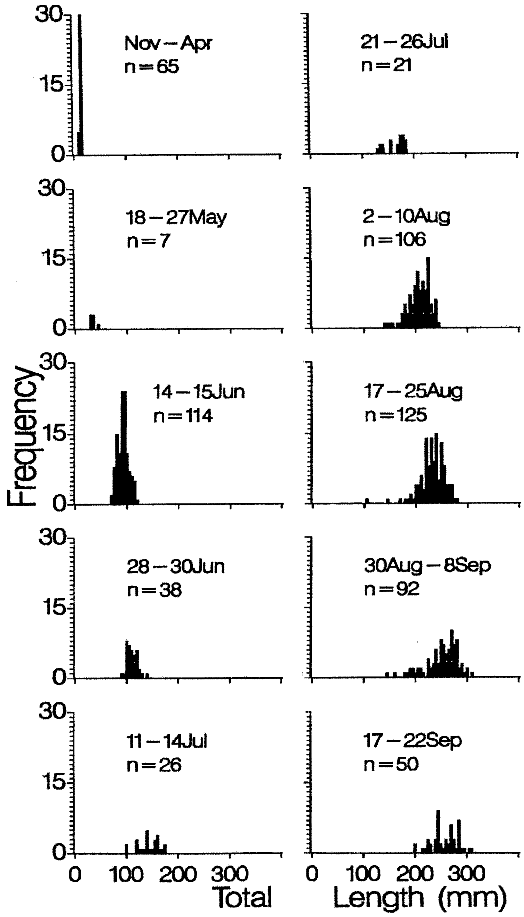

Fig. 3. Length-frequency distribution of young-of-the-year *Paralichthys dentatus* during the 1988–1989 sampling in Great Bay and Little Egg Harbor estuaries in New Jersey.

daily and fed the fish a daily ration of 5000 two-day-old *Artemia* sp./l.

Results

Occurrence and habitat use.—*Paralichthys dentatus* used the study area as a nursery from Nov. 1988 through Oct. 1989 based on the collection of numerous young-of-the-year. We collected individuals undergoing metamorphosis (n = 138, range = 11–17 mm TL, mean = 14.1 ± 1.2 SD mm TL) continuously in the plankton net from Nov. 1988 through April 1989, over a temperature range of 0–13 C (Fig. 2). No change in size was apparent from plankton collections. One additional larva (11 mm TL) was collected 31 May 1989 when the temperature was 18 C. In

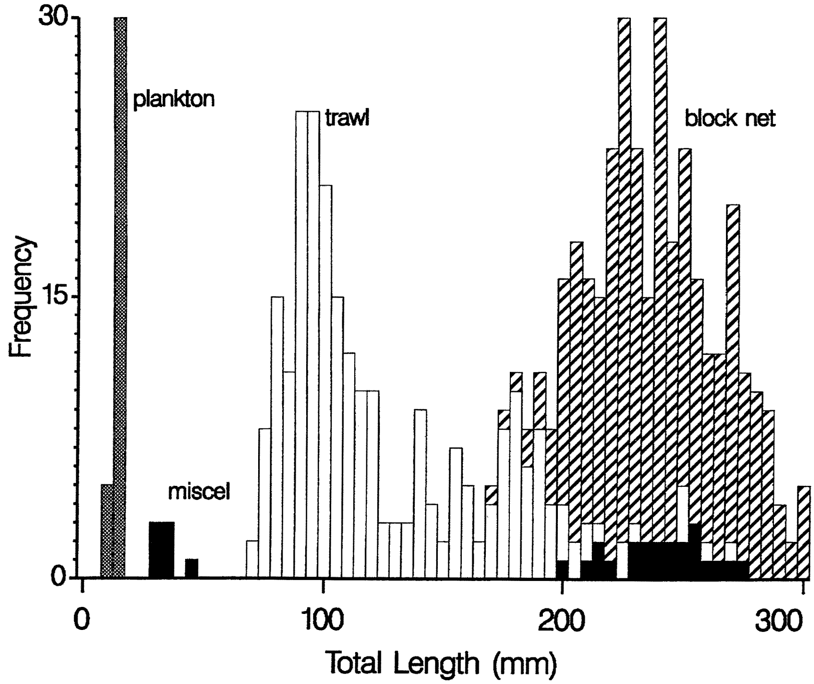

Fig. 4. Length frequency by gear type of all *Paralichthys dentatus* collected from Nov. 1988 through Sept. 1989 in Great Bay and Little Egg Harbor estuaries, New Jersey. Miscel = hook and line, gill net, fyke net, and pushnet.

addition, we collected a single juvenile (44 mm TL) in May from the study area and six others similar in size (30–36 mm TL) with a 1 × 1 m pushnet in shallow water over sand-mud substrate in adjacent Barnegat Bay. From June through Sept. 1989, we frequently collected young-of-the-year (60–326 mm TL) by otter trawl and block nets (Figs. 3–4). In June, we collected 98% of the young-of-the-year fish (n = 116) at the mouth or just inside two mesohaline subtidal marsh creeks, both approx. 10 km from Little Egg Inlet (stations 13, 15; Fig. 1). Both creeks shared several characteristics including clay/silt substrate (station 13, 90.5% clay/silt; station 15, 98.1% clay/silt) with large numbers of sessile hydroids, at average salinities of 20 ppt. During July 1989, fish became more widespread. We collected individuals at additional stations, where habitats varied from shallow mud flats to dredged channels (stations A, C, 6, 10, and 11; Fig. 1). By late Aug. through Sept. 1989, most fish were >200 mm TL, and we collected almost all from block nets in marsh creeks near Little Egg Inlet (Figs. 1, 4). In early Oct. 1989, we collected only two individuals during regular sampling, and presumably most fish had migrated offshore by this time.

During the same seasonal period that we collected young-of-the-year *P. dentatus* in the estuarine study area, they were rare in extensive trawl collections over the entire continental shelf. Sampling efforts by the National Marine Fisheries Service during the summer of 1977–1981 (Azarovitz, 1981) produced only one individual (140 mm TL) that might have been a young-of-the-year (G. Shepherd, National Marine Fisheries Service, Woods Hole, pers. comm.). Similarly, nearshore collections off New Jersey during 1989 only collected two potential young-of-the-year individuals in the summer but more (n = 31) after they migrated offshore in the fall (D. Byrne, Bureau of Marine Fisheries, New Jersey Department of Environmental Protection, Fish, Game, and Wildlife Service, pers. comm.).

Age composition and growth.—A single-year class dominated the *P. dentatus* collections in the present study. All individuals appeared to be young-of-the-year beginning with the metamorphosing larvae that entered during the winter and early spring to those of 200–326 mm TL by the following fall. In every sampling period (except late Sept.), there was a single-length

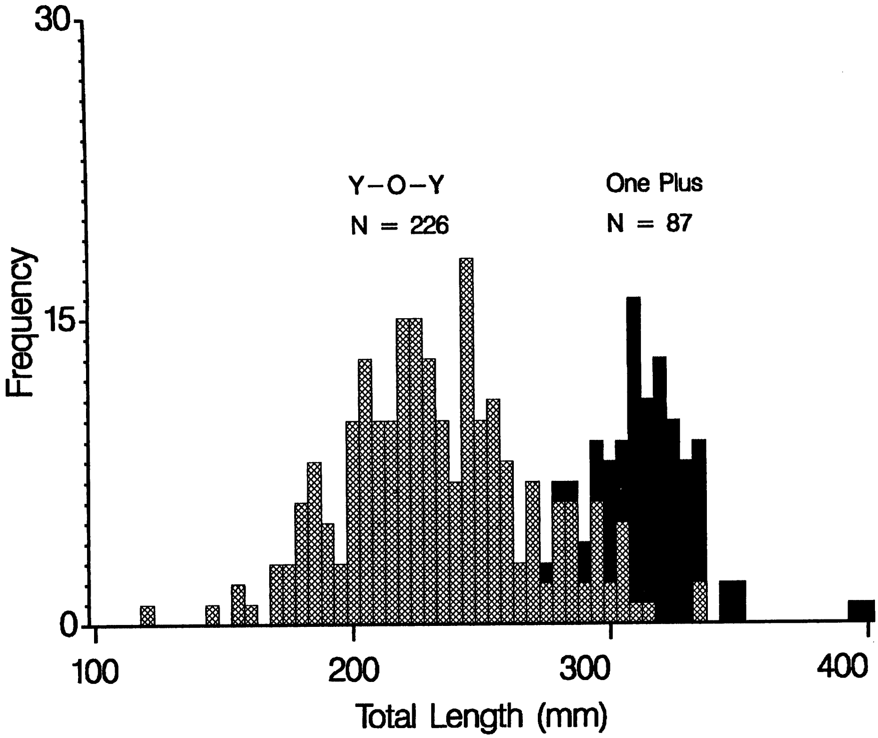

Fig. 5. Length-frequency distribution and absence (cross-hatched bars) or presence (solid bars) of first annulus in *Paralichthys dentatus* from New Jersey. Y-O-Y = young-of-the-year, no annulus; one plus = those fish showing first annulus.

mode of fish that increased in size over the next sampling period (Fig. 3). In addition, in a subsample of fish from this study (n = 188; range = 125–326 mm TL), none exhibited annuli on their otoliths (Fig. 5). In contrast, *P. dentatus* from continental shelf collections had clearly visible annuli in 61% (55 out of 90) of the otoliths from fish 276–335 mm TL collected from Aug. through Oct. and in 91% (32 out of 35) of the otoliths from fish 277–418 mm TL collected from Jan. through March (Fig. 5). In all samples combined, the first annulus formed over a range of 275–326 mm TL. Thus, during 1989, the *P. dentatus* in the study area attained 200–326 mm TL by the fall of the first year. Based on this interpretation, young-of-the-year *P. dentatus* grew an average of 1.9 mm/d from mid-May through Sept. (n = 579, $r^2 = 0.89$; Fig. 6).

Temperature effects on mortality.—Survival of metamorphosing larvae decreased drastically relative to controls when temperatures dropped below 2 C (Fig. 7). In trial 1, temperatures dropped steadily from 15 to 1 C over a 14-day period. Relatively little mortality (2%) occurred up to day 12. However, on days 13 and 14, temperatures dropped below 2 C causing 58% mortality. Temperatures then increased and fluctuated around 5 C but did not drop below 3 C, and during this period, mortality was lower (14%), for a total ambient temperature mortality of 74%. In the heated control group, little mortality occurred due to rearing environment, i.e., only one control fish died near the end of trial 1 (3% total mortality). In trial 2, in which a control was lacking, the lowest temperature exposure was 2 C; afterward, average temperatures gradually increased. During this period, mortalities were lower (31% total), and these occurred sporadically.

Discussion

The collections of larval and juvenile *P. dentatus* from the estuarine study area from Nov. 1988 through Sept. 1989, and lack of young-of-the-year individuals in continental shelf waters in the summer of 1989, confirm an earlier suggestion (Able et al., 1990) that southern New Jersey estuaries are nurseries for *P. dentatus*.

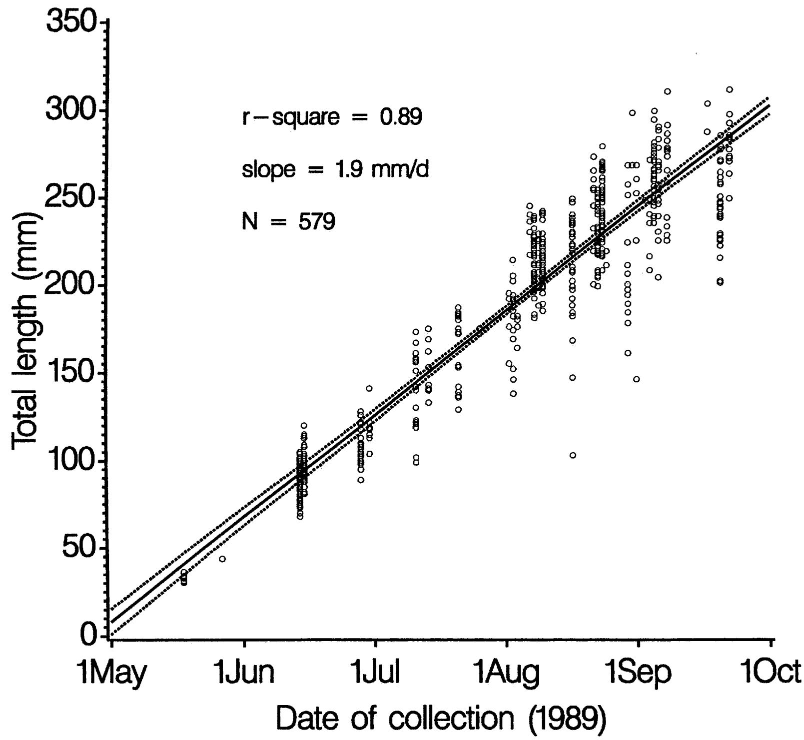

Fig. 6. Growth rate of young-of-the-year *Paralichthys dentatus* during 1989, as estimated by linear regression of total length on date of collection. Solid line = regression line; dotted lines = 99% confidence intervals; each circle = one fish.

The inability of previous investigators to recognize this pattern of use may have been due to (1) poor year classes during earlier studies; (2) low level of sampling in marsh creeks, where fish appear most abundant in early summer; and (3) the failure to recognize 200–326 mm TL individuals as young-of-the-year.

Year class strength may be affected by winter temperature in New Jersey estuaries. It is clear from our laboratory studies that very low temperatures (<2.0 C) are likely to be a source of mortality for metamorphosing individuals that overwinter in the estuary. We demonstrated that 58% of the total 74% mortality (trial 1) occurred at these temperatures. However, more important, we have also demonstrated that *P. dentatus* can survive New Jersey winter temperatures: we had 69% survival (31% mortality, trial 2) when ambient temperatures did not drop below 2 C. Also, recruitment of larvae to the study area occurred from Nov. 1988 through May 1989 and, thus, into the period of rising spring temperatures (Fig. 2). In previous years, almost all larvae were collected from Oct. through Jan. (Able et al., 1990). Perhaps the apparent greater abundance of the 1989 year class, certainly relative to the summer of 1988 when no juveniles were collected in a similar trawl survey (Szedlmayer and Able, pers. obs.), was in part due to movement into the estuary by metamorphosing larvae and survival during Feb. through April.

Specific habitat utilization patterns by *P. dentatus* may have prevented successful collections of juveniles in the past. In our study, they were clearly most abundant in marsh creeks. If prior investigators did not sample there, they would have had little success, at least during most of the summer. Unfortunately, the patterns of habitat utilization for all *P. dentatus* populations are not clear. In North Carolina, young-of-the-year *P. dentatus* were most abundant over open, sandy areas (Powell and Schwartz, 1977), but they also occurred in eelgrass (Adams, 1976) as has been shown in Chesapeake Bay (Orth and Heck, 1980). We collected them only rarely in these habitats in our study area.

The growth rate of *P. dentatus* in the summer from the present study area, and perhaps other more northern estuaries, is fast. By Sept. young-of-the-year fish attained 200–326 mm TL (Fig. 3). Similar sizes were attained by young-of-the-year *P. dentatus* in Great South Bay, Long Island (Poole, 1961). Previously, these Long Island data were not considered appropriate because they "represented an atypical fast growing year class" (Smith et al., NOAA, unpubl.). The sizes attained at the end of the first summer in New Jersey are much larger relative to North Carolina (males 167, females 171 mm TL; Powell, 1982). This difference may be the result of gear bias, i.e., our catch of *P. dentatus* in trawl samples dropped precipitously when fish grew larger than 200 mm TL. This occurred in early Aug. Subsequently, most of the young-of-the-year *P. dentatus* > 200 mm TL were collected by block net (Fig. 4). This is at the same time of year and size that there is an asymptote in the length of young-of-the-year *P. dentatus* in Pamlico Sound, North Carolina (Powell, 1974, 1982), where fish were collected solely by otter trawl. Another possibility is that the larger (>200 mm TL) *P. dentatus* moved out of these North Carolina estuaries in late summer. It is also possible that *P. dentatus* may simply grow slower in North Carolina.

In the present study, we feel that young-of-the-year *P. dentatus* moved out of the estuary in New Jersey in late summer and early fall. First, we collected very few *P. dentatus* after Sept. with any gear. Second, a trawl survey in depths of 3–30 m off the New Jersey coast in 1989 collected few young-of-the-year (<326 mm TL) *P. dentatus* in the summer (0.04 cpue/June), but more in the fall (0.33 cpue/Aug.–Sept., 0.46 cpue/Oct.–Nov.; D. Byrne, Bureau of Marine Fisheries, New Jersey Department of Environmental Protection, Fish, Game, and Wildlife Service, pers. comm.). This interpretation is the same as that for adults in New Jersey and other northern areas (Bigelow and Schroeder, 1953; Poole, 1962).

The perception that northern Mid-Atlantic Bight estuaries are not important nurseries (Poole, 1961; Rogers and Van Den Avyle, U.S. Fish and Wildlife Service, unpubl.) may have resulted, in part, from misinterpretation of juvenile ages and, as a result, underestimation of the young-of-the-year abundance. For example, Smith and Daiber (1977) considered the first well-defined annulus in otoliths of Delaware Bay *P. dentatus* to be formed at age 2 but at mean lengths of 289 mm TL. If we assume young-of-the-year *P. dentatus* from New Jersey and Delaware grow at similar rates, then a simpler explanation for the presumed disparity in size is that the first annulus of Delaware Bay fish actually represents age 1. As a result of this reinterpretation, young-of-the-year (<approximately 300 mm TL) *P. dentatus* were also common in Delaware Bay, based on their data.

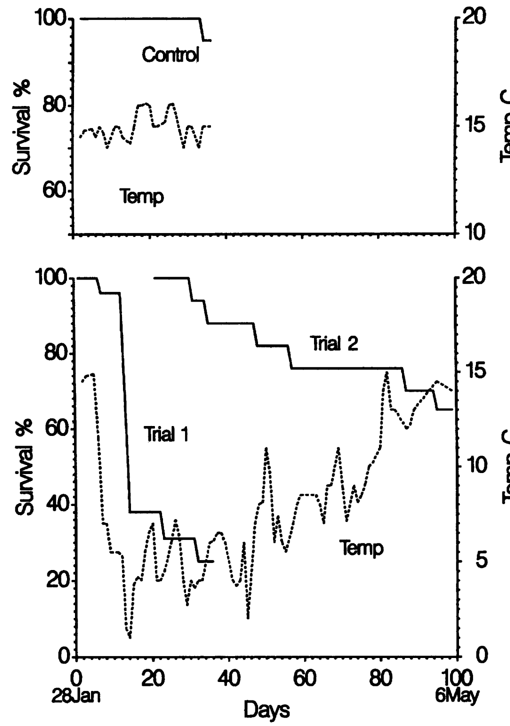

Fig. 7. Survival of postmetamorphic *Paralichthys dentatus* held in heated water conditions (control, approximately = 15 C) and in ambient water temperature conditions during winter–spring of 1989. Solid line = % survival; dotted line = temperature; trial 1 n = 17; trial 2 n = 17; control n = 21.

In addition, this interpretation of a larger size at the end of the first year (200–326 mm TL) implies that some *P. dentatus* may reproduce at age 1, based on the lengths at maturity (males 190, females 250 mm TL) provided by Morse (1981).

In summary, *P. dentatus* use New Jersey estuaries and probably others in the northern Mid-Atlantic Bight as nurseries to a much larger extent than previously recognized. In these estuaries, growth is fast, and fish achieve a larger size before leaving the estuary in the fall. Although temperatures below 2 C did cause mortality, many recruiting larvae can probably survive New Jersey winter temperatures or recruit after temperatures increase and, subsequently, use these northern estuaries as a nursery. The relative contribution of nursery areas in the northern Mid-Atlantic Bight, relative to those further south, remains to be determined.

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