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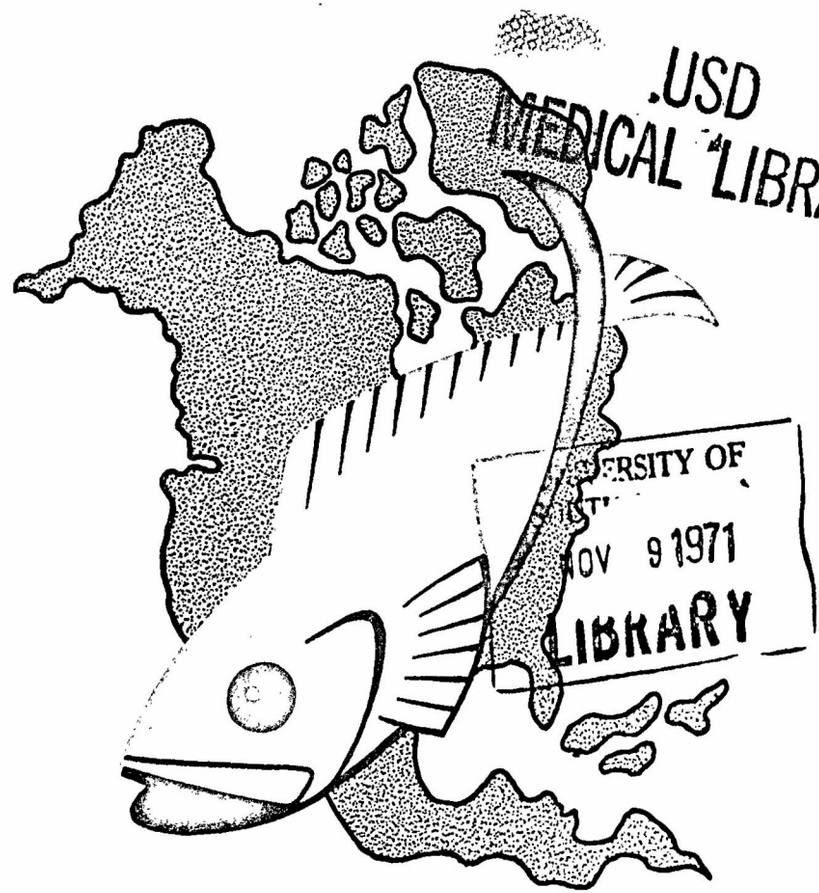

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THE AMERICAN FISHERIES SOCIETY

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Developmental Rates of *Menidia audens* with Notes on Salt Tolerance

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The University of Texas, Austin, Texas, and The University of Oklahoma Biological Station, Willis, Oklahoma

ABSTRACT

Fertilized eggs of *Menidia audens* were incubated at temperatures from 10.2 to 36.4 C, normal development occurred between 13.2 and 34.2 C, high survival was between 17.0 and 33.5 C, and optimal development seemed to be between 20 and 25 C. Cold lethality was associated with depletion of yolk supply prior to hatching. Eggs in ¼ sea water did as well as those in fresh water; development through eye pigmentation was normal even in full strength sea water. Adults were more salt tolerant with critical salinities being near full sea water.

INTRODUCTION

Reservoir construction and enlargement has placed large bodies of quiet water in biogeographic areas in which natural lakes are rare or absent; therefore, balanced and integrated lacustrine biotas are not locally available. Unfortunately, we can not wait until this fauna evolves. In the interim a species can become excessively abundant; many exotics have been introduced to control the pests, sometimes with the result that a second pest must also be controlled.

The control of pest organisms by carefully selected predators has been advocated by Train *et al.*, (1970). Biological control seldom results in extermination of the pest but may reduce the problem to manageable proportions. Cook and Moore (1970) have advocated the use of the Mississippi silversides, *Menidia audens*, to control the pestiferous gnat, *Chaoborus astictopus*, in Clear Lake, California. The availability of the Mississippi silversides as forage for game fish contributes to its desirability. If this fish is to be considered as a biological control agent, its life history must be fully understood so that reasonable predictions can be made.

This investigation was designed to determine tolerances of Mississippi silverside eggs and young to thermal and salinity stress. Several other items were observed that apply to the life history of *Menidia audens*. Some agreed with the published reports, some supplemented the available information, and others that were discordant were checked to confirm the validity of our observations which are reported below.

MATERIALS AND METHODS

Stocks of adult *Menidia audens* were obtained at several localities on the north shore of Lake Texoma, most notably at Mayfield Flat, Willis Bridge, and Willis Island, and returned to the University of Oklahoma Biological Station. The adults were placed in styrafoam coolers as soon as possible. Those left in the seine more than 10 seconds after beach-

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Life History and Ecology of the Cyprinid Fish *Notropis petersoni* in North Carolina Waters

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ABSTRACT

This study was designed to expand the knowledge of the life history and ecology of *Notropis petersoni* Fowler. *N. petersoni*, commonly called the coastal shiner, is found along the Coastal Plains from North Carolina to Mississippi. In North Carolina its range is confined to a few streams in the lower Cape Fear River Basin, in the Waccamaw River, and in Lake Waccamaw.

The food of the coastal shiner is principally crustaceans with plant material being taken incidental to feeding. Observation of *N. petersoni* in aquaria indicated that their diet depends on available food, however, they prefer zooplankton. The lotic population of *N. petersoni* appears to feed on the same type of material as the lentic populations. The pH range found in the habitat of *N. petersoni* was 5.3 to 6.9 with the minimum pH tolerance limit obtained for *N. petersoni* under laboratory conditions being 4.9. Dissolved oxygen ranged from 1.4 to 7.0 ppm under field conditions with a minimum tolerance limit of 0.9 ppm under laboratory conditions. The highest water temperature associated with *N. petersoni* was 84 F in lotic environments and 89 F in Lake Waccamaw. When water temperatures declined below 52 F, *N. petersoni* moved to deeper water.

Growth comparisons were made between lentic and lotic environments by the "t" test with the data indicating no significant difference between Lake Waccamaw, the lotic environment, and Livingston, Town, and Six Runs Creeks for age I and II fish. However, there was a significant difference between the Lake Waccamaw and the Northeast Cape Fear River populations.

INTRODUCTION

Notropis petersoni Fowler (Figure 1) is a small cyprinid fish found along the Coastal Plain from North Carolina southward to Lee County in peninsular Florida and west to the Jordan River, Mississippi (Swift, 1970). In North Carolina its range is confined to a few streams in the lower Cape Fear River Basin, in the Waccamaw River, and in Lake Waccamaw (Louder, 1962a, 1963; Bayless, 1963).

The Lake Waccamaw population of *N. petersoni* was previously regarded as a new species, *Notropis waccamanus* Fowler, (1942). Hubbs and Raney (1946) suggested that *N. petersoni* and *N. waccamanus* were closely related and might be considered a sub-species were it not for the difference in color. Frey (1951) studied the two species and concluded that there was no difference between them and that *N. waccamanus* was a synonym of *N. petersoni.*

Considering the small amount of life history data available on southeastern cyprinids (*i.e.*, Marshall, 1947a, 1947b; Hellier, 1967), the ecology and life history of *Notropis petersoni* were chosen for study.

METHODS AND PROCEDURES

Beginning in July, 1968, Lake Waccamaw was sampled intensively with a surface trawl, an AC–DC shocker, 5% emulsifiable rotenone, small seines of several mesh sizes, and a 25-foot, ¼-inch mesh, bag seine. The bag seine proved to be the most effective gear in the lake, whereas rotenone proved to be the most effective in sampling the streams.

N. petersoni were collected monthly in Lake Waccamaw from June, 1968 through December, 1969. The fish collected were used to determine habitat preferences, meristic characteristics, food habits, spawning period, development of eggs and larvae, age and growth, movement, gregariousness, as well as food for the predator fishes. Water temperatures and chemical samples were collected monthly using methods as outlined in *Standard Methods for the Examination of Water and Wastewater* (1966).

The specimens of *N. petersoni* were preserved in the field in 10% formalin. The entire digestive tracts were removed from a representative sample of fish monthly, preserved in 10% formalin, and the contents later examined in the laboratory at 10× magnifica-

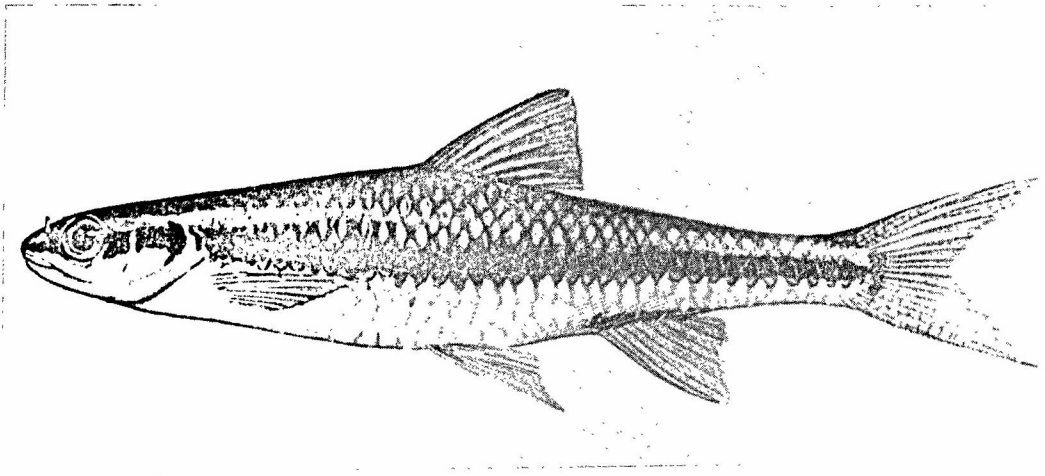

FIGURE 1.—Drawing of adult *Notropis petersoni*.

tion. Scales were removed from a representative sample for age and growth analysis. They were mounted on glass slides and the distances between the annuli were determined with an occular micrometer at 12.5×. Vertebrae counts were made from radiograms prepared by personnel from the National Marine Fisheries Service, Beaufort, North Carolina.

The male–female ratio of the adult population was determined from samples made during the spawning season. Egg counts and egg diameters were determined for *N. petersoni* from these collections with the aid of an ocular micrometer at 12.5×.

To determine the tolerance of the species to pH, several were transported in fox pails to the laboratory for experimentation under controlled conditions. *N. petersoni* were first held at the rate of 25 fish per 29-gallon aquarium at a water temperature of 70 F to determine the survival rates at different pH levels. This procedure was repeated three times. This was then followed by introduction from lentic environments into four large natural lakes, Singletary, Jones, Salters, and White Lakes. At the lakes, *N. petersoni* were held in welded wire cages, measuring 12″ × 12″ × 12″, for various periods of time. The cages were checked daily and the number of dead fish counted, recorded, and removed in order to determine survival rates. A Sargent electro pH meter was used to determine pH.

On one occasion, during the summer of 1969, *N. petersoni* were collected from Livingston Creek and transported to White Lake to determine if lotic inhabiting *N. petersoni* had a higher or lower survival rate than those of a lentic habitat. Ten fish in a wire cage were placed in White Lake and checked for survival. The remaining 56 fish were held in an aquarium at Elizabethtown for controlled survival comparisons with the lotic group.

Several attempts were made to artificially spawn *N. petersoni* in glass aquaria and in Lake Waccamaw. In addition, lake-side observations were made frequently at Lake Waccamaw to observe *N. petersoni* spawning in their natural habitat.

RESULTS AND DISCUSSION

Habitat and Ecology

The black-water streams in North Carolina where *N. petersoni* are found have sandy bottoms, a velocity of less than 1.0 feet per second under normal conditions, and have a low pH. The pH of the streams ranged from 5.3 to 6.9, dissolved oxygen from 1.4 to 7.0 ppm, carbon dioxide from 1.7 to 15.0 ppm, and alkalinity from 5.1 to 75.5 ppm. The highest recorded water temperature associated with this species in a lotic environment was 84 F (Bayless, 1963; Louder, 1962a, 1963).

Cover along streams having *N. petersoni* is

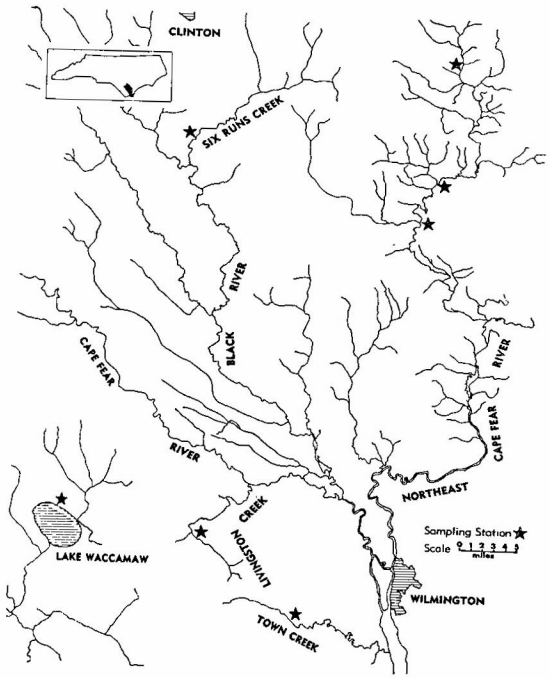

FIGURE 2.—Map showing geographic location of study area and sampling stations.

sparce to moderate and the cover type is bottom-land hardwoods. Because of the sandy soils of the lower Coastal Plain, silting of these streams seldom occurs.

The more common fishes associated with *N. petersoni* in North Carolina in the lotic environment are: golden shiner, *Notemigonus crysoleucas*; ironcolor shiner, *Notropis chalybaeus*; dusky shiner, *Notropis cummingsae*; pirateperch, *Aphredoderus sayanus*; warmouth, *Chaenobryttus gulosus*; redbreast sunfish, *Lepomis auritus*; and Johnny darter, *Etheostoma nigrum*.

Lake Waccamaw, the only lentic environment where *N. petersoni* are found in North Carolina is an 8938-acre natural lake located in southeastern North Carolina (Figure 2). It has a maximum depth of 10.8 feet with an average depth of 7.6 feet. It has 14.2 miles of shoreline and has a maximum width of 5.3 miles. The bottom of the lake is composed of sand, fibrous peat, and pulpy peat.

The pH of Lake Waccamaw is slightly acidic (6.6–6.8). The reason for the near neutral pH in an area of acid swamp drainage is that the water on the north shore lies in contact with a calcareous Miocene formation from which incoming swamp waters obtain enough calcium to raise the pH to near neutral (Frey, 1949). Water temperatures in this shallow lake vary less than two degrees from surface to bottom at any given time. Dissolved oxygen in the lake ranges from 7.9 to 8.5 ppm during the critical period of June through August. Free carbon dioxide ranges from 4.5 to 11.0 ppm and total alkalinity ranges from 16.0 to 24.0 ppm for the same critical period. Secchi disc readings taken during the year averaged 50 inches with a range of 31 to 55.

Thirty-seven species of fishes are known from Lake Waccamaw (Louder, 1961). Those species associated with *N. petersoni* in this lentic environment are: golden shiner; ironcolor shiner; waccamaw killifish, *Fundulus waccamensis*; mosquitofish, *Gambusia affinis*; pumpkinseed, *Lepomis gibbosus*; waccamaw darter, *Etheostoma perlongum*; and waccamaw silverside, *Menidia extensa*.

The more common species of aquatic vegetation found in the lake are: Maiden cane, *Panicum hemitomum*; yellow water lily, *Nuphar advena*; American lotus, *Nelumbo lutea*; bald cypress, *Taxodium distichum*; pickerel weed, *Pontederia cordata*; and cattail, *Typha latifolia* (Louder, 1961). Submergent vegetation is very rare in the lake due to the dark coloration of the water. *N. petersoni* seems to be associated with aquatic vegetation only during the breeding season.

Distribution of the species within the lake varies from month to month with the species being associated with shallow, dark-bottom areas. *Notropis petersoni* were usually collected with *Menidia extensa* and *Fundulus waccamensis* along the shoreline (Davis and Louder, 1969). *N. petersoni* appeared plentiful along the shoreline especially during the spring, summer, and fall months. When water temperatures drop below 52 F *N. petersoni* move to deeper waters. A pronounced movement away from the shore to deeper water also occurs in the summer when the lake water reaches 89 F.

The four natural lakes chosen to determine the low pH tolerance limit under natural con-

TABLE 1.—*Age composition and size of 308* Notropis petersoni *taken from North Carolina waters, 1969*

Age group	Year class	Number examined	Average Total Length at capture in Millimeters and (inches)	Average calculated length at each annulus in millimeters and (inches)		
				1	2	3
I	1968	127	46.3 (1.82)	25.4 (1.00)		
II	1967	161	61.0 (2.40)	23.4 (0.92)	46.6 (1.83)	
III	1966	20	70.5 (2.97)	23.3 (0.92)	44.4 (1.74)	59.1 (2.33)
Mean total length				24.2 (0.95)	46.4 (1.83)	59.1 (2.33)
Annual increment				24.2 (0.95)	23.0 (0.90)	14.7 (0.58)

ditions were Singletary Lake (572 acres), Jones Lake (224 acres), White Lake (1068 acres), and Salters Lake (315 acres) all located within 10 miles of Elizabethtown. The water qualities of the four lakes were similar with the exception of pH and light penetration (Frey, 1949; Louder, 1961). The pH values for the four lakes were 4.5, 4.5, 4.9, and 4.6, respectively. White Lake Secchi readings were 114 inches, whereas Singletary, Jones, and Salters Lakes had readings of 24 inches.

Coastal shiners were relocated from Lake Waccamaw into each of the four lakes in 1968. In White Lake, 13 shiners survived for 14 days and 5 for 91 days. In the other three lakes, Singletary, Jones, and Salters, all died within 12 hours.

In the summer of 1969, four additional relocations of *N. petersoni* into each of the four lakes were made to determine the low pH tolerance limit under natural conditions. All shiners died within 12 hours. Acidity readings were identical to those made in 1968, except in White Lake, which dropped from 4.9 in 1968 to 4.7 in 1969. Laboratory tolerance tests for pH showed that *N. petersoni* could not tolerate a pH of 4.7, but 50% could survive at 4.9.

Characteristics

A comprehensive description of *N. petersoni*, a close ally of *N. texanus* and *N. xaenocephalus* (Blair *et al.*, 1968), has been given by Suttkus and Raney (1955). Additional pertinent data found from this study are discussed briefly below.

Coloration of *N. petersoni* in North Carolina waters does not vary between sexes nor between streams, however the dusky colored lateral band was more pronounced on the Lake Waccamaw *N. petersoni* than on the lotic *N. petersoni*. When specimens from both lotic and lentic populations were preserved in formalin, no visual difference could be detected.

Meristic data for 98 *N. petersoni* collected from North Carolina waters showed a mean lateral line scale count of 36.5 with a standard deviation of 1.26. Number of vertebra, as determined from radiograms, ranged from 34–37 with a mean of 35.4 and a standard error of 0.13. Dorsal ray count was 8–9 and the anal ray count 7. When the lentic and lotic populations of *N. petersoni* were compared by the "t" test, no significant difference was found.

Age and Growth

Scales were collected from a total of 308 *N. petersoni* from five geographical locations (Figure 2). The mean calculated lengths at each annulus for 1, 2, and 3-year fish were 24.2, 46.4, and 59.1 mm with corresponding annual increments of 24.2, 23.0, and 14.7 mm, respectively (Table 1).

To determine if growth differences occurred in the different geographical areas, a comparison of the significance between differences was made by the "t" test. The data indicated no significant difference between Lake Waccamaw, the lotic environment, and Livingston, Town, and Six Runs Creeks for age I and II fish (Figure 3). However, there was a difference between Lake Waccamaw and the Northeast Cape Fear River populations.

N. petersoni collected from the Northeast Cape Fear River exhibited a significantly slower growth rate in comparison with the other areas (Figure 3). The mean growth rates for age I, II, and III year fish were 21.4,

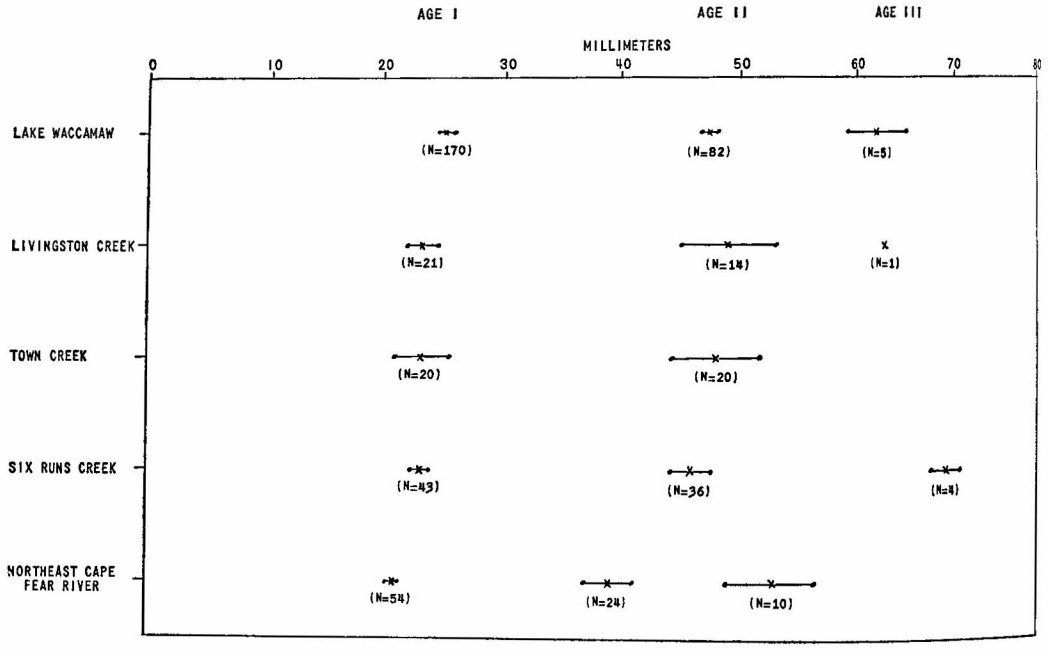

FIGURE 3.—Means and standard errors of total lengths, by year classes, of *Notropis petersoni* from five locations, 1969.

39.3, and 53.1 mm, respectively, with corresponding standard errors of 0.38, 4.93, and 3.58 mm. When growth was compared using the "t" test, between the Northeast Cape Fear River and the Livingston Creek populations, a significant difference was evident at age II and III. It is conclusive that the Northeast Cape Fear River *N. petersoni* grow much slower than those in the Cape Fear drainage. This poorer growth rate was first evident at the end of the first growing season.

Food Habits

The mouth of *N. petersoni* is large and terminal, both characteristics of carnivorous minnows. The digestive system is short and comprised of a small tubular stomach and a short intestine having two 180° bends. The contents of 180 Lake Waccamaw *N. petersoni* digestive tracts were examined for food content from July, 1968 through December, 1969.

Of the digestive tracts examined, 62% contained plant material consisting of single-celled algae and detritus, however, there was no indication that this material had or was being digested. Fifty-two percent of the tracts examined contained crustaceans and aquatic insect parts. The contents in the digestive tracts were impossible to identify to genera because they existed as fragmentary remains. This fragmentation was accomplished by the long, well developed pharyngeal teeth. Only 4% of the digestive tracts contained sand particles, indicating some feeding occurs on the bottom with most taking place in mid-water.

It was interesting to note that a significant movement in Lake Waccamaw of *N. petersoni* to the incoming streams occurred during and immediately after a heavy rainfall. Apparently, they feed on the incoming volume of food. Many predator species were also observed and collected near the mouths of the creeks during the periods of increased flows, possibly moving to feed on *N. petersoni*. Any unusual movement or disturbance in shallow water attracted *N. petersoni* in large numbers. Agitation of the water stirs up food on the bottom and makes it more readily available. Local bait dealers utilize this fact and feed the *N. petersoni* in the shallows, thus concentrating them and simplifying capture.

Digestive tract contents of 80 *N. petersoni*

collected from the five streams during the summer of 1969 were similar to those from Lake Waccamaw fish. The food items were only partly identifiable. Plant material appeared in approximately 70% of the 125 stomachs examined. The plant material was chiefly detritus and did not appear to be digested because much of the material was located at the lower end of the digestive tract. Remains of a few small aquatic beetles were observed in the stomachs, however these had been macerated almost beyond recognition. It is believed that crustaceans are the most important food source for *N. petersoni* since plant material is not being digested.

Observations of feeding in the streams were made on several occasions during periods of low water. *Notropis petersoni* could be observed in the riffle areas constantly searching for food. When approached from the bank, they quickly retreated to the deeper pool areas for safety.

The most noticeable difference found in the digestive tracts of *N. petersoni* from lotic environments was that 22% were devoid of food, whereas all digestive tracts examined from Lake Waccamaw fish were full. *Notropis petersoni* digestive tracts examined from the Northeast Cape Fear River contained the least volume of food of the six populations examined.

Notropis petersoni will consume algae and artificial foods such as ground pelletized trout chow, oatmeal, and cornmeal in the laboratory. In the aquarium most of the feeding is done in open water with a preference for suspended food particles, and only limited bottom feeding occurs.

Spawning and the Development of Eggs and Larva

To obtain a sex ratio, 500 *N. petersoni* were examined at random from haul seine samples. Of these, 208 (41.6%) were males and 292 (58.4%) were females, the females being somewhat larger. The sex ratio of males to females was 1:1.4.

From examination of the ovaries, gonads, and secondary sexual characteristics, it became apparent that the species does not reach sexual maturity until they are about 45 mm in total length, or in their third year of life. As spawning time approached, a single row of tubercles appeared around the front edge of the snout in males. At this time the females could be readily distinguished from the males by their robust appearance.

Increased activity occurred near the shoreline in the vast beds of maiden cane in the spring and spawning began when the water temperature reached 62 F in late April. It continued until the water temperature reached 78 F in mid-July. On June 16, 1969, at a water temperature of 68 F, it was found that 72% of 500 fish examined had spawned. The fishes' activity during spawning appeared to be more of a constant search for food with sexual activities being a secondary function.

Attempts to observe actual spawning activities were unsuccessful because of the black-stained water and the continuous wave action. Several attempts to spawn *N. petersoni* in 29-gallon glass aquaria and in a 1000-gallon concrete pool proved futile. An attempt was also made to strip eggs and sperm from the fish and artificially fertilize the eggs in petri dishes, however it proved impossible to obtain enough sperm to accomplish the project.

Egg counts were made from 25 female *N. petersoni.* The mean number of eggs found in four 40–50 mm fish was 328 with a standard deviation of 39.5; in fourteen 50–60 mm fish, 485 with a standard deviation of 127.9; in five 60–70 mm fish, 629 with a standard deviation of 41.7; and in two 70–81 mm fish, 854 with a standard deviation of 45.0.

The larval fish had a mean total length of 8 mm at the end of one month and 14 mm at the end of the second month after hatching. By September 18, early spawned *N. petersoni* had reached a mean total length of 19 mm in Lake Waccamaw. The young shiners were observed joining the schools of adults after their second month of life.

Stream inhabiting *N. petersoni* were found to have a later spawning period resulting from cooler spring stream temperatures. The spawning period, in the lotic environment, began when water temperatures reached 62 F from May through late August, whereas the lentic population in Lake Waccamaw spawned from late April through mid-July with the

spawning period occurring during June in both habitats.

Gregariousness and Movements

Adult *N. petersoni* were observed swimming in schools composed of a varying number of individuals. Schools of more than 500 fish were observed swimming in the beds of maiden cane during April, May, and June. As the young entered the adult population in September and October, the schools became composed of three age groups. This arrangement was unstable and was observed to change frequently. At all times, these fish were in constant search for food.

The stream populations of *N. petersoni* seldom were observed, however, observations were made in Livingston and Six Runs Creeks during periods of extremely low water. These two streams were clear and had definite pool and riffle areas. *N. petersoni* were observed to feed in the riffle areas and rest in the pools. Because of the many species of Cyprinidae in the streams, it was impossible to identify *N. petersoni* with any consistency by observations.

Economic Importance

N. petersoni is one of two important forage fishes in Lake Waccamaw and it is adapted to living under heavy predation in a lacustrine environment. The small shiners are extremely hardy and live well in captivity. Local bait dealers consider this species to be the most important small fish in the lake. The species is referred to locally as "smelt minnow." Bait dealers seine *N. petersoni* from the lake and sell them locally to fishermen fishing for largemouth bass, white perch, yellow perch, and bluegill.

The importance of *N. petersoni* as forage in the streams is probably not as vital as it is in Lake Waccamaw. During the stream surveys conducted by the North Carolina Wildlife Resources Commission (1960–66), Louder collected *N. petersoni* from 12% of the streams sampled in the Cape Fear River Watershed and Bayless collected *N. petersoni* from 18% of the streams sampled in the Northeast Cape Fear River Watershed. Bayless stated: "Coastal shiners are fairly abundant in the watershed and contribute substantially to the forage fish population."

SUMMARY

This study was undertaken to expand the knowledge of the life history and the ecology of this interesting fish. Data in this report indicate that the lentic and lotic forms of *N. petersoni* are the same species and do not justify a subspecies classification. Ecological studies of the species indicated that they are gregarious and feed chiefly on animal material, the plant material being eaten incidentally while feeding. Their digestive systems are very efficient and food items are macerated beyond identification.

The breeding season extends from April through July with water temperatures of 62–78 F. In streams the breeding season is somewhat later because of cooler, springtime stream temperatures. The young fish reach a total length of 8 mm by the end of the first month and 14 mm by the end of the second month after hatching. At approximately 18 mm they join the adult population, becoming sexually mature at 45 mm total length. The life span of *N. petersoni* is about three years and they spawn during their third and fourth year of life.

N. petersoni are hardy fish in aquaria, adjust to artificial foods, and are excellent bait for largemouth bass, white perch, yellow perch, and bluegill. They appear to be adapted to a lacustrine existence under heavy predation.

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